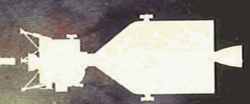
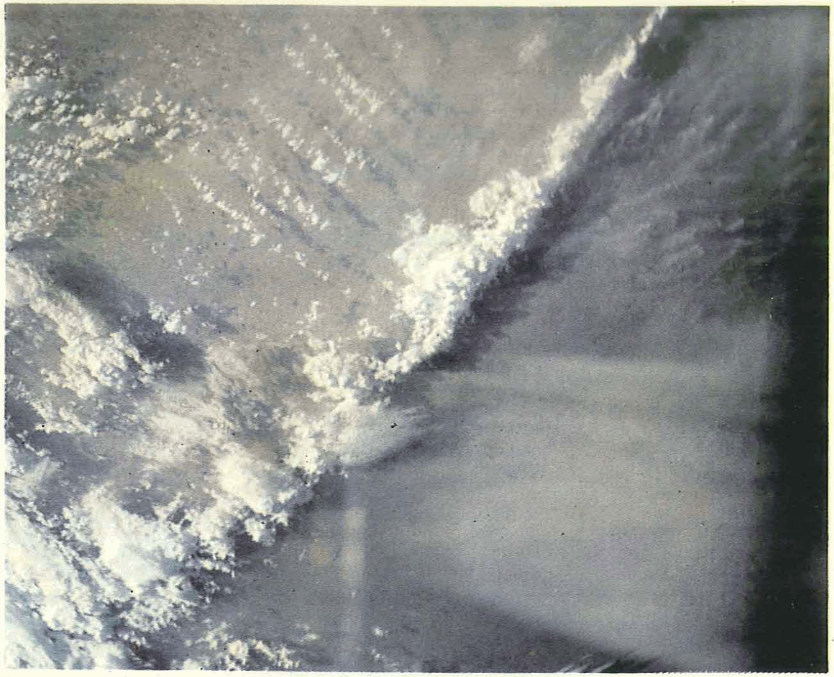
EP-6 Rev.

space... the new frontier

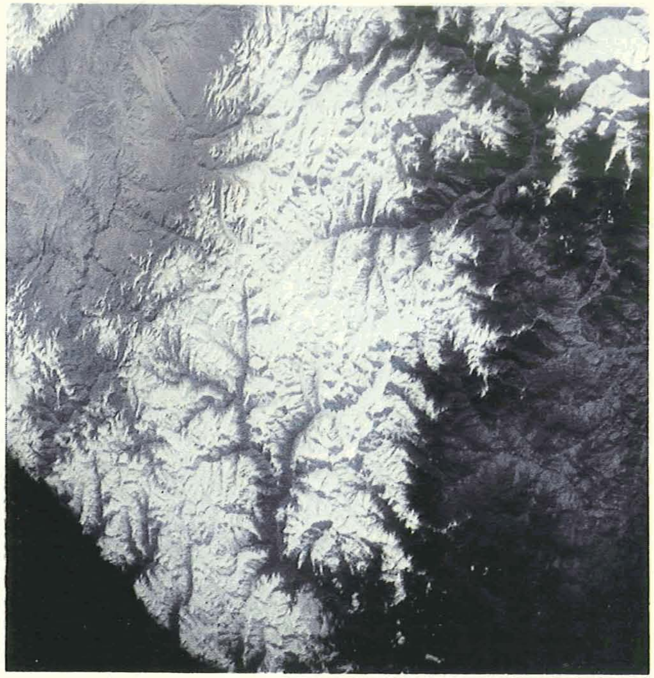


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

THE EARTH AS SEEN FROM THE MERCURY SPACECRAFT



GREAT INDIAN DESERT WEST OF DELHI—The lonely vastness of a great desert is immediately obvious to the camera at an orbital altitude of more than 100 miles over the earth.



HIMALAYAN MOUNTAINS—The total structure of a great mountain range is portrayed in a form never before available to the geologists.

"I took pictures over all areas of the world where there were objects that were photographically worth while," said L. Gordon Cooper, Jr., following his 22-orbit flight in the Mercury Spacecraft Faith 7, on May 15 and 16, 1963.

Astronaut Cooper's Faith 7 was in orbit more than 100 miles above the surface of the earth when he took the color photographs shown on this page, and on the back cover and inside back cover. Those which include the horizon give an impression of the astronaut's view of the earth's curvature, usually set off by the atmosphere showing as a band of blue.

The Indian Desert appears as a vast expanse of lonely sand, with cloud formations in a comprehensive pattern never before viewed by man. The Himalayan Mountains appear in a pattern of special interest to geologists. The Burma area photograph shows the coastline of the Bay of Bengal. Notable in the photo taken over Morocco is the contrast of mountains with cloud-covered ocean.

In every case, details of configuration are shown in color to marked advantage over black and white pictures such as those sent to earth from the weather satellite Tiros, although the Tiros pictures serve meteorological purposes well.

Cooper took his pictures of the earth through the window of the spacecraft, manually steering the Faith 7 to get the angles desired for various shots. The camera was hand held.

THE AGE OF SPACE

If there has been a single factor responsible for our success over the past two hundred years, it has been the characteristic American confidence in the future. It was such a confidence which brought the first colonists westward across the Atlantic to settle the Eastern shores. It was that same confidence which brought other generations westward across the continent to build up our country all the way to the Pacific.

Today there are those who argue that we should not push forward into new realms or new enterprises except when there is clear evidence of competition from other nations. I believe the American people reject the concept that their future shall be measured by the reaction to accomplishments of others.

America's commitment to the exploration of space for peaceful purposes is a firm commitment. We will not retreat from our national purpose. We will not be turned aside in our national effort by those who would attempt to divert us.

Our national purpose in space is peace—not just prestige.

—PRESIDENT LYNDON B. JOHNSON.

THE U.S. SPACE PROGRAM

THE U.S. SPACE program was undertaken in 1958, and accelerated in 1961, because two Presidents and the Congress considered it basic to our national strength and essential to our continued leadership of the free world.

Among the major motivations of the space program is the necessity that we retain unquestioned preeminence in all areas of science and technology, including the new arena of space. Others include the demands of national security, the potential economic benefits of space technology, the anticipated new scientific knowledge which exploration of space would yield, and finally, the stimulating effects of this challenging national enterprise on all segments of American society, particularly the young.

During the intervening years, the United States has made great progress in building the basic structure for preeminence in space. This is the structure which will, within this decade, enable man to explore the moon. Even more important, however, it is the structure which will give the Nation the capability to operate in and use space for whatever purpose the national interest may require—whether it be operations in near-earth orbit, or the search for extraterrestrial life on the planets beyond.

Among the important benefits of the hard-driving space program now underway are:

Development of high-thrust boosters with payload capabilities exceeding any others now known to exist.

Development of superior guidance and control, the perfection of rendezvous and docking techniques—the ability to join two spacecraft in orbit at 18,000 miles an hour—and the ability to maneuver accurately in the space environment.

Establishment of a structure of massive ground facilities to assemble, test, and launch space vehicles which will serve the Nation's needs for many years to come.

Development of a strong industrial base which will be able to undertake the development and manufacture of any space systems required in future years.

The development of great scientific competence in the Nation's universities and research laboratories on a broad basis throughout the Nation.

Training of scientists and engineers through the conduct of basic research in the universities, and support of predoctoral training grants.

Establishment of a reservoir of technicians in industry, training of astronauts and of military personnel for future needs in space.

For the first time in the history of mankind the opportunity to leave the earth and explore the solar system is at hand. Only two nations, the United States and the Soviet Union, today have the resources with which to exploit this opportunity. Were we, as the symbol of democratic government, to surrender this opportunity to the leading advocate of the Communist ideology, we could no longer stand large in our own image, or in the image that other nations have of us and of the free society we represent.

JAMES E. WEBB, *NASA Administrator*

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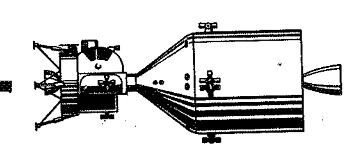
The Great Nebula in Orion, as seen and photographed in color at the Mount Palomar Observatory, is an exciting mass of white, blue and red. Blue indicates hot stars; the red areas are tenuous gas, predominantly hydrogen. The lower right area of the picture is obscured by a dark nebula. Also at lower right is silhouette of Apollo spacecraft. (See Chapter VII.)



CHAPTER I

SPACE AND YOU

SEARCHING OUT THE UNKNOWN

Man's curiosity has always driven him to search out the unknown and has led him to devise the means of exploring it. As man achieved the technological advances which permitted him to reach space, it was inconceivable that he should not explore it. As it was impossible in 1492 to forecast the benefits of the voyages of Columbus, so it is impossible now to foretell what man will gain from the exploration of space. It is, however, safe to predict that in the long run the most important and valuable return from space exploration will be the vast addition to man's store of knowledge about the universe in which he lives.

Man will establish permanent stations in space—laboratories, observatories, experimental testing platforms and way stations. He will visit the moon, Venus, and Mars. He will send probes to more distant planets and perhaps the stars. He may discover that life exists in space. He may communicate with other beings in space. Regardless of what form his exploration takes or what other results he may achieve—man's greatest benefits will still be the knowledge he brings back for the benefit of mankind.

Man's achievements in space since the first satellites were launched only a few short years ago have been tremendous, but they pale to feeble ventures in contemplation of future space explorations. Only in the light of what man has already done could he possibly look ahead with the almost certain knowledge that many of the projects he now looks forward to will be realized.

Man dreams of visiting or at least taking a look at the other planets in our solar system. He casts an eye at the other stars of our galaxy, the Milky Way.

STEP BY STEP INTO SPACE

Among the nine planets which revolve about our sun, earth ranks only fifth in size. Pluto, a "neighbor" in our solar system, is more than 3½ billion miles distant and yet it, like the earth, is held in its orbit by the massive gravitational attraction of the sun, and the sun is 100 times as massive as the largest planet in its family of 9.

Yet, this sun itself is only a minor star. Its nearest neighboring star is so far away that even billions of miles are too puny a measure of distance. We must use instead the light-year, the distance traveled in 1 year at the speed of light. Light travels 186,300 miles per second, making 1 light-year about 6 trillion miles. Proxima Centauri, the star nearest our sun, is 4⅓ light-years from earth. The farthest galaxy man can see in his biggest telescope is about 10 billion light-years away.

Both Proxima Centauri and our sun are stellar members of the galaxy we call the Milky Way, a grouping of an estimated 200 billion stars so immense it would take 100,000 years at the speed of light to traverse its length. And, this galaxy is only one of several billion within the range of the world's largest telescope.

Viewed in man's terms of time and distance, the challenge of space exploration might seem insuperable. Yet one has only to review the technological accomplishments of mankind in the 20th century and the "impossible" becomes merely "difficult."

Space does not submit readily to conquest. The exploration of space is following the pattern by which man mastered flight within the atmosphere, each new development providing a platform from which to take the next step and each step an increment of scientific knowledge and technological skill.

The first goal, of course, is the exploration of our own solar system. This in itself is an assignment of awesome dimensions, but one which few in a position to evaluate doubt can be accomplished. There are no plans, at the present, for exploration beyond our solar system—only dreams. But, who would say these dreams will not some day be realized.

THE EXPLORATION OF SPACE AND YOU

The exploration of space affects your life today; it will continue to affect your life more and more.

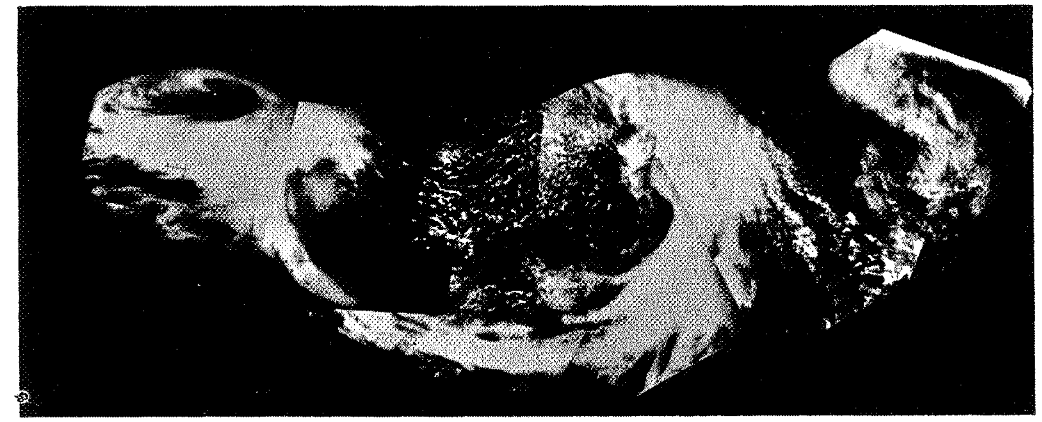
Man's activities in space affect your thinking, your reading, your conversation and many facets of your everyday life.

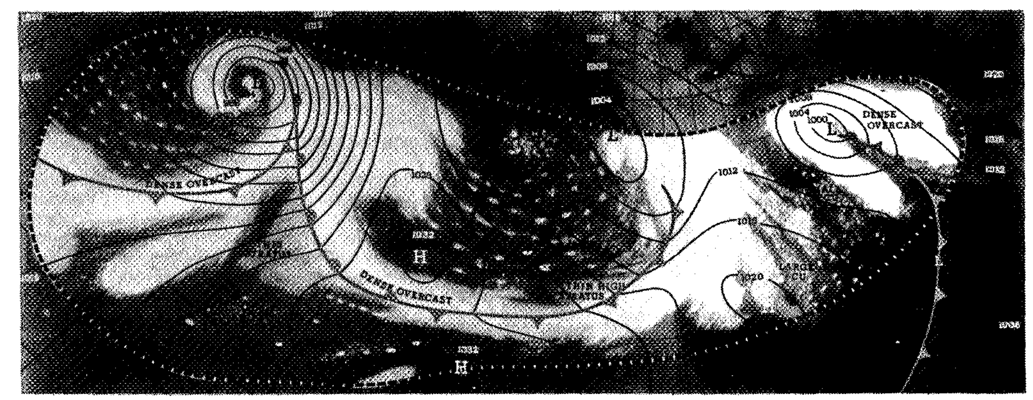
Space exploration is an issue in national and world politics. Our government has spent billions on research, development, testing, and production in the space field. Thousands of scientists, engineers, and other technicians are engaged in space activities.

Space exploration has altered the trend of science. If you are a student at any level, space affects your studies. Before long it may alter your entire course of education.

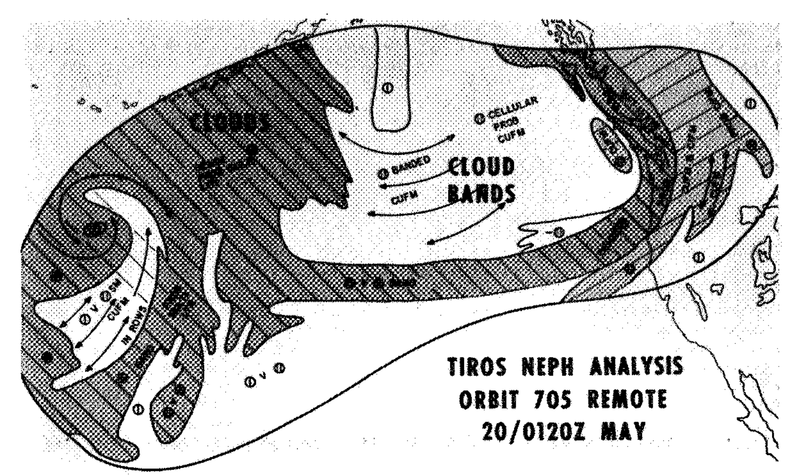
Whatever age you may be, it is probable that you come into almost daily contact with some product or byproduct which is the result of space research.

Drawing broadly from all fields of science and engineering, space technology offers promise of uncovering a flood of new benefits for mankind. NASA has established an Office of Technology Utilization to aid in identifying and disseminating those new processes, materials, and equipment which can improve life on earth.





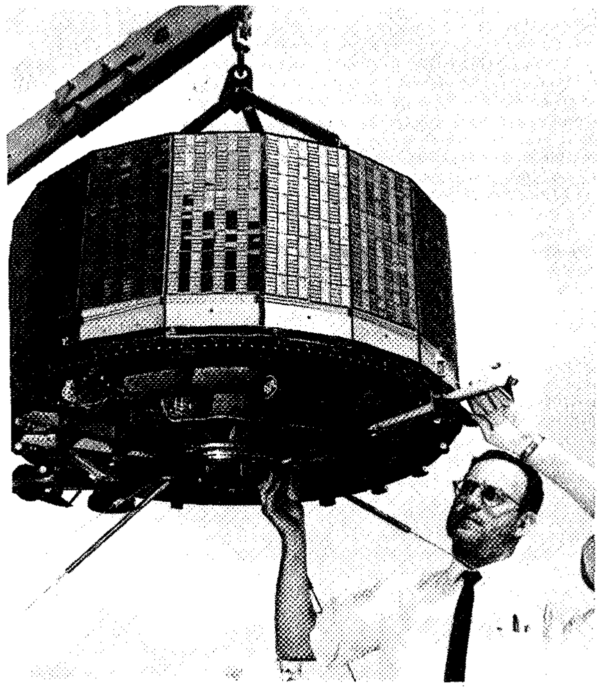
Information from mosaic of TIROS (meterological satellite) cloud pictures (top) is overlaid on map (above) and reduced to operational weather data (bottom) for incorporation in Weather Bureau analyses and forecasts.



Space and Weather

Satellites equipped with television cameras and infrared sensors make possible observations over areas not previously covered. They are also providing types of meteorological measurements which could not be obtained with other facilities. The reduction and analysis of these increased data, particularly from areas otherwise lacking observation, make possible better short-range forecasts, and may eventually permit improved long-range weather predictions.

With long-range prediction of rainfall or drought, communities could better prepare for control of their watersheds. Satellite observations provide warnings of tornadoes, floods, blizzards, hurricanes, and other catastrophic weather, enabling people to strengthen levees, take shelter, and make other preparations to minimize loss. Weather-sensitive industries such as shipping, airlines, agriculture, and construction gain enormously by improved weather forecasts that satellites make possible. Increased meteorological knowledge attained by study of satellite data may eventually enable man to modify weather to his advantage.



Scientist makes adjustment on TIROS III meteorological satellite.

Navigation by Satellite

It is estimated there are 20,000 surface craft at all times on the Atlantic Ocean alone. Hundreds of aircraft crowd the skies over much of the world. Accurate information as to his exact location has become a necessity to the navigator of every sea or air craft.

By using time signals and a radar locating phenomenon known as the Doppler Shift,* air and sea craft can receive information from navigational satellites which will pinpoint their location any time of day or night and in all kinds of weather and enable them to steer along safe courses.

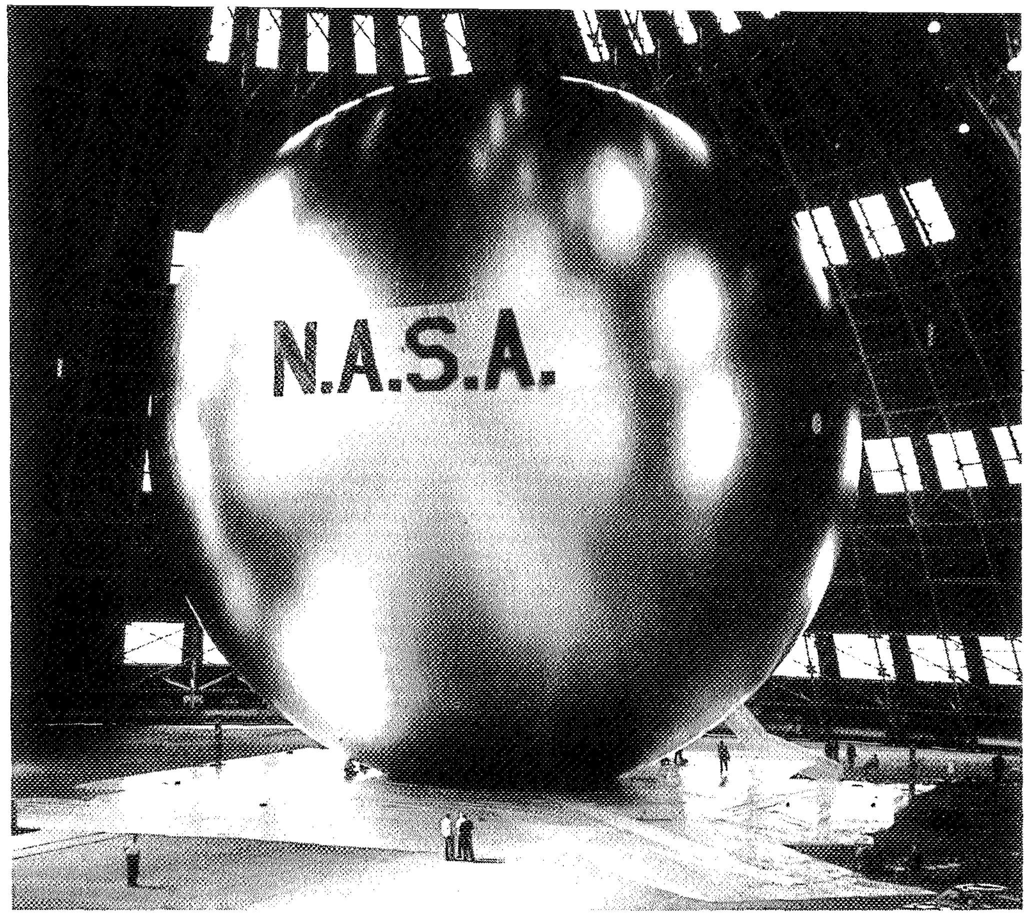
Communication via Satellite

Satellites have opened a new era in global communication. Echo, Telstar, and Relay have shown how manmade satellites can not only greatly augment current facilities but also make possible global telecasts and other types of world wide communication not now available.

In addition, the communications industry appears unamimous in its agreement that increased future demands for transoceanic telephone and telegraph services can be supplied at less cost by satellite systems than by laying new submarine cables.

Several types of communications satellite systems are being studied. One would be made up of huge aluminized plastic spheres

*The Doppler principle was set forth in 1842 by Christian Johann Doppler of Prague. He discovered that if the distance is changing between an observer and a source of constant vibration, the wave number appears to become greater than the true values if the distance between the observer and the source is being diminished—and appears to be less as this distance becomes greater. This is true of such constant vibrations as sound or light. The Doppler principle is applied to electromagnetic radiation in connection with radio and radar equipment to determine the speed and distance of moving objects in the air or in space. As measured from a ground station, electromagnetic signals change frequency as the satellite from which they are sent approaches and passes over a ground station. (This is known as the Doppler Shift.) By measurement of this shift, the future orbit of the satellite can be accurately predicted for as long as several days ahead. In the satellite navigation system, this Doppler Shift can be checked automatically by a



This 135-foot inflatable sphere has 20 times the rigidity of Echo I. It is designed to function as a passive communications satellite.

substantially larger than the 100-foot-diameter Echo I. These are called passive satellites because telephone and other messages are sent by bouncing radio waves from the satellites' reflective surfaces, much as a ball is bounced off a wall. Passive satellites require no complicated instrumentation.

Another system would employ "active-repeater" satellites. Such satellites are equipped with radio receivers and transmitters and other instruments to receive, store, amplify, and retransmit messages. They serve in effect as microwave radio relay stations in the sky.

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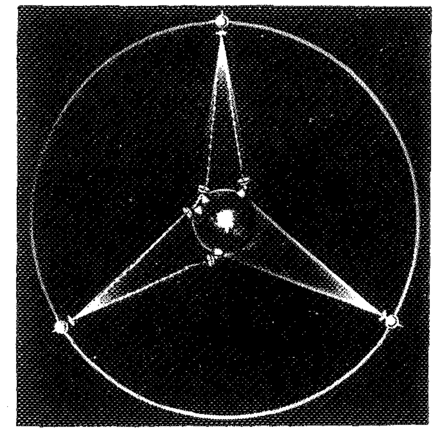
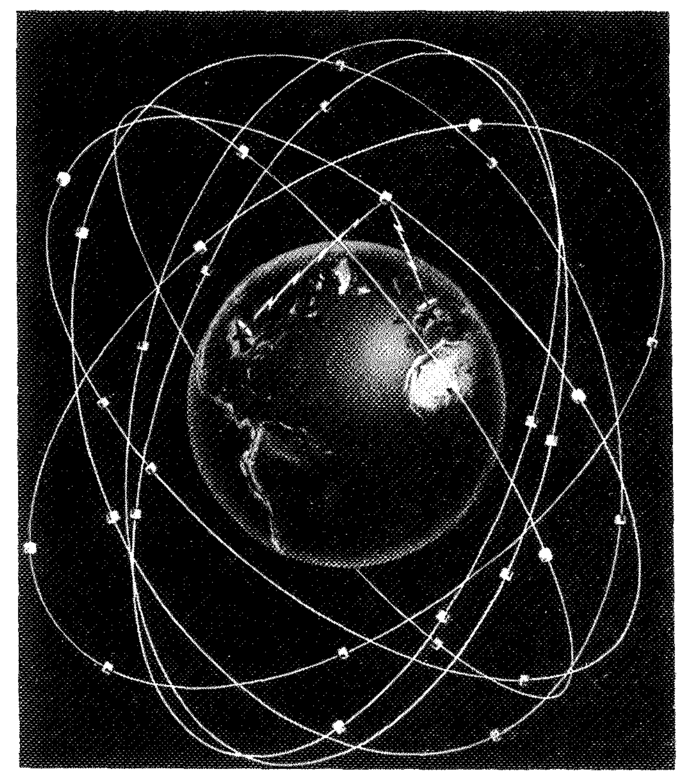
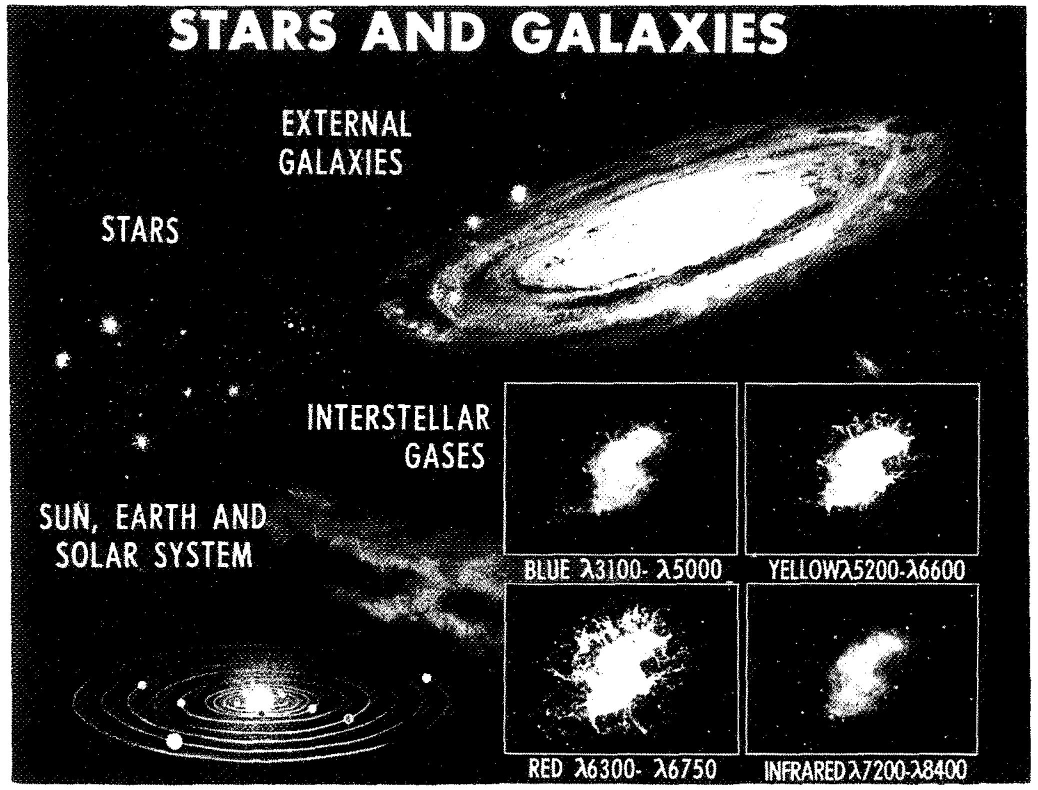
ground station against a time and frequency standard. This information is teletyped to a computing center where the satellite's position is accurately computed. Since the Doppler Shift is a direct measure of the rate of change of distance when the transmitter and the receiver are at a known location on the ground, future positions of the satellite can be calculated. (The satellite's orbit is governed by astronomical laws.)

The navigator either in the air or at sea receives this data from the ground station. Thus knowing the satellite's positions at future times, the navigator can combine this information with other signals received from the satellite to determine his own position on the surface of the earth.



Active-Repeater Satellite Systems: Synchronous Orbit (above), Medium Altitude (below).





New astronomy evolves from new capabilities. At lower right the Crab Nebula is shown as it appears photographed in several kinds of light—blue, yellow, red, and infrared.

Experimental programs are underway to test "active-repeater" satellites in medium-altitude (several thousand to 12,000 miles above the earth) orbits and in high-altitude "synchronous" orbits (approximately 22,300 miles above the equator). "Synchronous" satellites orbit the earth in the same length of time as the earth takes for one full rotation on its axis (24 hours). If the satellite's orbit is circular and in the same plane as the equator, the satellite will remain fixed over one spot on earth, like a point on a wheel rim to the nearest point on the hub. (A satellite's orbital plane may be likened to a flat plate passing through the center of the earth. The plate's edge is the satellite's orbit.)

The different technical approaches of the experimental communications satellites projects are providing an extensive variety of information that is advancing the time when an operational system will be established.

On February 1, 1963, the Space Communications Corp., created to set up and operate a network for global transmission of communications via satellite, received a certificate of incorporation from the Superintendent of Corporations, District of Columbia. The firm was authorized by Congress on August 31, 1962.

Astronomy

Astronomers have been hindered in their observations by the earth's atmosphere that, like a veil, blots out or distorts electromagnetic radiation.

About 99 percent of the atmosphere's air molecules are concentrated between the earth's surface and an altitude of about 20 miles. By placing telescopes and other equipment for studying the heavens in observatories above this altitude, man can see the universe from a vantage point above the haze of the atmosphere.

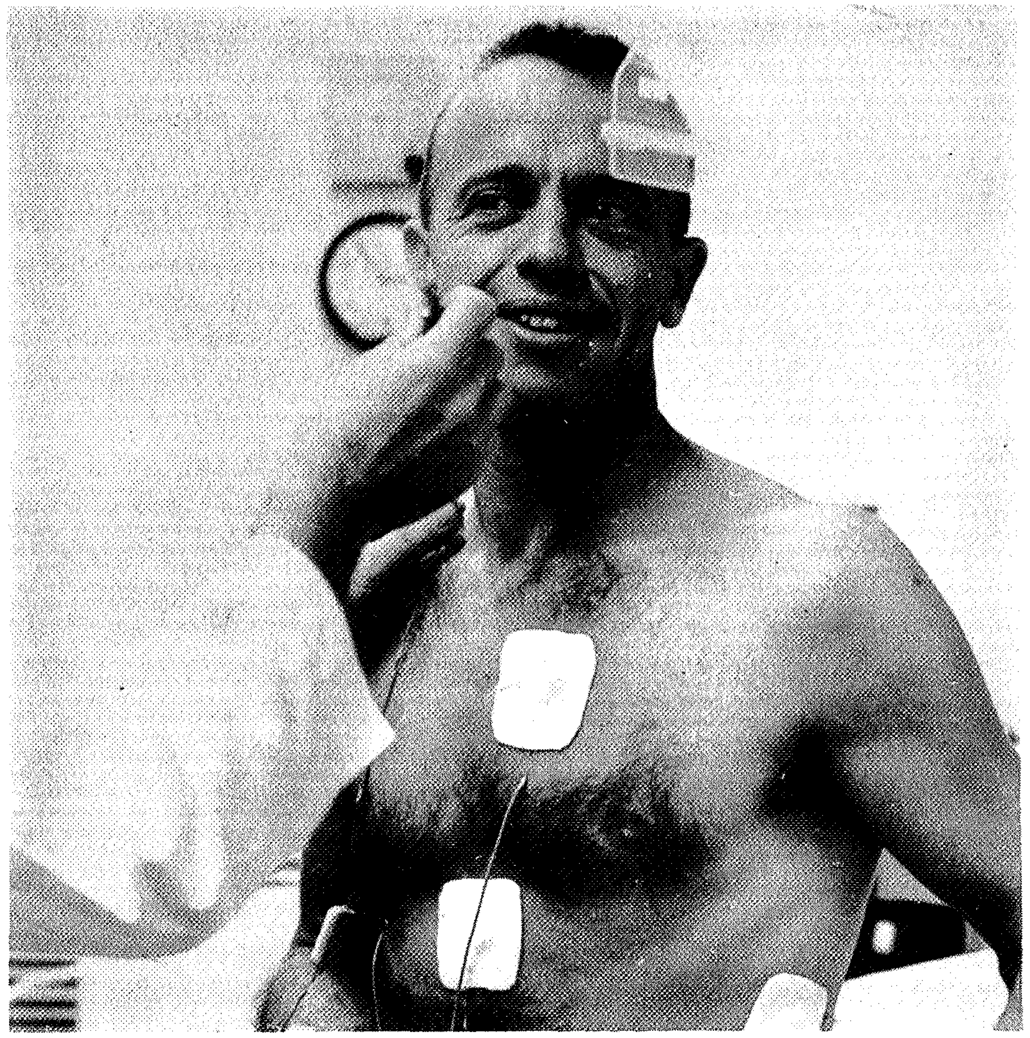
For example, the first of a series of orbiting solar observatories has provided tremendous quantities of new information about our sun; about how variations in solar activity influence earth's atmosphere and magnetic field; and about the amount of cosmic radiation that reaches earth's surface.

By means of future observatories of this type, man will be able to acquire more definite information about the nature and origin of the solar system. He will be able to view in greater detail the physical features of earth's moon, of Mars, and of other planets.

With his earth-based telescopes, man has gathered data about his own Milky Way galaxy and other galaxies. He has found evidence of planets revolving around other stars. Mounted on a platform in space, man's telescopes will be able to reveal hitherto unavailable information about stars and galaxies. Perhaps, they may enable him to learn about the existence of planets that resemble earth.

Geodesy and Space

Satellites assist in determining exact distances and locations and precise shapes of land and sea areas on earth. They also increase accuracy of measurements of the shape and size of the



Biosensors attached to body of Astronaut Alan B. Shepard, Jr., enabled medical officers on the ground to keep a constant check on his heartbeat, respiration, and other physiological functions during his space flight (see Chapter VII).

earth and of variations in terrestrial gravity. Such information will advance the preparation of accurate global maps and augment scientific knowledge about our planet.

Medicine

The study of aerospace medicine promises benefits for mankind in the treatment of heart and blood illnesses. Significant studies have been made on human behavior and performance under conditions of great stress, emotion and fatigue. Discoveries have been made as to what type of man can best endure long periods of isolation and removal from his ordinary environment. A derivative of hydrazine (isoniazid), developed as a liquid space propellant, has been found to be useful in treating tuberculosis and certain mental illnesses. And the space industry is producing such reliable and accurate miniature parts—such as valves—that they may some day be used to replace worn-out human organs.

In April 1963, an electroencephalogram depicting brainwaves from an American woman was sent across the Atlantic from England to the United States and a diagnosis returned via NASA's Relay communications satellite. The experiment, in which the brainwaves of a healthy individual were transmitted, was designed to test the possibility of swift diagnosis of brain disorders by specialists in different parts of the world through use of communications satellites. It points the way toward accelerated processing of medical data by use of communications satellites.

Scientists and dietitians are working directly on the problem of space feeding and nutrition. The information gained from this research can have a profound influence on future food and agricultural processes. This involves the growth of synthetic and new foods, and the process of compressing large numbers of calories into pill-size packages. It involves also new methods of food growth and storage.

NEEDED: SPACE SCHOLARS

No enterprise in history has so stirred the human imagination as the reaching of man into space.

New knowledge to cope with this new science is needed in almost every branch of technology. This need encompasses the basic sciences of physics, chemistry, engineering, and mathematics. It also includes biology, psychology, and almost every field of medicine.

Many colleges and universities have set up courses dealing with astronautics. High schools have space science courses or incorporate space concepts into physics and other science courses. Elementary curricula include space studies in their science program.

CHAPTER II

THE HISTORY OF SPACE FLIGHT

Illustration from first edition of Jules Verne's *From the Earth to the Moon*, published in 1865. Spaceship passengers are enjoying weightlessness.

The beginnings of thought about space flight were a mixture of imagination and vague concepts. The idea of leaving the earth to travel to a distant world developed only as understanding of the universe and the solar system evolved.

In 160 B.C. a part of "Cicero's Republic," entitled "Somnium Scipionis" (Scipio's Dream), presented a conception of the whole universe, a realization of the comparative insignificance of earth and the visualization of a vast panorama in which appear "stars which we never see from earth." Lucian of Greece wrote his Vera Historia in A.D. 160, the story of a flight to the moon. For centuries no further stories of space travel appeared. Only with the renaissance of science and the work of such men as Tycho Brahe, Copernicus, Kepler, Newton, and Galileo did men's minds again become receptive to the possibility of traveling to other worlds.

In rapid succession, such writers as Voltaire, Dumas, Jules Verne, Edgar Allan Poe, H. G. Wells, and many other lesser known authors filled the pages of literature with imaginative tales of space travel.

A fascinating novel is "The Brick Moon" by Edward Everett Hale, who is better known for his "The Man Without a Country." First published in 1869, "The Brick Moon" is the first known presentation on the injection of a manmade satellite into orbit. The novel was the first to discuss the manned orbital laboratory and weather, communications, and navigation satellites.

Today one has only to go to the closest magazine stand or bookstore to find similar stories. Dramatizations have appeared on the motion picture screen, radio, television, and the legitimate stage.

The history of rocket development is interwoven with evolving ideas of the universe and space travel, because only with the rocket principle is travel in space possible.

When the first rocket was fashioned remains a secret of the past, but there is no doubt that the earliest known direct ancestor of our present day rockets was a Chinese invention. In A.D. 1232, at Kai-fung-fu the Chinese repelled attacking Mongols with the aid of "arrows of flying fire." This was the first recorded use of rockets. These early rockets reached Europe by 1258. They are mentioned in several 13th- and 14th-century chronicles. In 1379, a lucky hit by a crude powder rocket destroyed a defending tower in the battle for the Isle of Chiozza. This was during the third and last Venetian-Genovese war of the 14th century. The

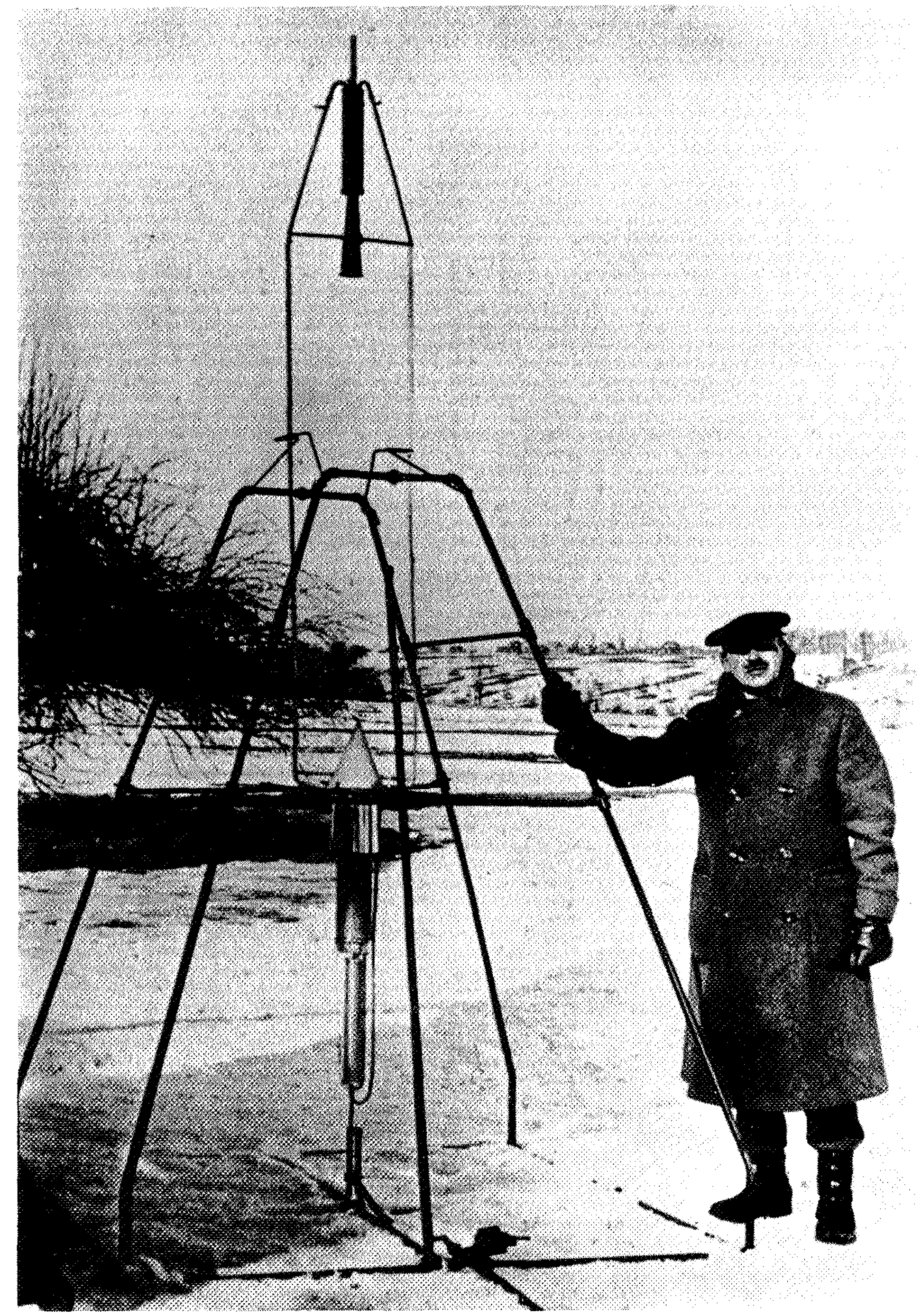
Genovese fleet sailed up the Adriatic, laid siege to and took Chiozza, although later losing the war when the Venetians bottled up the fleet in the Chiozza estuary.

The early 19th centry brought a period of intense interest in the military rocket. Great Britain's Sir William Congreve was the foremost name in rocketry at that time. He developed a solid propellant rocket which was used extensively in the Napoleonic Wars and the War of 1812. One of the more spectacular of the Congreve rocket achievements was the razing of the greater part of Copenhagen in 1807.

