Space Research: At a Crossroads

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The current state and future directions of the U.S. space-science program are assessed in the wake of the Challenger accident, the Gramm-Rudman-Hollings budget reduction act, and the report of the National Commission on Space. A renewed emphasis on moderate-scale, quick-response missions will be of special importance for scientific progress and will compensate in part for the postponement of most major space missions. Satellites and manned space stations in Earth orbit, along with unmanned planetary missions, will continue to be the dominant elements in the space program. Future progress and the continuation of U.S. leadership depend on the vitality of U.S. space research.

AT THE BEGINNING OF 1986, THE FUTURE OF THE U.S. space-science program had never seemed brighter. Planned launches of the Hubble Space Telescope, the Galileo orbiter and probe mission to Jupiter, and the International Solar Polar (Ulysses) mission, a joint project with the European Space Agency (ESA), were poised to provide a great leap forward in our research capability. The Space Shuttle was evolving into a useful carrier of scientific experiments as well; several Spacelab missions had been flown successfully, and a variety of small attached payloads and low-cost "Spartan" Shuttle-tended spacecraft were scheduled for launch in 1986 along with a series of major Spacelab payloads.

The Challenger accident on 28 January 1986 totally altered this picture. Of the significant space events planned for 1986, only the Voyager 2 encounter with Uranus took place.

We now face delays of at least 2 years for most space-science missions, and Spacelab and other Shuttle experiments will probably be postponed for an even longer period of time. In addition, the Gramm-Rudman-Hollings deficit reduction act led to a \$76-million decrease in space-science funding at the National Aeronautics and Space Administration (NASA) for fiscal year 1986. The inflation-adjusted space-science budget levels for 1987 and 1988 are not likely to be significantly above that of 1986. This funding austerity is being imposed at a time when it is evident that increased expenditures are necessary if we are going to maintain U.S. preeminence in space. One optimistic view is the report of the National Commission on Space (*1*), which proposes bold steps to colonize the solar system in the next century and emphasizes the future of space science in a highly positive manner.

Clearly, U.S. space science now stands at a crossroads. In this article I examine four areas that should be considered in any plan to bring U.S. space research through the present difficult period and to restore it to vitality in the future.

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Importance of Small-Scale Research Programs

In the planning of future space missions, there is an emphasis on large and bold new ventures that will expand our intellectual horizons and drive the development of new technology. A large measure of this emphasis is justified by the intrinsic scientific importance of such missions. Examples of approved projects in this class are the Hubble Space Telescope, the Galileo project, the Gamma Ray Observatory, and the Upper Atmosphere Research Satellite.

What is frequently overlooked is that the foundation for these large new missions is generally provided by precursor missions of more moderate scope and cost, the success of which rests on quite modest, small-scale research.

For example, the 1982 report of the National Academy of Sciences' Astronomy Survey Committee (*2*) identified an Advanced X-Ray Astrophysics Facility (AXAF) as the major new project of highest priority for astronomy and astrophysics for the 1980s. A critically important precursor of AXAF was the second High Energy Astronomy Observatory (HEAO-2) mission, a moderate-scale facility, launched in 1978, which demonstrated the feasibility and high scientific return of imaging x-ray optics. The justification for the HEAO series depended on the success of the small Uhuru satellite, launched in 1970, which revealed an extensive population of x-ray sources across the sky. However, all of these advances began with the pioneering discovery of the first cosmic x-ray source, Scorpius X-1, by means of a simple gas proportional counter aboard the brief flight of an Aerobee rocket in 1962. What is required in the future is a balanced program with a mixture of both large- and moderate-scale missions, augmented by strong support of small-scale research.

Small-scale research is of great value in the generation of new scientific ideas, the training and development of young scientists, and the creation of new technology. Scientists working in small groups in physics, chemistry, and biology laboratories have received a disproportionate number of Nobel prizes for work on quite modest experiments. By working on small-scale projects, students participate both in the design of an experiment and in the analysis of the results. They thus obtain an overall view of the scientific process—a "systems approach" to experiments in which changes can be introduced and consequences observed. Furthermore, such small projects offer the flexibility for rapid changes in research directions, so that innovation is encouraged. Although the benefits of small-scale research are recognized throughout the field of science (*3*), they are of special importance to our space program.

