Historical Survey Lecture

First Steps into Space, 1946-1978*

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REVIEWS of historic events can be approached in two very different ways. First, a detailed set of facts and data can be collected through literature search, aided by computers and other nonemotional reporting systems, resulting in a complete, accurate, but relatively impersonal listing of all the numerous events as they happened in the course of time. In the other approach, an individual is being asked to relate those events which stand out in his memory and which he believes, in retrospect, to have been exciting and important. This process results in a picture which is less complete, but certainly more colorful, and which reflects some of the continuous, often very vivid interplay between the unshakable laws of physics and the minds of those who are to transform those laws into man-made technical systems.

I was asked to describe, in the short span of thirty minutes, how man took his first groping steps into space during the past thirty years. Compared with the endless horizons that space offers to us, and with the vast promise it holds for man, those first steps were groping indeed. However, we should be encouraged by the achievements of these thirty years. More than 2000 launches of satellites and space probes were accomplished, with a success rate, at least in the U.S. program, of 88%. Systems for propulsion, guidance, control, telemetry, communications, and observations were invented, developed, and built to the highest standards of perfection. Instruments to study the Moon, Sun, planets (including our Earth), stars, galaxies, radiations and fields, and other phenomena of space brought a wealth of scientific knowledge that surpassed the wildest dreams of even those who have devoted their lives' work to the exploration of space.

For all times, the opening date of man's venture into space will be Oct. 4, 1957, when Sputnik I sent its soft, but insistent beep-beep to startled and incredulous listeners on Earth. Although the Space Age began on a note of national competition, its further evolution quickly proved that the uniting forces of space projects are much stronger than the dividing tendencies. Today, communication satellites form links between all nations on Earth; weather satellites supply every part of the globe with instant weather data; Earth-observing satellites furnish vital information about floods, droughts, snow cover, and crop status to all countries that need it. American and Russian launch rockets have placed satellites of numerous other nations into orbit. One of the great space projects presently under development, the Space Shuttle, represents a truly cooperative effort between nations: The U.S. is providing the space transportation system, and a consortium of ten European nations is building the Spacelab that will accommodate a variety of different payloads prepared by nations around the Earth.

The diagram in Fig. 1 shows the number of satellite and deep-space launches by the U.S. during the 20 yr following Sputnik; it represents more than 800 launches. During the same period, the USSR accomplished almost 1200 space launches. About 100 of these 2000 satellites and probes were built by other nations. The only detail shown in the diagram is the number of failures; to every engineering-minded person, the rapid and almost complete decline of launch failures is an impressive fact. Not shown in the figure is the great diversification of launch rockets, flight objectives, and payloads; this would be far too complex for one diagram. Instead, Fig. 2 shows how the main thrust of the space program has developed and changed through the years. The rocket and space flight history since 1946 evolved in phases of 3-5 years' length, each with its own characteristic trend and accomplishments.

Many of those who worked in rocketry during the war nurtured the hope that the time may come when rockets are used for the sole purpose of scientific exploration. For me, the realization that this time had indeed come occurred in the summer of 1946 on the White Sands Proving Grounds where some of the captured V-2's from Peenemuende were test-fired. Working on the gyro stabilization system near the top of the rocket high on a shaky ladder, I met a young scientist who stood nearby on another shaky ladder and fixed a little Geiger counter that he had built at the Naval Research Laboratory in Washington. The counter had a thin window to admit ultraviolet radiation from the Sun; the name of the young scientist was Herbert Friedman. For Dr. Friedman, this rocket flight in White Sands stood at the beginning of a brilliant career in space science. During the years to follow, there has been hardly a scientific committee or board of which he was not a member. In 1949, he discovered the emission of x-rays from the Sun; many other space discoveries followed, and as one of the principal investigators on the first High Energy Astronomical Observatory (HEAO) satellite, he may expect the best yet to come. His colleagues call Dr. Friedman simply "Mr. Space Science."

Launchings of old V-2 rockets for scientific purposes continued through 1952. Eight of them carried a second stage, a WAC Corporal, which gave them a greater altitude

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Ernst Stuhlinger studied physics under Hans Geiger at the University of Tuebingen, Germany. In 1936, he became assistant professor of physics at the Technical University of Berlin. He joined Wernher von Braun's rocket development team in Peenemuende in 1943 and moved to the United States in February of 1946. His field of work included guidance and control systems, electric spacecraft propulsion, and the planning and initiation of space science projects. From 1968 till 1976, Stuhlinger was Associate Director for Science at the G.C. Marshall Space Flight Center at Huntsville, Alabama. He retired from NASA in 1976 and became a member of the University of Alabama in Huntsville. In 1978, he spent six months at the Technical University of Munich as a recipient of the A. von Humboldt Award, working on a study of comet and asteroid missions with electrically propelled spacecraft.

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*This paper was invited for the 16th Aerospace Sciences Meeting as a historical survey. It is published here primarily for its historical interest to our readers and is not meant to be a comprehensive survey of the field. It represents solely the author's own experience and opinions.

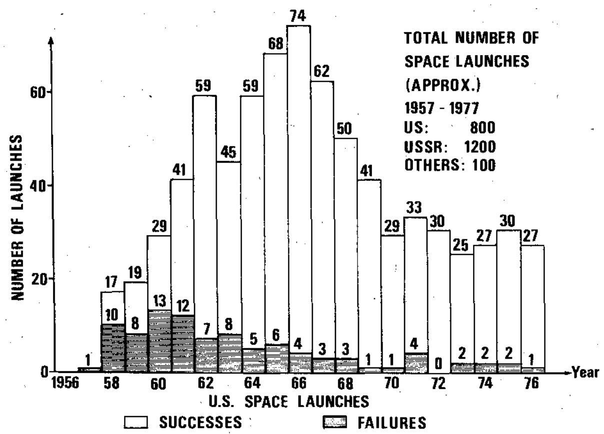

Fig. 1 Number of U.S. satellite and space probe launches, 1957-1976.

