Chapter 6

TOWARD A GOAL-ORIENTED CIVILIAN SPACE PROGRAM

Contents

LIST OF TABLES

Chapter 6

TOWARD A GOAL-ORIENTED CIVILIAN SPACE PROGRAM

POSSIBLE CIVILIAN SPACE GOALS

If the civilian space activities of the United States are to maintain widespread and enthusiastic public support, they should aspire to protect, ease, challenge, and/or improve the human condition. Such aspirations can and should be articulated in the form of long-range goals that would guide the conduct of the Nation’s space activities in general and a decision regarding possible acquisition of any “space station” in particular.

In order to prompt the formulation and subsequent discussion of future space goals and objectives, OTA has prepared a list of possible long-range goals and a set of nearer term objectives designed to address those goals. Although OTA does **not** recommend either this particular set of goals or its supporting family of objectives, they are intended to exemplify the **kind of goals and objectives around which consensus might well be formed so as to provide sensible guidance** for the Nation’s future space activities. The Advisory Panel for this assessment has taken an unusually active role in helping to formulate these goals and objectives. It is the Panel’s judgment that the goals and objectives proposed for discussion are reasonable and important.

The set of possible goals follows. (They should be read with reference to the six basic principles spoken to in the 1958 Space Act and discussed in the previous chapter.) Some of these can be defined in fairly specific terms, but others–no less significant—can be stated only in a more general and open-ended way:

- to increase the efficiency of space activities and reduce their net cost to the general public;
- to involve the general public directly in space activities, both on Earth and in space;
- to derive scientific, economic, social, and political benefits;
- to increase international cooperation and collaboration in and re space;
- to study and to explore the Earth, the solar system, and the greater physical universe; and
- to spread life, in a responsible fashion, throughout the solar system.[1]

These goals (some new, some already well-accepted) have been chosen so as to move U.S. space interests and activities closer to the mainstream of public interest and concern, while at the same time maintaining space leadership, enhancing national security, and developing new capabilities to respond to finding the unexpected in the cosmos.

---

[1] Undertaking this goal responsibly would entail preserving the pristine environments of other worlds for future study and appreciation. For example, there are bodies such as Europa and Titan, which have not yet been explored, where life may already exist. And there remains some residual controversy even about the possibility of microbes on Mars.

POSSIBLE CIVILIAN SPACE OBJECTIVES

In order to illustrate how the six basic civilian space goals suggested in the previous section could be addressed, this section identifies 10 specific objectives that the United States (in cooperation with other countries, in most cases) could attain within the second quarter-century of the space age. The particular objectives suggested here for further study and discussion are chosen to have a great impact and, taken as a group, to respond to a broad spectrum of public, private, professional, and international interests.

Of course, discussion of any of these conceptual objectives should actually be undertaken only with surface-based alternative and complementary activities clearly in mind. Some elements of a few are already under way in a modest fashion, but not in the sharply focused fashion suggested here. Some may turn out not to be feasible for technological, economic, or other reasons, Some could be attained in a very short time, but others will take many years. Some respond to objective needs, some respond to conceptual opportunities. Broad consensus on some should be rather easily reached, but others can be expected to provoke serious argument and perhaps even disagreement. They range in cost from near-zero to tens of billions of dollars. Some are chosen particularly because, in addition to the importance of their being achieved, they also invite the active and important partnership of other countries and the U.S. private sector.

These objectives are proposed under the assumption that the U.S. Government would still be expected to carry on, as today, a "core" space-related basic research program at the level of at least $1 billion annually (in constant dollars). Pure scientific research should continue to encompass such diverse space-related areas as astronomy, cosmology, life sciences, materials sciences, geodesy, magnetism, relativity, plasma physics, meteorology, atmospheric composition and dynamics, and programs of preparing for human lunar, asteroid, and planetary exploration and settlement. The basic research program would be expected to continue solar system exploration generally, including the planets, their moons, the Sun, comets and asteroids, and to improve the methods and means of transporting equipment and people in space. And it would be expected to develop, deploy, and use those "cutting edge" space technologies—large and sophisticated telescopes and interferometers that span the electromagnetic spectrum, microgravity furnaces, sophisticated and powerful Earth-oriented remote sensors, sophisticated space probes, etc.—that are required to make early and fundamental advances in these fields in a highly productive fashion.

The results of these basic research activities, of course, will be many and varied. In both the shorter and longer term they can have important public policy implications and, in general, they can eventually influence the cultural, economic, and national security interests of the country in many, and oftentimes unexpected, ways. As the roles and capabilities expected of our in-space infrastructure for the next two or three decades are considered, basic research activities should receive a high priority.[2] Continuing success in fundamental space research may be expected to facilitate the accomplishment of the objectives proposed here.

The titles of the 10 civilian space objectives follow. They are not rank-ordered:

1. Global Disaster Avoidance and Minimization.
2. Human Presence and Activities on the Moon.
3. Exploration of Mars and Some Asteroids.
4. Medical Research of Direct Interest to the General Public.
5. People, Drawn From the General Public, in Space.
6. Modernizing and Expanding International Short-Wave Broadcasting.
7. Providing Space Data Directly to the General Public.
8. Using Space and Space Technology for the Transmission of Electrical Energy.
9. Reducing the Cost of Space Operations, Especially Transportation.
10. Increasing Commercial-Industrial Space Sales.

The eventual acceptance of any or all of these objectives (along with their related costs) as actual national objectives would leave the priority among them, and the rate of public expenditure in addressing them, completely open. Each and all would be undertaken, if at all, only as the funds become available to do so.

Table 9 relates these 10 specific objectives to the broader goals.

A brief elaboration of each of the 10 follows.

'See the National Aeronautics and Space Act of 1958 (Public Law 98-361).