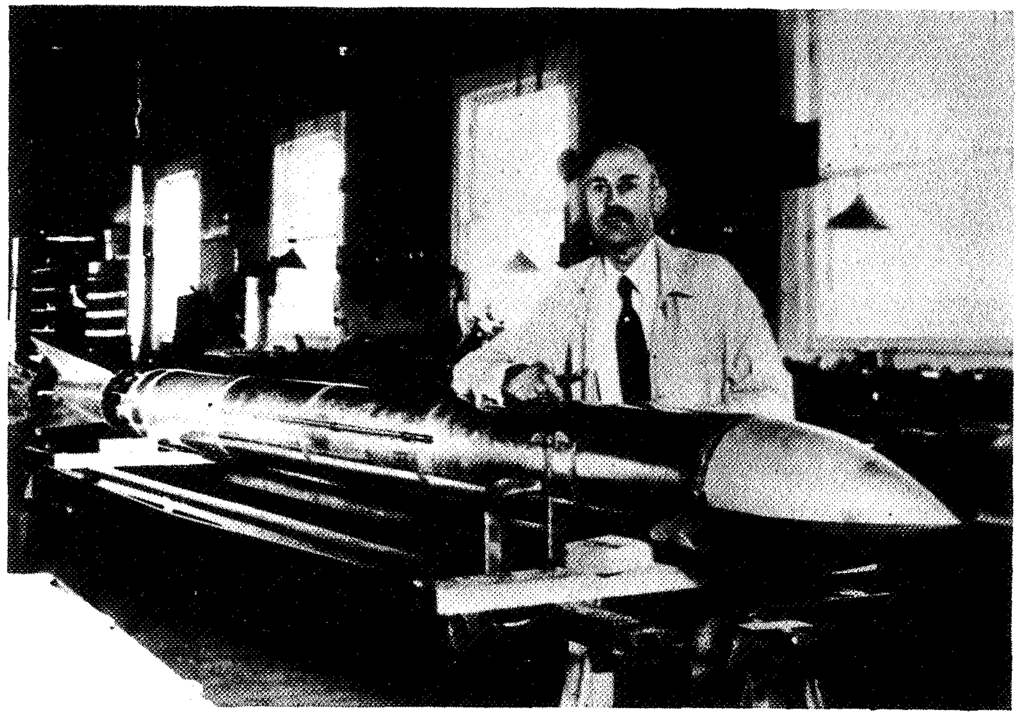
As so often happens with articles designed for war use, the Congreve rocket was adapted to humanitarian purposes. The most useful outgrowth was a lifesaving rocket first patented in Britain in 1838. This device (using a Congreve rocket) carried a line from shore to a stranded vessel, enabling the distressed crew to be pulled back to shore on a breeches buoy. This rocket was subsequently used by coastal rescue units.

Congreve developed the black powder rocket to just about its maximum capability. Almost a century passed before rocketry advanced. In 1903 a Russian schoolteacher, Konstantin Ziolkovsky, published the first treatise on space travel advocating the use of liquid fuel rockets. This paper remained unknown outside Russia, and at that time little attention was given it by other Russians.

While the theories of Ziolkovsky remained in obscurity, Hermann Oberth, a Rumanian-German, and Robert H. Goddard, an American, working separately, laid the basis for the age of modern rocketry. Professor Oberth provided the chief impetus for experimental rocket work in Germany when, in 1923, he published his book, "The Rocket Into Interplanetary Space." Professor Oberth discussed many of the problems still faced by present-day rocket scientists and explained the theories and mathematics involved in lifting an object from the surface of the earth and sending it to another world. The inspiration for the formation of the German Society for Space Travel (Verein fur Raumschiffahrt) came from Hermann Oberth's book. Both Oberth and Goddard favored the liquid fuel rocket. Much of the rocket work done in



March 16, 1926—a momentous day for rocket flight. Dr. Robert H. Goddard, American rocket pioneer, launched first liquid fuel rocket at Auburn, Mass. Dr. Goddard stands beside the rocket.



Dr. Goddard with one of his rockets at Roswell, N. Mex., in 1935.

American Rocket Society members test liquid fuel rocket in 1935.

Germany was based upon the research and some of the patents of Dr. Goddard.

Dr. Goddard, a professor at Clark University in Massachusetts, sent a finished copy of a 69-page manuscript to the Smithsonian Institution in 1919 as a report on the investigations and calculations that had occupied him for several years. This paper entitled, "A Method of Reaching Extreme Altitudes," caught the attention of the press because of a small paragraph on the possibility of shooting a rocket to the moon and exploding a load of powder on its surface.

Almost simultaneously with the publication of this paper, Dr. Goddard concluded that a liquid fuel rocket would overcome some of the difficulties encountered with the pellets of powder he had used to power his rockets. For the next 6 years, Dr. Goddard worked to perfect his ideas. By 1926 he was ready for an actual test flight. On March 16 of that year the world's first liquid fuel rocket was launched. The flight, while not spectacular in distance covered (184 feet), did prove this type of rocket would perform as Dr. Goddard had expected.

Public reaction to the increasing noise and size of Dr. Goddard's rockets forced him to leave Clark University for the southwestern United States where he could continue his work in more open spaces without endangering his neighbors. Through continual improvement, his rockets reached 7,500 feet by 1935 and speeds of over 700 miles per hour.

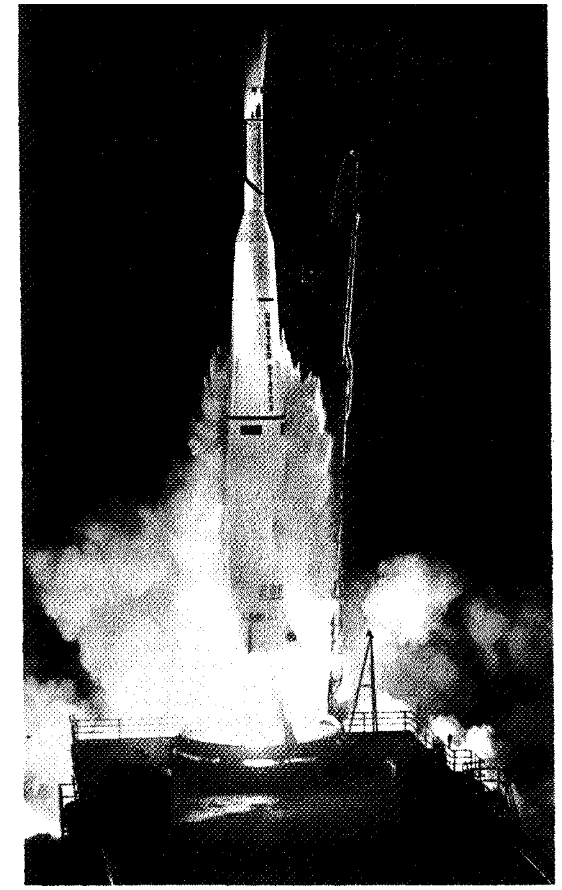
By the late 1930's Dr. Goddard was recognized, at least in professional circles, as probably the world's foremost rocket scientist. His work and patents were well known for years to the German Society for Space Travel. Members of this society developed the German V–2 guided missile used during World War II.

American rocket enthusiasts formed the American Interplanetary Society in 1930, later changing their name to the American Rocket Society. The test firings and meetings of this group stimulated a growing awareness of rocketry and its capabilities in the American public. Many members of this early society are responsible for current space programs.

The first instrumented rocket was launched by Dr. Robert H. Goddard on July 17, 1929. Its instruments consisted of a barometer and a thermometer, with a small camera focused to record their readings at maximum altitude.

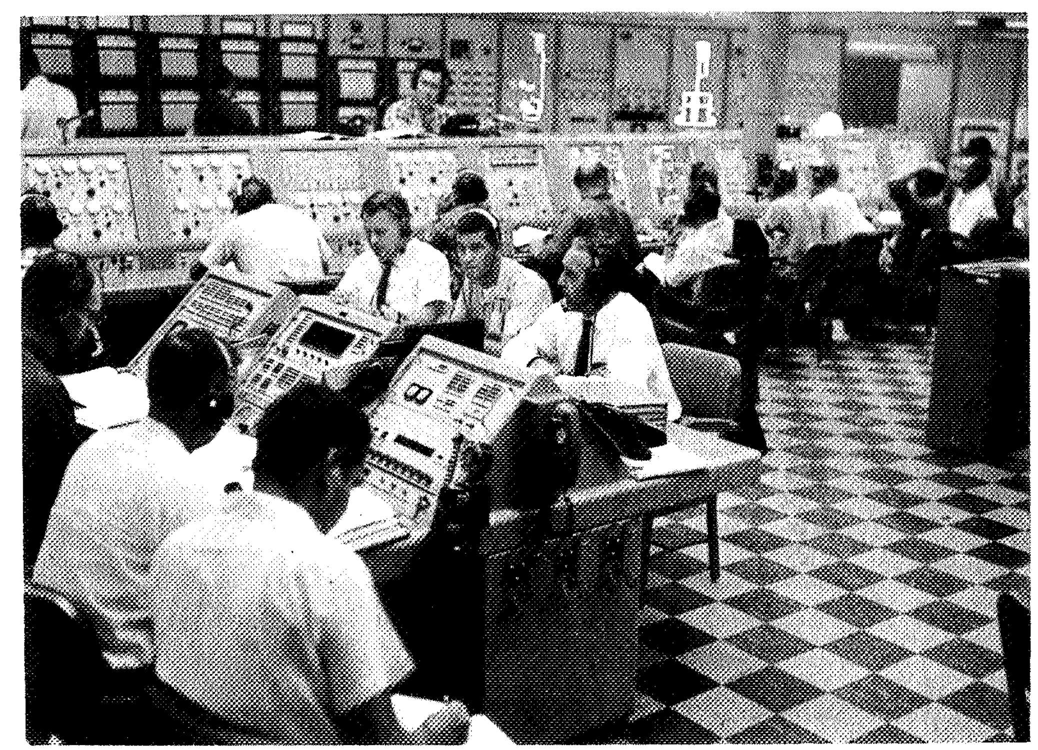
On October 4, 1957, the Soviet Union put the first manmade satellite, Sputnik I, into orbit. On January 31, 1958 the United States launched its first satellite, Explorer I.

The world had entered the Age of Space.



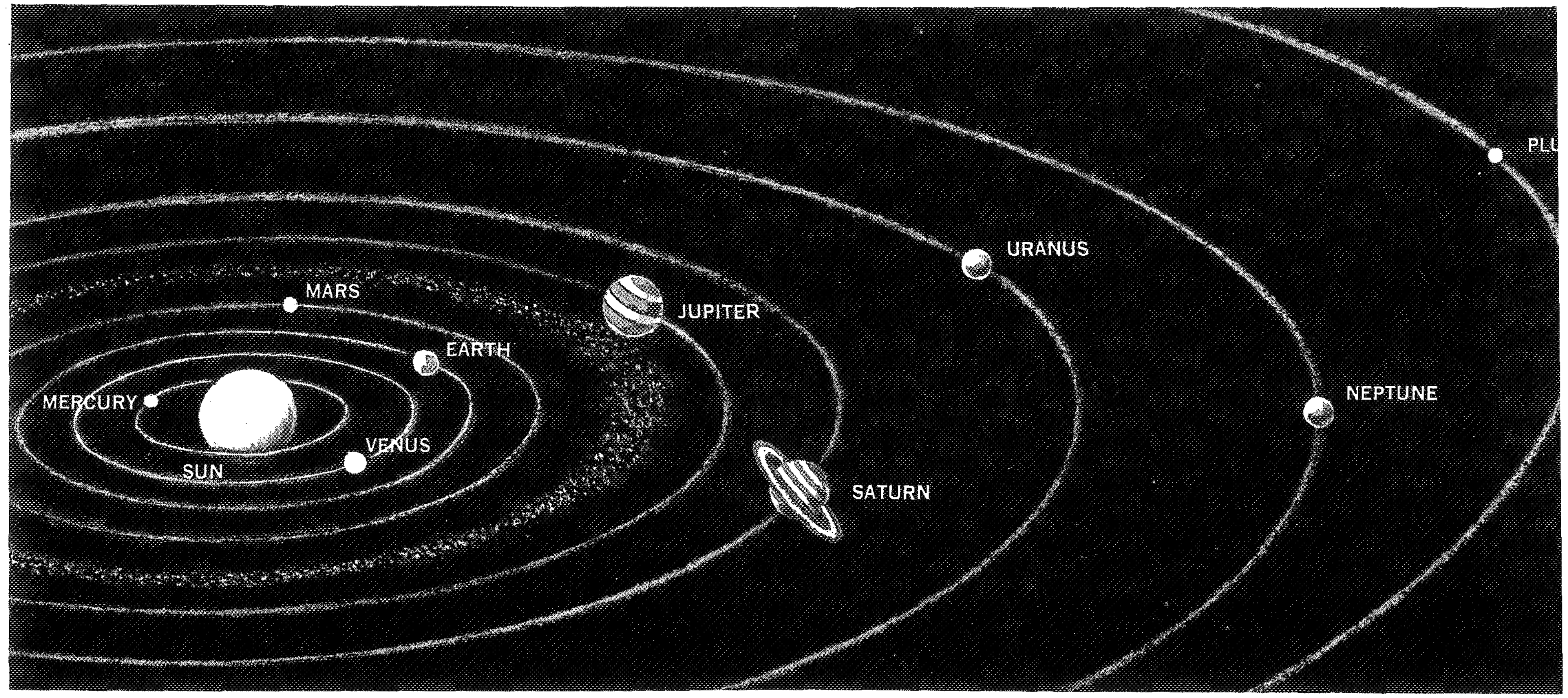
Delta launch vehicle carrying TIROS III meteorological satellite rises from launch pad at Cape Kennedy, Fla., July 12, 1961.

Blockhouse 34, Cape Kennedy, during flight test of 1.5-million-pound-thrust Saturn, October 27, 1961.



CHAPTER III

THE SOLAR SYSTEM



The solar system man hopes to explore is tiny in relation to the universe as a whole, but it is an area of tremendous magnitude in earth terms. Its primary, our sun, is a star located at the center of the system with nine planets revolving around it in near-circular orbits. Some of the planets, like earth, have natural satellites of their own (Jupiter has 12), and there are thousands of other bodies moving within the system.

The planets are held in their orbits by the sun's gravity. They all move in the same direction around the sun and their orbits lie in nearly the same plane, with Pluto the exception. Their orbital speeds are higher near the sun. Mercury, the planet nearest the sun, makes a circuit in 88 days. Earth's period of revolution is 365¼ days. Distant Pluto, more than 3½ billion miles from the sun takes 248 earth-years to make one circuit.

THE SUN

The sun represents more than 99 percent of the total mass of the solar system. Its mass is 330,000 times that of earth's and its volume more than a million times greater. The surface temperature of the sun is about 10,300° F. and the temperature at the interior some 50 millions of degrees F.

Every 11 years, the number of dark spots on the solar surface, called sunspots, reaches a maximum. These spots show strong magnetic fields. During the maximum of a sunspot period, the sun shows marked activity in shorter "wavelengths"—X-rays and ultraviolet radiation. Frequent solar eruptions and solar flares occur. These produce definite effects on earth, such as ionospheric disturbances, magnetic storms, interruptions of radio communications, unusual auroral displays, and a lowering of the average cosmic ray intensity. Giant solar flares are a hazard to manned space exploration in that they may subject man to lethal doses of radiation. A reliable system of forecasting major solar flares is crucial to the safety of men in space.

THE EARTH

The earth is fifth in size among the nine planets. It has a diameter of 7,927 miles at the Equator, and 7,900 miles at the poles. The earth's circumference is about 25,000 miles and it has an area of approximately 196,950,000 square miles. It travels around the sun an average speed of 18.52 miles per second.

Life on earth is sustained by the light and the heat of the sun. Earth's weather and even its atmospheric conditions are greatly affected by solar energy.

Atmospheric pressure at the surface of the earth amounts to about 1 ton per square foot. This pressure decreases as the altitude increases. Thus, 99 percent of the atmosphere lies below 20 miles and all but one-millionth of the atmosphere lies below 60 miles.

Although there is no exact or recognized boundary, this fact has led many space scientists and space writers to place the beginning of space—as far as earth is concerned—at 60 miles above the earth's surface.

THE MOON

The moon is a satellite of the earth and revolves about earth from west to east every 27 days, 7 hours, and 43 minutes. It accompanies earth on its annual revolution about the sun. The moon's distance from earth varies from 221,463 miles when the moon is at perigee (nearest to the earth) to 252,710 miles when the moon is at apogee (farthest from the earth). The mean distance is 238,857 miles.

The moon is 2,160 miles in diameter. Its mass is about one-eightieth that of earth and its volume one forty-ninth. The area of the moon is about one-fourth the surface of the earth and its circumference is about 6,800 miles.

Moon's orbit around earth is an ellipse and its orbital speed averages 2,287 miles per hour. It travels faster near perigee and slower near apogee. Because it rotates in exactly the same length of time as it takes to revolve about earth, the moon always presents its same side toward earth. It appears to have no atmosphere.

The moon has definite mountain ranges and many of its areas are covered with closely ranged peaks. Many of these tower 20,000 feet high and some rise to nearly 30,000 feet. On the side visible to earth, the moon has about 30,000 craters of varying depths, probably caused by meteors.

Early astronomers thought that certain dark areas of the moon were covered with water and named them as seas and oceans. Actually, the moon has had no trace of water within historical time and most astronomers believe that it is covered by a layer of dust. However, the character of the lunar surface fundamentally is still an important scientific unknown.

From the scientific standpoint, exploration of the moon is of great importance. Having neither wind nor rain nor significant mountain-building activity, the moon's surface is almost changeless. Thus, the moon offers an opportunity to study the matter of the solar system practically as it was billions of years ago. Such study may help answer some of the key questions of science—how was the solar system created; how did it develop; how did life originate?

THE PLANETS

The planets of the solar system, in order of distance from the sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.

Of these, space explorers are most interested in Venus and Mars, again because they are closest and because we know more about them.

The orbit of Mars is, of course, outside that of earth. At most favorable opposition, Mars is just over 34 million miles away (as compared to the 221,463 miles which separate the earth and the moon at most favorable opposition).

Mars and the earth move about the sun in the same direction but not at the same speed or distance. Mars makes one revolution about the sun in 687 earth-days, while the earth makes the same trip in 365¼ days.

Mars has a diameter of 4,140 miles, a little more than half that of earth, while its mass is only 0.1078 that of the earth.

Mars has an atmosphere but not one in which man could live. It has been compared to earth's at an altitude of 56,000 feet. At the Martian equator the temperature ranges from 50° F. above zero at noon to about 90° F. below zero at night.

Mars is frequently called the red and green planet because to the naked eye Mars appears as a dot of pale red. Through a telescope Mars is ordinarily a reddish disk. At certain seasons of the Martian year, green areas appear. These may or may not be green vegetation conforming to season changes. After several months the green shades change to yellow and finally into chocolate brown.

If these colors actually denote vegetation, most scientists believe it to be some kind of lichen which can grow in very little soil, live on a minimum of moisture, and withstand extreme cold.

Most earth scientists believe there is some form of primitive plant life on Mars but discourage any speculation about little green men.

VENUS—A GLOOMY, LIFELESS DESERT

The orbit of Venus, inside that of the earth, at times brings the cloud-covered planet to within 26 million miles, nearer to the earth than any of the other planets. Venus orbits the sun every 225 earth-days.

Venus has a diameter of 7,610 miles, or just about 317 miles smaller than the earth. Its mass is 82 percent of the earth's, and its surface gravity, 86 percent of earth's.

Venus is enveloped by an apparently unbroken mass of clouds that have blocked attempts at direct visual observation of the planet's surface. Knowledge of Venus has been dependent on analysis of radar echoes, sunlight reflection, and natural radio emissions from a distance of more than 26 million miles.

On December 14, 1962, NASA's Mariner II spacecraft achieved a significant breakthrough in advancement of knowledge about Venus by making the first relatively closeup study of the planet, flying as near to it as 21,648 miles. Analyses of data from Mariner and information from earth-based studies have indicated that Venus may be a gloomy, lifeless desert.

Mariner indicated that the temperature of Venus' surface may be as hot as 800° Fahrenheit. This temperature is hot enough to melt lead and precludes the possibility of life like that on earth.

The Venusian clouds, that start 45 miles above the planet's surface and rise to about 60 miles, have temperatures of 200° F. at their base; −30° F. at their middle level; and −60° F. at their upper level. Mariner detected no openings in the clouds.

Analysis of spectroscopic data obtained by earth-based telescopes indicates that carbon dioxide is a constituent of the Venusian atmosphere. Moreover, there are indications that the Venusian atmosphere is 10 to 30 times denser than earth's. Presumably, these atmospheric conditions contribute to the planet's high temperature by creating a greenhouse effect in which the sun's heat reaches the planet's surface but is hindered in reradiation to space.

Ground-based radar studies provide evidence that each Venusian day or night lasts more or less 112½ earth-days, and that on Venus, the sun rises in the west and sets in the east. Scientifically speaking, Venus appears to rotate every 225 days with respect to the sun and backward with respect to earth.

Ordinarily, because of Venus' indicated slow rotation, its night side should get very cold and its day side very hot. However, Mariner did not find any appreciable temperature difference on the planet. This suggests that the planet's atmosphere must be circulating vast quantities of heat from the day to the night sides. Such a massive heat transfer could generate searing winds that lash the planet's scorching surface.

Some radar reflections from Venus are characteristic of those made by sand or dirtlike material. If sand covers the surface of Venus, the high winds could create sand storms of tremendous proportions.

CHAPTER IV SPACE PROBES AND SATELLITES—GENERAL PRINCIPLES

MOTION OF BODIES IN SPACE

Any manmade vehicle launched into space will move in accordance with the same laws that govern the motions of the planets about the sun, and the moon about the earth.

Prior to the time of Copernicus, man generally accepted the belief that the earth was the center of the solar system. His efforts to explain the motion of the planets on this assumption failed. Copernicus pointed out that the difficulties in explaining the planetary movement observations disappeared if one assumed that the sun was the center of the solar system, and that the planets revolved about the sun.

Years later, Galileo took up the defense of Copernicus' theory. With experiments such as the dropping of two different size masses from the Leaning Tower of Pisa, he started the thinking which led to our current understanding of the laws of motion.

In the early 17th century, Johannes Kepler formulated three laws which described the motions of the planets about the sun. They are:

1. Each planet revolves about the sun in an orbit that is an ellipse, with the sun at one focus of the orbital ellipse.
2. The line from the center of the sun to the center of a planet (called the radius vector) sweeps out equal areas in equal periods of time.
3. The square of a planet's period of revolution is proportional to the cube of its mean distance from the sun.

These laws, together with Sir Isaac Newton's laws of gravitation and motion, are important to space research. They make it possible to deduce mathematically the motions of the planets and other bodies in the solar system and to calculate flight paths to these bodies.

GRAVITY

Newton (in addition to his laws of motion) formulated the law of gravitation, which is concerned with the mutual attraction, or "pull," that exists between all particles of matter. In its most simple form, Newton's law says this:

All bodies, from the largest star in the universe to the smallest particle of matter, attract each other with what is called a gravitational attraction.

The strength of their gravitational pull is dependent upon their masses. The closer two bodies are to each other, the greater their mutual attraction.

Specifically, two bodies attract each other in proportion to the product of their masses and inversely as the square of the distance between them.

Earth, a body moving in space, has a gravitational pull. It pulls anything within its sphere of influence toward the center of the earth at increasing speed. This acceleration of gravity on earth at its surface is used as a basic measurement. It is known as 1 gravity or 1 "g".

Earth's gravitational influence is believed to extend throughout the universe, although the force weakens with distance and becomes virtually impossible to measure.

Any vehicle moving in space is subject to gravity. The vehicle, having mass, is itself a space body. Therefore it attracts and is attracted by all other space bodies, although the degree of attraction of distant bodies is too small to require consideration. A vehicle moving between the earth and the moon would be influenced by both bodies, and also by the sun.

SATELLITES AND SPACE PROBES

Man's activities in the field of space exploration have been confined thus far to space probes and satellites.

A space probe has come to be known as any vehicle launched into space which does not and is not intended to achieve moon or planetary orbit. (It may fall into sun orbit.) It is an instrumented vehicle launched into space for the purpose of obtaining new knowledge through the instruments it carries.

Sometimes the aim of such a probe is simply to make measurements or gather data of any kind deep in space and without any particular reference to any celestial body such as the moon or a planet. In such cases it is sufficient to simply project the object into space at speed great enough to achieve the distance desired. In other instances, it may be desired to project the space probe close to the moon or Venus, for example. In such cases exact guidance and timing requirements must be met. Velocity requirements vary for different missions.

A satellite is an attendant body which revolves about another body, usually with reference to the solar system. (The body revolved about is known as the primary.) Up until the last decade the term had been used almost exclusively in reference to natural celestial bodies, such as the moon revolving about the earth. Since 1957 it has also come to mean a manmade body placed in orbit around the earth or around any other celestial body—and in such cases is an artificial satellite.

An artificial satellite of the earth, for example, is simply a manmade moon. In revolving about the earth it must obey the same laws that the natural moon does, and that the planets obey in revolving about the sun.

WHAT KEEPS A SATELLITE UP?

As indicated above, satellites are subject to the same physical laws that govern motions of all bodies in space. These include not only Newton's laws of gravity and Kepler's laws of planetary motion but also Newton's laws of motion.

One of the latter laws is that a body remains at rest or in a state of motion *in a straight line* unless acted upon by an external force. Obviously, the external force drawing the satellite from a straight path is earth's gravity.

A part of Newton's second law of motion is that a force acting upon a body causes it to accelerate in the direction of the force. For one thing, this means that earth's gravity causes the satellite to fall toward earth.

What occurs with a satellite is that gravity to a degree has overcome the kinetic energy, or energy of motion, that tends to move the satellite in a straight line. Therefore, the satellite veers toward earth.

However, the satellite's kinetic energy is pushing the satellite forward every second that gravity is drawing the satellite inward. The satellite has sufficient kinetic energy so that its downward curving path continually misses or overshoots the earth. As a result, the satellite's motion is an elliptical or circular orbit around earth.

LAUNCHING A SATELLITE INTO ORBIT

To place a satellite in orbit it is necessary to accelerate the vehicle to orbital velocity, a velocity at which its speed is offset by gravity so that it will go into orbit as explained above.

Since gravitational attraction decreases with the distance from the primary, a different orbital velocity is required for each distance from the primary.

For a satellite relatively close to earth, around 200 miles, the velocity required is about 18,000 miles per hour.

A vehicle placed in orbit as far away as the moon (roughly 240,000 miles) would need only to have an orbital velocity of about 2,000 miles an hour.

This does not mean that attainment of the far-out orbit would be easier. Considerable additional force must be used to push a satellite out to that distance.

It is virtually impossible to launch a satellite into an exactly circular orbit. (For one reason the earth is not precisely spherical.) Usually, its path is elliptical. The perigee (distance nearest the earth) may be only a hundred-or-so miles while the apogee (distance farthest from the earth) may be many thousands of miles from earth.

A satellite launched into an orbit parallel to and 22,300 miles over the Equator is termed "synchronous," "fixed," or "stationary." This satellite will take about 24 hours to complete one trip around the world, the same time the earth takes for one full rotation on its axis. Therefore, the satellite remains fixed more or less over one spot on earth. To a ground observer, the satellite would appear to stand still.

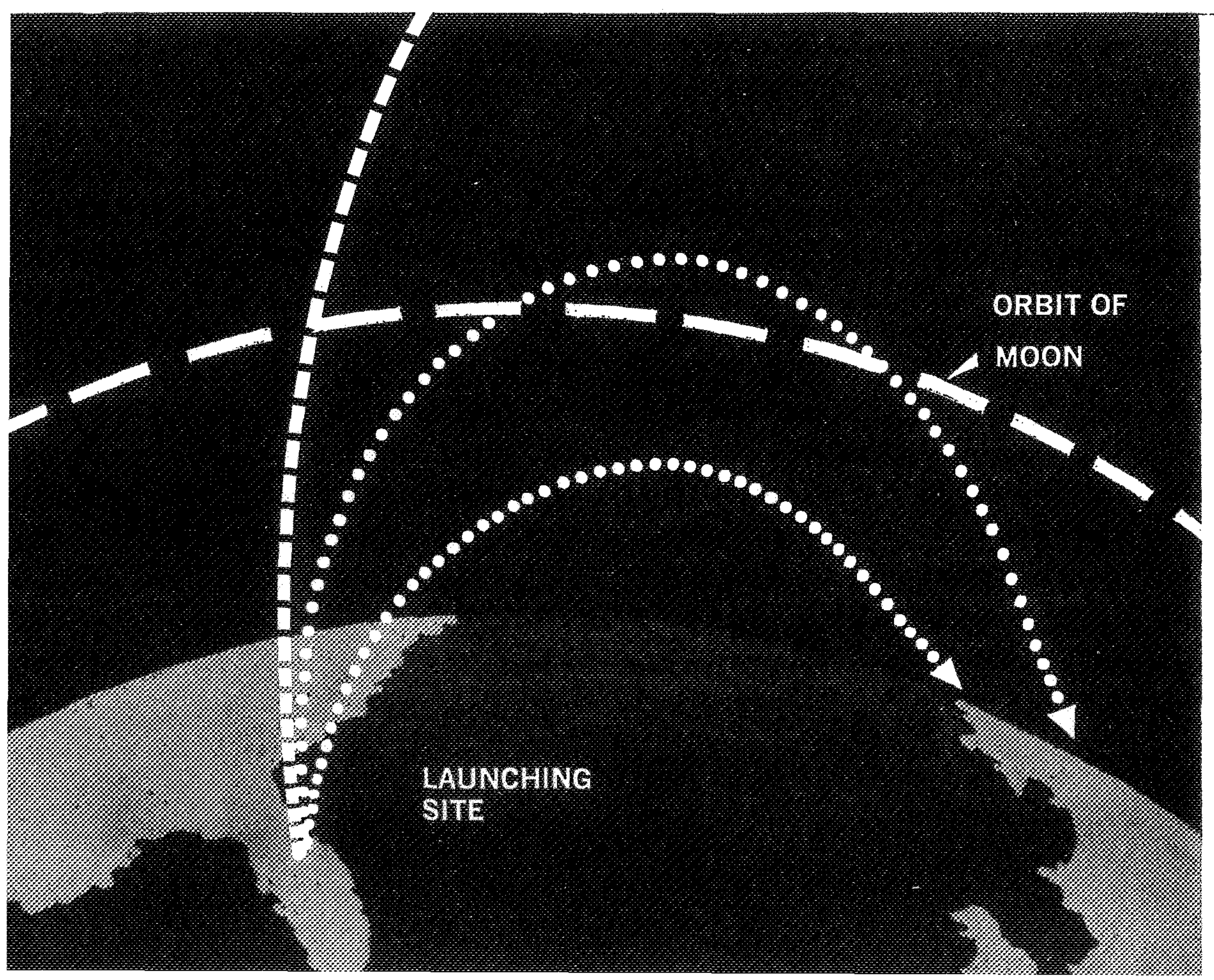
ESCAPE VELOCITY

Any space probe or satellite launched on a space exploration mission must achieve escape velocity; that is, must overcome the pull of earth's gravity. This is done by accelerating the vehicle to a given speed. Since the force of earth's gravity declines with distance from the center of the earth (as noted before), the minimum speed required to overcome gravity varies.

At or near the earth's surface, the speed required to overcome gravity is slightly more than 7 miles a second, or about 25,000 miles per hour. At an altitude of 500 miles, the speed needed to escape earth drops to 23,600 miles per hour. At a 5,000-mile altitude, the required speed is 16,630 miles per hour.

The attainment of escape velocity does not mean that the spacecraft is free of earth's gravitational influence (which extends to infinity). It means that even without additional power, the craft will not fall back to earth.

Parabolic path followed by probe reaching escape velocity (from the surface of the earth 25,000 miles per hour).



Imagine a launch vehicle rocketing a spacecraft from earth. The rocket follows an elliptical path. If its velocity reaches 25,000 mph, the ellipse does not close and the spacecraft completely escapes from earth. As it races into space, the spacecraft may be slowed down by earth's gravity, but it will continue outward—until it becomes subject to the sun's gravity—and never return to earth.

Launching a spacecraft into an escape trajectory is somewhat analogous to rolling a ball up a smooth, frictionless hill whose slope is continuously decreasing. (The slope of the hill compares to the force of gravity.) If the ball is not rolled fast enough, it will gradually slow until its velocity is exhausted. At this point it will momentarily pause before rolling back down hill, arriving at the bottom at the same velocity at which it left. There are several ways to succeed in getting the ball up the hill: (1) throw it with greater initial force; (2) carry it part way up the hillside before throwing; or (3) apply continual force until the top is reached.

Similarly—in space exploration a vehicle may be launched into space by application of the same principles mentioned above. As in (1) we can provide sufficient initial thrust to accelerate a rocket to 25,000 miles an hour, total escape velocity. It is possible to do this with a single-stage vehicle if we provide it with sufficient power to give it the thrust necessary before burnout. The second method (2) involves using a rocket to get through the lower atmosphere while reserving additional rockets for later stages of the flight through the upper and less dense atmosphere and into space. The third method of the analogy (3)—that of applying continual power—is possible but not efficient with present propulsion systems.

Spacecraft launchings today are usually accomplished by the second method. Two or more rockets are stacked, one on top of another, and each of these stages fired in sequence. The velocity increases because each succeeding rocket before firing is traveling with the velocity achieved by the preceding stage. In addition, the gravitational attraction is less because of the altitude already reached by the earlier stages. Lack of drag from atmospheric friction at high altitudes also provides an advantage.

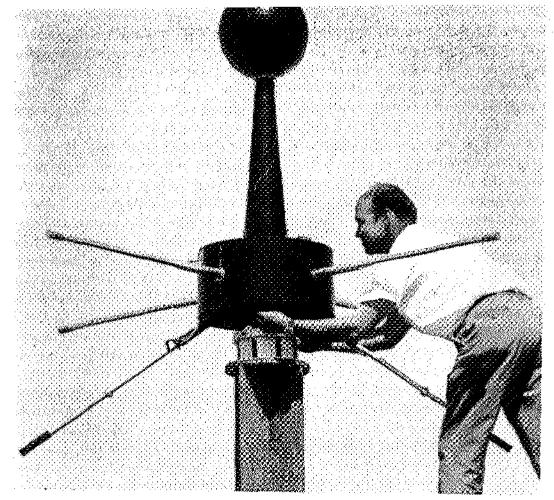
CHAPTER V

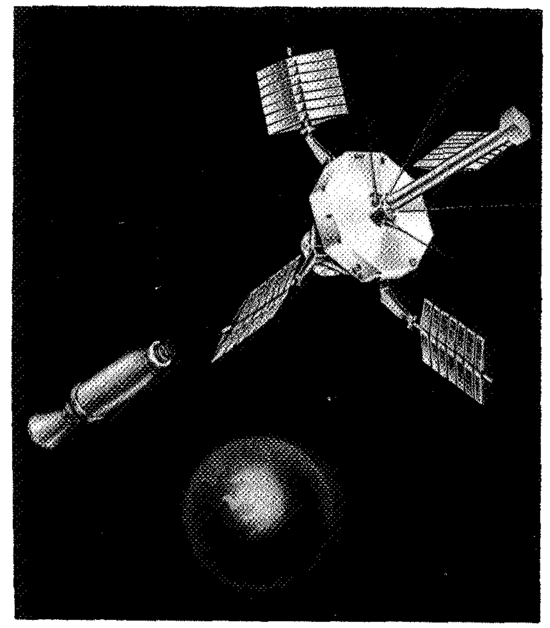
UNMANNED SATELLITES AND SOUNDING ROCKETS

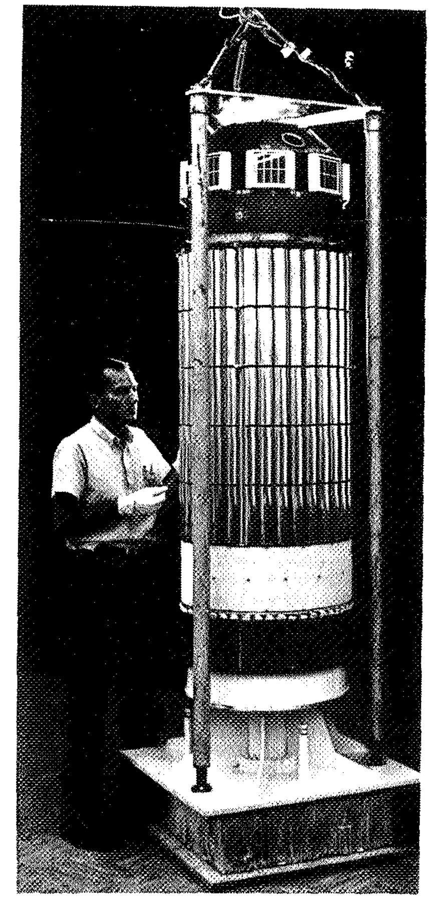
This chapter describes space programs in which satellites and sounding rockets are employed to increase knowledge about the earth and its cosmic environment and about the universe. In the few short years since orbiting of the first artificial satellite, man has gained from his satellites and sounding rockets new and often startling knowledge about earth and the portion of space which surrounds it. Among these findings are:

- Discovery of the intense Van Allen Radiation Region in space around the earth.
- Determination that the earth's geoid is pear shaped with the stem end at the North Pole, and not a sphere flattened at the poles.
- Verification of a theory that sunlight exerts pressure.
- Mapping of the magnetic fields girdling the earth.
- Increased understanding of the effects of solar events on the upper atmosphere and magnetic field.
- Evidence that micrometeoroids (tiny bits of matter in space) can puncture thin metallic walls. (Previously, this hazard posed to spacecraft was presumed but not proved.)

A résumé of U.S. programs for the exploration and practical utilization of space by means of unmanned instrumented satellites and sounding rockets is presented below.







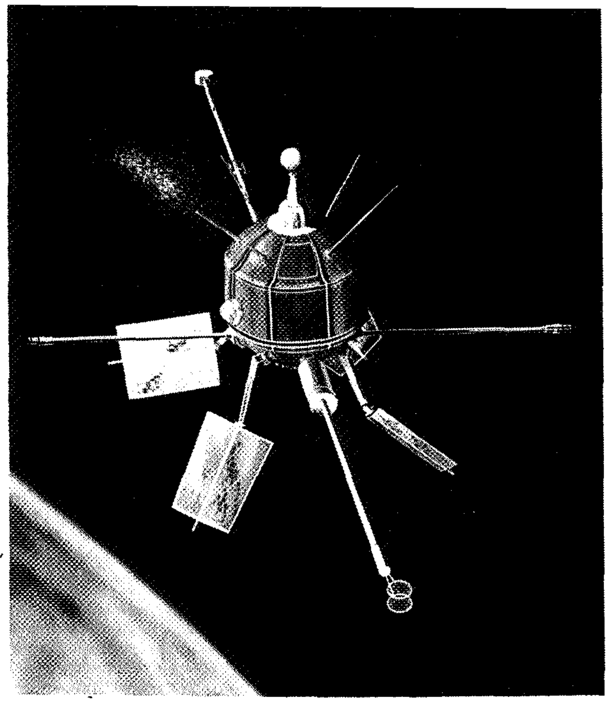
Contours of Explorer satellites are about as diverse as their missions: Explorer X (top left) to acquire data on magnetic fields in space. (Launched March 25, 1961.)

Explorer XII (bottom left) to gather data on radiation and magnetic fields in space (artist's conception). (Launched August 16, 1961.)

Explorer XVI (right) to obtain data on micrometeoroids (cosmic dust) (artist's conception). (Launched December 16, 1962.)

SCIENTIFIC SATELLITES AND SOUNDING ROCKETS

The Explorer Satellites—These are satellites designed to carry a limited number of scientific experiments. Their orbits, which vary widely in altitudes and inclination, are especially selected to serve the purposes of the particular experiments aboard. Because Explorers are of relatively simple design and take less time to prepare and assemble, they are widely used in NASA's cooperative international satellite program. Explorers are used by NASA to study (1) the atmosphere and ionosphere, (2) the magnetosphere and interplanetary space and (3) astronomical and astrophysical phenomena.



Artist's conception of Ariel, United-Kingdom-United States satellite launched to study the ionosphere.

Explorer 1, the first satellite put in orbit by the United States, was launched January 31, 1958. Weighing 30.8 pounds, Explorer I measured cosmic rays, micrometeoroids, and temperature. In confirming the existence of the theorized Van Allen radiation region, Explorer I made the most important single contribution of the International Geophysical Year.

Succeeding Explorers, of many different shapes and sizes, have obtained great quantities of valuable information on meteoroids; temperatures and pressures; radiation and magnetic fields; effects of solar activity on the earth environment; behavior of energetic particles; solar pressure; composition of the ionosphere; and gamma rays. Others have mapped the near-earth radiation region and the area of the earth's magnetic influence in space.

Vanguard—Project Vanguard was inaugurated as part of the American program for the IGY. The first Vanguard satellite went into orbit on March 17, 1958, reaching an apogee (highest point) of 2,453 miles and a perigee (lowest point) of 409 miles. Its scientific payload weighed 3¼ pounds and returned geodetic observations including the determination that the earth's geoid is slightly pear shaped. Vanguard I is still in orbit and is expected to continue circling the earth for several hundred years. One transmitter, powered by solar cells, has continued to send signals.

The second Vanguard was launched in February 1959, with a payload of 20¾ pounds for weather data collection. The third Vanguard, launched September 1959, carried 50 pounds of instruments and provided a comprehensive survey of the earth's magnetic field, detailed location data on the lower edge of the Van Allen Radiation Region, and count of micrometeoroid impacts.

International Satellites—These are joint projects of mutual interest carried out by scientists of the United States and other countries in line with policies set down in the Space Act of 1958. By 1964, ten such cooperative satellite projects with four nations were contemplated, in progress or completed.

In some cases, experiments developed by other nations are included in satellites made and launched by the United States. In others, both experiments and satellites are built by the other nations and the United States provides the launch vehicles, launch facilities and other supporting effort. In addition, experiments from other nations sometimes are selected in competition with domestic proposals for inclusion on NASA satellites.

ARIELS—Ariel I, a cooperative project with the United Kingdom, was the world's first international satellite. It was launched by NASA, April 26, 1962, with experimental apparatus built by the United Kingdom. It has provided information on the variation of cosmic rays with earth latitude and intensities of radiation in the Van Allen radiation region. Ariel I information also has enabled scientists to correlate solar data with ionospheric properties.

Ariel II, containing three British-built experiments was launched March 27, 1964, to measure galactic radio noise, vertical distribution of ozone in the upper atmosphere and the number and size of micrometeoroids. A third British satellite is planned to extend the studies.

ALOUETTE—The Canadian satellite Alouette was orbited by a U.S. launch vehicle September 28, 1962, to gather data on electron density in the ionosphere (by means of radio echos), cosmic noise, radio signals produced by atmospheric lightning, and to detect energetic particles. A second, redesigned Alouette will complement and extend the same experiments.

ISIS—A series of completely new spacecraft called ISIS, for International Satellite for Ionospheric Studies, is planned. Additional experiments considered for the ISIS series include electron and ion probes to measure the temperature and densities of hydrogen, helium and oxygen present at satellite altitudes and an ion mass spectrometer to confirm the identification of individual ions.

FRENCH-U.S. PROJECT—Agreement has been reached for the United States to launch a satellite funded and built by France to investigate very low frequency (VLF) electro-magnetic wave propagation in the ionosphere and irregularities of ionization distribution in the ionosphere. Other experiments aboard will study VLF propagation waves and radio noise, antenna impedance, electron densities, and transmission characteristics. Feasibility of the satellite's experiments was determined by a cooperative sounding rocket program successfully conducted at NASA's Wallops Station.

SAN MARCO—This cooperative project with Italy calls for launching a satellite to measure atmospheric density and ionosphere propagation. The experiments and the spacecraft will be built by the Italians for launching aboard a NASA Scout. The launch site will be an Italian-operated platform in the Indian Ocean off the east coast of Africa. It is planned to put the satellite into an equatorial orbit.

WORLDWIDE—The United States cooperates with about 100 nations in sounding rocket studies, in meteorological and communications satellite programs and in tracking and acquiring data from satellites and lunar and interplanetary spacecraft, both manned and unmanned, and in programs of technical training and educational and visitor exchanges.

Interplanetary Explorer Satellites—The Interplanetary Explorers provide data on radiation and magnetic fields between the earth and moon for scientific research and to aid in planning for the Apollo manned flight to the moon. The first of this series, Explorer XVIII, was launched November 27, 1963, and achieved an orbit with an apogee of about 23,000 miles and perigee of approximately 120 miles. (The term IMP for Interplanetary Monitoring Platform has been used for the Interplanetary Explorers.)

