CONGRESS OF THE UNITED STATES
CONGRESSIONAL BUDGET OFFICE

MAY 1988

# The NASA Program in the 1990s and Beyond

A SPECIAL STUDY

# THE NASA PROGRAM
# IN THE 1990s AND BEYOND

The Congress of the United States
Congresssional Budget Office

## NOTES

All costs are expressed in 1988 dollars of budget authority, unless otherwise noted.

All years are fiscal years, except when applied to launch schedules.

## PREFACE

The United States space program stands at a crossroads. The momentum of the National Aeronautics and Space Administration (NASA) program over the last 20 years has brought NASA to a point where new activities will require substantial increases in the agency's budget. Critics of the NASA program have called for even more ambitious goals, most prominently an expansion of manned space flight to the Moon or Mars. Fiscal concerns, however, may limit even the more modest set of activities envisioned by NASA. This special study, requested by the Senate Committee on Commerce, Science, and Transportation, examines the broad options for the U.S. space program in the 1990s. In keeping with the mandate of the Congressional Budget Office (CBO) to provide objective nonpartisan analysis, the report makes no recommendations.

David H. Moore, of CBO's Natural Resources and Commerce Division, prepared the report under the supervision of Everett M. Ehrlich. Frances M. Lussier of CBO's National Security Division and Michael Sieverts of CBO's Budget Analysis Division provided valuable comments and assistance. Many outside reviewers made useful comments and criticisms. Amanda Balestrieri edited the manuscript. Margaret Cromartie prepared early drafts of the report, and Kathryn Quattrone prepared the final draft for publication.

James L. Blum
Acting Director

May 1988

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## SUMMARY

The Administration's 1989 budget request for the National Aeronautics and Space Administration (NASA)--including $6 billion (in current dollars) for the space station over the next three years--raises vital issues regarding the future of the NASA program. On a current dollar basis, the fiscal year 1989 proposal is 27 percent higher than the $9 billion appropriated in 1988. If NASA is to carry out the program it has envisioned (referred to as the "core program" in this study), then additional increases in funding will be required through the remainder of the century. To extend and exploit the technology and infrastructure created by NASA since the conclusion of the Apollo program in the early 1970s, the annual NASA budget under the core program would rise to $14.4 billion (1988 dollars) by 1993 and $16.4 billion (1988 dollars) by 2000.

The core program lies between two extremes that clearly illustrate the difficult choices involved in setting future U.S. space policy. At one end of the spectrum, new and ambitious initiatives beyond the core program, such as a lunar outpost or a manned expedition to Mars at the turn of the century, could more than triple NASA's current real budget by 2000. At the other end of the spectrum, if NASA were to limit its future spending to its current real level, it would be forced either to stretch out into the next century its planned space station and the other projects in the core program, or to adopt a less ambitious set of goals that de-emphasize manned space flight activities in favor of unmanned missions. Holding the NASA budget to its current real level would therefore limit the international leadership of the United States in space activities. This, in fact, is the difficult choice facing the Congress: whether to increase dramatically the commitment of the United States to preeminence in space exploration or to adapt the U.S. space program to a limited budget.

## EVOLUTION OF NASA's CORE PROGRAM

After the Apollo mission to the Moon was completed in 1972, NASA embarked on a long-term project to build a reusable transportation system, space platforms (most notably a permanently manned space station), and a space-based data and communications network. These long-term plans provide the starting point for the Congressional Budget Office (CBO) estimate of the NASA core program presented in this study. The justification for these major investments was their promise for the future rather than their immediate contributions to the nation's accomplishment in space. They were to provide higher quality and more cost-effective science, exploration, and commerce from the 1980s to the end of the century.

Despite the repercussions of the explosion of the Challenger orbiter in January 1986, the course set in the 1970s and 1980s remains the agency's plan. But many aspects of this core program represent departures from past NASA efforts--notably, the scale of the projects, the interdependence among the different parts of the core program, and the significant annual expenditures necessary to operate facilities, such as the shuttle system, after they are built.

The shuttle system, with its three airplane-like orbiters and supporting facilities, is the best example of these trends in the NASA program. In 1970 and 1980, the shuttle was the largest item in the NASA budget. Even in 1988, a year when the shuttle did not fly, the program consumed $3.2 billion. This amount represents a third of NASA's budget and does not include the shuttle's share of federal employees and program support carried in NASA's $1.7 billion research and program management budget. But since virtually every part of the NASA program depends on the shuttle, these expenditures must be made. The degree of interdependence within the NASA program will rise in the 1990s as space science and applications come to rely not only on the shuttle system and NASA's Earth orbit and deep space tracking networks, but also on the manned and unmanned space platforms planned for development in the space station program. This interdependence offers better, and ultimately more cost-effective, space activity. But it also exposes final missions to the physical, fiscal, and technical problems in the infrastructure on which they depend.

The Block One starter space station in the core program should cost about $19 billion in 1987 through 1996 (including operations), but, as with the shuttle, its effects on the budget will reach far beyond this initial expense. Once constructed, it could cost about $1.0 billion to $1.5 billion annually to operate. Moreover, a large part of the space station's value lies in making other space projects more productive (for example, by servicing satellites, providing an orbiting laboratory, or prepositioning materials for a high-orbit "spaceport" or a lunar base). If these other projects are not funded, the value of the space station is significantly reduced. Committing resources to the space station, therefore, may lead to even greater long-term NASA spending.

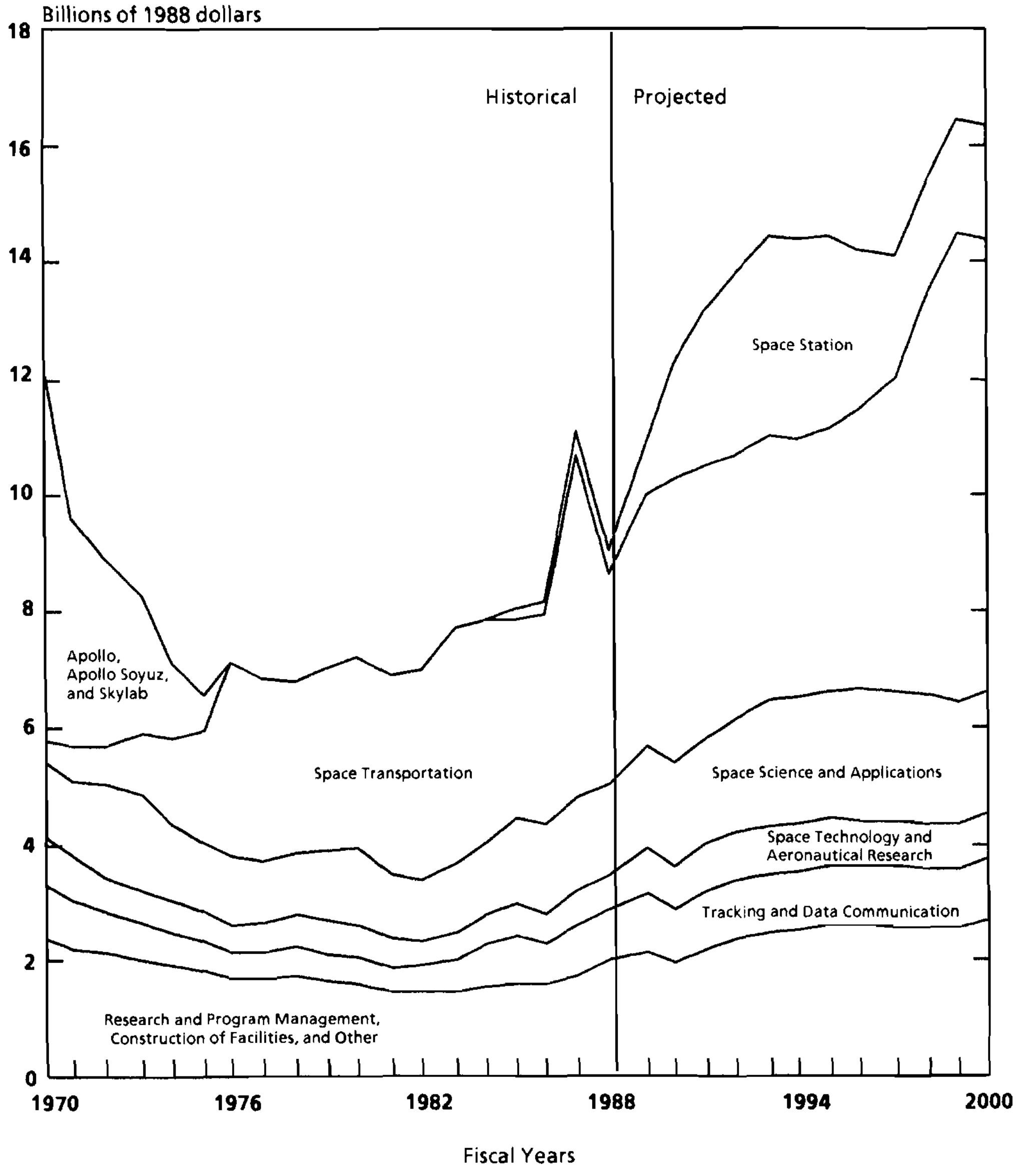
## THE NASA CORE PROGRAM FOR THE 1990s

NASA's activities through the 1990s will be dominated by continuing development of its space infrastructure, operating the space transportation system, and moving forward to a new group of science missions that take advantage of the infrastructure in low Earth orbit. Summary Figure 1 presents the CBO estimate of the annual funding requirements for the NASA core program through the year 2000. It shows that the activities included in the core program could require NASA's annual budget to grow from $9.0 billion in 1988 to $14.4 billion by 1993, and to $16.4 billion by 2000.

Spacecraft developed in the 1980s, but grounded by the loss of the Challenger and the subsequent two and one-half year hiatus in shuttle flights, will be launched in 1989 and during the early 1990s. These missions include the Hubble Space Telescope, a series of smaller physics and astronomy satellites, the Galileo probe to Jupiter, experiments in processing materials on the shuttle, the Advanced Communication Technology Satellite, and various Earth and environmental observation missions, including the Upper Atmospheric Research Satellite. Many of these missions will test the ability of the infrastructure investments of the past two decades to deliver high-quality, cost-effective science.

Space transportation and the space station program are the major investment activities NASA proposes for the 1990s. Transportation

Summary Figure 1.
NASA Budget: Historical and Projected (the "Core Program")




SOURCES: Historical data, NASA budget plans as presented in *NASA Budget Estimates* for various years, and Congressional Budget Office projections.

investment and development averages $2.5 billion annually from 1989 through 2000, and includes major improvements in the current shuttle system (such as the Advanced Solid Rocket Motor), replacement orbiters to be procured during the 1990s, a family of in-space transportation vehicles (the Orbital Maneuvering and Orbital Transfer vehicles), and a replacement for the shuttle system to come into service sometime after 2000. The space station program--including the manned laboratory modules, an unmanned polar platform in a polar orbit, an emergency escape vehicle, and operations--will require $3.0 billion to $3.5 billion annually from 1992 through 1995.

Operating the current shuttle system, conventional rocket services, and a planned unmanned cargo carrier using the shuttle system's propulsion system (the Shuttle C) would cost as much as $3.1 billion annually by 1996, when operations of the Shuttle C are intended to begin. Operating the space station might cost as much as $1.5 billion annually beginning in 1999. Operating and maintaining the tracking and data network for low Earth orbit and deep space would cost an additional $1 billion annually, with the space shuttle, the space station polar platform, and manned laboratory modules as primary users.

Funding for space science and applications in the core program rises from the 1988 level of $1.5 billion to $2.2 billion by 1995. This funding supports the development of planned future missions in physics and astronomy, planetary exploration, and environmental and Earth observation; it also supports processing materials and life science programs related to the space station.

The physics and astronomy program is the largest single area of activity in space science and applications. It includes the Advanced X-Ray Astronomy Facility (proposed as a new start in the Administration's fiscal year 1989 budget request) in the early 1990s and the Space Infrared Telescope Facility later in the decade. Operating these two "Great Observatories" and their two already developed companions, the Hubble Space Telescope and the Gamma Ray Observatory, could require more than $0.2 billion annually by 2000. New planetary missions include the Comet Rendezvous/Asteroid Flyby and a probe to Saturn. The Earth Observation System would provide an integrated system to monitor and analyze natural and human influences on the Earth and its environment.

NASA's space research and technology program explores propulsion, supporting human activity in space, and automated systems and sensors--activities that are the foundation for all NASA space projects. The core program includes funding in this area of $0.4 billion annually. Developing large systems such as the shuttle and the space station pushes technology forward in these areas, but only as far as required to complete the project at hand. Unconstrained research is necessary to define the possibilities for future missions and to permit informed choices about these missions based on realistic forecasts of costs, schedules, and available technology.

Finally, the core program includes an annual average from 1989 through 2000 of $2.3 billion for research and program management and construction of facilities. Research and program management is by far the largest item and reflects the upward trend in the rest of the NASA program. Other NASA activities, such as safety and quality assurance, use of technology, and commercial programs, are projected forward at constant dollar levels over the 1990s.

This core program carries with it technical and cost uncertainties. Transportation costs may be reduced if efficiencies not previously realized are achieved in operating the shuttle system, or if unforeseen revenues are received from the private sector or other parts of the federal government. But cost overruns in major development efforts such as the space station, shuttle improvements, or large space science projects will affect not only these projects, but also the projects to which they are related. The additional costs inflicted on all NASA programs by the grounding of the shuttle system since the Challenger accident furnish an example of these effects.

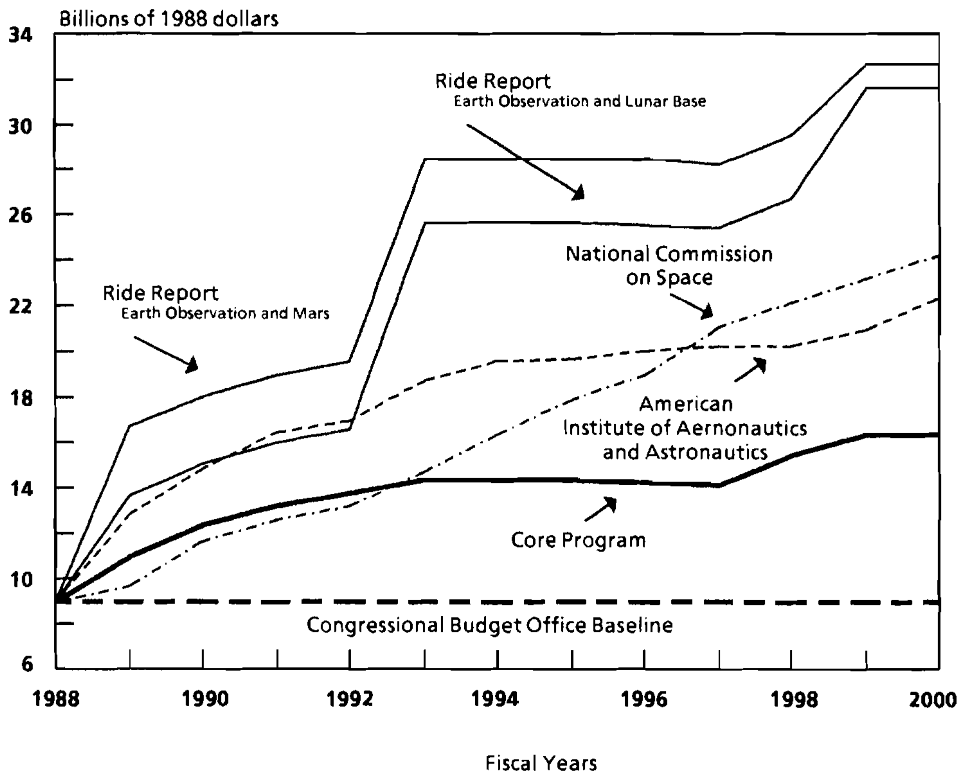
## ALTERNATIVES TO THE CORE PROGRAM

Two broad alternatives to the core program are open to the Congress:

- Mandate more ambitious goals than the core program and dedicate even more of the nation's resources to the civilian space program than those required by the core program, perhaps $30 billion annually by 2000; or o Maintain NASA spending at the current level and stretch out or dramatically restructure the civilian space program, primarily by de-emphasizing manned space activities.

