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Space Science, Space Technology and the Space Station

The space-station program will seriously diminish the opportunities for advancing space science and technology if it proceeds as planned. Most national goals in space are better realized by robot spacecraft

by James A. Van Allen

There is something about the topic of outer space that induces hyperbolic expectations. With no difficulty at all I can think of a billion-dollar space mission before breakfast any day of the week and a multibillion-dollar mission on Sunday. Ordinarily I do not inflict such visions on my fellow citizens, but I note that proposals of comparable or lesser merit and of much greater cost receive public attention, and some are influential in high circles of government. I submit that the proposed permanently manned space station is in this category.

A National Commission on Space, mandated by Congress and appointed by the president, has bravely undertaken to foresee the course of the U.S. space effort over the next 50 years. The commission's final report, to be released in March, will take it for granted that the space station will be operating in orbit within a decade, as President Reagan announced in his 1984 State of the Union message. According to the timetable of the National Aeronautics and Space Administration, the initial operations capability of the space station is to be achieved by 1993. Official estimates set its development costs at $8 billion in constant 1984 dollars, but the true costs will probably be many times that preliminary figure. There have been no announcements about the costs of operating and maintaining the station in orbit or about the costs of the equipment needed to make the station a useful facility for scientific and technical purpose.

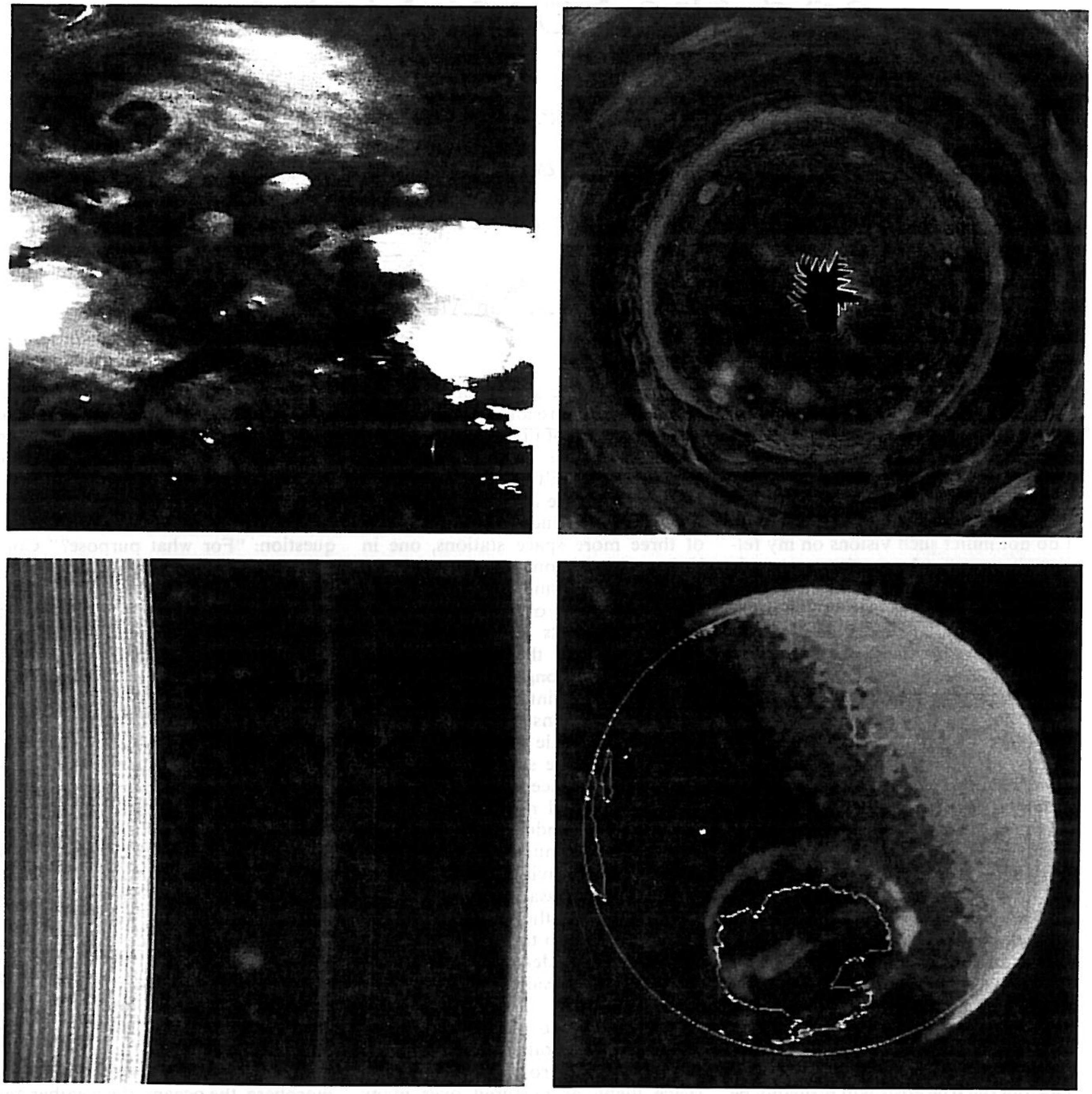
With the space station in place, the National Commission on Space envisions a number of options for building what it calls the "infrastructure required for the initial exploration and occupation of the inner solar system." The options include the construction of three more space stations, one in high earth orbit, one in lunar orbit and one in orbit around the planet Mars; the deployment of additional space stations in orbits around the earth-moon system or the earth-Mars system, to serve as long-range "buses" for earth-moon or interplanetary transport, and the construction of several vehicles to shuttle astronauts among the various space stations, moon and planets. The concept of a joint U.S.-U.S.S.R. manned mission to land on Mars has been endorsed by many officials both in and out of NASA. The presence of people living and working in space, with necessarily elaborate provisions made for their health and well-being, is common to all the major options being considered for recommendation to the president.

The acceptance of such grandiose proposals by otherwise rational individuals stems from the mystique of space flight, as nurtured over many centuries by early writers of science fiction and their present-day counterparts. Indeed, to the ordinary person space flight is synonymous with the flight of human beings. The simple taste for adventure and fantasy expressed in that sentiment has been elevated in some quarters to the quasi-religious belief that space is a natural habitat of human beings. According to this belief, the real goal of the space program is to establish "man's permanent presence in space," a slogan that does not respond to the simple question: "For what purpose?" Coupled with the public acclaim for the manned Apollo missions to the moon, this kind of advocacy has committed NASA to an overriding emphasis on the development of manned space flight: roughly two-thirds of the agency's funding is allocated to that objective.