How does one provide, in practice, for the proper support of small-scale research in space science? The answer is clear: through frequent flight opportunities. Or, in the words of Dyson, "Quick is beautiful" (*4*, p. 127).

In the past, frequent flight opportunities were provided by rockets, balloons, small missions funded through the NASA Explorer program, and components of NASA's Observatory series, such as the Orbiting Solar Observatory, the Orbiting Geophysical Observatory, and the experimental Nimbus series of Earth-observing satellites. Balloon and rocket experiments are still highly useful in some scientific disciplines and should be retained in these. However, the flight opportunities formerly furnished by the Explorer program and the various Observatory series have decreased to a small fraction of their rates of 10 to 15 years ago. Scientific investigations have moved beyond initial reconnaissance into a phase that demands more capable and sophisticated payloads, and the base of disciplines covered by the Explorer program has increased.

It was hoped that the Space Shuttle could provide these frequent flight opportunities; indeed, it was beginning to become a viable research vehicle, as new experiment carriers and techniques were developed and as some of the more innovative Spacelab experiments were scheduled. However, the backlog of payloads and the increased scrutiny that will result from the Challenger accident, combined with the projected delay in resuming Shuttle launches, are having a devastating effect on the Shuttle science program. The near-term problem of simply getting payloads into orbit—both free-flyers and planetary missions—compounds the difficulty of establishing a balance between large- and small-scale NASA space programs.

One step could be taken immediately that would substantially and rapidly alleviate both of these problems: a dramatic increase in the Explorer program, together with a near-term emphasis on the Planetary Observers and the creation of new, small-scale flight opportunities in the earth sciences. The early Explorers 1, 2, 3, and 4 were designed, built, tested, and launched in a matter of months by the University of Iowa and the Jet Propulsion Laboratory. The first of the much larger and more complex Interplanetary Monitoring Probes was started in August 1961 and launched in November 1963. Healthy and vigorous Explorer and Planetary Observatory programs would provide a positive stimulus to space science.

The Explorer program would also bring into focus the question of access to space. The Presidential Commission on the Space Shuttle Challenger Accident noted in its recommendations (*5*, p. 201): "The nation's reliance on the Shuttle as its principal space launch capability created a relentless pressure on NASA to increase the flight rate. Such reliance on a single launch capability should be avoided in the future." The near-term damage and disruption of the nation's space research program by the Challenger accident requires that NASA move rapidly toward the use of expendable launch vehicles as well as the Shuttle. The smaller Explorers and Planetary Observers require modest launch capabilities that can be met by more readily available launch vehicles. The development of inexpensive and reliable access to space should remain one of NASA's most important goals.

Role of NASA in the Future

The basic role of NASA now and in the future should be to lead the nation into space. The number of scientific disciplines in which experiments in space can be carried out has steadily increased. Space has provided us with a cosmic laboratory in which to observe the complex space-plasma processes that shape the interaction of Earth and its magnetosphere with the heliosphere, and we have begun to unravel the many subtle connections between our planet and the sun. Within our own solar system, we will soon have completed reconnaissance of all the planets except Pluto and will have sent probes or landers to Venus, Mars, Jupiter, and Earth's moon. The HEAO series of missions, the International Ultraviolet Explorer, the Infrared Astronomy Satellite (IRAS), and a host of other missions have yielded remarkable advances in astrophysics.

Momentum is now building as well for still greater exploitation of space techniques for the study of Earth. A quarter-century of weather-satellite observations, combined with numerical modeling, have transformed weather prediction from an art, only a generation ago, into the science of today. The Landsat Earth-remote-sensing data available since 1972 have revealed the enormous power of such techniques for the study of Earth's land surfaces, and the 1978 flight of Seasat did the same for ocean studies from space. The next decade will see a new generation of specialized Earth-study missions, such as the joint U.S.–French Topex/Poseidon project for studies of ocean circulation and the Geopotential Research Mission for measurements of the geoid and mapping of convective patterns in Earth's mantle. In the 1990s, a global Earth Observing System is planned to record continuous, long-term data on the state and evolution of Earth processes. With the future availability of the Space Shuttle and the increased future capability of the Space Station, the horizon of science and its applications will be further broadened by investigations of materials science in space and of space biology.