Table 9.—Possible Goals and Objectives

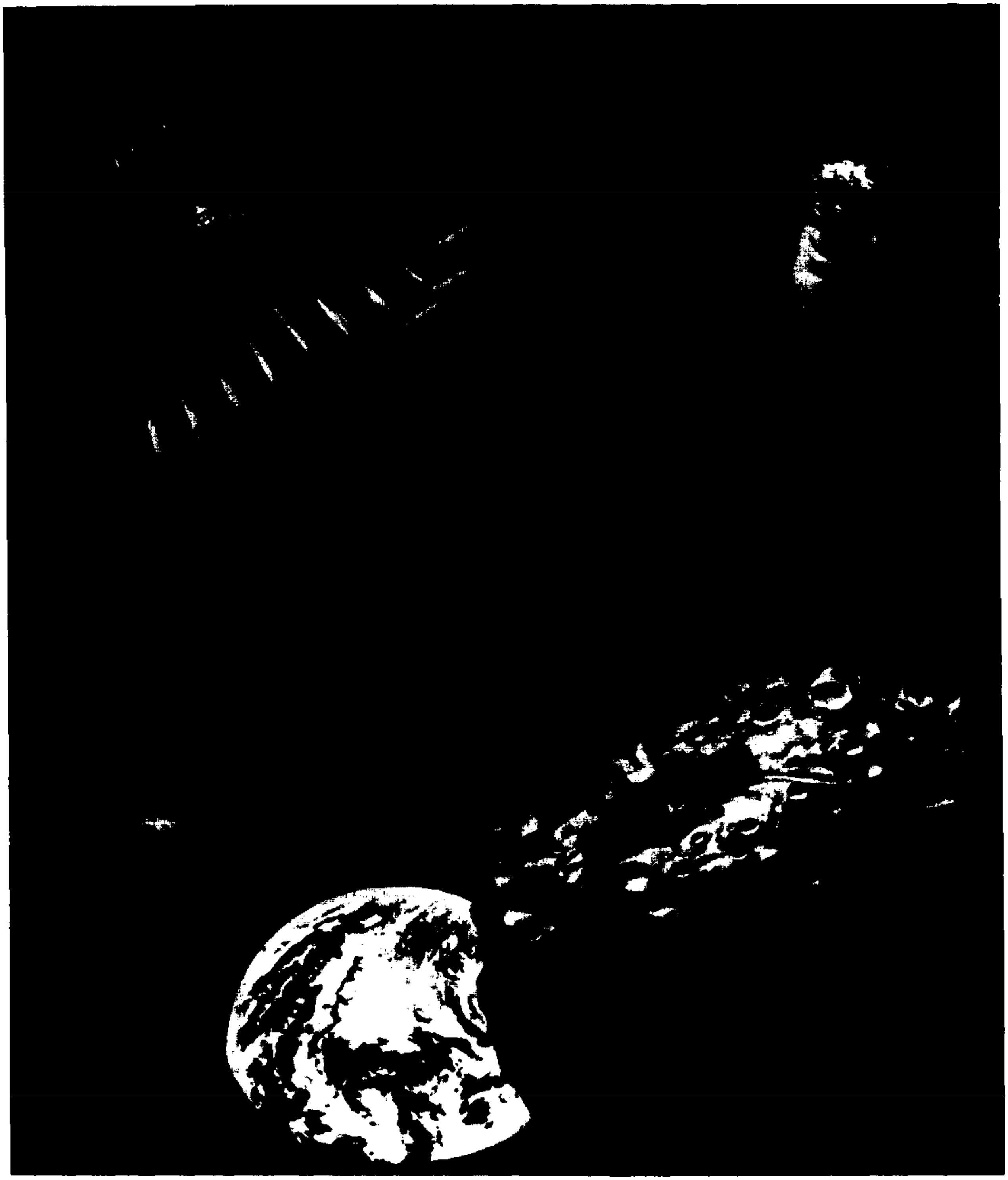
	Goals						
	Increase space activities' efficiency; reduce their net cost	Involve the general public directly	Derive economic benefits	Derive scientific, political, and social benefits	Increase inter-national cooperation	Study and explore the physical universe	Bring life to the physical universe
Objectives:							
1. Establish a global information system/service re natural hazards	N	N	P	Y	Y	N	N
2. Establish lower cost reusable transportation service to the Moon and establish human presence there	Y	P	P	Y	Y	Y	Y
3. Use space probes to obtain information re Mars and some asteroids prior to early human exploration	N	N	N	Y	Y	Y	N
4. Conduct medical research of direct interest to the general public	N	N	P	Y	P	N	N
5. Bring at least hundreds of the general public per year into space for short visits	N	Y	Y	Y	Y	N	Y
6. Establish a global, direct, audio broadcasting, common-user system/service	N	P	P	Y	Y	N	N
7. Make essentially all data generated by civilian satellites and spacecraft directly available to the general public	N	Y	P	Y	Y	N	N
8. Exploit radio/optical free space electromagnetic propagation for long-distance energy distribution	N	N	Y	P	Y	N	N
9. Reduce the unit cost of space transportation and space activities[a]	Y	N	Y	Y	N	N	N
10. Increase space-related private sector sales[a]	Y	N	Y	N	N	N	N

[a] This would advance the prospects of successfully addressing all other "goals."

Y: Yes; N: No; P: Perhaps; depends on how carried out.

1. **Global Disaster Avoidance and Minimization.—In cooperation with the other countries of the world, our Government and** our scientific and engineering communities could be set to the task of beginning to provide a global, space-related, Earth-monitoring system/service which would provide fundamental information to the world's political leaders, organizations, and institutions to assist them in dealing, satisfactorily, with macroscopic "life-and-death" problems in such areas as weather, climate, air and water purity, food production, seismology, and resource conservation. It would be designed to complement related surface-based system/services, taking specific advantage of the in-situ measurement and monitoring perspectives that only appropriate sensors located in space could offer. Attention could be concentrated on earthquakes, tsunamis, ozonosphere perturbations, severe storms, environmental pollution, the carbon dioxide "greenhouse" effect, volcanic effluvia, etc. Well before the year 2000 this operational global system/service could be in place, monitoring and studying the Earth's space and atmosphere, and surface and subsurface, for characteristics and changes relevant to such problems, and supplying both immediate and longer term "warning" information promptly, directly, and in a form useful to nontechnicians.

These are problems that have inherent multinational elements of potentially grave hazard. And this type of space-related system/service could be developed, installed, and used in such a fashion as to obviate the serious concerns raised by some countries over what they consider to be undue surveillance of a military-political nature, or the kind of monitoring that could provide an undue economic advantage to some countries. The original elements of this system/service could be continually improved on as new scientific knowledge is obtained, new space-related measurement techniques are perfected, and experience is gained in the reliability, utility, and cost of space-related services in comparison with analogous services that could be provided at the sur-



M

N

face. It could, of course, draw heavily on any "global habitability" scientific studies. And it could provide information that would be useful in furthering study of "nuclear winter. "

2. Human Presence and **Activities on the Moon.** –Our Government and our scientific and engineering communities in government, universities, and the private sector, could be given the task of establishing a modest, permanent, habitable facility on our Earth's Moon. Such a facility would allow physical, chemical, geological, and cosmological studies to begin there in earnest–with the entire activity involving as many countries as possible. The U.S. private sector in concert with the Government could also be challenged to provide facilities and services there that would open up the Moon to travel, recreation, sports and other cultural, commercial, and industrial pursuits. Three important elements of this program could be: 1) the development of a relatively low-cost, human transportation system/service between low-Earth-orbit and the Moon [see objective (9)]; 2) consideration of producing oxygen on the Moon from lunar materials as a source of rocket oxidant for return trips and for life support (i. e., using solar energy to release oxygen from Moon rocks); and 3) a search for abundant supplies of water/ice in the cold-traps at the lunar poles.

A primary cost-driver for human settlement on the Moon, and other celestial objects, will be the reliability and efficiency of the technology which would enable such settlements to provide livable atmospheres, grow their own food, and build effective and durable habitats using local materials.