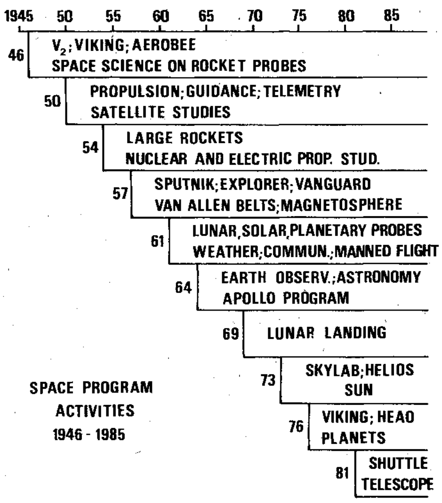

Fig. 2 Space program activities, 1946-1985.

capability. The record height, reached in 1949, was almost 400 km. While these test flights were occurring, a new rocket for high-altitude flights took shape—the Viking. Developed by a Navy team under Milton Rosen and Ernst Krause and built by Glenn L. Martin in Baltimore, it carried scientific payloads up to 400 kg to maximum altitudes of 260 km. The third member in the early high-altitude rocket family, Aerobee, began its active life in the late 1940's. For almost three decades, it served its purpose extremely well, carrying numerous scientific payloads to altitudes of more than 300 km.

Following the early successes of high-altitude rocket flights, intense work programs developed to perfect rocket propulsion systems, inertial guidance systems, and telemetry systems for data transmission from space to Earth. The famous H-1 engine, for example, which powered a number of rockets for military and nonmilitary applications, was developed by the Rocketdyne Corporation at that time. It opened a proud line of highly successful rocket engines, culminating in the powerful F-1 that sent the Apollo capsule on its way to the Moon. The Shuttle engine, with the highest performance rating of any existing rocket motor, derives from the same ancestry.

While a healthy effort developed at industry to transform the elements of rocket and space technology into programs of industrial production, the minds of many of the early space enthusiasts reached out toward new horizons. In 1947, an Upper Atmosphere Research Panel was established, later to become the Rocket and Satellite Research Panel. The idea of artificial Earth satellites did not have to be invented; this had been done almost 300 yr earlier by no lesser man than Isaac Newton, who proved the feasibility of Earth satellites by applying Newton's laws to a bullet fired from a hypothetical gun on a high mountain top. Wernher von Braun had learned as a school boy how to calculate the satellite's velocity as a function of its altitude. When the Redstone guided missile took shape in the early 1950's, he realized that the time for the first satellite had come, and he submitted a detailed technical plan for "Project Orbiter" to his Army Headquarters in 1954. Other groups had similar thoughts, and when plans began in 1955 for a Geophysical Year of internationally coordinated observations of the Earth, President Eisenhower announced that the United States would launch a "small, unmanned satellite" as a contribution to the International Geophysical Year. A committee then decided that Project Vanguard, proposed by a Navy team and based on a combination of Viking and Aerobee rockets, should be chosen as carrier for a 3¼-lb satellite, rather than the Army-sponsored Project Orbiter proposed by the team in Huntsville.

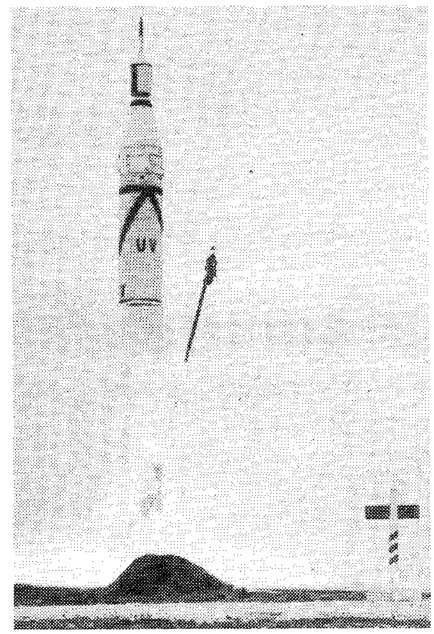

Fig. 3 Launching of Explorer I on Jan. 31, 1958.

Success with the launchings of V-2's, Vikings, and Aerobees not only stimulated plans for satellites, it provided encouragement for studies of even greater projects. During his years in Fort Bliss, Wernher von Braun worked out, in great technical detail, the concept of a manned rocket journey to Mars, and showed, based on existing technology, that such a journey would be feasible. This little booklet brought space closer to man on Earth. Although the proposed vehicles, and particularly their chemical propulsion systems, would be considered clumsy and obsolete today, this "Mars Project" study will remain a milestone in the history of space flight for all times.