Summary Figure 2 presents CBO's estimates of the NASA annual budget required by the core program and alternatives to it. Summary Box 1 compares the status of the U.S. space program during the 1990s under the broad options of the NASA core program, the new initiatives, and the budget-constrained programs as they relate to infrastructure, space science, applications and exploration, and research and technology.

Summary Figure 2.
NASA Budget Options, 1988-2000




SOURCE: Congressional Budget Office estimates.

## SUMMARY BOX 1
## ALTERNATIVE NASA PROGRAMS FOR THE 1990s

The core program and alternatives to it differ in three ways: first, in the transportation, on-orbit facilities, and tracking and data communications *infrastructure* they would operate or develop; second, in the *space science, applications, and exploration* under way to exploit the capability of the available infrastructure; and, third, in the future missions toward which their *research and technology* bases are directed.

### THE CORE PROGRAM

*Infrastructure*, which enables man's presence in space, is a central feature of the core program. The shuttle system would fly 8 to 14 times a year, and would be augmented by traditional rocket services, providing the equivalent of two and one-half additional shuttle flights annually. The unmanned cargo carrier, Shuttle C, would be launched twice a year by 1996, with the potential to carry the equivalent of two manned orbiter flights on each flight. The first generation of in-space transportation--the orbital maneuvering and space transfer vehicles--would be developed by the late 1990s. A new manned transportation system would be developed to replace the shuttle by 2005. Block One of the space station, which includes the manned laboratory modules and the polar platform, would be built and operated by 1997. Satellite servicing facilities and co-orbiting man-tended platforms (used for particularly sensitive experiments) would be added by the year 2000. The Tracking and Data Relay Satellite network (TDRS) would be in place with perhaps three satellites in operation by 2000.

*Space science, applications, and exploration* would focus in the early 1990s on missions delayed by the Challenger accident; among these missions are the Galileo probe to Jupiter, the Hubble Space Telescope, and the Gamma Ray Observatory. The last two observatory missions would be serviced by the shuttle orbiters throughout the decade and, sometime after 1995, would be joined by two additional orbiting observatories developed during the 1990s. New planetary missions, the Comet Rendezvous/Asteroid Flyby, and a Saturn probe would be in flight in the mid-1990s, as results from the missions to Jupiter, Venus, and Mars are analyzed. The Environmental Observation System, using the space station polar platform and other U.S. and allied spacecraft in higher orbits, would monitor natural and human effects on the Earth's atmosphere and climate by the late 1990s. The space station would also host an aggressive program of research on processing materials and on life sciences.

*Research and Technology* would be well-funded and oriented toward human voyages to the Moon or Mars, but actual missions to those destinations would still be in development.

### NEW INITIATIVES

While proposals to go beyond the 1990s core program include some initiatives that do not involve manned exploration in the next two decades, human expansion beyond Earth's orbit is the major focus of these programs.

*Infrastructure* requirements of these new initiatives vary depending on the program adopted. The core space transportation system and the core space station are common to all the initiatives. Additional Earth-to-orbit transportation to carry people and cargo, and more facilities in orbit (beyond the shuttle system and space station) would be needed to support either the construction of space vehicles for a Mars expedition, or continuing logistical support for a lunar base. In-space transfer vehicles would be necessary to move large numbers of people back and forth to construction activities or a Moon base.

**SUMMARY BOX 1**

NEW INITIATIVES
(Continued)

*Space Science, Applications, and Exploration* would be directed toward human expansion beyond the Earth's orbit shortly after the turn of the century. The new initiatives that emphasize a phased expansion, starting with a return to the Moon (as recommended by the National Commission on Space), feature a lunar base where astronomical observation would be undertaken and technologies developed to extract fuel and oxygen from lunar materials. A series of unmanned missions to Mars would probably be undertaken, leading to a manned mission as early as 2005 in those programs calling for such a mission. Unmanned missions to Mars would include robotic surveys and a sample return mission.

*Research and Technology* would be oriented to the problems of moving and sustaining humans in space. Manned initiatives planned for early in the next century would require a significant research effort, particularly in life science research aboard the space station to determine how humans best survive and function in space.

BUDGET-CONSTRAINED OPTIONS

Restricting NASA's annual budget to the 1988 level of $9 billion requires the core program to be *stretched out* well into the next century, or *restructured* to de-emphasize manned space activities.

*Infrastructure* development and operation dominates both the core program and more ambitious space programs. Stretching out the infrastructure investment plan means pushing back the space station into the next century and not expanding the capability for Earth-to-orbit or in-space transportation. Generally tight budgets would permit some operational savings, however, since restricted spending for space science would lower the demand for launch services. Restructuring NASA's program would involve changing the current program's emphasis on manned activities. The first step would be to cancel the space station, perhaps in favor of less capable but also less costly periodically manned space platforms. In such a program, the manned orbiter fleet would be used only where essential: to visit platforms and serve as an orbiting laboratory.

*Space Science, Applications, and Exploration* under either option would benefit from the eventual launch of the backlog of payloads and experiments delayed by the Challenger accident. Stretching out the core program would involve a slowdown in the development of a new space science mission, since funding for the space station would consume a large part of a reduced annual budget. Major observatory or planetary missions, or both, would be deferred until the late 1990s, and the Earth Observation System would be scaled down because the space station polar platform would not be available until after 2000. Restructuring would permit a quicker pace in scientific research, since more funds would be available and activities involving human flight scaled back. Neither option would enable human expansion beyond Earth's orbit in the foreseeable future; the stretched-out program would limit the pace of such expansion through budget constraints, and the restructured program would eliminate all such missions by conscious choice.

*Research and Technology* under a stretched-out option would be funded at the current level, but still directed toward a set of complex manned missions in the future. Under a restructured option, the research and technology program would be constrained in its funding but would be more focused on automated (as opposed to manned) space activity.

## New Initiatives

Several major reports have evaluated the nation's space program and suggested that NASA should aim for new, even more ambitious goals in space and be given the resources to achieve them. The National Commission on Space (NCS) in its 1986 report, *Pioneering the Space Frontier* (the *NCS Report*), proposed a building-block approach, extending human activities from low Earth orbit to the Moon and Mars over the next 50 years. A 1987 report, *The Civil Space Program: An Investment in America* (the *AIAA Report*), by the American Institute of Aeronautics and Astronautics (AIAA), a professional society, advocated a similar agenda. A NASA report prepared by Sally Ride, *America's Future in Space* (the *Ride Report*), develops a set of options for a more aggressive space program that includes a manned sprint to Mars (a mission skipping a return to the Moon and proceeding to Mars as early as 2005), a lunar base, a more aggressive unmanned program of solar system exploration, and a sophisticated and extensive Earth Observation System. The *Ride Report*'s options are all structured to produce major results by 2010.

Manned initiatives leading to the Moon or Mars during the first decade of the next century would require spending above the core program level, and above NASA's Apollo peak spending of $22 billion in 1965. The cost estimate for the program contained in the *NCS Report* diverges sharply from that for the core program in the mid-1990s, increasing NASA's annual budget to $15 billion in 1995 and almost $25 billion by 2000. The funding requirements for the program outlined in the *AIAA Report* exceed those of the core program from 1989 onward, also requiring over $20 billion by 2000. The estimated cost of the *Ride Report* initiatives is even higher, requiring over $30 billion annually by 2000.

## Budget-Constrained Options

Were the Congress to hold NASA's budget to its 1988 levels, NASA's program would either have to be stretched out or restructured. Stretching out the core program would involve delaying the space station program into the next century, and deferring additional investment in transportation. Restructuring the program would decrease the role of manned space flight and cancel the space station program in favor of using periodically manned facilities for materials research and unmanned scientific spacecraft.

The stretched-out and restructured programs differ most dramatically on the issue of the space station. Stretching out the current core program within a no-growth budget involves funding the space station at $1.5 billion annually and permitting NASA to carry budget authority forward to meet funding peaks as required. Other NASA activities would be slowed down to accommodate this funding, but less spending on transportation would be necessary in the 1990s as budget constraints slowed down the development of major payloads. The restructured program includes only $0.5 billion annually for activities similar to the space station--primarily for periodically manned orbiting laboratories and shuttle-based experiments. Funding in research and technology and in the space science and applications programs is below the core program levels, but above the stretched-out program estimates, since a part of the annual savings from the elimination of the space station program is redistributed toward these areas. Space transportation funding is increased to procure conventional rocket services that can meet the higher launch demand resulting from increased spending for space science and applications payloads requiring launch services.

## WHAT IS AT STAKE?

Traditionally, the civilian space program has been justified as a means to realize human destiny, an investment in the international standing of the United States, and a provider of economic benefits. The first rationale is beyond the scope of this analysis, but the broad alternative paths suggested for NASA can be evaluated against their potential to maintain the U.S. position as an international leader in space and, in relative terms, against the extent to which they provide economic benefits. Yet, the uncertainties of estimating the technical and scientific returns to the NASA program prohibit comparing the civilian space program with other federal investment in science and technology or other federal spending that benefits society.

## International Leadership

The consensus of recent studies of the civilian space program is that the core program would grant the United States a significant leadership position in civilian space efforts, despite the fact that the cost of being an international leader in space has increased as the cost of large-scale space activity has risen, and as more competitors--European nations, Canada, China, and Japan--have initiated serious civilian space programs.

The new-initiative packages would all serve to enhance U.S. leadership in space. The manned activities in particular would provide highly visible symbols of national technical competence. The restructured program, while forgoing leadership in manned space areas, would permit both a focus and leadership in automated space activities. The stretched-out program would provide for a space station early next century, but at the cost of reduced accomplishment elsewhere in the program.

## Economic Benefits

The civilian space program provides an economic return by creating public goods and services, stimulating private-sector research and development, and directly encouraging the creation of new industries that use the space environment. In general, the more that is spent on space activities, the more benefits will be provided in these areas.

NASA's activities provide the public good of scientific and technical knowledge. Spending more on space science will provide more of this public good, but it is nonetheless difficult to judge if the benefits derived from, for example, a manned Mars mission, are commensurate with their cost. The NASA program also benefits the larger economy by stimulating private-sector research and development. NASA programs may create technologies that can be spun off to private firms and ultimately contribute to economic growth. Some analysts have suggested, however, that spin-offs are less likely to occur in the development of large operational systems, like the shuttle or the space station, than in the basic research and technology program. NASA may also indirectly improve private-sector research by enlarging the pool of scientists and engineers.

The attempt to encourage space-based industries is not new to NASA: satellite communications and land remote sensing (a form of sophisticated satellite photography) are already major examples. This type of industrial policy strategy now exists in the area of processing space materials, where prospects exist for improving earth-based products, and for manufacturing drugs and materials for advanced computer chips. The core program, through the space station, supports this type of activity, whereas new initiatives tend to emphasize providing public goods that would add to new space industries primarily in the infrastructure area. The stretched-out and restructured programs approach the processing of materials in different ways. The stretched-out option keeps the possibility of a permanently manned facility alive, but the implicit dilution of effort would leave the NASA program in the 1990s unable to devote significant resources to developing experiments with space materials and processing. The restructured option may allow these efforts to advance by targeting them for resources saved by eliminating other NASA projects.

In general, more ambitious programs will deliver more economic benefits. But it is difficult to determine whether these benefits are commensurate with the increase in costs, in relation not only to the set of space program options open to the United States, but also to broader scientific and technology options and to other federal spending.

## INCREASING THE EFFECTIVENESS OF NASA's SPENDING

Regardless of whether the Congress calls on NASA to do more or less than the current program, pressure will be present to increase the effectiveness of NASA's spending. Several proposals in this area have been endorsed by NASA and are included in the current program. International cooperation in science and infrastructure is included--for example, European countries, Japan, and Canada would participate in the space station. The program also includes cooperation with other U.S. government agencies--for example, the Department of Defense in the space transportation area.

The Administration's 1989 budget request for NASA includes multiyear funding for the space station. This funding would put into effect a long-standing suggestion to improve the effectiveness of NASA spending by allowing the agency to plan and execute its programs without concern that subsequent Congressional action will force wasteful changes in plans. Were multiyear funding applied to many large NASA programs, an additional benefit would be to increase visibility for the many apparently small new programs that will require much greater support in later years. Multiyear appropriations would also increase the attractiveness of the United States as a partner in international joint ventures. The flexibility of the Congress in enacting deficit control measures, however, would be decreased. Moreover, those programs granted advanced appropriations could receive preferential treatment, perhaps unintended by the Congress, relative to other NASA activities or to unrelated spending should the Congress seek to reduce all spending by across-the-board freezes or cuts.

As NASA continues to devote a substantial part of its budget to developing and operating infrastructure, some have suggested that the federal government should encourage direct private investment in space infrastructure. NASA's 1988 appropriation called for the agency to conclude an agreement to lease the Industrial Space Facility, a proposed orbiting laboratory to be visited by the shuttle astronauts for the purposes of experimenting with life-support systems and processing materials in low-gravity conditions. The national space policy has directed NASA to purchase launch services rather than launch vehicles, to encourage private providers of such services. The key issues are a government commitment not to compete with the private sector, and guaranteed federal procure-ment of a substantial part of the private providers' initial offering of services to the market.

Advocates of this strategy argue that the private sector will be able to provide facilities and services more cheaply than NASA, thereby permitting the public sector to accomplish its business at a lower cost and perhaps inducing other private investors requiring space infrastructure to manufacture in space goods and services that are sold on Earth. The advocates' first point is untested, but is more likely to hold if the technology underlying the infrastructure is well understood. Their second point is also as yet unproven; in such areas as materials science, a long period of government support may be required to develop useful technologies and products, regardless of whether or not the costs of infrastructure and other services are reduced below current levels.

# CHAPTER I

# INTRODUCTION

During 1987, the National Aeronautics and Space Administration (NASA) focused its attention on returning the shuttle system to flight; it also took part in the Administration's reassessment of what direction the civilian space program should take for the remainder of the century. The conclusion of this reassessment, as expressed in the Administration's national space policy statement and NASA's fiscal year 1989 budget proposal, is that future program strategy will maintain its current emphasis on operating manned facilities in low orbit around the Earth (referred to as low Earth orbit), but that NASA should also adopt the goal of expanding human activity beyond the Earth's orbit.1/

Thus, the shuttle system would continue to be the hub of the civilian space transportation system, and substantial resources would be devoted to enhance its capability. More important, for the 1990s, NASA would continue to give its highest priority to a permanently manned space station. The President's budget submission to the Congress for fiscal year 1989 includes $6 billion (in current dollars) in funding for such a facility--$1 billion in 1989, $2 billion in 1990, and $3 billion in 1991.2/ Beyond these efforts, NASA's budget request for fiscal year 1989 includes funding for the Pathfinder Program, a research and technology initiative that will begin NASA's effort to expand human activity beyond Earth's orbit.

Hence, the Congress faces some difficult questions about the adequacy and affordability of the current civilian space program: whether or not major new initiatives are required to meet the nation's space policy goals, and whether or not such new initiatives--or even the current program--can be supported without significant funding in-

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1. Congressional Research Service, *Civilian Space Policy under the Reagan Administration: Potential Impact of the January 1988 Directive*, Report No. 88-237 (March 1988), pp. 8 and 9.