3. Obtaining Information Required for Eventual Human Exploration of Mars and Some Asteroids. —The Soviet Union has stated that it expects to explore, and have some of its people establish a presence on, the planet Mars. The United States could also aspire to do so when the technology is in hand to allow it to be done at relatively low cost, when adequate Mars-related data and information are also in hand, and when our experience in settling on the Moon gives us the confidence that we can do so successfully and efficiently [see objective (2)]. Early programs to develop and use lower cost transportation, housing, and people-related services in establishing low-Earth-orbit and lunar residential and work places could all keep analogous Mars objectives specifically in mind. Over the next 10 to 20 years, crewless space probes, with characteristics specifically reflective of our intention to have some of our men and women visit the surface of Mars early in the next century, could be sent there. Specific plans could see a human exploration program commence on the satisfactory completion of our initial settlement on the Moon, provided the cost of doing so is then seen to be acceptable.

Of course, the space probes could, as well, search for information of importance to a better understanding of our own terrestrial circumstances and processes. And consideration could be given to exploring a few of the asteroids as wel l.

4. **Medical Research of Direct Interest to the General Public.– For over 20 years, the space programs** of both the United States and the Soviet Union have been concerned with the ability of men and women to survive and function well in space. Space provides a special environment, marked particularly by the near absence of gravity, within which several diseases and related human physiological processes might now begin to be profitably investigated. Important topics relevant not only to future space dwellers, but also to the Earth population as well, could include research on hypertension, osteoporosis (a disorder involving loss of bone mass highly prevalent in older women), osteoarthritis (which affects over 16 million Americans), weight control, energy metabolism, digestive function, and body fluid balance.

To elaborate on one such opportunity: experimental evidence, gathered from both animals and humans in space and in certain Earth-based simulations of some of the conditions of space flight, suggests that there may bean analogy between some of the physiological changes that occur in the absence of gravity and those changes which take place during the normal aging process. For example, as cosmonauts and astronauts adapt to longer duration living in essentiaJJy weightless conditions in space, they experience atrophied muscles, brittle bones, and decreased cardiovascular and respiratory capacity, i.e., physiological conditions similar to those which accompany senescence. Further experimental studies in research programs carried on at the Earth's surface and on the Shuttle-Spacelab may confirm that, inasmuch as the human aging process evolved under conditions of constant gravity here on Earth, removal of this force over long periods of time in space results in changes in the aging process and its rate—changes that could be studied in weightlessness with an explicit intention of relating any findings to the general population. Given the importance of scientific studies of aging to all of the world's people as individuals, and the effects of an aging population on many economic, social, and political institutions, if surface and Shuttle-Spacelab "space station" studies are encouraging, the United States could inaugurate a major international research program in the fields of gerontology and geriatrics that would encompass related experimentation both in space and on the Earth's surface.

5. **People, Drawn From the General public, in Space.—The Government is now moving to expand human use of the Shuttle to include a very few nontechnician "communicators" per year on Earth-space flights. Within the next decade, we** could have space "Lodge/Habitats" established in low-Earth-orbit, with the Shuttle being used to see hundreds of persons per year, the great majority of whom would be representative of various professional and cultural sectors and the general public (i.e., nonastronauts and nonspace technician workers) drawn from the United States and rest of the entire world's population, being transported there to spend a short time in space. The entire activity could be operated as a sound, albeit innovative, commercial enterprise carried on in cooperation with the U.S. Government; there should be little or no net out-of-pocket cost to the Government as a consequence of this cooperation. The enterprise could be conducted so as not to favor the rich—all of our citizens should have some opportunity to visit there. And such "Lodge/Habitats," and the activities that they, and the Shuttle, could allow to commence in space, could be used to help the world celebrate the next "Millennium" in an extraordinary fashion.

Only when a large number of our citizens, representative of a broad cross-section of our society, begin to experience the "space adventure" directly, will the space domain and space activities gradually begin to move into the mainstream of our national interests and concerns.

~his objective and objective (7) have in common the aim of making the space domain, and space science and technology, much more accessible to the general public.]

6. **Modernizing and Expanding International Short-Wave Broadcasting.–Hundreds of millions of people, world-wide, regularly listen to speech and music programs broadcast via shortwave by more than 100 countries. Because of the inherent characteristics of the ionosphere which influence the way by which the broadcast signals** are propagated, this service is limited at best and oftentimes is of poor quality, reliability, and coverage. Also, shortwave broadcasting has become a matter of growing international political contention because of its dominance by the major countries and the growing interference to reception caused by increasing use of the sharply limited useful radio-wave spectrum by very powerful surface transmitters. A cooperative U.S. Government-private sector initiative could lead an international effort to establish a global system, employing sophisticated and powerful direct broadcast satellites, that could replace most of today's individual country shortwave stations well within a decade. Developed as an international common-user system, use of its services could allow broadcasters throughout the world, regardless of their size, location, or political persuasion, to reach audiences in other countries clearly and reliably, and at relatively modest cost. Such a service could go far toward meeting a standard of nation-to-nation broadcasting equitability simply not physically possible under today's surface-based shortwave broadcasting circumstances. Briefly, it would be a more efficient, effective, and fair way of accomplishing the kind of shortwave broadcasting now done from the Earth's surface. And, as well, the prospect of wholly new kinds of international programming and international marketing services could be opened.

7. **Providing Space Data Directly to the General Public.—"The** wholesale introduction of computers into [the home and especially] into class-

rooms since 1980 amounts to a quiet revolution that will help meet the demands of scientific and technological change as well as economic computation in world markets."[3] Nearly 80 percent of our junior and senior high schools now have computers and it is expected that the number in our public schools will reach 600,000 by next year. A computer network now interconnects 200 university sites, and the number of terminals is expected to reach 150,000 soon.

A high school teacher in the United Kingdom has attained international attention by having his students ''tune in" to signals from Soviet spacecraft and deduce information about the crafts' characteristics and activities. The cultural, social, and economic implications of having a large and growing segment of our population using increasingly sophisticated computers in their homes, businesses, grade and high schools, universities, etc., promise to be enormous. Many of these individuals and organizations could now be supplied, in near-real-time and at modest cost, with the nonclassified and nonproprietary data generated by payloads of public satellites and spacecraft generally, by designing them to allow direct readout of the space signals transmitted from them and/or by providing the data promptly and generally from central collection points. For instance, a recent Shuttle/Spacelab flight resulted in the generation of 20 million video frames, 900 frames of film, and 2 trillion bits of data. Hundreds of thousands of people have already taken the opportunity simply to listen in, passively, to surface-space voice communications—and made modest payments to do so. Making data available on the atmosphere, surface and subsurface characteristics of the bodies in our solar system, including the planet Earth, and spacecraft operating data as well—all directly, while they were being generated–could allow and prompt a much greater direct public involvement, both here and abroad, in the publicly supported U.S. civilian space program. As well, it could increase, by orders of magnitude, today's study and appreciation of these space data, spacecraft technology, and space activities generally, especially by our younger people. In time, the market could well prompt the creation of "service-added" organizations that could prepare various educational packages with a wide variety of users in mind: students of various ages and interests and many of the general public with home TV receivers, video recorders, and computers.