The next phase in the space program, beginning around 1954, put emphasis on big military rockets. Those were the years of Redstone, Thor, Jupiter, Atlas, and Titan. Each of these rockets, although developed for the Armed Forces, was used for many space launches of scientific payloads. A number of modifications of the basic Thor rocket, among them Thor-Agena and thrust-assisted Thor, were developed, specifically for the launching of satellites and space probes. Beginning around 1959, more than 200 of these vehicles carried satellites and probes to their destinations. A smaller cousin of this family, the Delta rocket, managed by the Goddard Space Flight Center, has successfully launched satellites and probes more than a hundred times from about 1960 on. Atlas, the venerable workhorse in the rocket stable, placed no less than 150 satellites and probes into their orbits, 35 of them with the hydrogen-oxygen powered Centaur as upper stage which made its debut in 1963. Titan, the powerful long-range missile which has been almost as prolific as Atlas in launching satellites and probes, was combined half a dozen times with Centaur stages for demanding space missions such as Helios (1974 and 1976) and Viking (1975). The Centaur stage is managed by the NASA Lewis Research Center. Smaller satellites have found a very effective and reliable launch vehicle in the Scout, managed by the NASA Langley Research Center. About 65 satellites were successfully orbited by Scout rockets, the first of them in 1961. All of these satellite and probe launchers will continue their lines of duty until the Shuttle, combined with suitable upper stages, can take over.

While these rockets with their upper stages are almost tailormade for the launching of satellites into near-Earth orbits, their performances, limited by the energy content of chemical propellants, are marginal for deep space projects which require considerably more propulsive energy than satellite launchings. Two advanced, nonchemical propulsion systems entered the field of active study and experimentation in the early 1950's—the nuclear rocket and the electric propulsion system. Both would be well suited even for manned missions to Mars—the nuclear rocket with short-time, powerful bursts of thrust; the electric rocket with a thrust of low, but continuing force.

In September of 1956, a Redstone rocket, equipped with two solid-propellant upper stages, reached an altitude of 1100 km and covered a range of 5500 km in a flight program for the testing of re-entry nosecones. The same rocket type, with a third upper stage, would have been able to launch a 10-kg satellite. However, the Navy Project Vanguard was underway at that time, aiming for a satellite launching late in 1957. There were several indications, including direct pronouncements by Russian scientists, that the USSR was also planning to launch a satellite during the International Geophysical Year. In an effort to help accelerate the American satellite project, the Army team offered to give full support to the Navy team which was plagued by a string of mishaps during 1957, but the Navy remained firm. The Russians surprised and impressed the world by launching Sputnik I on Oct. 4, 1957. After their second successful launch which carried the dog Laika into orbit, the Redstone team received orders to build and launch a U.S. satellite; 84 days later, on Jan. 31, 1958, it was in orbit as Explorer I. It carried two small Geiger counters, prepared by Dr. Van Allen and his team members at the State University of Iowa. Figure 3 shows the launching of Explorer I. The satellite, with the third stage attached, is shown in Fig. 4. The man pointing at the satellite is Dr. George Ludwig, who later became Director of Satellite Data Systems at the NASA Goddard Space Flight Center.

The first successful Vanguard satellite was launched in the spring of 1958. More Sputniks, Explorers, and Vanguards followed, and the small group of early orbiters soon developed into populous generations of bigger and better satellites. Figure 5 shows Explorer VII launched in 1959. Explorer I demonstrated the tremendous research and discovery potential of satellites. It detected the Van Allen radiation belts that surround the Earth, a discovery which led to the recognition that the Earth is enclosed by a magnetosphere which protects it against the solar wind, and against many of the cosmic ray particles that would hit our atmosphere if the Earth had no magnetic field. Figure 6 shows a schematic sketch of the magnetosphere and of its interactions with the solar wind.

Shortly after the satellite era had begun, satellites were put to many of the practical uses that had been predicted by such early pioneers as Ganswindt, Esnault-Pelterie, Goddard, Tsiolkovskii, and Oberth. Satellites began to look at the Earth's surface and at cloud formations; they served as communication relays and as navigational aids; they sensed ultraviolet, cosmic, and gamma radiations; they determined the frequency of meteroid impacts on test surfaces; and they carried telescopes viewing the Sun, Moon, planets, stars, and galaxies. During the early 1960's, satellites gave us instant global communications, a worldwide weather service, and means to observe and monitor our Earth. Space probes provided the first close look at our neighbors in space; lunar photos were furnished by Ranger spacecraft, and in 1965, Mariner 4 took pictures of Mars from 10,000 km.

A few years after the successful launching of the first satellites, space engineers had developed enough confidence in their designs to put men on some of the spacecraft. Yuri Gagarin, in another all-time first for the USSR, orbited the Earth in April of 1961. One month later, Alan Shepherd rode in the Mercury capsule of a Redstone rocket over a ballistic trajectory of 500 km, and in February, 1962, John Glenn became the first Earth-orbiting American astronaut. Almost a year earlier, in May of 1961, President Kennedy had declared the landing of American astronauts on the Moon a national

Fig. 4 Explorer I satellite, with third stage solid-propellant rocket.

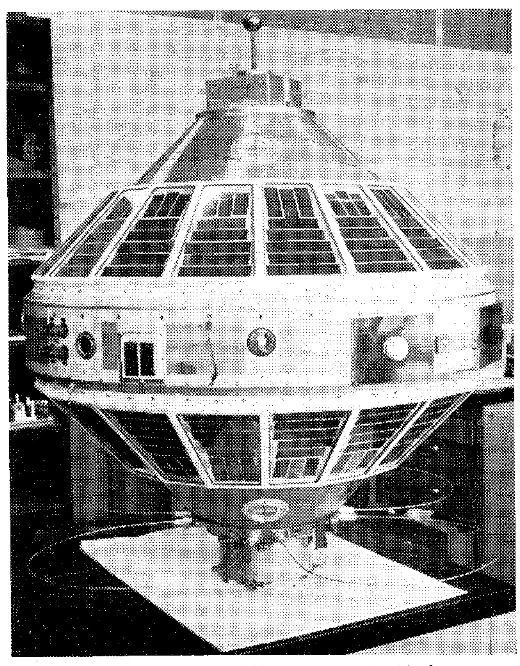

Fig. 5 Explorer VII, launched in 1959.