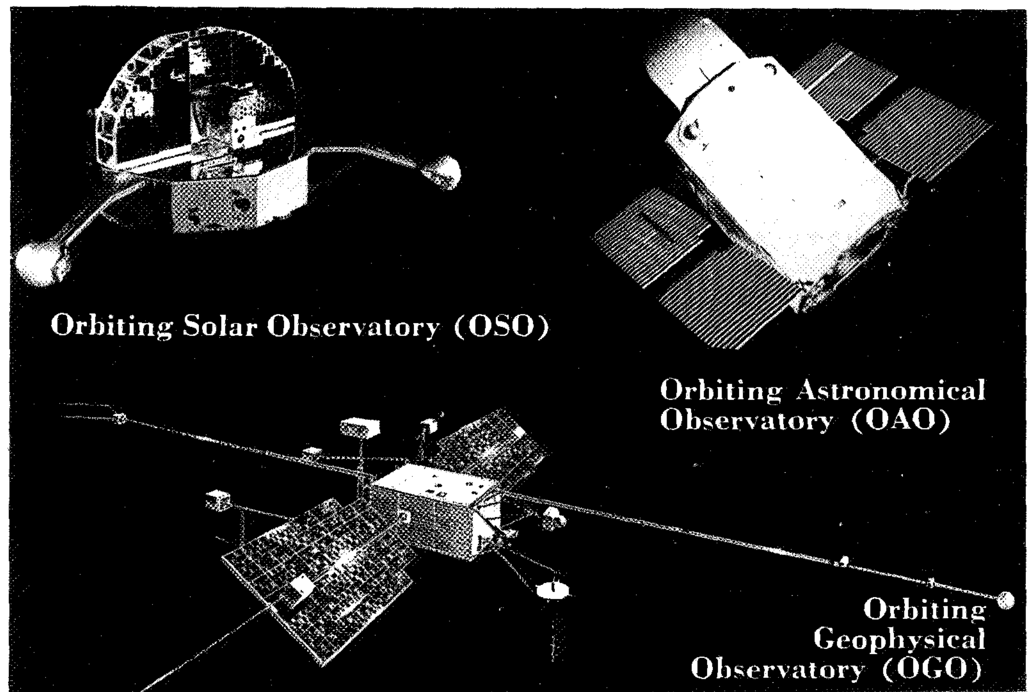
Initial Interplanetary Explorer Satellites are powered by solar cells. Solar cells are photoelectric devices that convert sunlight to electricity; they provide power for most U.S. spacecraft. Later Interplanetary Explorer Satellites will be equipped with nuclear generators that convert heat from the radioisotope plutonium 238 into electricity. (See "Transit," below.) Advantages of nuclear generators over solar cells are that they are not adversely affected by natural radiation; and they eliminate the requirement for devices to orient the spacecraft so that its solar cells face the sun.

Standardized Satellites—Several types of standardized satellites are being developed, including the orbiting solar, astronomical, and geophysical observatories.

The standardized satellite is a basic structure, complete with power supply, telemetry, data storage facilities, and other fundamental equipment. Its modular compartments will be capable of carrying many different experiments on any one mission. Each of the standardized satellite's modules will be a simple, plugged-in electronic building block. Thus the structure can be fabricated independently, with any experiment designed to fit one or more modules.

ORBITING ASTRONOMICAL OBSERVATORY (OAO)—Man's study of the universe has been narrowly circumscribed because the atmosphere blocks or distorts much electromagnetic radiation (X-rays, infrared rays, ultraviolet rays) from space. These emissions can tell much about the structure, evolution, and composition of celestial bodies. OAO will make it possible to observe the universe for extended periods from a vantage point above the shimmering haze of the lower atmosphere that contains 99 percent of earth's air.

OAO will see celestial bodies shining steadily against a black background. It will clearly delineate features which from the earth are either fuzzy or indistinguishable. Astronomers predict that OAO will furnish a wealth of new knowledge about the solar system, stars, and composition of space.



OAO will be a precisely stabilized 3,200-pound satellite in a circular orbit about 475 miles above the earth. It will carry about 1,000 pounds of experimental equipment such as telescopes, spectrometers, and photometers. The scientific equipment will be supplied to NASA by leading astronomers.

The standardized OAO shell, which will be employed for many different types of missions, will contain stabilization, power, and telemetry systems. Two silicon solar-cell paddles and nickel-cadmium batteries will furnish a minimum average usable power supply of 270 watts.

The height of the satellite is about 9⅔ feet with sunshade down. The satellite is about 16.2 feet wide with solar paddles extended. Shell width is about 6.6 feet.

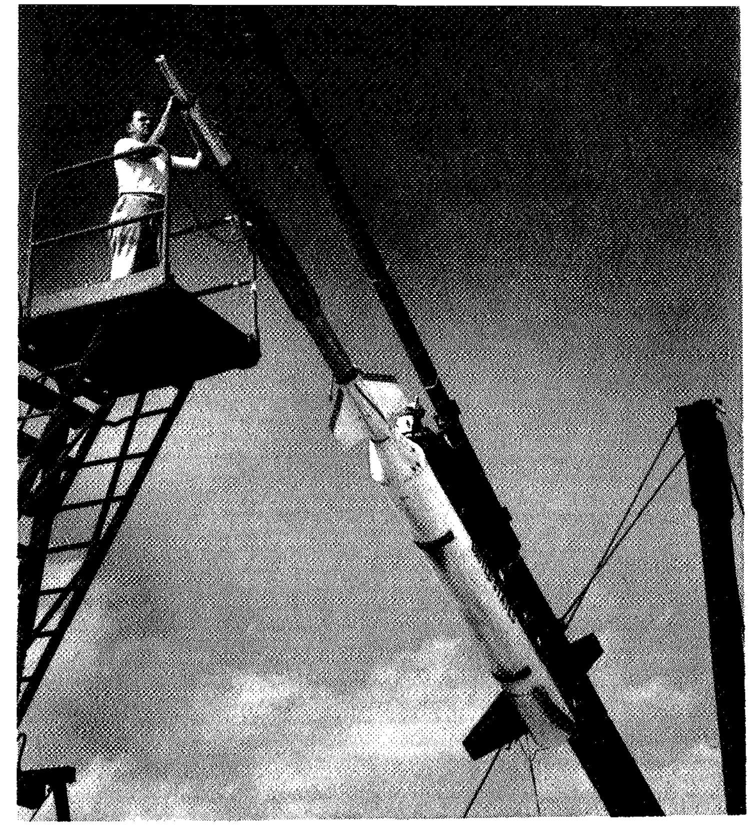
ORBITING SOLAR OBSERVATORY (OSO)—OSO is a series of satellites intended for intensive study of the sun and solar phenomena from a point above the disruptive effects of the atmosphere. The observatory is designed to carry such instruments as X-ray and Lyman Alpha spectrometers, neutron flux sensors, and gamma ray monitors. Like OAO, OSO scientific equipment is supplied NASA by leading astronomers.

The first of these observatories, OSO 1, was launched March 7, 1962. From an approximately 350-mile altitude, nearly circular orbit, the 440-pound spacecraft pointed instruments at the Sun's heart with an accuracy comparable to hitting a penny a half mile away with a rifle bullet.

Data from OSO 1 have provided deeper insight into the functioning of the sun, and suggest that techniques could be developed for forecasting the major solar flares that flood space with intensities of radiation lethal to man and detrimental to instruments.

OSO 1 and its comparable successors are about 37 inches high, 44 inches in diameter at the wheel-shaped section, and weigh about 350 pounds. OSO will be launched into a circular orbit about 300 miles above the earth. Power supply will originate from solar cells and nickel-cadmium batteries.

ORBITING GEOPHYSICAL OBSERVATORY (OGO)—OGO is a standardized satellite which will be able to carry 50 different geophysical experiments on a single mission. Scientific instruments will vary from mission to mission but the basic satellite structure will be the same.



Nike-Cajun sounding rocket

OGO will be launched on a regular schedule into preassigned trajectories. When launched into an eccentric orbit (perigee about 150 miles, apogee about 60,000 miles), OGO becomes EGO (Eccentric Geophysical Observatory). EGO will study energetic particles, magnetic fields, and other geophysical phenomena requiring such an orbit.

When launched into a low-altitude polar orbit (apogee about 500 miles, perigee about 140 miles), OGO is POGO (Polar Orbiting Geophysical Observatory. In this orbit, it will be instrumented chiefly for study of the atmosphere and ionosphere, particulary over the poles.

OGO will be about 6 feet long and 3 feet square, excluding solar paddles, and weigh about 900 pounds, including 150 pounds of instruments. Later versions may weigh about 1,500 pounds and include a spherical piggyback satellite. Certain experimental sensors will be placed on booms extending from OGO because they might be affected by the satellite's body. Solar cells and nickel-cadmium batteries will provide an average power supply of 50 watts.

Discoverer (U.S. Air Force)— Using a Thor-Agena booster, the first Discoverer was launched February 28, 1959, with a 245-pound instrument payload. It was the first U.S. satellite to be placed in polar orbit; that is, it circled the earth at the poles instead of the Equator.

The next six Discoverers were launched with the primary mission of testing experimental techniques for space cabin recovery either at sea or in midair. The first such recovery—by a ship-helicopter team at sea—was accomplished on August 11, 1960, from Discoverer XII which had been launched the day before.

The first midair recovery was Discoverer XIV at 8,000 feet by a C–119 aircraft 360 miles southwest of Hawaii on August 18, 1960. The reentry vehicle weighed 300 pounds and was ejected from the satellite by a timing device. Its descent was slowed by retrorocket and parachute.

Space capsule recovery is foremost among the techniques being developed in the Discoverer program. In addition to checking recovery techniques, the Discoverer satellites carry devices to gather data on propulsion, communications, and orbital performance. Several other ejected payloads have been recovered in midair. Discoverer XXI, launched in February 1961, achieved the first successful start of a rocket (the Agena) in space.

Discoverer satellites have provided significant data on atmospheric phenomena and on radiation, micrometeoroids, magnetic fields, and natural radio signals in space.

Sounding Rockets—Man's early adventures into atmosphere and space were with sounding rockets. The first were accomplished by the early rocket societies in several countries and more notably by Dr. Robert Goddard, an American. Sounding rockets may be of one or more stages. Generally speaking, they are designed to attain altitudes up to about 4,000 miles and return data by telemetry or capsule recovery. Those designed for lower altitude may simply investigate geophysical properties of the upper atmosphere surrounding the earth. These have returned information on atmospheric winds, the earth's cloud cover, and the properties of the ionosphere. Higher altitude sounding rockets have sent back data on cosmic rays, the radiation belts, ultraviolet rays, solar flares, and many other cosmic phenomena. Literally hundreds have been launched in this country and by other nations.

Sounding rockets permit the performance of scientific studies in a vast region of the atmosphere too low for satellites and too high for balloons to reach. The area ranges from about 20 to 100 miles in altitude. Another significant, but less known, value derived from sounding rockets is the in-flight development testing of instruments and other equipment intended for use in satellites. By first checking out the performance of these components during sounding rocket flights in the near-earth space environment, greater satellite reliability is assured and costly failures may be avoided. New experimenters from universities, industry and foreign organizations find the sounding rocket program a logical and inexpensive starting point for gaining experience in space science techniques.

When instrumented payloads pass the 4,000-mile altitude they sometimes are called geoprobes. Examples of geoprobes are the P–21, launched October 19, 1961, and the P–21a, launched March 29, 1962, to measure ionosphere characteristics by day and by night. Both were carried to about 4,200 miles altitude by

Table 1.—NASA SOUNDING ROCKETS

Rocket	Payload Weight (Pounds)	Operating Altitude (Miles)
Aerobee 150 and 150A	150	130
Aerobee 300	50	230
Arcas	12	30
Argo D–4 (Javelin)	100	630
Argo D–8 (Journeyman)	100	1380
Astrobee 1500	100	1470
Loki	6	40
Nike-Apache	50	160
Nike-Cajun	50	110

NASA Scout launch vehicles. Their results confirmed the existence of a helium gas region in the atmosphere wedged between a region where oxygen predominates and one where hydrogen is the dominant gas. Explorer VIII, launched November 3, 1960, provided the first indication of the helium layer.

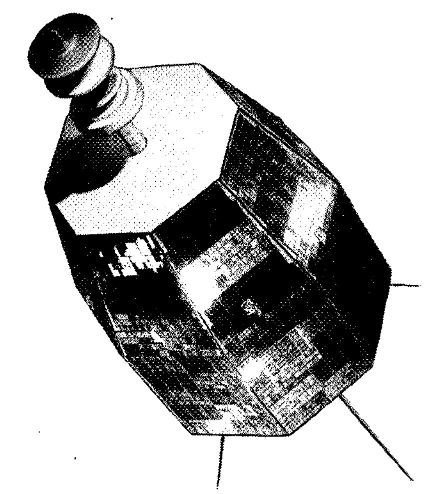
Typical of sounding rockets employed in scientific programs are:

AEROBEE—First fired November 14, 1947, Aerobee launchings included the solar beam experiment program to monitor background radiation from the sun during quiet periods of solar activity; studies of ultraviolet radiation of the stars and nebulae; gamma radiation studies; and many other scientific programs.

NIKE—With upper stages, the Nike has been employed largely in upper atmosphere experiments. In one experiment, a series of small grenades are ejected and exploded at intervals along the rocket's trajectory. The explosion's location is determined by radar and/or optical methods; the time of arrival of the sound wave front at the ground is measured by microphones. This information with appropriate meteorological data on the lower altitudes indicates wind and temperature as a function of altitude. Another kind of experiment releases a sodium vapor trail which glows orange in twilight along the upper portion of the rocket's trajectory. The deformations of this trail are recorded on time lapse photographs from which wind information is derived. A third method is the pitot-static tube experiment by which atmospheric density, temperature, and wind data are derived from measurements of pressure during flight of the rocket.

ARGO—Argo rockets have been utilized in a number of experiments, the most spectacular of which was NERV (Nuclear Emulsion Recovery Vehicle). On September 19, 1960, a four-stage Argo D–8 fired an 83.6-pound NERV from Point Arguello, Calif., to a maximum altitude of 1,260 miles. NERV carried a nuclear emulsion (a photographic film extremely sensitive to charged particles) which was exposed during flight to record radiation particles. NERV was recovered in the Pacific Ocean about 1,300 miles from Point Arguello. Its emulsion has provided significant data on radiation, particularly in the Van Allen Radiation Region.

ARCAS AND LOKI—These small meteorological sounding rockets provide information about the atmosphere at altitudes from about 20 to approximately 40 miles. The rockets eject such sensors as chaff, parachutes, inflated spheres, and bead thermistors at the high points of their trajectories and these provide information about the atmosphere as they fall to earth. (The bead thermistor is in a package that radios its temperature information to earth. The chaff, parachute, and inflated sphere provide information on wind. The inflated sphere also provides information on air density.)



Relay communications satellite

Biosatellites—The Biosatellites will carry into space a wide variety of plants and animals ranging from micro-organisms to primates. The experiments are aimed primarily at studying the biological effects of zero gravity or weightlessness, weightlessness combined with a known source of radiation, and removal of living things from the influence of the earth's rotation. They are expected to contribute to knowledge in genetics, evolution, and physiology, and to gain information about the dangers facing man during prolonged flight in space.

APPLICATION SATELLITES

Space technology is being turned to immediate practical use in two ways. One is identifying and making widely known the new processes and techniques developed in the space program which can stimulate creation of new industrial processes, methods, and products, and add new dimensions to everyday living. Another involves development of satellite systems for aid in such fields as weather forecasting, communications, and navigation.

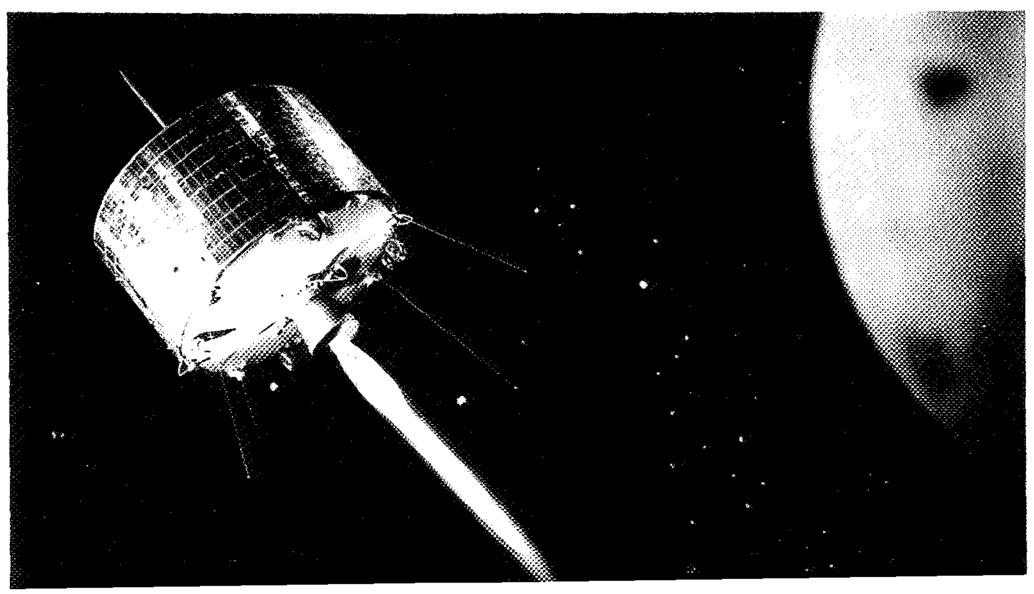
Echo—Echo I, orbited on August 12, 1960, proved that it is possible to communicate between distant areas on earth by reflecting radio microwaves from a manmade satellite. Echo I is fabricated of aluminum-vapor-coated polyester film 0.0005 inch thick (about half the thickness of the cellophane wrapping on a cigarette package). It is 100 feet in diameter and weighs 132 pounds. Radio signals are literally bounced off the satellite from one point on the earth to another.

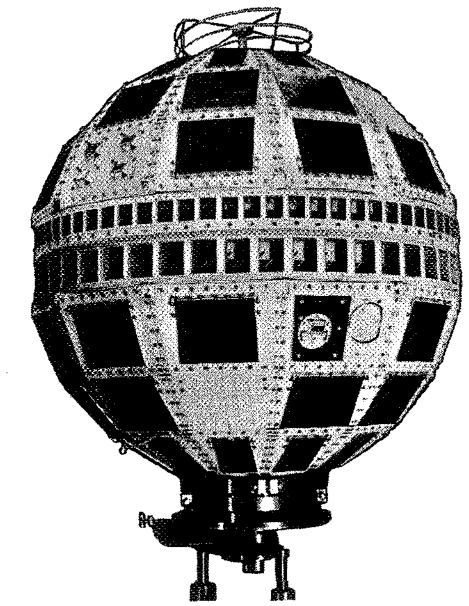
Echo II, launched January 25, 1964, is 135 feet in diameter—as tall as a 13-story building—and weighs 600 pounds. Made up of a laminate of aluminum foil and polymer plastic about 0.00075 inch thick, it is 20 times as rigid as Echo I. Echo II is the first satellite to be used in cooperation with the U.S.S.R.

Relay—NASA's Project Relay is designed to test intercontinental transmission of telephone, television, teleprint, and facsimile radio signals via a medium-altitude (several thousand to 12,000 miles) active-repeater satellite. "Active-repeater" refers to Relay's capability to receive, amplify, and retransmit signals. Relay is also instrumented to report on the functioning of its equipment and on radiation in space. The first Relay satellite, launched December 13, 1962, has made possible hundreds of demonstrations of transoceanic and intercontinental communication via satellite. Among its transmissions were color telecasts and the stirring black-and-white telecast of President Kennedy as he signed a congressional bill bestowing honorary American citizenship on Sir Winston Churchill, the United Kingdom's most honored statesman.

Relay 1 weighs 172 pounds. Including an 18-inch broadband antenna, it is 33 inches long. Its maximum breadth is 29 inches. Initially, Relay's orbit ranged from 820 to 4,612 miles above the surface of the earth.

Syncom communications satellite.





Telstar communications satellite

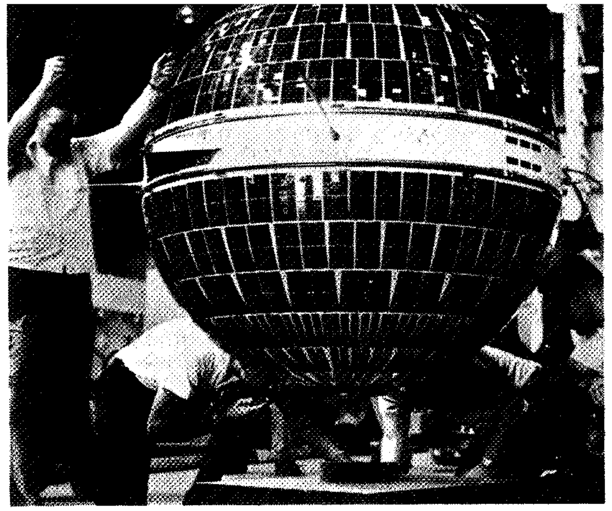
Relay II, launched January 21, 1964, was used in the first transmissions via communications satellite between the United States and Japan.

Syncom—Syncom is an experiment employing "active-repeater" satellites in "synchronous" orbits for a global communications system. "Synchronous" satellites, orbiting at 22,300 miles above the Equator, travel around the world in the same time that it takes the earth to rotate around its axis. The potential advantage of a "synchronous" communications satellite system is that newer satellites, theoretically as few as three, are needed for global coverage than if lower altitude satellites are used.

Syncom is a purely experimental satellite, is 28 inches in diameter, 25 inches high, and weighs 150 pounds, including the 90-pound apogee rocket motor that enabled it to attain the circular orbit about 22,300 miles above earth. Contact with Syncom 1, launched February 14, 1963, was lost shortly after the apogee motor stopped firing.

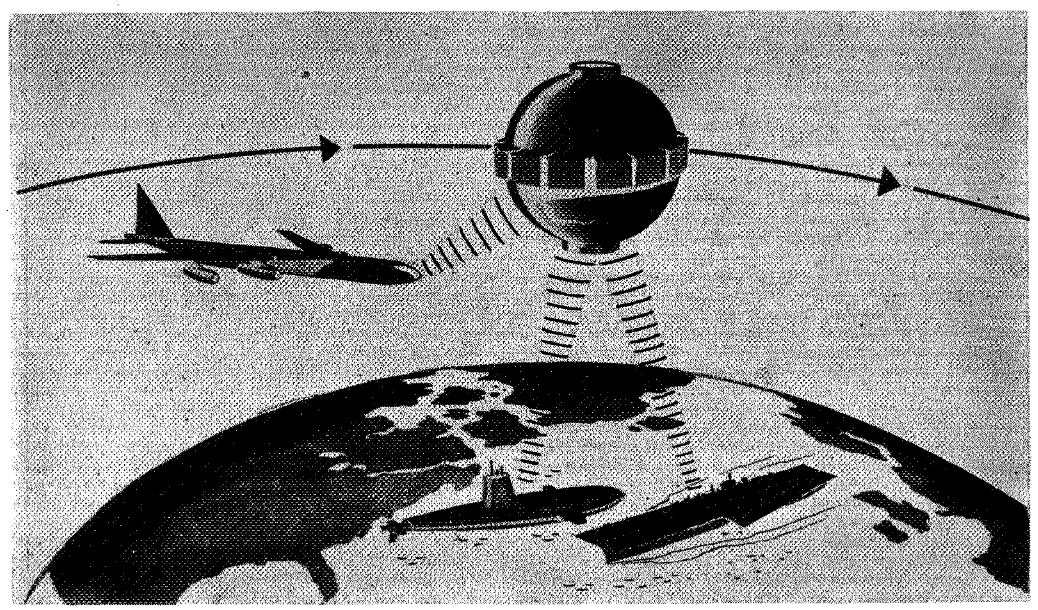
Syncom II, launched July 26, 1963, was placed in a synchronous orbit and moved to a position over Brazil. Numerous messages, including a telephone conversation between the United States President and the Nigerian Prime Minister, have been relayed via Syncom II, which also relayed the communications for the first two-hemisphere press conference.

Telstar—Telstar—like Relay—is an experimental project in the employment of medium-altitude active-repeater satellites for global communication links. Because the two satellites differ in important



Courier satellite

Transit system is designed to aid navigation.



structural and technical features, they provide a basis for comparison of divergent designs and facilitate acquisition of information needed to develop equipment for operational use. A 34½-inch diameter, spherical satellite, Telstar was developed by the American Telephone & Telegraph Co. Telstar 1 weighs 170 pounds; Telstar 2, 175 pounds.

Under a cooperative agreement, NASA is responsible for launching, tracking, and data acquisition in the Telstar project. The company reimburses NASA for all costs of such activities. A condition of the agreement makes the information produced by the Telstar project available to all interested scientists and engineers.

Telstar 1, launched July 10, 1962, made communications history by relaying the first telecast from the United States to Europe the same day, and the first live telecast from England to the United States on July 11, 1962. Its initial orbit ranged from 593 to 3,503 miles above earth.

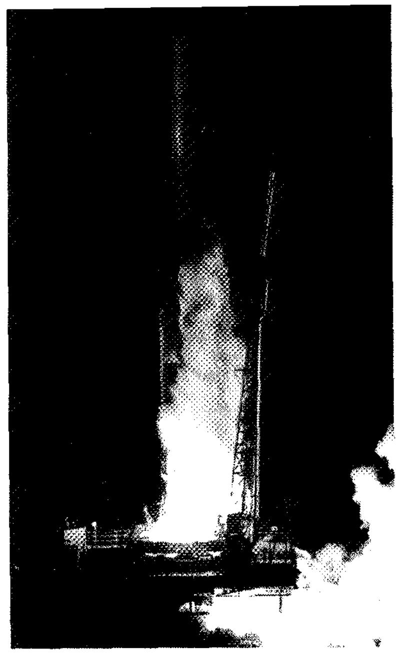
Telstar 2, launched May 7, 1963, was injected into an initial orbit with perigee or low point at 604 miles, and apogee or high point at 6,713.3 miles. The purposes of the higher altitude were to increase transmission times between the United States and Europe and to reduce the period that the satellite spends in the most intense portion of the Van Allen Radiation Region. Moreover, the transistors of Telstar 2 have been redesigned to avoid the radiation damage that eventually silenced Telstar 1.

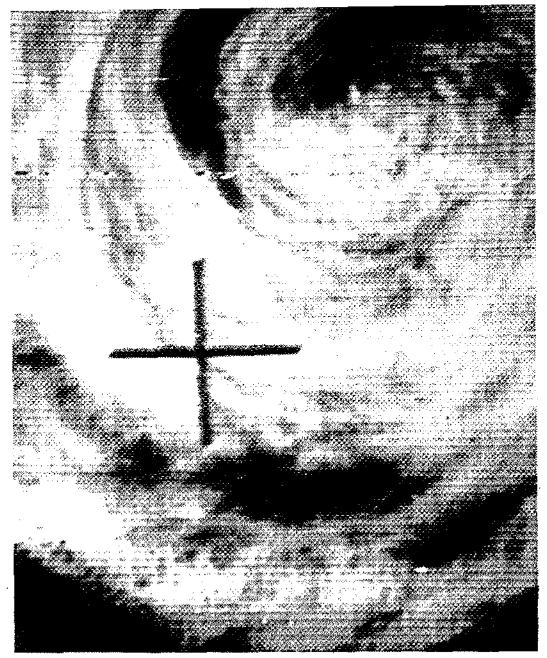
Courier—Courier 1–B, a U.S. Army satellite launched October 4, 1960, tested the feasibility of employing "active-repeater" satellites for long-distance communications. Its total payload of 500 pounds included 300 pounds of electronic equipment, among which were 1,300 transistors. Power was supplied by 19,200 solar cells. Other equipment included four transmitters, four receivers, five tape recorders, two microwave antennas, four whip antennas, a VHF diplexer, a command decoder and space backup equipment. It received, stored, and transmitted messages sent to it from several points on earth, effectively proving the feasibility of a satellite communications system.

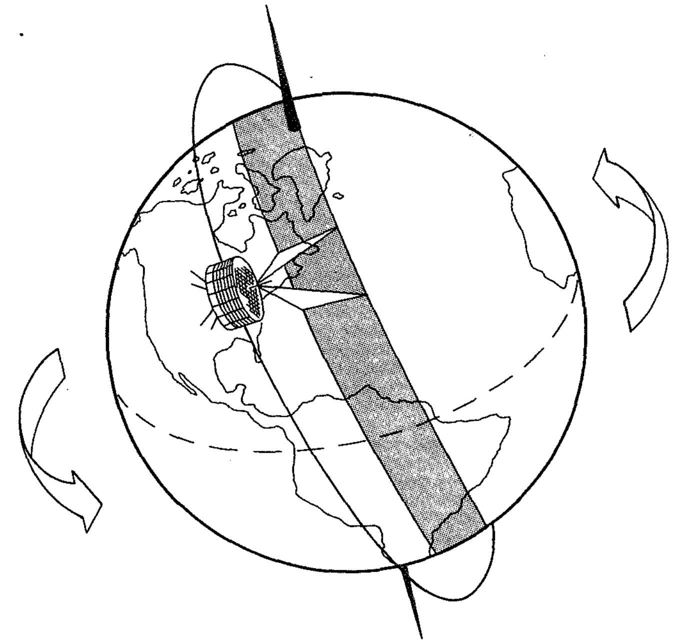
Courier had an initial apogee (maximum altitude in orbit) of 658 miles, and perigee (minimum altitude in orbit) of 501 miles. It operated successfully until October 23, 1960, when an undetermined malfunction rendered it inoperative.

Score—Score, a U.S. Army communications satellite, launched December 18, 1958, accomplished the first transmittal of the human voice from space. Its payload was 150 pounds of receiving, recording, and transmitting apparatus. Among the messages it recorded and relayed from ground stations was a 1958 U.S. Presidential Christmas message to the world. Score operated successfully for the life of its chemical batteries (approximately 30 days).

Transit—Transit is a U.S. Navy program leading to an operational satellite system for worldwide all-weather navigation. The Transit operational system, consisting of four satellites in proper orbit, will provide accurate data for navigational fixes to ships and aircraft throughout the world on an average of once every 1¾ hours. Transit I–B was launched April 13, 1960, carrying a







Left to right:
Delta launch vehicle carrying TIROS VI weather satellite into orbit.
Vortex (storm) off Newfoundland, photographed by TIROS V meteorological satellite.
Drawing of "Cartwheel" TIROS in polar orbit.

payload weight of 265 pounds. This included two ultra-stable oscillators, an infrared scanner, two telemetering receivers and transmitters plus solar cells and nickel-cadmium batteries for power. Transit I–B proved the feasibility of an all-weather navigation satellite system.

The launch of Transit II–A, on June 22, 1960, was the first U.S. experiment to put two payloads in orbit simultaneously. The satellites were attached to each other and separated by a spring, just after going into orbit. Data from Transit II–A were used in a continuing geodetic study program.

Transit III–B, launched February 21, 1961, was the first satellite in the Transit program to include as part of its instrumentation a memory system. (A memory system enables Transit to receive information on its orbital parameters [orbital path data] from an injection station and to give this information to ships or aircraft for use in computing their locations.) Tests with the Transit III–B memory system proved the feasibility of injecting data into and recovering data from the satellite.

Transit IV–A, launched June 29, 1961, carried the first nuclear power system into space, a SNAP (System for Nuclear Auxiliary Propulsion) type generator. This SNAP generator, shaped like a slightly elongated grapefruit, was developed by the Atomic Energy Commission. It weighs about 4½ pounds and is capable of producing 3 watts of power, sufficient to run two of Transit IV–A's four transmitters.

The SNAP generator fuel is plutonium 238 which has a "half life" of 89.6 years. Its radioactivity will decline only 50 percent during that period, so such a space generator is theoretically capable of powering a space transmitter for an extremely long time. To avoid any danger of accidental radiation hazard, the casing containing the plutonium 238 was designed to be strong enough to survive the force of an explosion (in case of mishap at launching) and to burn up on reentry.

Transit V–A, launched December 18, 1962, was to be the first of a four-satellite operational network that would enable ships to pinpoint their positions in any weather. A malfunctioning command receiver prevented the satellite from performing as planned. This was the first time that the radio command equipment of the Transit system has failed to work.

NASA and the Department of Defense have signed an agreement which assigns to NASA the responsibility for exploring possible nonmilitary use of the Transit system.

West Ford—West Ford is a U.S. Air Force project to orbit millions of short fine copper wires, called dipoles, creating a radio-reflective band around the world. Experiments will determine whether long-distance communication can be accomplished by bouncing radio waves from the band.

TIROS—About 350,000 usable cloud pictures have been obtained from TIROS satellites since the launch of TIROS I on April 1, 1960. TIROS is an acronym for television and infrared observation satellite. As this indicates, TIROS' main sensors are television cameras to take cloud and other pictures and infrared sensors to measure reflected solar radiation and emitted terrestrial heat radiation.

The increased observations of the earth's atmosphere made possible by TIROS have contributed to accuracy of weather forecasts. Both the pictures and infrared data are utilized in research to improve understanding of whether. Moreover, TIROS has demonstrated the potential of meteorological satellites for giving valuable information on river and sea ice and furnishing information on snowcover for use in predicting the extent of spring flooding. Other possible uses of TIROS data are being examined.

The drum-shaped TIROS satellites are about 19 inches high and 42 inches in diameter. They weigh from 263 to 287 pounds. Their orbits range from 367 to 604 miles above earth.

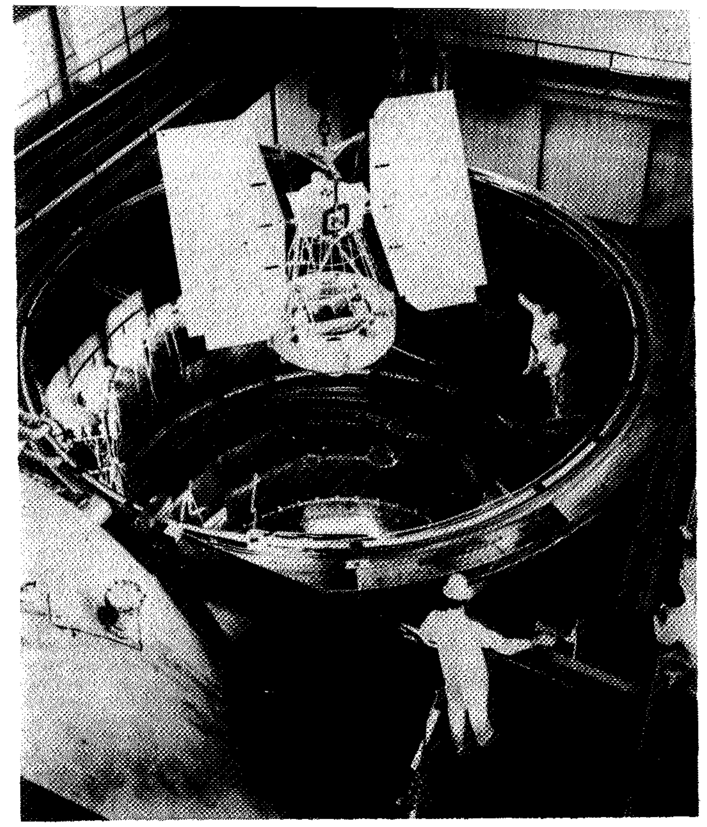
Within a few days after TIROS I was launched, its reports were applied to day-to-day whether forecasting operations.

TIROS II, launched November 23, 1960, confirmed the capability of infrared sensors to provide cloud cover information on the earth's night side where television images are usually inadequate.

TIROS III was launched July 12, 1961, so that its observational period would coincide with the hurricane season. The satellite has furnished extensive data on the origin, development, and movement of these destructive storms.

On September 11, 1961, TIROS III demonstrated the tremendous potential of weather satellites in a particularly striking manner. On that day, observing 25 million square miles of the earth, it spotted the suspicious cloud formation later designated as Hurricane Esther and provided data on Hurricanes Betsy (as it degenerated), Carla, and Debbie and Typhoons Pamela and Nancy. On a later day, TIROS III warned of the regeneration of the dangerous Typhoon Sally. In addition, the satellite provided data on less spectacular wheather phenomena which proved valuable in forecasting for aviation and other activities.

TIROS IV, launched February 8, 1962, provided numerous clear pictures of atmospheric conditions and transmitted excellent photographs of sea ice in the Gulf of St. Lawrence and surrounding areas. It also contributed to the development of special storm advisories for Australia, Japan, the Malagasy Republic (Madagascar), Mauritania (in West Africa), and the Republic of South Africa.



Full-scale Nimbus model is lowered into space environmental chamber for testing.

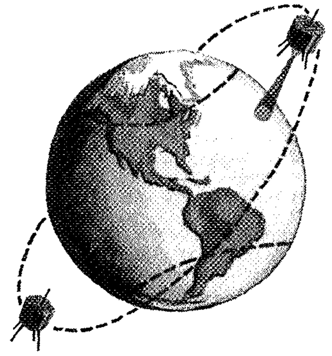
TIROS IV helped in weather support for the Mercury orbital flights of John H. Glenn, Jr., and M. Scott Carpenter.

TIROS V was launched on June 19, 1962, with the principal mission of "hurricane hunting." The satellite accomplished its task admirably by providing the pictures through which most of the tropical storms occurring during the summer of 1962 were first discovered. Moreover, it provided important information about the remaining storms and was instrumental in tracking the storms and providing data for hurricane and typhoon warnings. TIROS V was also employed to provide weather data for the Mercury orbital flight of Walter M. Schirra, Jr., on October 3, 1962.

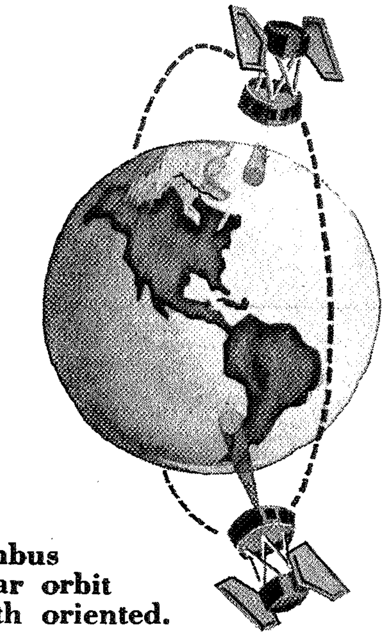
TIROS VI, launched September 18, 1962, supplemented the observations of TIROS V. It provided weather data for Schirra's Mercury orbital flight after TIROS V failed. It also furnished weather data for the orbital flight of L. Gordon Cooper, Jr., which took place May 15 and 16, 1963.

TIROS VII was orbited June 19, 1963. Its launch was timed to obtain cloud pictures during the 1963 tropical storm season.

TIROS VIII, launched December 21, 1963, inaugurated use of an automatic picture transmission (APT) system permitting reception of pictures by inexpensive, portable ground stations.



TIROS
inclined orbit
space oriented.



Nimbus
polar orbit
earth oriented.

Studies relative to an initial operational weather satellite system based upon TIROS technology have been completed by NASA and the U.S. Weather Bureau. The system will be called TOS, an acronym for TIROS Operational Satellite.

TOS will feature the NASA-developed "cartwheel" configuration. This kind of satellite differs from TIROS I through VIII in that the spacecraft rolls on its curved sides like a wheel. Each of the two TOS cameras, mounted 180 degrees apart along the satellite's circular edge, will take pictures at the instant it is pointed at earth.

TOS will be launched into near-polar orbits, enabling their cameras to observe the entire globe. TIROS I through VIII, launched into east-west orbits, provided a coverage of about 20 percent.

TOS will also employ advanced television cameras and the APT system. The latter was tested by TIROS VIII. TIROS IX, to be launched in the latter part of 1964, will be the first research and development test of the wheel TIROS in polar orbit.

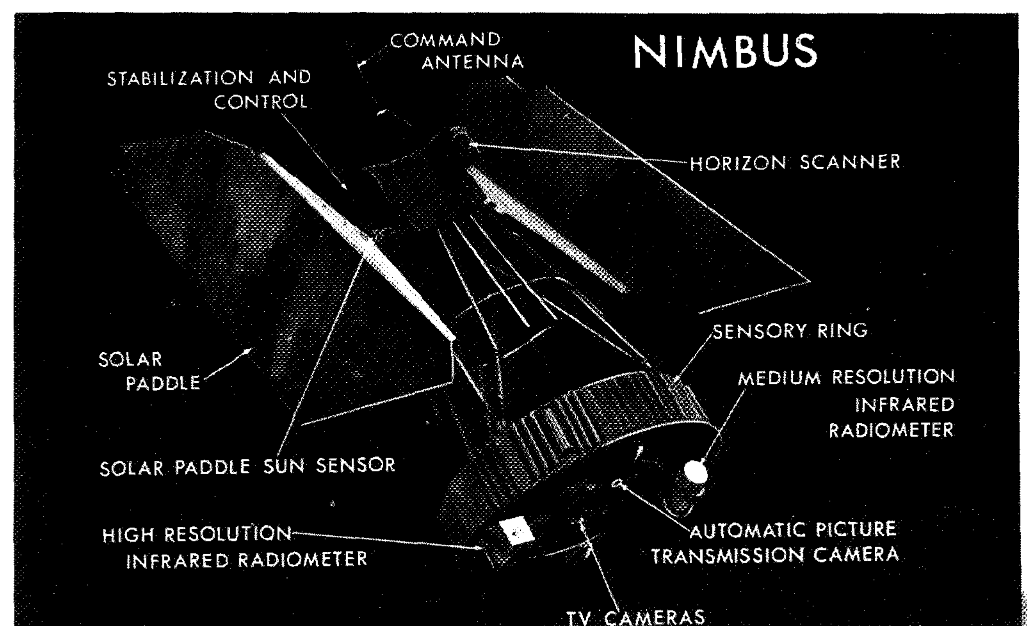
Nimbus—Experience with TIROS has aided in development of the next generation of meteorological satellites. This series, designated "Nimbus," will have cameras and infrared sensors which always face the earth. Its near polar orbit will enable it to view every area on earth at least once a day.

The first Nimbus satellites will weigh about 750 pounds and have an orbit about 500 miles above the earth.

Navigation and Air Traffic Control Satellite—NASA is studying a satellite system to aid aircraft and ships in determining their exact locations regardless of weather. The system will also serve to control air traffic and to facilitate air-sea rescue operations. Plans call for the equipment on the satellite, ships, and airplanes to be simple and durable. Moreover, the ship and aircraft equipment will be relatively easy to operate and maintain. As currently envisioned, the system would operate as follows: The ship or aircraft radios a signal to the satellite which relays it to a ground station. Computers at the ground station, utilizing the satellite as a reference point, calculate the position of the plane or ship and flash this information via the satellite to the ship or aircraft. The operation takes less than a second.

Advanced Technology Satellite—Three kinds of satellite experiments are planned to test in space promising satellite technology and equipment developed in ground laboratories. The first Advanced Technology Satellite will be launched into a 6500-mile-altitude orbit to evaluate a new kind of earth-orientation system. Later satellites will be launched into synchronous orbits (see *Syncom*, above). Among advanced techniques and equipment to be tested in synchronous orbits are stabilization and orientation, meteorological sensors and components, and earth-pointed antenna systems. The experiments will contribute to development of operation communications, meteorological, and navigation satellites and of improved scientific satellites.

Nimbus meteorological satellite (artist's conception).