8. **Using Space and Space Technology for the Transmission of Electrical Energy.** -In effect, any radio communication involves the transmission of energy through the Earth's atmosphere and/or space—albeit at miniscule power levels. A few years ago, tens of thousands of watts of continuous microwave power were transmitted in free space with very high efficiency and reliability, and multi hundred million dollars per year Defense programs are now anticipated that would see at least 10 megawatts transmitted through the atmosphere and/or space via collimated and directed microwave and optical electromagnetic beams. Use of such methods and means might allow electricity to be distributed usefully across space. Energy sources could be located in geostationary orbit and/or on the lunar surface and the energy transmitted to the Earth's surface. Or energy could be supplied from the Earth's surface, as needed, to geosynchronous orbit and to a million miles or more beyond, at any desired power level. Given that the cost of electricity is very much higher in orbit (where it is provided by solar cell/battery combinations) than at the Earth's surface, the latter might be able to be done competitively at an earlier date.

The ready availability of such electrical energy in space could allow a complete rethinking of the design and use of space assets and activities in such space-related areas as communications, navigation, position-fixing, remote sensing, and even transportation. This is because systems designers could anticipate having tens of megawatts (or more) of electrical power available in space, whereas they now have only kilowatts and still only tens of kilowatts by the middle of the next decade, and system operators would have to pay only for the amounts of power that the systems would actually consume, just as at the surface. In addition, many areas of the world have enormous renewable energy potentials (especially hydro, but solar as well when the conversion process becomes economically attractive), but they are located too far from other areas which

---

[3] *Christian Science Monitor,* Jan. 6, 1984.

need such energy. A reliable, cost-competitive and efficient solution to the very long-distance (several thousands of miles, and intercontinental) transmission problem could allow surface-generated (N. B., in this case not in-space generated, as in the Solar Power Satellite concept) electricity to be distributed via space. Most importantly, electricity generated by renewable sources could be treated as an exportable commodity, and international and intercontinental distribution and load-shedding could become a global possibility—to great economic, social, and political advantage.

And, of course, when such technology is reliably and economically in hand, it could be used to supply electrical "fuel" to spacecraft on voyages to and from the Moon, and farther.

9. **Reducing the Cost of Space Transportation. —Whatever other measures are used to characterize civilian space activities, that of the enormous cost of in-orbit assets and activities is certain to be listed.** The primary "cost-driver" is that of space transportation for people and physical assets. For the predictable future, it will cost well over $1 ,000/lb (1984$) to place human and equipment payloads into 200-mile high-Earth orbit, in an era when, near the Earth's surface, they can be transported by aircraft over 10 times the distance at one-thousandth of this cost. Such a great cost differential continues to be one of the greatest inhibitions, perhaps the greatest inhibition, to our investment in, and use of, our Earth's space. We could now begin to look well beyond the Shuttle, and the specific technologies, fuels, payloads, and operations basic to its design and use. We could mount large-scale, advanced technology development programs that would address promising methods and means of providing reliable space transportation at much lower unit cost, giving full consideration to the future circumstance of the much greater space traffic volumes that such lower costs could engender. An initial objective could be to reduce the cost per pound for transport between the Earth's surface and low-Earth-orbit by an order of magnitude.

10. Increasing Commercial-industrial Space Sales.–The United States has spent well over $200 billion (1984$-adjusted) to learn how to enter space, to survive and function in it, and to use it. In doing so, the Nation has accrued an enormous reserve of space knowledge, assets, and experience, and created a sophisticated high-technology space industry administered and managed by Government and non-Government professionals in essential harmony with many other professionals in our university community. With one important exception, the entire civilian space effort has continued to be supported from the public purse. The time has now been reached when our private sector—commercial-industrial-financial—could begin to assume an increasing responsibility for the conduct of our civilian space activities. The one exception, the private satellite communications business, has already reached sales of some $2 billion per year and continues to grow at an average 15 percent per year rate, compounded. Government organizations, policies, activities, and leadership could now be structured not only to see that the growth in this one economically successful space field is maintained, but that other space fields (navigation, position-fixing, tourism, remote sensing, and materials processing) are likewise explicitly encouraged to grow and prosper. The President has announced a space strategy "to encourage American industry to move quickly and decisively intc space. Obstacles to private sector space activities will be removed, and we'll take appropriate steps to spur private enterprise in space, " And the Space Act has now been changed so as to require NASA to "seek and encourage . . . the fullest commercial use of space." New businesses, increased employment, increased sales here and abroad, the introduction of new and useful public and private services, and larger Federal, State, and local tax revenues all lie in prospect, once the present private sector learns how to moderate its dependence on the Government's largess and its slow-paced, structured way of doing business, and new private, competitive, entrepreneurial activities are formed and grow. One of the most important civilian space objectives now could be that of seeing that procurement of more and more of our space assets, and the conduct of more and more of our space activities, become commercialized, so that: 1) the net burden of space activities on the public purse is sharply reduced, and 2) the Government can apply its resources to the achievement of objectives that either are not appropriate to the private sector or lie beyond its capabilities.

As these economic benefits grow, they could be looked at as offsetting, at least to some extent, the cost of our publicly supported space program. Social benefits also must be kept in mind, since a fundamental purpose of government is that of meeting important public needs that the private sector inherently cannot.

Of course, a number of other objectives could also be entertained. These could include: increased emphasis on a solar system exploration program, augmenting the expected wide-ranging *core* solar system exploration program mentioned earlier; a global person-to-person satellite communications system/service; an in-space "sophisticated-machine" experimental and demonstration program; etc. It is clear that when truly imaginative minds become impressed with the broad dimensions of the space domain–not only its physical magnitude and character but the opportunity for innovative uses–there is little apparent limit to the number and kinds of concepts for exploring and using it for earthly benefit.

Underlying a decision to pursue any or all of these objectives would be a concern for the basic welfare of our own and indeed all of the world's people; a challenge to international cooperation in large, exciting, and peaceful activities; a challenge to the basic innovativeness and cost consciousness of our private sector; a commitment to the permanent human investiture and considered development of both our Earth's space and our Moon; and a general sense of "spirit-lifting."

