Chapter 1

EXECUTIVE SUMMARY

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INTRODUCTION: RELATION OF A "SPACE STATION" (I. E., SPACE INFRASTRUCTURE) TO THE U.S. FUTURE IN SPACE

Atter the expenditure of some $200 billion (1984$) since the launch of its first spacecraft in early 1958, the United States has obtained the scientific knowledge and developed the technological capability and professional expertise to succeed in virtually any theoretically possible civilian space venture that it may choose to undertake, But America's second quarter-century of space activities promises to differ markedly from the first, almost wholly exploratory, era. If space is to be successfully developed in roughly the same fashion as have other, more familiar natural resources and environments, the next stage will be characterized by establishing and securing the capabilities to support routine, operational activities there. In this report, OTA refers to the range of in-space facilities and services that would support such activities as "infrastructure."

Important steps in the considered development of space have already been taken. By any standard, the satellite communications industry is a great success; its revenues have reached the multibillion-dollar per year level and are growing at an annual rate of 15 percent. Massive launch facilities, expendable launch vehicles, and the space Shuttle *now* provide routine access to much of near-Earth space; used in conjunction with a global communications network and surface data processing facilities, they provide a sophisticated, though limited, range of services to their users.

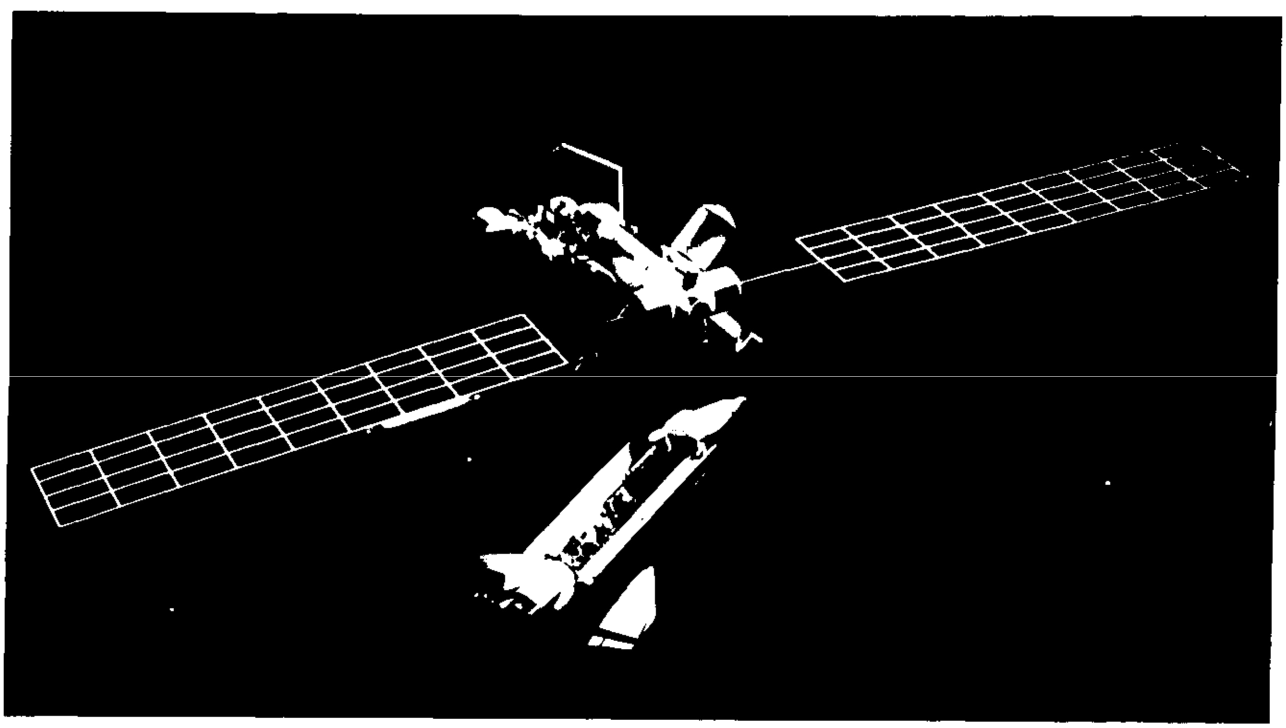


Photo credit: National Aeronautics and Space Administration

A large, inhabited "space station" in low-Earth-orbit is one approach to the establishment of a long-term infrastructure in space. The concept shown here (being visited by the space Shuttle) is a NASA designed and built model used for illustration throughout early 1984.

Another sign of strength is the maturity of the U.S. aerospace industry. This sector is now beginning to position itself to provide space assets and services independently, and now anticipates conducting some in-space investigations and commercial-industrial activities, privately financed, either on its own or in combination with other business concerns. And other countries now have capabilities to do many things in space—capabilities that continue to grow rapidly.

For years, leaders of the U.S. civilian space community have advanced the view that the next major logical step in space should be the acquisition of specific, permanent in-space infrastructure: a civilian "space station. "

In this context, Congress, in July of 1982, asked OTA to undertake an assessment of "Civilian Space Stations"; this report is the product of that request. The OTA assessment was requested originally by the Senate Committee on Commerce, Science, and Transportation, later (in October 1982) by the House Committee on Science and Technology. The assessment was endorsed in August 1982 by the House Committee on the Budget and the Senate Committee on Appropriations. The various committee interests were stated as follows:

- **Senate Committee on Commerce, Science, and Transportation:** assess the need for a permanent orbiting facility; examine the major technological alternatives and their related costs and benefits; focus on the different space station designs and orbits, the range of feasible applications for the project, the benefits and drawbacks of utilizing existing concepts, the estimated costs for potential missions and design options, and prospective private sector and international involvement.
- **House Committee on Science and Technology:** undertake an independent, rigorous, balanced study of the need for a space station; address "the hard questions"; not only look at what a station can do that cannot be done better some other way, but also evaluate alternatives to a space station. "In short, the assessment should address and document the real forces driving us to build a space station. "
- **House Committee on the Budget:** estimate the effect of a space station's cost on the NASA budget and the overall Federal budget; and consider the roles of the Department of Defense, the international community, and the private sector in the development, production, and operation of an inhabitable space station.
- **Senate Committee on Appropriations:** estimate the relative merits-of in-habitable and u nonhabitable space platforms; estimate the role automation/robotics can be expected to play in the construction and eventual use of space platforms; and estimate the costs associated with the range of design options.

This assessment has attempted to be responsive to the entire range of congressional interest, with the exception of the interest of the House Committee on the Budget in the role of the Department of Defense.