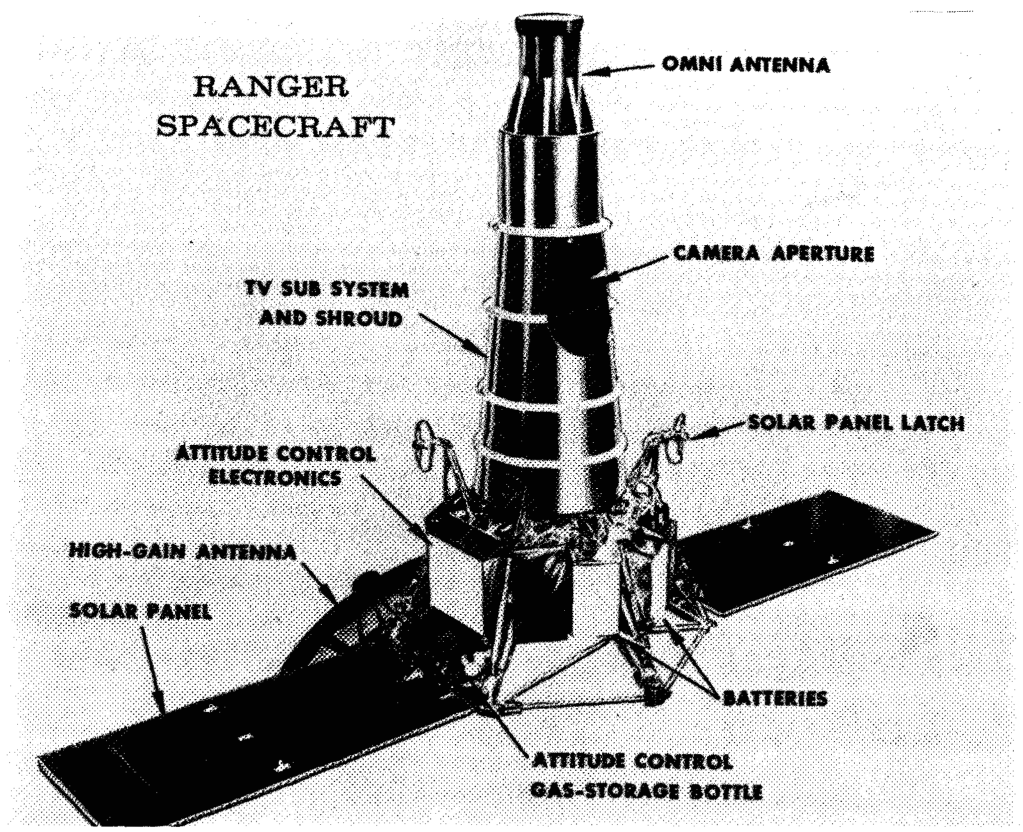


CHAPTER VI

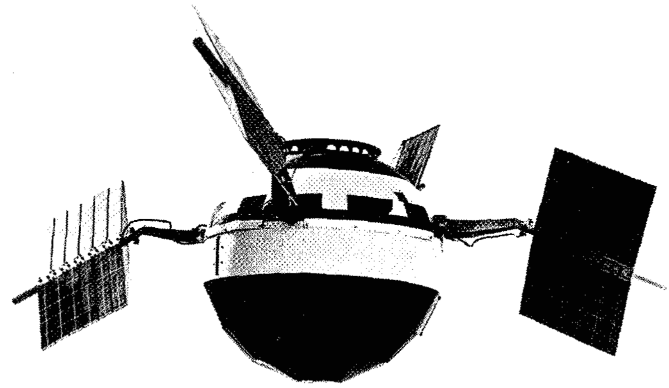
UNMANNED LUNAR AND INTERPLANETARY SPACECRAFT

Among the major goals of the U.S. scientific space program is exploration of the moon and certain of the planets. Short of manned landings, unmanned instrumented spacecraft are the best means of acquiring information about other celestial bodies. Such information will also aid in preparations for eventual landings of men on the moon and on other planets of our solar system. Among the unmanned lunar and interplanetary exploration vehicles are:

Pioneer—The first of a series of long-distance space probes designed to investigate interplanetary environment, Pioneer I, launched October 11, 1958, determined the radial extent of the Van



RANGER SPACECRAFT



Pioneer V space probe

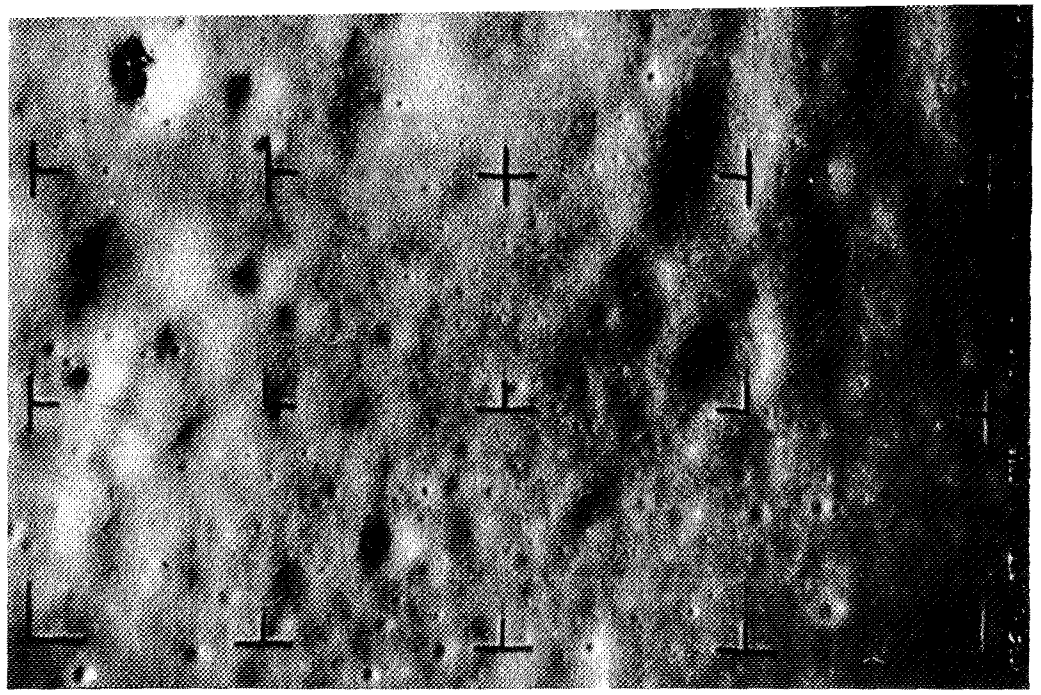
Allen Radiation Region, made the first determination of the density of micrometeoroids in space, and first observed the hydromagnetic oscillation of the earth's magnetic field. Pioneer V, launched March 11, 1960, explored interplanetary space between the orbits of the earth and Venus. It also made the first measurements of solar flare effects in interplanetary space and on June 26, 1960, established a radio communication record of 22.5 million miles which held until the Mariner II experiment (see *Mariner* below). The first attained an altitude of 70,700 miles. Pioneer IV, launched March 3, 1959, came within 37,300 miles of the moon before going into orbit around the sun. Pioneer V is also in orbit around the sun.

NASA plans call for another series of Pioneer experiments to begin in 1964. These spacecraft will monitor solar radiation and interplanetary magnetic fields to a distance of more than 50 million miles from earth. The purpose of this program is to advance understanding of the sun and of interplanetary space for scientific reasons and for planning manned interplanetary flights.

Ranger—The Ranger project comprises a series of spacecraft for gathering data about the moon and testing elements of space technology required for future lunar and interplanetary missions.

The Rangers are equipped with television cameras to take pictures that will distinguish features as small as three feet across on the lunar surface. (The best telescopes on earth can resolve lunar features no smaller than about two thousand feet across.) They are designed to begin televising pictures to earth when they are about 1,000 miles from the moon and continue sending photographs until they crash to destruction on the moon.

The information obtained through the Ranger program is expected to enhance substantially mankind's knowledge of the moon and contribute to planning for manned lunar exploration.



This photograph of the moon's surface was taken by Ranger VII at about three miles altitude and 2.3 seconds before impact in the Sea of Clouds. The crater, upper left, with two rock masses protruding into sunlight, is about 300 feet across.

Early Ranger experiments did not attain their goals, but they did advance spacecraft technology in such areas as midcourse correction, attitude control and stabilization, and injection into a lunar trajectory from a parking orbit around earth. Ranger IV, launched April 23, 1962, was the first U.S. spacecraft to land on the moon. Ranger VI, launched January 30, 1964, precisely impacted the moon's Sea of Tranquility 66 hours later, but its television equipment failed to operate.

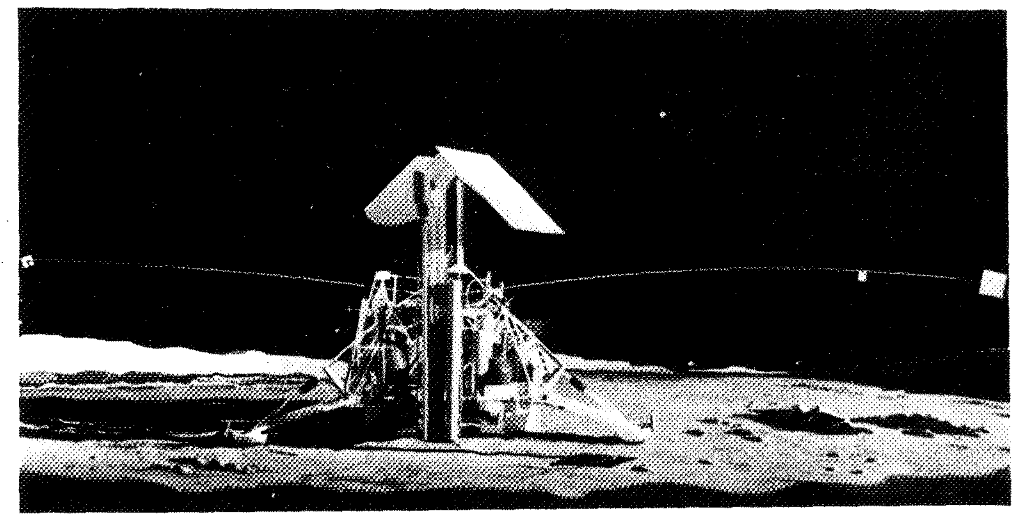
Ranger VII, on July 31, 1964, completed a "textbook" flight to the moon, landing on target in the Mare Nubium (Sea of Clouds). Before impacting, the spacecraft transmitted 4,316 excellent pictures from altitudes ranging from 1,300 miles to 1,000 feet from the lunar surface.

Features the size of a bushel basket are distinguishable in the closer pictures and scientists hailed the achievement as representing an improvement in resolution by a factor of 2000.

Surveyor—Surveyor will mark the next giant stride in lunar exploration beyond Ranger. It is designed to decelerate from the lunar approach velocity of 6,000 miles per hour, or 9,000 feet per second, to a touchdown speed of less than 15 feet per second.

Surveyor will be equipped with television cameras to take pictures while landing, scan the moonscape after landing, and monitor the spacecraft's instruments. The Surveyor will analyze lunar surface material, check the moon's surface for strength and stability, and measure meteorite bombardment, and moonquakes. Surveyor will not only advance man's knowledge of the moon but also contribute to manned exploration by demonstrating the technology for a soft landing and by verifying the suitability of sites for manned landings. Moreover, the information it furnishes on meteorite bombardment will aid in design of protective shielding for the manned spacecraft and the astronaut's space suits.

Lunar Orbiter—NASA plans to send a series of spacecraft into lunar orbit to obtain photographs of the moon's surface that will aid selection of landing areas for the Surveyor spacecraft and the Apollo lunar expedition. The Lunar Orbiters will also add to knowledge about the size, shape, and other characteristics of the moon and increase accuracy of information relative to the moon's gravitational pull. The latter is important to planning lunar orbit rendezvous and other maneuvers around the moon.



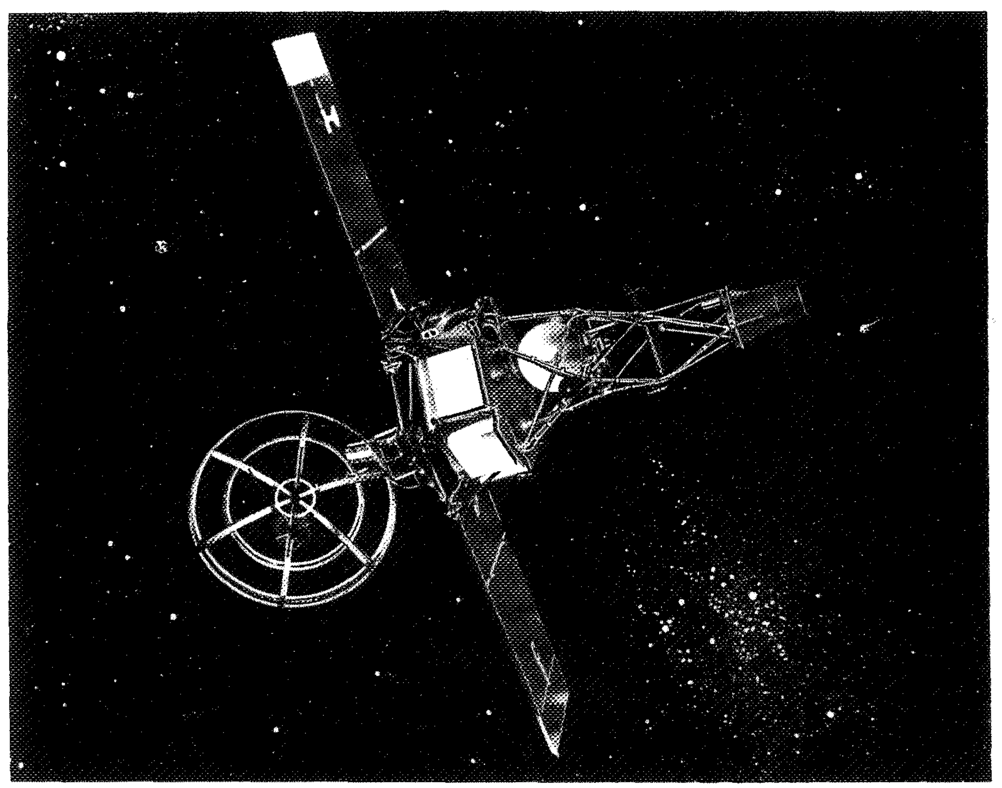
Surveyor lunar spacecraft

Mariner—On December 14, 1962, NASA's Mariner II spacecraft flew as close as 21,648 miles to Venus, giving man his first relatively close-up observation of earth's cloud-covered neighbor. This Venus flyby climaxed an epic space experiment that significantly advanced knowledge about Venus (see ch. III) and about interplanetary space. On January 3, 1963, when contact with earth was lost, the 449-pound Mariner II was nearly 6 million miles beyond Venus and was 53.9 million miles from earth. Contact with Mariner up to a distance of 53.9 million miles established a new record in long-distance communication.

Among concepts of interplanetary space for which data were provided by Mariner II are the following:

- The solar wind, consisting of hot electrified gases, rushes outward constantly from the turbulent surface of the sun.

Mariner interplanetary spacecraft

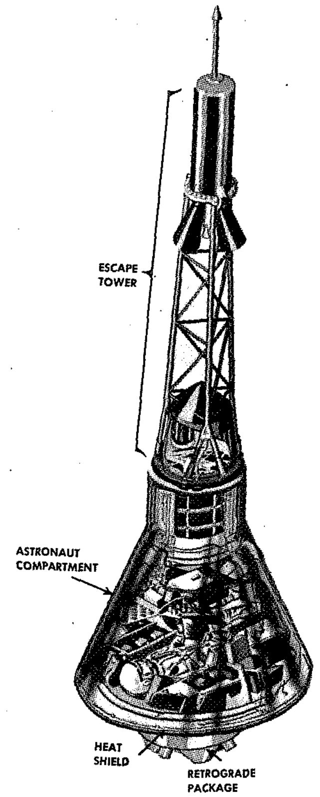


- The density, velocity, and temperature of the wind fluctuate with changes in solar activity, particularly with occurrence of solar flares.
- The solar wind influences the amount and intensity of cosmic radiation in the solar system.
- The solar wind creates interplanetary magnetic fields and modifies and distorts these fields and earth's magnetic field.
- Weak magnetic fields (relative to that of earth) are nearly always present in interplanetary space.
- The amount and intensity of cosmic radiation in space between Earth and Venus appear to be uniform throughout space.
- Reliable radio communication between Earth and spacecraft are possible over interplanetary distances.
- Micrometeoroids (tiny bits of matter in space) are far less numerous in interplanetary space than around Earth. (This information was derived from data sent by Mariner II, Pioneer probes, and earth satellites.)
- Refinement of important measurements: the Astronomical Unit (AU) which is the mean distance from Earth to Sun; the mass of the moon; and the mass of Venus.

Mariner is the designation of a series of spacecraft designed to fly in the vicinities of, and send information about Venus and Mars. Two Mariners will attempt to fly close to Mars in late 1964. For the 1966 opportunity, heavier Mariner spacecraft will be launched by a Centaur vehicle to Mars to carry far more scientific equipment and make more refined observations. NASA is studying a series of larger spacecraft called Voyager which may be launched by a Saturn rocket toward the near planets in the late 1960's and early 1970's to search for possible life on the planetary surfaces.

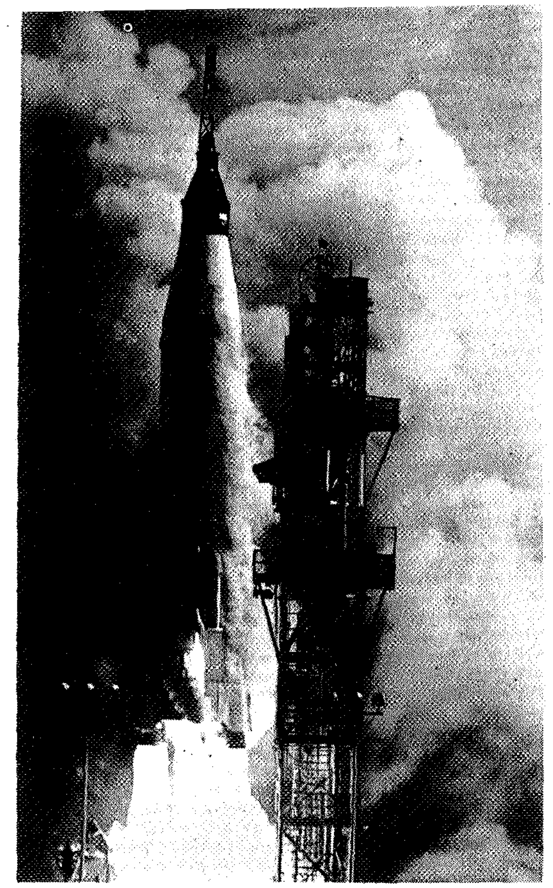
CHAPTER VII

MANNED SPACE EXPLORATION



(Left) Cutaway of Mercury spacecraft. Mounted on spacecraft is escape tower. Below craft is retrorocket pack. Both are jettisoned during flight mission (artist's conception).

(Right) Mercury spacecraft boosted by a modified Atlas launch vehicle.



Man has been defying the elements since he appeared on earth. Driven by the necessity of survival, by his love of adventure and by an insatiable curiosity where the unknown is concerned, he has braved the oceans, the mountains, the deserts, the skies, and finally space.

For several centuries man has lifted himself into the air with balloons but it was not until this, the 20th century, that Orville Wright, in 1903, made man's first powered flight. His average speed for the trip was 31 miles an hour.

Both the speed and the altitude of man's flights have increased since that time—slowly at first and then by great leaps. The speed of sound (about 735 miles an hour) was exceeded in 1947. Present-day aircraft fly regularly at twice that speed. The X–15 has flown more than 4,100 miles an hour.

Now, in space, man has achieved altitudes measured in hundreds of miles and speeds measured in thousands of miles per hour.

As far as the rigid requirements of space travel are concerned, man is not the most efficient mechanism. He requires an environment very closely resembling that in which he lives on earth. In order to survive he needs adequate oxygen, barometric pressure, temperature control, and the elimination of toxic agents. He is a relatively heavy object and the equipment required to protect him in space flight of even short duration weighs hundreds of pounds.

In space, man must cope with isolation and confinement, even radiation which menaces his life. His efficiency and reliability are variable. As a power source he is slow and frequently inaccurate. He requires rest, food, and relaxation, and unlike a machine, he is not expendable.

Notwithstanding all this, there has never been any doubt that man would challenge the dangers of space as he has challenged every other unknown. For, in spite of his shortcomings, man brings to space exploration certain attributes which no one has ever succeeded in building into a machine. He brings intelligence, judgment, determination, courage, and creativity. He can use all of these attributes in case of the unforeseen. By simply adding man and his capabilities to a machine its chances of success in a space mission are enormously increased.

PROJECT MERCURY

Project Mercury placed the first Americans into space. The pioneering project was organized in October 5, 1958, to orbit a manned spacecraft, investigate man's reaction to, and abilities in, space flight, and recover safely both man and spacecraft.

Project Mercury experiments demonstrated that the high-gravity forces of launch and of atmosphere entry and weightlessness in orbit for as much as 34 hours do not impair man's ability to control a spacecraft. It proved that man not only augments the reliability of spacecraft controls but also can conduct scientific observations and experiments that expand and clarify information from instruments.

Moreover, man can respond to and record the unexpected, a faculty beyond the capability of a machine which can be programmed only to deal with what we know or expect. In addition, Mercury has confirmed that man can consume food and beverages while weightless, if these are in suitable containers such as squeeze tubes. Finally, Mercury has laid a sound foundation for the technology of manned space flight.

The first American rocketed into space was Astronaut Alan B. Shepard, Jr., on May 5, 1961. A Redstone rocket launched him from Cape Canaveral (now Kennedy), Florida. His Mercury spacecraft was launched to an altitude of about 115 miles and reached a top speed of approximately 5000 miles per hour during a suborbital flight of slightly more than 15 minutes. He landed in the Atlantic Ocean about 302 miles from the Cape.

The first American to orbit the earth was Astronaut John H. Glenn, Jr. Launched by an Atlas booster, his Mercury spacecraft circled the earth three times on February 20, 1962. During his orbital flight, his altitude ranged from 86 to 141 miles. His speed was about 17,500 miles per hour.

Some features of these and other Mercury manned flights are noted in the following table.

HIGHLIGHTS OF MANNED MERCURY FLIGHTS

Astronaut	Date	Flight Time*	Orbits	Spacecraft Name
Alan B. Shepard, Jr.	5/5/61	00:15:22	Suborbital	Freedom 7
Virgil I. Grissom	7/21/61	00:15:37	Suborbital	Liberty Bell 7
John H. Glenn, Jr.	2/20/62	04:55:23	3	Friendship 7
M. Scott Carpenter	5/24/62	04:56:05	3	Aurora 7
Walter M. Schirra, Jr.	10/3/62	09:13:11	6	Sigma 7
L. Gordon Cooper, Jr.	5/15, 16/63	34:19:49	22	Faith 7
Totals		53:55:27	34	

*Hours: Minutes: Seconds

Astronaut Cooper's flight of 34 hours, 19 minutes, and 49 seconds, was the longest of the Mercury missions. Following his journey, America's manned space flight program moved beyond Mercury to Project Gemini with plans for astronauts to remain in orbit for as long as two weeks.

The aggregate flight time for suborbital and orbital Mercury manned flights was 53 hours, 55 minutes, and 27 seconds. Plans call for the astronauts to practice for about 2000 hours in orbit around the earth before the first three-man crew embarks in the Apollo spacecraft for the moon.

Descriptions of the Gemini and Apollo project follow.

PROJECT GEMINI

Project Gemini, in which the Department of Defense is participating with NASA, is the next major step after Mercury in the U.S. manned space flight program. Its purposes are—

(1) To determine how man will perform and behave, and how his abilities as pilot and controller of his craft will be affected during prolonged space flights of as much as 2 weeks.

(2) To develop techniques for orbital rendezvous and docking—the bringing together and coupling of craft in orbit.

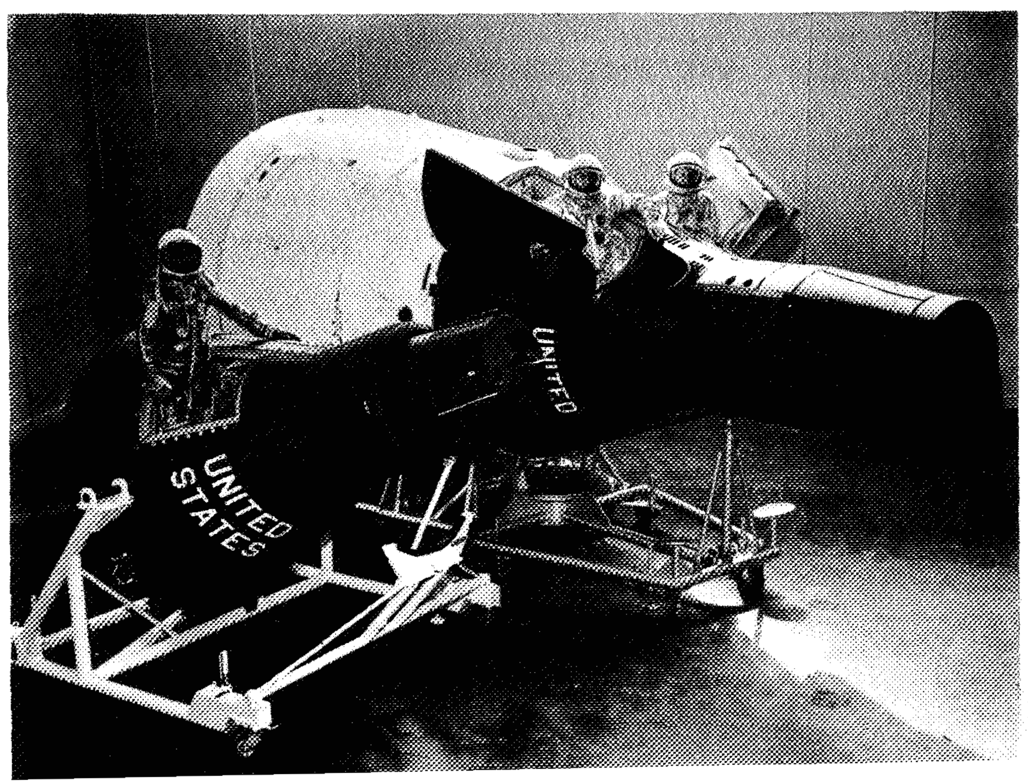
(3) To carry out scientific and technical investigations of space.

(4) To demonstrate controlled entry into the atmosphere and controlled landing at a selected site.

Plans call for a series of 12 Gemini flight experiments to meet these goals. The first, an unmanned flight test of the Gemini spacecraft—Titan launch vehicle combination, was conducted on April 8, 1964.

In the test, a boilerplate (engineering and test model) of the two-man Gemini spacecraft, its adapter section (see below), and the second stage of the Titan launch vehicle were sent into orbit. Review of results of this experiment indicates that all objectives were accomplished. Orbital altitudes ranged from 204 miles to 99.6 miles. No attempt was made to return the craft to earth.

Mercury one-man spacecraft alongside mock-up of two-man Gemini.



Spacecraft Resembles Mercury

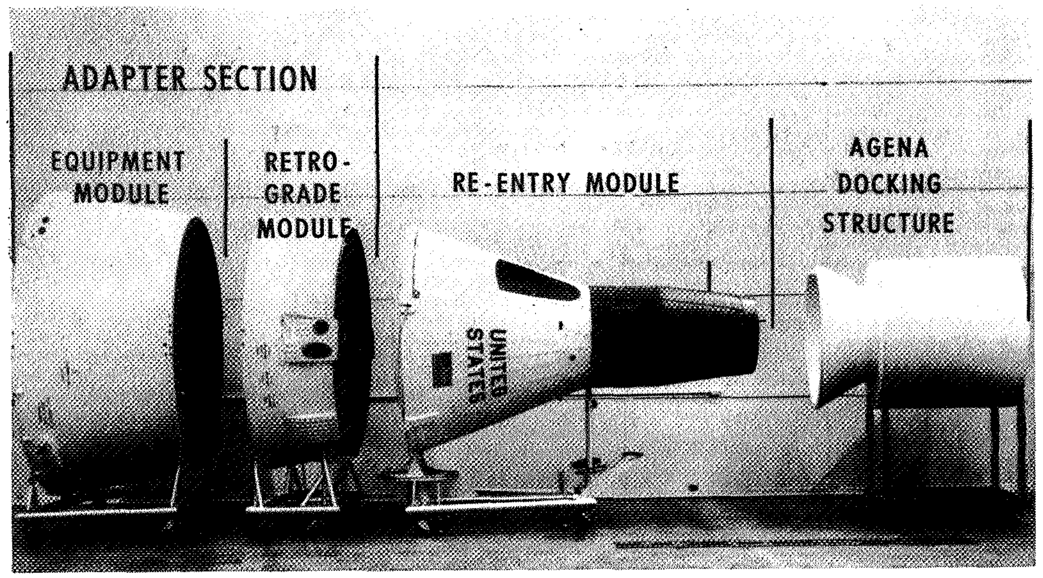
The two-man Gemini spacecraft externally resembles the Mercury spacecraft, but is 1½ feet wider at the base and lengthened proportionately. It has about 50 percent more cabin space than Mercury and weighs about 7,000 pounds. Unlike Mercury, most Gemini electronic components are outside the crew compartment and installed in easily removable units, thereby facilitating check-out and maintenance.

In addition to life-support equipment, Gemini contains docking apparatus for coupling with another craft in space; a computer and instruments for guidance and control to aid in navigation, rendezvous, atmosphere reentry, and landing; radar for rendezvous operations; and a landing and recovery system among which are such equipment as a paraglider (explained below), landing gear (a spoon-shaped nose ski and two outrigger skids); tracking beacons, flashing lights, and two-way voice radios. In case of emergency during launch or the recovery phase of a Gemini flight, the pilots can employ their ejection seats which operate like those in high-performance fighter aircraft. The pilots have two windows, instead of the single porthole of the Mercury spacecraft.

Two-Piece Adapter Section Attached

An adapter section consisting of the retrograde and equipment modules partially obscures Gemini's resemblance to Mercury. Attached to the heat shield, the section is 7½ feet in diameter at the top, 10 feet in diameter at the base, and 7½ feet long. It weighs about 2,200 pounds.

The retrograde module, which is attached to Gemini's heat shield, contains the braking rockets that slow Gemini down from orbital speed so that the spacecraft can fall to earth. This module also contains a propulsion system to enable Gemini to maneuver in orbit. The module is discarded just before entry into the atmosphere.



The equipment module contains fuel, fuel cells (they create electricity and drinking water through a chemical reaction of hydrogen and oxygen), oxygen for breathing, and a propulsion system for maneuvering in space. The equipment module is discarded during preparation for atmosphere entry.

Orbital Rendezvous—a Major Goal of Gemini

Project Gemini will provide the first American demonstration of orbital rendezvous—a skill which is crucial to the mastery of space. Orbital rendezvous is a part of the technology that must be developed to land American explorers on the moon in this decade and to conduct the advanced ventures of the future.

In the Gemini orbital rendezvous mission, an Atlas will launch into a circular orbit a fully fueled Agena rocket modified for linkup with the Gemini spacecraft. A Titan II booster will then launch Gemini into an elliptical orbit whose high point or apogee intersects the Agena orbit. At the proper time, a Gemini tail rocket will be fired at apogee, placing Gemini relatively close to and in the same orbit as the Agena. (See illustration.)

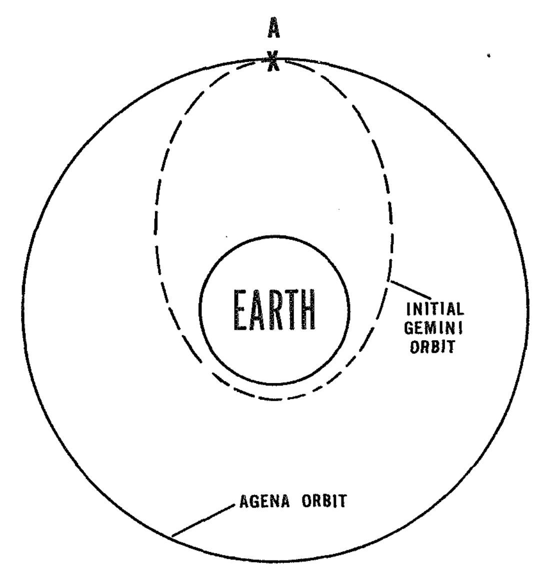
The astronauts, aided by radar and computer information, will fire maneuvering rockets to close in on Agena. As they near Agena, they will reduce the difference in speed between the two

Separated segments of Gemini mock-up. At right is docking structure of Agena which contains apparatus for link-up of spacecraft and rocket.

craft to about 1½ miles per hour, while whirling around the earth at about 18,000 miles per hour. Then, they will gingerly align the nose of Gemini with the matching slot of Agena and gently nudge the nose into the slot. Coupling will be automatic; the astronauts will be able to use Agena's propulsion system as well as Gemini's for any further orbital maneuvers.

Gemini Crew May Step Into Space

During advanced stages of the Gemini program, one or both of its pressure-suited crewmen may open the hatch and emerge from the orbiting spacecraft. Moreover, they may push themselves from the craft and appear to float in space as they speed around the earth at about 18,000 miles per hour. For this operation, they will be tethered to the craft to insure their safety. Gemini will store sufficient oxygen to refill its cabin when the astronauts return.



Gemini Agena Orbital Rendezvous.

Artist's conception of Gemini spacecraft closing in on Agena rocket in rendezvous experiment.

PROJECT APOLLO

Apollo is the biggest and most complex of the manned space flight projects. Its goal is to land American explorers on the moon and bring them safely back to earth.

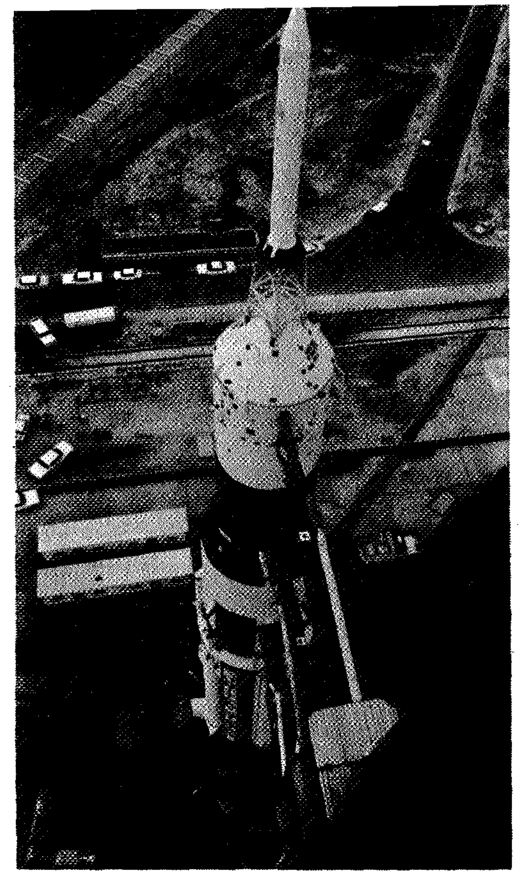
Three-Man Spacecraft Will Be Composed of Three Modules

The Apollo spacecraft is made up of three sections or modules:

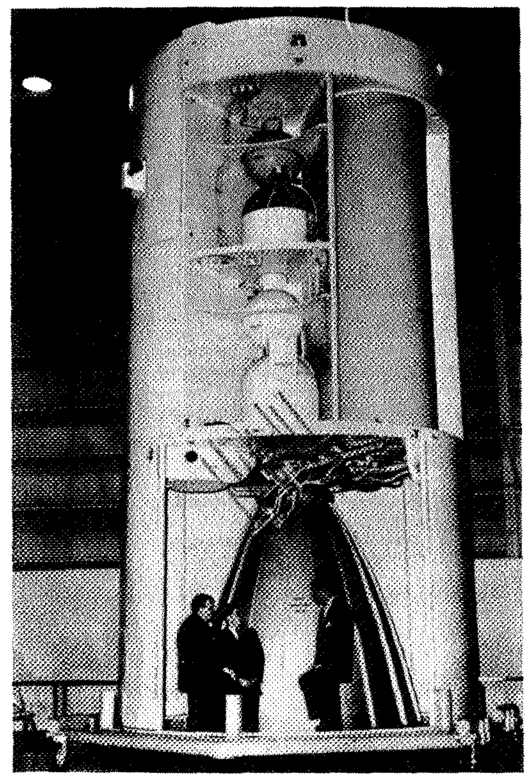
(1) COMMAND MODULE—The command module is designed to accommodate three astronauts in a "shirtsleeve" environment; i.e., the astronauts will be able to work, eat, and sleep in the module without pressure suits. The command module, like the crew compartment of an airliner, has windows, and contains controls and instruments (including a computer) of various kinds to enable the astronauts to pilot their craft. Moreover, since the command module is the only one of the three modules which will return to earth, it is built to survive the tremendous deceleration forces and intense heating caused by entry into the atmosphere at 25,000 miles per hour. This is the speed on return to earth from a lunar or an interplanetary mission. In the atmosphere, the Apollo crew will be able to guide the spacecraft to a selected landing field. The command module weighs about 5 tons. It stands 11 feet tall and has a base diameter of about 13 feet.

(2) SERVICE MODULE—The service module is equipped with rocket engines and fuel supplies to enable the astronauts to propel their craft into and out of lunar orbit and to change their course in space. It will be jettisoned just before the Apollo enters earth's atmosphere. The service module weighs 24 tons. It is 23 feet long and 13 feet in diameter.

(3) LUNAR EXCURSION MODULE—The lunar excursion module (LEM) is the space ferry that will take two Apollo astronauts down to the moon, carry them from the moon's surface into lunar orbit, and rendezvous with the Apollo command and service modules in lunar orbit. At launch from earth, the LEM weighs about 14½ tons. It is some 20 feet high and has a base diameter of 13 feet. Among the LEM's equipment are



Boilerplates of Apollo service and command modules are mounted on Saturn I launch vehicle. Thin rocket at top is part of escape mechanism that carries spacecraft from launch vehicle in case of trouble.



Mock-up of Apollo service module.

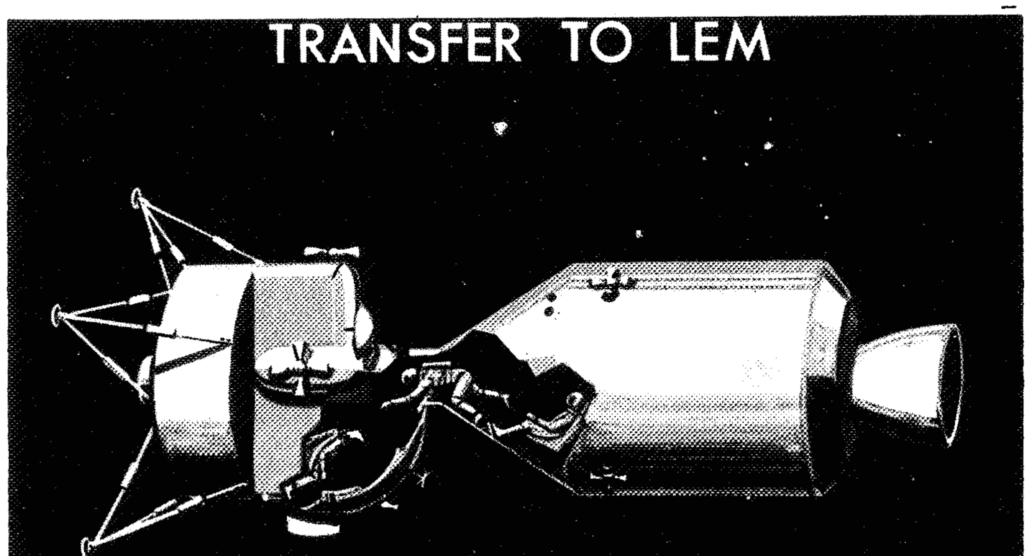
rockets for slowing down before landing on the moon, rockets for launch from the moon and for maneuvering in orbit, and five spiderlike legs that are extended to support the spacecraft on the moon's surface. The legs and landing rockets are left on the moon. After the two-man crew of the LEM returns to the command module, the LEM is jettisoned in lunar orbit.

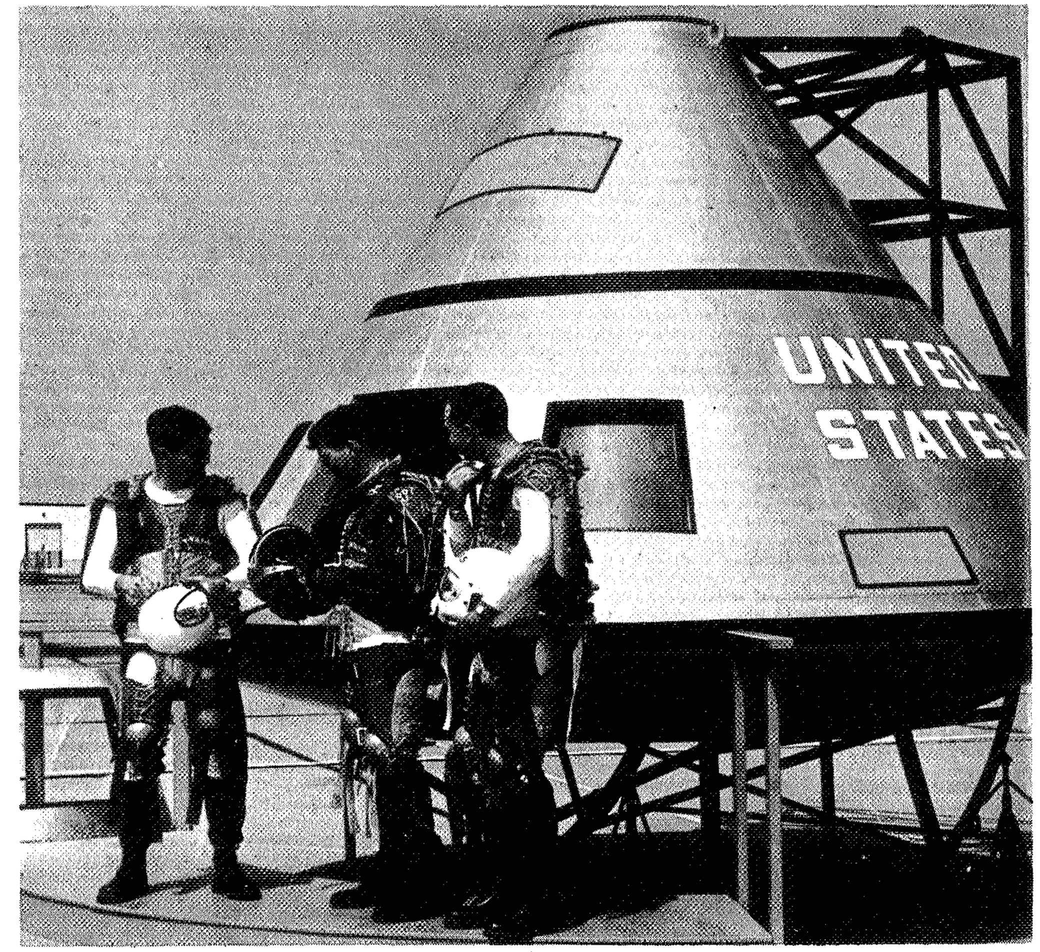
Three Steps to the Moon

The Apollo mission is planned for accomplishment in three steps:

(1) A Saturn I launch vehicle launches unmanned boilerplate (engineering and test) models of the Apollo command and service modules into earth orbit. The first of three planned tests was conducted on May 28, 1964. Among the purposes of this testing are determining the structural characteristics of the launch escape system and performance of the launch escape system during separation from the spacecraft and demonstrating the compatibility of spacecraft research and development instrumentation and communication systems with launch vehicle systems.