The directions embodied in NASA's budgetary policy ignore the basic history of space flight: in the more than 28 years since the launching of *Sputnik I* the overwhelming majority of scientific and utilitarian achievements in space have come from unmanned, automated and commandable spacecraft. For example, the program of unmanned planetary exploration has been brilliantly successful and has made immense contributions to human knowledge. Robot satellites in earth orbit have revolutionized global communications and navigation, and they have yielded fundamental advances in our understanding of the atmosphere, the oceans, the weather and the distribution of natural resources. Finally, they have enhanced national security by making it possible to monitor military activities abroad.

Let me make it clear that I have no hesitation in granting the technical feasibility of a space station or of a system of space stations, given adequate resources for the purpose. Furthermore, I have no doubt that significant uses of space stations can be identified. The issue is not a technical one, however; the space-station program will consume a major fraction of the resources available for our national space activities. The plans for a space station therefore raise basic questions about the economic, political and cultural objectives of the U.S. in space.

Space science and technology are now mature enough to allow a competent, well-defined and realistic selection of goals and the assignment of well-reasoned priorities among them. Then and only then is it sensible to consider the best technical means for achieving these goals, the appropriate time scales and the necessary resources. As I see it, the primary goals of the space program include strictly utilitarian objectives, whose costs and ben-



DETAILED IMAGES of the distant planets betoken the accomplishments of the unmanned, scientific space program. The image at the upper left shows a storm on Mars; it was transmitted by the *Viking Orbiter 1* spacecraft and processed in false colors to highlight the details of the storm. At the upper right is an image of Jupiter, which has been constructed by a computer from data transmitted by the *Voyager 1* spacecraft to show the planet as it would appear from directly above its south pole; no spacecraft has ever made a real photograph of Jupiter from that vantage. There is no photographic data from the black, irregular region at the pole. The bright red band in the false-color image at the lower left is a thin ring in the Encke division in the outer main ring (ring *A*) of Saturn; the data for the computer-generated image were gathered by a photopolarimeter aboard the *Voyager 2* spacecraft, which recorded the occultation of starlight passing through the rings. In the image at the lower right the theta-aurora of the earth is shown as a yellow ring and crossbar, on which the outline of Antarctica has been superposed. The image was transmitted by the *Dynamics Explorer 1* satellite. The first three images were prepared by the Jet Propulsion Laboratory and are shown courtesy of the IBM Gallery of Science and Art in New York City. The image of aurora over Antarctica is shown courtesy of Louis A. Frank of the University of Iowa.

efits are relatively easy to determine, and cultural objectives, whose costs and benefits are harder to calculate.

One category of utilitarian objectives is the set of military applications that are deemed to be in the national interest. A second category includes civil applications of space technology that either are in the national interest as public services or are capable of paying for themselves in the marketplace. As for the cultural objectives, it seems reasonable to grant that there is value to the shared, vicarious sense of adventure that was generated by the Apollo program and similar efforts. Such a social sense can therefore probably be counted as a cultural objective. By the same token, one must grant that the conduct of scientific observations and experiments in space, without any guarantee that they will pay off in useful technology, is a legitimate cultural objective. Of course, purely scientific activity almost always yields practical applications, some of consummate importance, and so there is no implied assumption in classifying science as a cultural objective that it will not turn out to have quantifiable, utilitarian benefits as well.

Because the space program was primarily military in its inception, it seems appropriate to begin with this set of utilitarian objectives. The military applications of the space program can be further classified as defensive and offensive. Up to now, I am happy to say, the defensive applications have dominated, thanks in no small part to a succession of treaties and United Nations resolutions on the peaceful uses of outer space. Such defensive functions include worldwide reconnaissance and surveillance, oceanography, geodesy, communications, meteorology and navigation.

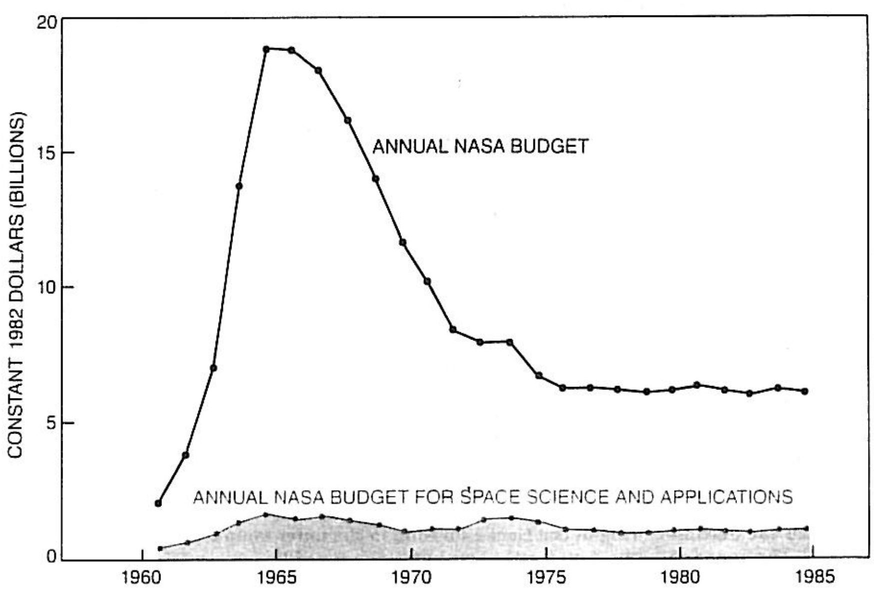
There is some persuasion to the argument that high-quality, reciprocal reconnaissance by all potential adversaries diminishes world tension: by providing advance notice of military deployments it reduces the element of surprise and buys time for intensified negotiation. The logical extension of this line of thought is that the U.S., the U.S.S.R. and the People's Republic of China should operate a joint reconnaissance program so that all observations and their interpretation would be shared. Such an arrangement would make the entire matter an academic exercise and give to warfare the aura of futility it richly deserves in the contemporary world. Military activities in space have been carried out almost exclusively by unmanned satellites, and there is every reason to think this will continue to be the case.

Yet advocates of manned missions in space argue that only a manned spacecraft makes it possible to repair robot satellites in orbit or to replace all or some of their parts. The argument attacks a straw man. Many unmanned spacecraft now deployed have expected operating lifetimes of 10 years or more, and they incorporate automatic or commandable redundancy to help ensure their longevity. Moreover, the technical obsolescence of most flight equipment over a period of 10 years makes repair or refurbishment in orbit a capability that has little or no economic justification.