2. *The Budget of the United States Government, Fiscal Year 1989*, p. 2b-6.

creases. This Congressional Budget Office (CBO) study addresses the content, likely achievements, and estimated cost of a logical extension of the current program (referred to as the core program) and explores two alternatives to it that might be pursued through the end of the century. The study also considers methods to increase the effectiveness of NASA spending.

The study's analysis relies primarily on NASA planning documents and cost estimates, and on those of NASA's network of specialized Advisory Council committees. The broad outlines of NASA's core program include estimated costs and schedules for major investment projects, missions, and ongoing operations. The first major alternative to the core program is a set of new initiatives that proponents view as necessary to place the United States among the leading spacefaring nations at the turn of the century. A second alternative would be one of two scaled-down versions of the core program that could be supported without real increases in the NASA budget.

The core program and the two alternatives to it are largely based on the traditional rationales for the civilian space program. The United States has pursued civilian space activities for a variety of reasons. Manned space flight has been justified as an imperative of human existence. Its proponents view it as a manifest destiny, demanding a human presence as far into space as technology permits. The accomplishments of the civilian space program also contribute to the international presence and stature of the United States. More concretely, the civilian space program provides the public goods of scientific knowledge, spins off technology to unrelated areas that private firms can profitably exploit, and may demonstrate the economic potential of certain products and services that require the use of the space environment.

## NASA's RECENT PROGRAM AND BUDGET HISTORY

A previous CBO study noted that the accident of the space shuttle Challenger in January 1986 would affect all NASA programs far into the future by requiring new expenditures for space transportation, delaying programs that depend on space flight (such as scientific payloads), and raising the implicit price of all activities that depend on space flight, including the space station.3/ Thus, during the 1990s, the U.S. space program will accomplish less than originally foreseen at a higher-than-expected cost. Nevertheless, the scientific benefits of the nation's investment in space infrastructure will be realized, albeit later than expected, when such projects as the Hubble Space Telescope, the Galileo probe to Jupiter, the Magellan probe to Venus, the Mars Observer probe, spacelab flights, and the Upper Atmospheric Research Satellite are launched over the next several years. The Challenger accident, while a significant influence on the NASA program, is not likely to change that program's essential elements as they have evolved since the successful conclusion in the early 1970s of the Apollo missions to the Moon.

Figure 1 shows NASA's budget and its major components over the past 19 years. The agency's real purchasing power declined from 1970 to a low point in 1975, stayed flat through 1978, and has increased slowly but erratically since that time. NASA's share of the federal budget reached almost 4 percent during the peak Apollo years of 1964 and 1965, but fell as low as 0.7 percent in the mid-1980s. Funding to develop, build, and operate the shuttle system--the first building block of the low-Earth-orbit infrastructure--increased through 1977 and remains a large share of the budget through 1988. Box 1 describes the shuttle or space transportation system and its various components.

The program to restore the shuttle fleet to flight and to replace the orbiter Challenger is responsible for the recent upward trend in the NASA budget. The investment in space transportation infrastructure dominates other components of the agency's program, since virtually all of the other program elements depend on the shuttle for access to space and, in many cases, for a base of operation once in orbit. The setbacks to the shuttle program have been more extensive than the loss of an orbiter. In fact, in reassessing the space transportation system, NASA has concluded that additional and unanticipated investment in space transportation will be necessary during the 1990s to complete the transportation portion of its program, and that the

3. Congressional Budget Office, "The 1988 Budget and the Future of the NASA Program," Staff Working Paper (March 1987).

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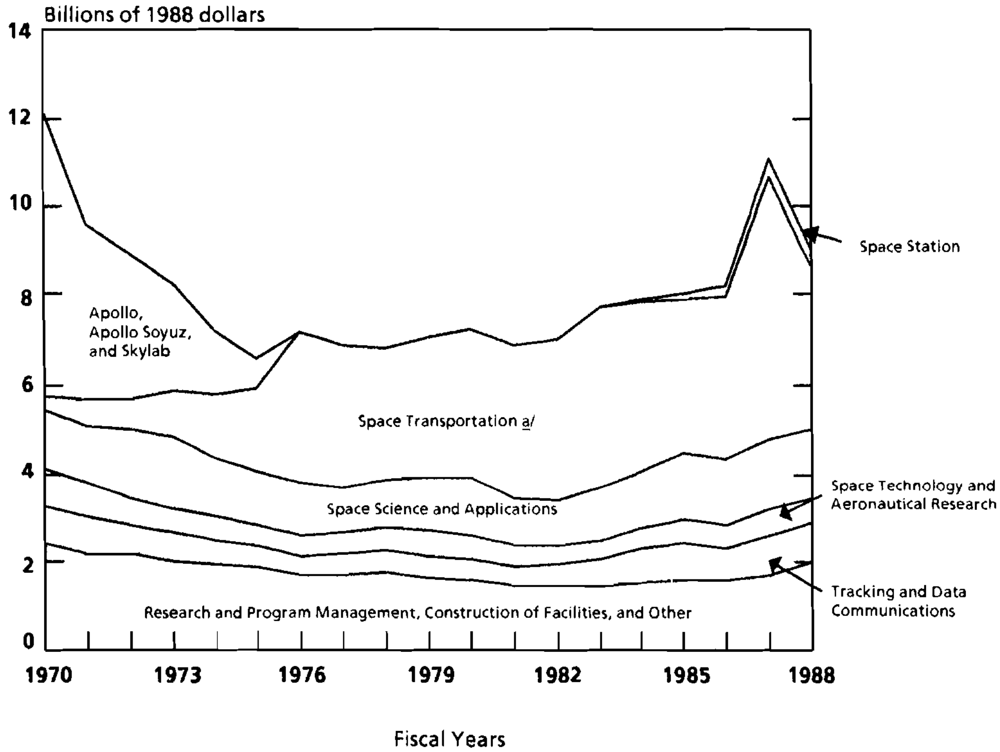
Figure 1.
NASA Budget, 1970-1988




SOURCE: Congressional Budget Office based on NASA budget plans as presented in *NASA Budget Estimates*, various years.

a. Includes expendable launch vehicles for space science and applications missions.

manned shuttle should be complemented by a substantial number of expendable launch vehicles. The remaining major elements of the NASA program are space science and applications (including the missions to other planets, the astronomical observation platforms, and Earth observation), space technology and aeronautical research, and institutional support.4/

4. This analysis does not discuss NASA's aeronautical research and technology program, although these activities are included at their current real dollar levels in all budget estimates.

**BOX 1**
**THE SHUTTLE SYSTEM**

The linchpin of the current NASA program is the space transportation system (sometimes called the shuttle system). Space science and technology programs currently depend on the shuttle system to launch satellites in orbit around the Earth, or probes to the planets, or to carry instruments and round-trip experiments. As a purely logistical matter, the over two and one-half year grounding of the shuttle system has left NASA with very limited access to space until the shuttle returns to flight.

Three airplane-like manned spacecraft, referred to as orbiters or shuttles, are the most visible part of the system. A fourth orbiter to replace the Challenger is being produced. During a shuttle flight, an orbiter is launched into space by two solid-fuel rockets (called solid rocket boosters), to which the orbiter is attached, and by three liquid-fuel engines that are contained in the spacecraft fuselage, but draw fuel from a large fuel tank (called the external tank) attached to the underbelly of the orbiter between the two solid-fuel rockets.

Each orbiter can carry a variety of cargoes to and from space--satellites, instruments, or a laboratory unit called a spacelab that expands the volume of space in which people can work. Shuttle-borne satellites that require orbits higher than 160 to 200 nautical miles are typically attached to rockets and carried in the shuttle cargo bay. After the shuttle reaches its orbit, the satellites are then launched by their rockets to their final Earth orbits or beyond to the planets. These "upperstage" rockets come in a variety of sizes designed to service different payloads.

The shuttle system includes a great deal more than the visible hardware and activity of a typical flight. Incorporated in the system are launch and landing facilities, manufacturing plants for major components (such as the booster rockets and fuel tanks), and a large institutional and management structure. These operations are spread over the major NASA centers, most prominently the Kennedy Space Center in Florida, the Marshall Space Flight Center in Alabama, and the Johnson Manned Space Flight Center in Texas. Personnel from both NASA and private contractors are involved.

## Developing a Low-Earth-Orbit Infrastructure

The statutory basis of the NASA program is the Space Act of 1958, as amended (Public Law 85-568). The act is specific in including as objectives of the agency both the use of space for science and commerce, and the capability to reach space and function in it. This last objective--creating an infrastructure--has sparked the development and operation of launch and space propulsion systems, tracking and data support (both on the ground and via satellite), and facilities in orbit such as Skylab or the proposed space station.5/ The cost of such infrastructure investments is high and lasts for several years. The stream of benefits, however, can be substantial and accrue over a long period of time.

Currently, the NASA program is at the midpoint of an ambitious effort to develop an infrastructure that would enable manned and unmanned space activity to take place in low Earth orbit. Representing substantial past investments in this infrastructure, and accounting for over half of NASA's resources during the 1980s, are the space transportation system (the fleet of shuttle orbiters, facilities, and related equipment) and the Tracking and Data Relay Satellite system (TDRS, three satellites and a ground station, capable of replacing the global ground tracking and data communications network used by spacecraft in low Earth orbit).

NASA plans to continue its infrastructure investment program throughout the 1990s by developing and building a permanently manned laboratory facility--the space station--and associated unmanned platforms. Moreover, the space station is at the center of NASA's transformation from the single large project team, which landed men on the Moon, to an agency that develops, builds, and (in some cases) operates the infrastructure necessary to conduct science and commerce in low Earth orbit, as well as to provide a point of departure for exploration beyond Earth's orbit.

5. A series of Office of Technology Assessment reports provides a detailed account of the NASA program during the 1970s and 1980s and develops the concept of space infrastructure. See Office of Technology Assessment, *Civilian Space Policy and Applications* (June 1982); *International Cooperation and Competition in Civilian Space Activities* (July 1985); *Civilian Space Stations and the U.S. Future in Space* ( November 1984).

Space Science and Infrastructure Investment

The space science and applications program includes a diverse list of activities. The planetary exploration and physics and astronomy programs together account for over 50 percent of the total space science and applications program, and illustrate a trend toward large-scale projects in these areas. Space applications include traditional satellite services--for example, telecommunications--and a newer set of activities such as processing materials in space. The space science and applications budget (excluding the expendable launch vehicle procurement included in the account in the early 1970s) dipped with the entire NASA program budget in the 1970s. Since 1985, however, it has consistently surpassed its 1970 real dollar level, even though the NASA budget as a whole has not.

In one sense, space science is the ultimate user and beneficiary of the infrastructure investment program. The infrastructure strategy should increase the productivity of space science projects by lowering the cost of delivering and operating science payloads. For example, a single shuttle flight could permit Earth, atmospheric, and astronomical observation to be undertaken and, at the same time, provide an orbiting laboratory for research on materials and life science. Moreover, the shuttle opens the prospect of servicing satellites in orbit, thus permitting sensors and instruments to be replaced without incurring the cost of building and launching a completely new spacecraft. The resources required to build the space transportation system, however, have necessarily limited the resources available for space science activities and, hence, the flow of new experimental results. In addition, expected decreases in the cost of launching the shuttle have not been achieved, since the space shuttle's current annual flight rate is far below that anticipated by its designer during the 1970s.6/

In part of the space science and applications program, the emphasis on large projects found in the whole NASA program is being replicated in miniature. For example, the physics and astronomy program focuses on developing, constructing, and operating the Great Observatory Program that would, if fully developed, consist of four

6. Congressional Budget Office, *Setting Space Transportation Policy for the 1990s* (October 1986), p. 11.

orbiting platforms. The first two of these would be the Hubble Space Telescope and the Gamma Ray Observatory. The budget profiles of these projects are similar to other new space infrastructure investments--funding increases to a peak during the middle years of development and construction, and then tails off, with a long operating cost trail while the facility is used and scientific rewards are gained.

## The Technology Base

NASA is often criticized for devoting too little of its budget to developing new technology and for undertaking too little basic research. The agency's real dollar spending in its space research and technology program has fallen in the post-Apollo era. The funds are specifically earmarked for basic research and technology activities untied to any particular development effort. These activities help to define the technical possibilities available for missions under long-term consideration--for example, a Moon base or a Mars colony--and may be helpful in determining the relative benefits, technical risks, and costs of alternative new missions.

Large development efforts such as the space shuttle or the space station programs undoubtedly help advance basic technology and, unlike generic technology efforts, are ends in themselves. However, even the best efforts to develop technology within a development program run the risk of failing to explore promising areas by being tied to a specific vision of a finished system. In a recent assessment of NASA's research program, the National Research Council concluded that the current emphasis on large operational programs like the shuttle has left too little funding for NASA's pure technology demonstration efforts and has seriously depleted NASA's stock of basic research and technology.7/

## Institutional Support

NASA's institutional support budget includes research and program management (RPM), primarily federal employees and contract

7. National Research Council, *Space Technology to Meet Future Needs* (Washington, D.C.: National Academy Press, 1987), p. viii.

services, and construction of facilities. Taken together these expenditures have accounted for roughly 20 percent of the NASA budget. The agency's federal work force has dramatically declined since its peak Apollo year, 1967, in which almost 36,000 full-time and temporary personnel were employed. Federal personnel fell to 32,500 in 1970, to 25,500 in 1975, and to around 22,500 in the 1980s.8/ As the shuttle system moved toward operational status, the RPM budget began to increase--a trend that will continue if the infrastructure for low Earth orbit is operated as anticipated.

## CHARACTERISTICS OF THE NASA PROGRAM

The focus of the post-Apollo NASA program on the development and operation of the low-Earth-orbit infrastructure, and the accompanying trend toward increasingly large space science projects, give the current program its structure. Taken together, the large scale of NASA's recent investments, the interdependence among infrastructure and project development and operation, and the long operational lives of projects and investments characterize major parts of the NASA program for the 1990s.

### Large-Scale Projects

Throughout the development of the low-Earth-orbit infrastructure program, expenditures on the shuttle system have dominated the NASA budget. Within particular areas of the space science program, projects like the Hubble Space Telescope or the Galileo mission to Jupiter accounted for large portions of program budgets over many years. The NASA program epitomizes a general trend in U.S. science and technology policy toward large-scale projects, or "big science." 9/

This trend within the NASA program was recently noted by a NASA Advisory Council committee review of the space science and

8. National Aeronautics and Space Administration, *Pocket Statistics* (January 1988), p. C-24.

9. Genevieve J. Knezo and Richard Rowber, "Big and Little Science," *Congressional Research Service Review*, vol. 9, no. 2 (February 1988), pp. 6-8, and Congressional Research Service, *World Inventory of 'Big Science' Research Instruments and Facilities*, Report No. 88- 33SPR (December 1986).

applications programs. It expressed concern about the balance within the program between big science and a lower-cost, more diversified set of projects.10/ The dominance of large projects in the NASA program is consistent with a governmentwide trend toward larger-scale projects--for example, the proposed Superconducting Super Collider (estimated to cost $5.3 billion in current dollars).11/ Since most significant scientific concerns may require enterprises on an ever larger scale, the trend itself may not be a matter of choice in the civilian space program. Nevertheless, the scale of space activity increases the cost of developing new endeavors, and makes the space program inflexible and vulnerable to cost and schedule delays in its major projects. The need for large-scale funding can stretch beyond development into years of operation--the fixed cost of operating a facility like the shuttle system is characteristically high. In both project development and subsequent operation, civilian space is becoming an all-or-nothing proposition.