(2) The more powerful Saturn I–B launches the complete Apollo spacecraft (all three modules) into earth orbit. At launch, the command module with its rocket-powered escape tower is at the top. Under this is the service module and then the LEM. In orbit, the crew will detach the command and service modules from the LEM, turn the combined command and service modules

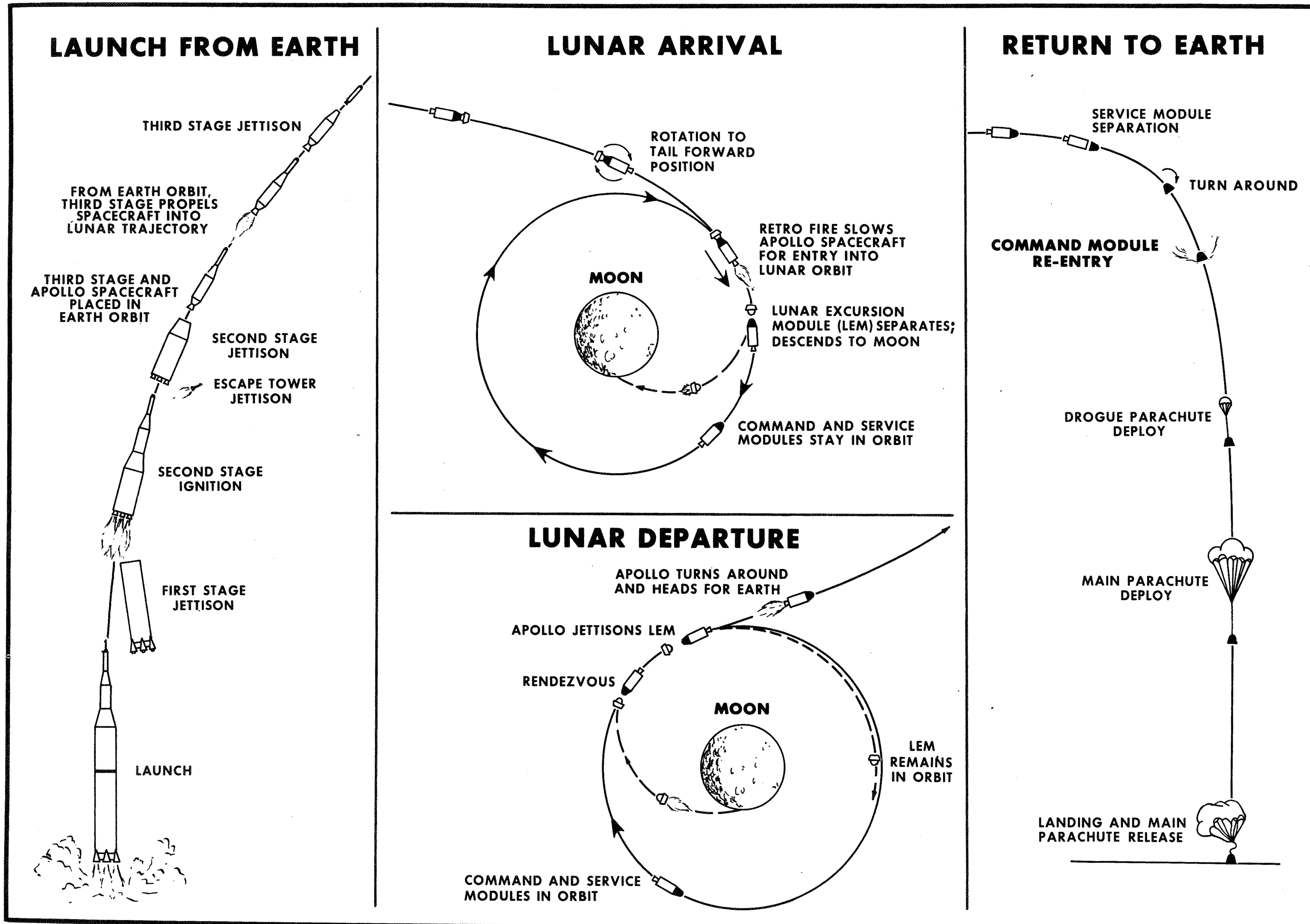




Mock-up of Apollo command module.

around, and link the command module's nose to the nose of the LEM. Then, two astronauts enter the LEM through an airlock, disconnect the LEM and fly it about, and join again with the command module.

(3) The Saturn V launch vehicle starts Apollo on its lunar exploration mission. The entire assembly stands about 365 feet tall (more than the length of a football field) and weighs about 6 million pounds at launch. The fuel of the first two Saturn stages and part of the third stage is employed to place Apollo into earth orbit. At the proper position and time for achieving a lunar trajectory, the third stage is refired, accelerating the assembly to almost 25,000 miles per hour.



Sequence of major events in Apollo lunar landing mission.

After burnout of the third stage, the crew disconnects the joined command and service modules (parent craft) and connects the command module nose to nose with the LEM.

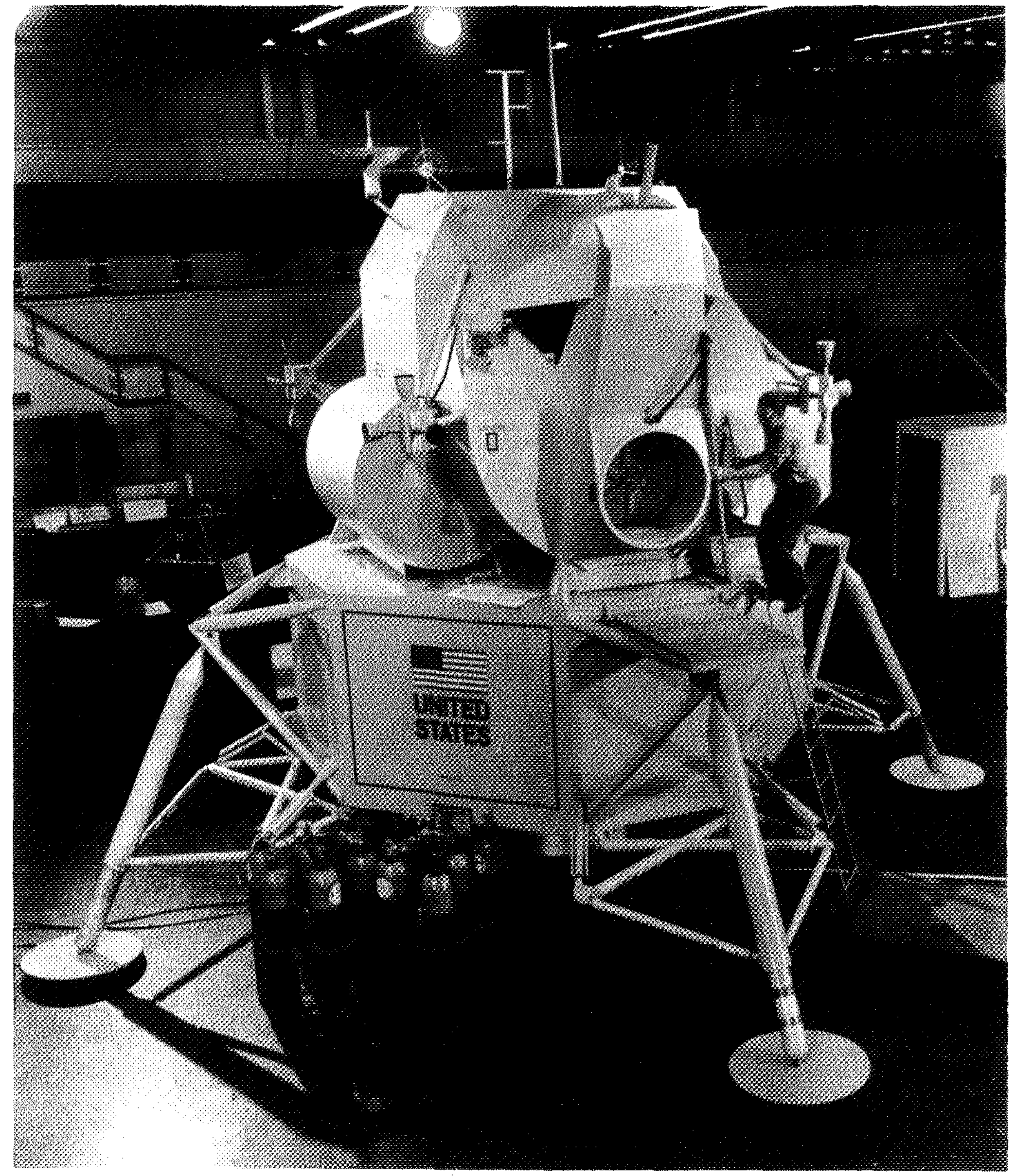
After reaching the moon's vicinity, Apollo is rotated to a tail forward position and a rocket in the service module is operated to swerve Apollo into a circular orbit about 100 miles above the moon. Two astronauts will enter the LEM, detach it, and land it on the moon while the third crewman remains with the parent craft, which continues to orbit the moon.

The two astronauts explore the moon's surface near their landing site, take pictures, collect samples, and conduct scientific experiments. Then, they enter their LEM and launch it to a rendezvous with the parent craft. After the two astronauts have rejoined the other astronaut in the parent craft, they jettison the LEM. Then, they fire a rocket in the service module to boost the parent craft out of lunar orbit toward earth.

One of the most critical phases of the return to earth is atmosphere entry. At a speed of 25,000 miles per hour (which is the earth-approach velocity of a spacecraft returning from a lunar mission), a spacecraft must follow an extremely precise course called an entry corridor to avoid burning up or bouncing back into space. The crew operates rockets in the service module to adjust Apollo's course properly. When they are in the entry corridor, they jettison the service module.

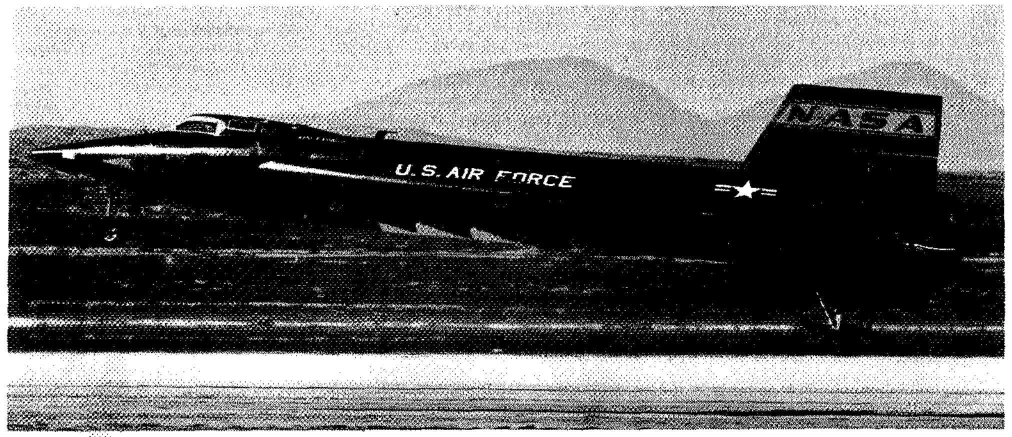
After the searing heat and heavy deceleration forces of atmosphere entry are passed, the command module opens first a small and then a large parachute to stabilize and slow the spacecraft for a landing. Recovery forces deployed in the expected landing area race to pick up spacecraft and crew for their triumphal return home.

Apollo, like Mercury and Gemini, will be the product of no one American industrial firm. A spacecraft vehicle is so complex and requires skills and techniques in so many fields that no one company possesses more than a part of them. Normally, a number of companies are awarded study contracts which will result in proposals for the spacecraft desired. It is common practice for the designers, in such cases, to form teams of other companies to join in the preparation of a final proposal. Together these companies may contribute skills in such areas as propulsion, communications, guidance, telemetry, and control. Later the company awarded the contract will participate with other firms as associate contractors to develop and produce the vehicle.



Mock-up of Apollo Lunar Excursion Module.

These companies in turn call on others for certain skills and techniques, and together they devise and produce the thousands upon thousands of component parts in a major space vehicle. Literally hundreds of companies will have participated in the completed product.



X–15 research airplane comes in for a landing.

X–15 RESEARCH AIRPLANE

The X–15 research airplane is a manned vehicle for carrying out space and aeronautics research at the threshold of space. Propelled by a 57,000-pound thrust rocket that provides the equivalent of 400,000 horsepower, the X–15 holds the world aircraft records for altitude (over 66 miles) and speed (more than 4,100 miles per hour).

An Air Force, Navy, and NASA project, the X–15 is fundamentally a flying laboratory. It has furnished information for design of high-altitude hypersonic (speed more than five times that of sound) and supersonic aircraft, including the contemplated supersonic commercial air transport. It has provided data on pilot-controlled atmosphere entry and on man's physiological and psychological reactions to piloting spacecraft and high-altitude high-speed aircraft. It is continuing to serve as a test vehicle for future projects in aeronautics and space.

In the space science fields, the X–15 has photographed the stars in ultraviolet wavelengths from above the murky deneseness of the lower atmosphere. The ultraviolet light from stars is expected to contain clues to their origin, evolution, and constituents, and possibly may answer questions relative to the origin of the universe. The aircraft is also providing information on meteors, radiation, and atmospheric density at altitudes above 100,000 feet.

The X–15 is 50 feet long and has a 22-foot wing span. It is carried aloft by a B–52 aircraft and launched at about 42,000 feet. It maneuvers in the thin air of the upper atmosphere where conventional aerodynamic controls are useless by employing hydrogen peroxide jets in the nose and wing.

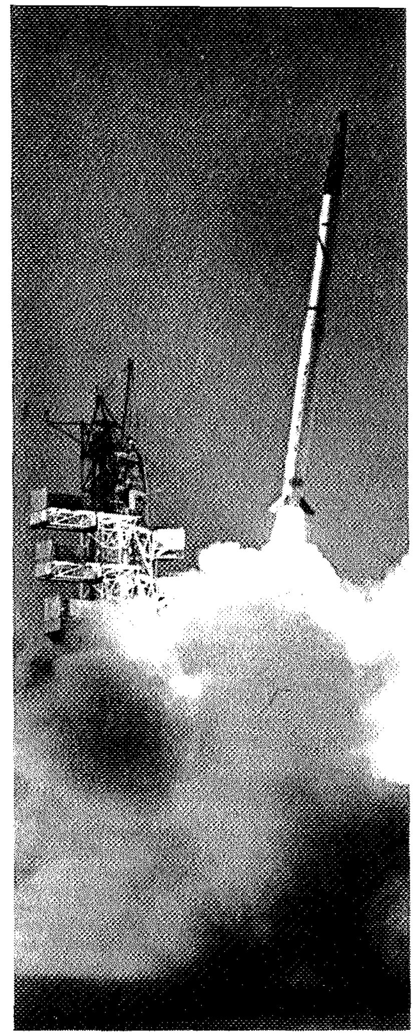
Since its first powered flight on September 17, 1959, the X–15 has made almost 100 flights with only 2 landing mishaps. In neither case was the pilot injured. The many flights have resulted in the accumulation of a vast amount of data on piloting craft that are part airplane and part spacecraft.

Advanced Manned Mission Studies

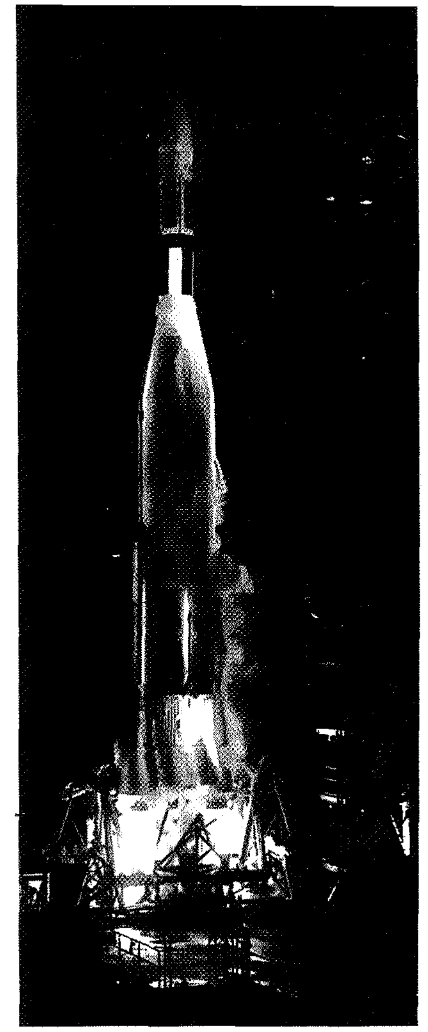
NASA is continuing studies of the technology required for possible future manned space projects which are determined to be in the national interest. Among these are extended exploration of the moon, establishment and operation of a manned orbital laboratory, and manned flights to Mars and Venus.

CHAPTER VIII

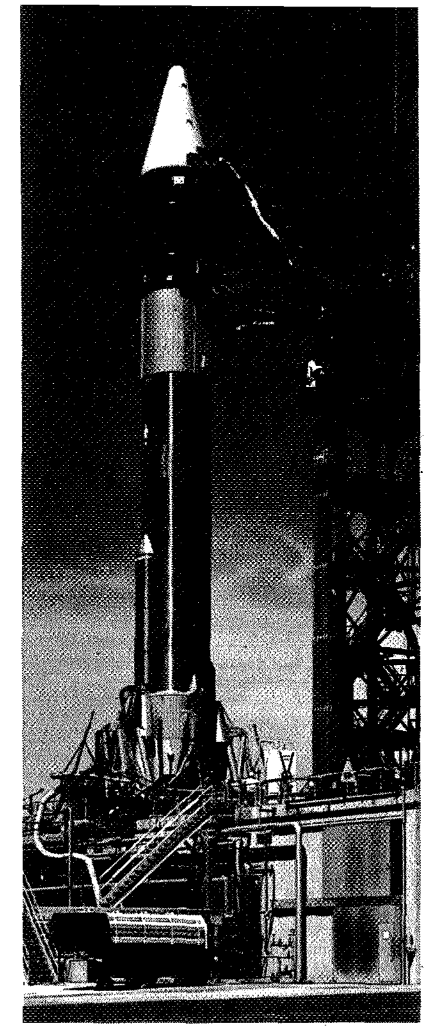
THE SPACE LAUNCH VEHICLES



Scout



Atlas Agena B



Centaur

The United States employs a fleet of launch vehicles for rocketing spacecraft into earth orbit and beyond. The range of vehicles makes possible the selection of the particular one that will most economically and efficiently accomplish a space mission. Repeated use of the same launch vehicles also contributes to development of reliability in these rocket systems.

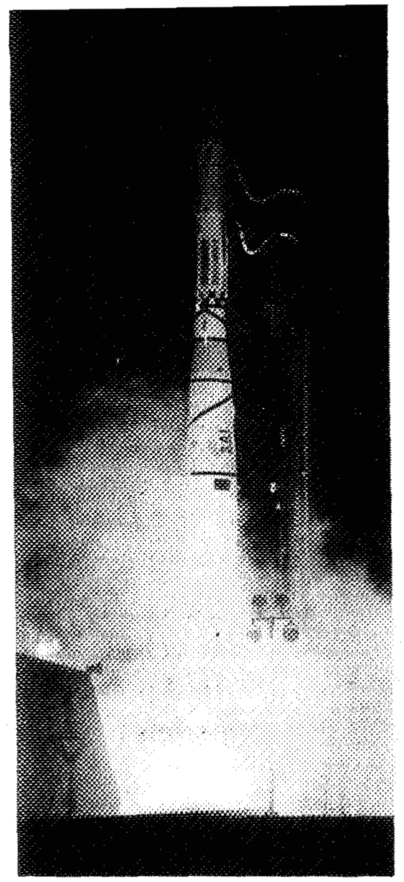
Launch vehicles employed by the United States are briefly described below.

Scout—Scout is a four-stage solid-propellent vehicle for small satellites and probes. It can place a payload of about 220 pounds into 300-mile orbit or can lift useful payloads as high as 4,000 miles in vertical probe experiments. The 65-foot-long Scout is the Nation's only all-solid propellent launch vehicle.

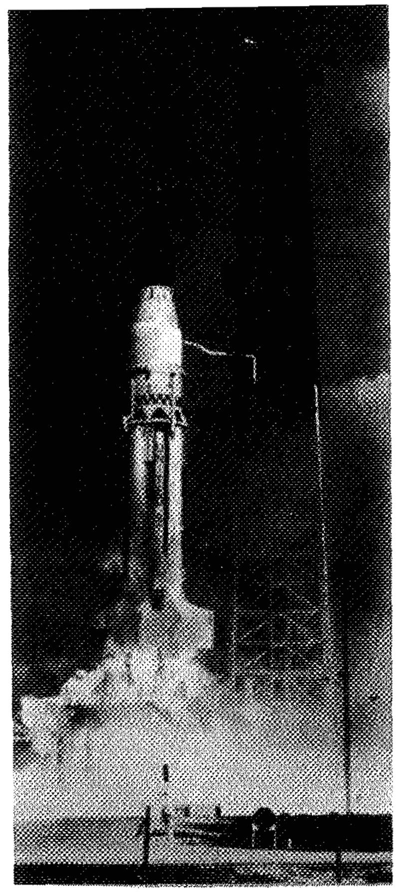
Delta—The Delta has three stages and stands 90 feet high. Delta can place about 500 pounds into a 300-nautical-mile orbit or rocket a 60-pound probe to moon's vicinity. Delta is one of the most reliable of U.S. launch vehicles with a long list of successes to its credit.

Thor-Agena B—Developed by the U.S. Air Force and adapted by NASA to civilian space programs, Thor-Agena B is a two-stage, 76-foot-high vehicle capable of placing 1,600 pounds into a 300-nautical-mile orbit, or some 600 pounds into a 1,200-nautical-mile orbit.

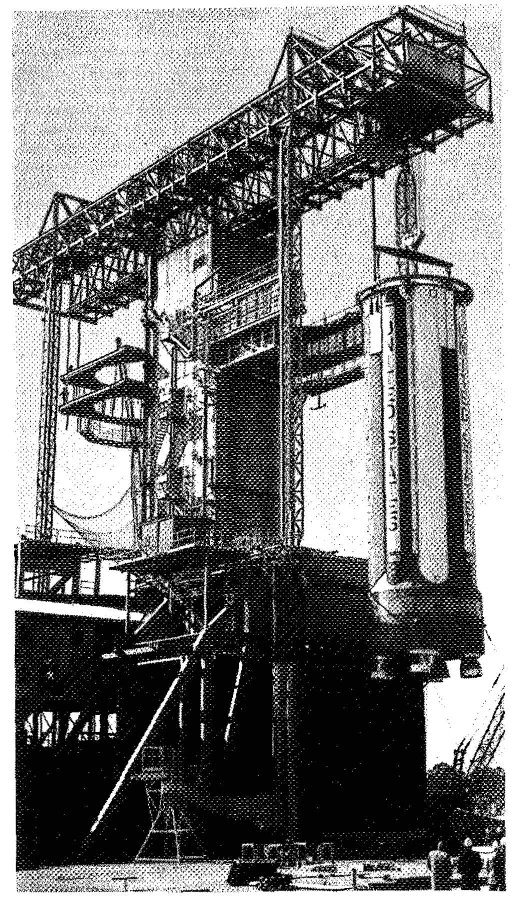
Atlas D—Atlas D is a 1½-stage liquid-propellent vehicle used to launch the Mercury spacecraft into earth orbit. Its three engines, all of which are ignited at launch, provide about 367,000 pounds of thrust. The outer two engines, counted as a half stage, are jettisoned at the end of their burning time. The inner rocket, called the sustainer engine, burns until orbit is attained. The 72-foot-



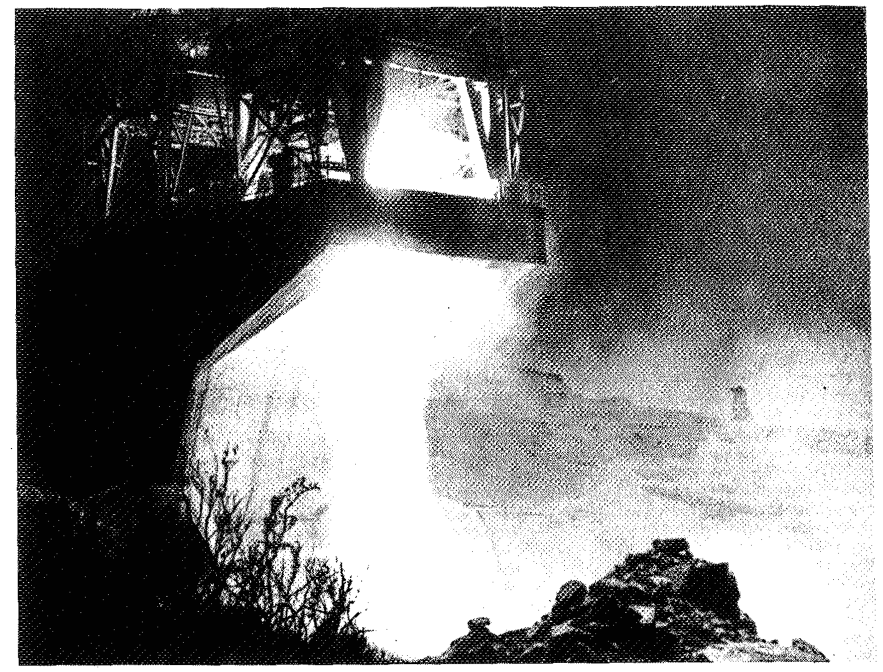
Thor-Agena B



Saturn I successful launch with live first and second stages.



Saturn I first stage is hoisted into static test stand.



Ground firing test of 1.5-million-pound-thrust F–1 engine.

long Atlas D can launch a satellite weighing about 3,000 pounds into an orbit approximately 100 nautical miles above earth.

Atlas-Agena B—The Atlas-Agena B developed by the U.S. Air Force and adopted by NASA to civilian space programs, is a two-stage space launch vehicle system designed principally for launching heavy communications and other scientific satellites and for close approach or hard landing in early lunar explorations. Atlas-Agena B, which became operational in 1961, can place about 5,000 pounds into a 300-nautical-mile orbit or launch a 750-pound lunar probe. It stands approximately 100 feet high.

Centaur—The Centaur, in development for use as a high-performance, general-purpose launch vehicle, uses an Atlas first stage and a second stage powered by two engines using a combination of liquid hydrogen and liquid oxygen. Centaur is actually the name of the second stage from which the entire vehicle takes its designation. Centaur can place 8,500 pounds into a 300-nautical-mile orbit or launch a 1,300-pound spacecraft to Venus or Mars, or rocket a 2,300-pound spacecraft to the moon. The liquid-hydrogen liquid-oxygen propellent combination employed in the upper stage generates about 40 percent more thrust than would be produced by the same weight of conventional rocket fuels such as refined kerosene and liquid oxygen. Centaur is the first U.S. launch vehicle employing the high-energy liquid-hydrogen liquid-oxygen propellent.

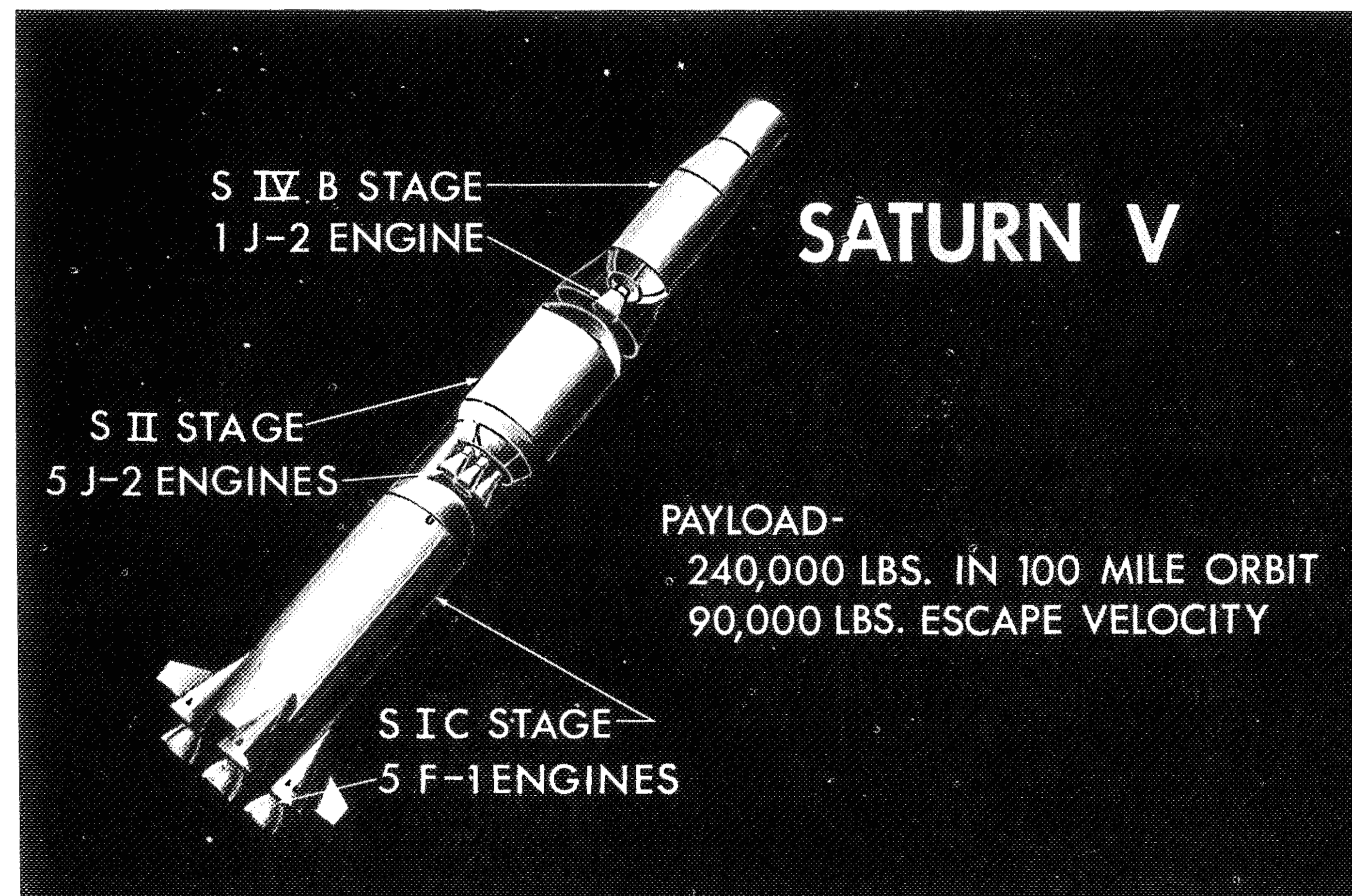
Titan II—Titan II, a two-stage U.S. Air Force booster, has been chosen to launch the Gemini two-man spacecraft. The vehicle utilizes a kind of liquid propellant that can be stored indefinitely in its fuel tanks. Thus, unlike other liquid-fuel rockets whose propellants must be held at cryogenic (intensely cold) temperatures, Titan II can be fueled well ahead of a launch and need not be drained of fuel if a launch is postponed. Titan II stands 90 feet tall and has a launch thrust of 430,000 pounds. It can place a spacecraft weighing about 7,000 pounds into orbit around earth.

Table 3.—PRINCIPAL USES OF LAUNCH VEHICLES

LAUNCH VEHICLE	EMPLOYMENT
Scout	Small Explorer satellites and geoprobes such as P-21 and P-21a
Delta	Meteorological satellites (TIROS); communications satellites (Telstar, Echo, Relay, and Syncom); and scientific satellites such as Explorers XII, XIV, XV, and XVII, Ariel, Orbiting Solar Observatory, and the Interplanetary Explorers
Thor-Agena B	Scientific satellites such as Alouette, Orbiting Geophysical Observatory; applications satellites such as Advanced Echo communications satellite and Nimbus weather satellite
Atlas D	Project Mercury
Atlas-Agena B	Unmanned lunar and interplanetary probes such as Ranger Lunar Orbiter, and Mariner; Orbiting Astronomical Observatory; heavy advanced communications satellites; Project Gemini
Atlas-Centaur	Surveyor spacecraft for soft landing on the moon; advanced spacecraft of the Mariner kind for exploration of Mars and Venus
Titan II	Project Gemini
Titan III	U.S. Air Force Manned Orbital Laboratory
Saturn I	Project Apollo earth-orbital flights of boilerplate command and service modules
Saturn IB	Project Apollo earth-orbital flights of command, service, and lunar excursion modules (complete Apollo spacecraft); orbital rendezvous rehearsals
Saturn V	Project Apollo lunar exploration mission

Titan III—Titan III is conceived as a three-stage, 103-foot-tall launch vehicle intended for a great number of space missions involving satellites weighing from 5,000 to 25,000 pounds. One of its missions will be the launch of the Air Force Manned Orbital Laboratory. Titan III is based on Titan II, modified principally by strapping two large solid-fuel rockets to its sides and adding a liquid-propellent third stage. Titan III is a project of the U.S. Air Force. Total liftoff thrust will be about 2 million pounds.

Saturn I—Saturn I is part of a family of three launch vehicles that NASA is developing for its Apollo program. The launch vehicles will also be employed in other scientific space projects. In Apollo, Saturn I will launch boilerplates (engineering and test models) of the command and service modules on earth-orbital flights.



Saturn I is a two-stage liquid-propellent launch vehicle. It will be 125 feet tall and, excluding fins, have a base diameter of 21.6 feet. The first stage, consisting of a cluster of eight engines generating 1.5 million pounds of thrust, has successfully completed a series of flight tests. This stage is the free world's most powerful existing booster.

The second stage is a cluster of six engines burning high-energy liquid-hydrogen and liquid oxygen, and producing a thrust of 90,000 pounds. Saturn I will be able to launch into orbit spacecraft weighing as much as 11 tons. Saturn I was formerly called Saturn C–1.

A series of ten Saturn I test flights began with the successful launch on October 27, 1961, of a powered Saturn I first stage and an inert second stage. Three other tests of the first stage followed.

On January 29, 1964, NASA successfully launched a Saturn I with live first and second stages. The principal goals of this flight, the fifth in the series, were to make additional tests of the first stage, to demonstrate separation of the first from the second stage, and to check the functioning of the second stage which is fueled by liquid hydrogen instead of the more conventional refined kerosene.

In addition to accomplishing all mission objectives, this launch placed the world's heaviest satellite, weighing about 19 tons, into earth orbit. The satellite consisted of the spent upper stage, instrument unit, and sand-filled nose cone.

On May 28, 1964, NASA conducted the sixth Saturn flight test. It was the first of three Saturn I launches of unmanned models of the Apollo command and service modules (see Chapter VII, "Manned Space Exploration"). Other Saturn I flights (8, 9, and 10) are scheduled to carry giant size meteoroid detection satellites into orbit. The sixth Saturn flight is part of the vehicle's development program with primary emphasis on testing the propulsion system.

Saturn IB—Saturn IB, previously termed Saturn C–1B, will launch all three modules of the Apollo spacecraft into orbit. This vehicle will be employed for the so-called rendezvous rehearsal phase of Apollo. The Saturn IB will have the same first stage as Saturn I. Its second stage, however, will consist of a single engine fueled by liquid-hydrogen and liquid oxygen, and generating 200,000 pounds of thrust. With this second stage, Saturn IB will stand 141 feet high and be able to orbit a spacecraft weighing 16 tons.

Saturn V—For the Apollo lunar exploration mission and certain unmanned interplanetary flight experiments, NASA is developing Saturn V, formerly called the Saturn C–5 or Advanced Saturn. Saturn V is the most powerful launch vehicle under development by the United States. Its first stage, about 33 feet in diameter (excluding fins), will consist of five engines, each generating as much thrust as all eight engines of Saturn I or Saturn IB. The aggregate thrust of these five engines is 7.5 million pounds. Upper stage powerplants will consist of 200,000-pound-thrust rocket engines fueled by liquid hydrogen and liquid oxygen. Five of these will make up the second stage; one, the third. Saturn V will be able to launch a spacecraft weighing 30 tons to Mars or Venus, rocket a 45-ton spacecraft to the moon, or place a 120-ton satellite into orbit around earth.

CHAPTER IX THE BIOLOGY OF SPACE

WHAT MAN FACES IN SPACE

To survive and to fulfill the missions assigned to him in space, man must learn to live there with a reasonable degree of comfort, efficiency, and freedom of movement. The greatest problem posed for man in this regard is the necessity of creating for himself in space an environment which will reasonably duplicate the one he is accustomed to on earth.

Man is a complex mechanism. He has developed through thousands of years of living under one set of general conditions. Although he can be trained and acclimatized, he cannot be reengineered. He must take his manner of living with him wherever he goes. This involves not only the air he breathes and the temperature and humidity he feels, but also his protection from heat, cold, weightlessness, and radiation. In addition to these, there are the related problems of food and water and the disposal of human wastes—plus the factors of fatigue and boredom.

Both liquid and semisolid foods packaged in squeeze tubes are a part of an astronaut's menu.

Man uses in the neighborhood of 2 pounds of oxygen each day. This he gets, of course, from the atmosphere. In space there is no atmosphere. For human breathing purposes the atmosphere ends well below 50,000 feet. An aircraft pressurizes its cabin from surrounding atmosphere even at 40,000 feet, but because a spacecraft has no surrounding atmosphere, it must be pressurized from one of three sources carried along: compressed gaseous oxygen, liquid oxygen or chemical compounds which liberate oxygen.

Cosmic rays lose their original power and intensity when they enter the atmosphere. But, in space outside the atmosphere, any object is exposed to a powerful bombardment of cosmic ray particles.

Sunburn is caused by the ultraviolet rays of solar radiation. On earth the atmosphere gives lifesaving protection from solar radiation. But out in space its intensity is lethal.

Thousands of tiny meteoroids cross the regions of space. As they enter the atmosphere they normally are set afire by friction, become meteors, and burn up. But they constitute a possible hazard to any craft in space.

There are many psychological problems. Man is accustomed to a certain day-and-night cycle and performs best when he works, eats, and sleeps in his usual manner. He must be able to walk about and shift positions, to flex his arms, legs, and neck. He must have some sort of visual orientation within the spacecraft and he must be able to make minor adjustments in his environment (like raising or lowering the lights) just to relieve the monotony. In space, man faces the problem of fatigue—the kind that comes from long commitment to one task and confinement within a relatively small compartment. This fatigue results in impaired judgment, decline in alertness, irritability, and indecision. His power of perception suffers.

FOOD IS A MORALE FACTOR

Food is highly important to the space explorer both for nutrition and sustaining his morale. The cook, the engineer, the flight surgeon, and the nutrition expert have all combined in creating a menu the astronaut will look forward to, and of giving him a way to eat it. Three general feeding plans have been worked out for space flights. The first covers a short trip of 2 or 3 days. The second covers from 3 days to several months. The third or long-range covers a flight extending over months or years.

The first or short-range plan includes food bars, each of 250 calories, cut into bite-size pieces; water in plastic bags with plastic drinking tubes; both liquid and semisolid foods packaged in squeeze tubes (soup, meat, fruit, chocolate, milk, ham, turkey, and cheese); dehydrated foods and fruit juices to be reconstituted with water.

For the longer range missions, ranging from 3 days to several months, the food experts assume that space scientists will have perfected a means of producing artificial gravity within the spacecraft. They also assume that water will be recovered from the atmosphere within the spacecraft and from body waste, purified and reused.

Where weight and space are crucial, the meals will consist of precooked, dehydrated food, plus ordinary beverages.

Where weight is less of a problem, food would include canned, dehydrated, and instant types, none of which would require refrigeration. Spices, herbs, condiments, pickles, jellies, raisins, nuts, and candy would also be available.

Where weight and space are of no concern, the meals would be very much like those served today on the most modern commercial airliner.

For the long flights in the relatively distant future, those flights which may last for months or years, it is not feasible to carry expendable supplies. Such flights will require a completely regenerative, closed and balanced ecological system capable of producing food and oxygen (and absorbing carbon dioxide), and of recycling wastes to supply materials essential to the human body.

Since earth, itself, is a successful closed ecological system, man will probably take earth as his model in creating such a system for space. The regenerative cycle is well established by Nature. Man and other animals eat the plants of earth, the products of the sea (and each other), return their wastes and even their bones to the earth in the recycling process.

ENABLING MAN TO LIVE AND WORK IN SPACE

Steps have already been taken toward development of an artificial closed-cycle ecological system for space flight. Among those under development are prototype systems that can sustain five men in shirtsleeve comfort for 30 to 60 days; four men for 3 to 6 months; and eight men for a year. The systems will be designed to purify water and air for reuse and provide for waste disposal and for food.

Tests are being conducted to learn how man will perform and how he will react in the relative isolation of long space flights. One volunteer remained for about 5 months in a compartment approximately the size of an efficiency apartment. During the experiment, he performed directed tasks in sequence as if he were piloting a spacecraft but he saw no one else and had only voice contact with the outside. Tests with two or more volunteers are scheduled.

NASA is observing the effects of strong magnetic fields on organisms to determine any adverse effects from surrounding manned spacecraft with magnetic fields as a radiation shield. The artificial magnetic fields would function just like earth's magnetic field which diverts much lethal radiation hurtling to earth from outer space.

Biologists are considering induced hibernation for long space trips. An additional attribute of hibernation is that it appears to increase resistance to radiation.

NASA is studying algae and other plants as possible sources for a continued food supply. Moreover, studies are being carried out on development of compact, lightweight, nutritious, palatable, and morale-supporting meals that require neither refrigeration nor heating.

Some of these are in puree form to be taken from tubes; others are in solid form and must be chewed. (Foods that can be chewed are most desirable.) Some of the solid foods are dehydrated or freeze dried and must be reconstituted with water. In many cases, however, the moisture required can be supplied by the astronaut's salivary glands.

Space suits are being fabricated that will protect man from high vacuum, temperature extremes, small meteoroids, and radiation in space or on the airless moon, yet permit reasonable freedom of movement.

A series of recoverable bioscience satellites will provide information about the effects of weightlessness for as long as a year on animals and plants. Scientists generally agree that lengthy periods of weighlessness can reduce muscle tone; i.e., weaken muscles. However, other biological effects are still to be determined.

Crewless instrumented spacecraft, such as Ranger, Surveyor, and Mariner, will precede man to the moon and planets. They will transmit vital information about the celestial body that he is to explore and about what he will face on the voyage through black uncharted space.

Orbiting Solar Observatories, Pioneer spacecraft, and interplanetary monitoring platforms (IMP) will furnish data on radiation and other space phenomena and contribute to development of reliable methods for forecasting large solar flares. Such flares flood space with lethal intensities of radiation.

THE SEARCH FOR EXTRATERRESTRIAL LIFE

In a related program, NASA is investigating the possibility of life elsewhere than on earth. Life normally results where the conditions for it are appropriate. However, most scientists agree that the appropriate conditions need not necessarily resemble those on earth nor must all life be comparable to earth forms.

The conditions of space are simulated in earth-based laboratories. Micro-organisms are inserted in simulators to determine whether and how long organisms can survive the temperature extremes, high vacuum, and radiation of space. The results of these studies may have important implications relative to life on other planets.

Life scientists have simulated in the laboratory the kind of environment believed to exist on Mars. They have discovered that certain terrestrial lichens, mosses, and bacteria can survive for a limited time in this kind of environment. This does not necessarily mean that such organisms live on Mars but that organisms such as these could live on Mars. In the opinion of scientists, Mars is the best candidate in the solar system for some sort of life like that on earth.

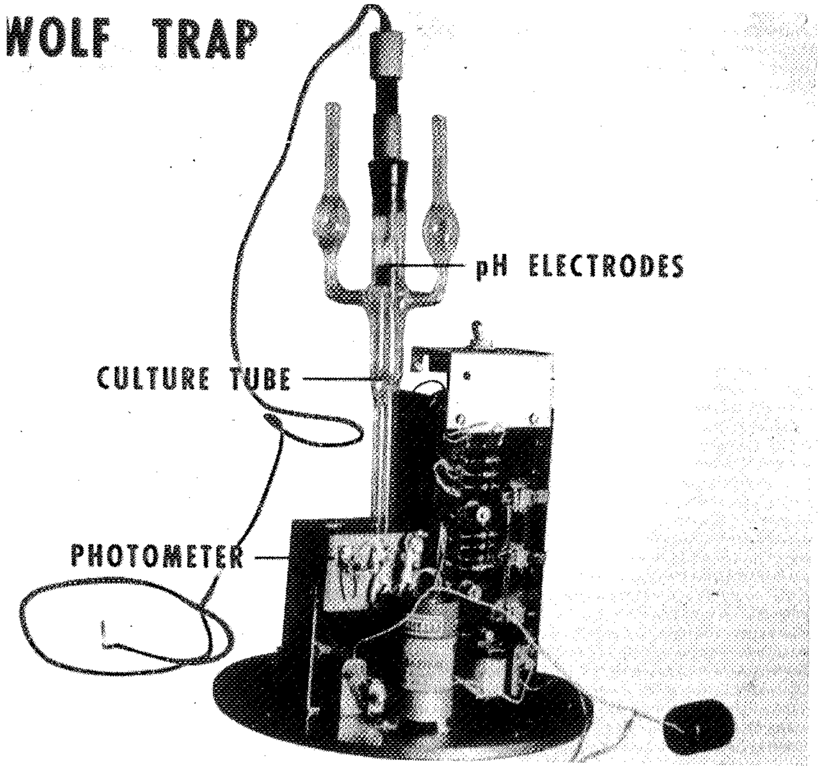
Balloon-borne instruments have made infrared studies of Mars. These and other studies detected minute quantities of water vapor and considerable carbon dioxide in the atmosphere. Their existence suggests the possibility that specially adapted lower forms of life may exist on the Red Planet.