Offensive military deployments in space, such as antisatellite weapons, pose deep questions of national purpose that lie mostly outside the scope of this article. Whether or not one shares my belief that the calls for a military buildup in space are to be deplored, one may see in such a buildup a potential for growth that would remove the basis for my concerns about science and the space station. Thus, goes the argument, however regrettable you may find the military buildup, the tradeoff is that under the comparative largesse of the military umbrella you can have a manned space station and a vigorous, unmanned scientific space program as well.

At first glance the point has considerable force. For those of us who remember the national trauma following the successful launching of the first Soviet satellite in October, 1957, there is little doubt that the military uses of space have provided the most powerful incentives for our subsequent effort. Indeed, President Lyndon Johnson once said that the benefits of the U.S. system of satellites for military reconnaissance had more than paid for the entire national program in space. Nevertheless, citing such statements in the present context ignores the changes in military-funding policies that have been mandated by Congress since the early 1970's. The Department of Defense must now adhere to a relatively narrow definition of what constitutes its mission: much of the loss in support from the Department of Defense for the basic sciences in the early 1970's can be traced to this evolution of policy. In justifying its expenditures the Department of Defense is unlikely to squander its credibility before Congress by supporting huge undertakings that are not manifestly in defense interests. I suspect that neither the space station nor many of the scientific interests with which it competes will receive any significant subsidies from the Defense Department budget.

One is left, therefore, to consider the objectives in space that are not overtly military in nature. The history of the civil space program in the U.S. shows that following the peak in funding generated by the Apollo program in the mid-1960's, appropriations fell by



ANNUAL BUDGET for the National Aeronautics and Space Administration in constant 1982 dollars is plotted on the graph in black; the budget for space science and applications is superposed on the graph in color. NASA's greatest spending took place in the mid-1960's, during the development of the manned Apollo missions to the moon. The growth of space science and applications in that period did not keep pace with the growth in the manned space program. Since then the overall NASA budget has fallen to about a third of its peak value, and about 15 percent of the total has been allocated to science and applications.

a factor of three in constant dollars. Since that drop more than a decade ago the funding has remained essentially constant. One may wish that it were otherwise, as I do, but the present level of Federal support has been established by our complex social and political processes, and it is difficult, if not impossible, to responsibly foresee any sizable increase in it in real dollars in the next decade. Conversely, it is reasonable to expect that the funding level in constant dollars will not shrink significantly in the near term.

Thus it appears that the U.S. has achieved an approximate equilibrium between advocates and skeptics as to the proper overall level of our national civil space effort. I shall therefore adopt the assumption of an essentially constant level of such funding for the next decade as basic to my discussion. What this means is that establishing the national priorities in space in the civil sector is a zero-sum game: any increase in one element of the NASA budget must inevitably result in an equal decrease somewhere else.

A second major category of national objectives in space is the development of space technology, including the space station and the other "infrastructure" referred to by the National Commission on Space. Advocates of the manned space station often act pained and perplexed when budgetary constraints are invoked. Do we—that is, I and those of my colleagues who are members of the "loyal opposition"—not realize that once the space station is in place the costs and effort required for commercial and scientific objectives will be reduced dramatically? Are we not aware of the so-called coattail effect, whereby the manned space program allegedly builds up enough momentum in the national space program to carry along all the other projects? Have we become so enamored of the capabilities of commandable spacecraft that we have ignored the fact that a man in space can carry out these tasks more efficiently and with less effort?

To answer these questions the history of the space program, and particularly that of the Space Transportation System, would seem to be a more reliable guide than the promises and forecasts made by interested parties. The present Space Transportation System includes a fleet of four manned, orbiting space shuttles, each of which is in essence a high-velocity aircraft and spacecraft that is launched by rockets, flies in low-altitude orbit about the earth, reenters the earth's atmosphere on command and lands on a very long airstrip. The development and initial operation of the Space Transportation System has cost American taxpayers about $30 billion to date, with much smaller but still substantial contributions from European nations through the European Space Agency. The four shuttles in the current U.S. fleet were and still are conceived as service vehicles for the space station, and so it is appropriate to consider the shuttle as a key element in the U.S. manned space program for the next 20 years.

The space shuttle represents the natural aspiration of aeronautical engineers to push the state of their art to its limits. Although I heartily applaud its impressive technical successes, I find the economic justification for building it to be quite unpersuasive, and I have so testified to the Office of Technology Assessment and to a succession of congressional committees beginning in 1971. Those of us who were on the losing side of the debate in the early 1970's as to the wisdom of developing the shuttle have no difficulty remembering the claims then being made. In brief, our opponents argued that the

Fully commercial applications
Worldwide network of satellite relays in synchronous orbits for transmission of television broadcasts, telephone and telegraphic messages and data. Operated by COMSAT, INTELSAT and private corporations
Military applications
Worldwide network of telecommunication satellites in synchronous and intermediate-altitude orbits
Worldwide network of Transit and Global Positioning System satellites for navigational purposes. Current accuracy to within 30 meters at any point on or in the vicinity of the earth. Potential accuracy to within one cêntimeter. Lower accuracy system also available for civil purposes
Networks of reconnaissance and surveillance satellites
Networks of meteorological satellites
Partly commercial and partly Governmental civil applications
Meteorological satellites for surveying and forecasting current global weather
Landsat and other satellites for survey of mineral resources, vegetation, icebergs, snow cover, water resources, water pollution, health of crops and geological features and for mapping
Scientific investigations and achievements
Electromagnetic and corpuscular classes of radiation from the sun and their effects on the earth
Dynamics of the solar atmosphere
In situ measurements of charged-particle populations and magnetic and electric fields in the ionospheres, the radiation belts and the magnetospheres of the earth, Mercury, Venus, Mars, Jupiter and Saturn
Plasma physical effects associated with natural and artificial comets
Geological surveys of the moon, the earth, Mercury, Venus, Mars, the satellites of Mars, Jupiter and Saturn
Closeup study of the rings of Jupiter and Saturn
Precise characterization of external magnetic fields of the moon, the earth, Mercury, Venus, Mars, Jupiter and Saturn
Detailed study of the structure, composition and dynamics of the earth's atmosphere and exploratory study of the atmospheres of Venus, Mars, Jupiter, Io, Saturn and Titan
Precise characterization of the external gravitational fields of the moon and the earth
Comprehensive observation of the solar wind and of shock waves, energetic solar particles and galactic cosmic rays in interplanetary space out to a distance of 3.4 billion miles from the sun and continuing outwards
Comprehensive surveys of stellar and planetary sources of gamma rays, X rays and ultraviolet, infrared and radio-frequency radiation and the detailed spectral study of selected sources
Marked advances in understanding the origin and evolution of the solar system and of stars and galaxies
Significant contributions to fundamental plasma physics and its role in planetary and astrophysical systems
Study of ocean currents and the global dynamics of the oceans
Negative evidence on the past or present existence of living organisms on the surface of Mars

MAJOR ACCOMPLISHMENTS of the unmanned space program are summarized in the table. They include commercial and military applications of space technology, civil applications that are partly public and partly commercial and many scientific accomplishments.

shuttle would supplant all expendable launch vehicles, such as the Scout, Delta, Atlas and Titan rockets, and that by the early 1980's there would be 50 shuttle flights per year. Each flight would deliver 50,000 pounds into low earth orbit at a cost of $100 per pound. Of the 50 annual flights at least four would carry spacecraft for the exploration of other planets.