Box I.—Opportunities in Space Science

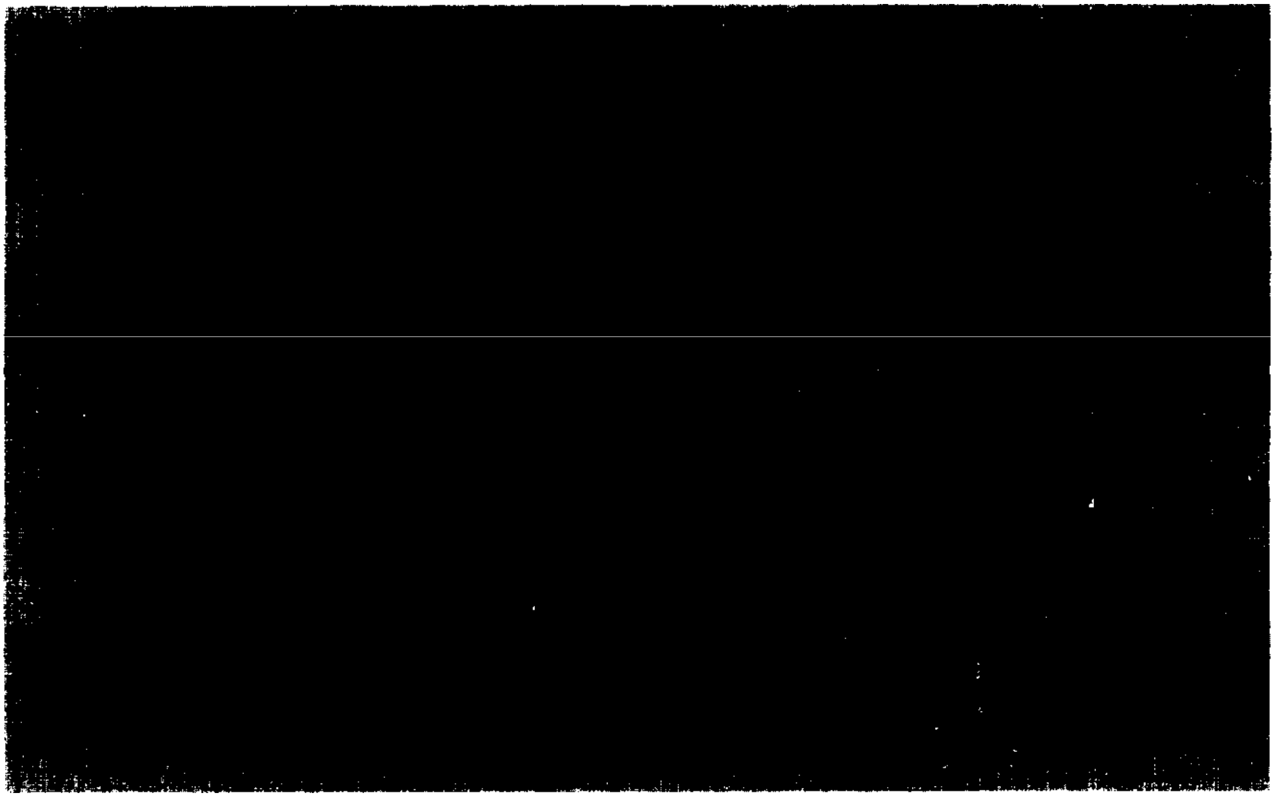
The past 25 years have seen a spectacular increase—both in breadth and in depth—in our understanding of our surroundings in space through the use of space technology. Every planet visible to the naked eye, from Mercury to Saturn, has been examined close-up by fly by, orbiter, and/or lander space vehicles. Major advances have been made in our knowledge of the Sun, the interplanetary medium, the stars, and the galaxy. Entire new fields such as X-ray and gamma ray astronomy have opened up. There is now evidence from the Infrared Astronomy Satellite that 10 to 20 percent of Sun-like stars may have some sort of planetary system. Much has been learned about the behavior of human beings in the space environment, although it is fair to note that none of this can be described as fundamental biology.

There is an extraordinary opportunity to build on these advances in the near future. The technology is now in hand for a wide variety of space vehicles: some could rove over the exotic surface of Mars; others could return samples from cometary nuclei; others could land in the presumptive liquid hydrocarbon oceans of Titan and sample the organic chemistry there (thought to be similar to the chemistry that 4 billion years ago on Earth led to the origin of life); and still others could fly into the Sun, acquiring and transmitting data until they burn up. Trips with human crews to the Moon and to asteroids (dating back to the origin of the solar system) that come near the Earth are possible for considerably less than the cost of the Apollo voyages to the Moon.

Among the many accessible objectives in high-energy astrophysics and space astronomy are investigations of massive black holes, quasars and pulsars, a resolution of the vexing problem of the "missing mass," and major advances in our understanding of the origin, nature, and fate of the universe. Major steps forward in the search for other planetary systems and other lifeforms can also be anticipated.

In terms of the fundamental understanding of our physical universe and ourselves, there has never been a period more promising than the next decade, if adequate funds are allocated and if "space station" and other programs are designed to maximize such research opportunities.

After careful study, and the weighing of costs and alternatives, it seems reasonable to observe that any decision to pursue them could be taken as reflective of enlightened U.S. leadership in the thoughtful, bold, imaginative, and purposeful development and use of space.



INDICATED INFRASTRUCTURE

Some of these objectives, if they are to be achieved, would require certain elements of in-space infrastructure; others, depending on how they would be carried out, may or may not require such elements; still others would require none. The manner in which the United States obtains any of this infrastructure should reflect, to the maximum, our already great investment in space technology and operations; whenever reasonably possible, it should be obtained at the lowest capital, and operations and maintenance, cost to the public purse. It would embrace the views of NASA's chief scientist: "In assembling the necessary hardware, the watchword is 'inheritance' . . . projects and spacecraft are to make maximum use of what has been done before . . . and use much common or hand-me-down technology, as much as possible rather than build custom hardware. . . ."[4]

If the Government's large capital costs for development and production are to be minimized and the private sector strengthened, then serious consideration should be given to encouraging the private sector to provide infrastructure elements, through sales, long-term leases, or on the basis of charges for actual service use, that meet Government performance specifications.

---

[4] **Dr. Frank McDonald, quoted in** *The Christian Science* **Monitor, Dec. 28, 1983, p. 14.**

Box K.—"Space Station" as a Focus for Automation Research

NASA is a national resource, a technology-driver for the whole Nation. International competition in automation technologies is a serious threat to U.S. commercial-industrial leadership. The "space station" program would be a good opportunity to help move our R&D efforts in automation onto a faster track. It has the additional advantage that there are no overriding institutional constraints, e.g., that workers would be concerned about the loss of their jobs as a direct consequence of introducing automation, or that certain important technology demonstrations would be too costly in the context of terrestrial practice.

Currently, much of the research in artificial intelligence is being focused on near-term applications; similarly, the development of robotics is tightly constrained by the current requirements of Earth applications. The "space station" program could provide an R&D incentive to work on research topics that are at once truly advanced and germane to the "real world." Possible R&D objectives could include a free-flying robot operating under supervisory control to service and maintain sophisticated satellites, or an automated system to undertake hazardous tasks such as handling cryogenic fuels.

If automation R&D were seriously undertaken in connection with a "space station" program, the many tasks needed to operate the system could be analyzed to select several generic problems of clear relevance to Earth applications. These could include the development of dexterous fingers and hands, flexible manipulators, and advanced sensors, and, especially, the integration of real-time sensing data into the knowledge base of expert systems. In addition, new parallel processing hardware would be required to meet the weight and real-time constraints of space applications. All of these components are necessary to obtain truly flexible control in not wholly determined task environments such as are found in space (or in mining, shipbuilding, undersea work, construction, firefighting, and medicine), in contrast to those of the factory production line. Such a space program would present the opportunity to develop and demonstrate coordinated, integrated control over a wide variety of interacting systems.