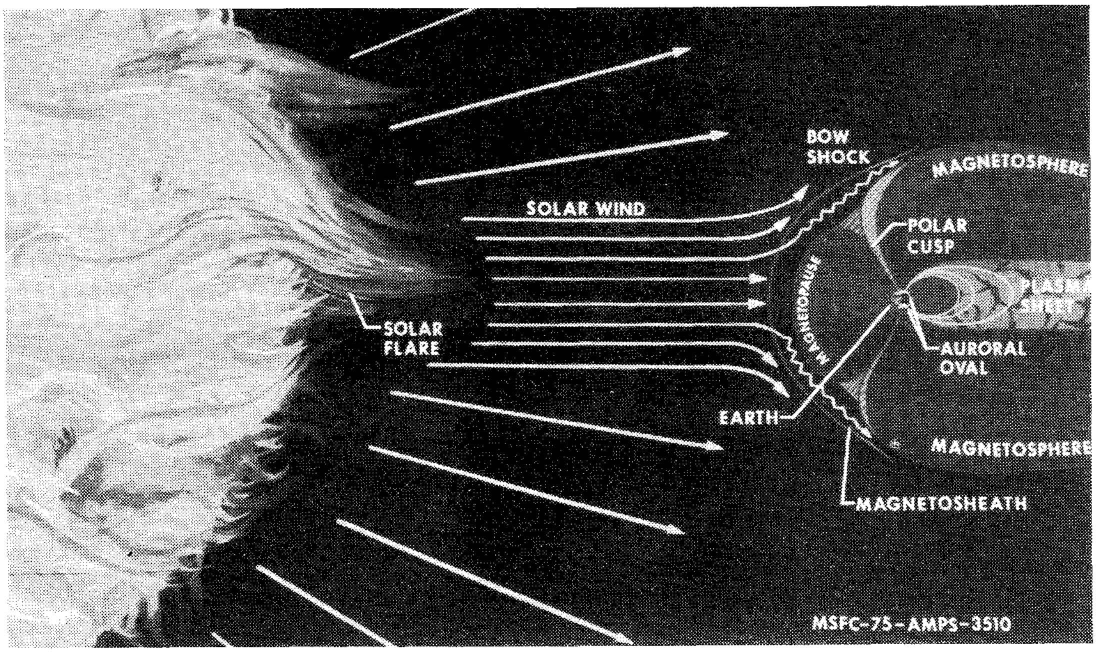

Fig. 6 Magnetosphere and solar wind.

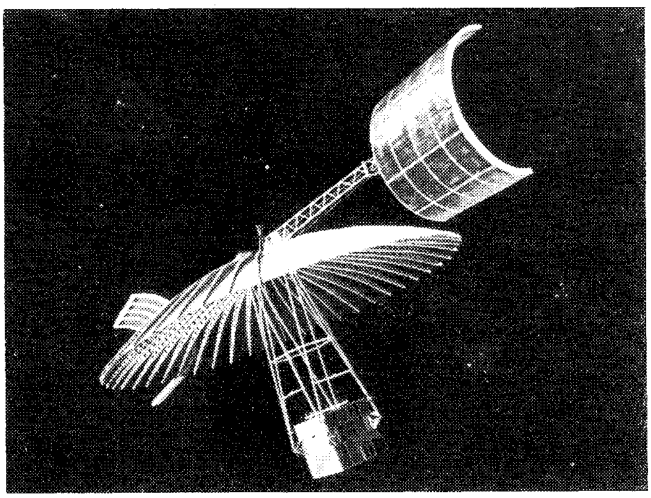

Fig. 7 Advanced technology satellite, ATS 6 (geosynchronous communication relay).

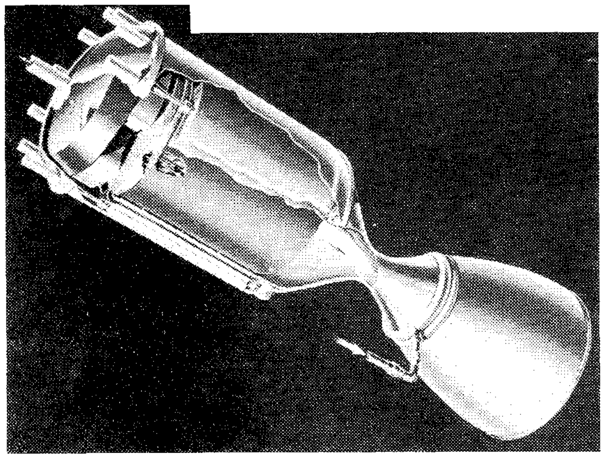

Fig. 8 Typical nuclear rocket engine.

goal of the decade. Project Apollo was inaugurated, and it quickly became the overriding space project of the sixties. The first member of the family of Saturn rockets, Saturn I, had been started in 1958, Saturn IB followed, and the real Apollo launch rocket, Saturn V, began its development in 1962. The project met with unparalleled success. All of the thirty Saturn rockets which were launched performed well, and six Apollo capsules, carrying twelve astronauts, landed on the Moon. All astronauts returned safely to Earth.