However, this increase in the number of scientific disciplines requiring access to space poses problems for NASA. The expansion calls for diverse new missions and a broader scientific and engineering base. One means of maintaining, or even enhancing, the current viability of the space program is to enlist the increased participation of other government agencies in the management and financial support of space activities in appropriate areas.

Particularly in the field of materials science, space biology, and medicine, the National Science Foundation (NSF) and the National Institutes of Health should be encouraged to play a major role in support of space research. In all of these program areas, microgravity environments offer research opportunities that are extensions of current ground-based programs. The space laboratories conceived for these areas in the era of the Space Station will, at least initially, be adaptations of the facilities now being used in conventional laboratories. It is natural for the government agencies presently sponsoring materials science and biology to move increasingly, with NASA's cooperation, into space research in a direct-support role.

Space also affords the global view now required for further, fundamental advances in earth sciences. Studies sponsored by the National Academy of Sciences (*6*) and the NASA Advisory Council (*7*) emphasize the importance of space observations in probing the complex interactions among Earth's atmosphere, oceans, biosphere, and land surfaces. These studies underscore the need for a systems approach to the understanding of global change.

However, such an approach is complicated by both bureaucratic and political considerations. At present, three U.S. agencies—NASA, the National Oceanic and Atmospheric Administration (NOAA), and NSF—have a significant share in the funding of earth sciences, and others (for example, the Departments of Energy, Agriculture, Interior, and Defense) also have Earth-study programs. Furthermore, the global study of Earth is inherently international. The land area and population of the United States each comprise only 5 percent of Earth's total land area and population. Broad international cooperation is necessary for truly global Earth studies. These studies require the calibration and validation of in situ measurements, the exchange of satellite data, and active collaborations in modeling and understanding Earth. Such international cooperation is complicated by the multiplicity of U.S. agencies involved in earth sciences programs.

One possible solution would be to combine elements of NASA, NSF, NOAA, and other civilian agency programs and responsibilities in the earth sciences into a new agency that would focus on earth sciences and natural resources. This idea is not a new one, but it gains new cogency from the growing recognition of the importance of adopting a global perspective in Earth studies. In government bureaucracies such sweeping changes are often not feasible. A more modest step might be to create a small, elite, lead agency, with the present agencies that focus on earth sciences retaining special areas of competence, such as NOAA's maintenance of long-term databases and NASA's development of new technologies and instrumentation for space-related studies. This concept of a lead agency would simplify definition of a comprehensive approach to the study of global change, eliminate possible duplications of activities, and greatly aid in the planning of international programs in earth sciences.

International Cooperation

The U.S. space program continues to be strongly influenced by international competition and cooperation. The initial competitive challenge from the Soviet Union in space was the dominant factor shaping the early course of the U.S. space program. By contrast, international cooperation with Western Europe, Canada, Japan, and other nations began almost as a "Marshall Plan for space." Now, however, the European Space Agency and Japan have developed strong space programs that provide both competition for, and opportunities for cooperation with, our own space efforts. For example, these groups compete for provision of launch services, but plans are developing for cooperation in the construction and operation of the Space Station. A similar duality is found in the space science and applications area. The success of the ESA Giotto mission to Halley's comet and the impact of the French SPOT (Système Probatoire d'Observation de la Terre) Earth-observing satellite are strong indicators of the maturity of the European space program.

The Soviet Union has pursued a vigorous planetary exploration program, producing missions to Venus that have been a technical and scientific success. The manning of the Salyut-Soyuz space station complex for record lengths of time demonstrates Soviet competence in manned space flight. By flying cosmonauts from other socialist countries and from France and India, the Soviets have also used space as an effective political tool. Significant enhancements of the Soviet space science program are evident in their Vega mission to Halley's comet, the Mir space station, the planning of the Phobos mission to Mars, and new missions in high-energy astrophysics. Furthermore, the Soviets have invited some of the most productive research groups in Western Europe to provide experiments for these flights. Such cooperation provides access to advanced technology that the U.S.S.R. does not presently possess and also furthers political ties with Western Europe. The political factor remains a vital part of the space picture and is one reason why attention must be given to future international cooperation.