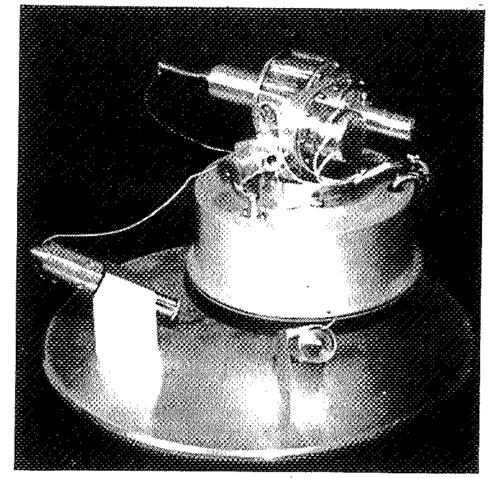
During its exploration of the moon, NASA plans to analyze lunar materials for signs of life. Such analysis may disclose remnants of extinct life or organic substances that might signify the presence of life. On the other hand, the study may bring to light prelife chemicals (chemicals identified with life) that have accumulated through natural processes over millions of years but have not been organized into living things. Such a find would be invaluable to the study of how life orginated or evolved.

As part of this program, NASA is also supporting the examination of meteorites for organic compounds and studying the origin of compounds of living organisms under primeval geochemical conditions.

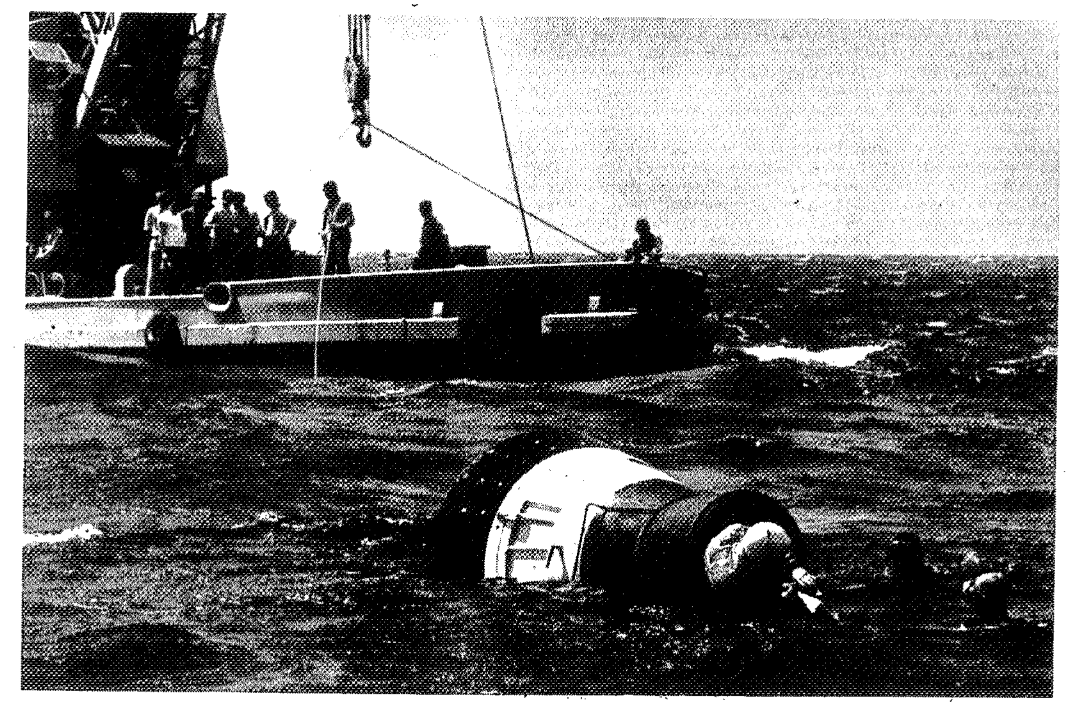
Several life detection devices are being readied for landing on other planets. These miniature laboratories are primarily designed to report on microbial life. They are quite small, and some weigh as little as 1½ pounds.

One is named *Gulliver* for Jonathan Swift's fictional discoverer of the tiny Lilliputians. After landing, Gulliver will fire adhesive cords outward and then reel them in. It is expected that dust and other surface substances will adhere to the cords. The cords will be immersed into or drenched by a nutrient solution containing radioactive carbon. If earthlike organisms are present, they will ingest and ferment the solution, creating radioactive carbon dioxide gas. This would be registered by a Geiger counter and the exciting results transmitted to earth.





"Gulliver"



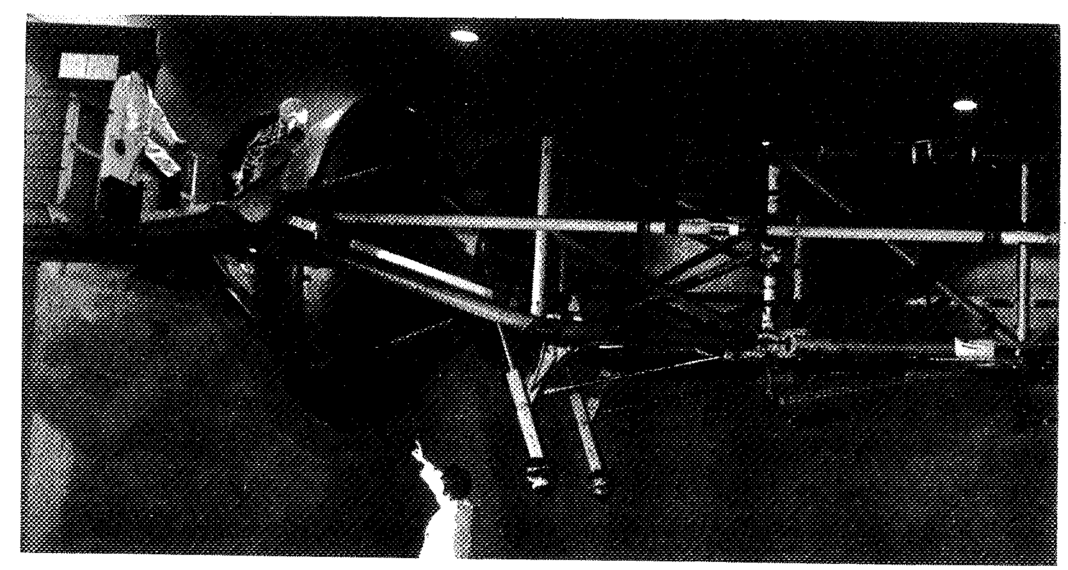
Astronaut Training: Egress

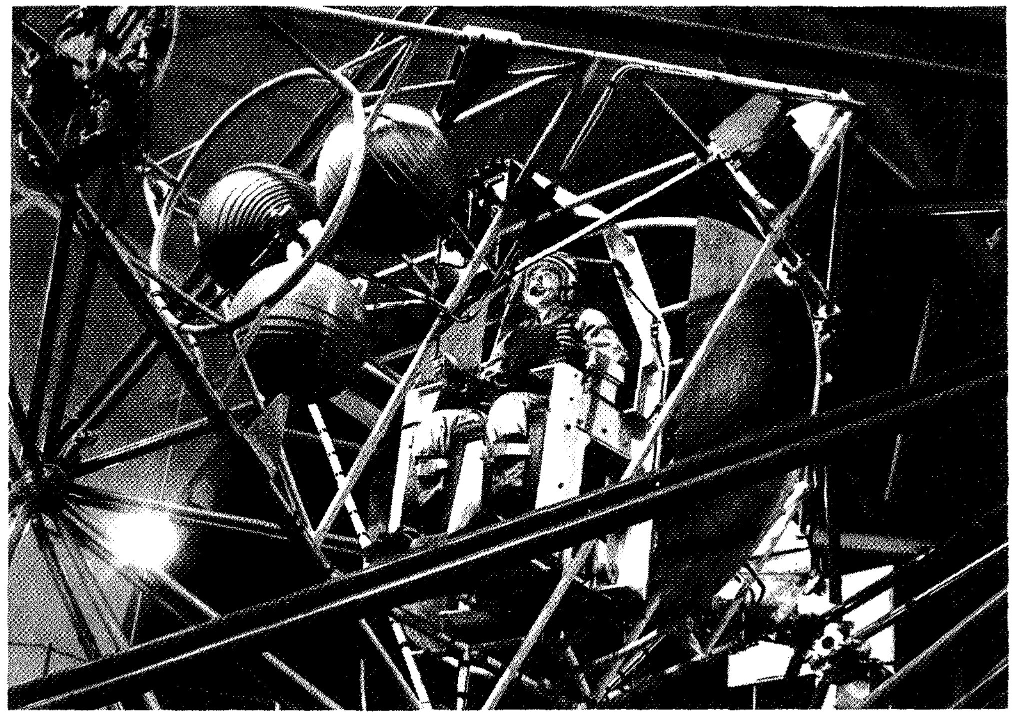
Another device, which operates on a similar principle, is the *Wolf Trap*, named for its designer Dr. Wolf Vishniac. The Wolf Trap will suck in samples of soil and air and immerse them in nutrient solutions. If the samples contain organisms, the solutions will undergo changes in acidity and turbidity which would be reported to earth.

Among the other life detection devices are the *Multivator* which is in effect a miniature laboratory that can make 24 biochemical tests for organisms, a microscope which can radio images back to earth, and a TV telescope that can survey the landscape for such possible signs of life as moving or waving objects.

Newer approaches include devices for determining the characteristic absorption of polypeptides and DNA in the *UV range;* for determining *optical rotation* (typical of complex molecules of living or once living systems); *gas chromotography* for the detection and analysis of various life related materials; and *mass spectroscopy* for the identification of relatively large submolecular groups by means of density. Another device may consist of a simple colorimeter which will measure the visible light absorption reaction (*"J" bands*) between certain dyes and proteins. Recent

Astronaut Training: High "G"





Astronaut Training: Disorientation

experiments have shown that by varying the pH and temperature, it may be possible to render this device "analytical" not only with respect to proteins but also with respect to other biologically significant molecules.

SELECTION AND TRAINING OF AMERICAN ASTRONAUTS

In the tests made before selecting the first American astronauts, in April 1959, aerospace medical experts found there is no specific type of personality which is uniformly superior. The experts discovered that those who performed best were simply mentally and physically well adjusted—and strongly motivated.

When the first American astronauts were chosen, the National Aeronautics and Space Administration set the requirements very high. To qualify, each astronaut had to be a test pilot, a jet pilot, and to have 1,500 or more hours of flight time. He had to have an engineering degree or its equivalent, be under 40, be no taller than 5 feet 11 inches and weigh no more than 180 pounds.

More than 100 men who met this requirement volunteered. NASA interviewed 69, chose 32 for final mental and physical tests, and finally selected 7. All came from the military services, three Air Force, three Navy, and one Marine. Their names: Capt. Leroy G. Cooper, Jr., Capt. Virgil I. Grissom, and Capt. Donald A. Slayton, Air Force; Lt. Comdr. Malcolm S. Carpenter, Lt. Comdr. Walter M. Schirra, Jr., and Lt. Comdr. Alan B. Shepard, Jr., Navy; Lt. Col. John H. Glenn, Jr., Marine Corps. Shepard was chosen to make the first flight into space and Grissom the second.

The astronauts were subjected to probably the most rigorous training program ever devised for man. They have had survival tests for the desert and for the sea. They fly regularly in the fastest jetplanes to maintain flight proficiency and reaction. They practiced removing themselves from the Mercury space cabin under practically every circumstance. They spend hours in a human centrifuge which simulates every erratic flying condition. They experienced weightlessness in especially devised aircraft. They learned star identification and celestial navigation.

Wearing pressure suits they were subjected to the same low-pressure environment as an actual Mercury flight. On the centrifuge each astronaut was subjected to about 16 gravity forces, the highest possible "g" load to be encountered on a Mercury flight. (The maximum "g" force actually experienced in Mercury flights was 11.) They have become familiar with every major component part of the Mercury space cabin.

In September 1962, NASA named nine volunteers to its pool of astronaut-trainees for Projects Gemini and Apollo. For the most part, the physical, psychological, educational, and experience criteria under which the men were chosen were similar to those of the original seven Mecury astronauts.

The newer standards, however, reduced the top age limit from 40 to 35 because of the long-range nature of the Apollo program, opened the way for civilian volunteers, and extended academic requirements to include a degree in either engineering, biological sciences, or physical sciences. The 9 trainees were chosen from about 250 applicants.

Of the nine astronaut-trainees, seven are from the military services and two are civilian. They include: Neil A. Armstrong, a test pilot of the X–15 research airplane; Maj. Frank Borman, U.S. Air Force; Lt. Charles Conrad, Jr., U.S. Navy; Lt. Comdr. James A. Lovell, U.S. Navy; Capt. James A. McDivitt, U.S. Air Force; Elliot M. See, Jr., civilian test pilot; Capt. Thomas P. Stafford, U.S. Air Force; Capt. Edward H. White II, U.S. Air Force; and Lt. Comdr. John W. Young, U.S. Navy.

In October 1963, NASA named 14 new astronaut-trainees, boosting its total manpower pool for manned space flight to 30. The new trainees are: Maj. Edwin E. Aldrin, Jr., U.S. Air Force; Capt. William A. Anders, U.S. Air Force; Capt. Charles A. Bassett II, US. Air Force; Lt. Alan L. Bean, U.S. Navy; Lt. Eugene A. Cernan, U.S. Navy; Lt. Robert B. Chaffee, U.S. Navy; Michael Collins, U.S. Air Force; R. Walter Cunningham, a civilian; Capt. Donn F. Eisele, U.S. Air Force; Capt. Theodore C. Freeman, U.S. Air Force; Lt. Cmdr. Richard F. Gordon, Jr., U.S. Navy; Russell L. Schweickart, a civilian; Capt. David R. Scott, U.S. Air Force; and Capt. Clifton C. Williams, Jr., U.S. Marine Corps.

Recruitment of additional astronaut-trainees is contemplated.

For Projects Gemini and Apollo, the astronauts must receive training beyond that given for Mercury. They must learn to navigate their craft in the blackness of space, correct their flight paths, and control their landings on the earth and moon. They must learn how to check out and launch their craft from earth orbit, from an orbit around the moon, and from the surface of the moon where no great assembly of launch operations personnel is available. They must learn the technology of spacecraft, launch vehicles, ground facilities, and flight operations that are far more complex than those of Mercury.

Astronaut Training: Zero Gravity

SCIENTISTS TO BE TRAINED AS ASTRONAUTS

NASA plans to include qualified scientists among the astronauts who will fly the Apollo spacecraft to the moon. NASA made the decision in response to suggestions from the scientific community. The scientists will be included in the earliest appropriate stage of the Apollo project.

In the interim, other steps are being taken to assure that science is given proper emphasis in the manned space flight program. Among these are the training of astronauts in science and in scientific procedures, making scientific measurements during manned flights, and establishment of a Manned Space Science Division in the Office of Space Sciences and Applications.

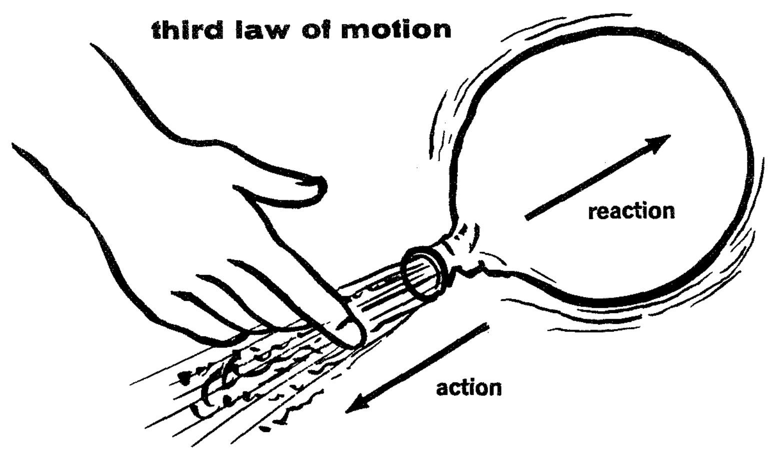
CHAPTER X SPACE EXPLORATION—THE TECHNIQUES

The fundamental requirements of any space vehicle include systems for propulsion, guidance, communications, and tracking.

The rocket engine is a form of jet propulsion. In the 17th century, Sir Isaac Newton expressed three laws of motion which are fundamental to any discussion of jet propulsion:

1. A body remains at rest or in a state of motion in a straight line unless acted upon by an external force.

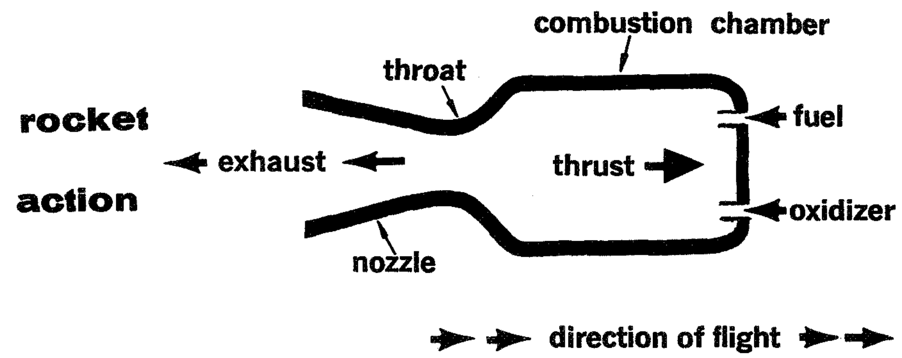
2. A force acting upon a body causes it to accelerate in the direction of the force, the acceleration being directly proportional to the force and inversely proportional to the mass of the body.



3. To every action, there is an equal and opposite reaction.

The third Newtonian law contains the basic principle of jet propulsion. In any type of jet, the action is a stream of mass escaping through an exhaust nozzle. In the process of escaping, it creates a reaction in the opposite direction, that is, in the direction in which the vehicle is flying. The degree of force provided by this reaction is measured in pounds of thrust.

In a turbojet engine such as those now powering commercial airliners, the escaping mass is a stream of gas created by burning a mixture of fuel and air, the air serving as the "oxidizer," or the substance which provides the oxygen needed to burn the fuel.



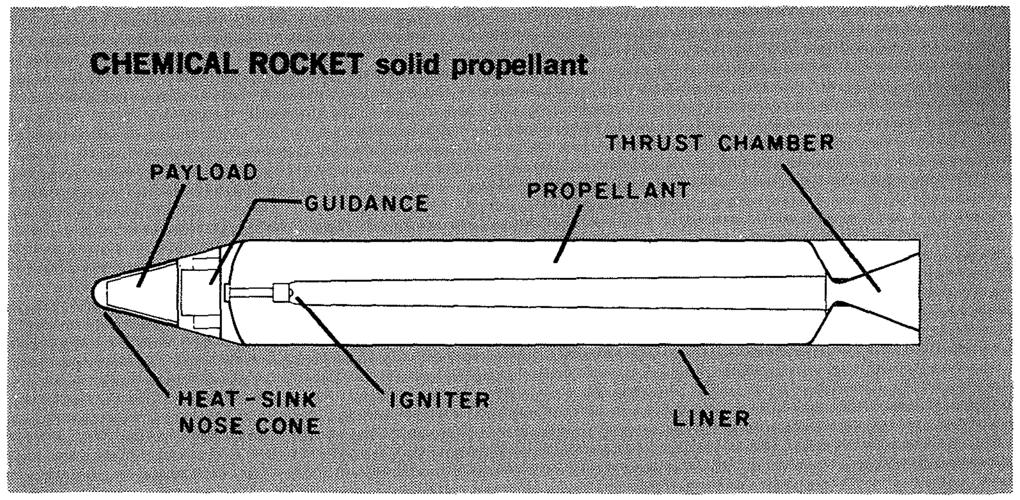
Fuel and oxidizer are fed into a combination chamber and ignited, forming the propulsive gas which, escaping at high velocity, provides thrust.

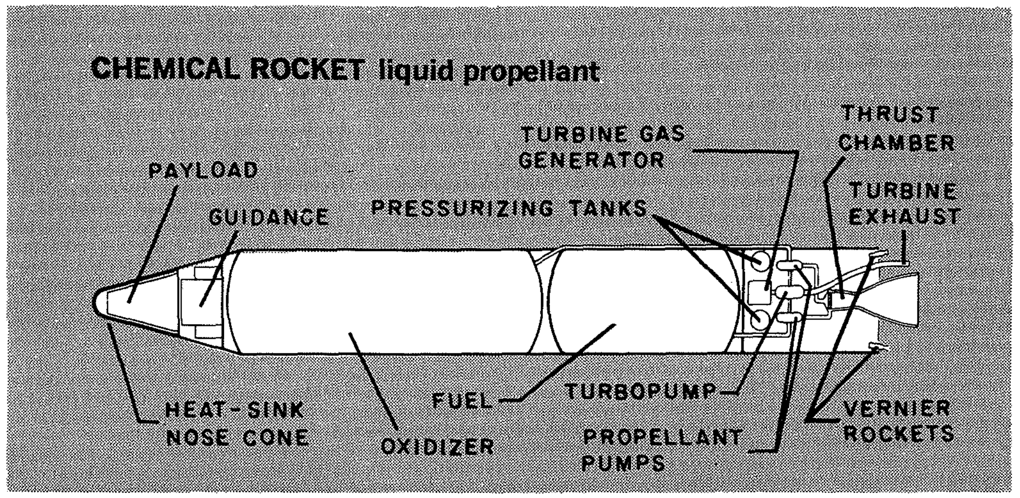
The rocket engine differs in that it needs no outside air for combustion. Instead, it carries its own fuel and oxidizer, which are burned in a combustion chamber, producing hot gases which are exhausted through a nozzle at temperatures of several thousands of degrees Fahrenheit. In thus expelling the mass as a "jet," the rocket recoils in the opposite direction in exactly the same way that a gun recoils when a bullet is fired from it. In the case of the gun, however, the recoil is due to the sudden single impulse caused by the ejection of the bullet. In the rocket engine, the recoil is spread out over the period of burning of the rocket's propellants. This continuing thrust provided by the rocket jet is balanced by an equal and opposite thrust on the rocket itself, causing the rocket to move in the direction opposite to that of the jet and accelerating it in accordance with the second of Newton's laws.

ROCKET PROPELLANTS

Current rocket propulsion systems are based on the use of chemical propellants, which may be either liquid or solid.

In a liquid propellent rocket, the propellants are stored in tanks and fed into the burning chamber either under the driving force of a high-pressure gas or by means of high-speed pumps. Ordinarily, liquid propellent rockets are "bipropellent" vehicles; that is, they use two different liquids, one (such as refined kerosene or liquid





hydrogen) as fuel; the other (such as nitric acid or liquid oxygen) as the oxidizer. There are, however, monopropellent liquid rockets, in which a single propellant is decomposed to produce the jet.

A solid propellent rocket is one in which the fuel and oxidizer are mixed in solid form, usually as a powdery or rubbery mixture known as the "grain" or "charge." The grain is packed in the rocket casing, which serves as both storage and burning chambers.

In general, liquid propellent rockets are considerably more complex than solid propellent rockets. However, it is possible to control the combustion in liquid propellent rockets with the simple closing or opening of a valve while the burning of a solid mass as in the solid rocket is extremely difficult to stop.

Rocket Engine Performance

There are a number of measures of rocket performance which need definition. They include—

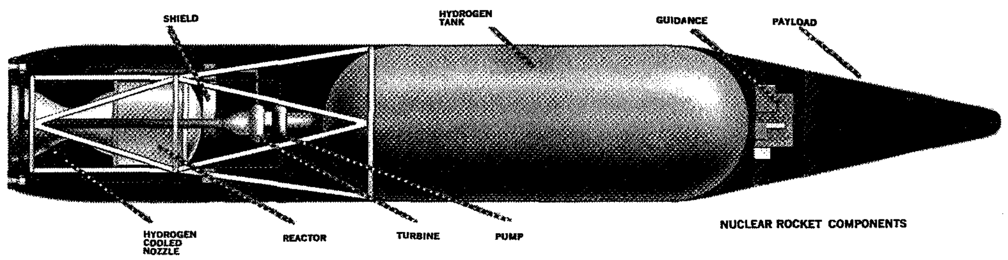
THRUST—This is the reaction force exerted on the vehicle by the rocket jet, or the "push." Two major factors determine the amount of thrust: the rate at which the propellants are burned and the velocity at which the resulting gases are exhausted. Thrust is measured in pounds.

The thrust of a rocket vehicle launched from the ground must be greater than the loaded weight of the vehicle. Thus, if large masses are to be lifted from the ground into an orbit about the earth or ejected farther into space, correspondingly large thrusts are required. When a specific job permits a small payload, a low thrust will suffice to accomplish the mission.

THRUST-TO-WEIGHT RATIO—This ratio is a comparison of the engine thrust with the vehicle's total weight. It is particularly significant, because thrust alone is not indicative of a vehicle's potential for velocity or range. Ten million pounds of rocket thrust will not lift a 10-million-pound vehicle from the ground. Yet, if the vehicle that weighs 10 million pounds on the ground is already in orbit where it is weightless, a few pounds of thrust applied for an extended period can accelerate it eventually to enormous velocities.

As an example of thrust-to-weight ratio, let us take the Saturn V-Apollo combination. The entire assembly will weigh about 6 million pounds at launch. First stage thrust is 7.5 million pounds. Thus, the thrust-to-weight ratio at launch is 7.5 to 6 or, mathematically reduced, 5 to 4 or 5:4. This ratio will change as the vehicle gains altitude, because thrust increases as atmospheric pressure drops and weight decreases as propellants are consumed and distance from the ground becomes greater.

SPECIFIC IMPULSE—Specific impulse is the amount of thrust derived from each pound of propellant in 1 second of engine operation. It is expressed in seconds. Specific impulse means to the rocket engineer much the same as does miles per gallon to the motor-



Nuclear propulsion is one of the systems being developed to obtain high performance vehicles.

ist; it is a measure of the efficiency with which the rocket propellants are being used to generate thrust.

Greater specific impulse means that more push is derived from each pound of propellant. This can make possible reduction in amount or weight of the propellant required for a given mission and permit a decrease in size and weight of propellent tankage. On the other hand, greater specific impulse enables a rocket to launch heavier payloads and send them farther into space.

Most of today's rocket engines burn a mixture of refined kerosene and liquid oxygen that has a specific impulse of 300 seconds. The Atlas-Centaur and the Saturn group of launch vehicles will have upper stages burning liquid hydrogen and liquid oxygen, providing a specific impulse of 400 seconds.

Eventually, nuclear rockets may become available. In such rockets, liquid hydrogen, which has a temperature of 423° below zero F., will be pumped into the core of a nuclear reactor, swiftly heated to about 4,000 F., and expelled from the rocket nozzle with a specific impulse of 800 to 1,000 seconds. Beyond this are ion rockets, a form of electric propulsion generating thrust of but a few pounds, but theoretically having specific impulses of 10,000 to 15,000 seconds.

EXHAUST VELOCITY—Exhaust velocity of a rocket denotes the speed at which the jet gases are expelled from the nozzle. This exit speed depends upon propellent-burning characteristics and overall engine efficiency.

MASS RATIO—This is the relationship between a rocket vehicle and the propellant it can carry, obtained by dividing the total mass at takeoff by the total mass remaining after all propellants are consumed. High mass ratio, and high exhaust velocity or specific impulse, are the most important factors in determining the velocity and range of a vehicle, hence the most important goals of rocket research.

Excluding the effects of gravity and air resistance, a rocket vehicle with a mass ratio of 2.72 to 1 will achieve a speed equal to its exhaust velocity. A 7.4-to-1 mass ratio, considered feasible for single-stage rockets, will produce vehicle speeds of twice the exhaust velocity. A 20-to-1 ratio would produce speeds three times the exhaust velocity, but this would require a structure, including payload, amounting to no more than 5 percent of the total takeoff weight and it is not likely that such a structure could stand up under the stresses of vehicle operation.

Inasmuch as the improvement of mass ratio improves the total rocket vehicle performance, then any device by which useless mass can be eliminated as soon as it is no longer needed should improve the performance of a rocket. This is the idea behind the so-called "step" or multistaged rocket.

In such a vehicle a series of rockets are mounted on each other. The first rocket fires, carrying the remaining rockets up to its terminal velocity. At the end of its burning, the first rocket is discarded, thereby reducing the overall mass of the combination, and the second rocket is ignited. After the end of the burning of the second rocket, it is discarded in turn, and the third rocket is ignited.

This is continued for as many stages as are used in the combination. By this device the overall mass ratio of the combined system is improved far beyond that obtainable in single-stage vehicles. Roughly, the mass ratio of the combination is equal to the product of the mass ratio of the individual stages.

It is obvious from the foregoing that design of a vehicle for space exploration is an extraordinarily complex task. The designer must take into consideration the weight, volume, and energy potential of a propellant; the weight, shape, and volume of the vehicle structure; the weight and volume of the payload; the weight and power of the engine or engines; and the effects of atmospheric resistance and gravity.

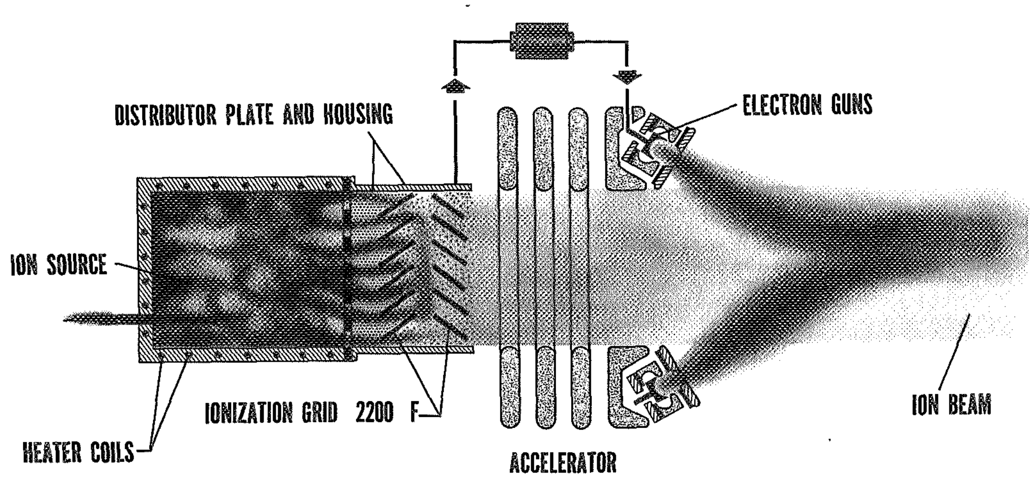
Most of these considerations are contained in a basic equation, the most important elements of which are exhaust velocity and mass ratio. An increase in either one automatically increases the speed of the vehicle.

Future Propulsion

The performance available to chemical rockets is clearly limited by the roughly 400 seconds' specific impulse that constitutes the theoretical maximum and by the mass ratios obtainable with best engineering practice. In order to obtain vehicles with performance great enough to carry out long-term and extreme distance space missions, it will become necessary to develop new propulsion systems with performance capabilities superior to those of the chemical rocket. Looking toward exploration of the solar system, research is being conducted on such propulsion systems as the following:

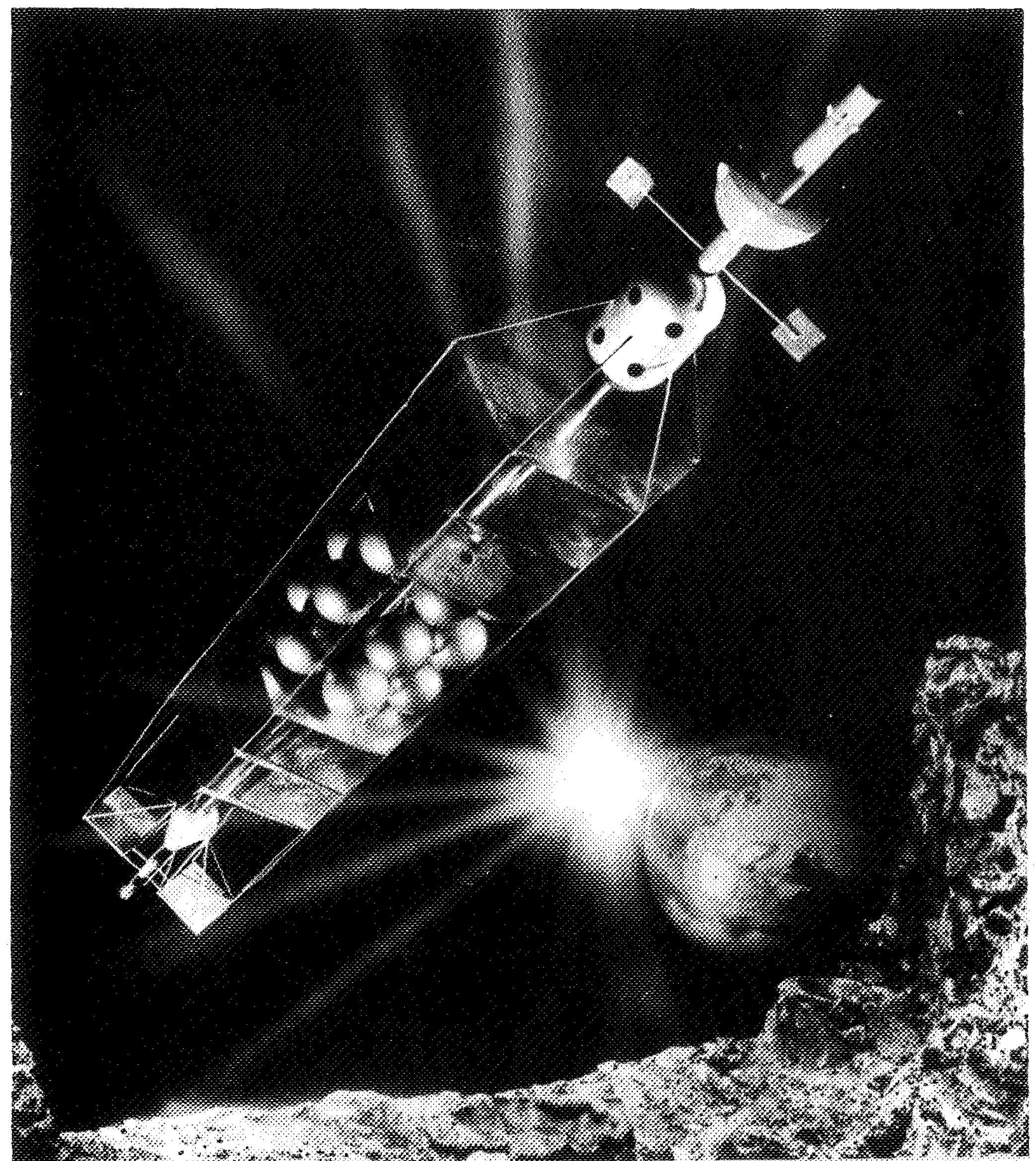
NUCLEAR FISSION—This is a powerplant which uses the enormous heat of nuclear fission (atom splitting) in a nuclear reactor to heat a "working fluid," which might be hydrogen, helium, or ammonia in liquid form. This heated fluid would then be channeled through a nozzle in the conventional rocket fashion. It is estimated that specific impulses ranging from 800 to 1,000 seconds can be obtained with this system.

NUCLEAR FUSION—This term denotes a type of rocket in which light atomic nuclei are fused or united to form heavier nuclei. Very high specific impulses measured in millions of seconds should be obtainable, but the system presents a massive problem of containing the incredibly hot gases which would result. For example, to fuse deuterium (a form of hydrogen), temperatures of hundreds of millions of degrees would be needed, and no known



Simplified diagram of ion rocket.

Nuclear-powered spacecraft (artist's conception).



solid materials could contain such a gas. Scientists have tried channeling the jet by means of appropriately shaped magnetic fields but all such efforts as yet have been without success. The superheated gases have broken the restraints of the magnetic fields before the extreme conditions needed for fusion have been attained.

NASA–AEC NUCLEAR ROCKET ENGINE PROGRAM (ROVER)—NASA and the Atomic Energy Commission are conducting the Rover program to develop a practicable nuclear rocket engine at the earliest possible date. Research will be continued to improve nuclear propulsion. Current projects employ nuclear fission and liquid hydrogen. They are:

(1) Kiwi, to develop the best reactor design for a nuclear rocket. The Kiwi, reactors, like the flightless New Zealand bird for which they are named, will never fly, because they are not intended for flight use. They are ground-test equipment.

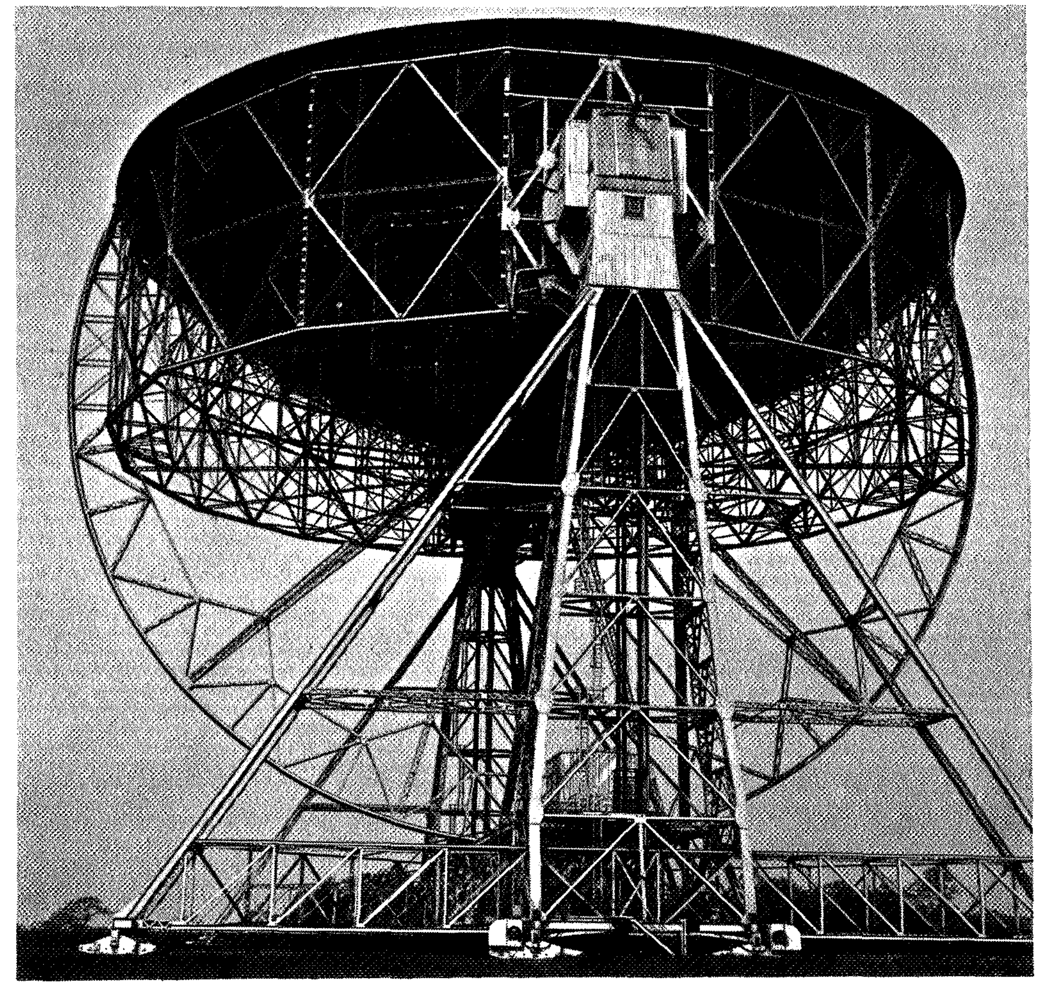
(2) NERVA, for Nuclear Engine for Rocket Vehicle Application, to employ the first operational nuclear rocket engine.

(3) Advanced research to improve nuclear rocket systems.

ION ROCKET ENGINES—Distances to earth's nearest planetary neighbors, Mars and Venus, are measured in the millions of miles; to the farthest known planet in our solar system, Pluto, in the billions of miles; and to other possible solar systems in light-years. (A light-year is about 6 trillion miles, the distance that light travels in a year.)

A fundamental requirement for manned flight even in our solar system is a form of propulsion that can operate for long periods with little fuel and can accelerate craft to velocities of hundreds of thousands of miles per hour. Ion rocket engines theoretically meet these requirements.

The ion rocket functions by electrical acceleration of charged particles to produce thrust. The propellant most commonly used is the rare element cesium. When heated, the atoms of cesium become ionized; that is, an electron is stripped from each atom, and the resulting ionized atom, or ion, is positively charged. The ions are accelerated to tremendous velocities before ejection from the rocket nozzle. While there are mechanical design problems with ion rockets, they have already demonstrated the advantages they



The 250-foot-diameter radio telescope at Jodrell Banks, England, has been used to track many U.S. Satellites and deep space probes.

will have, when perfected, over other engines, when long interplanetary voyages are undertaken.

Ion rockets produce very little thrust. They would be used after chemical, nuclear, or other kinds of rockets have provided the tremendous shove needed to place a spacecraft into orbit and beyond. Once this is done, the low thrust of the ion engine—in the weightless and airless environment of space—can gradually accelerate the spacecraft to an enormous velocity.

The ion rocket's fuel consumption is extremely low; as a result, it can supply a sustained thrust for long periods. Moreover, it can be easily stopped and restarted through relatively simple electrical switching.

In addition to offering the most promise for long manned space flight, ion engines will also be useful to control for extended periods the orbits and orientation of such spacecraft as synchronous weather and communications satellites and earth-orbiting space laboratories.

SERT (*S*pace *E*lectric *R*ocket *T*est) consists of a series of flights to test the operation of ion engines in space, to gain greater insight in their functioning, and to develop techniques for operational use.

ARC JET ENGINE—This engine is similar to a chemical rocket, except that it uses fuel and electrically created heat instead of fuel and an oxidizer. As an example, a propellent gas such as liquid hydrogen is pumped into the chamber where it is electrically heated to several thousand degrees and expelled through the rocket nozzle. The exhaust velocities, thrust, and specific impulse theoretically obtainable are far in excess of any known chemical or nuclear fission system.

PLASMA ACCELERATOR—The plasma accelerator employs electric heat on a propellent gas whose atoms can be easily ionized. As a result, a stream of ions called a plasma is created. A magnetic field accelerates the gas particles to very high velocity before ejecting them through the rocket nozzle. Specific impulses that may be attained are many times those of chemical, nuclear, or arc jet engines.

PHOTON ROCKET—Light exerts pressure, hence a more remote possibility is the photon rocket, wherein photons, or light particles, would provide the thrust. Such rockets would be capable of extremely high specific impulses, but would require radiation of tremendously intense beams of light. For the time being such rockets must be considered only speculative.

POWER IN SPACE

Spacecraft generally require light weight, compact, long-lived equipment that can supply electrical power at given levels. For the most part, U.S. spacecraft are powered by solar-cells—photoelectric devices that convert sunlight to electricity. However, the United States is studying a broad range of methods for powering spacecraft.