There is a striking disparity between those claims and the present situation. In 1985 only 10 shuttle flights were carried out at a true launching cost of at least $5,000 per pound, or about $2,000 per pound in 1971 dollars, a figure 20 times greater than the original estimate. No planetary spacecraft has been launched in the four years of shuttle operations.

The source of the disparity between promise and realization can be traced to NASA's gross underestimate of developmental costs and its gross overestimate of the space traffic that could reasonably be expected aboard the shuttle. As a result NASA made a wildly overoptimistic estimate of the cost-effectiveness of the shuttle compared with that of the existing expendable launch vehicles or their evolutionary descendants. I see no reason to be any more confident about NASA's economic forecasts for the space station.

There is another reason to doubt NASA's assurances that the space station will make it easier to carry out other national objectives in space. In the summer of 1981, faced with serious delays and major cost overruns on the shuttle, NASA decided that development of the shuttle must proceed, come what might to other ongoing projects. The result was a "slaughter of the innocent": massive cuts, postponements and cancellations of dozens of programs, many of which were already in advanced stages.

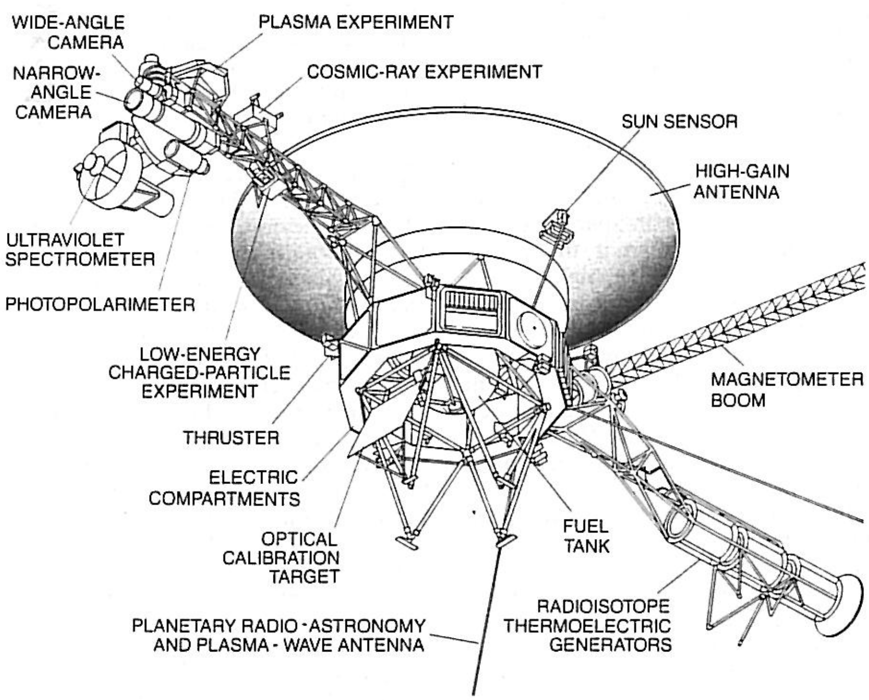
For example, the shuttle forced the cancellation of the U.S. member of a pair of complementary spacecraft for the International Solar Polar Mission. The surviving member of the pair, now known as *Ulysses*, was developed by the European Space Agency with the participation of some U.S. scientists and will be launched in May after a delay of approximately two years. Well-developed plans for a U.S. mission to encounter Comet Halley and subsequently to rendezvous with Comet Tempel II were also abandoned because of the shuttle. The major mission to the planet Jupiter known as *Galileo* was canceled for a time because of shuttle funding allocations, and although the mission was later reinstated, the shuttle is largely responsible for its three-year delay.

NASA's single-minded devotion to the space shuttle went unchecked for the first eight months of the Reagan Administration, and when the president finally appointed his own NASA administrator, the cuts were so deep that many of them had to be rescinded. Among other projects NASA had threatened were the worldwide Deep Space Network for tracking and receiving data from planetary missions; the ongoing reception of data from the planetary probes *Pioneer 10* and *Pioneer 11;* the reception of data from the *Pioneer Venus 1;* NASA's Infrared Observatory at Mauna Kea in Hawaii; the reception of data from the deep-space missions of *Voyager 1* and *Voyager 2;* the reception of data from the earth-orbiting satellites *IMP-7* and *IMP-8*, and the plans for further missions to Venus and Mars. In addition the shuttle caused a slowdown in the development of a gamma-ray observatory, substantial reductions in the funding of supportive space science and technology in the universities, the elimination of the office for solar-terrestrial physics programs at NASA's headquarters, the indefinite postponement of new solar-terrestrial and atmospheric research satellites in earth orbit and the indefinite postponement of the development of advanced communications technology. Finally, the provisions for developing significant scientific payloads to be flown on the shuttle are meager.

Two more arguments are sometimes advanced by the proponents of the manned space program and these must be addressed. One argument is a peculiar reading of the history of the space program that I referred to above as the coattail effect. According to this view, the entire program of space science for the past three decades would have either been nonexistent or run on a very small scale had it not been for the manned program. This assertion is impossible to either prove or disprove; one cannot rerun history with different boundary conditions. Nevertheless, I can offer several reasons for doubting the assertion.

In 1946 the U.S. began a vigorous and successful program of high-altitude rocket flights carrying scientific instruments. The work was given much impetus during the International Geophysical Year in 1957–58, and it served as the technical and scientific basis for all the subsequent advances in the scientific and utilitarian use of earth satellites and interplanetary and planetary spacecraft. The major period of growth in these fields coincided with the Apollo program, but in my view neither set of activities depended to any important extent on the other.

Both the scientific activities and the Apollo program took place in an optimistic, expansionist epoch in national and international history, as did all kinds of other scientific activities unrelated to space. Many other major research agencies of the Federal Gov-



***VOYAGER 2* spacecraft is shown schematically. It has already probed Jupiter, Saturn and their systems of satellites and rings; this month it will be the first spacecraft to encounter the planet Uranus. The author served as chairman of the committee that developed the mission.**

ernment have grown to a sustained level of support comparable to that of the research component of NASA without the benefit of huge, public spectaculars; examples include the National Institutes of Health, the National Science Foundation, the U.S. Geological Survey, the Department of Energy and the National Oceanic and Atmospheric Administration.