Economic considerations also require a greater degree of international cooperation. The great observatories of astrophysics—the Hubble Space Telescope, the Gamma Ray Observatory, the Advanced X-Ray Astrophysics Facility, and the Space Infrared Telescope Facility—are moderate- to large-scale missions with an average international contribution of about 10 percent. Future astronomical observatories, such as a Large Deployable Reflector in space and space interferometers, will be larger, more complex, and more costly. Neither the United States, nor Western Europe, nor Japan will be able to afford duplicate missions. Similar arguments apply to other space research fields.

International cooperation is essential for political and economic reasons, and its importance will increase. The most desirable approach to this cooperation could be an informal "cartel" arrangement among various space agencies that would coordinate a series of scientific missions or space facilities through multilateral or bilateral agreements. Such an arrangement would be an attempt to maximize the scientific return from the total available space resources, although we recognize that science is only one of the factors that motivates us to undertake space missions. Major instruments for such a space mission would then be provided by different countries. Thus, American experimenters would both compete and cooperate across the "cartel boundaries." Space missions are inherently complex, so it is logical to put the spacecraft and operations under the control of a single agency. Such an arrangement would extend our present international program with an increased emphasis on cooperative planning. An alternative, but inherently more complex, approach envisions an agency such as CERN (the Organisation Europeene pour la Recherche Nucleaire). The ESA could be regarded as the prototype for such an arrangement. In any case, for many reasons it is desirable that the U.S.S.R. become a full participant in such cooperative activities. Particularly in the case of the cartel plan, technology transfer would be held to a minimum, since there would be exchange only of experiments in the form of "sealed black boxes," rather than detailed specifications of hardware or data-system components. Perhaps other approaches should also be pursued; different arrangements might be applied to different research areas. Recently, Wasserburg (*8*) presented an analysis of international cooperation in the planetary program with particular emphasis on unmanned sample returns from Mars, Venus, and comets.

Long-Range Goals in Space

The National Commission on Space, under the chairmanship of Thomas Paine, has presented a bold vision of the future (*1*). Their views of the probable development of space science and of the space infrastructure in low-Earth orbit reflect a broad consensus of the scientific community. For the distant future, the commission envisages the construction of large transportation systems to the moon and Mars, to be followed by the establishment of permanent colonies on these distant bodies—civilization moving out into the solar system.

However, I believe the real growth areas for space during the next 50 years in all probability will remain in the domain of Earth-orbiting missions in the following areas:

1) The continuing evolution of communication satellites along with more specialized missions such as the Global Positioning Satellites and the vast array of new services they will provide.

2) The development of comprehensive Earth-observing systems as the indispensable factor in establishing a program to understand Earth's environment and to monitor global change.

3) Fundamental studies of material sciences, chemical processes, and life sciences in a microgravity environment that could provide the foundation for space manufacturing.

4) Construction and maintenance of very large astrophysical observatories that will allow us to "look out" in all wavelength regimes from radio and infrared to gamma rays to the edge of the observable universe and examine in detail the properties of nearby stars.

5) An assembly and transportation node for planetary exploration missions and large spacecraft in synchronous orbit.

Continuing progress in all of these areas depends on a strong space research and technology program. These future programs will involve the active participation of man in space, with the Space Station as a necessary facility as a laboratory and as a means of assembling and servicing large spacecraft and experiments. Along with these activities, there should be a strong program of planetary studies. These studies would determine the present physical and chemical states of all the planets and their moons, as well as small bodies such as comets and asteroids, in order to understand the origin and behavior of our own solar system as well as the formation of other planetary systems.

One can also speculate which of these objectives may have the greatest impact on the public imagination. This impact will depend on the development of technology in that era. Tomorrow's technology is based not only on the technology of today but also on the dreams, visions, and aspirations of those human beings who stand behind it. These less tangible hallmarks of an age may offer more insight into the future than the concrete objects that age has produced. We must look at the cultural and spiritual influences on those who have led the development of new technologies. The creation of new designs and construction techniques that led to the building of the great cathedrals throughout Europe in medieval times is one of the most impressive examples of cultural influence on the development of technology.