Improved Solar Cells— Studies are in progress to increase the efficiency of solar cell systems and to develop techniques for making them resistant to radiation damage.

Fuel Cells—Fuel cell research is continuing, particularly on the type that converts hydrogen and oxygen to electricity with drinking water as a byproduct.

Sunflower—In Project Sunflower, an umbrella-like reflecting apparatus is being developed. It will focus the sun's heat to boil mercury which expands through a turbine and drives an electrical generator. The Sunflower reflector will have a diameter of 32 feet.

SNAP—SNAP, or Systems for Nuclear Auxiliary Power, includes a series of projects by NASA and the Atomic Energy Commission to develop compact lightweight, nuclear-electric power for spacecraft (and possibly for ships and aircraft). The systems under study will provide a range of electrical power from 2½ watts to 1,000 kilowatts. They will be able to power everything from a tiny radio transmitter to the ion electric engine and other electrical equipment of an interplanetary manned spacecraft. A series of *R*eentry *F*light *D*emonstrations (RFD) are in progress to identify and eliminate any possible hazard of SNAP systems to people on earth. In these tests, a nonradioactive reactor mockup is launched by a Scout vehicle on a suborbital trajectory to see whether it will completely burn up during entry into the atmosphere.

A SNAP device, incidentally, may provide the high power by which a communications satellite can beam radio and television programs direct to the home receiver, instead of through special ground stations with supersensitive receiving antennas.

GUIDANCE IN SPACE

Space exploration makes use of several fundamental forms of guidance. These are inertial or programmed; semi-inertial, that is, basically inertial but having some outside guidance added; radio or command; celestial or star tracking; and infrared.

Because the inertial system is completely independent of information outside the spacecraft, it is presently most relied upon for space travel.

Inertial guidance is the method of determining the position and velocity without referring in any way to the world around the vehicle. This system does not depend upon receiving radio signals, a measurement or a count of any kind. Its fundamental devices are accelerometers, memory devices, and gyroscopes. It depends upon measuring the acceleration of the vehicle by measuring the force exerted on a body within the vehicle due to this acceleration. This is the same force that pushes us back into our seats when an automobile starts moving or increases speed.

Theoretically, inertial guidance can take a vehicle to any point any place in the universe.

Semi-inertial guidance has basically the same equipment as inertial guidance and uses the same technique except that it also contains equipment to receive other information. This may come by command from the earth or aboard the craft or it can also be in a form of star tracking.

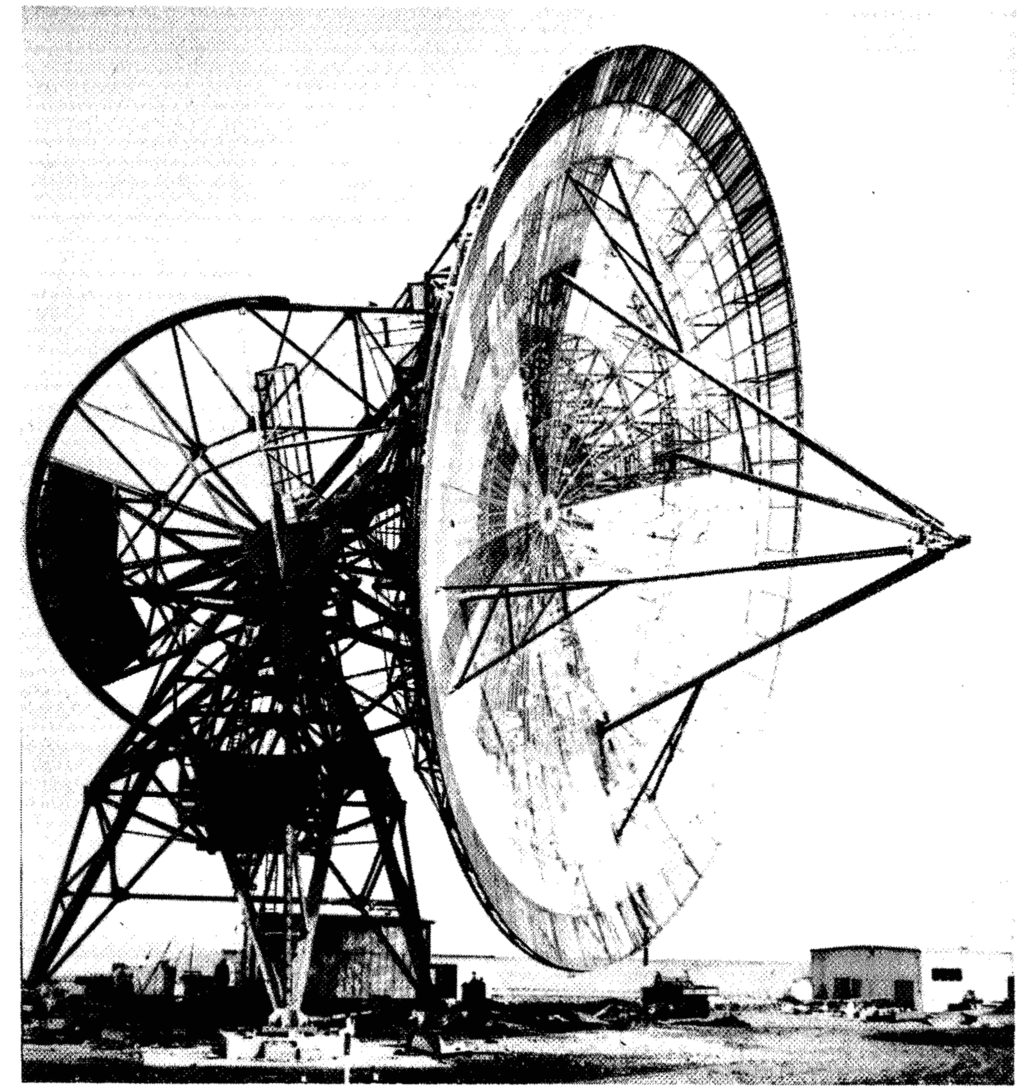
One of the basic requirements of the inertial system is that the exact location of launch be known. By adding a star-tracking device which can obtain a fix once it is out of the atmosphere, this necessity is eliminated. The star tracker supplies the information by taking a fix on a predetermined star and then computing the position of the spacecraft relative to earth.

The use of command or radio guidance, of course, requires that the space vehicle contain a receiver capable of accepting directions from ground stations and of executing these commands through its control system.

Celestial bodies emit infrared rays. These rays can be detected by a photoelectric device which translates the infrared variations into voltage changes. These changes provide guidance information—hence infrared guidance.

COMMUNICATIONS

Telemetry in its modern usage refers primarily to the utilization of radio to make measurements at a remote location and to transmit these measurements for reproduction at some nearby location. The information obtained may be in a form suitable for display, for recording, or for use in computing machines.



Deepspace 85-foot diameter tracking antenna, Woomera, Australia.

In unmanned space exploration, telemetry has helped perfect the design of every vehicle by monitoring its performance during flight. When a space vehicle fails, the data which have been telemetered back from its flight, however brief, tell the space scientist what went wrong.

In manned flight, telemetered signals supplement the messages sent back by the astronaut and permit the use of complex computing equipment on the ground which would be much too heavy to carry in the space vehicle.

The power required to send telemetered signals from satellites and space probes is infinitely smaller than that required for commercial radio and television stations. Signals of the 3-watt transmitter of Mariner II were received on earth from a distance of 53.9 million miles.

One reason why such ranges can be achieved with so little power is that ground radio systems used to communicate with spacecraft have extremely sensitive receivers. For example, the 85-foot-diameter antennas that communicated with Mariner II are about 20,000 times more sensitive than the average rooftop television antenna.

Radio telescope studies have shown that with sufficiently powerful transmitters and sensitive receivers, we can communicate over interplanetary distances.

However, there are problems. One is that beyond the solar system, so many stars and other celestial entities emit radio waves that they pose a threat to clear communication with spacecraft. Another limiting factor is distance itself. Radio waves travel at about the speed of light which is approximately 186,000 miles per second. It would take only about 5 minutes for a message sent from earth to reach Venus, when Venus is closest to earth. However, a message from earth to a spacecraft in the vicinity of Pluto would take more than 5 hours to reach its destination.

The signals emitted by spacecraft permit ground stations to track them with a high degree of accuracy.

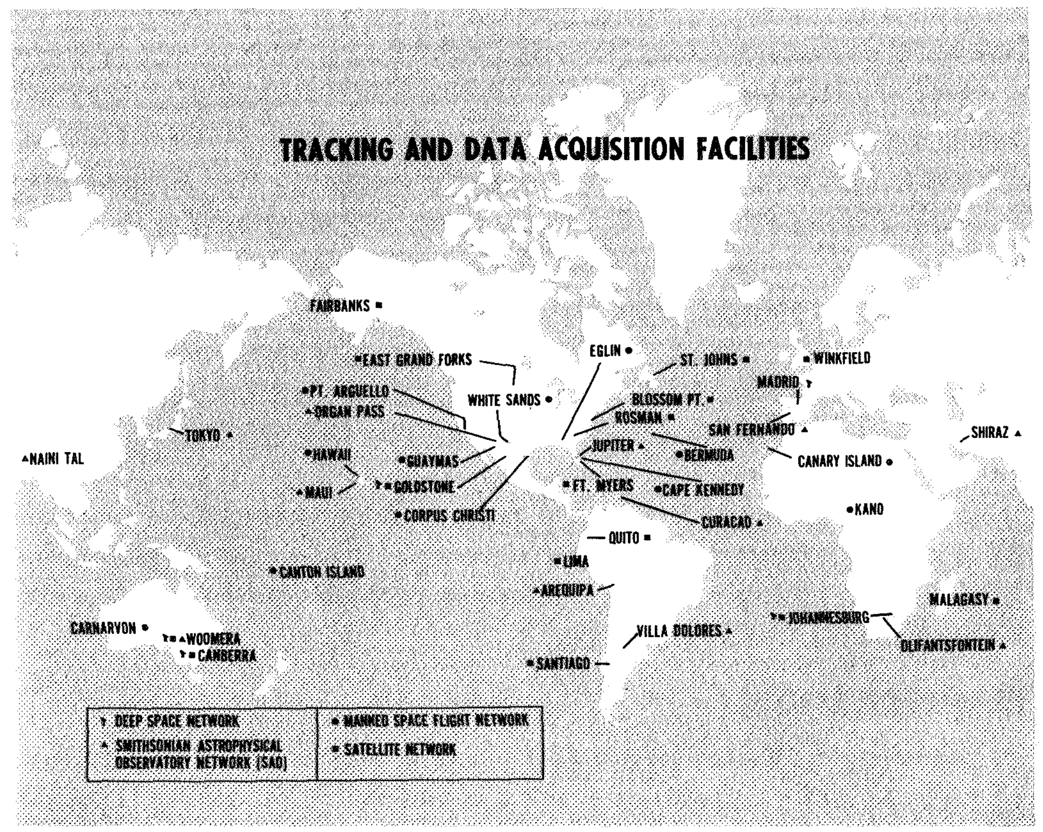
Power for the transmitters may come from chemical batteries with varying periods of life, from solar cells (often with a very long life), or from other power sources. Nuclear devices such as SNAP offer the greatest promise.

Unmanned spacecraft may carry one or more transmitters, sending over VHF or UHF in a number of channels. Manned spacecraft carry more varied transmitting equipment as a guarantee against practically any emergency.

The manned Mercury flights, for instance, carried, as we have noted elsewhere, multiple communications systems. There was ultra high frequency and high frequency for voice use. There were two UHF telemetry links. In addition there was a separate emergency two-way voice system of UHF and HF transceivers.

TRACKING

NASA operates three ground tracking data acquisition networks. One, the Scientific Satellite (formerly Minitrack) Network, established during the International Geophysical Year, efficiently tracks and gathers data transmitted from unmanned scientific satellites such as Explorer. Another, the Deep Space Network, is equipped with powerful transmitters and sensitive receivers which can maintain contact with spacecraft traveling to the moon and beyond. The Manned Flight Network, built to meet the specific requirements of Project Mercury, is capable of faster data handling and tracking than the Scientific Satellite Network. It is described under "Tracking Manned Flights" below.



In addition, the Smithsonian Astrophysical Observatory operates a worldwide system of telescopic cameras for optical tracking of satellites.

Tracking Manned Flights

Tracking, monitoring, and control of manned spacecraft is accomplished through the use of the Manned Space Flight Network, which includes 12 land-based tracking and data acquistion stations, a central data processing and computer center, and mobile tracking and telemetry ships as necessary to support the mission.

The 12 land-based stations in the United States and 6 foreign countries, in sequence from launch, are:

1. Cape Kennedy, Fla., with Grand Bahama Island, Grand Turk Island, San Salvador, Antigua
2. Bermuda
3. Canary Islands
4. Kano, Nigeria
5. Carnarvon, Australia
6. Canton Island
7. Kauai Island, Hawaii
8. Point Arguello, Calif.
9. Guaymas, Mexico
10. White Sands, N. Mex.
11. Corpus Christi, Tex.
12. Eglin, Fla.

The network stations, including ships whose positions are not listed above as they vary with the mission, are geographically placed to provide the most efficient tracking and telemetry coverage between the latitudes of approximately 35° North and 35° South, within which were the project Mercury flights and where the Gemini and Apollo spacecraft orbits will be contained.

All of the tracking posts are connected by a communications network to a NASA Communications and Computing Center in the NASA Goddard Space Flight Center at Greenbelt, Md., near Washington, D.C., Headquarters, and to the manned Space Flight Control Center at Cape Kennedy and the Integrated Mission Control Center, Houston, Tex. Cable, land lines and radio are used. While this network consists primarily of a teletype system, it is backed up in most cases by a voice system from outlying stations.

As the spacecraft passes over each station, a message is sent by flight controllers in that station to the Communications Center and immediately on to the Control Centers at Cape Kennedy and Houston. The Communications Center also relays the message to other stations

The Manned Space Flight Network is continuously being modified and augmented to meet the requirements of advanced space missions for both Gemini and Apollo. Moreover, equipment is being installed in the Deep Space Network stations to accommodate them to the requirements of Project Apollo, which is designed to land American explorers on the moon and return them safely to earth.

The command center for manned flights under both the Gemini and Apollo projects will be the Integrated Mission Control Center which will be located at NASA's Manned Spacecraft Center, Houston, Tex.

RESEARCH IS FUNDAMENTAL TO SPACE EXPLORATION

Basic research, which is fundamental not only to progress in space but also to all mankind's advances, is being conducted to solve the myriad problems involved in space exploration. Representative investigations of space flight include techniques for improving navigation, guidance, and control; development of methods for rendezvous of craft in space; launching from and landing on the moon or planets other than earth; and determining entry corridors or flight paths for safe passage of spacecraft and occupants through the atmospheres of the earth and other planets. Underlying these theoretical studies is the application of celestial mechanics dealing with the laws that govern motions of bodies in space. Aiding the theoretical studies are flight simulators, wind tunnels, other laboratory devices, computer technology, and actual experiments in space.

As an example, increased knowledge has been gained through theoretical and laboratory studies on what happens to spacecraft entering earth's atmosphere at speeds of about 25,000 miles per hour. This is the velocity that spacecraft will have when they return to the vicinity of earth after a mission to the moon. In Project Fire, an actual instrument payload will be launched on a suborbital trajectory and then accelerated down into the atmosphere to a speed of about 25,000 miles per hour. The project's purpose is to supply definitive information to supplement analytical and wind tunnel research on atmosphere entry at 25,000 mph.

Explorer XVI was orbited December 16, 1962, to determine the hazards that tiny meteoroids, bits of matter racing through space, pose to spacecraft. Explorer XVI data proved that such meteoroids can puncture thin metal surfaces. Previously, this had been presumed but not proved. To acquire further data on meteoroid hazards and how to design spacecraft to cope with danger, NASA plans to launch two giant-size meteoroid satellites in conjunction with flight tests of the Saturn I launch vehicle. The satellites will have a surface area of about 2,000 square feet, as compared with the 25-square-foot area exposed by Explorer XVI. The satellites' greater size, larger exposed areas, and increased skin thicknesses are expected to make new information available as to the penetrating power, distribution, and size of meteoroids, both large and small.

In ground laboratories, engineers are firing tiny projectiles at tremendous velocities into various kinds of materials and structures. The purpose is to determine the structures that can survive the explosive impact of micrometeoroids by gaining deeper insight into the effects of such collisions.

Materials, systems, and structures must also be developed that can function in the hostile environment of space. For example, a vacuum such as in space can cause unearthly changes in objects. Rubber becomes hard and brittle and oil vaporizes. Moreover, radiation modifies materials and can damage equipment A major consideration in designing and constructing spacecraft is development of materials, structures, and equipment that are resistant to radiation and can function in a vacuum. The vacuum and radiation of space are being simulated in laboratories on earth for research in support of space flight.

Still another problem is temperature control. The side of a body in space that faces the sun can become very hot while the other side becomes extremely cold. To date, temperature control of spacecraft has been accomplished principally by use of passive temperature control systems such as metals, ceramics, and plastics that are good heat conductors, by louvers that permit built-up heat to escape, and by use of dark and light colors for heat absorption and reflection.

For space missions to Mercury or to Jupiter and the outer planets, active refrigeration and heating systems powered by a nuclear electric generating device such as SNAP are required. Development of such systems is under study.

Considerable research has been carried out in laser technology. The laser (for light amplification by stimulated emission of radiation) produces an extremely narrow and intense light beam of uniform wave length. Ordinarily, light—as from a bulb—is scattered and is a mixture of colors or frequencies. Laser devices have already been used in medicine and appear to have enormous potential for industrial processes, research studies, and communication.

NASA is studying employment of laser technology for satellite tracking. The laser appears to offer two principal advantages over radio tracking; it can be far more accurate and it does not require electrical power aboard a spacecraft. In tracking, laser beams are bounced from a reflector on the satellite. The time the beam takes for the round trip and the angle of the beam enable scientists to calculate the spacecraft's location.

It has been estimated that about 70 percent of spacecraft costs involve electronic systems through which the vehicles are guided and function and through which contact with earth is maintained. As an example, the Mercury spacecraft—a relatively simple vehicle compared to those for advanced missions—contains 7 miles of electrical wiring, hundreds of switches, instruments, radios, lights, and other electronic apparatus. Advanced research into the technology of electronics and related fields is important to the success of space exploration. One of the major areas in which space engineers are currently engaged is microelectronics—reduction in size and increase in efficiency and reliability of electronic circuits and other devices. As an example, microelectronics, sometimes called integrated circuitry, has reduced the size of all the circuits in a radio to fit a case smaller than a sugar cube.

To prepare for missions beyond Apollo, NASA studies are in progress on such possible future projects as a lunar base, a manned flight to Mars, and a manned orbital laboratory.

GLOSSARY OF FREQUENTLY USED SPACE TERMS

The following material has been excerpted from the Short Glossary of Space Terms, NASA publication SP–1. It includes words frequently appearing in popular space literature.

ablating material. A material designed to dissipate heat by vaporizing or melting.
Ablating materials are used on the surfaces of some reentry vehicles. Ablating materials absorb heat by increase in temperature and change in chemical or physical state. The heat is carried away from the surface by a loss of mass (liquid or vapor). The departing mass also blocks part of the convective heat transfer to the remaining material.

ablation. The removal of surface material from a body by vaporization, melting, or other process; specifically the intentional removal of material from a nose cone or spacecraft during high-speed movement through a planetary atmosphere to provide thermal protection to the underlying structure. See **ablating material.**

abort. To cancel or cut short a flight.

absolute temperature. Temperature value relative to absolute zero.

absolute zero. The theoretical temperature at which all molecular motion ceases.
"Absolute zero" may be interpreted as the temperature at which the volume of a perfect gas vanishes, or more generally as the temperature of the cold source which would render a Carnot cycle 100 percent efficient. The value of absolute zero is now estimated to be —273.16° Celsius (Centigrade), —459.69° Fahrenheit, 0° Kelvin, and 0° Rankine.

acceleration. The rate of change of velocity.
Decrease in velocity in sometimes called "negative acceleration."

accelerometer. An instrument which measures acceleration or gravitational forces capable of imparting acceleration.
An accelerometer usually uses a concentrated mass (seismic mass) which resists movement because of its inertia. The displacement of the seismic mass relative to its supporting frame or container is used as a measure of acceleration.

acoustic velocity. The speed of propagation of sound waves. Also called "speed of sound."

acquisition. 1. The process of locating the orbit of a satellite or trajectory of a space probe so that tracking or telemetry data can be gathered. 2. The process of pointing an antenna or telescope so that it is properly oriented to allow gathering of tracking or telemetry data from a satellite or space probe.

acquisition and tracking radar. A radar set that locks onto a strong signal and tracks the object reflecting the signal.

active. Transmitting a signal, as "active satellite," in contrast to "passive."

adsorption. The adhesion of a thin film of liquid or gas to the surface of a solid substance. The solid does not combine chemically with the adsorbed substance.

aerobiology. The study of the distribution of living organisms freely suspended in the atmosphere.

aerodynamic heating. The heating of a body produced by passage of air or other gases over the body, significant chiefly at high speeds, caused by friction and by compression processes.

aerodynamics. The science that treats of the motion of air and other gaseous fluids, and of the forces acting on bodies when the bodies move through such fluids, or when such fluids move against or around the bodies, as "his research in aerodynamics."

aerodynamic vehicle. A device, such as an airplane, glider, etc., capable of flight only within a sensible atmosphere and relying on aerodynamic forces to maintain flight.
This term is used when the context calls for discrimination from "space vehicle."

aeroembolism. 1. The formation or liberation of gases in the blood vessels of the body, as brought on by a change from a high, or relatively high, atmospheric pressure to a lower one. 2. The disease or condition caused by the formation or liberation of gases in the body. The disease is characterized principally by neuralgic pains, cramps, and swelling, and sometimes results in death. Also called "decompression sickness."

aerolite. A meteorite composed principally of stony material.

aeronomy. The study of the upper regions of the atmosphere where physical and chemical reactions due to solar radiation take place.

aerospace. (From aeronautics and space.) Of or pertaining to both the earth's atmosphere and space, as in "aerospace industries."

aerospace medicine. That branch of medicine dealing with the effects of flight through the atmosphere or in space upon the human body, and with the prevention or cure of physiological or psychological malfunctions arising from these effects.

aerothermodynamic border. An altitude at about 100 miles, above which the atmosphere is so rarefied that the motion of an object through it at high speeds generates no significant surface heat.

aerothermodynamics. The study of the aerodynamic and thermodynamic problems connected with aerodynamic heating.

airglow. A relatively steady visible emission from the upper atmosphere, as distinguished from the sporadic emission of aurorae.

air sounding. The act of measuring atmospheric phenomena or determining atmospheric conditions at altitude, especially by means of apparatus carried by balloons or rockets.

albedo. The ratio of the amount of electromagnetic radiation reflected by a body to the amount falling upon it, commonly expressed as a percentage.
The term is used especially in reference to sunlight reflected from the moon or the planets.

alpha particle. A positively charged particle emitted from the nuclei of certain atoms during radioactive disintegration. The alpha particle has an atomic weight of 4 and a positive charge equal in magnitude to 2 electronic charges; hence it is essentially a helium nucleus.

ambient. Specifically, pertaining to the environment about a flying aircraft or other body but undisturbed or unaffected by it, as in "ambient air," or "ambient temperature."

analog computer. A computing machine that works on the principle of measuring, as distinguished from counting, in which the input data are made analogous to a measurement continuum, such as voltages, linear lengths, resistances, light intensities, etc., which can be manipulated by the computer.
Analog computers range from the relatively simple devices of the slide rule or airspeed indicator to complicated electrical machines used for solving mathematical problems.

angel. A radar echo caused by a physical phenomenon not discernible to the eye.

angstrom. A unit of length, used chiefly in expressing short wavelengths. Ten billion angstroms equal 1 meter.

annular eclipse. An eclipse in which a thin ring of the source of light appears around the obscuring body.

anoxia. A complete lack of oxygen available for physiological use within the body. Compare **hypoxia.**
"Anoxia" is popularly used as a synonym for "hypoxia." This usage should be avoided.

antigravity. A hypothetical effect that would arise from some energy field's cancellation of the effect of the gravitational field of the earth or other body.

aphelion. The point at which a planet or other celestial object in orbit about the sun is farthest from the sun.

apogee. In an orbit about the earth, the point at which the satellite is farthest from the earth; the highest altitude reached by a sounding rocket.

apogee rocket. A rocket attached to a satellite or spacecraft designed to fire when the craft is at apogee, the point farthest from the earth in orbit. The effect of the apogee rocket is to establish a new orbit farther from the earth or to allow the craft to escape from earth orbit.

arc-jet engine. A type of electrical rocket engine in which the propellant gas is heated by passing through an electric arc.

areo. Combining form of **Ares** (Mars) as in "areography."
Words with "areo" are considered pedantic by some, thus "geography of Mars" is preferred to "areography."

artificial gravity. A simulated gravity established within a space vehicle, as by rotating a cabin about an axis of a spacecraft, the centrifugal force generated being similar to the force of gravity.

asteroid. One of the many small celestial bodies revolving around the sun, most of the orbits being between those of Mars and Jupiter. Also called 'planetoid', 'minor planet'. See **planet.**
The term "minor planet" is preferred by many astronomers but "asteroid" continues to be used in astronomical literature, especially attributively, as in "asteroid belt."

astro. A prefix meaning "star" or "stars" and, by extension, sometimes used as the equivalent of "celestial," as in astronautics.

astroballistics. The study of the phenomena arising out of the motion of a solid through a gas as speeds high enough to cause ablation; for example, the interaction of a meteoroid with the atmosphere.

Astroballistics uses the data and methods of astronomy, aerodynamics, ballistics, and physical chemistry

astrobiology. The study of living organisms on celestial bodies other than the earth.

astrodynamics. The practical application of celestial mechanics, astroballistics, propulsion theory, and allied fields to the problem of planning and directing the trajectories of space vehicles.

astronaut. 1. A person who occupies a space vehicle. 2. Specifically one of the test pilots selected to participate in Project Mercury, the first U.S. program for manned space flight.

astronautics. 1. The art, skill, or activity of operating space vehicles. 2. In a broader sense, the science of space flight.

astronomical unit. In the astronomical system of measures, a unit of length usually defined as the distance from the earth to the sun, approximately 92,900,000 statute miles or 149,600,000 kilometers.

atmosphere. The envelope of air surrounding the earth; also the body of gases surrounding or comprising any planet or other celestial body.

atomic clock. A precision clock that depends for its operation on an electrical oscillator (as a quartz crystal) regulated by the natural vibration frequencies of an atomic system (as a beam of cesium atoms or ammonia molecules).

attitude. The position or orientation of an aircraft, spacecraft, etc., either in motion or at rest, as determined by the relationship between its axes and some reference line or plane such as the horizon.

aurora. The sporadic visible emission from the upper atmosphere over middle and high latitudes. Also called "northern lights."

axis. (pl. axes) 1. A straight line about which a body rotates, or around which a plane figure may rotate to produce a solid; a line of symmetry. 2. One of a set of reference lines for certain systems of coordinates.

azimuth. Horizontal direction or bearing.

backup. 1. An item kept available to replace an item which fails to perform satsifactorily. 2. An item under development intended to perform the same general function performed by another item also under development.

Baker-Nunn camera. A large camera used in tracking satellites.

ballistics. The science that deals with the motion, behavior, and effects of projectiles, especially bullets, aerial bombs, rockets, or the like; the science or art of designing and hurling projectiles so as to achieve a desired performance.

ballistic trajectory. The trajectory followed by a body being acted upon only by gravitational forces and the resistance of the medium through which it passes.

A rocket without lifting surfaces is in a ballistic trajectory after its engines cease operating.

balloon-type rocket. A rocket, such as Atlas, that requires the pressure of its propellants (or other gases) within it to give it structural integrity.

beam. A ray or collection of focused rays of radiated energy. Radio waves used as a navigation aid.

beam-rider. A craft following a beam, particularly one which does so automatically, the beam providing the guidance.

binary notation. A system of positional notation in which the digits are coefficients of powers of the base 2 in the same way as the digits in the conventional decimal system are coefficients of powers of the base 10.

Binary notation employs only two digits, 1 and 0, therefore is used extensively in computers where the "on" and "off" positions of a switch or storage device can represent the two digits.

In decimal notation $111 = (1 \times 10^2) + (1 \times 10^1) + (1 \times 10^0) = 100 + 10 + 1 =$ *one hundred and eleven.*

In binary notation $111 = (1 \times 2^2) + (1 \times 2^1) + (1 \times 2^0) = 4 + 2 + 1 =$ *seven.*

bionics. The study of systems which function after the manner of, or in a manner characteristic of, or resembling, living systems.

bipropellant. A rocket propellant consisting of two unmixed or uncombined chemicals (fuel and oxidizer) fed to the combustion chamber separately.

bird. A colloquial term for a rocket, satellite, or spacecraft.

bit. (From binary digit.) A unit of information.

black box. Colloquially, any unit, usually an electronic device such as an amplifier, which can be mounted in a rocket, spacecraft, or the like as a single package.

blackout. 1. A fadeout of radio communications due to environmental factors such as ionospheric disturbances, or a plasma sheath surrounding a reentry vehicle. 2. A condition in which vision is temporarily obscured by a blackness, accompanied by a dullness of certain of the other senses, brought on by decreased blood pressure in the head and a consequent lack of oxygen, as may occur in pulling out of a high-speed dive in an airplane.

blip. See "pip."

blockhouse. (Also written "block house.") A reinforced-concrete structure, often built underground or partly underground, and sometimes dome-shaped, to provide protection against blast, heat, or explosion during rocket launchings or related activities; specifically, such a structure at a launch site that houses electronic control instruments used in launching a rocket.

boilerplate. As in "boilerplate capsule," a metal copy of the flight model, the structure or components of which are heavier than the flight model.

boiloff. The vaporization of a cold propellant such as liquid oxygen or liquid hydrogen, as the temperature of the propellant mass rises as in the tank of a rocket being readied for launch.

booster. Short for "booster engines" or "booster rocket."

booster engine. An engine, especially a booster rocket, that adds its thrust to the thrust of the sustainer engine.

booster rocket. 1. A rocket engine, either solid or liquid fuel, that assists the normal propulsive system or sustainer engine of a rocket or aeronautical vehicle in some phase of its flight. 2. A rocket used to set a missile vehicle in motion before another engine takes over.

In sense 2 the term "launch vehicle" is more commonly used.

boostglide vehicle. A vehicle (half aircraft, half spacecraft) designed to fly to the limits of the sensible atmosphere, then be boosted by rockets into the space above, returning to earth by gliding under aerodynamic control.

braking ellipses. A series of elipses, decreasing in size due to aerodynamic drag, followed by a spacecraft in entering a planetary atmosphere.

In theory, this maneuver will allow a spacecraft to dissipate energy through aerodynamic heating without burning up.

breakoff phenomenon. The feeling which sometimes occurs during high-altitude flight of being totally separated and detached from the earth and human society. Also called the "breakaway phenomenon."

burn. A period during which a rocket engine is firing, as in "second burn," the second period during a flight in which the engine is firing.

burnout. 1. An act or instance of the end of fuel and oxidizer burning in a rocket; the time at which this burnout occurs. Compare **cutoff.** 2. An act or instance of something burning out or of overheating; specifically, an act or instance of a rocket combustion chamber, nozzle, or other part overheating so as to result in damage or destruction.

capsule. 1. A boxlike component or unit, often sealed. 2. A small, sealed, pressurized cabin with an internal environment which will support life in a man or animal during extremely high altitude flight, space flight, or emergency escape.

celestial mechanics. The study of the theory of the motions of celestial bodies under the influence of gravitational fields.

celestial sphere. An imaginary sphere of infinite radius concentric with the earth, on which all celestial bodies except the earth are assumed to be projected.

centrifuge. Specifically, a large motor-driven apparatus with a long arm at the end of which human and animal subjects or equipment can be revolved and rotated at various speeds to simulate very closely the prolonged accelerations encountered in high-performance aircraft, rockets, and spacecraft.

chase pilot. A pilot who flies in an escort airplane advising a pilot who is making a check, training, or research flight in another craft.

checkout. A sequence of actions taken to test or examine a launch vehicle or spacecraft as to its readiness to perform its intended function.

chemical fuel. 1. A fuel that depends upon an oxidizer for combustion or for development of thrust, such as liquid or solid rocket fuel or internal-combustion-engine fuel; distinguished from nuclear fuel. 2. A fuel that uses special chemicals, such as a boron-based fuel.

chemical rocket. A rocket using chemical fuel, fuel which requires an oxidizer for combustion, such as liquid or solid rocket fuel.

chemosphere. The vaguely defined region of the upper atmosphere in which photochemical reactions take place.

cislunar. (Latin *cis* "on this side.") Of or pertaining to phenomena, projects, or activity in the space between the earth and moon, or between the earth and the moon's orbit.

closed ecological system. A system that provides for the maintenance of life in an isolated living chamber such as a spacecraft cabin by means of a cycle wherein exhaled carbon dioxide, urine, and other waste matter are converted chemically or by photosynthesis into oxygen, water, and food.

coherent. Of electromagnetic radiation, being in phase so that waves at various points in space act in unison.

cold-flow test. A test of a liquid rocket without firing it to check or verify the efficiency of a propulsion subsystem, providing for the conditioning and flow of propellants (including tank pressurization, propellent loading, and propellent feeding).

comet. A luminous member of the solar system composed of a head or coma at the center of which a presumably solid nucleus is sometimes situated, and often with a spectacular gaseous tail extending a great distance from the head.

The orbits of comets are highly elliptical.

command. A signal which initiates or triggers an action in the device which receives the signal.

communications satellite. A satellite designed to reflect or relay radio or other communications waves.

companion body. A nose cone, last-stage rocket, or other body that orbits along with an earth satellite.

complex. Entire area of launch site facilities. This includes blockhouse, launch pad, gantry, etc. Also referred to as a "launch complex."

composite materials. Structural materials of metal alloys or plastics with built-in strengthening agents which may be in the form of filaments, foils, or flakes of a strong material.

composite propellant. A solid rocket propellant consisting of a fuel and an oxidizer.

computer. A machine for carrying out calculations and performing specified transformations on information.

configuration. A particular type of a specific aircraft, rocket, etc., which differs from others of the same model by virtue of the arrangement of its components or by the addition or omission of auxiliary equipment as "long-range configuration," "cargo configuration."

conic. A conic section.

conic section. A curve formed by the intersection of a plane and a right circular cone. Usually called "conic."

The conic sections are the ellipse, the parabola, and the hyperbola; curves that are used to describe the paths of bodies moving in space.

The circle is a special case of the ellipse, an ellipse with an eccentricity of zero.

console. An array of controls and indicators for the monitoring and control of a particular sequence of actions, as in the checkout of a rocket, a countdown action, or a launch procedure.

A console is usually designed around desklike arrays. It permits the operator to monitor and control different activating instruments, data recording instruments, or event sequencers.

control. Specifically, to direct the movements of an aircraft, rocket, or spacecraft with particular reference to changes in altitude and speed.

control rocket. A vernier engine, retrorocket, or other such rocket, used to guide or make small changes in the velocity of a rocket, spacecraft, or the like.

corona. The faintly luminous outer envelope of the sun. Also called "solar corona."

The corona can be observed at the earth's surface only at solar eclipse or with the coronagraph, a photographic instrument which artificially blocks out the image of the body of the sun.

cosmic dust. Small meteoroids of a size similar to dust.

cosmic rays. The extremely high energy subatomic particles which bombard the atmosphere from outer space. Cosmic-ray primaries seem to be mostly protons, hydrogen nuclei, but also comprise heavier nuclei. On colliding with atmospheric particles they produce many different kinds of lower-energy secondary cosmic radiation.

COSPAR. Abbreviation for "Committee on Space Research," International Council of Scientific Unions.

countdown. The time period in which a sequence of events is carried out to launch a rocket; the sequence of events.

cryogenic propellant. A rocket fuel, oxidizer, or propulsion fluid which is liquid only at very low temperatures.

cryogenic temperature. In general, a temperature range below about —50° C.; more particularly, temperatures within a few degrees of absolute zero.

cutoff. An act or instance of shutting something off; specifically in rocketry, an act or instance of shutting off the propellent flow in a rocket, or of stopping the combustion of the propellant.

data reduction. Transformation of observed values into useful, ordered, or simplified information.

deceleration. The act or process of moving, or of causing to move, with decreasing speed; the state of so moving.

deep space net. A combination of three radar and communications stations in the United States, Australia, and South Africa so located as to keep a spacecraft in deep space under observation at all times.

deep space probes. Spacecraft designed for exploring space to the vicinity of the moon and beyond. Deep space probes with specific missions may be referred to as "lunar probe," "Mars probe," "solar probe," etc.

destruct. The deliberate action of destroying a rocket vehicle after it has been launched, but before it has completed its course.

Destructs are executed when the rocket gets off its plotted course or functions in a way so as to become a hazard.

digital computer. A computer which operates on the principle of counting as opposed to measuring. See **analog computer.**

diplexer. A device permitting an antenna system to be used simultaneously or separately by two transmitters. Compare with **duplexer.**

dish. A parabolic type of radio or radar antenna, roughly the shape of a soup bowl.

display. The graphic presentation of the output data of a device or system as, for example a radarscope.

docking. The process of bringing two spacecraft together while in space.

Doppler shift. The change in frequency with which energy reaches a receiver when the source of radiation or a reflector of the radiation and the receiver are in motion relative to each other. The Doppler shift is used in many tracking and navigation systems.

dosimeter. A device, worn by persons working around radioactive material, which indicates the amount (dose) of radiation to which they have been exposed.

Dovap. From Doppler, velocity and position, a tracking system which uses the Doppler shift caused by a target moving relative to a ground transmitter to obtain velocity and position information.

drogue parachute. A type of parachute attached to a body, used to slow it down; also called "deceleration parachute," or "drag parachute."

duplexer. A device which permits a single antenna system to be used for both transmitting and receiving.

"Duplexer" should not be confused with "diplexer," a device permitting an antenna system to be used simultaneously or separately by two transmitters.

dynamic pressure. (Symbol **q.**) 1. The pressure exerted by a fluid, such as air, by virtue of its motion. 2. The pressure exerted on a body, by virtue of its motion through a fluid, for example, the pressure exerted on a rocket moving through the atmosphere.

eccentric. Not having the same center; varying from a circle, as in "eccentric orbit."

ecliptic. The apparent annual path of the sun among the stars; the intersection of the plane of the earth's orbit with the celestial sphere.

This is a great circle of the celestial sphere inclined at an angle of about 23°27′ to the celestial equator.

ecological system. A habitable environment, either created artificially, such as in a manned space vehicle, or occurring naturally, such as the environment on the surface of the earth, in which man, animals, or other organisms can live in mutual relationship with each other.

Ideally, the environment furnishes the sustenance for life, and the resulting waste products revert or cycle back into the environment to be used again for the continuous support of life.

ejection capsule. 1. In an aircraft or manned spacecraft, a detachable compartment serving as a cockpit or cabin, which may be rejected as a unit and parachuted to the ground. 2. In an artificial satellite, probe, or unmanned spacecraft, a boxlike unit usually containing recording instruments or records of observed data, which may be ejected and returned to earth by a parachute or other deceleration device.

electric propulsion. The generation of thrust for a rocket engine involving acceleration of a propellant by some electrical device such as an arc jet, ion engine, or magnetohydrodynamic accelerator.

electromagnetic radiation. Energy propagated through space or through material media in the form of an advancing disturbance in electrical and magnetic fields existing in space or in the media. Also called simply "radiation."

electron. The subatomic particle that possesses the smallest possible electric charge.

The term "electron" is usually reserved for the orbital particle whereas the term "beta particle" refers to a particle of the same electric charge inside the nucleus of the atom.

electronic data processing. The use of electronic devices and systems in the processing of data so as to interpret the data and put it into usable form.

ellipse. A plane curve constituting the locus of all points the sum of whose distances from two fixed points called "loci" is constant; an elongated circle. See conic section.

The orbits of planets, satellites, planetoids, and comets are ellipses; center of attraction is at one focus.

environment. An external condition or the sum of such conditions, in which a piece of equipment or a system operates, as in "temperature environment," "vibration environment," or "space environment."

Environments are usually specified by a range of values, and may be either natural or artificial.

epoch. A particular instant for which certain data are valid.

escape velocity. The radial speed which a particle or larger body must attain in order to escape from the gravitational field of a planet or star.

The escape velocity from Earth is approximately 7 miles per sec.; from Mars, 3.2 miles per sec.; and from the Sun, 390 miles per sec. In order for a celestial body to retain an atmosphere for astronomically long periods of time, the mean velocity of the atmospheric molecules must be considerably below the escape velocity.

exobiology. The study of living organisms existing on celestial bodies other than the earth.

exoshpere. The outermost, or topmost portion of the atmosphere.

In the exosphere, the air density is so low that the mean free path of individual particles depends upon their direction with respect to the local vertical, being greatest for upward moving particles. It is only from the exosphere that atmospheric gases can, to any appreciable extent, escape into outer space.

exotic fuel. Any fuel considered to be unusual, as a boron-based fuel.

explosive bolt. A bolt incorporating an explosive which can be detonated on command, thus destroying the bolt. Explosive bolts are used, for example, in separating a satellite from a rocket.

extraterrestrial. From outside the earth.

eyeballs in, eyeballs out. Terminology used by test pilots to describe the acceleration experienced by the person being accelerated. Thus the acceleration experienced by an astronaut at liftoff is "eyeballs in" positive g in terms of vehicle acceleration), and the acceleration experienced when retrorockets fire is "eyeballs out" (negative g in terms of vehicle acceleration).

fallaway section. A section of a rocket vehicle that is cast off and separates from the vehicle during flight, especially such a section that falls back to the earth.

fatigue. A weakening or deterioration of metal or other material, or of a member, occurring under load, especially under repeated, cyclic, or continued loading.

field. A region of space at each point of which a given physical quantity has some definite value, thus a "gravitational field," an "electric field," a "magnetic field," etc.

film cooling. The cooling of a body or surface, such as the inner surface of a rocket combustion chamber, by maintaining a thin fluid layer over the affected area.

fixed satellite. An earth satelilte that orbits from west to east at such a speed as to remain constantly over a given place on the earth's equator.

flare. A bright eruption from the sun's chromosphere.

Flares may appear within minutes and fade within an hour. They cover a wide range of intensity and size, and they tend to occur between sunspots.

Flares are related to radio fadeouts and terrestrial magnetic disturbances.

flashback. A reversal of flame propagation in a system, counter to the usual flow of the combustible mixture.

flux. The rate of flow of some quantity, often used in reference to the flow of some form of energy.

flying test bed. An aircraft, rocket, or other flying vehicle used to carry objects or devices being flight tested.

free fall. 1. The fall or drop of a body, such as a rocket, not guided, not under thrust, and not retarded by a parachute or other braking device. 2. Weightlessness.

g or G. An acceleration equal to the acceleration of gravity, approximately 32.2 feet per second per second at sea level; used as a unit of stress measurement for bodies undergoing acceleration.

gamma ray. An electromagnetic radiation of wave form emitted by a radioactive nucleus and similar to X-rays but of higher energy and shorter wavelength.

gantry. A frame structure that spans over something, as an elevated platform that runs astride a work area, supported by wheels on each side; specifically, short for "gantry crane" or "gantry scaffold."

gantry scaffold. A massive scaffolding structure mounted on a bridge or platform supported by a pair of towers or trestles that normally run back and forth on parallel tracks, used to assemble and service a large rocket on its launching pad. Often shortened to "gantry." Also called "service tower."