## Growing Interdependence

A second characteristic of the NASA program is a general interdependence among its elements. A planned layer of space platforms in low Earth orbit would be an indispensable element of specific space science missions. Programs looking "down" (Earth and environmental observation) and programs looking "up" (physics and astronomy) would have their instruments changed on platforms while in orbit, removing the need to launch new, single-purpose spacecraft. Like the shuttle, these platforms--the most important of them being the space station--would be designed to undertake many, rather than single, missions. The success of these efforts will be ultimately evaluated not only in terms of advances in the technology of space infrastructure and space science, but also in terms of the reduced cost of missions that are made feasible.

A review of the space science and applications program during the 1980s shows two distinct trends toward interdependence. First, the

10. National Aeronautics and Space Administration, Advisory Council, *The Crisis in Space and Earth Science: A Report of the Space and Earth Science Advisory Committee* (November 1986), p. 12.

11. *The Budget of the United States Government, Fiscal Year 1989*, pp. 2b-6.

budget is dominated by a number of large projects that would depend on the shuttle system for launch or servicing in orbit or both, and on the space tracking and data communications networks (the TDRS and ground-based deep space network) to return data to Earth. Among these projects are the Hubble Space Telescope, the Gamma Ray Observatory, and the Galileo mission to Jupiter. Second, numerous smaller projects would be flown on a space shuttle round trip, including experiments in life sciences and processing materials, and a wide array of sensors designed to observe the Earth or outer space.

While increased interdependence offers the possibility of lower mission costs, it also increases the risks in cost and schedule faced by any particular mission. The planetary missions initiated in the mid-1970s, such as Galileo to Jupiter, depended on the then-untested shuttle system for transportation to low Earth orbit and on untested upper-stage rockets to launch the missions from low Earth orbit to their ultimate destinations. These missions have been vulnerable not only to their own technical problems or funding constraints, but also to those of the other projects (such as the shuttle) they have relied on. Consequently, planetary scientists have expressed a preference for traditional launch vehicles over the shuttle. The current program, however, includes many such missions, where cost and schedule risks are compounded by similar risks in the transportation and space station programs.

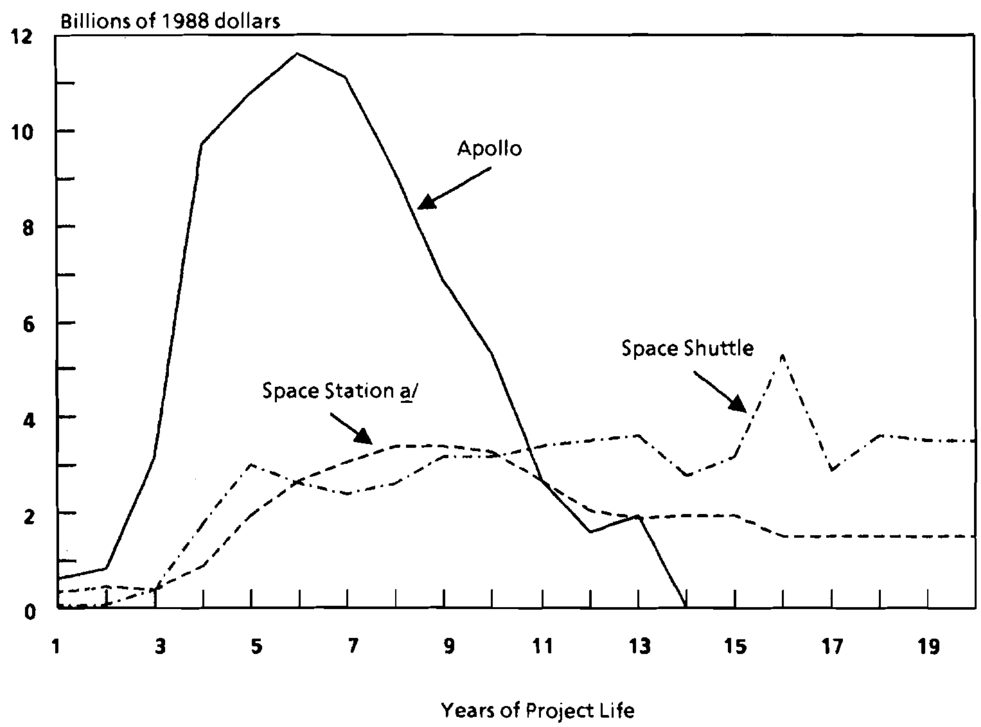
## Long Life Cycles and Continuing Operating Costs

The shuttle program illustrates an important new budgetary pattern in the current NASA program: a number of years of high expenditures covering development and construction of a system, followed by an indefinite period of lower but continuous expenditures on operations and maintenance to allow the system to deliver its benefits. This profile differs from the Apollo profile, in which the absolute level of funding accorded a single program rose dramatically to dominate the agency's budget but then fell to zero over a span of 14 years. Figure 2 compares the absolute level of funding and its profile over time for the Apollo program with the two most prominent investments in space infrastructure--the shuttle system and the space station--the latter on a projected cost basis. From the vantage point of the whole NASA budget, the many years of operating costs associated with infrastructure investment imply an increasing NASA budget over time if a cycle is established of adding a new generation's development cost to the previous generation's operating cost.

## Direction for the 1990s

The momentum of the NASA program over the last 15 years gives some indication of NASA's implicit plan for the 1990s. The implicit plan carries a basic set of costs and anticipated accomplishments that

Figure 2.
Cost of Space Programs




SOURCE: Congressional Budget Office estimates and NASA budget estimates, various years.

a. Projected costs.

constitute a core program, against which one can measure alternative programs incorporating major new initiatives. In this way, new initiatives can be examined in terms of how they would enhance the U.S. space program and how much additional growth in the NASA budget would be necessary to pay for them.

The long-term direction of the NASA program has become easier to predict because it includes projects with operation and maintenance costs extending long into the future, and because of interdependence among project elements. Today's program provides a basis for a new series of space efforts (as opposed to the Apollo program, which reached a logical conclusion after the series of manned moon landings in the late 1960s and early 1970s). The infrastructure built in this decade and the next will have a given set of applications, and these applications will form the core of the future program. Moreover, the decision to establish permanent human habitation in low Earth orbit implies continued investment in current or new manned transportation systems. Thus, the future NASA program will become increasingly determined by choices made years earlier: strong incentives will exist to fund new missions in order to rationalize the use of the infrastructure already provided, just as strong incentives now exist to buy the infrastructure needed to enable the new missions.

CHAPTER II

# THE NASA CORE PROGRAM IN THE 1990s

The program that the National Aeronautics and Space Administration is now developing for the 1990s is a logical extension of its current one and is referred to as the core program in this study. Since NASA has no official core program, this study has derived its content, schedule, and estimated cost from a variety of sources, which are described in detail in the Appendix. At the center of the core program is the continued development, operation, and exploitation of NASA's infrastructure in low Earth orbit. Using the infrastructure investment of the past two decades will provide important scientific returns. Beyond these projects and missions lies the next logical step in the NASA program--the space station, a project that indicates the new initiatives that NASA may undertake in the next century.

While this core program is the logical extension of NASA's current efforts, it calls for far greater resource commitments than the current NASA program receives. If the entire core program were undertaken, NASA spending would rise from the Congressional Budget Office baseline of $9.0 billion in 1988 to $14.4 billion in 1993 and $16.4 billion in 2000.1/ Moreover, these estimates do not allow for the cost or scheduling risks that accompany pioneering projects. Thus, maintaining NASA's current policy directions will call for significant increases in spending during the next decade.

1. Throughout this study, the term Congressional Budget Office baseline refers to a modified CBO baseline, not the baseline as constructed under the requirements of the Balanced Budget and Emergency Deficit Control Reaffirmation Act of 1987 (Public Law 100-119). In the modified baseline, the total program budget for NASA for fiscal year 1988 is $9,026 million, which includes new budget authority of $8,926 million plus $100 million of unobligated balances transferred to the research and development account from funds appropriated in 1987 for replacing the Challenger orbiter. The modified CBO baseline assumes no real increases in NASA's budget from 1988 levels, and it forms the basis for the budget-constrained program options discussed in Chapter III. For more information on baseline concepts, see Congressional Budget Office, *The Economic and Budget Outlook: Fiscal Years 1989-1993* (February 1988), Appendix D.

## OVERVIEW OF THE CORE PROGRAM

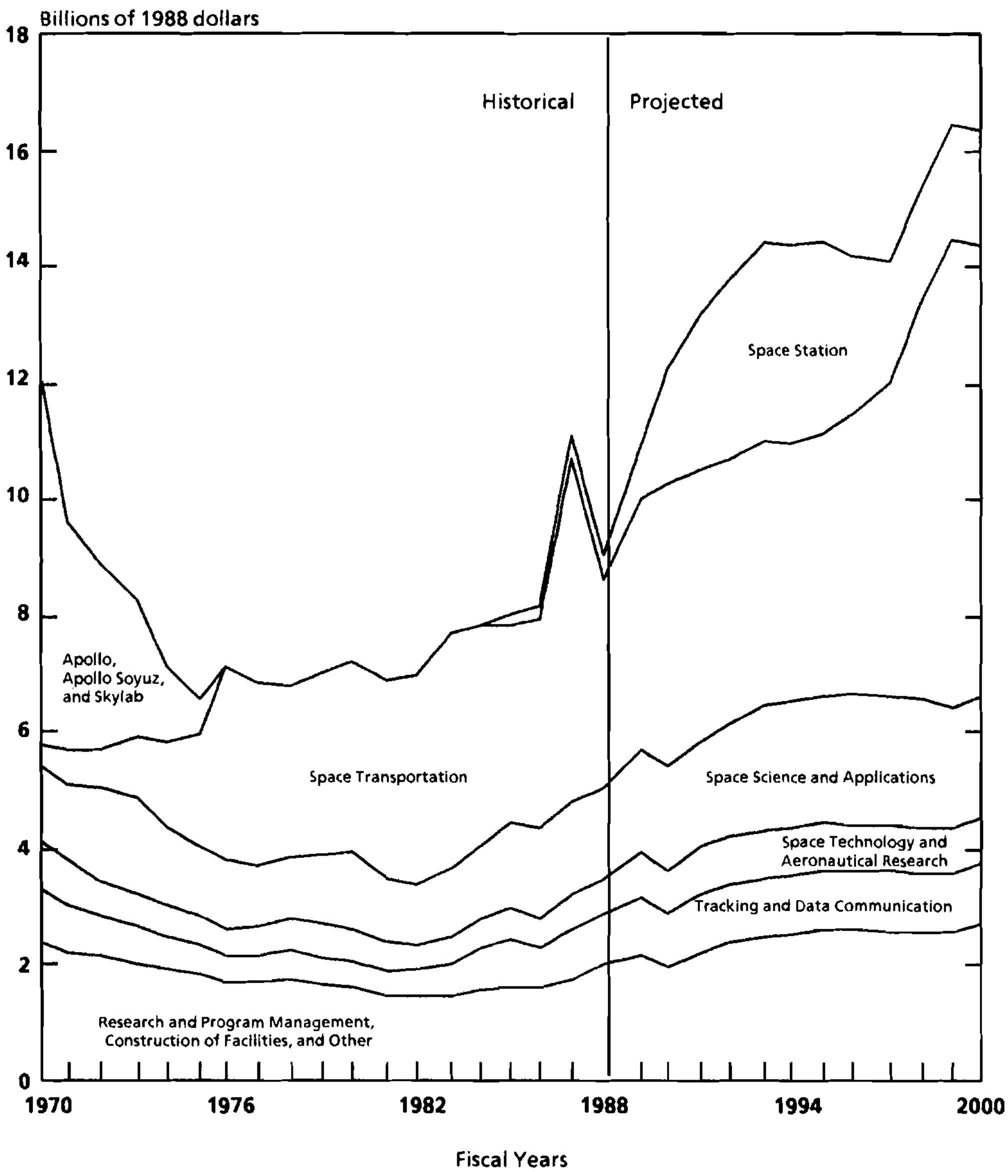
The core program consists of two distinct phases through the end of the century: the first, through the mid-1990s, is dominated by developing, procuring, and deploying the space station; the second, during the latter half of the 1990s, is focused on using the station and developing a new transportation system to replace the shuttle system. Figure 3 presents the estimated cost of the NASA core program for major components and shows its relation to the NASA program of the past 19 years.

Using space infrastructure during the 1990s should deliver a wide range of benefits in the areas of space science, applications of space science, and demonstration of technology. The long-deferred benefits of investments made during the 1970s and 1980s should be realized in the areas of planetary exploration, physics and astronomy, and environmental observation. Several related missions will test the major premises of the program: the Hubble Space Telescope and the Gamma Ray Observatory must deliver better, more cost-effective science for a long period of time to justify past investments. The space station program will demonstrate construction in space during its development phase. In operation, the space station will provide an orbiting laboratory for processing materials and conducting research on the life sciences. Thus, the core program of the 1990s, rather than being another prelude to accomplishment, would produce significant national achievements even if no major new initiatives were added.

The initial buildup in the NASA budget during the early 1990s would require annual real (post-inflation) growth in the NASA budget of just under 10 percent through 1993. The increase in the NASA budget required for this period is for the space station and associated transportation investment. Real spending would decline somewhat in the mid-1990s and then rise again--to $16.4 billion by 2000--to support development of a new space transportation system to replace the shuttle system some time early in the next century.

As was the case for the existing NASA program, the 1990s core program is presented in four parts--low-Earth-orbit infrastructure, space science and applications, technology development, and institutional support. The presentation of budget estimates in this analysis

## Figure 3.
## NASA Budget: Historical and Projected




SOURCES: Historical data, NASA budget plans as presented in *NASA Budget Estimates* for various years, projected data, and Congressional Budget Office estimates.

is a reordered version of NASA's own budget estimates. The space transportation category includes the spending in the NASA research and development accounts labeled "Space Transportation Capability Development" and the development funding for the Transatmospheric Vehicle, or the National Aerospace Plane, included in the Aeronautical Research and Space Technology account.2/

## THE LOW-EARTH-ORBIT INFRASTRUCTURE PROGRAM

Expanding and operating the capability to function in low Earth orbit is likely to consume about 70 percent of NASA's annual budget throughout the 1990s. As shown in Figure 3, developing, procuring, and operating space transportation facilities--predominantly the shuttle--will continue to be the largest single item in the infrastructure budget during the 1990s. The space station will be NASA's largest new investment during the 1990s. In the latter half of the 1990s, new investment is foreseen for a manned transportation system to replace the shuttle, and for a transfer vehicle capable of operating between the high geostationary orbit occupied by communications satellites and the low Earth orbit of the space station. Operating and maintaining the Tracking and Data Relay Satellite (TDRS) system that directs the flow of information from numerous spacecraft in Earth's orbit and the deep space tracking network for planetary spacecraft is projected to require roughly $1 billion annually through the end of the century.3/

### Space Transportation

Space transportation will continue to be a major part of the NASA program through the remainder of the century, with budgeted resources almost doubling by the year 2000, as shown in Table 1. The space transportation element of the core program consists of three major parts: first, operating and modifying existing systems to carry

2. National Aeronautics and Space Administration, *Budget Estimates, Fiscal Year 1989* (1988).

3. National Aeronautics and Space Administration, Office of Space Operations, *Fiscal Year 1988 Budget Runout* (April 1987).

payloads from the Earth to low Earth orbit; second, developing and procuring existing and new systems to move people and cargo within low Earth orbit, and to move them between that orbit and the higher orbits occupied by sensing and communication satellites; and, third, by the late 1990s, completing full-scale development of a new system to replace the shuttle. A less costly item on NASA's space transportation agenda is limited participation with the Department of Defense in the development of next-generation transportation technologies, like the National Aerospace Plane, and more generic research included in the space and aeronautical research program. The major projects in the space transportation core program are described briefly in Box 2.