The development of modern rocket technology represents another example. At the beginning of this century, the dream of exploring the solar system lay behind the visionary scientific and engineering analysis of Konstantin Tsiolkovsky in the Soviet Union and, later, Hermann Oberth in Germany. This dream also led Robert Goddard to develop the first successful liquid-fueled rocket in the mid-1920s. The vision of these three men was, in part, ignited by the science fiction of authors Jules Verne and, especially, H. G. Wells. Wells's novel *War of the Worlds* inspired Goddard in 1932 to write the author a letter (*9*, p. 821), which said in part:

> In 1898, I read your *War of the Worlds*. I was sixteen years old, and the new viewpoints of scientific applications, as well as the compelling realism . . . made a deep impression. The spell was complete about a year afterward, and I decided that what might conservatively be called "high altitude research" was the most fascinating problem in existence. . . . How many more years I shall be able to work on the problem, I do not know; I hope, as long as I live. There can be no thought of finishing, for "aiming at the stars," both literally and figuratively, is a problem to occupy generations, so that no matter how much progress one makes, there is always the thrill of just beginning. . . .

In a sense we have fulfilled the dream of Goddard and the other early space pioneers and have gone beyond them. We have landed spacecraft on Venus and Mars; man has walked the surface of the moon and returned to Earth with lunar samples. Man will certainly return to the moon, and eventually he will walk on Mars. It may be argued, however, that these things will happen not as the result of some great national program, but rather as a straightforward extension of the vast capability that we will have created in low-Earth orbit.

We should also bear in mind that most of the solar system is inhospitable to humans. We will probably never visit Mercury and Venus or venture to Jupiter and beyond. The "welcome mat" is out only on the moon, Mars, and the asteroids. Planetary science and exploration, however, will remain of great significance as we seek to understand the origin of our solar system and the place of Earth within this system. The development of automated rovers on Mars and on asteroids; unmanned sample returns from Mercury, Venus, and Mars; and more detailed studies of the giant outer planets could advance the development of robotics and technology.

If we look today for dreams in our culture analogous to those that motivated the early rocket pioneers, we are struck by the popular and scientific interest in going beyond our solar system and reaching out to the stars. As evidenced by the success of films such as Steven Spielberg's *E.T.*, there is an interest at all levels of our society in the possibility of intelligence and civilizations elsewhere in the universe. The 1983 results from the Infrared Astronomy Satellite, which provided evidence of possible planetary systems forming around the star Vega, struck a responsive chord in members of both the scientific community and the general public. The follow-up studies of another "IRAS source," β Pictoris (*10*), showed that with sophisticated optical techniques, it was possible to image a circumstellar disk around a star some 53 light-years away from a ground-based observatory.

The next step in the human venture outside our solar system is the search for extrasolar planetary systems by using the astrometric capability of the Hubble Space Telescope and results from the European Hipparcos astrometric satellite. A consortium of investigators from the University of Arizona and the NASA/Ames Research Center are now working on a far more sensitive telescope for planetary detection to be flown on the Space Station. Alternative approaches are also being explored by several other U.S. research groups. Beyond this, space-based interferometers can be developed for examining nearby stars with the same resolution we can now achieve for the sun with a telescope of moderate size. It will then be possible to identify those stellar systems that should be more closely studied as possible sites for intelligent life.

If we detect the presence of intelligent life beyond our solar system, will we then try to build the "Starship Enterprise," or will we communicate through exchanges of great packets of information, which we already know how to transmit at the speed of light? Interstellar communications will permit us to "visit" with our nearest neighbors across the vast reaches of interstellar space. These same technological advances, essential for the study of nearby planetary systems, will enable us to discern the small-scale structure of the "engines" at the hearts of quasars, and new instruments, such as the Large Deployable Reflector, will allow us to "look back in time" to the early stages of the universe. The cumulative effect of these studies could have a profound impact on the future development of our society, since they will give us a different view of our place in the universe.

As Stephen Weinberg, theoretical physicist and Nobel laureate, remarked at the dedication of the Instituto Astrofisico de Canarias in the Canary Islands (*11*, p. 18):

> For one reason or another, the exploration of the universe plays a role for us today somewhat like that played by the exploration of the earth in the time of Columbus. . . . One great difference is that, while the exploration of the world set the nations of Europe at each other's throats, the exploration of the universe has tended to bring them together.

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