Almost in the shadow of the brilliant Apollo Project, other space projects went through their paces. Weather and communication satellites were perfected; orbiting solar observatories studied the Sun; steller astronomy began to evolve with the Orbiting Astronomical Observatory series. One of the latest additions to the communication satellite family, ATS 6, is shown in Fig. 7. Russian and American probes landed on the Moon, planetary probes flew by Mars and Venus. Riccardo Giacconi and his co-workers discovered the first stellar source of x-rays in the constellation of Scorpius. During the fifteen years following this discovery, more than 300 stellar x-ray sources were found.

Much effort was spent on the nuclear rocket, shown in Fig. 8, which presented a number of extremely tough engineering problems. During the early phases of the project, it had been hoped that specific impulses as high as 1100 s could be obtained; performance at this level would have been necessary to make the nuclear rocket a useful system for manned planetary flight. The basic idea behind the nuclear rocket system certainly has its merits; however, as the project went through the sobering process of engineering, it lost so much of its original attractiveness that the final product no longer appeared to be a promising contender for manned planetary flight. The project was discontinued as a solid-core reactor project, but studies continue on gas-core reactors which promise higher specific impulses.

Electric rocket systems went through a different path of development. Step by step, they presented a textbook example of project development as they proceeded through the stages of basic idea, technical concept, application studies, component development, performance verification, product improvement, systems engineering, reliability testing, flight qualification, and mission readiness. This program was a cooperative effort between the NASA/Lewis Research Center, the Marshall Center, Jet Propulsion Laboratory, and several industrial corporations, among them Electro-Optics, Hughes Research Labs., Rockwell International, Boeing, and others. Figure 9 shows a sketch of a thrust unit built by Hughes Research Labs. A complete thruster, ready for use, is shown in Fig. 10. A first flight test, SERT I, was successfully performed in 1963; it proved the soundness of the principle

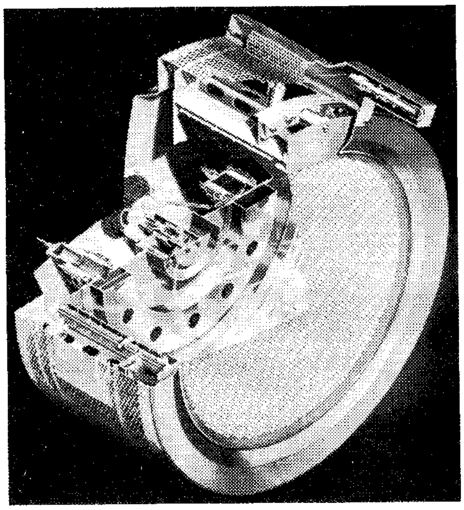

Fig. 9 Electric thruster (Hughes Research Laboratories).

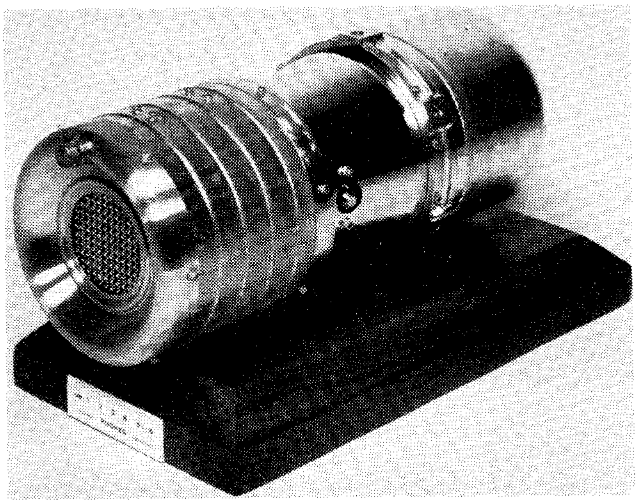

Fig. 10 Electric thruster for satellite attitude control (Hughes Research Laboratories).

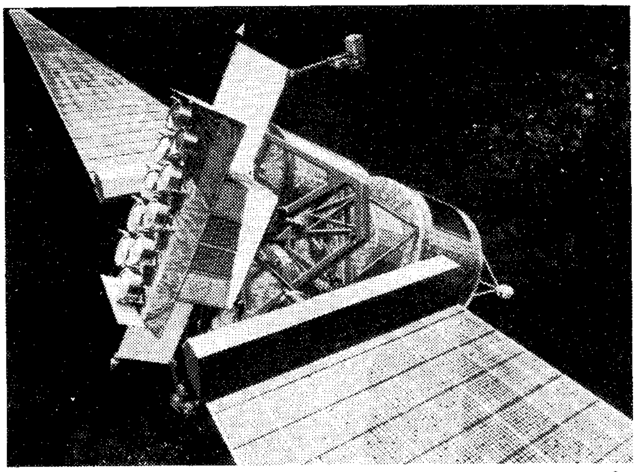

Fig. 11 Solar-electric propulsion stage for interplanetary spacecraft.