Operating and Improving Existing Systems. NASA's 1989 request for operating existing Earth-to-orbit space transportation systems--the shuttle and conventional rockets--would require about $2.3 billion. This figure is estimated to climb to $2.5 billion by 1992 as more conventional rocket services are added to shuttle operations. This spending would support 8 to 14 manned shuttle flights, and expendable launch vehicle flights carrying the equivalent of 2.5 additional shuttle flights. These operating rates are consistent with the current NASA transportation plan and reflect the move away from a shuttle-only system to a mixed fleet, using both manned shuttle flights and unmanned rockets.4/ Beginning in 1996, two launches of the Shuttle C, an unmanned cargo carrier using the shuttle propulsion system, are also included in the core program.5/ These launches, estimated to cost $0.3 billion each, would increase operating costs for Earth-to-orbit space transportation to $3.1 billion annually.

Following the logic of the National Research Council's (NRC) 1987 report on the space station, the core program includes funding just short of that necessary to procure two additional orbiters beyond the existing three and the Challenger replacement now in production. The NRC pointed out that even if the probability of losing an orbiter were 1 percent or 2 percent rather than the demonstrated value of 4

4. National Aeronautics and Space Administration, *Payload Flight Assignments NASA Mixed Fleet* (October 1987).

5. National Aeronautics and Space Administration, "Definition of a Space Transportation System Cargo Element," Request for Proposal (1987).

TABLE 1. CORE PROGRAM SPACE TRANSPORTATION ANNUAL BUDGET AUTHORITY (In millions of 1988 dollars)

| | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|
| **Operating and Modifying Current Systems** | | | | | | | |
| Space Transportation System Operations a/ | 1,800 | 1,810 | 2,101 | 2,000 | 2,000 | 2,000 | 2,000 |
| Expendable Launch Vehicle Operations b/ | 0 | 28 | 186 | 400 | 500 | 500 | 500 |
| Spacelab Operations c/ | 74 | 67 | 76 | 75 | 75 | 75 | 75 |
| Shuttle C Operations d/ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Space Transportation System Production and Capacity Development e/ | 1,452 | 1,088 | 1,332 | 1,175 | 900 | 780 | 780 |
| Orbiter Procurement f/ | 2,062 | 0 | 0 | 420 | 420 | 420 | 420 |
| Shuttle System Advanced Solid Rocket Motor g/ | 0 | 0 | 0 | 175 | 225 | 210 | 140 |
| Shuttle C h/ | 0 | 0 | 0 | 25 | 75 | 200 | 300 |
| **Developing and Operating In-Orbit Transportation i/** | | | | | | | |
| Orbital Transfer Vehicle h/ | 0 | 0 | 0 | 0 | 0 | 0 | 50 |
| Upperstage Vehicle Procurement c/ | 161 | 155 | 140 | 140 | 140 | 140 | 140 |
| Other Transportation Development e/ | 271 | 388 | 385 | 300 | 290 | 200 | 200 |
| **Developing New Earth-to-Orbit Systems** | | | | | | | |
| Shuttle System Replacement Development j/ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| National Aerospace Plane g/ | 46 | 53 | 80 | 135 | 85 | 20 | 15 |
| Total | 5,867 | 3,589 | 4,300 | 4,845 | 4,710 | 4,545 | 4,570 |

SOURCES: Congressional Budget Office and other estimates, as specified below.

a. Congressional Budget Office estimate based on average 1983-1989 shuttle operation cost of $1.7 billion 1988 dollars, adjusted upward to account for anticipated flight rate during the 1990s.

b. National Aeronautics and Space Administration estimate, and CSP Associates, *NASA Program 1988-1989* (Boston: CSP Associates, December 1987).

c. Constant dollar spending at 1989 requested level based on National Aeronautics and Space Administration, *Budget Estimates Fiscal Year 1989* (February 1988).

d. Shuttle C operating rate during the 1990s based on National Aeronautics and Space Administration, "Definition of a Space Transportation System's Cargo Element," Request for Proposal (1987). Cost per launch based on NASA, Office of Space Flight, *Space Transportation for the Space Station: A NASA Report to Congress* (January 1988), p. 17.

(Continued)

TABLE 1. (Continued)

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|
| **Operating and Modifying Current Systems** | | | | | | | |
| Space Transportation System Operations a/ | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| Expendable Launch Vehicle Operations b/ | 500 | 500 | 500 | 500 | 500 | 500 | 500 |
| Spacelab Operations c/ | 75 | 75 | 0 | 0 | 0 | 0 | 0 |
| Shuttle C Operations d/ | 0 | 0 | 600 | 600 | 600 | 600 | 600 |
| Space Transportation System Production and Capacity Development e/ | 780 | 780 | 780 | 780 | 780 | 780 | 780 |
| Orbiter Procurement f/ | 420 | 420 | 420 | 420 | 420 | 420 | 420 |
| Shuttle System Advanced Solid Rocket Motor g/ | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Shuttle C h/ | 300 | 300 | 0 | 0 | 0 | 0 | 0 |
| **Developing and Operating In-Orbit Transportation i/** | | | | | | | |
| Orbital Transfer Vehicle h/ | 100 | 400 | 500 | 350 | 100 | 0 | 0 |
| Upperstage Vehicle Procurement c/ | 140 | 140 | 140 | 140 | 140 | 140 | 140 |
| Other Transportation Development e/ | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| **Developing New Earth-to-Orbit Systems** | | | | | | | |
| Shuttle System Replacement Development j/ | 0 | 45 | 70 | 380 | 1,740 | 3,000 | 3,000 |
| National Aerospace Plane g/ | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Total | 4,430 | 4,525 | 4,825 | 5,435 | 6,895 | 8,005 | 7,755 |

e. Congressional Budget Office estimate based on National Aeronautics and Space Administration 1989 request, adjusted downward to account for development cost of major shuttle modifications such as the Advanced Solid Rocket Motor and Shuttle C, shown as separate items.

f. Congressional Budget Office estimate, based on the assumption that two additional orbiters are procured during the 1990s at a cost of $2.6 billion each.

g. Congressional Budget Office estimate based on National Aeronautics and Space Administration data.

h. Congressional Budget Office estimate based on discussions with industry.

i. A part of the "other transportation development" category addresses Earth-to-orbit systems through the mid-1990s.

j. Mid-1990s start date is based on National Aeronautics and Space Administration, "Space Transportation Architectures and Technologies," a presentation of the Department of Defense/National Aeronautics and Space Administration Steering Group (May 12, 1987). Congressional Budget Office cost estimate based on shuttle development costs.

## BOX 2
## CORE PROGRAM SPACE TRANSPORTATION ACTIVITIES

### SPACE TRANSPORTATION OPERATIONS

Space transportation operations include the activities necessary to plan, launch, and fly Earth-to-orbit space transportation for NASA's mixed fleet of manned orbiters, unmanned vehicles included in the shuttle system, and conventional rockets.

*Space Shuttle.* Fleet of manned orbiters operating at an annual rate of 8 to 14 flights.

*Expendable Launch Vehicle.* A mixture of conventional rocket services having the annual carrying capacity of two and one-half shuttle flights.

*Shuttle C Operations.* Two flights annually starting in 1996 of an unmanned cargo carrier attached to the shuttle's propulsion system, with the capability of lifting 100,000 pounds to low Earth orbit.

*Spacelab.* Funding to support the flight operations of periodic spacelab missions. A spacelab is a pressurized laboratory module carried in the space shuttle cargo bay that permits the shuttle crew to conduct a variety of experiments.

### SPACE TRANSPORTATION DEVELOPMENT AND INVESTMENT

Space transportation development and investment includes the activities that increase the capabilities of Earth-to-orbit and in-space transportation vehicles and systems.

*Space Shuttle.* Modifying the space shuttle system--for example, modernizing the data processing hardware and software for launch, flight, and landing operations, and possibly the orbiters themselves.

*Advanced Solid Rocket Motor.* A program to enhance the performance and improve the quality of the shuttle solid rocket boosters. It is anticipated that the ASRM will increase the shuttle's payload capacity by over 12,000 pounds, roughly 20 percent.

*Orbiter Replacement.* Replacing shuttle orbiters at a rate of one orbiter every six and one-half years.

*Shuttle C (cargo).* A program to develop an unmanned cargo-carrying attachment to the shuttle system propulsion system. Initial expectations are that the rocket would carry 100,000 pounds to 120,000 pounds to low Earth orbit.

*Orbital Maneuvering Vehicle.* A reusable vehicle capable of operating from the shuttle orbiter or the space station with the capability to move cargo in low Earth orbit.

*Orbital or Transfer Space Vehicle.* A reusable in-space vehicle capable of operating from the shuttle orbiter or the space station that moves cargo from low Earth orbit to higher orbits.

*Shuttle II.* An as yet undefined manned system to replace the shuttle.

*National Aerospace Plane.* A cooperative development program with the Department of Defense to create a space transportation vehicle with the attributes of a conventional jet aircraft.

percent, an orbiter would be damaged beyond repair once every five to eight years.6/ Beginning in 1990, the core program budget includes $4.4 billion spread over 11 years to cover the cost of a replacement orbiter every 6.5 years. Procuring orbiters in the 1990s implies that a replacement for the shuttle system would not be forthcoming until some time after 2000. However, funding for a replacement system, included in the core program at the $45 million level beginning in 1995 and rising to $3 billion by 1999, would have to occur earlier and at a higher level to produce a replacement launch system in this decade. Thus, if the replacement orbiters were not procured, the resulting resources would probably be absorbed by the need for a replacement system, unless the major defense and science payloads due to be launched and serviced by the shuttle were canceled.

NASA has proposed two major enhancements to the shuttle system over the next five years. The Advanced Solid Rocket Motor program is aimed at increasing the power and reliability of this part of the shuttle's propulsion system, and will require development funding of $1.0 billion between 1989 and 1992.7/ The Shuttle C, estimated to cost $1.2 billion to develop, would replace the piloted orbiter with an unmanned cargo carrier to provide NASA and the Department of Defense with the capability to launch 100,000 to 120,000 pounds into low Earth orbit.8/

The core program budget also maintains funding of roughly $1 billion annually through 1991. These funds are to cover modifications to the shuttle begun in response to the Challenger accident's investigation and for the underlying improvement program for all aspects of the system including mission planning; launch, flight, and landing operations; on-board computer systems; and propulsion systems. An additional improvement in the shuttle system, referred to as the extended duration orbiter, will permit the flight time of a shuttle mission to increase from 7-10 days to 14-16 days by increasing the electrical power storage capacity of the orbiter. From 1992 through 2000,

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6. National Research Council, *Report of the Committee on the Space Station* (Washington, D.C.: National Academy of Sciences, November 1987), p. 24.

7. Statement of Richard Truly before the House Subcommittee on Space Science and Applications, Committee on Science, Space, and Technology, Washington, D.C., March 31, 1988.

8. National Research Council, *Report of the Committee on the Space Station*, p. 23.

funding in the shuttle production and capability development account would be maintained at a constant level of $780 million to cover this continuous process of improvement and modification.9/

Developing Transportation in Space. Many payloads carried to low Earth orbit in the shuttle require "in-space" transportation to get to other orbits. Expendable "upperstage" vehicles are the current technical option for travel between low and high Earth orbits, and are included in the program at the constant dollar level proposed for 1989--namely, $140 million. The orbital maneuvering vehicle (OMV), currently in development, would ferry cargo in low Earth orbit, for example, between the space station and platforms in the same orbit. The space or orbital transfer vehicle (OTV) will be the first of a family of spacecraft moving back and forth between higher orbits and the low Earth orbit of the space shuttle or the space station. This capability is needed to service satellite platforms in the higher geostationary orbit (an equatorial orbit that keeps pace with the surface of the Earth) and eventually travel between the Earth and the Moon. The OTV project is included in the budget during the 1990s as a major project, while the OMV (and several smaller efforts, such as the tethered satellite program) is included in the "other space transportation" category.

Replacing the Shuttle System. The core budget includes significant support for developing a system to replace the shuttle late in the 1990s.10/ The experience with shuttle operations and improvements, the results of the space research and technology program, and the progress and direction of the Air Force's Advanced Launch System program will all shape the replacement system. There will certainly have to be a manned successor to the shuttle, given the operational requirements of the space station and other orbiting platforms. The funding levels to develop a replacement for the shuttle included in the

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9. For information about general improvements, see American Institute of Aeronautics and Astronautics, *The Civil Space Program: An Investment in America* (Washington, D.C.: AIAA, December 1987), pp. 27-30. For detailed information system requirements, see General Accounting Office, *Space Operations, NASA's Use of Information Technology* (1987), Appendix II.

10. National Aeronautics and Space Administration, "Space Transportation Architectures and Technologies," a presentation to the Department of Defense/NASA Space Transportation Joint Steering Group (May 12, 1987).

late 1990s are derived from comparable shuttle development experience during the 1970s.11/

Space transportation remains the cornerstone of the NASA program. In large part, the unanticipated investment in transportation made over the last three years, and that likely to be made in the near future, is motivated by the need to service the space station and related space platforms during their lives. More generic research on transportation, to evaluate and demonstrate the technologies needed for manned missions to the Moon or Mars, is included in the research and technology development part of the program. Actual development of these systems, however, would be a new initiative beyond the scope of the core program.

## Space Station and Related Space Platforms

The centerpiece of NASA's new infrastructure investment during the 1990s is the space station program. NASA would require $29 billion of budget authority from 1989 through 2000 for the most expansive version of the program, as shown in Table 2. This fully developed space station would include a crew rescue vehicle and expansion of the basic space station (currently being debated). The program is international in scope and includes Canada, Japan, and 11 European nations (through the European Space Agency). The planned fiscal and physical commitment of each of these international partners is shown in Table 3.

Under current plans, the space station program consists of three major parts. The Block One configuration includes four habitable modules (three laboratories--one U.S. and two foreign--and living space for crew ) mounted in the center of a truss structure--a latticework of support beams--with devices to capture solar power on each end. Block One is to be launched by 19 space shuttle flights into a 28.5 degree orbit and would be operational by the mid-1990s. Also included in Block One is a "polar platform," a physically unrelated, unmanned, but ultimately serviceable observation platform to be launched in the

11. Congressional Budget Office, *Pricing Options for the Space Shuttle* (March 1985), p. 13.

TABLE 2. CORE PROGRAM SPACE STATION FUNDING, 1987-2000
(In millions of 1988 dollars)

| | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|
| Block One (Manned laboratory, central truss, and polar platform) a/ | -- | -- | -- | 1,905 | 2,440 | 2,735 | 2,465 |
| Block Two (Upper and lower truss, and service bay) b/ | -- | -- | -- | 0 | 0 | 0 | 0 |
| Crew Emergency Rescue Vehicle c/ | -- | -- | -- | 50 | 150 | 200 | 500 |
| Operations d/ | -- | -- | -- | 25 | 70 | 165 | 425 |
| Total | 433 | 392 | 920 | 1,980 | 2,660 | 3,100 | 3,400 |

SOURCE: Congressional Budget Office estimates based on National Aeronautics and Space Administration data.

NOTE: Dashes for 1987 through 1989 indicate that program totals were not broken down into the categories shown.

a. National Aeronautics and Space Administration, *Capital Development Plan for Space Station* (March 1988).