The second argument often put forward in favor of a manned space program is that a person in a spacecraft is superior to any conceivable machine because of judgment, resourcefulness, flexibility and the like. If one considers the complexity and sophistication of modern space equipment and the ready control of such equipment by command from earthbound stations, such an argument has very limited validity.

My own feelings about this issue are aptly expressed by a story from the early development of large balloons and manned balloon flight. At that time, about 30 years ago, there were advocates of the idea that a large network of manned balloons should be maintained and continually replenished for the purpose of observing both natural and artificial activities on the earth. The classic comment on ideas of this nature was made by Edward P. Ney of the University of Minnesota, who was one of the pioneers in the use of balloons for scientific purposes. Ney had given a public lecture on some of his work in the late 1950's. In the ensuing discussion period a member of the audience stood up to ask a question. "Professor Ney, please tell me: Is there anything a man can do in a balloon gondola that an instrument cannot?" Ney's answer, after only a moment's hesitation, was, "Yes, there is. But why would anyone wish to do it at such a high altitude?"

INTERNATIONAL SOLAR POLAR MISSION (U.S. SATELLITE OF PROPOSED PAIR)	CANCELED
U.S. MISSION TO COMET HALLEY	CANCELED
GALILEO PROBE TO JUPITER	CANCELED (LATER RESCINDED)
DEEP SPACE NETWORK FOR TRACKING PLANETARY MISSIONS	THREATENED CLOSING
DATA RECEPTION FROM *PIONEER 10* AND *11*	TERMINATED (LATER PARTLY RESCINDED)
DATA RECEPTION FROM *PIONEER VENUS 1*	TERMINATED (LATER PARTLY RESCINDED)
INFRARED OBSERVATORY AT MAUNA KEA, HAWAII	CLOSED (LATER RESCINDED)
DATA RECEPTION FROM *VOYAGER 1* AND *2*	CUT BACK (LATER PARTLY RESCINDED)
DATA RECEPTION FROM *IMP-7* AND *IMP-8*	TERMINATED (LATER PARTLY RESCINDED)
LANDSAT PROGRAM	CUT BACK
GAMMA-RAY OBSERVATORY	DELAYED SEVERAL YEARS
PLANNED MISSIONS TO VENUS AND MARS	CANCELED (REVIVED IN REDUCED FORM AFTER DELAYS OF SEVERAL YEARS)
SUPPORTING UNIVERSITY RESEARCH	CUT BACK
NASA OFFICE FOR SOLAR-TERRESTRIAL PHYSICS PROGRAMS	CLOSED
PLANNED SOLAR-TERRESTRIAL AND ATMOSPHERIC RESEARCH SATELLITES	INDEFINITELY POSTPONED
SCIENTIFIC PAYLOADS ABOARD SPACE SHUTTLE	INADEQUATELY PROVIDED FOR
ADVANCED COMMUNICATION TECHNOLOGY	INDEFINITELY POSTPONED

"SLAUGHTER OF THE INNOCENT" was the result of the decision made by NASA in 1981 to proceed with the development of the space shuttle over all other projects. The table summarizes the effects of the decision. Some of the program cuts have since been rescinded, but the effect has been a severe chill on scientific and other civilian activities in space.

The burden of experience is that, apart from serving the spirit of adventure, there is little reason for sending people into space. On the contrary, there are strong reasons for keeping operating personnel on the earth. The life-support systems and the overriding concern for the safety of personnel in any manned space mission are extremely costly and restrictive. Moreover, most space missions of scientific or utilitarian importance require high earth orbits, lunar orbits, interplanetary orbits or planetary orbits that involve months or years of in-flight operation. Such missions will be inaccessible to manned spacecraft for many years to come.

Some experiments one would like to carry out in space require highly stable platforms and the accurate aiming of scientific instruments, and so they must be free of vibrations and accelerations. An astronaut's sneeze could wreck a sensitive experiment in a microgravitational field; clouds of gas or droplets from thrusters of the spacecraft or from dumps of water or urine ruin the local vacuum and optical observing conditions, and complex magnetic and electric fields associated with manned spacecraft preclude certain kinds of radio observations.

The simplest repair and refurbishment of equipment in space requires heroic measures, even if the equipment is accessible. The high cost of such "space rescues" casts grave doubt on their economic viability. Moreover, it is much harder and more expensive to design and build space equipment in such a way that it can be repaired and refurbished in space than it is to build equipment that need not meet such specifications.

Inside a spacecraft the working conditions for people are extremely restrictive and the resources available for experimental work are limited. Simple functions that can be carried out by a skilled technician are all that can be expected, whereas all the real sophistication and resourcefulness of an in-flight experiment must be exercised by radio command or built into the equipment before the flight, just as they are in a robot spacecraft. Nearly all investigations can be monitored and controlled much more effectively by people on the ground, who are working under far more comfortable and efficient conditions and with easy access to all the resources available there. Finally, the apparatus in an unmanned spacecraft does not get tired, it is free of human contamination and it is not subject to the kind of human error that can result from onboard manipulation.

All the foregoing leads one to conclude that the development of advanced technology for launching and maintaining people in space is a goal largely independent of other legitimate national objectives in outer space. There is a large and diverse body of other civil applications of space technology that deserve consideration on their own merits. Foremost among such applications is worldwide telecommunications by satellite relays. More than half of all transoceanic communications go by way of satellite relays, and this capability is being continually expanded. Furthermore, domestic communications in far-flung countries such as Canada and Indonesia have been revolutionized by satellite methods.

Some 20 years ago I was among those who expressed great hope that satellite communications would be employed in worldwide educational efforts, particularly within developing countries. The hope was based on the recognition that substantial benefits to shuttle would supplant all expendable launch vehicles, such as the Scout, Delta, Atlas and Titan rockets, and that by the early 1980's there would be 50 shuttle flights per year. Each flight would deliver 50,000 pounds into low earth orbit at a cost of $100 per pound. Of the 50 annual flights at least four would carry spacecraft for the exploration of other planets.