The report has examined the range of technology required of permanent space infrastructure as well as the broader policy questions arising from NASA's proposal of a particular constellation of infrastructure elements. **Overall, the considered development of space through the paced acquisition of appropriate elements of space infrastructure is a key to maintaining America's leadership in space. However, because the Nation does not have clearly formulated long-range goals and objectives for its civilian space activities, proceeding to realize the present NASA "space station" concept is not likely to result in the facility most appropriate for advancing U.S. interests into the second quarter-century of the Space Age.**

RATIONALE FOR SPACE INFRASTRUCTURE

Several countries are competent in the conduct of space investigations and the development and use of space technology. These countries are now providing growing economic competition for the United States through development, acquisition, and operation of their own elements of infrastructure. The Soviet Union has made a commitment to the permanent occupancy of space, has operated orbital stations with human work crews for over a decade, and is showing interest in providing competitive space services. Thus, if the United States is to continue as the leader in civilian space activities, Congress must give serious thought to the kind of space infrastructure to be developed, the long-term goals that that infrastructure is to serve, and the public-private and international arrangements that will take best advantage of it.

Future development of more sophisticated space science and applications capabilities—e.g., staging of planetary exploration missions or assembly of large communications platforms—would be markedly facilitated by the existence of appropriate elements of space infrastructure. It is assumed in this report that, whatever decisions are made regarding space infrastructure, publicly supported space science and space applications will continue at roughly their present level of appropriations (over $1 billion per year, as measured in constant dollars).

Although the United States already has acquired some initial elements of space infrastructure, these are insufficient to undertake a number of desirable activities in an efficient and effective manner. The acquisition of some additional permanent in-space infrastructure elements would:

- allow sophisticated experiments in life and materials sciences to be conducted;
- permit fuel to be stored and supplies to be warehoused in low-Earth-orbit;
- initiate more efficient staging of voyages to high orbits, the Moon, planets, and asteroids;
- allow the initial trial of new instruments, activities, and procedures; and
- allow the repair and maintenance of increasingly complex and specialized satellites and common carrier platforms.

The ability to undertake these activities, all of which would support space science and applications, constitutes a persuasive rationale for acquiring appropriate elements of permanent space infrastructure. At present, the more appropriate would be those which allowed the satisfactory conduct of: 1) life and materials sciences experiments, and 2) satellite servicing. However, by the same token, sufficient resources to ensure that these science and applications activities actually *are* undertaken must be assured; otherwise, the rationale for the infrastructure vanishes.

Box A.—What Is Space Infrastructure?

The terms "space station" or "space transportation node" are most accurately and usefully understood as identifying elements of long-term, perhaps permanent, in-space infrastructure, for the most part concentrated initially in low-Earth-orbits (LEO). These elements would provide in-space structure, electrical power, thermal control, warehousing, stability (*re* location, attitude, and temperature), communications, fuel, associated docking and air lock capabilities, local transportation, LEO-GEO (geosynchronous orbit) transportation, and, if staffed by men and women, life support, and residential and working space. Because it is expected to be sophisticated, and useful for periods of several decades, this space infrastructure (used in concert with other infrastructure elements already in hand such as the Kennedy launch complex, the global data relay communications system, the Shuttle, etc.) could provide a new and qualitatively different regime of space assets, allow the provision of new space services, and support the conduct of space activities in a new and presumably more efficient and effective manner. Space infrastructure provides methods and means that assist in addressing space end objectives.

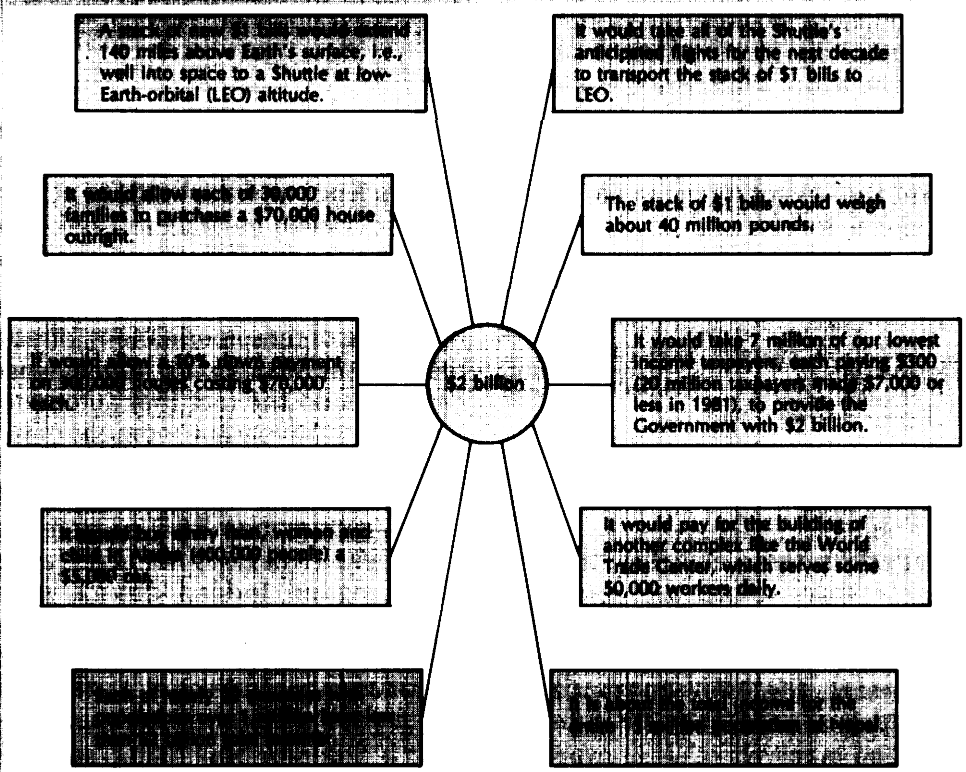
A persuasive case can also be made for seeing that some of these permanent infrastructure elements allow an on-board human work force. This case rests on the fact that automated facilities, whether relatively autonomous or teleoperated, capable of supporting all of the activities listed above will not be available before 2000, even if a large automation R&D program is begun immediately. (This does not argue against such an R&D program. Indeed, there is good reason to expect that sophisticated automation will be necessary for the future development of space as well as for non-space-related Earth applications. It might well be appropriate, therefore, to initiate such a program now. Later, with the results of this program in hand, informed judgments could be made about the most sophisticated mix of human and machine workers.)