(Continued)

mid-1990s. The polar platform, as its name implies, is to be placed in an orbit passing over the north and south poles rather than the 28.5 degree orbit of the manned elements of the space station program. NASA's inclusion of the platform in the space station program has been criticized because there is only a limited connection between the permanently manned laboratory and the platform.12/ Moreover, the very uncertain status of future manned launches from the currently mothballed Vandenberg shuttle launch site calls into question the serviceability of the polar platform, one of its more attractive features.13/ The current national space strategy does not permit polar

12. For example, the National Research Council concluded, "The Committee finds no intrinsic operational or strong scientific relationship between the space station, on the one hand, and the polar platform on the other." *Report of the Committee on the Space Station* (September 1987), p. 14.

13. The Vandenberg shuttle launch facility is operated by the Department of Defense. In the wake of the Challenger accident and the resulting move to conventional rockets, it is unclear whether DoD will ever operate its shuttle launch facility.

TABLE 2. (Continued)

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|
| Block One (Manned laboratory, central truss, and polar platform) a/ | 2,330 | 1,665 | 820 | 0 | 0 | 0 | 0 |
| Block Two (Upper and lower truss, and service bay) b/ | 95 | 600 | 1,035 | 1,070 | 915 | 475 | 475 |
| Crew Emergency Rescue Vehicle c/ | 400 | 200 | 0 | 0 | 0 | 0 | 0 |
| Operations d/ | 590 | 800 | 825 | 1,000 | 1,000 | 1,500 | 1,500 |
| Total | 3,415 | 3,265 | 2,680 | 2,070 | 1,915 | 1,975 | 1,975 |

b. National Aeronautics and Space Administration, "Space Station," Briefing to Senate Commerce Committee (May 1987).

c. Congressional Budget Office estimate based on National Research Council, *Report of the Committee on the Space Station* (September 1987), p. 30.

d. Through 1996, National Aeronautics and Space Administration, *Capital Development Plan for Space Station* (March 1988); thereafter Congressional Budget Office estimate based on *Report of the Committee on the Space Station* (September 1987), pp. 28-32.

launches from the Kennedy Space Center because the launch vehicle would ascend over populated areas rather than the Atlantic Ocean. Instead, polar launches are made from the west coast where the north-south ascent required for a polar orbit can occur over the Pacific Ocean. Automated alternatives to shuttle-based servicing are now being considered within NASA. The program elements in Table 2 also list a Crew Emergency Rescue Vehicle that is assumed to be assimilated into the Block One configuration under the core program.14/

The second element of the space station, Block Two, is an expansion of the manned element of Block One to include an "upper" and "lower" truss structure, a satellite servicing bay, and a detached space platform in the same orbit that can be visited and serviced by the space station crew. The specific features of Block Two expansion may

14. National Research Council, *Report of the Committee on the Space Station*, p. 46.

TABLE 3. FOREIGN CONTRIBUTIONS TO THE INTERNATIONAL SPACE STATION

| Partner | Activity | Estimated Nominal Dollar Cost (Millions) |
|---|---|---|
| European Space Agency | Laboratory Module, polar platform and co-orbiting free flyer | 4,200 |
| Japan | Japan Experimental Module | 2,000 |
| Canada | Mobile Servicing Module | 800 |

SOURCE: National Aeronautics and Space Administration.

change as the purposes of the station, beyond those currently defined, are identified. As the estimated cost of the Block One program has increased, the status of Block Two has become increasingly unclear, and the possibility exists that Block Two will be abandoned or at a minimum delayed into the next century.

When the development phase of the space station program is completed, a stream of operational costs must be paid over the remaining life of the project, perhaps 30 years, to realize the benefits of the investment beyond the achievement itself and the experience gained in construction. Limited operations are expected to begin after the sixth space shuttle assembly flight, so some science and applications work could be undertaken as early as the mid-1990s.15/ As a consequence of the desire to gain operational benefits as early as possible and the need for planning, spending on operations begins in 1990 and builds toward a $1.5 billion annual level by 1999.

During the 1990s, the most prominent uses of the Block One space station will be in the areas of life science and the processing of materials in space. The polar platform will provide Earth and environmental observation data. Results in all of these areas will

15. National Aeronautics and Space Administration, *Space Station Development Plan* (April 1988).

require the use of the full array of infrastructure facilities developed in the 1970s and 1980s, and those to be developed in the 1990s. Science on the space station will require logistical support by the shuttle system and the data transmission capabilities of the TDRS. The polar platform, while launched on an expendable rocket, is designed to be serviced by the shuttle, and would be the most significant user of the TDRS, given the anticipated large volume of data it will gather. The resulting level of interdependence would be above that of the current shuttle-dependent set of space science missions and would carry with it the risks of increased costs and schedule delays.

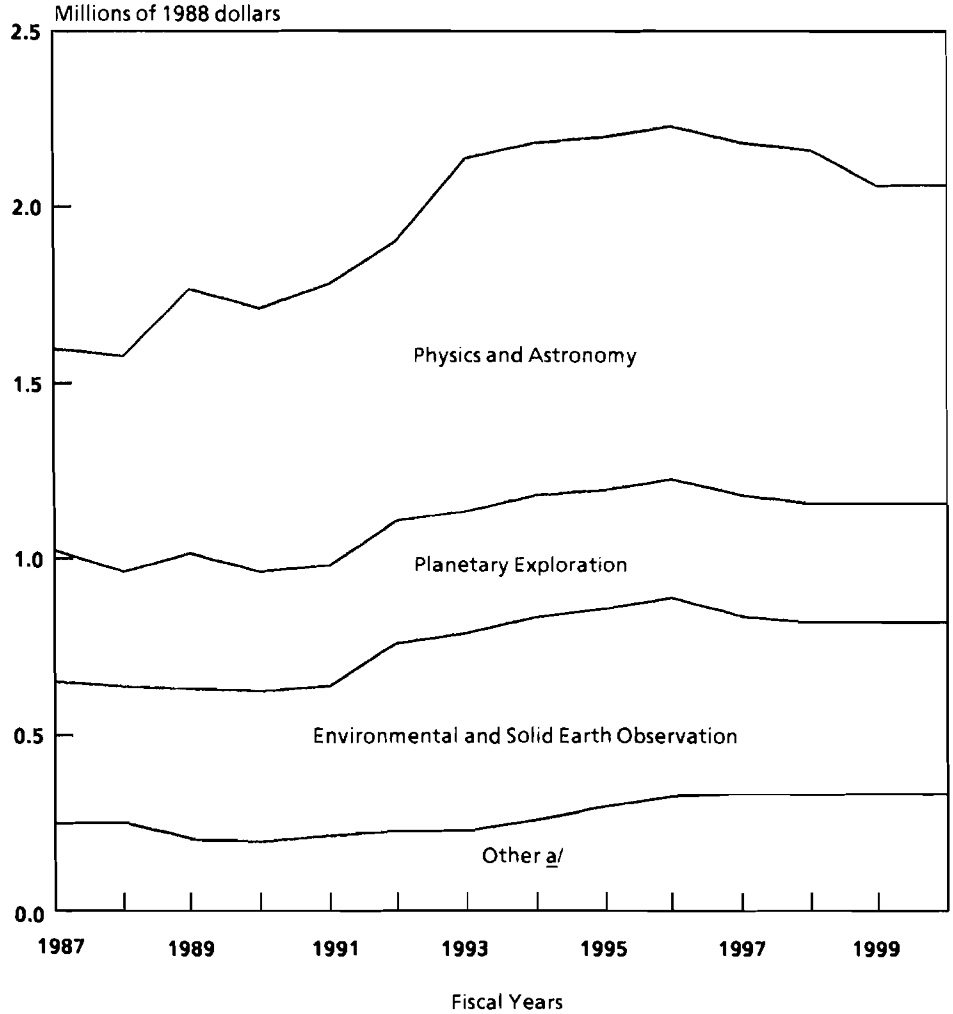
## SPACE SCIENCE AND APPLICATIONS

Accomplishing the objectives of the NASA space science and applications program during the 1990s will require substantial growth in funding, from a 1988 level of $1.6 billion to $2.2 billion by the mid-1990s, as Figure 4 shows. The core of the space science and applications program includes launching and operating those missions delayed by the Challenger accident, developing long-planned new missions, preparing and eventually using the space station facility, and providing operational support, particularly for long-lived multimission space platforms. Major space science and applications missions are described in Box 3. As noted, estimates of the funding necessary to carry out this program are derived from a series of reports prepared during the 1980s by NASA's Advisory Council committees.16/

Three areas of the space science and applications program--physics and astronomy, planetary exploration, and environmental and solid Earth observation--account for 85 percent of the space science and applications program in 1988 and are projected to maintain an 80 percent share during the 1990s. In the second half of the 1990s, parts of the program--notably life science and processing materials re-

16. For an overview of four major space science and applications programs and estimated funding requirements, see NASA Advisory Council, *The Crisis in Space and Earth Science* (1986).

Figure 4.
Space Science and Applications Core Program, 1987-2000




SOURCE: Congressional Budget Office estimates based on National Aeronautics and Space Administration Advisory Council, *The Crisis in Space and Earth Science* (November 1986), pp. 12-14.

a. Includes information systems, communications, processing materials in space, and life sciences.

lated to the space station--grow more quickly than the three original areas. The core program includes low levels of funding for two other programs--information systems and communications. The communications program is maintained at only $20 million annually after the completion of the Advanced Communications Technology Satellite program in 1990. In recent years, the Congress included funding for satellite communications despite the Administration's desire to cut the program dramatically. A more aggressive effort in communications could increase this program's funding by $50 million to $100 million annually.

## Missions Delayed by the Challenger Accident

The backlog of space science and applications missions delayed as a result of the Challenger accident in 1986 represents an expensive deferral of benefits and scientific results from the mid-1980s to the early 1990s.17/

The Hubble Space Telescope is the most costly and arguably the most significant of these delayed missions. The pre-launch nominal dollar cost of the telescope will exceed $1.5 billion when it is launched in 1989. When it becomes operational, it will be the be first of four planned orbiting observatories. The four Great Observatories and two related ground-based facilities--the National New Telescope and the Very Long Baseline Array (a network of radio telescopes)--will provide historically unparalleled sensitivity across the electromagnetic spectrum. The Hubble Space Telescope, though confined to a range of wavelengths just exceeding the visible spectrum, represents a 25-fold increase in sensitivity to the visible spectrum over the most powerful ground-based optical telescopes.

The space telescope represents a break from past U.S. missions for space science and applications. The project should operate for 20 years, and will be managed under contract with the independent Hubble Space Telescope Science Institute that will, among its other duties, allocate use of the telescope among interested scientists. Moreover, it will be the first test of NASA's low-Earth-orbit infrastructure strategy, since it would not be a feasible mission without the space

17. Congressional Budget Office, "The 1988 Budget and the Future of the NASA Program" (March 1987), pp. 42-43.

## BOX 3
## MAJOR ACTIVITIES IN SPACE SCIENCE AND APPLICATIONS IN THE CORE PROGRAM

### PLANETARY EXPLORATION

The core program uses the NASA Advisory Council's *Planetary Exploration Through the Year 2000: A Core Program*. This analysis establishes a typology of missions and priorities, and a funding level of $320 million (in 1984 dollars) annually, under which the core program can be accomplished. Parts of the program have been adopted, while others are still in the proposal stage.

*Galileo*. A probe to Jupiter, delayed by the Challenger accident, to be launched in late 1989 or early 1990. Development is essentially complete.

*Magellan*. A mission to Venus to complete the mapping of the planet's surface. Launch is scheduled for 1989.

*Mars Observer*. A mission to Mars with the goal of analyzing the composition of the planet's surface and the role of water in its climate. Launch is scheduled for 1992.

*Ulysses*. An international cooperative mission to study the Sun. Development is essentially complete, with the launch scheduled for 1990.

*Comet Rendezvous/Asteroid Flyby*. The first U.S. mission to explore these types of smaller bodies, designed to provide insight into the early history of the solar system. Funding begins in the early 1990s.

*Titan Probe/Radar Mapper*. A probe similar to the Galileo mission to Jupiter, designed to explore and map Saturn's largest satellite, Titan. Funding is to begin in the 1990s after the Comet Rendezvous/Asteroid Flyby start.

### PHYSICS AND ASTRONOMY

The broad outlines of the physics and astronomy core program are those included in the NASA Advisory Council report, *The Crisis in Space and Earth Science*. These have been pushed back in time to account for the delay and cost of the Challenger accident.

*Hubble Space Telescope*. The first of four orbiting observatories with capabilities in the visible spectrum. The telescope is currently awaiting launch in 1989 and is designed to be operated for 20 years if periodically visited by the shuttle.

## BOX 3

### PHYSICS AND ASTRONOMY
(Continued)

*Gamma Ray Observatory.* The second orbiting observatory covering the high-energy portion of the spectrum. Development continues, with launch anticipated for 1990.

*Advanced X-Ray Astrophysics Facility.* An X-ray observatory, the third of the orbiting observatories, included in the core program in the early 1990s.

*Space Infrared Telescope Facility.* The final orbiting observatory covering the infrared portion of the spectrum, included as a core program during the 1990s.

*Explorer Program.* A set of smaller, lower-cost missions designed to answer a variety of questions of interest to the program. A constant level of activity is included in the core program throughout the 1990s.

### SOLID EARTH AND ENVIRONMENTAL OBSERVATION

The broad outlines of the core program are drawn from a NASA Advisory Council Report, *Earth System Science: Overview.* The report includes both current missions and a vision for the 1990s.

*Ocean Topographical Experiment.* A satellite designed to study the relation between wind and ocean currents. TOPEX is an international cooperative venture with a launch on a European Space Agency rocket scheduled for the early 1990s.

*Upper Atmosphere Research Satellite.* A satellite program to measure the upper atmosphere's content of ozone, chemicals affecting ozone, and the general chemical makeup of the atmosphere as it is affected by natural and human-induced changes. Launch is scheduled for 1991.

*Earth Observation System.* A master plan for observing the Earth including polar, space-station-based and geostationary sensors, and supporting ground facilities. A variety of current activities including atmospheric and other sensing instruments carried on the space shuttle will feed into this mid-1990s mission.

shuttle for launching, servicing, and recovery. The TDRS system will transmit the images it gathers to Earth, and the space station will service the telescope. Servicing the physical facility in orbit, changing its instruments, and coordinating the many demands from ground-based observers to use the telescope will require continuing expenditures of $100 million annually over the 20-year working life of the space platform.

The space telescope's high development cost, multiple users and missions, need for service by other elements of the low-Earth-orbit infrastructure, and substantial recurring costs make it the prototype for many projects in the core program culminating in the space station. Benefits could be substantial, but so are the costs and risks. NASA has limited experience with servicing equipment in orbit, and unanticipated servicing difficulties could limit the life of the project. A major failure in the shuttle system leading to downtime of two years could force the cancellation of key servicing visits, again limiting the life of the telescope.

While investments in space science and applications missions will occur later than planned, and cost more than anticipated because of the Challenger accident, it is still likely that they will take place. Indeed, the two Great Observatories already built (the Gamma Ray Observatory and the Hubble Space Telescope), the four planetary spacecraft now completed or well along in development, an existing cluster of smaller solar physics spacecraft, the Upper Atmospheric Research Satellite, and the Advanced Communication Technology Satellite are all in their respective fields as advanced as, if not more advanced than, the efforts of any other nation. For example, in planetary exploration, an area where deficiencies in the U.S. program are frequently noted, the Galileo mission to Jupiter (due to be launched in 1989 and to arrive at Jupiter in 1995, after flying by and transmitting data about four previously unexplored asteroids) will be the most advanced planetary exploration of the outer planets to date. Upon arrival in the Jovian system, the spacecraft will release a probe toward Jupiter's surface and then remain in the area of Jupiter for four years observing the planet and its moons. Claims that the United States has relinquished its role as a leading spacefaring nation do not take full account of these likely achievements during the 1990s.