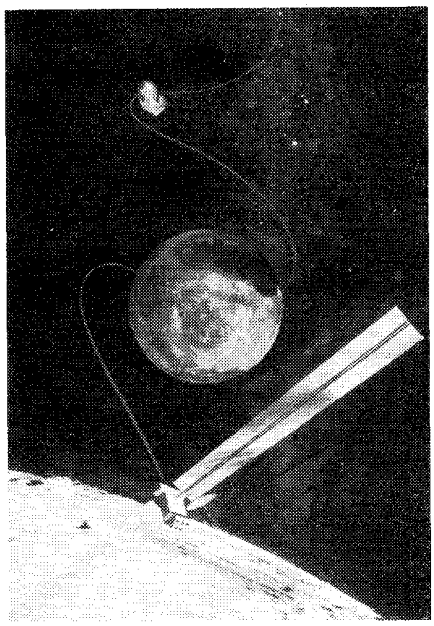

Fig. 12 Solar-electric spacecraft encountering an asteroid and a planetary moon.

and of performance calculations. A second flight test, SERT II, took place in 1970. Its main objective, long-duration testing under flight conditions, was met beyond expections; even today, after almost eight years in orbit, one of the two SERT II thrusters is still operable, without signs of performance degradation. In laboratory testing, electric thrusters have successfully completed several long-duration tests, each lasting for over 15,000 hours. Several Russian spacecraft were launched during the 1960's with electric thrusters as attitude control systems.

Electric propulsion systems will be applicable to a number of planetary and interplanetary spacecraft for missions which are difficult to accomplish with chemical rockets, simply because the total impulse which a solar-powered electric thruster can produce over a sufficiently long time with a given total mass, including power source and propellant, is considerably greater than the total impulse which a chemical propulsion system of the same total mass can produce. An artist's concept of an electrically propelled spacecraft is shown in Fig. 11. Promising electric propulsion missions include orbiters around Mercury, Venus, Mars, Jupiter, and around some of the planetary moons (Fig. 12), and also rendezvous probes to asteroids and comets (Fig. 13), and solar probes toward the poles of the Sun. Once a nuclear-electric power source of 200-300 kw is available for spacecraft, electrically propelled vehicles will be very efficient, fast, and useful systems for a thorough exploration of the outer planets, including Pluto. In all of these projects, the spacecraft carries a relatively large power supply. When it arrives at its target, power from this source becomes available for instrumentation and data transmission—an additional bonus of electric propulsion systems.

Throughout the years, a number of space scientists showed great interest in space projects involving electric propulsion systems. However, all of these interests could not yet be collimated and focused sufficiently to make a convincing argument for the decision-makers in the space program to place the priority for an electric propulsion system above the priorities of other space projects. Electric propulsion, therefore, has remained the "propulsion system of tomorrow." Electric propulsion protagonists were encouraged recently when NASA decided in favor of solar/electric propulsion and against space propulsion by solar sail in a comparative study of the two systems. The next step, authorization of the development of a basic solar-electric propulsion module for a variety of planetary and interplanetary spacecraft, has not yet been taken. This step will finally make electric propulsion the "propulsion system of today."

Before the decade of the sixties was over, Neil Armstrong and Buzz Aldrin landed on the Moon, fulfilling President Kennedy's promise. All of a sudden, the Moon's material and surface structure, its magnetic field and atmosphere, even its

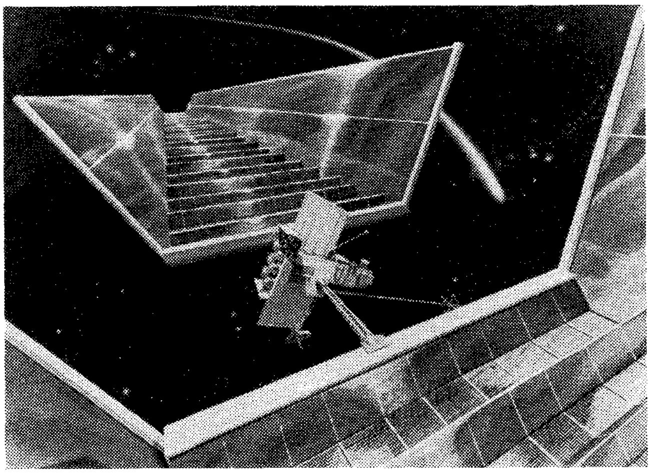

Fig. 13 Solar-electric spacecraft on a Comet Halley rendezvous mission.

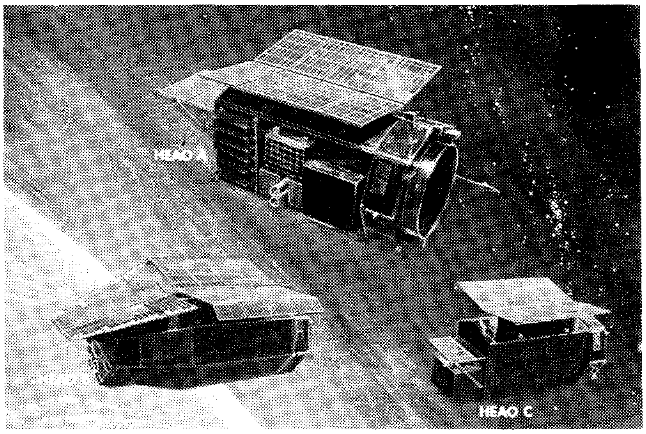

Fig. 14 High Energy Astronomical Observatory (HEAO) A, B, and C.

interior and its evolution, could be studied at close range. Our knowledge of the Earth's natural satellite took a fantastic jump, and yet, so many new questions arose that the desire for more research and exploration became one of the immediate results of the Apollo project.

Building on the success of Apollo, and utilizing many of the systems developed for that project, NASA was quick to have the Moon flights followed by Project Skylab, our first real station in orbit. Again, the project proved to be an unexpectedly rich source of new knowledge and experience. Man-in-space, imaging of the Earth, astronomical observations, and, very particularly, an intense study of the Sun characterized the activities on Skylab.