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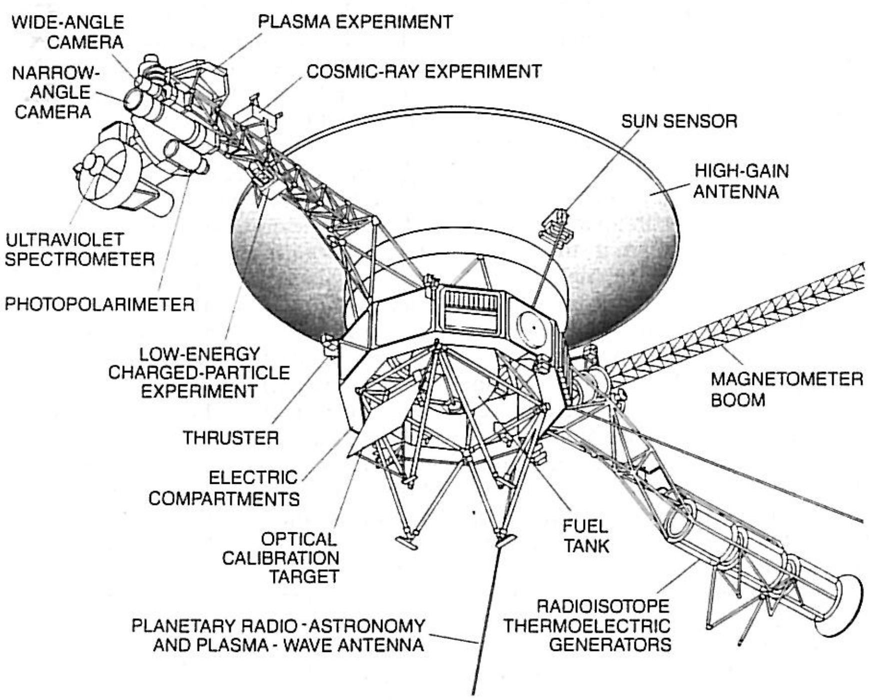

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ernment have grown to a sustained level of support comparable to that of the research component of NASA without the benefit of huge, public spectaculars; examples include the National Institutes of Health, the National Science Foundation, the U.S. Geological Survey, the Department of Energy and the National Oceanic and Atmospheric Administration.

The second argument often put forward in favor of a manned space program is that a person in a spacecraft is superior to any conceivable machine because of judgment, resourcefulness, flexibility and the like. If one considers the complexity and sophistication of modern space equipment and the ready control of such equipment by command from earthbound stations, such an argument has very limited validity.

My own feelings about this issue are aptly expressed by a story from the early development of large balloons and manned balloon flight. At that time, about 30 years ago, there were advocates of the idea that a large network of manned balloons should be maintained and continually replenished for the purpose of observing both natural and artificial activities on the earth. The classic comment on ideas of this nature was made by Edward P. Ney of the University of Minnesota, who was one of the pioneers in the use of balloons for scientific purposes. Ney had given a public lecture on some of his work in the late 1950's. In the ensuing discussion period a member of the audience stood up to ask a question. "Professor Ney, please tell me: Is there anything a man can do in a balloon gondola that an instrument cannot?" Ney's answer, after only a moment's hesitation, was, "Yes, there is. But why would anyone wish to do it at such a high altitude?"

INTERNATIONAL SOLAR POLAR MISSION (U.S. SATELLITE OF PROPOSED PAIR)	CANCELED
U.S. MISSION TO COMET HALLEY	CANCELED
GALILEO PROBE TO JUPITER	CANCELED (LATER RESCINDED)
DEEP SPACE NETWORK FOR TRACKING PLANETARY MISSIONS	THREATENED CLOSING
DATA RECEPTION FROM *PIONEER 10* AND *11*	TERMINATED (LATER PARTLY RESCINDED)
DATA RECEPTION FROM *PIONEER VENUS 1*	TERMINATED (LATER PARTLY RESCINDED)
INFRARED OBSERVATORY AT MAUNA KEA, HAWAII	CLOSED (LATER RESCINDED)
DATA RECEPTION FROM *VOYAGER 1* AND *2*	CUT BACK (LATER PARTLY RESCINDED)
DATA RECEPTION FROM *IMP-7* AND *IMP-8*	TERMINATED (LATER PARTLY RESCINDED)
LANDSAT PROGRAM	CUT BACK
GAMMA-RAY OBSERVATORY	DELAYED SEVERAL YEARS
PLANNED MISSIONS TO VENUS AND MARS	CANCELED (REVIVED IN REDUCED FORM AFTER DELAYS OF SEVERAL YEARS)
SUPPORTING UNIVERSITY RESEARCH	CUT BACK
NASA OFFICE FOR SOLAR-TERRESTRIAL PHYSICS PROGRAMS	CLOSED
PLANNED SOLAR-TERRESTRIAL AND ATMOSPHERIC RESEARCH SATELLITES	INDEFINITELY POSTPONED
SCIENTIFIC PAYLOADS ABOARD SPACE SHUTTLE	INADEQUATELY PROVIDED FOR
ADVANCED COMMUNICATION TECHNOLOGY	INDEFINITELY POSTPONED

"SLAUGHTER OF THE INNOCENT" was the result of the decision made by NASA in 1981 to proceed with the development of the space shuttle over all other projects. The table summarizes the effects of the decision. Some of the program cuts have since been rescinded, but the effect has been a severe chill on scientific and other civilian activities in space.

The burden of experience is that, apart from serving the spirit of adventure, there is little reason for sending people into space. On the contrary, there are strong reasons for keeping operating personnel on the earth. The life-support systems and the overriding concern for the safety of personnel in any manned space mission are extremely costly and restrictive. Moreover, most space missions of scientific or utilitarian importance require high earth orbits, lunar orbits, interplanetary orbits or planetary orbits that involve months or years of in-flight operation. Such missions will be inaccessible to manned spacecraft for many years to come.

Some experiments one would like to carry out in space require highly stable platforms and the accurate aiming of scientific instruments, and so they must be free of vibrations and accelerations. An astronaut's sneeze could wreck a sensitive experiment in a microgravitational field; clouds of gas or droplets from thrusters of the spacecraft or from dumps of water or urine ruin the local vacuum and optical observing conditions, and complex magnetic and electric fields associated with manned spacecraft preclude certain kinds of radio observations.

The simplest repair and refurbishment of equipment in space requires heroic measures, even if the equipment is accessible. The high cost of such "space rescues" casts grave doubt on their economic viability. Moreover, it is much harder and more expensive to design and build space equipment in such a way that it can be repaired and refurbished in space than it is to build equipment that need not meet such specifications.

Inside a spacecraft the working conditions for people are extremely restrictive and the resources available for experimental work are limited. Simple functions that can be carried out by a skilled technician are all that can be expected, whereas all the real sophistication and resourcefulness of an in-flight experiment must be exercised by radio command or built into the equipment before the flight, just as they are in a robot spacecraft. Nearly all investigations can be monitored and controlled much more effectively by people on the ground, who are working under far more comfortable and efficient conditions and with easy access to all the resources available there. Finally, the apparatus in an unmanned spacecraft does not get tired, it is free of human contamination and it is not subject to the kind of human error that can result from onboard manipulation.