## Developing New Missions

The NASA space science and applications communities, including industrial and academic constituencies, engaged in program and budget planning exercises in the mid-1980s.18/ These efforts identified a set of missions that logically follow those delayed by the Challenger accident and thus are part of the core of the space science and applications program through the 1990s. In many cases, like their predecessors, these new missions will be large, entail continuous, long-term operation and maintenance costs, and rely on the infrastructure built since 1970. In the area of planetary exploration, however, some smaller-scale missions will take place independently of the shuttle system.

The agenda in astronomy and physics will continue to focus on the Great Observatory space platforms. The Advanced X-Ray Astrophysics Facility (included in the NASA 1989 budget requests as a new start), the Space Infrared Telescope Facility, and new ground-based optical and radio telescopes are viewed by NASA as essential follow-ons to the Hubble Space Telescope and the Gamma Ray Observatory in completing a revolutionary increase in the technology of astronomy. Taken together with the activities for the smaller-scale explorer program and the operational, research, and analysis spending necessary to produce the scientific gains permitted by the new observatories, the physics and astronomy program retains slightly less than half of the space science and applications effort through the 1990s.

The solid Earth and environmental observation core program follows the larger trend toward long-lived, expensive missions. Using the space station's associated polar platform and other spacecraft in the higher geostationary orbit, an Earth Observation System (EOS) would integrate observation and analysis of the solid Earth, continental movements, volcanic and earthquake activity, the biosphere, the network of living organisms and related processes, and the atmosphere.19/ The EOS is included in the core budget at a level of $250 million annually, roughly half of the solid Earth and environ-

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18. NASA Advisory Council, *The Crisis in Space and Earth Science*.

19. NASA Advisory Council Earth System Sciences Committee, *Earth System Science Overviews: A Program for Global Change* (May 1986).

mental observation budget for several years in the mid-1990s. The practical applications of this system are held to be in short-term weather forecasting, in long-term climatic change forecasting, and in assessing the consequences of human activity, such as industrial effluents or deforestation, on the environmental balance of the Earth. Like the orbiting observatories, the EOS will rely on the low-Earth-orbit infrastructure. As planned, the system will use a variety of instruments on the polar platform to gather information best obtained from this orbit. An additional platform in the higher, geostationary orbit will be used to gather appropriate observations. The polar platform will be the heaviest user of the TDRS, providing an almost continuous flow of information to the ground. While the EOS dominates the solid Earth and environmental observation core program, a number of smaller, more limited missions (such as the Tropical Rainfall Missions) are also included.

The EOS also illustrates a trend toward cooperation both internationally and among various U.S. government departments. This cooperation has been motivated by a convergence of missions and requirements and the high cost of this type of mission. The polar platform will be shared by NASA and the National Oceanic and Atmospheric Administration, which plans to use its space on the observation platform for weather forecasting instruments now flown on single-mission spacecraft. This shared use of an infrastructure element should lower the overall cost to the government of the missions it supports in polar orbit. The EOS plan includes international cooperation through data exchange and access, and the coordination of spacecraft and missions financed by different governments.

The planetary exploration program also incorporates a set of missions that are intended to succeed the missions delayed by the Challenger accident or that are in current development. The core activities and cost estimates in this area rely on a pair of reports by the Solar System Exploration Committee of the NASA Advisory Council. The committee recommended two specific missions to follow those delayed or in development--the Comet Rendezous/Asteroid Flyby (CARF) and the Titan Probe/Radar Mapper, subsequently renamed Cassini. These two missions would be developed during the period from 1990 through 1995. The core program assumes that an unspecified set of additional missions would result in a constant long-term funding level of $320 million (1984 dollars), as was proposed by the committee. 20/

As a group, the planetary exploration missions are not as integrated with the low-Earth-orbit infrastructure as are those of the physics and astronomy, and solid Earth and environmental programs. While the shuttle would be a backup launch vehicle for U.S. planetary missions, their primary vehicles are intended to be large expendable launch vehicles. For the generation of missions included in the core program, the space station does not provide indispensable services, although future missions could use the space station as a port of entry for missions returning samples from Mars or the asteroids.

## Operations, and Research and Analysis

The development and launch of a spacecraft are only the beginning of the process of scientific inquiry. The major activities and costs in the space science and applications program are the operation of spacecraft in flight and the collection and analysis of data provided by these missions. Table 4 shows this funding for 1988 and the request for 1989, accounting for one-third of the space science and applications budget. The core program also anticipates that roughly one-third of the science and applications budget will be devoted to operations and research and analysis during the 1990s.

## Equipping and Using the Space Station

The core program includes a slow buildup in funding the areas of life sciences and processing of materials--the two parts of the space science program anticipated to make most use of the space station during the 1990s. The current program includes planning for this buildup, but contains few details about what instruments and equipment will be developed and procured. The cost of the space station estimated by CBO does not include funding to develop or undertake scientific or commercial research, or for specific pieces of equipment and instru-

20. NASA Advisory Council, Solar System Exploration Committee, *Planetary Exploration Through Year 2000: A Core Program* (1983).

mentation necessary for these activities. These items are covered in this part of the core program.

## DEVELOPMENT OF TECHNOLOGY

Program and mission planners in the civilian space program must base their planning decisions on the technology available at the moment. While some development programs push the limits of technology, the demands of developing a specific system limit the extent to which technological progress can be assumed. In order to prepare itself to make the best choices regarding mission and system development for its future program, the core program includes a component for expanded space research and technology development.

TABLE 4. RESEARCH AND ANALYSIS AND OPERATIONS FUNDING, 1988 AND 1989 (In millions of 1988 dollars)

| | 1988 | 1989 |
|---|---|---|
| Physics and Astronomy | 214.9 | 237.6 |
| Life Sciences | 38.6 | 45.8 |
| Planetary Exploration | 142.6 | 190.4 |
| Solid Earth Observation | 21.1 | 22.2 |
| Environmental Observation | 103.2 | 122.8 |
| Communications | 14.1 | 10.1 |
| Total | 534.5 | 628.8 |

SOURCE: National Aeronautics and Space Administration, *NASA Budget Estimates, Fiscal Year 1989.*

The first phase of this expansion is the Civilian Space Technology Initiative, which increases space research and technology activity in the areas of propulsion, automation and robotics, vehicles, information systems, power, and large structures and control. The initiative is an umbrella under which these enabling technologies would receive increased funding at a constant level of 40 percent above the 1987 level. Pathfinder, a separate initiative focusing on manned programs, has been proposed in the 1989 budget. It includes technology demonstration programs emphasizing the space transfer vehicles, life sciences, and operational technologies necessary for manned exploration of the solar system. The core budget projects funding at a level of $380 million from 1992 through 2000 to extend activities that are similar to Pathfinder.21/

## BUILDING AND MAINTAINING NASA AS AN INSTITUTION

Several areas of the NASA program can be grouped together and categorized as institution building and maintenance. These elements of the core program and their projected funding requirements are listed in Table 5. The dominant element of this group of activities is the research and program management (RPM) budget, which funds the salaries of NASA's federal workers and related contract services. These budgets have grown and shrunk as NASA's funding for development and operation has changed. The core program's RPM budget is a simple forecast based on the relationship between program spending and RPM spending from 1970 through 1988.

Budget authority devoted to encouraging the use of NASA technology and commercial programs may grow in anticipation of greater activity as the space station era approaches. A portion of the funds in the commercial area will be used to procure equipment and instruments that will be employed in demonstrating concepts for new commercial prospects.22/

21. This level is less than half of that proposed in the National Research Council's technology study; see National Research Council, *Space Technology to Meet Future Needs* (1987), p. 130.

22. Recent proposals would add $400 million to $700 million from 1989 through 1992 to the Commercial Programs budget to lease space on a commercially developed space station, periodically visited and manned by space shuttle crew members.

TABLE 5. CORE PROGRAM INSTITUTIONAL SUPPORT 1987-2000 (In millions of 1988 dollars)

| | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|
| Commercial Programs and Technical Utilization | 42 | 74 | 55 | 55 | 55 | 55 | 55 |
| Safety, Reliability, and Quality Assurance | 12 | 14 | 21 | 20 | 20 | 20 | 20 |
| Construction of Facilities | 174 | 178 | 271 | 250 | 250 | 250 | 250 |
| Research and Program Management | 1,497 | 1,743 | 1,821 | 1,630 | 1,870 | 2,065 | 2,155 |
| Total | 1,726 | 2,009 | 2,168 | 1,955 | 2,195 | 2,390 | 2,480 |

SOURCE: Congressional Budget Office estimate.

(Continued)

## SENSITIVITIES AND RISKS IN THE CORE PROGRAM

NASA's core program for the 1990s is dominated by operating and developing space transportation, and developing the space station. Accordingly, the major sensitivities in the estimated funding requirements are in these areas. The estimates of costs for the Advanced Solid Rocket Motor and the Shuttle C could be too low, since the recent history of investment in space transportation has not been encouraging. For example, NASA's high-energy upperstage vehicle, the Shuttle/Centaur program, experienced cost overruns of $100 million during an initial effort of $150 million and was ultimately canceled.23/ Shuttle C, however, is somewhat peripheral in NASA's plans, and could eventually be dropped, lowering development costs over the 1990-1994 period by a total of $1.2 billion and operating costs by $600 million each year from 1994 to 2000. In addition, NASA could receive reimbursements from the Department of Defense and other parts of the federal government for launch services in

23. House Committee on Science and Technology, *Centaur Cost Schedule and Performance Review*, 99:2 (August 7, 1986), pp. 1-2.

TABLE 5. (Continued)

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|
| Commercial Programs and Technical Utilization | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Safety, Reliability, and Quality Assurance | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Construction of Facilities | 250 | 250 | 250 | 250 | 250 | 250 | 250 |
| Research and Program Management | 2,205 | 2,280 | 2,270 | 2,265 | 2,230 | 2,225 | 2,390 |
| Total | 2,530 | 2,605 | 2,595 | 2,590 | 2,555 | 2,550 | 2,715 |

the 1990s, lowering its requirements for direct appropriations to operate the shuttle system. Finally, long-expected operational efficiencies could also lower funding requirements for the operation of the shuttle.

Development costs for the space station could also be lower in the mid-1990s, if a decision is made not to proceed with the Block Two portion of the space station. General concern exists, however, that the cost of the Block One station will escalate as unforeseen problems are encountered in the actual construction phase. The NRC's space station study was skeptical about the NASA estimates, stating, "...the committee gained further insights into these estimates [of space station costs]. On balance, these insights decreased the Committee's confidence in the earlier estimates."24/ Among the issues noted were program changes, cost modeling deficiencies, and a lack of definition in certain key systems. NASA has testified that delays caused by the Congressional decision not to provide requested funding will ultimately increase the total cost of the programs, as the fixed cost of maintaining the NASA and contractor space station teams will be $50 million a month by late 1988. Were space station cost overruns to occur,

24. National Research Council, *Report of the Committee on the Space Station*, p. 28.

TABLE 6. HUBBLE SPACE TELESCOPE COST ESTIMATES, 1978, 1982, AND 1988 (In millions of 1982 dollars)

| | 1978 | 1982 | 1988 |
|---|---|---|---|
| Estimated Total Cost | 540-595 | 700-750 | 1,316 |
| Cost Growth from 1978 (In percents) | n.a. | 28 | 135 |

SOURCE: Congressional Budget Office estimates based on National Aeronautics and Space Administration data.

NOTE: n.a. = not applicable.

they would either require additional funding above the core program level, or entail later delivery of results within the core program. The latter would have the effect of diminishing the productivity of all space science and applications spending in a way similar to the ripple effect of the grounding of the shuttle following the Challenger accident, thereby illustrating the risk of interdependence.25/

The funding profiles in the space science and applications estimates also include large investment projects that could experience major cost overruns if recent history is repeated. Table 6 above shows a history of cost increases in the Hubble Space Telescope program, that are in part explainable by the Challenger accident, but were also evident before that time, since estimated real development costs increased by 20 percent between 1978 and 1982. More recently, the Advanced Communications Technology Satellite has been beset by overruns, and concerns have been expressed about the costs and schedules of the Magellan, Mars Observer, Galileo, and Ulysses programs.26/ As in transportation and the space station programs, the options are either to fund space science overruns if they occur, or to maintain the funding profiles in the core program and defer benefits.

25. Congressional Budget Office, "The 1988 Budget and the Future of the NASA Program," Chapter II.

26. General Accounting Office, "Prerelease Briefing to Senate Commerce Committee Staff" (March 1988).

The fact that complex space infrastructure and spacecraft programs are likely to experience cost overruns and delays is not an indictment of NASA. Such events may be inherent in the process or beyond NASA's control rather than being an institutional failing. Nevertheless, recent history illustrates well the risk that the core program will either cost more than expected or deliver its returns later than anticipated.

CHAPTER III

# ALTERNATIVES TO THE CORE PROGRAM

The National Aeronautics and Space Administration's core program has been criticized on a number of fronts. At issue is how much of the nation's resources should be allocated to NASA, what the civilian space program should produce over the next two decades, and how important the space program is to the United States. The NASA budget for 1988 was $9 billion. The core program would require $16.4 billion annually by the year 2000. Aggressive new manned initiatives, such as a Moon base or a Mars mission, could increase the NASA budget to $30 billion annually by the year 2000. At the other extreme, some critics propose that NASA be restricted to its current spending level and design a program consistent with that funding.

## POSSIBLE NEW SPACE INITIATIVES

Advocates of an expanded NASA program for the 1990s are in general agreement about long-term space policy goals, a sequence of steps to reach these goals, their supporting rationales, and, in very broad terms, how much an intensified civilian space effort might cost. Advocates of a larger space program draw support from a number of recent reports and studies, most notably *Pioneering the Space Frontier*, the report of the National Commission on Space (referred to as the *NCS Report*) and NASA's *Leadership and America's Future in Space* (referred to as the *Ride Report*).1/ These reports, and a growing number of others, advocate dramatic increases in NASA's activity beyond the core program. This study also focuses on a report by the American Institute of Aeronautics and Astronautics (the *AIAA*

1. National Commission on Space, *Pioneering the Space Frontier* (New York: Bantam Books, 1986); National Aeronautics and Space Administration, *Leadership and America's Future in Space* (August 1987).

*Report*) as it examines the possible content of a NASA program including major new initiatives.2/

The activities widely proposed for an intensified NASA program would include a broader application of space technology to Earth and environmental observation, new and more sophisticated unmanned exploration of the solar system, and manned exploration followed eventually by manned facilities on both the Moon and Mars. The sequence of steps necessary to carry out this agenda would require additional investment in technology and infrastructure in the early 1990s, and greater activity in the second half of the decade to begin specific missions. Ambitious manned initiatives, such as those proposed in the *Ride Report* and the *NCS Report*, could require the NASA budget to more than triple by the end of the century.

The initiatives included in this analysis by no means exhaust the options to expand the civil space program. Proposals other than those discussed below include establishing a geostationary manned space station, positioning large satellites to collect solar energy and beam power back to Earth, and constructing various types of facilities using the large external tank discarded by each shuttle mission.3/ The *AIAA Report* proposes less dramatic expansions of the core program for communications and land remote sensing satellites. However, the alternative policies presented here are those most widely discussed in the space community.