After Skylab astronauts had taken their close look at the Sun, a period of unmanned spacecraft began in the American space program which will last for a number of years. Helios, built by West Germany and launched by NASA, approached the Sun closer than any other spacecraft before. Viking, a Mars landing project that had been under development for many years, was an outstanding success as far as the technical performance of nearly all the systems and subsystems was concerned. It did not discover life on Mars, although it detected some strange chemical processes which do not seem to liken processes known on Earth. Again, the project left the fervent desire among its project scientists to return to Mars with new instruments, to go to different places, and even to use a vehicle that could move over the surface in search of compounds that would possibly be related to the evolution of life.

As early as 1923, Professor Oberth wrote in his now-famous book "Rockets for Planetary Flight" that Earth-

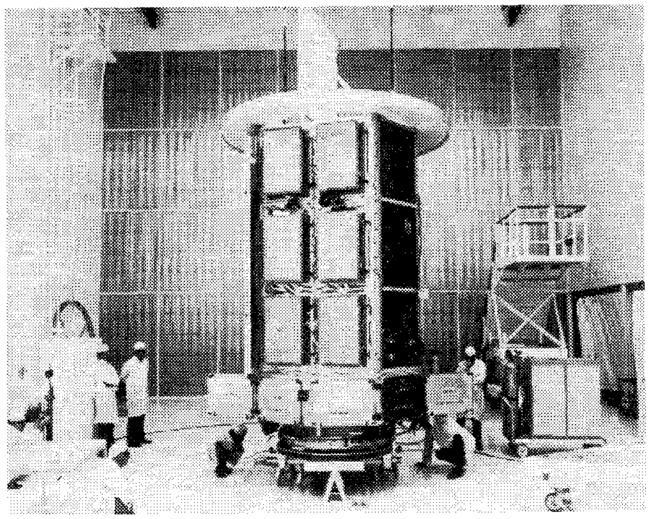

Fig. 15 High Energy Astronomical Observatory (HEAO A), assembly and testing.

orbiting satellites would be ideal observing platforms for astronomical telescopes because there is no atmosphere to absorb radiation and to disturb the images. Astronomers began early during the space program to prepare telescopes for rockets and satellites, and exciting results have been obtained from the beginning of these projects on OSO, OAO, UHURU, Skylab, and other flights. Almost 14 years ago, members of the Marshall Center proposed plans for an astronomical satellite that was to carry instruments for high-energy types of radiation, mainly UV, x-rays, and gamma rays. After some years of planning, the project developed into a well-organized NASA program of three vehicles, HEAO A, B, and C (see Fig. 14), to be launched in 1977, 1978 and 1979. Program management was assigned to the Marshall Center; members of the Goddard Space Flight Center shared the responsibility for the scientific program. HEAO A was launched in the summer of 1977, carrying four experiments to study UV and x-ray emissions from numerous sources in the sky. Figure 15 shows HEAO A during assembly and testing in the hangar. One of the four principal investigators is Herbert Friedman, still of the Naval Research Laboratory in Washington. Instead of a small Geiger counter with an active area of three square centimeters and an observing time of a few minutes, he prepared for this flight an array of Geiger counters covering several square meters, and he expects an active lifetime in orbit on the order of a year—an increase in sensitivity by a factor of two billion! HEAO A has now been in orbit for half a year; its instruments are performing admirably well, and there are many indications that the scientific yield of this project will be outstanding. HEAO A will show us an x-ray sky with a large number of distinct objects; it will give energy spectra of many of the x-ray and UV sources, and it will probably furnish a far better understanding of such exotic and mysterious objects as quasars and black holes.

The queen among all the space astronomy projects, though, is undoubtedly the Space Telescope, formerly called the Large Space Telescope or LST. Dreams of a large telescope in space had been familiar to astronomers ever since Hermann Oberth had mentioned its feasibility, and probably even earlier. When the first satellites proved that instruments could be launched into orbit and controlled to a high degree of accuracy for long periods of time, the dreams began to transform into reality. Professor Lyman Spitzer of Princeton University rallied many of his astronomy colleagues behind his proposal of a large space telescope. Herbert Friedman, Arthur Code, Leo Goldberg, Alan Sandage, Jesse Greenstein and many others gave it their wholehearted support. Members of the Marshall Center worked out plans of a telescope satellite that could carry a 3-m instrument and maintain an

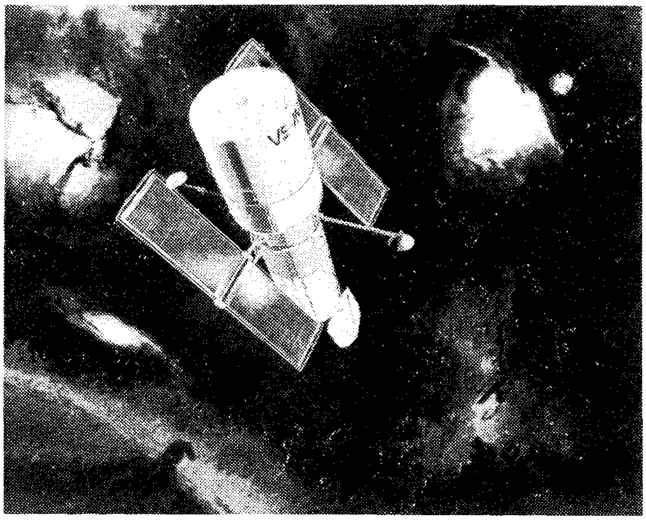

Fig. 16 Space Telescope in orbit.