All the foregoing leads one to conclude that the development of advanced technology for launching and maintaining people in space is a goal largely independent of other legitimate national objectives in outer space. There is a large and diverse body of other civil applications of space technology that deserve consideration on their own merits. Foremost among such applications is worldwide telecommunications by satellite relays. More than half of all transoceanic communications go by way of satellite relays, and this capability is being continually expanded. Furthermore, domestic communications in far-flung countries such as Canada and Indonesia have been revolutionized by satellite methods.

Some 20 years ago I was among those who expressed great hope that satellite communications would be employed in worldwide educational efforts, particularly within developing countries. The hope was based on the recognition that substantial benefits to mankind can result even from the spread of simple literacy and a knowledge of basic arithmetic. In 1974 an Advanced Technology Satellite in synchronous orbit was assigned to deliver elementary educational materials in India on an experimental basis. In all technical respects the experiment was an unqualified success, but there are still many thorny cultural, sociological and political issues to resolve.

Telecommunications is the only application of space technology that has achieved economic viability, in the sense that the direct beneficiaries ask for certain services and both voluntarily and consciously pay their full costs. Thus I distinguish between the market support of a commercial service and the taxpayer support of a government service in the public interest. The future growth rate of satellite communications will be determined by market forces, at least in the short term, although eventually there will be technical limits to that growth.

Some planners envision a gradual transfer of most domestic communications within the U.S. to satellite systems. At the same time there are immensely promising developments in the transmission of information by modulated beams of laser light carried by optical fibers. Tens of thousands of miles of optical fibers are already installed between cities in the U.S., and a transatlantic cable of optical fibers is under construction. Optical-fiber carriers may therefore come to dominate high-traffic communications between fixed points in the next 20 years, and so they may limit or slow the growth of corresponding techniques in space. Of course, optical fibers cannot be used for communications to or from mobile stations, such as aircraft in flight and ships at sea. All these matters are under continuous engineering study by many private corporations and government agencies in Europe, Japan, the U.S. and, undoubtedly, the U.S.S.R. A proper role for NASA in this field is to conduct advanced research and contribute to the development of hybrid communications systems.

The other principal civil application of space technology comes under the generic term remote sensing. Remote sensing includes not only ordinary photoreconnaissance, including what have become routine forecasts of the weather on a worldwide scale, but also the imaging of the earth's surface and atmosphere over a broad range of electromagnetic frequencies. There have been exquisite instrumental developments in the field, and it is now possible to choose well-defined frequency bands of radiation in the radio, infrared, visible, ultraviolet and X-ray portions of the electromagnetic spectrum. For example, the two automated satellites *Landsat 4* and *Landsat 5* carry instruments called thematic mappers, which map radiation emissions from the earth's surface in several frequency bands that are important to geologists in their search for worldwide mineral resources.

Such applications of remote sensing yield substantial public and private benefits, but they still have not met the crucial test of full commercial success. The Landsat program, for example, operates under the Department of Commerce as a data-service agency to industry and to other Government agencies, but it is heavily subsidized by the Government. Virtually the entire field of remote sensing, as well as the many other useful applications of space technology such as surveying and aircraft and marine navigation, remains in the realm of Government services. As such, they are all exposed to budget cuts caused by reallocations of funding to the manned space program; indeed, the Landsat program has suffered severely for precisely this reason.

Ironically, far more tenuous proposals are put forward as justifications for building the shuttle and the space station. One example is the processing of materials in space; for example, it has been widely advertised that the microgravitational environment of space can be exploited to grow large crystals of ultrahigh purity or to refine pharmaceuticals on a commercially viable scale. Objective studies of this subject by the National Research Council and other agencies do not support such sanguine expectations. The studies review the relatively meager results in the field to date and endorse the validity of further exploratory investigation. Nevertheless, they conclude that the prospects for viable commercial applications have as yet no convincing foundation commensurate with the costs of space flight.

Another proposal that has been given much public exposure is the solar-power satellite. The satellite is envisioned as a solar-power collector, some 20,000 acres in area, that would be assembled in earth orbit. Microwave beams would transmit the solar energy to receivers at stations on the earth, which would deliver the energy over conventional power lines. I am gratified to learn that the voice of sanity has placed this proposal in limbo. Former senators James G. Abourezk (D—S.D.) and Floyd K. Haskell (D—Colo.) have pointed out that the estimated cost of one such satellite would be equivalent to the cost of providing every U.S. household with a simple solar-energy collector that would meet 65 percent of its energy needs.

These two examples, space manufacturing and the solar-power satellite, are leading elements in forecasts of an explosive rate of growth in space traffic. I am not so foolish as to suggest that such undertakings are totally out of the question at some time in the remote future. Not one of them, though, withstands critical scrutiny in the context of the 20th century, and their ratio of cost to benefit may never be less than unity.

The two major cultural objectives of the U.S. in space demand quite different consideration. The first is the realization of a kind of collective human adventure. Popular interest in real—as opposed to fictional—space activity was highest during the first manned landing on the moon in July, 1969. In subsequent years the role of the space program in creating vicarious adventure has dwindled markedly, having been supplanted to a considerable extent by the romance of motion pictures depicting far more dramatic exploits. The American public has now spent more than $200 million to see *Star Wars* and hundreds of millions of dollars more to see its derivative successors; the total is about the sum needed to carry out a major planetary mission. I draw no moral from these facts, but I do consider them a point of reference concerning the public motivations for manned space flight.