As the Shuttle development program comes to a close, thousands of in-house engineers and technical support staff and, in principle, as much as $2 billion (1984$) per year in contract funds under its present $7 billion (1984$) "budget envelope" will be freed up to be applied to one or more new programs. If NASA is to maintain its current size—a size that NASA leaders judge to be acceptable to the general public–the combination of people and funds that could soon become available suggests, strongly, that any new programs must include development and acquisition of a great deal of new technology, preferably related to having people in space; large numbers of technologists would be gainfully employed both in NASA and in the space industry under contract to NASA.

In addition, many believe that NASA might not long survive in its present form without a single, large, "people-in-space" program upon which a majority of its energies are focused. If a number of smaller programs were initiated instead, each of them, it is thought, could be terminated

Box [illegible]—$2 Billion

[illegible] acquiring in-space infrastructure is beyond the imagi-[illegible] of its magnitude, the sum of $2 billion is chosen, [illegible] what could be involved in the Government's ob-[illegible] be spent. This amount is: 1) approximately the annual [illegible] and 2) the amount NASA estimates is needed [illegible] one initial pressurized module that would allow [illegible] expects that 4 to 5 such modules plus other associated [illegible] civilian "space station" by the early 1990s.



without widespread objections arising in the political process.

Finally, NASA may have thought it prudent to propose a "space station" program rather than some other large endeavor(s) (e. g., a return of Americans to the Moon, or sending people on an expedition to Mars, etc.), both because the former had been carefully studied over the years, representing, in NASA's view, a natural complement to the Shuttle, and because alternative large programs seemed too grandiose, have not recently been discussed with the general public, and, therefore, were less likely to enlist the required support, both within and without the administration.

All of these considerations, taken together, are clear incentives for the space technology leaders, both Government and industry, to opt for a combination of a Shuttle-like "methods and means" activity, rather than to accept the position of a much smaller Federal agency or to fight for approval of one or more large, new space "end" programs.

But while **the case to be made** for acquiring ***some*** **long-term, inhabitable infrastructure in low-Earth-orbit is persuasive, OTA concludes that there is no compelling, objective, external case either for obtaining all of *the particular array*** of **elements that NASA now describes under the rubric of "The Space Station, " or for obtaining this or any other array *in the general manner* that** NASA is now ex**pected to pursue, or for paying *the particular public cost* that** NASA **now estimates is required. As the infrastructure would be of a broadly general-purpose nature, to be used to support over 100 conceptual uses (few of which have** been sharply defined or have gained wide acceptance as important objectives of the space program), there is no necessity for obtaining all of this particular array soon.

INFRASTRUCTURE OPTIONS

The fact that the United States has already developed a wide variety of space capabilities means that it has genuine choices–both of what infrastructure elements it places in orbit and of how these elements are to be acquired and used. It is around these choices that the difficult issues lie; by and large, the technology is either in hand or can be readily developed.

Technology Options

It **must be emphasized that the particular constellation of space infrastructure elements that** NASA **currently aspires to develop, construct, deploy, and operate is only one alternative in a wide range of options. Simply put, there is no such thing as "the space station. " What is under discussion is a *variety of sets of infrastructure elements,* ranging from modest extensions of current capabilities to more sophisticated, capable, and costly ensembles than NASA is** now **suggesting.**

As one way of presenting the variety of technology options available, OTA has prepared tables 1 and 2.[1]

There is one fundamental infrastructure option that requires particular mention: should the elements be wholly automated or should they house a human crew? Conceptually, useful space infrastructure could be designed either to include a human work crew or to depend on sophisticated machines unattended in space or operated via communication links with the surface. Despite the fact that the relative efficiency and/or effectiveness of these two quite different approaches have been extensively debated for years, no general consensus has emerged. However, if sophisticated new space activities are to be supported by in-space infrastructure as soon as the early 1990s, there will have to be a human presence.

[1]Ch. 3 of this report discusses infrastructure options in detail.

Table I.—Comparison of Some Options[a] for Low-Earth-Orbit Independently Operating Infrastructure

	Shuttle Orbiter	Extended Duration Orbiter: Phase I	Extended Duration Orbiter: Phase II	Free-flying spacelab (developed as permanent infrastructure)	NASA Infrastructure aspirations: Initial operational capability	NASA Infrastructure aspirations: Mature, fully developed
Date available (assuming start in 1985)	Now	1988	1990	1990	1992	1996-2000
Cost[b] (billions of fiscal year 1984 dollars)	None	0.2	0.5	2-3	8	20
Characteristics						
Power to users (kW)	7	7	20	6	80	200
Pressurized volume (m^3)	60	60	100 (with Spacelab habitat)	100	200	300
Nominal crew size	6	5	5	3	8	20
Miscellaneous	Can accept Spacelab	No new technology	New technology required; modest laboratory space	Modest crew accommodations	Orbital maneuvering vehicle plus two free-flying unpressurized platforms	Reusable orbital transfer vehicle plus several more platforms
Capabilities[c]						
Time on Orbit	10 days	20 days	50 days	Unlimited (60-90 day resupply)	Unlimited (90 day resupply)	Unlimited (90 day resupply)
Laboratories for:						
Life sciences	Moderate	Moderate	Considerable	Extensive	Extensive	Extensive
Space science/applications	Modest	Modest	Modest	Modest	Extensive	Extensive
Materials science	Some	Some	Moderate	Moderate	Extensive	Extensive
Technology development	Modest	Modest	Some	Moderate	Extensive	Extensive
Observatories	No	Modest	Modest	Modest	Extensive	Extensive
Data/communication node	No	No	No	No	Considerable	Extensive
Servicing of satellites	Modest	Modest	Modest	Modest	Considerable	Extensive
Manufacturing facility (materials processing)	No	No	Modest	Modest	Considerable	Extensive
Large structure assembly	No	No	No	Modest	Moderate	Extensive
Transportation node	No	No	No	No	Moderate	Extensive[d]
Fuel and supply depot	No	No	No	No	No	Considerable
Response to reasons advanced for space infrastructure						
Maintain U.S. space leadership and technology capability	No	Modest	Modest	Modest	Considerable	Extensive
Respond to U.S.S.R. space activities	No	Modest	Modest	Modest	Considerable	Extensive
Enable long-term human presence in space	No	Modest	Modest	Considerable	Extensive	Extensive
Attention-getting heroic public spectacle	No	Modest	Modest	Modest	Modest	Modest
Extended international cooperation	Modest	Modest	Moderate	Moderate	Moderate	Moderate
Promote U.S. commercialization of space	Modest	Modest	Modest	Considerable	Considerable	Considerable
Maintain vigorous NASA engineering capability	No	No	No	Modest	Extensive	Extensive
Enhance national security, broadly defined	No	No	No	Modest	Unclear	Unclear
Space travel for non-technicians	Modest	Modest	Modest	Modest	Considerable	Considerable

[a] Listed options are illustrative examples; the list is not exhaustive.
[b] Costs include design, development, and production; launch and operational costs are not included. Some costs are estimated by the Office Of Technology Assessment; others were provided to OTA.
[c] Clearly judgmental.
[d] Including launch to the Moon, Mars, and some asta:otis.