This structure is a latticed arrangement of girders, tubing, platforms, cranes, elevators, instruments, wiring, floodlights, cables, and ladders—all used to attend the rocket.

garbage. Miscellaneous objects in orbit, usually material ejected or broken away from a launch vehicle or satellite.

gas cap. The gas immediately in front of a meteroid or reentry body as it travels through the atmosphere; the leading portion of a meteor. This gas is compressed and adiabatically heated to incandescence.

generation. In any technical or technological development, as of a missile, jet engine, or the like, a stage or period that is marked by features or performances not marked, or existent, in a previous period of development or production, as in "second generation rocket."

geo. A prefix meaning "earth," as in "geology," "geophysics."

Most writers use the established terms such as "geology" to refer to the same concept on other bodies of the solar system, as "the geology of Mars," rather than "areology" or "marsology," "geology of the moon," rather than "selenology."

geocentric. Relative to the earth as a center; measured from the center of the earth.

geodetic. Pertaining to geodesy, the science which deals with the size and shape of the earth.

geomagnetism. The magnetic phenomena, collectively considered, exhibited by the earth and its atmosphere; by extension, the magnetic phenomena in interplanetary space.

geophysics. The physics of the earth and its environment, i.e., earth, air, and (by extension), space.

Classically, geophysics is concerned with the nature of physical occurrences at and below the surface of the earth including, therefore, geology, oceanography, geodesy, seismology, hydrology, etc. The trend is to extend the scope of geophysics to include meteorology, geomagnetism, astrophysics, and other sciences concerned with the physical nature of the universe.

geoprobe. A rocket vehicle designed to explore space near the earth at a distance of more than 4,000 miles from the earth's surface. Rocket vehicles operating lower than 4,000 miles are termed "sounding rockets."

giga. A prefix meaning multiplied by 1 billion.

gimbal. 1. A device with two mutually perpendicular and intersecting axes of rotation, thus giving free angular movement in two directions, on which an engine or other object may be mounted. 2. In a gyro, a support which provides the spin axis with a degree of freedom.

gnotobiotics. The study of germ free animals.

gravitation. The acceleration produced by the mutual attraction of two masses, directed along the line joining their centers of mass, and of magnitude inversely proportional to the square of the distance between the two centers of mass.

gravity. The force imparted by the earth to a mass on, or close to the earth. Since the earth is rotating, the force observed as gravity is the resultant of the force of gravitation and the centrifugal force arising from this rotation.

g-suit or G-suit. A suit that exerts pressure on the abdomen and lower parts of the body to prevent or retard the collection of blood below the chest under positive acceleration.

g-tolerance. A tolerance in a person or other animal, or in a piece of equipment, to an acceleration of a particular value.

guidance. The process of directing the movements of an aeronautical vehicle or space vehicle, with particular reference to the selection of a flight path or trajectory.

gyro. A device which utilizes the angular momentum of a spinning rotor to sense angular motion of its base about one or two axes at right angles to the spin axis. Also called "gyroscope."

hardness. Of X-rays and other radiation of high energy, a measure of penetrating power. Radiation which will penetrate a 10-centimeter thickness of lead is considered "hard radiation."

heat exchanger. A device for transferring heat from one fluid to another without intermixing the fluids.

heat shield. Any device that protects something from heat.

heat sink. A material capable of absorbing heat; a device utilizing such a material and used as a thermal protection device on a spacecraft or reentry vehicle.

hold. During a countdown: To halt the sequence of events until an impediment has been removed so that the countdown can be resumed, as in "T minus 40 and holding."

hot test. A propulsion system test conducted by actually firing the propellants.

human engineering. The art or science of designing, building, or equipping mechanical devices or artificial environments to the anthropometric, physiological, or psychological requirements of the men who will use them.

hypersonic. 1. Pertaining to hypersonic flow. 2. Pertaining to speeds of Mach 5 or greater.

hypersonic flow. In aerodynamics, flow of a fluid over a body at speeds much greater than the speed of sound and in which the shock waves start at a finite distance from the surface of the body.

hypoxia. Oxygen deficiency in the blood, cells, or tissues of the body in such degree as to cause psychological and physiological disturbances.

Hypoxia may result from a scarcity of oxygen in the air being breathed, or from an inability of the body tissues to absorb oxygen under conditions of low ambient pressure. In the latter case, water vapors from body fluids increase in the sacs of the lungs, crowding out the oxygen.

igniter. Any device used to begin combustion, such as a spark plug in the combustion chamber of a jet engine, or a squib used to ignite fuel in a rocket.

impact area. The area in which a rocket strikes the earth's surface.

Used specifically in reference to the "impact area" of a rocket range.

impact bag. An inflatable bag attached to a spacecraft or reentry capsule to absorb part of the shock of landing.

inertial guidance. Guidance by means of acceleration measured and integrated within the craft.

infrared. Infrared radiation; electromagnetic radiation in the wavelength interval from the red end of the visible spectrum on the lower limit to microwaves used in radar on the upper limit.

insertion. The process of putting an artificial satellite into orbit. Also the time of such action.

interferometer. An apparatus used to produce and measure intereference from two or more coherent wave trains from the same source.

Interferometers are used to measure wavelengths, to measure angular width of sources, to determine the angular position of sources (as in satellite tracking), and for many other purposes.

ion. An atom or molecularly bound group of atoms having an electric charge. Sometimes also a free electron or other charged subatomic particle.

ionosphere. The part of the earth's outer atmosphere where ions and electrons are present in quantities sufficient to affect the propagation of radio waves.

Kepler's laws. The three empirical laws describing the motions of planets in their orbits, discovered by Johannes Kepler (1571–1630). These are: (1) The orbits of the planets are ellipses, with the sun at a common focus. (2) As a planet moves in its orbit, the line joining the planet and sun sweeps over equal areas in equal intervals of time. Also called "law of equal areas." (3) The squares of the periods of revolution of any two planets are proportional to the cubes of their mean distances from the sun.

laser. (From light amplification by stimulated emission of radiation). A device for producing light by emission of energy stored in a molecular or atomic system when stimulated by an input signal.

launch pad. The load-bearing base or platform from which a rocket vehicle is launched. Usually called "pad."

launch ring. The metal ring on the launch pad on which a missile stands before launch.

launch vehicle. Any device which propels and guides a spacecraft into orbit about the earth or into a trajectory to another celestial body. Often called "booster."

launch window. An interval of time during which a rocket can be launched to accomplish a particular purpose as "liftoff occurred 5 minutes after the beginning of the 82-minute launch window."

liberation. A real or apparent oscillatory motion, particularly the apparent oscillation of the moon.

Because of liberation, more than half of the moon's surface is revealed to an observer on the earth, even though the same side of the moon is always toward the earth because the moon's periods of rotation and revolution are the same.

liftoff. The action of a rocket vehicle as it separates from its launch pad in a vertical ascent.

A liftoff is applicable only to vertical ascent; a takeoff is applicable to ascent at any angle. A liftoff is action performed by a rocket; a launch is action performed upon a rocket or upon a satellite or spaceship carried by a rocket.

liquid-propellant rocket engine. A rocket engine fueled with a propellant or propellants in liquid form. Also called "liquid-propellant rocket."

Rocket engines of this kind vary somewhat in complexity, but they consist essentially of one or more combustion chambers together with the necessary pipes, valves, pumps, injectors, etc.

longitudinal axis. The fore-and-aft line through the center of gravity of a craft.

lox. 1. Liquid oxygen. Used attributively as in "lox tank," "lox unit." Also called "loxygen." 2. To load the fuel tanks of a rocket vehicle with liquid oxygen. Hence, "loxing."

Mach number. (After Ernst Mach (1838–1916), Austrian scientist.) A number expressing the ratio of the speed of a body or of a point on a body with respect to the surrounding air or other fluid, or the speed of a flow, to the speed of sound in the medium; the speed represented by this number.

If the Mach number is less than one, the flow is called "subsonic" and local disturbances can propagate ahead of the flow. If the Mach number is greater than one, the flow is called "supersonic" and disturbance cannot propagate ahead of the flow, with the result that shock waves form.

magnetic storm. A worldwide disturbance of the earth's magnetic field.

Magnetic storms are frequently characterized by a sudden onset, in which the magnetic field undergoes marked changes in the course of an hour or less, followed by a very gradual return to normality, which may take several days. Magnetic storms are caused by solar disturbances, though the exact nature of the link between the solar and terrestrial disturbances is not understood. Sometimes a magnetic storm can be linked to a particular solar disturbance. In these cases, the time between solar flare and onset of the magnetic storm is about 1 or 2 days, suggesting that the disturbance is carried to the earth by a cloud of particles thrown out by the sun.

magnetohydrodynamics. The study of the interaction that exists between a magnetic field and an electrically conducting fluid. Also called "magnetoplasmadynamics," "magnetogasdynamics," "hydromagnetics," "MHD."

magnetometer. An instrument used in the study of geomagnetism for measuring any magnetic element.

magnitude. Relative brightness of a celestial body. The smaller the magnitude number, the brighter the body.

Decrease of light by a factor of 100 increases the steller magnitude by 5.00; hence the brightest objects have negative magnitudes. (Sun: —26.8; mean full moon: —12.5; Venus at brightest: —4.3; Jupiter at opposition: —2.3; Sirius: —1.6; Vega: +0.2; Polaris: +2.1). The faintest stars visible to the naked eye on a clear dark night are of about the sixth magnitude.

main stage. 1. In a multistage rocket, the stage that develops the greatest amount of thrust, with or without booster engines. 2. In a single-stage rocket vehicle powered by one or more engines, the period when full thrust (at or above 90 percent) is attained. 3. A sustainer engine, considered as a stage after booster engines have fallen away, as in the main stage of the Atlas.

manometer. An instrument for measuring pressure of gases and vapors both above and below atmospheric pressure.

maser. An amplifier utilizing the principle of microwave amplification by stimulated emission of radiation. Emission of energy stored in a molecular or atomice system by a microwave power supply is stimulated by the input signal.

mass. The measure of the amount of matter in a body, thus its inertia.

The weight of a body is the force with which it is attracted by the earth.

mass-energy equivalence. The equivalence of a quantity of mass m and a quantity of energy E, the two quantities being related by the mass-energy relation $E=mc^2$, where c=the speed of light.

mass ratio. The ratio of the mass of the propellant charge of a rocket to the total mass of the rocket charged with the propellant.

mate. To fit together two major components of a system.

mega. A prefix meaning multiplied by 1 million as in "megacycles."

memory. The component of a computer, control system, guidance system, instrumented satellite, or the like designed to provide ready access to data or instructions previously recorded so as to make them bear upon an immediate problem, such as the guidance of a physical object, or the analysis and reduction of data.

meteor. In particular, the light phenomenon which results from the entry into the earth's atmosphere of a solid particle from space: more generally, any physical object or phenomenon associated with such an event.

meteoric. Of or pertaining to meteors, or meteroids.

meteorite. A meteoroid which has reached the surface of the earth without being completely vaporized.

meteoroid. A solid object moving in interplanetary space, of a size considerably smaller than an asteroid and considerably larger than an atom or molecule.

meteorological rocket. A rocket designed primarily for routine upper-air observation (as opposed to research) in the lower 250,000 feet of the atmosphere, especially that portion inaccessible to baloons; i.e., above 100,000 feet. Also called "rocketsonde."

micro. 1. A prefix meaning divided by 1 million. 2. A prefix meaning very small as in "micrometeorite."

micrometeoroid. A very small meteoroid or meteoric particle with a diameter in general of less than a millimeter.

microwave region. Commonly that region of the radio spectrum between approximately 1,000 megacycles and 300,000 megacycles.

mini. A contraction of "miniature" used in combination, as in "minicomponent," "miniradio," "minitransistor."

miniaturize. To construct a functioning miniature of a part or instrument. Said of telemetering instruments or parts used in an earth satellite or rocket vehicle, where room is at a premium. Hence "miniaturized," "miniaturization."

missile. Any object thrown, dropped, fired, launched, or otherwise projected with the purpose of striking a target. Short for "ballistic missile," "guided missile."

Missile is loosely used as a synonym for "rocket" or "spacecraft" by some careless writers.

mockup. A full-sized replica or dummy of something, such as a spacecraft, often made of some substitute material, such as wood and sometimes incorporating functioning pieces of equipment, such as engines.

modulation. Specifically, variation of some characteristic of a radio wave, called the "carrier wave," in accordance with instantaneous values of another wave, called the "modulating wave."

Variation of amplitude is amplitude modulation, variation of frequency is frequency modulation, and variation of phase is phase modulation. The formation of very short bursts of a carrier wave, separated by relatively long periods during which no carrier wave is transmitted, is pulse modulation.

module. 1. A self-contained unit of a launch vehicle or spacecraft which serves as a building block for the overall structure. The module is usually designated by its primary function as "command module," "lunar landing module," etc. 2. A one-package assembly of functionally associated electronic parts; usually a plug-in unit.

molecule. An aggregate of two or more atoms of a substance that exists as a unit.

monopropellant. A rocket propellant consisting of a single substance, especially a liquid, capable of producing a heated jet without the addition of a second substance.

multiplexer. A mechanical or electrical device for sharing of a circuit by two or more coincident signals.

multiplexing. The simultaneous transmission of two or more signals within single channel.

The three basic methods of multiplexing involve the separation of signals by time division, frequency division, and phase division.

multipropellant. A rocket propellant consisting of two or more substances fed separately to the combustion chamber.

multistage rocket. A vehicle having two or more rocket units, each unit firing after the one in back of it has exhausted its propellant. Normally, each unit, or stage, is jettisoned after completing its firing. Also called a "multiple-stage rocket" or, infrequently, a "step rocket."

nano. A prefix meaning divided by 1 billion, as in "nanosecond," one-billionth of a second.

neutron. A subatomic particle with no electric charge, having a mass slightly more than the mass of the proton.

Newton's laws of motion. A set of three fundamental postulates forming the basis of the mechanics of rigid bodies, formulated by Newton in 1687.

The first law is concerned with the principle of inertia and states that if a body in motion is not acted upon by an external force, its momentum remains constant (law of conservation of momentum). The second law asserts that the rate of change of momentum of a body is proportional to the force acting upon the body and is in the direction of the applied force. A familiar statement of this is the equation

$$F = ma,$$

Where F is vector sum of the applied forces, m the mass, and a the vector acceleration of the body. The third law is the principle of action and reaction, stating that for every force acting upon a body there exists a corresponding force of the same magnitude exerted by the body in the opposite direction.

noise. Any undesired sound. By extension, noise is any unwanted disturbance within a useful frequency band, such as undesired electric waves in a transmission channel or device. When caused by natural electrical discharges in the atmosphere noise may be called "static."

normal shock wave. A shock wave perpendicular, or substantially so, to the direction of flow in a supersonic flow field. Sometimes shortened to "normal shock."

nosecone. The cone-shaped leading end of a rocket vehicle, consisting of (a) of a chamber or chambers in which a satellite, instruments, animals, plants, or auxiliary equipment may be carried, and (b) of an outer surface built to withstand high temperatures generated by aerodynamic heating.

In a satellite vehicle, the nosecone may become the satellite itself after separating from the final stage of the rocket or it may be used to shield the satellite until orbital speed is accomplished, then separating from the satellite.

nova. A star which suddenly becomes many times brighter than previously, and then gradually fades.

nozzle. Specifically, the part of a rocket thrust champer assembly in which the gases produced in the chamber are accelerated to high velocities.

nuclear fuel. Fissionable material of reasonably long life, used or usable in producing energy in a nuclear reactor.

nuclear radiation. The emission of neutrons and other particles from an atomic nucleus as the result of nuclear fission or nuclear fusion.

nuclear reactor. An apparatus in which nuclear fission may be sustained in a self-supporting chain reaction. Commonly called "reactor."

nucleus. The positively charged core of an atom with which is associated practically the whole mass of the atom but only a minute part of its volume.

A nucleus is composed of one or more protons and an approximately equal number of neutrons.

occultation. The disappearance of a body behind another body of larger apparent size.

When the moon passes between the observer and a star, the star is said to be occulted.

octave. The interval between any two frequencies having the ratio of 1 : 2.

orbit. 1. The path of a body or particle under the influence of a gravitational or other force. For instance, the orbit of a celestial body is its path relative to another body around which it revolves. 2. To go around the earth or other body in an orbit.

orbital elements. A set of 7 parameters defining the orbit of a satellite.

orbital period. The interval between successive passages of a satellite.

orbital velocity. 1. The average velocity at which an earth satellite or other orbiting body travels around its primary. 2. The velocity of such a body at any given point in its orbit, as in "its orbital velocity at the apogee is less than at the perigee."

order of magnitude. A factor of 10.

Two quantities of the same kind which differ by less than a factor of 10 are said to be of the same order of magnitude. "Order of magnitude" is used loosely by many writers to mean a pronounced difference in quantity but with the difference much less or much more than a factor of 10.

oxidizer. Specifically, a substance (not necessarily containing oxygen) that supports the combustion of a fuel or propellant.

pad. The platform from which a rocket vehicle is launched. See "launch pad."

paraglider. A flexible-winged, kite-like vehicle designed for use in a recovery system for launch vehicles or as a reentry vehicle.

passive. Reflecting a signal without transmission, as "Echo is a passive satellite." Contrasted with "active."

payload. 1. Originally, the revenue-producing portion of an aircraft's load, e.g., passengers, cargo, mail, etc. 2. By extension, that which an aircraft, rocket, or the like carries over and above what is necessary for the operation of the vehicle during its flight.

peri. A prefix meaning near, as in "perigee."

perigee. That orbital point nearest the earth when the earth is the center of attraction.

That orbital point farthest from the earth is called "apogee." Perigee and apogee are used by many writers in referring to orbits of satellites, especially artificial satellites, around any planet or satellite, thus avoiding coinage of new terms for each planet and moon.

perturbation. Specifically, a disturbance in the regular motion of a celestial body, the result of a force additional to those which cause the regular motion.

photon. According to the quantum theory of radiation, the elementary quantity, or "quantum," of radiant energy.

photon engine. A projected type of reaction engine in which thrust would be obtained from a stream of electromagnetic radiation.

Although the thrust of this engine would be minute, it may be possible to apply it for extended periods of time. Theoretically, in space, where no resistance is offered by air particles, very high speeds may be built up.

photosphere. The intensely bright portion of the sun visible to the unaided eye.

physiological acceleration. The acceleration experienced by a human or an animal test subject in an accelerating vehicle.

pickoff. A sensing device, used in combination with a gyroscope in an automatic pilot or other automatic or robot apparatus, that responds to angular movement to create a signal or to effect some type of control.

pickup. A device that converts a sound, view, or other form of intelligence into corresponding electric signals (e.g., a microphone, a television camera, or a phonograph pickup).

pico. A prefix meaning divided by 1 million million.

pip. Signal indication on the scope of an electronic instrument, produced by a short, sharply peaked pulse of voltage. Also called "blip."

pitchover. The programed turn from the vertical that a rocket under power takes as it describes an arc and points in a direction other than vertical.

planet. A celestial body of the solar system, revolving around the sun in a nearly circular orbit, or a similar body revolving around a star.

The larger of such bodies are sometimes called "principal planets" to distinguish them from asteroids, planetoids, or minor planets, which are comparatively very small.

An inferior planet has an orbit smaller than that of the earth; a superior planet has an orbit larger than that of the earth. The four planets nearest the sun are called "inner planets"; the others, "outer planets." The four largest planets are called "major planets." The word "planet" is of Greek origin meaning, literally, wanderer, applied because the planets appear to move relative to the stars.

plasma. An electrically conductive gas comprised of neutral particles, ionized particles, and free electrons but which, taken as a whole, is electrically neutral.

plasma engine. A reaction engine using magnetically accelerated plasma as propellant.

A plasma engine is a type of electrical engine.

plasma jet. A magnetohydrodynamic rocket engine in which the ejection of plasma generates thrust.

plasma sheath. An envelope of ionized gas that surrounds a body moving through an atmosphere at hypersonic velocities.

The plasma sheath affects transmission, reception, and diffraction of radio waves, thus is important in operational problems of spacecraft.

polarization. A state of electromagnetic radiation in which transverse vibrations take place in some regular manner; e.g., all in one plane, in a circle, in an ellipse, or in some other definite curve.

posigrade rocket. An auxiliary rocket which fires in the direction in which the vehicle is pointed, used for example in separating two stages of a vehicle.

precession. The change in the direction of the axis of rotation of a spinning body or of the plane of the orbit of an orbiting body when acted upon by an outside force.

pressure suit. A garment designed to provide the human body an environment above ambient pressure so that respiratory and circulatory functions may continue normally, or nearly so, under low-pressure conditions, such as occur at high altitudes or in space without benefit of a pressurized cabin.

pressurized. Containing air, or other gas, at a pressure that is higher than the pressure outside the container.

prestage. A step in the action of igniting a large liquid rocket taken prior to the ignition of the full flow, and consisting of igniting a partial flow of propellants into the thrust chamber.

primary. 1. Short for "primary body." 2. Short for "primary cosmic ray."

primary body. The spatial body about which a satellite or other body orbits, or from which it is escaping, or towards which it is falling.

The primary body of the moon is the earth; the primary body of the earth is the sun.

primary cosmic rays. High-energy particles originating outside the earth's atmosphere.

Primary cosmic rays appear to come from all directions in space.

probe. Any device inserted in an environment for the purpose of obtaining information about the environment, specifically, an instrumented vehicle moving through the upper atmosphere or space, or landing upon another celestial body in order to obtain information about the specific environment.

prominence. A filament-like protuberance from the visible portion of the sun.

propellant. Short for "rocket propellant."

proton. A positively charged subatomic particle of a positive charge equal to the negative charge of the electron but of 1,837 times the mass; a constituent of all atomic nuclei.

proving stand. A test stand for reaction engines, especially rocket engines.

purge. To rid a line or tank of residual fluid, especially of fuel or oxygen in the tanks or lines of a rocket after a test firing or simulated test firing.

quantum theory. The theory (first stated by Max Planck before the Physical Society of Berlin on December 14, 1900) that all electromagnetic radiation is emitted and absorbed in "quanta" each of magnitude $h\nu$, h being Planck's constant and ν the frequency of the radiation.

radar astronomy. The study of celestial bodies within the solar system by means of radiation originating on earth but reflected from the body under observation. See **radio astronomy.**

radiation. Short for "electromagnetic radiation," "nuclear radiation."

radiation pressure. Pressure exerted upon a body by electromagnetic radiation incident upon body.

radiation shield. 1. A device used on certain types of instruments to prevent unwanted radiation from biasing the measurement of a quantity. 2. A device used to protect bodies from the harmful effects of nuclear radiation, cosmic radiation, or the like.

radiator. 1. Any source of radiant energy, especially electromagnetic radiation. 2. A device that dissipates heat from something, as from water or oil, not necessarily by radiation only.

Generally, the application of the terms "radiator" (in sense 2) or "heat exchanger" to a particular apparatus depends upon the point of view: If the emphasis is upon merely getting rid of heat, "radiator" is most often used, or sometimes "cooler," if the emphasis is upon transferring heat, "heat exchanger" is used—but these distinctions do not always hold true.

radio astronomy. The study of celestial objects through observation of radiofrequency waves emitted or reflected by these objects.

radio meteor. A meteor detected by the reflection of a radio signal from the meteor trail of relatively high ion density (ion column).

Such an ion column is left behind a meteoroid when it reaches the region of the upper atmosphere between about 80 and 120 km, although occasionally radio meteors are detected at higher altitudes.

radiosonde. A balloon-borne instrument for the simultaneous measurement and transmission of meteorological data.

radio telescope. A device for receiving, amplifying, and measuring the intensity of radio waves originating outside the earth's attmosphere.

reaction control system. A system of controlling the attitude of a craft when outside the atmosphere by using jets of gas in lieu of aerodynamic control surfaces.

reaction engine. An engine that develops thrust by its reaction to ejection of a substance from it; specifically, such an engine that ejects a jet or stream of gases created by the burning of fuel within the engine.

A reaction engine operates in accordance with Newton's third law of motion; i.e., to every action (force) there is an equal and opposite reaction. Both rocket engines and jet engines are reaction engines.

readout. The action of a radio transmitter transmitting data either instantaneously with the acquisition of the data or by play of a magnetic tape upon which the data have been recorded.

readout station. A recording or receiving ratio station at which data are received from a transmitter in a probe, satellite, or other spacecraft.

real time. Time in which reporting on events or recording of events is simultaneous with the events.

For example, the real time of a satellite is that time in which it simultaneously reports its environment as it encounters it; the real time of a computer is that time during which it is accepting data.

recombination. The process by which a positive and a negative ion join to form a neutral molecule or other neutral particle.

recovery. The procedure or action that obtains when the whole of a satellite, or a section, instrumentation package, or other part of a rocket vehicle is recovered after a launch; the result of this procedure.

recycle. In a countdown: To stop the count and to return to an earlier point in the countdown, as in "we have recycled, now at T minus 80 and counting." Compare **hold.**

red shift. In astronomy, the displacement of observed spectral lines toward the longer wavelengths of the red end of the spectrum. Compare **space reddening.**

The "red shift" in the spectrum of distant galaxies has been interpreted as evidence that the universe is expanding.

reentry. The event occurring when a spacecraft or other object comes back into the sensible atmosphere after being rocketed to altitudes above the sensible atmosphere; the action involved in this event.

reentry vehicle. A space vehicle designed to return with its payload to earth through the sensible atmosphere.

reentry window. The area at the limits of the earth's atmosphere through which a spacecraft in a given trajectory can pass to accomplish a successful reentry.

regenerative cooling. The cooling of a part of an engine by the propellant being delivered to the combustion chamber; specifically, the cooling of a rocket-engine combustion chamber or nozzle by circulating the fuel or oxidizer, or both, around the part to be cooled.

regenerator. A device used in a therodynamic process for capturing and returning to the process heat that would otherwise be lost.

relativistic. In general, pertaining to material, as a subatomic particle, moving at speeds which are an appreciable fraction of the speed of light.

relativity. A principle that postulates the equivalence of the description of the universe, in terms of physical laws, by various observers, or for various frames of reference.

rendezvous. The event of two or more objects meeting at a preconceived time and place.

A rendezvous would be involved, for example, in servicing or resupplying a space station.

retrorocket. (From "retroacting.") A rocket fitted on or in a spacecraft, satellite, or the like to produce thrust opposed to forward motion.

revolution. Motion of a celestial body in its orbit; circular motion about an axis usually external to the body.

In some contexts the terms "revolution" and "rotation" are used interchangeably; but with reference to the motions of a celestial body, "revolution" refers to the motion in an orbit or about an axis external to the body, while "rotation" refers to motion about an axis within the body. Thus, the earth revolves about the sun annually and rotates about its axis daily.

rocket. 1. A projectile, pyrotechnic device, or flying vehicle propelled by a rocket engine. 2. A rocket engine.

rocket engine. A reaction engine that contains within itself, or carries along with itself, all the substances necessary for its operation or for the consumption or combustion of its fuel, not requiring intake of any outside substance and hence capable of operation in outer space. Also called "rocket motor."

rocket propellant. Any agent used for consumption or combustion in a rocket and from which the rocket derives its thrust, such as a fuel, oxidizer, additive, catalyst, or any compound or mixture of these. "Rocket propellant" is often shortened to "propellant."

rocketsonde. Meterological rocket.

rockoon. A high-altitude sounding system consisting of a small solid-propellant research rocket launched from a large plastic balloon.

The rocket is fired near the maximum altitude of the balloon flight. It is a relatively mobile rocket-sounding system, and has been used extensively from shipboard.

roll. The rotational or oscillatory movement of an aircraft or similar body which takes place about a longitudinal axis through the body—called "roll" for any amount of such rotation.

rotation. Turning of a body about an axis within the body, as the daily rotation of the earth. See **revolution.**

rumble. A form of combustion instability, especially in a liquid-propellant rocket engine, characterized by a low-pitched, low-frequency rumbling noise; the noise made in this kind of combustion.

satellite. 1. An attendant body that revolves about another body, the primary; especially in the solar system, a secondary body, or moon, that revolves about a planet. 2. A manmade object that revolves about a spatial body, such as Explorer I orbiting about the earth.

scrub. To cancel a scheduled rocket firing, either before or during countdown.

secondary cosmic rays. Secondary emission in the atmosphere stimulated by primary cosmic rays.

selenocentric. Relating to the center of the moon; referring to the moon as a center.

selenographic. 1. Of or pertaining to the physical geography of the moon. 2. Specifically, referring to positions on the moon measured in latitude from the moon's equator and in longitude from a reference meridian.

sensible atmosphere. That part of the atmosphere that offers resistance to a body passing through it.

sensor. The component of an instrument that converts an input signal into a quantity which is measured by another part of the instrument. Also called "sensing element."

service tower=gantry scaffold.

shadowgraph. A picture or image in which steep density gradients in the flow about a body are made visible, the body itself being presented in silhouette.

shield. Short for "radiation shield"; "heat shield."

shock tube. A relatively long tube or pipe in which very brief high-speed gas flows are produced by the sudden release of gas at very high pressure into a low-pressure portion of the tube; the high-speed flow moves into the region of low pressure behind a shock wave.

The shock tube is used as a tool in the study of gases or as a kind of intermittent wind tunnel.

shot. An act or instance of firing a rocket, especially from the earth's surface, as "the shot carried the rocket 200 miles."

sidereal. Of or pertaining to the stars.

solar radiation. The total electromagnetic radiation emitted by the sun.

solid propellant. Specifically, a rocket propellant in solid form, usually containing both fuel and oxidizer combined or mixed and formed into a monolithic (not powdered or granulated) grain. See **rocket propellant** and **grain.**

solid-propellant rocket engine. A rocket engine using a solid propellant. Such engines consist essentially of a combustion chamber containing the propellant, and a nozzle for the exhaust jet, although they often contain other components, as grids, liners, etc. See **rocket engine.**

sonic. 1. Aerodynamics: Of or pertaining to the speed of sound; that moves at the speed of sound, as in 'sonic flow'; designed to operate or perform at the speed of sound, as in "sonic leading edge." 2. Of or pertaining to sound, as in "sonic amplifier."

solar wind. A stream of protons constantly moving outward from the sun.

sonic boom. A noise caused by the shock wave that emanates from an aircraft or other object traveling in the atmosphere at or above the speed of sound.

sonic speed. The speed of sound; by extension, the speed of a body traveling at Mach 1.

Sound travels at different speeds through different mediums and at different speeds through any given medium under different conditions of temperature, etc. In the standard atmosphere at sea level, sonic speed is approximately 760 miles per hour.

sophisticated. Complex and intricate; making use of advanced art; requiring special skills to operate.

sounding. 1. In geophysics, any penetration of the natural environment for scientific observation. 2. In meteorology, same as upper-air observation. However, a common connotation is that of a single complete radiosonde observation.

sounding rocket. A rocket designed to explore the atmosphere within 4,000 miles of the earth's surface.

space. 1. Specifically, the part of the universe lying outside the limits of the earth's atmosphere. 2. More generally, the volume in which all spatial bodies, including the earth, move.

space-air vehicle. A vehicle that may be operated either within or above the sensible atmosphere.

spacecraft. Devices, manned and unmanned, which are designed to be placed into an orbit about the earth or into a trajectory to another celestial body.

space equivalent. A condition within the earth's atmosphere that is virtually identical, in terms of a particular function, with a condition in outer space.

For example, at 50,000 feet the low air pressure and the scarcity of oxygen create a condition, so far as respiration is concerned, that is equivalent to a condition in outer space where no appreciable oxygen is present; thus, a physiological space equivalent is present in the atmosphere.

space medicine. A branch of aerospace medicine concerned specifically with the health of persons who make, or expect to make, flights into space beyond the sensible atmosphere.

space probe. See **probe.**

space reddening. The observed reddening, or absorption of shorter wavelengths, of the light from distant celestial bodies caused by scattering by small particles in interstellar space. Compare **red shift.**

space simulator. A device which simulates some condition or conditions existing in space and used for testing equipment, or in training programs.

spatial. Pertaining to space.

specific impulse. A performance parameter of a rocket propellant, expressed in seconds, and equal to thrust (in pounds) divided by weight flow rate (in pounds per second). See **thrust.**

spectrometer. An instrument which measures some characteristics such as intensity, of electromagnetic radiation as a function of wavelength or frequency.

spectrum. 1. In physics, any series of energies arranged according to wavelength (or frequency); specifically, the series of images produced when a beam of radiant energy, such as sunlight, is dispersed by a prism or a reflecting grating. 2. Short for "electromagnetic spectrum" or for any part of it used for a specific purpose as the "radio spectrum" (10 kilocycles to 300,000 megacycles).

stage. A propulsion unit of a rocket, especially one unit of a multistage rocket, including its own fuel and tanks.

stage-and-a-half. A liquid-rocket propulsion unit of which only part falls away from the rocket vehicle during flight, as in the case of booster rockets falling away to leave the sustainer engine to consume remaining fuel.

standard atmosphere. A hypothetical vertical distribution of atmospheric temperature, pressure, and density which, by agreement, is taken to be representative of the atmosphere for purposes of pressure altimeter calibrations, aircraft performance calculations, aircraft and rocket design, ballistic tables, etc.

stationary orbit. An orbit in which an equatorial satellite revolves about the primary at the same angular rate as the primary rotates on its axis. From the primary, the satellite thus appears to be stationary over a point on the primary.

subatomic particle. A component of an atom, such as an electron, a proton, a meson, etc.

subsonic. In aerodynamics, dealing with speeds less than the speed of sound (see sonic speed), as in "subsonic aerodynamics."

sunspot. A relatively dark area on the surface of the sun, consisting of a dark central umbra and a surrounding penumbra that is intermediate in brightness between the umbra and the surrounding photosphere.

sunspot cycle. A periodic variation in the number and area of sunspots with an average length of 11.1 years, but varying between about 7 and 17 years.

supersonic. Pertaining to speeds greater than the speed of sound. Compare **ultrasonic.**

sustainer engine. An engine that maintains the velocity of a missile or rocket vehicle, once it has achieved its programed velocity through use of a booster engine.

synchronous satellite. An equatorial west-to-east satellite orbiting the earth at an altitude of 22,300 statute miles at which altitude it makes one revolution in 24 hours, synchronous with the earth's rotation.

synergic curve. A curve plotted for the ascent of a rocket, space-air vehicle, or space vehicle calculated to give the vehicle an optimum economy in fuel with an optimum velocity.

This curve, plotted to minimize air resistance, starts off vertically, but bends towards the horizontal between 20 and 60 miles altitude.

tektite. A small glassy body containing no crystals, probably of meteoritic origin, and bearing no antecedent relation to the geological formation in which it occurs.

Tektites are found in certain large areas called "strewn fields." They are named as minerals with the suffix "ite," as "australite," found in Australia; "billitonite," "indochinite," and "rizalite," found in Southeast Asia; "bediasite" from Texas, and "moldavite" from Bohemia and Moravia.

telemetry. 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.

terminator. The line separating illuminated and dark portions of a nonluminous body, as the moon.

terrestrial. Pertaining to the earth.

thermal. Pertaining to heat or temperature.

thermodynamic. Pertaining to the flow of heat or to thermodynamics.

thermodynamics. The study of the relationships between heat and other forms of energy.

thermonuclear. Pertaining to a nuclear reaction that is triggered by particles of high thermal energy.

thrust. 1. The pushing force developed by an aircraft engine or a rocket engine. 2. Specifically, in rocketry, the product of propellant mass flow rate and exhaust velocity relative to the vehicle.

topside sounder. A satellite designed to measure ion concentration in the ionosphere from above the ionosphere.

tracking. The process of following the movement of a satellite or rocket by radar, radio, and photographic observations.

trajectory. In general, the path traced by any body, as a rocket, moving as a result of externally applied forces.

Trajectory is loosely used to mean "flight path" or "orbit."

transducer. A device capable of being actuated by energy from one or more transmission systems or media and of supplying related energy to one or more other transmission systems or media, as a microphone, a thermocouple, etc.

transfer orbit. In interplanetary travel an elliptical trajectory tangent to the orbits of both the departure planet and the target planet.

transit. 1. The passage of a celestial body across a celestial meridian; usually called "meridian transit." 2. The apparent passage of a celestial body across the face of another celestial body or across any point, area, or line.

translunar. Of or pertaining to space outside the moon's orbit about the earth.

transponder. A combined receiver and transmitter whose function is to transmit signals automatically when triggered by an interrogating signal.

T-time. Any specific time, minus or plus, as referenced to "zero," or "launch" time, during a countdown sequence that is intended to result in the firing of a rocket propulsion unit that launches a rocket vehicle or missile.

ullage. The amount that a container, such as a fuel tank, lacks of being full.

ultrasonic. Of or pertaining to frequencies above those that affect the human ear, i.e., more than 20,000 vibrations per second.

The term "ultrasonic" may be used as a modifier to indicate a device or system intended to operate at an ultrasonic frequency.

Although "supersonic" was formerly used in acoustics synonymously with "ultrasonic," this usage is now rare.

ultraviolet radiation. Electromagnetic radiation shorter in wavelength than visible radiation but longer than X-rays; roughly, radiation in the wavelength interval between 10 and 4,000 angstroms.

Ultraviolet radiation from the sun is responsible for many complex photochemical reactions characteristic of the upper atmosphere, e.g., the formation of the ozone layer through ultraviolet dissociation of oxygen molecules followed by recombination to form ozone.

umbilical cord. Any of the servicing electrical or fluid lines between the ground or a tower and an upright rocket missile or vehicle before the launch. Often shortened to "unbilical".

upper-air observation. A measurement of atmospheric conditions aloft, above the effective range of a surface weather observation. Also called "sounding," "upper-air sounding."

Van Allen Belt, Van Allen Radiation Belt, Van Allen Radiation Region. (For James A. Van Allen, 1915– The zone of high-intensity radiation surrounding the earth beginning at altitudes of approximately 500 miles.

vehicle. Specifically, a structure, machine, or device, such as an aircraft or rocket, designed to carry a burden through air or space; more restrictively, a rocket craft.

This word has acquired its specific meaning owing to the need for a term to embrace all flying craft, including aircraft and rockets.

vernier engine. A rocket engine of small thrust used primarily to obtain a fine adjustment in the velocity and trajectory of a ballistic missile or space vehicle just after the thrust cutoff of the last propulsion engine, and used secondarily to add thrust to a booster or sustainer engine. Also called "vernier rocket".

visible radiation. Electromagnetic radiation lying within the wavelength interval to which the human eye is sensitive, which is from approximately 0.4 to 0.7 micron (4,000 to 7,000 angstroms). This portion of the electromagnetic spectrum is bounded on the short-wavelength end by ultraviolet radiation, and on the long-wavelength end by infrared radiation.

weight. The force with which an earthbound body is attracted toward the earth.

weightlessness. 1. A condition in which no acceleration, whether of gravity or other force can be detected by an observer within the system in question. 2. A condition in which gravitational and other external forces acting on a body produce no stress, either internal or external, in the body.

Any object falling freely in a vacuum is weightless, thus an unaccelerated satellite orbiting the earth is "weightless" although gravity affects its orbit. Weightlessness can be produced within the atmosphere in aircraft flying a parabolic flight path.

whistler. A radiofrequency electromagnetic signal sometimes generated by lightning discharges.

This signal apparently propagates along a geomagnetic line of force, and often "bounces" several times between the Northern and Southern Hemispheres. Its name derives from the sound heard on radio receivers.

X-ray. Electromagnetic radiation of very short wavelength, lying within the wavelength interval of 0.1 to 100 angstroms (between gamma rays and ultraviolet radiation). Also called "X-radiation," "Roentgen ray."

X-rays penetrate various thicknesses of all solids and they act upon photographic plates in the same manner as light. Secondary X-rays are produced whenever X-rays are absorbed by a substance, in the case of absorption by a gas, this results in ionization.

yaw. 1. The lateral rotational or oscillatory movement of an aircraft, rocket, or the like about a transverse axis. 2. The amount of this movement; i.e., the angle of yaw.

zero g=weightlessness.

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☆ U.S. GOVERNMENT PRINTING OFFICE : 1964 O—735–673

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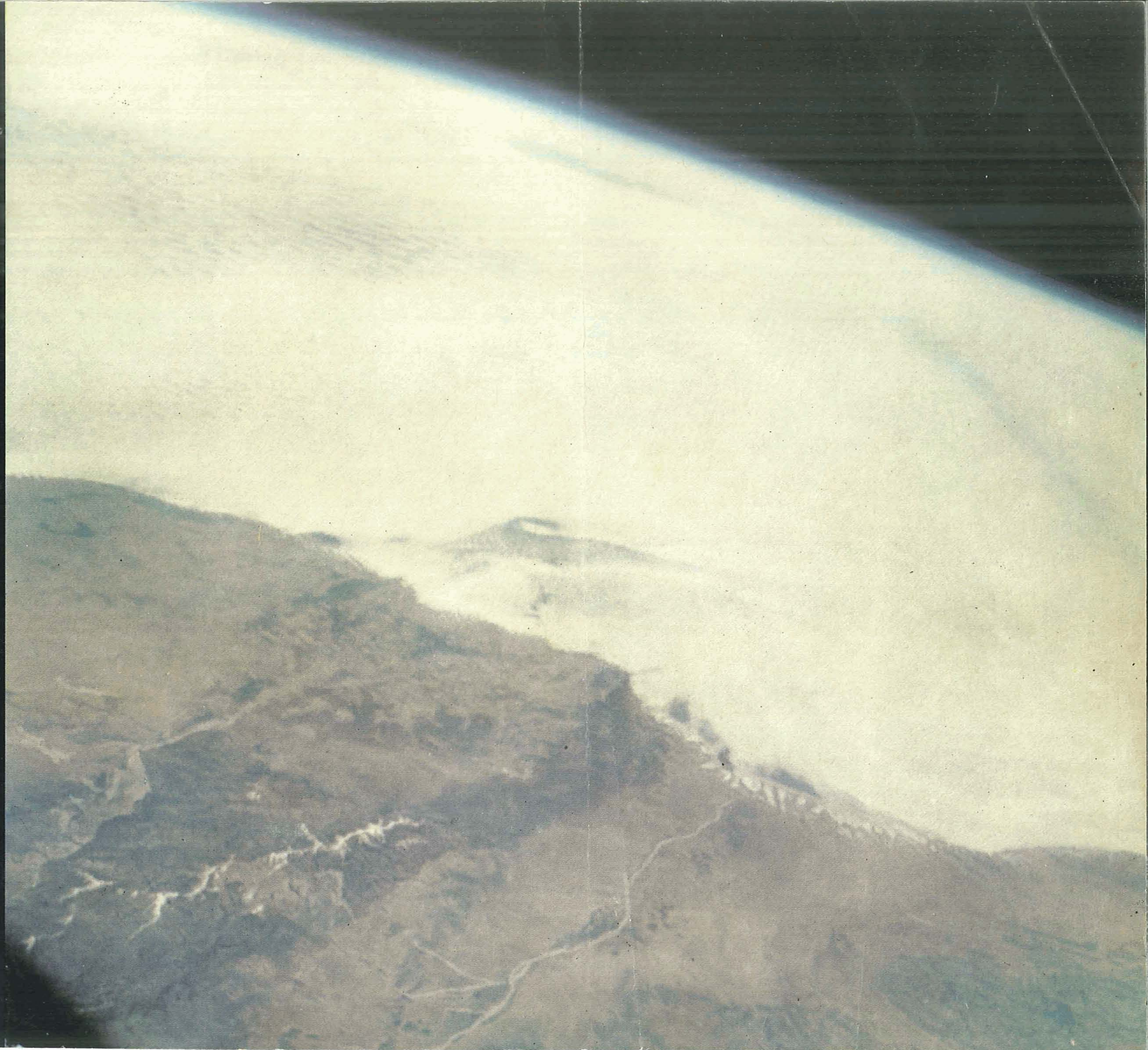

MOROCCO—The earth's curvature is apparent in this color picture, which shows the Atlas Mountains (lower left) and the cloud-covered Atlantic Ocean. The blue band at the horizon is produced by the atmosphere.

BURMA—The contrast between land and ocean areas is particularly well portrayed in this picture taken by Astronaut Cooper as Faith 7 passed over the west coast of Burma, west of Rangoon. At left is the Bay of Bengal, at right is the Irrawaddy River.