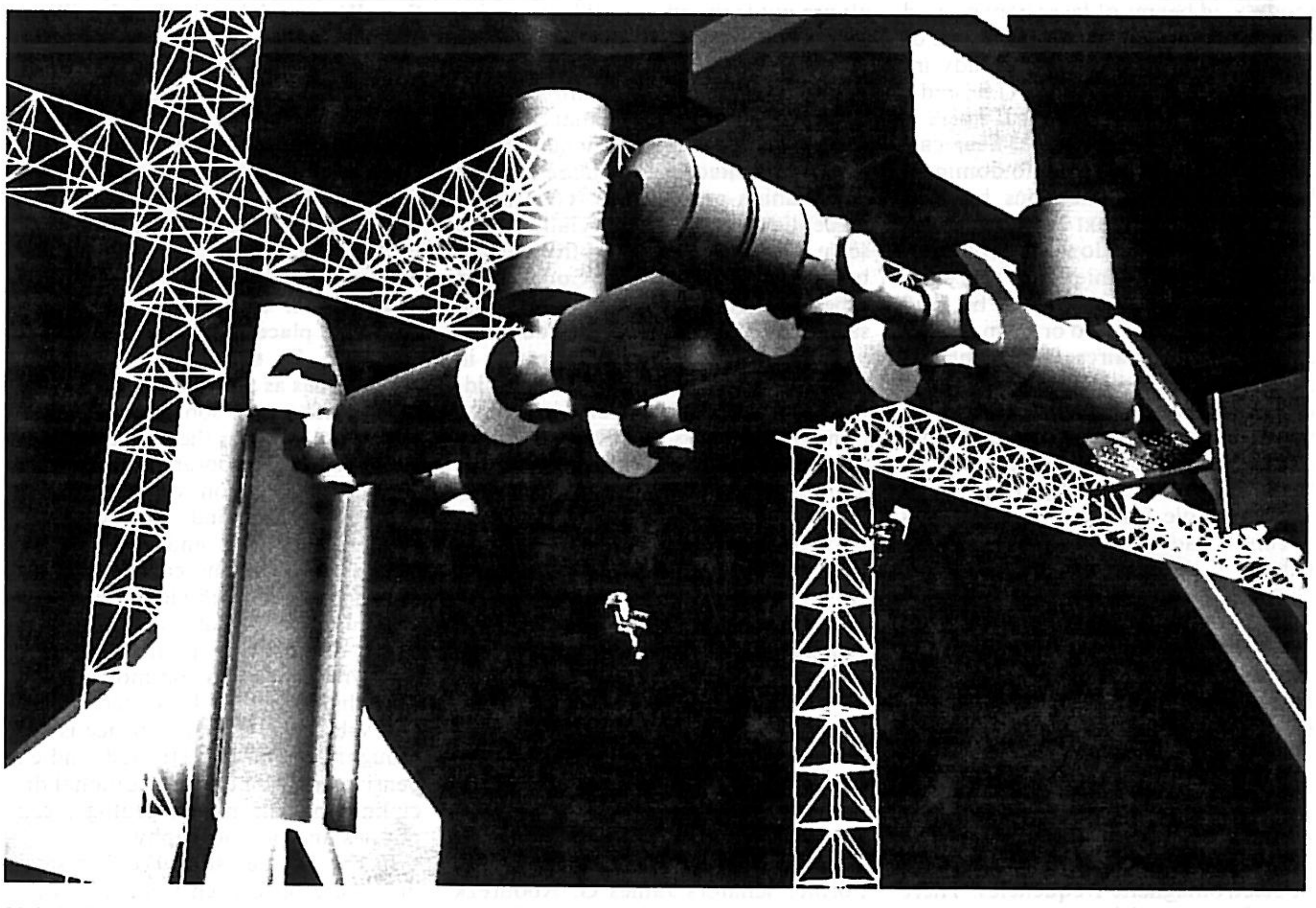
The second cultural objective in space is the conduct of space science. A possible definition of the term is the investigation of natural phenomena that take place above the surface of the earth. By this definition astronomy qualifies as the most ancient of the space sciences. A somewhat different definition, which is the one usually intended by contemporary practitioners, is the investigation of phenomena, both terrestrial and extraterrestrial and both natural and artificial, by means of apparatus carried aloft in rocket-propelled vehicles. Thus space science is not a clearly delineated scientific discipline in the usual sense of the term; instead its common element is a shared set of basic techniques. The substance of space science is best thought of as a sophisticated, and expensive, mixture of the traditional disciplines of astronomy, geology, geophysics and oceanography.

In the decades since the first satellites there have been tremendous advances in observing and understanding the oceans, the atmosphere, the ionosphere and the magnetosphere of the earth, the many types of radiation from the sun and their effects on the earth, and the nature and evolutionary history of the moon and planets. There have been many discoveries of basic importance to stellar astronomy. All the objects of the solar system as well as the interplanetary medium are now accessible to closeup study. Probes have been dispatched to the planets Mercury, Venus, Mars, Jupiter and Saturn, and some of them will also transmit data from Uranus and Neptune. *Pioneer 10,* one of my favorite spacecraft, has been operating in flight for nearly 14 years and is now the remotest manmade object in the universe. It is still functioning well into the outer heliosphere and is farther from the sun than Pluto is. A few months ago the *International Comet Explorer* flew through the coma of Comet Giacobini-Zinner, and this month *Voyager 2* will be the first spacecraft to make an encounter with Uranus.

The scientific community has developed a great variety of superb instruments that can withstand the rigors of launching, and space science is teeming with fresh discoveries and well-formulated plans for the future. Support is now moderately secure for the ongoing missions of the *International Ultraviolet Explorer,* the *Dynamics Explorer,* the *International Sun-Earth Explorer* and the Pioneer and Voyager spacecraft. Yet the number of new opportunities for flight has been reduced markedly in the 1980's by cancellations and prolonged delays.

The major emphasis in recent years in space science has been on billion-dollar missions, such as the Space Telescope, the *Galileo* mission to Jupiter, the Viking landers on Mars and the Voyager probes. This trend also accounts in part for the reduction in scientific payloads; indeed, the Space Telescope and *Galileo* are the only major U.S. scientific spacecraft that have been or will be scheduled for launching in the years from 1983 through 1988. Such missions represent a tendency within space science toward ever greater complexity and sophistication, and they do have high merit. Unfortunately, however, like the large, manned space projects, they tend to squeeze out more flexible and much less expensive undertakings that historically have been highly productive. Smaller projects nurture space science on a broad, national basis and continue to have a potentially important role in our national program, but they are now nearly extinct.

In the meantime the European Space Agency, Japan and the U.S.S.R. are forging ahead with important scientific missions. The progressive loss of U.S. leadership in space science can be attributed, I believe, largely to our excessive emphasis on manned space flight and on vaguely perceived, poorly founded goals of a highly speculative nature. Given the current budgetary climate and a roughly constant level of public support for civil space ventures, the development of a space station, if pursued as now projected, will seriously reduce the opportunities for advances in space science and in important applications of space technology in the coming decade.



SPACE STATION, if it were constructed, could resemble the design shown here, but fundamental decisions about the design are still pending. The latest version of the basic structural design differs from a previous one in having two main "towers" instead of one. In this computer-generated image of the current version only the shuttle-docking area of the space station is shown, and the scale of the structure is indicated by the human figures near one of the towers. At this stage the two designs and, indeed, several others can be quickly interchanged on the color monitor of a computer-aided design system, such as the one responsible for the image shown, made by the McDonnell Douglas Corporation. Nevertheless, the current NASA schedule for development calls for the electronic image to be translated into a real device in earth orbit by the year 1993. The cost of that effort may be as high as $30 billion in constant 1984 dollars.