Table 2.—Space Infrastructure Platforms[a] That Could Be Serviced by Shuttle or an Orbital Maneuvering Vehicle

	Unpressurized coorbiting platforms (serviced by means of extravehicular activity)				Pressurized platforms (serviced internally while docked)	
	SPAS	MESA	LEAS ECRAFT	EURECA	Space Industries' Platform	European Modified Spacelab
Date available						
(now, or approximate, assuming start in 1985)	Now	Now	1986	1987	Late 1980's	1989
Cost[b]						
(billions of fiscal year 1984 dollars)	0.005	0.01	0.2	0.2	0.3	0.6
Characteristics						
Power to users (kW)	0.6	0.1	6	2	20	6
Pressurized volume (f?)	None	None	None	None	2,500	3,000
Nominal crew size	None	None	None	None	1-3 only when docked	3
Miscellaneous	3,000 lb Payload	200 lb Payload	20,000 lb Payload	2,000 lb Payload	25,000 lb Payload	20,000 lb Payload
Capabilitiesc						
Time on orbit	10 days	8 months	Unlimited	6 months	3-6 months	Unlimited
Laboratories for:						
Life sciences	No	No	Modest	Modest	Modest	Moderate
Space science/applications	Modest	Modest	Modest	Modest	No	Moderate
Materials science	Modest	No	Modest	Modest	Moderate	Moderate
Technology development	No	No	Modest	Modest	Moderate	Modest
Observatories	No	No	Modest	Modest	Modest	Moderate
Data/communication node	No	No	No	No	No	No
Servicing of satellites	No	No	No	No	No	No
Manufacturing facility (materials processing)	No	No	Considerable	Modest	Extensive	Considerable
Large structure assembly	No	No	No	No	No	No
Transportation node (assembly, checkout, and launch)	No	No	No	No	No	No
Fuel and supply depot	No	No	No	No	No	No
Response to reasons advanced for space infrastructure						
Maintain U.S. space leadership and technology capability	No	No	Modest	No	Modest	No
Respond to U.S.S.R. space activities	No	No	Modest	No	Modest	Modest
Enable long-term human presence in space	No	No	No	No	No	No
Attention-getting heroic public spectacle	No	No	No	No	No	No
Extended international cooperation	Yes	No	No	Yes	No	Unclear
Promote U.S. commercialization of space	Unclear	Modest	Considerable	No	Considerable	No
Maintain vigorous NASA engineering capability	No	No	No	No	No	No
Enhance national security, broadly defined	No	No	No	No	No	No
Space travel for non-technicians	No	No	No	No	No	No

[a] Listed platforms are illustrative examples; the list is not exhaustive.
[b] Costs include design, development, and production; launch and operational costs are not included. Some costs are estimated by the Office of Technology Assessment; others were provided to OTA.
[c] Clearly judgmental.

Procurement Options

Inasmuch as there is an affirmative answer to the question of whether to acquire some long-term, in-space infrastructure, the decision of how it is to be acquired must be faced. In many respects, this second decision is just as important as the first. The mode of acquiring new, long-term, in-space assets and services should be influenced by a clear understanding of the context in which space activities are expected to be carried on. And the decision as to how to acquire these assets and services will have a significant impact on future space activities.

There are four main factors that could heavily influence procurement choices:

- Several foreign countries are now capable of producing and operating substantial elements of space infrastructure.
- Using its own resources, the U.S. private sector is now capable of producing much of the infrastructure currently envisioned and offering it for sale or lease to the Government or the private sector.
- NASA would prefer to acquire the infrastructure under its own aegis and in the same general way that it has acquired other large space systems (except for Spacelab).
- Other large and sophisticated civilian space programs-can be easily imagined that would require professional skills and funds of the kind and magnitude now envisioned for a "space station. "

Congress and the President have approved NASA's request to initiate a "space station" program, and NASA appears to be moving to acquire such infrastructure in much the same fashion that it acquired the Shuttle:

- A great deal of new technology would be developed, acquired, and used, essentially all of which would be publicly funded.
- NASA would arrive at and issue detailed engineering specifications for, and exercise close management control over, the technology to be acquired.
- This infrastructure would be procured by NASA with Federal funds. The U.S. private sector would not be prompted to use its own resources to provide a substantial portion of the infrastructure.
- The international role would be limited. NASA would not seek the kind of close collaboration that would result in shared authority, even if doing so might result in substantial capital cost reduction for the United States.

A significantly different acquisition approach– **another option—would** have the following elements:

- As much as is reasonably possible, already developed, tested, and paid-for technology would be used to achieve an adequate initial operating capability, with development of new technology undertaken only where demonstrably required to lower overall cost of ownership.
- NASA would prompt our private commercial-industrial-financial sectors to develop and produce, with their own resources and on a genuinely competitive basis, as many of the Government-required civilian "space stat ion' assets and services as they can; NASA would facilitate their efforts to do so; and they could be offered to NASA on a sale, lease or payment-for-service basis.
- NASA, in obtaining the elements not provided by the private sector, would emphasize management methods specifically designed to take the best advantage of the now quite sophisticated U.S. space industry.
- NASA would negotiate collaborative agreements with other cooperating countries that would see all partners share in the benefits of such an initial operating capability at a reduced acquisition cost to the U.S. Government for its share.

This second approach would imply that NASA would hand off much (perhaps most) of the more mundane "space station" work by paying the private sector to do it, thereby conserving its skills and resources so that they could be focused on more challenging space goals and objectives, including development of the very advanced technology (e. g., bipropellant engines, a reusable orbital transfer vehicle, etc.) required to address them—an activity which, for the most part, the private sector cannot justify.

These two options are at opposite ends of a spectrum of approaches to the acquisition of long-term space infrastructure. In determining which approaches from this spectrum are most likely to influence the evolution of space activities in a desirable direction, Congress may wish to consider the following questions:

- Should the Government be allocating its professional skills and experience to the development of (a) incremental or (b) fundamental advances in technology?
- Which approach is most likely to stimulate the "commercialization of space?"
- What level of international collaboration is really desirable?
- What other large and important space ends should be addressed in the next decade in addition to the acquisition of in-space infrastructure methods and means?