Beyond these advantages would come the general development of more sophisticated knowledge and experiential bases in our scientific and engineering communities.

Obtaining space infrastructure in this fashion is not only a reasonable and effective use of U.S. space assets, but it could reduce the difficulty of obtaining public funds for the scientists, engineers, managers, and equipment needed to pursue more, and more important, space ends.

The main elements of longer term space infrastructure called for in pursuing the 10 objectives are:[5]

- an LEO capability to assemble and check out the large and sophisticated satellites and space structures needed to provide both the hazard-prevention and the direct audio broadcast global system/service [objectives (1) and (6)];
- an LEO human residential and working space to be used for medical research [objective (4)];
- a transport staging facility to support efficient travel to geostationary orbit, the Moon, and beyond, using reusable orbital transfer vehicles or other vehicles. This would address objectives (1), (2), (3), (6), (9), and **possibly** (8); and
- a storage facility in LEO would allow use of full Shuttle loads, helping objective (9), and staffed LEO laboratory facilities could promote objective (1 O).

Of course, if such infrastructure elements were available for the specific purposes that justify their acquisition, they could be used for additional purposes also.

Note that, in essence, provision of the infrastructure needed to pursue two of the larger scale

---

[5] **No additional space infrastructure elements are needed to achieve objective (7).**

objectives [(2) and (4)] could accommodate most of the needs of all of the other eight. In what follows, therefore, the cost of this infrastructure is included under these two objectives.

And note that no Government development of free-flying platform infrastructure elements is called for; they (e.g., MESA, SPAS, LEASECRAFT, EURECA, and the Space Industries platform) could and probably would be designed, developed and installed by our private sector, and/or other countries, and offered to the civilian space community—both Government and private interests—under appropriate sale or lease arrangements, where they could be used for the conduct of scientific research or the production of various materials under microgravity conditions.

Finally, note that large amounts of very costly electrical power (with initial capital costs as high as $10,000 per watt) are not called for in LEO; some 20 kilowatts would appear to be sufficient. Larger amounts appear to be needed only for any eventual commercial-industrial materials processing, and could then be provided and financed by the private sector in anticipation that such processing will prove to be profitable.

COST AND SCHEDULE

Attaining all of these 10 suggested conceptual objectives would cost money—overall, a great deal of money. In table 10, rough estimates are made for the cost of each of them, and the length of time over which each would be pursued. in all cases the cost estimates are rounded off to one figure. And, again, the maximum use of: 1) already developed and paid-for space technology, 2) the most truly competitive procurement methods, and 3) the most modern and least burdensome acquisition strategies and procedures, are all fundamental assumptions.

OTA's first rough estimate of the total cost of attaining all 10 of the objectives is some $40 billion (1 984$) over the next 25 years. But, seemingly in the nature of things, long-term high technology development programs such as these invariably encounter unforeseen difficulties and experience the pressure of unexpected external events. Indeed, the total cost should be understood to be no less than $40 billion (1 984$), and perhaps considerably more–as much as, say, $60 billion (1984$).[6] Given the early period at which these estimates are made, there cannot be great confidence in their detailed accuracy. But such accuracy is not needed for the illustrative purposes for which they were developed.

if work were to commence on all of them now, the bulk of the cost would occur over the next 15 years.

Space transportation costs are not included in these estimates, except for an additional $0.1 billion (1984$) or so for each LEO-lunar orbit flight. Rather, it is assumed that some 10 Shuttle surface-LEO flights per year, at an average cost of about $0.1 billion (1984$) each, would be budgeted for all Government-sponsored civilian research and development purposes, including those considered here.

Clearly, these costs are great in total sum, especially in the face of other important calls upon Federal tax revenues during an area of multi hundred billion dollar annual deficits in the Federal budget.

While the total cost of our publicly funded civilian space program will reflect the magnitude and character of the objectives addressed in the program, and these will, in turn, reflect political decisions, the unit costs to acquire and operate the technology will reflect engineering and management decisions.

Beyond the observation that, in some general fashion, the cost will increase with the magnitude,

---

[6] ''In recent decades the average overrun on major programs, in constant dollars and constant quantities, has been slightly over 50 percent. The average schedule milestone has been missed by a third of the time initially projected. The average time to develop new systems has, until recently been increasing at the rate of three months per year . , each year. " Norman R. Augustine, "The Aerospace Professional . . . and High-Tech Management, " *Aerospace America,* March 1984, p. 5.

Table 10.—Cost and Schedule to Satisfy Objectives Suggested for Discussion

Objectives	Total cost[a] (billions, 1984 dollars)	Duration (years)
1. Establish a global information system/service re natural hazards	2	10
2. Establish lower cost reusable transportation service to the Moon and establish human presence there[b]	20	15, 25
3. Use space probes to obtain information re Mars and some asteroids prior to early human exploration	2	15
4. Conduct medical research of direct interest to the general public[d]	6	5, 25
5. Bring at least hundreds of the general public per year into space for short visits[e]	0.5	5, 25
6. Establish a global, direct, audio broadcasting, common-user system/service	2	10
7. Make essentially all data generated by civilian satellites and spacecraft directly available to the general public	0	25
8. Exploit radio/optical free-space electromagnetic propagation for long-distance energy distribution[f]	0.5	10
9. Reduce the unit cost of space transportation and space activities[h]	5	15
10. Increase space-related private sector sales[h]	0.5	25
	- $40[i]	

[a] Costs are for development and acquisition. Operations and maintenance costs are not Included, except for some launch and operations costs noted for objectives 2, 3, and 4.

[b] 15 years to establish the settlement, and 3 visits/year at $0.1 billion each (Plus basic Shuttle launch costs) over the following 10 years.

[c] On the average, one probe every 3 years and S0.4 billion each.

[d] $2 billion over 5 years t. establish a life sciences laboratory in LEO, and $0.2 billion/year thereafter to operate it. This laboratory could also be used for materials science and other research.

[e] 5 years to establish a LEO "lodge-habitat, " and its continuing use thereafter.

[f] $0.05 billion/year In addition to DOD expenditures.

[g] $0.3 billion/year for a 15-year technology development effort to reduce space transportation unit costs.

[h] This would also help efforts directed toward the other objectives.

[i] The actual cost could be as high as $60 billion (1984 dollars), if costs exceed initial predictions by 50%.

generality, and sophistication of the space capability acquired, it is difficult–indeed, it is impossible, at this time—to estimate the eventual cost to the Government of addressing these objectives and obtaining the required infrastructure. A number of the significant infrastructure "cost-drivers" are presented in chapter 4. Suffice it to say here that there are a number of factors that could influence the net cost to the taxpayer for acquiring space infrastructure, and many opportunities to minimize this net cost that could be grasped by vigorous and imaginative NASA management. Appendix D speaks to the matter of cost containment.