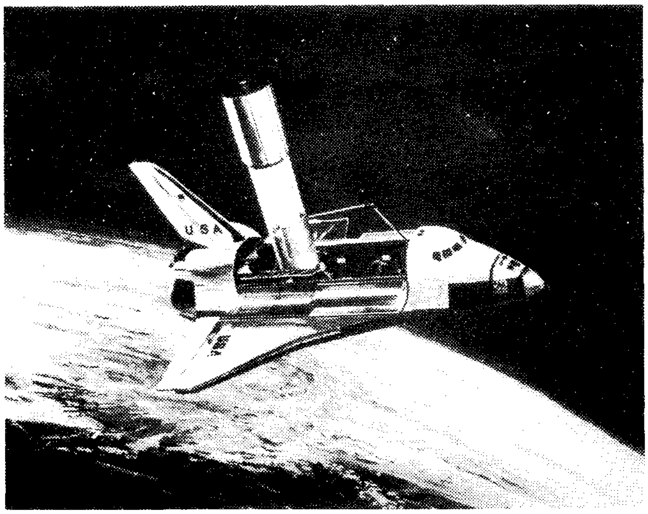

Fig. 18 Shuttle deployment of Space Telescope.

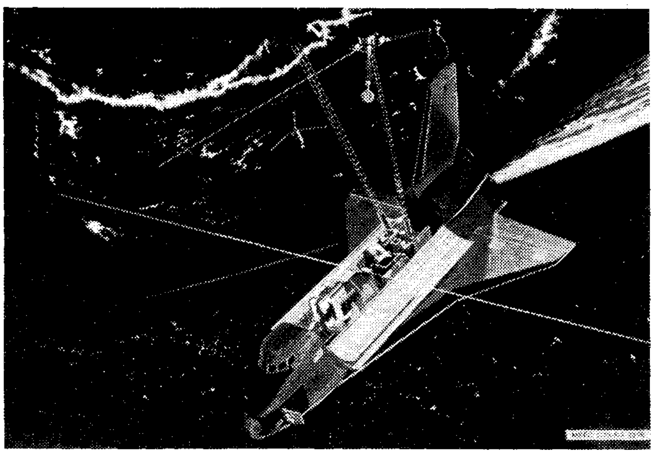

Fig. 17 Shuttle-Spacelab insturments for magnetospheric observations.

attitude stability commensurate with the optical capability of such an instrument; NASA supported the project by establishing a planning team with members from Headquarters, the Goddard Center, and the Marshall Center, and by stimulating many of the professional astronomers to support the project. The Marshall Center was assigned the role of overall project management. In 1972, the Center was fortunate enough to acquire as project scientist an astronomer of highest professional standing, Professor Charles R. O'Dell, Director of the Yerkes Observatory. He was promoted to Associate Director for Science at the Marshall Center in 1976. A very intense effort of planning, design, and experimentation during the past five years has resulted in a superb telescope project (Fig. 16). With a mirror of 2.4 m diameter, it will provide an optical resolution in the space environment which is about ten times finer than the best resolution obtainable on the Earth's surface. It will be able to detect astronomical objects about a hundred times fainter than the faintest objects visible from Earth, and it will be able to probe a volume of the universe which is about a thousand times larger than the volume in which we can detect and study objects from Earth. The angular stability of the telescope satellite is almost inconceivable. Imagine a lever of 10 km length, one end is fixed, the other end is moved by the thickness of a sheet of paper; this angular movement is all that will be permitted for the space telescope during a period of 1-2 hours! Instruments behind the mirror system will be designed to register very faint objects, to record the detailed structures of galaxies, quasars, and other extended objects, and to determine the spectral emissions of stars and other celestial objects from the far ultraviolet through the visible to the infrared region. Astronomers expect to acquire enough new knowledge through the space telescope to answer some of the most burning questions of modern science: What is the structure of the universe? Does it expand continuously or will it reverse its expanding trend from time to time? How do the quasars generate their unbelievably large amount of power? Do black holes exist and where are they? Even now, four years before the launching of the space telescope, there is a consensus among astronomers that this instrument, once it has begun its work in orbit, will change and enrich our understanding of the universe as much as Galileo's first telescope did 370 years ago.

Skylab, Viking, HEAO, and the Space Telescope have paralleled another project in the American space program which soon will introduce a most profound change in the character of space flight. All the rockets used for innumerable space launchings of past years had one feature in common—they could be used only once. The new project, the Space Shuttle, represents a reusable space transportation system. It will be launched into orbit as a rocket, and it will return to Earth as an airplane. After refurbishment, it will be ready for reuse.

The Shuttle will begin its operational phase in the early 1980's. Among the payloads planned for Shuttle-launches are scientific instruments for the observation of Earth and atmosphere; physics and biology experiments; systems for the production and processing of materials under weightlessness; prototypes of advanced systems for weather observations and for communications; probes for planetary and deep-space exploration; satellites for observations of the magnetosphere and of space radiations (Fig. 17); and, very importantly, the space telescope (Fig. 18). Once the space telescope has been launched, it will be visited by the Shuttle every few months for maintenance purposes.

This was a very condensed review of our first tentative steps into space during the past thirty years. Where will the next thirty years take us? We have gained a foothold in a new territory; we have begun to explore and to utilize; and we will most certainly continue the process of expanding our spheres of activity, and our horizon of knowledge, as man has always done ever since he made his appearance on this planet.