Congress may also wish to keep in mind that the choice of approach to infrastructure acquisition will also affect its eventual cost to the taxpayer. Beyond the observation that, in some general fashion, the cost will increase with the capability and sophistication of the infrastructure, accurate cost estimates are very difficult to make.[2] However, the following are important cost factors:

1. the total capability acquired–which, as suggested by the examples listed in the tables of infrastructure options, can encompass a considerable range;
2. the extent to which already developed, tested, and paid-for technology is used, v. a focus on new technology with its higher development cost and greater risk of cost overruns;
3. the substitution, where feasible, of automated systems for the accomplishment of tasks previously undertaken only by human beings;
4. the manner by which the infrastructure is acquired–i.e., the extent to which NASA puts the engineering challenge on the space industry by issuing performance specifications, rather than continuing to issue detailed engineering specifications and managing the acquisition process in detail;
5. the effectiveness of NASA's efforts to persuade our private sector to develop infrastructure assets and services "on their own, " and to provide them to the Government at purchase, lease, or payment-for-service prices lower than those achievable by the Government;
6. the effectiveness of NASA's efforts to effect eventual private sector operation of the infrastructure and its related activities;
7. the extent to which large and rapid expansion of military space research, development, test, and evaluation (RDT&E) activities increases costs in the civilian space sector also;[3]
8. the extent to which any "Christmas-tree effect" takes place within NASA, whereby the infrastructure acquisition management is persuaded by the NASA Centers to allow the cost of desirable but nonessential RDT&E activities to be included in the acquisition program; and
9. the effectiveness of NASA's efforts to arrive at large-scale collaboration and related cost-sharing arrangements with other countries.

These points address only the initial capital cost of this infrastructure—to this cost must be added its ongoing operation and maintenance costs; the cost of instruments and equipment needed for scientific experimentation in association with its use; and the interest cost of any money borrowed to fund the acquisition program. And it must be remembered, too, that the infrastructure will eventually become obsolete or wear out.

It is clear that there are many opportunities to reduce infrastructure net cost that could be grasped by a vigorous, imaginative, and determined NASA management.[4]

These considerations suggest that, over the next year or two, at least as much attention should be given to identifying the best ways by which the country should set about the permanent development of space as there is given to any technologi-

[2] See ch. 4 of this report for a discussion of cost estimation considerations.

[3] Classified material was not used in preparing this report.

[4] Cost reduction measures are discussed in app. D of this report

cal advances and operational capabilities that are to be obtained.

Funding Rate Options

Another way of thinking about space infrastructure is to estimate how much of it could be obtained if different annual funding rates were established. Thus, to provide an independent basis of comparison with the civilian "space station" program now apparently favored by NASA, OTA has estimated what new space capabilities could be provided, by when, for various annual average Government funding rates. No changes to present NASA acquisition procedures or NASA anticipated acquisition costs are assumed. Arbitrary annual average funding levels of $0.1, $0.3, $1, and $3 billion per year (1984$) were chosen to illustrate the number and kind of space infrastructure elements that could be acquired over periods of 5, 10, or 15 years.

The results of these 12 funding scenarios are given in table 3, which shows the funding rate, number of years, total expenditure, and kinds of infrastructure elements acquired.[5] The elements are divided into those that can operate independently (e.g., the Shuttle Orbiter and a "space station" central base) and those that depend on being serviced or maintained from one of the independent elements (i.e., by an orbital maneuvering vehicle, a local in-space transportation system operated from a "space station" central element, or directly by the Shuttle).

Table 3 lists the following (among other) elements of space infrastructure that could be acquired over various acquisition intervals:

1. At $0.1 billion per year: probably no "permanently manned" facility could be ob-

[5] Additional discussion of funding rate options can be found in ch. 4 of this report.

Table 3.—Some Illustrative Space infrastructure Acquisitions Possibie at Various Annuai Average Federai Funding Rates (all amounts in billions of *1984* dollars)

			Space acquisition[a]				
				Dependent elements			
Funding rate ($&r)	Number of years	Total expenditures ($)	Independent infrastructure element[b]	Unpressurized platforms[c]	Pressurized platform[d]	Space-based transport vehicles	Beyond geostationary orbit spacecraft elements
0.1[e]	5	0.5	EDO I[f] (20 days, 5 crew)	2	—	—	—
	10	1	EDO II (50 days, 6 crew)	3	—	—	—
	15	1.5	EDO II (50 days, 6 crew)	3	1	—	—
0.3	5	1.5	EDO II (50 days, 6 crew)	3	1	—	—
	10	3	Free-flying Spaceiab modules' (permanent, 3 crew)	1	1	OMV	—
	15	4.5	2 free-flying Spacelab modules in both 28 degree and polar orbits (3 crew each)	2	1	OMV	—
	5	5	Space transportation center (4 crew)	–	—	OMV; ROTV	—
	10	10	NASA initial operating capability "space station"[g] (8 crew)	2	1	OMV; ROTV	—
	15	15	NASA growth "space station"[g] (12 crew)	3	1	OMV;ROTV	—
	5	15	NASA growth "space station"[g] (12 crew)	3	1	OMV; ROTV	—
	10	30	NASA mature "space statlon"[g] (16 crew) Shuttle-Derived Cargo Vehicle (SDV)	3	2	OMV;ROTV	Lunar capable ROTV; staffed Lunar facility
	15	45	NASA mature "space station"[g] (18 crew, SDV)	5	3	OMV; ROTV	Lunar capable ROTV; staffed Lunar facility; Mars voyage

[a] Tables 1 and 2 present characteristics and capabilities of Infrastructure elements in detail.
[b] Extended Duration Orbiters (EDO) are limited in their stays on orbit; other Independent elements are long-term.
[c] Platforms of the LEASECRAFT/EURECA type.
[d] Platforms of the modified free-flying Spacelab/Space Industries type with their own electrical power and pressurization systems.
[e] At $0.1 billion/yr, no long-term, staffed Infrastructure elements are possible.
[f] EDO I (Extended Duration Orbiter, Phase I) and the Spacelab modules have limited electrical power (about 7 kW).
[g] The NASA "space station" elements are expected to operate as transportation and servicing centers as well as laboratories. They would have sufficient power for extensive materials processing.
[h] A significant part of the cost of a human visit to Mara could be provided in this case.

tained even by the year 2000. Further extension of capabilities of the Shuttle system and unpressurized platform developments could be obtained. The acquisitions could be: a development of the Extended Duration Orbiter (EDO) Phase 1, for 20-day orbit stays, over a 5-year period; or EDO Phase II, for 50-day orbit stays, over 10 years or longer, plus two or three free-flying unpressurized platforms such as EURECA, LEASECRAFT, and/or the Space Industries' platform (assuming that the Government would make an outright purchase of such platforms).