To this point, only the initial capital cost of LEO infrastructure has been considered. To this cost must be added its ongoing operation and maintenance (O&M) costs (and the O&M costs of lunar infrastructure also); the cost of instruments, furnaces, etc., needed for scientific experimentation in association with its use; and the interest cost of any money borrowed to fund the acquisition program.[7] We must remember, too, that infrastructure eventually becomes obsolete or wears out, and, since its support services will come to be depended on, this implies that some form of amortization and replacement will be called for.

A consequence of the successful attainment of any or all of these unit cost reduction objectives—and reduction in the unit cost of space

---

[7] Any such cost is not allocated (if indeed it were possible to allocate it) on a program-by-program basis. But, in the overall, the more than $100 billion per year now required to be paid on the Federal debt is a cost of Government that must be considered by Congress, at least implicitly, in all of its authorization and appropriation actions—in the space area as for all others.

transportation generally—would be to attract more private interest to space activities. NASA, in turn, would then be able to apply more scientific, engineering, and management attention, and more of its research, development, test, and evaluation funds, to the development of truly "cutting edge" technology in support of its science, exploration, and other activities.

CONCLUSIONS

To create a truly modern civilian space program, the United States now might well move to adopt up-to-date, long-term goals in the civilian space area, and to initiate work on a first family of specific space objectives to address over the next 20 to 25 years, If such goals and objectives were set, the Nation would have a clearer picture of the kind of space infrastructure required to meet the objectives, as well as the cost and schedule under which this infrastructure could be obtained.

The United States would also be able to treat its publicly supported civilian space program more explicitly as a direct investment of great potential economic importance, in addition to the other benefits that it provides. This might in turn ensure that the program's public costs would be prudently contained, that its economic benefits would be substantially and objectively enlarged, and that it would serve the broadest public interest.

Finally, if an early, paced transfer of management attention, commitment, and resources takes place away from further major development and/or production of Shuttle capability, and if there is a vigorous and innovative pursuit of Government cost sharing with other countries and our own private sector, then the 10 objectives outlined here–or others analogous to them–could be aggressively pursued, and probably attained relatively soon, within the appropriations now expected to be received by NASA. And the attainment of these objectives would entail the acquisition of much of the in-space infrastructure that NASA now aspires to acquire. Also, if there is a continuing increase in extra-NASA payments for use of Shuttle services, and if the private space-related sector succeeds in continuing to grow at anything like its present rate, thereby generating rapidly increasing tax revenues, these important "offsetting" incomes could be taken into consideration by Congress when passing on NASA appropriations.

Indeed, a reasonable extrapolation from present funding circumstances would suggest that, by the end of this century, our publicly supported space program could be much larger than it is today.

It must be emphasized that whether or not, as a matter of public policy, our tax-supported civilian space program should be allowed to grow to the magnitudes discussed here as possible is not an issue addressed in this report. Rather, it is important to appreciate that, under certain conditions, expenditures for this program could be considered to be offset to a large extent by revenues, thus giving Congress more flexibility in setting expenditure levels than it has today. An important element of public debate about our space future, therefore, should be about the allocation of public, economically related investments therein—for we need no longer consider our public space expenditures as consumption expenditures that underwrite the salaries of astronomers, the technologies required for exploring the solar system, and the intangibles of "space leadership. "

The promising prospects now in view indicate what agenda items should be emphasized in public policy considerations of our long-term civilian space interests. For if, over the next quarter-century, we modernize our civilian space goals and lay out a family of objectives for our civilian space activities much broader than those usually discussed; if we determine to focus our Government and private sector skills on building, together, a great commercial-industrial-financial private sector space business in the face of growing international competition; if we administer and manage our space activities with vigor, imagination, and statesmanship; and if we take the lead in orchestrating the space interests and activities of all of the friendly countries of the world; then we can move civilian space activities into the mainstream of America's— indeed, the world's— interests, reap great political, social, and economic benefits, and very soon begin to have our men and women strike out across the solar system.