2 At $0.3 billion per year: within 5 years, the acquisitions could be an EDO II plus several (perhaps pressurized) platforms. Over 10 years, there could be acquired: 1) the first permanently orbiting, Spacelab-derived habitable modules in 28.5° LEO that could support three people; 2) an orbital maneuvering vehicle (OMV) (enabling servicing of nearby satellites); and 3) a few free-flying platforms. in 15 years, there could be obtained either: 1) two free-flying Spacelabs, one in polar orbit, one at 28.5° LEO; or 2) much more capable permanent infrastructure at 28.5° than that which could be acquired in 10 years.

3 For $1 billion per year: within 5 years, there could be acquired: 1) a permanent LEO facility operating as a transportation node; 2) an OMV; and 3) a reusable orbit transfer vehicle capable of transporting spacecraft to and from higher, including geostationary, orbit. In 10 years the initial operating capability (IOC) infrastructure now favored by NASA could be acquired. In 15 years, nearly all of the infrastructure now seriously considered by NASA could be acquired.

4. At $3 billion per year (assuming that only funds, not technology or other factors, would be the pacing program factor): NASA's fully developed "space station" could become available in somewhat more than 5 years. In 10 years, this infrastructure plus a geostationary platform, plus a Shuttle-derived cargo vehicle for lower cost fuel and cargo transfer to LEO, plus a lunar facility ready for occupancy and continuing operation would become possible. In 15 years, NASA's complete infrastructure aspirations and a lunar settlement could be in hand and, perhaps also, plans for seeing a human crew travel to the vicinity of Mars and back could be well advanced.

These projections are for infrastructure acquisition only; operational costs are not included. Also, there is a basic difference between the costs associated with Shuttle-type vehicles and permanently orbiting facilities. The use of an EDO to conduct extended science or development activities with a crew would involve launch costs each time it went into orbit; use of a permanent facility would require resupply several times per year, but the cost for each flight could be shared with other payloads. For example, if 12 dedicated 30-day EDO flights were conducted per year, about $1 billion (1984$) in annual transportation costs would be involved; in comparison, the cost of 4 partial-load Shuttle launches per year to resupply a permanent facility would total $100 million to $400 million (1 984$).

NEED FOR GOALS AND OBJECTIVES

In view of the variety of possible ensembles of infrastructure, the different methods of acquiring them, and the range of funding rates at which they could be acquired, how are the choices to be made? **In general, these choices should not be made without prior agreement on the future direction of the civilian space activities of the United States; however, the infrastructure elements for which identifiable, serious users have "hard" requirements might well be acquired within the next decade.** In the meantime, the most effective way to determine our direction in space would be a national discussion of, and eventual agreement on, a set of long-range goals which the United States expects its civilian space activities to address.

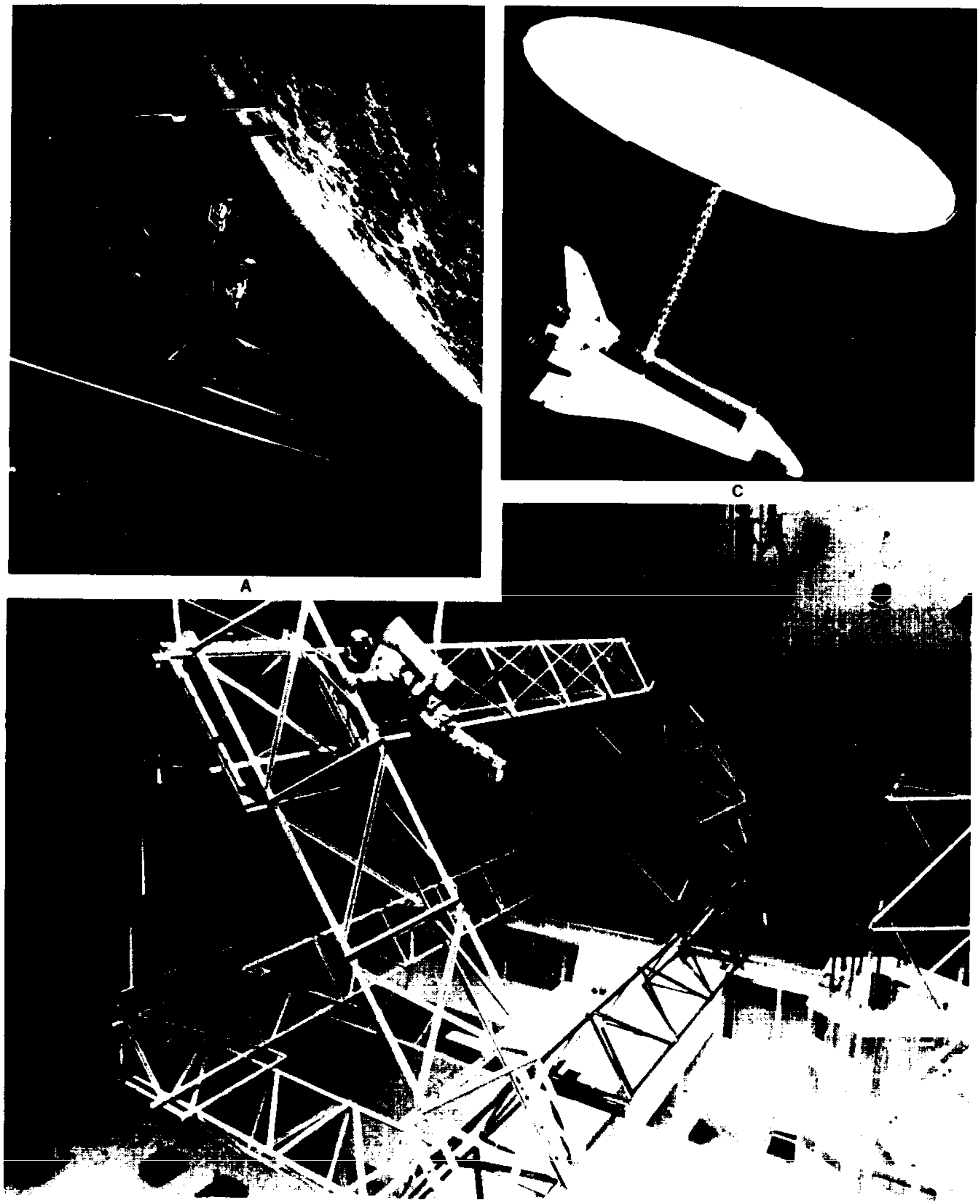


Photo credit" National Aeronautics and Space Administration

One alternative to the development of new technology is to use the space Shuttle for many advanced operations in low-Earth-orbit. Shown here: (A) servicing satellite in April 1984; (B) assembly of a large structure in orbit—here simulated in water; and (C) a deployable antenna.

Today, unfortunately, there is general agreement neither on such a set of long-range goals nor on a set of specific objectives which, as they are addressed, would serve as milestones of progress toward those goals. If future civilian space-related goals and objectives are to be effective in providing direction to U.S. space efforts, they should be such as to command widespread attention; have inherent humanitarian and scientific interest; foster development of new technology; have relevance to global issues; prompt international cooperation; and involve major participation of our private sector.

Such a set of goals and objectives would allow a clear determination of the basic characteristics of the infrastructure elements actually needed, and of the means and rate whereby these elements should be acquired. **In the absence of such goals and objectives, and with the great uncertainties in the estimate of any infrastructure cost to the public, OTA concludes that it is impossible to judge,** objectively, whether **or not most of the infrastructure elements proposed to date—and, in particular, many of the set currently proposed by NASA—are truly appropriate and worth their substantial cost.**

SOME POSSIBLE GOALS AND OBJECTIVES

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 of 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 national goals proposed for discussion are as follows:

- to increase the efficiency of space activities and reduce their net cost to the general public;
- to involve the 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 regarding space;
- to study and explore the Earth, the solar system, and the greater physical universe; and
- to spread life, in a responsible fashion, throughout the solar system.

OTA has also formulated, as milestones to mark progress toward these goals, the following family of 10 objectives. Table 4 relates these objectives to the six goals. Some of the objectives are readily achievable; others may not be, but still represent legitimate targets.[6] They are not rank-ordered.

1. A space-related, global system/service could be established to provide timely and useful information regarding potentially hazardous natural circumstances found in the Earth's space and atmosphere, and at and below its surface.
2. A transportation service could be established to and from the Earth's Moon, and a modest human presence established there, for scientific and other cultural and economic purposes.
3. Space probes could be used to obtain the information and experience specifically required to plan for further exploration of the planet Mars and some asteroids.
4. Medical studies of direct interest to the general public, including study of the human aging process, could be conducted through scientific experiments that compare physiological, emotional, and social experience in the absence of gravity with experience gained in the conduct of related surface studies.

[6] A full discussion of the objectives appears in ch. 6 of this report.

Table 4.—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 broad-casting, common-user system/sewice	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 transpor-tation and space activities	Y	N	Y	Y	N	N	N
10. Increase space-related private sector sale&	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.

5. At least hundreds of members of the general public per year, from the United States and abroad, could be selected on an equitable basis and brought into space for short visits there.
6. A direct audio broadcasting, common-user system/service could be established that would be available to all of the countries of the world on an economical and equitable basis.
7. In general, all of the nonclassified and nonprivate communications from, and nonproprietary data generated by, all Government-supported spacecraft and satellites could be made widely available to the general public and our educational institutions in near-real-time and at modest cost.
8. Radio and optical free-space electromagnetic propagation techniques could be exploited in an attempt to allow reliable and economic long-distance transmission of large amounts of electrical energy, both into space for use there, and from space, lunar, and remote Earth locations for distribution throughout the world.
9. The unit cost of space transportation, for people and equipment, between the Earth's surface and low-, geosynchronous-, and lunar-Earth orbit could be sharply reduced.
10. Space-related commercial-industrial sales in our private sector could be stimulated to increase at a rate comparable to that of other high-technology sectors, and our public expenditures on civilian space assets and activities could reflect this revenue growth.

Congress and the President have now agreed on legislation that will establish a National Commission on Space. This commission will be well-positioned to initiate and sponsor a national debate on the future direction of U.S. space activities. The goals and objectives suggested here may provide a substantial starting point for further discussion.

INFRASTRUCTURE REQUIRED BY THE PROPOSED GOALS AND OBJECTIVES

Technology

Some of these objectives, if they are to be achieved, will 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 will require none. The manner in which the United States obtains any of this infrastructure should reflect, as much as possible, 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.

If the Government's large capital costs for development and production are to be minimized and the private sector strengthened, then serious consideration might well be given to encouraging the private sector to provide infrastructure elements that meet Government performance specifications, rather than detailed engineering specifications. These elements could be provided to others as well as to the Government through sale, long-term leases, or on the basis of charges for actual service use.

The main elements of longer term space infrastructure called for in pursuing the family of 10 objectives are:[7]

a. 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)];
b. an LEO human residential and working space to be used for medical research [objective (4)], and possibly for space visits [objective (5)];
c. 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
d. a storage facility in LEO would allow use of full Shuttle loads, helping objective (9), and staffed LEO laboratory facilities could promote (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 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; these elements (e.g., MESA, SPAS, EURECA, LEASECRAFT, the Space Industries platform, etc.) could and probably would be designed, developed, and installed by our private

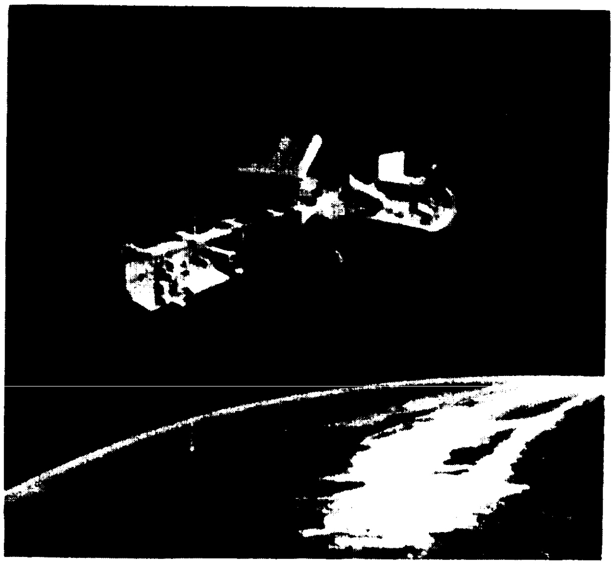


Photo credit: National Aeronautics and Space Administration

Free-flying platforms such as the one depicted in this artist's concept offer one option for relatively low-cost space infrastructure elements.