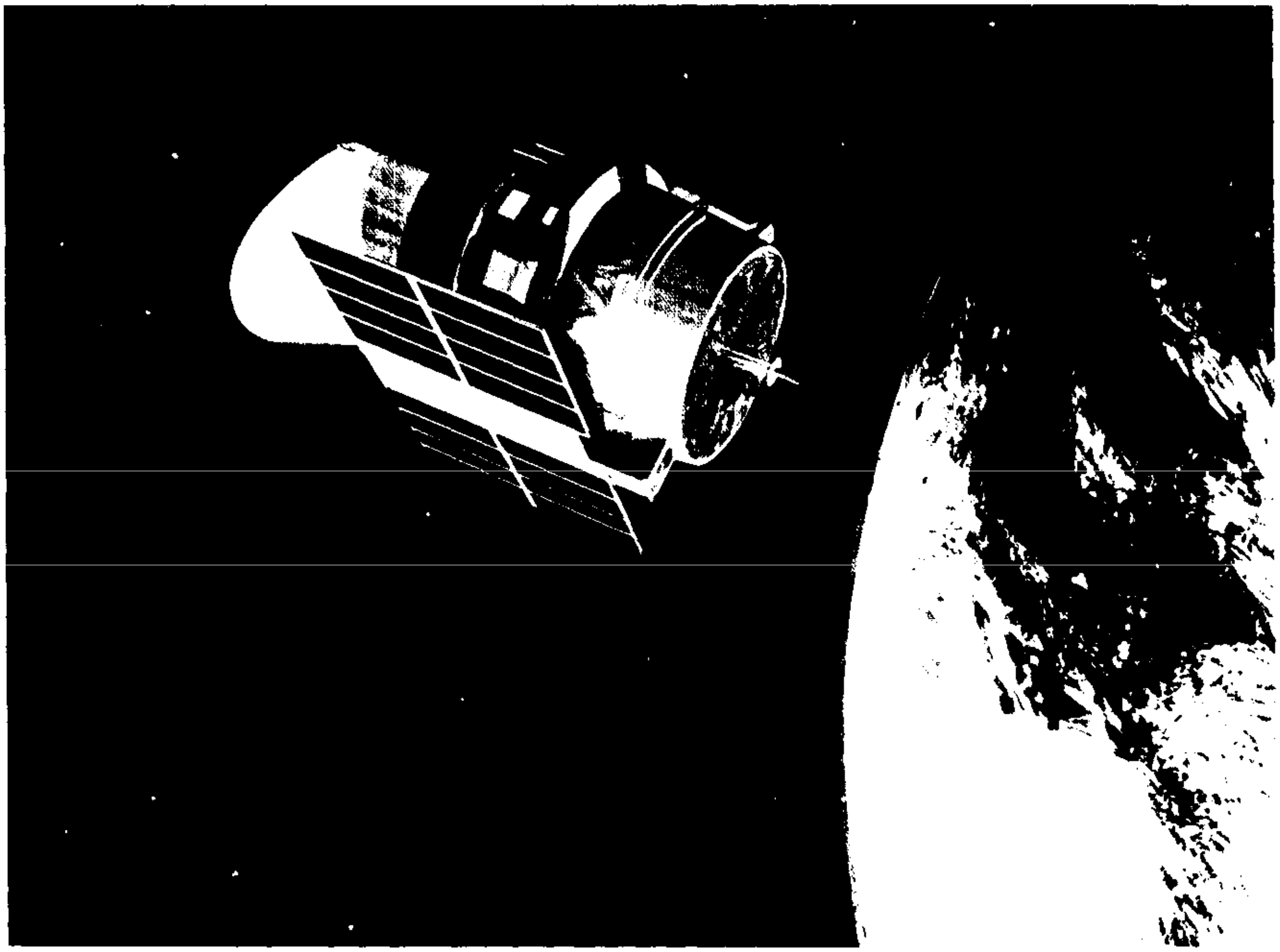


Photo credit National Aeronautics and Space Administration

Space technology has opened up the entire universe to observation and scientific research. Satellite (IRAS), a joint **project of the United States, the United Kingdom, and the Netherlands, produced dramatic revelations about the characteristics of other stars in our galaxy.**

FINAL OBSERVATIONS

Congress and the United States will soon have an unprecedented opportunity to rethink its basic views and interests in the civilian space area through the creation, and subsequent endeavors, of a "National Commission on Space. " Public Law 98-361 mandates that such an extraordinary Commission be formed.

In preparation for doing so, a few observations should be made about a truly fundamental concern held by many regarding our publicly supported civilian space program–a concern that, for the most part, goes unvoiced by professionals associated with this program, but which should be dealt with in any fundamental reexamination of it. In so doing, we should keep in mind that the essential magnitude and character of this program was set a generation ago in response to the major national security concern raised by the launch of Sputnik by the U. S. S. R., and subsequent international events and our perceptions thereof. Thus, the basic nature was set in another era to serve the needs of that era and, fundamentally, has changed little, even though those needs have long since been met.

This concern may perhaps best be expressed in question form: How can the U.S. people and Government justify, today, continuing to make such truly great and continuing public expenditures on space related matters perceived by most of our general public as (however at times interesting, and even exciting) lying well outside of the mainstream of their personal interests and concerns, particularly now that our military space program serves to offset most perceived U.S.S.R. space-related military "threats," and during an extended period of unusual national financial stringency?

As Congress begins to ponder this question, it might start by reflecting on an observation made recently by Freeman Dyson: " . . . if I look at, say, Senate hearings and Congressional Committees, they tend to pay **too much attention to scientists. They're always talking very much in quantitative terms and technical details** when the problems really aren't there. They very seldom ask, 'Well, what's all this **good** for?' " (Emphasis in the original .)8

In response to this question, many might be willing, in principle, to give the Government the "benefit of the doubt" when its leaders point out (as **they have nearly every year for** the past dozen, at least), that eventually such R&D expenditures will return economic benefits many times over. While there is a general consensus that, in macroeconomic terms, economic "spinoff" to the private sector has been significant, outside of the satellite communications area it has not been possible to identify with objective confidence, to date, that such great economic returns have been obtained (though there are grounds for hope that eventually satellite navigation and materials processing in space may also provide significant economic benefits).[9] And, of course, the same prospect for economic return could be advanced also about many other economically related R&D areas, high technology and not, in which Government expenditures are either essentially zero or only a very small fraction of today's annual $7 billion public civilian space expenditures. So there is understandable reserve and questioning about such a response. For most of us, $7 billion per year is a great deal of money.

Well beyond these kinds of considerations is the ethical concern of whether or not scientists, engineers, and managers should be paid so very well by the public to spend additional large sums of public funds each year to do such things as take photographs of distant planets. Many take the view that, with the immediate, continuing, and enormous problems faced by hundreds of millions of people throughout the world, with millions of U.S. (tax-paying) families having to live on a truly modest income or, indeed, having to deal with the lack of employment, with interest

---

[8] *The Washington Post,* **Apr. 9, 1984,** p.B-11.

[9] **However difficult it may be to quantify the benefits of space R&D, one can say with confidence that the use of weather satellites has saved thousands of lives. In addition, the use of surveillance satellites has resulted in savings to the Government that are on the order of tens to hundreds of billions of dollars.**

payments on our Federal debt now costing us over $100 billion per year, supporting space research and exploration of this great magnitude just doesn’t seem to be a sensitive and equitable use of public funds or even, to some, a particularly decent human avocation.

The more general pro forma response to this concern, at least in part, is that: “ . . . life is unfair. ” Life is unfair. But most of us would probably agree that we all do have some obligation, when reasonably possible, to attempt to redress some of these sobering societal imbalances and that, at the very least, those who are generously supported by the public to engage in civilian space activities should share widely in the discharge of this obligation.

Another general pro forma response is that most grave and widespread human problems seemingly cannot be addressed by space-related activities, any more than they can be by a ballet production or a walk in a park.

In this assessment the more direct and useful response is that some of our civilian space program objectives can be purposely selected to see that space is used, specifically, to make progress toward important agreed-on societal ends. The suggested family of 10 conceptual objectives has been crafted so as to see that some of them speak directly to a few of the most fundamental human concerns that space and space technology can indeed be used to “get at”: better protection from natural disasters, better communications among the world’s governments and peoples in our nuclear weapons age, and greater understanding of physical conditions that affect all of us as we grow older. They are of such a basic nature as to be of potential value to “all mankind. ”

And, as well, a basic theme suggested here is that the publicly supported civilian space program now could be organized and conducted to a considerable extent as a public investment program in basic science and high technology, and that its leaders now could be charged, explicitly, with overseeing all of our public space activities with a fundamental view in mind: that these activities lead, in both the shorter and longer run, to the creation of wholly new commercial-industrial-financial ventures, and to truly large-scale, rapid, objectively measurable, national economic growth —with all that this implies for the delivery of new, useful, public and private goods and services, increased employment, increased deficit-offsetting tax revenues, and a more competitive international trading position.

And another basic theme is that the U.S. Government could now endeavor to orchestrate the interests and capabilities, however diverse and/or small, of all of the friendly peoples of the world in cooperative civilian space activities.

If the United States does all of these things, and does them in a truly efficient and productive manner, then we would see space being used, where space can sensibly be used, both to **protect and to ease the human condition.**

With the creation of such major space-related programs to address such basic human concerns, and appreciating that most of us the world over, much of the time, “do not live by bread alone,” we can in more reasonable conscience also continue to undertake—and even perhaps enlarge upon—space-related activities that, as well, **challenge the human condition: we can strike out from the Earth for the** Moon,[10] for the planets and asteroids, and indeed fix our eyes on ‘‘distant stars.

But only if we pay our ethical dues to our fellow countrymen and women and to “all mankind”- and only if we meet our financial obligations as we go.

---

[10] An OTA Working paper giving the thoughts of six philosophers on **“The Philosophical Implications of Establishing Permanent Human Presence in Space” is available from the OTA Science, Transportation, and Innovation Program office.**