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

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 remote sensing, the conduct of scientific research, or the production of various materials under microgravity conditions.

Finally, note that very large amounts of very costly electrical power in LEO (with an initial capital cost of as much as $10,000 per watt) are not called for; 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

Attaining all of the proposed objectives would, overall, cost a great deal of money. In the accompanying table s, rough estimates are made for the cost of each of them, and the length of time over which each would be pursued to completion. It is a fundamental assumption that maximum use will be made of: 1) already developed and paid-for technology, 2) the most truly competitive procurement methods, and 3) the most modern and least burdensome acquisition strategies and procedures.

A first rough estimate of the total cost[8] of attaining all 10 of the proposed objectives is no less

[8] App. F of this report discusses costs in detail.

Table 5.—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 ther#	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	6	5, 25
5. Bring at least hundreds of the general public per year into space for short visits[9]	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	0.5	10
9. Reduce the unit cost of space transportation and space activities[g,h]	5	15
10. Increase space-related private sector sales[h]	0.5	25
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[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 t. 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 yeara and $0.4 billion each.
[d] $2 billion over 5 Yearn 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 t. 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%.

than $4o billion and perhaps considerably more (as much as $60 billion [1 984$]) over the next 25 years. Table 5 itemizes the estimated costs for all the objectives. Given that these estimates are made at an early stage, there cannot be great confidence in their detailed accuracy, but such accuracy is unnecessary for the illustrative purposes being served here.

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 flight from low-Earth-orbit to lunar orbit. Rather, it is assumed that some 10 Shuttle surface-LEO flights per year at an average cost of about $0.1 billion (1 984$) each by early in the next decade would be budgeted for all Government-sponsored civilian R&D purposes, including those considered here.

Financing

There are many matters that must be given careful consideration before a national commitment to undertake such large, lengthy, and costly public activities could be made. Certainly among the most important are the sources and magnitude of funds that can be reasonably expected to be available.

If the funding previously spent on Shuttle development (approximately $2 billion per year) is continued but reallocated towards the initial objectives, and if the NASA appropriation (approximately $7 billion per year) is augmented by a real growth of 1 percent per year, and if truly collaborative cost-sharing international agreements could be reached whereby other friendly countries would contribute, say, an additional amount equal to one-third of this subtotal, we could look forward to approximately the following amounts being available for the initial 10 objectives:

Reprogramming of the Shuttle development effort fund level of $2 billion per year for 25 years	– $ 50 billion
1 percent per year “real growth” over 25 years applied to these objectives	– $ 25 billion
Cost-sharing by other countries	– $ 25 billion
Total	– $100 billion

Amounts spent for related space research, development, test, and evaluation by the U.S. private sector would be added to this total.

As these figures are considered, it should be kept in mind that space is a high-technology domain. Increasing private sector interest in exploiting the economic potential of space invites comparison of growth rates in other high-technology sectors. If private sector space-related sales continue at a rate of 10 percent per year (a conservative estimate for high-technology sectors), the tax revenues derived therefrom would, over the next quarter-century, be quite substantial. And to the extent that public funding of Government space activities is understood as “offset” by these tax revenues (as they sometimes are in the aeronautics area) the net cost to the public for such space activities would be substantially reduced. [9]

Clearly, under such circumstances, funding limitations would not prevent the United States from undertaking an ambitious publicly supported civilian space program throughout the next quarter of a century.

[9] App. F of this report discusses these prospects at length.

SHAPE OF THE SPACE FUTURE

There are important changes under way in how space activities are carried on. The number of important players is increasing as space expertise and experience spreads, economic considerations are becoming more important, and security considerations are already the subject of widespread debate. If the United States is to maintain its leadership role in civilian space activities, it must be prepared to make fundamental shifts in policy and practice.

Photo credit: National Aeronautics and Space Administration

Communications satellites in geosynchronous orbit (such as Webster VI, shown here) can provide continuous coverage of large portions of the Earth's surface for relay of radio, television, and telephone signals.

International

International space activities will continue to expand, both in numbers of countries involved and in absolute magnitude of their capabilities. There is every reason to expect that the spacefaring nations of the world will find it in their interest to participate in the considered development of near-Earth space, and perhaps all countries would like to engage in civilian space activities to some extent. The OTA report on *International Cooperation and Competition in Civilian Space Activities*[10] addresses a wide range of issues arising in this area, and appendix C of this report discusses the variety of ways in which the United States and other friendly countries might, in concert, develop, operate, and use long-term in-orbit infrastructure.

[10] *International Cooperation and Competition in Civilian Space Activities,* Office of Technology Assessment, U.S. Congress, OTA-ISC-239, in press.

Private Sector

To date, private sector interest in space has been confined primarily to the successful satellite communications business and the support of Government activities. However, there is tangible evidence that a number of private concerns will soon begin to offer assets and services on a fee-for-service or lease basis, both to the Government and to other private interests. The projected needs of space science and space applications, for example, constitute a ready market for providers of various future infrastructure system/services.

New Role for NASA

In view of the significant changes in the way that space activities will be carried on in the future, NASA may well have to make certain fundamental shifts of attitude and operation. In the past, it has been NASA's responsibility to meet any given national space objective by itself; in the future, it should be NASA's responsibility to see that the objective is met. That is, NASA should now aspire to the much broader role of seeing that others in our private sector and throughout the world do much more of what it does today.

In the simplest of terms: if NASA is to rise successfully to the challenges now emerging in the national and international space arena, it should place relatively less emphasis on accomplishing by itself those things that our private sector or other friendly nations can satisfactorily do, either alone or with NASA assistance. It can succeed in this only by continuing to cooperate with both, and by broadening this cooperation so as to prompt and assist both to extend their space-related capacities, confidence, and commitment. And it could emphasize such cooperation in the acquisition of in-space infrastructure—i. e., a "space station."

Released from its present relatively near-term focus, NASA could concentrate more of its own professional activities on the most important and exciting of everything else in and concerning space, the things that no one else can or will do: the very best of space-related science; the cutting edge of space-related technology development; the boldest of space-related explorations and developments.

Finally, NASA and other space-related offices in the executive branch should see that their activities continue to be conducted, and the results thereof continue to be used, not only to increase knowledge and to address important social and political goals, but now also to enable our private space sector to increase its non-Government sales—the sales that generate the taxes that help to pay for Government space activities.

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