The new initiatives suggested in proposals to expand the NASA program illustrate the role of generic technology in new large-scale ventures, particularly those involving humans. Moreover, they reemphasize the central role of space infrastructure, since all of the initiatives require dependable and more capable transportation from Earth to low Earth orbit, in-space transfer vehicles, and more capacity to support humans once they are in orbit. Where manned operations are concerned, a faster pace in life sciences research is also a requirement. Advances in automated systems will also be necessary to undertake many of these initiatives.

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2. American Institute of Aeronautics and Astronautics, *The Civil Space Program: An Investment in America* (Washington, D.C.: AIAA, 1987).

3. NASA Advisory Council, *Report of the Task Force on the Role of Man in Geosynchronous Orbit* (February 1987).

The general direction taken by the advocates of new space initiatives has been established for a long time. For example, in December 1969, the then NASA Administrator Thomas Paine outlined, in an article entitled "Next Steps in Space," a vision of NASA's future that included a reusable rocket plane to "shuttle" between Earth and Earth's orbit, deep space probes powered by nuclear rockets, and a permanently manned space station in low Earth orbit to support low gravity research, Earth and astronomical observation, and the servicing of applications satellites. Paine anticipated these developments would occur during the 1970s and 1980s, culminating with a manned mission to Mars in the mid-1980s.4/ Nuclear rockets and the timing hoped for by Paine and NASA have not come to pass, but the agency's program continues to emphasize the shuttle for transportation and the manned space station as a focal point of activity in low Earth orbit and as a starting point for future manned and unmanned activities in higher Earth orbits and beyond. Not surprisingly, the broad outlines of this strategy are similar to the vision articulated 17 years later by the National Commission on Space, chaired by Thomas Paine, in the *NCS Report*.

## Rebuilding the Technology Base

A consensus among the advocates of new civilian space initiatives is that major new investments in space research and technology activities must be pursued to push beyond the space station era. The proposals for new initiatives tend to draw attention to the final results--for example, a Moon base. Yet, the most immediate activities necessary to realize these goals by the end of the century are in basic research and technology. The National Research Council presents the most detailed picture of the technology effort necessary to support a new generation of space missions.5/ Examining a 30-year period, the NRC's report analyzes the nation's technology needs in propulsion, support for humans in space, automation and robotics, power, materials and structures, and information systems and sensors, with a broad set of possible mission goals in mind. A central conclusion to be drawn

4. Thomas O. Paine, "Next Steps in Space," *National Geographic*, vol. 136, no. 6 (December 1969), pp. 793-797.

5. National Research Council, *Space Technology to Meet Future Needs* (Washington, D.C.: National Academy Press, 1987), Chapter I.

from this analysis is that NASA's emphasis on large operational systems, such as those that characterize the low-Earth-orbit infrastructure project, has left the technology base too weak even to specify new mission goals without several years of substantial investment. The advocates of new initiatives may not accept the full implications of this conclusion that choices among mission options should not be made without narrowing the technical uncertainties surrounding the relative costs and schedules of different prospective missions. But most of them recognize that the first step toward the Moon, Mars, or a new level of Earth monitoring entails basic research and development of technology on Earth.

## Expanded Earth and Environmental Observation

NASA has traditionally focused part of its research and development activity on applying space technology to service public needs or to demonstrate the potential of space activities for private profit. Examples are the early development of communication satellites, weather satellites, and the Landsat Earth remote sensing program. An expansion of space observation of the Earth and its environment is a logical next step along the road. The *Ride Report* describes an aggressive initiative of this type under the name "Mission to Planet Earth." Both the AIAA and NCS reports advocate similar, but slower, expansions of this type of activity.

The *Ride Report*'s "Mission to Planet Earth" scenario builds on the plan for an integrated Earth Observation System presented by the NASA Advisory Council.6/ The project would require new facilities in space and on the ground. Space assets would include:

- Four platforms deployed between 1994 and 1997 in polar orbit to provide frequent coverage of the entire Earth;

- A companion set of five platforms in geostationary orbit deployed between 1996 and 2000 to provide continuous coverage of particular parts of the Earth;

6. NASA Advisory Council, Earth System Science Committee, *Earth System Science: A Program for Global Change* (1986).

- Sensors attached to the space station for atmospheric monitoring; and

- Enhancement and expansion of the Tracking and Data Relay Satellite system to manage the flow of information to ground receiving stations.

On the ground, receiving stations and hardware and software for data analysis would also be needed. In keeping with the direction of the entire NASA program, the platforms are intended to be serviceable either by unmanned automated vehicles launched from the shuttle or by an expendable launch vehicle. Once established, the system could provide traditional weather, land remote, ocean, and atmospheric sensing capabilities to evaluate natural changes in the ecology, as well as those caused by human processes. Practical applications of such a system include forecasting weather and climatic change, and monitoring levels of industrial pollution.

The *Ride Report* includes cooperation both internationally and among various government agencies in its "Mission to Planet Earth" scenario. It proposes that four of the nine platforms be provided by Japan and the eleven European nations belonging to the European Space Agency, and that the National Oceanic and Atmospheric Administration and National Science Foundations of the United States provide significant funding.

## Unmanned Exploration of the Solar System

A second type of initiative emphasizing unmanned activity would be an aggressive expansion of U.S. unmanned exploration of the solar system. The NCS and the AIAA call for such a program, and the *Ride Report* features such activities as an independent option or as a precursor to manned exploration of Mars. The NASA Advisory Council has also presented a detailed inventory of planetary missions that could be undertaken during the 1990s.7/

7. NASA Advisory Council, *Planetary Exploration Through 2000: An Augmented Program* (1986).

The core program for the early 1990s includes two proposed but unapproved missions--the Comet Rendezvous/Asteroid Flyby (CRAF) and a probe to Titan, the largest moon of Saturn, called the Cassini mission. (Both of these missions, however, are included as new initiatives rather than as part of NASA's core program in the *Ride Report*). A highlight of the next stage of planetary exploration would be an unmanned mission to return samples from Mars that would probably be preceded by several robotic rovers and would itself precede a manned mission. As the NASA Advisory Council notes, however, an intensified program of unmanned exploration has possibilities other than Mars open to it. Additional missions to the Outer Planets--Jupiter and beyond--could be pursued, such as a follow-on to the Cassini mission or missions to smaller bodies in the solar system--for example, a mission to return samples from a comet or an asteroid.

These more aggressive planetary missions would build on the results of the core program and use the transportation and space station infrastructure developed in the core program. Larger unmanned probes could be assembled in orbit. Missions would return their cargoes to the space station for preliminary analysis, and the samples would subsequently be returned to Earth by the shuttle. The technology necessary to mount this type of planetary exploration would include advanced robotics and automation.

## Manned Exploration Initiatives

The most prominent proposed additions to the NASA agenda for the 1990s are manned missions to the Moon or Mars or both. The three overview studies all propose manned exploration and habitation of the solar system as ultimate goals for NASA. The *Ride Report* presents, but does not endorse, a "Humans to Mars" scenario that would launch a manned expedition on a 14-month round trip to Mars by 2005. This type of mission would require an aggressive life sciences program and extensive unmanned exploration of Mars during the 1990s. The *Ride Report* scenario proposes three missions to Mars culminating in a permanent outpost by 2010.

The NCS presents an alternative route to Mars that begins with a return to the Moon by 2005. Consistent with its building block approach to manned exploration of the solar system, the NCS proposes an orderly expansion of space transportation and operations infrastructure. For the 1990s, it focuses on Earth-to-orbit transportation, developing orbital transfer vehicles, and developing an Earth "spaceport" in an orbit higher than that of the core space station between the Earth and the Moon. Early in the next century, the *NCS Report* foresees a return to the Moon, from which a manned expedition to Mars would begin, perhaps as early as 2015. Mars would be approached via its moons, using a system of cycling spacecraft that would make the round trip journey to Mars and back every three years. This approach, when contrasted with that of the "Humans to Mars" in the *Ride Report*, leads to a 10- to 15-year delay in sending a manned mission to Mars, but permits developing an infrastructure (such as the "spaceport") that would facilitate sustained human presence beyond Earth. The AIAA assessment generally supports the Mars expedition of the NCS, but is not specific as to when further expansion of human space exploration would begin.

All three of the assessments of potential expansion of the NASA program ultimately advocate establishing a permanently inhabited outpost on the Moon. The outpost would require a logistical and transportation infrastructure capable of supporting sustained human presence. Exploration of the Moon and astronomy would be among the scientific activities undertaken at the outpost. Equally important, the Moon base would provide an opportunity to test whether space resources could support human habitation, since attempts would be made to extract oxygen and fuels from lunar materials and use these materials for a shield against radiation on the Moon and in space.8/

## BUDGET IMPLICATIONS OF NEW INITIATIVES

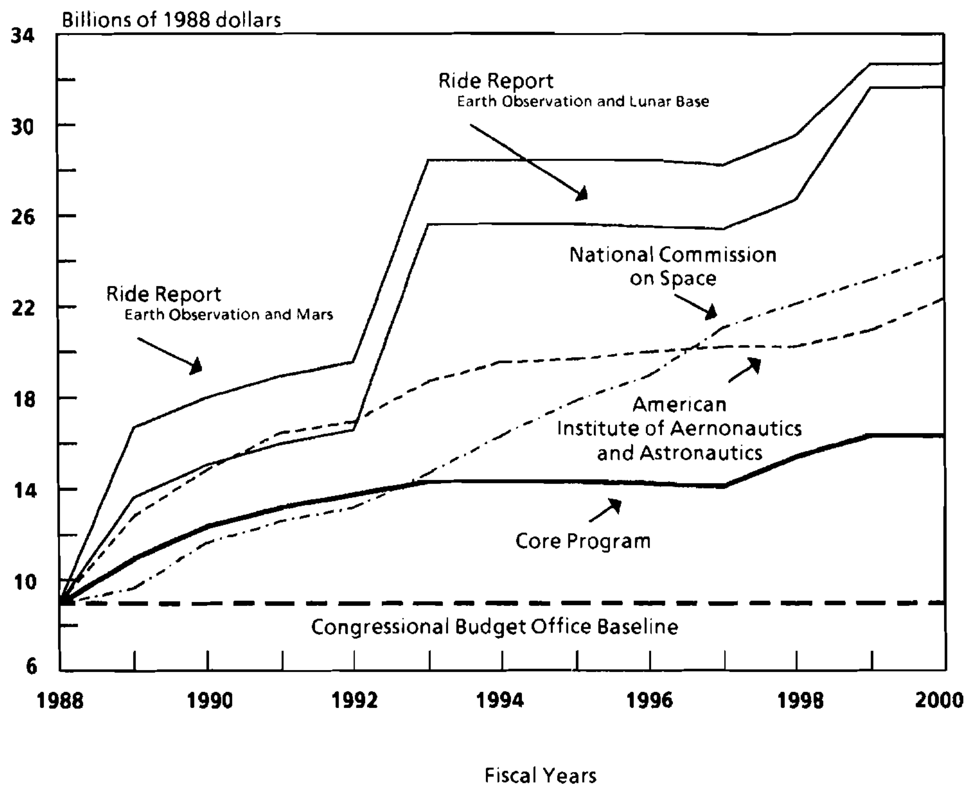
Adopting these new initiatives involving human presence beyond low Earth orbit would require an annual NASA budget in excess of $20 billion by the mid-1990s, and could require more than $30 billion annually by 2000. While the cost estimates provided for the core pro-

8. John S. Lewis and Ruth A. Lewis, *Space Resources Breaking the Bonds of Earth* (New York: Columbia University Press, 1987), Chapter 7.

gram in this analysis, and those for expansions of the NASA program in the three reports cited here, are at best rough beyond the three- to five-year time horizon, they indicate the levels of commitment required to pursue the types of goals included in each set of program activities. Figure 5 presents the Congressional Budget Office baseline (constant 1988 funding), the core program, and CBO cost estimates derived from the three summary reports.

The NCS and AIAA reports both provide the annual estimated costs for the programs they advocate, as shown in Figure 5. The *Ride*

Figure 5.
NASA Budget Options, 1988-2000




SOURCE: Congressional Budget Office estimates.

*Report* did not include dollar cost estimates of the initiatives it considered. Instead, comparative resource requirements were provided for each initiative in two bar graphs with undefined dollar scales. CBO estimated the annual budget requirements of the two *Ride Report* packages in Figure 5 in a two-step process. First, its established the value of the *Ride Report* scales by comparing the "Mission to Planet Earth" capabilities with the Environmental Observation System capabilities for which cost estimates were available, and by comparing the total requirements of the "Exploration of the Solar System"--the *Ride Report's* unmanned exploration of the solar system scenario--with those of missions included in the proposal for which cost estimates were available.9/ Second, having established the value of the resource requirement scales, CBO broke down the total cost estimates for each project into annual costs that were consistent with achieving the schedule milestones for each *Ride Report* initiative. Each of the two *Ride Report* budget profiles includes the "Mission to Planet Earth" initiative and one of the major manned exploration missions, in order to provide comparability with the broader NCS and AIAA programs.10/

None of the programs presented represents a detailed plan including program and mission level schedules, cost estimates, and annual budgets. Thus, comparison among the total cost estimates is difficult. While the *NCS Report* provides both cost and schedule information, it does not provide a cost breakdown for even the largest subparts of its program. The *Ride Report*, even if costs are derived as described above, is similarly lacking in detail. The AIAA provides more detail in some areas, but does not include schedule milestones for the major activities it advocates, such as a Moon base and a manned Mars mission; instead, it refers in general terms to an "evolutionary path."

To the extent that the NCS program and the *Ride Report* options can be compared, the higher costs of the *Ride Report's* Moon base option relative to the NCS's comparable milestone may be attributable to refinements in the planning for such a mission because the *Ride Re-*

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9. As given in NASA Advisory Council, *Planetary Exploration Through the Year 2000: An Augmented Program* and *Earth System Science: A Program for Global Change.*

10. An independent estimate of the cost of the *Ride Report* initiatives also placed the NASA annual budget above $30 billion by 2000. See Federation of American Scientists, *The Public Interest Report* (November 1987).

*port*'s initial cost estimates were reviewed more than a year later than those of the NCS. In addition, more specialized reviews of requirements and cost have surfaced, such as the NRC's review of the research and technology program that advocates a $1 billion annual program to fulfill a set of mission requirements arguably less demanding than the *Ride Report* options.11/ Moreover, the NCS estimates probably do not take full account of the cost implications of the Challenger accident, a contention supported by the fact that the NCS program cost estimates are lower than the core program estimates until 1992. The high cost of the *Ride Report*'s "Humans to Mars," relative to all of the other programs, is driven by its timing, which requires a manned mission to Mars by 2005, as opposed to the more measured pace advocated by the *NCS Report* and the *AIAA Report*. This more measured pace is also suggested by the *Ride Report*'s Moon-base scenario, if the Moon base is viewed as a stepping stone to Mars.

## BUDGET-CONSTRAINED OPTIONS

Even without new initiatives, NASA's plans to develop further and operate its low-Earth-orbit infrastructure during the 1990s will require increased funding. At the same time, concern over the growth of the federal deficit and the view that, independent of the deficit, current spending levels for the space program are adequate and should not be increased, suggest program options for NASA based on a fixed level of resources. Conceptually, two broad options are open: first, to slow down the core program by stretching out current projects and delaying the start of new projects, and second, to restructure the NASA program so that it will require less federal spending.

The two options developed below are constrained to constant dollar real funding. Any funding increases above this level will allow the option that stretches out the core program to progress with fewer delays and the option that restructures the core program to move more quickly. Modest rates of growth in the NASA budget however, would be unlikely to relieve the tension in the program between the costs of operating and investing in infrastructure and the costs of investing in space science and applications, and in new technology.

11. National Research Council, *Space Technology to Meet Future Needs*, p. 129.

Stretching Out the Core Program

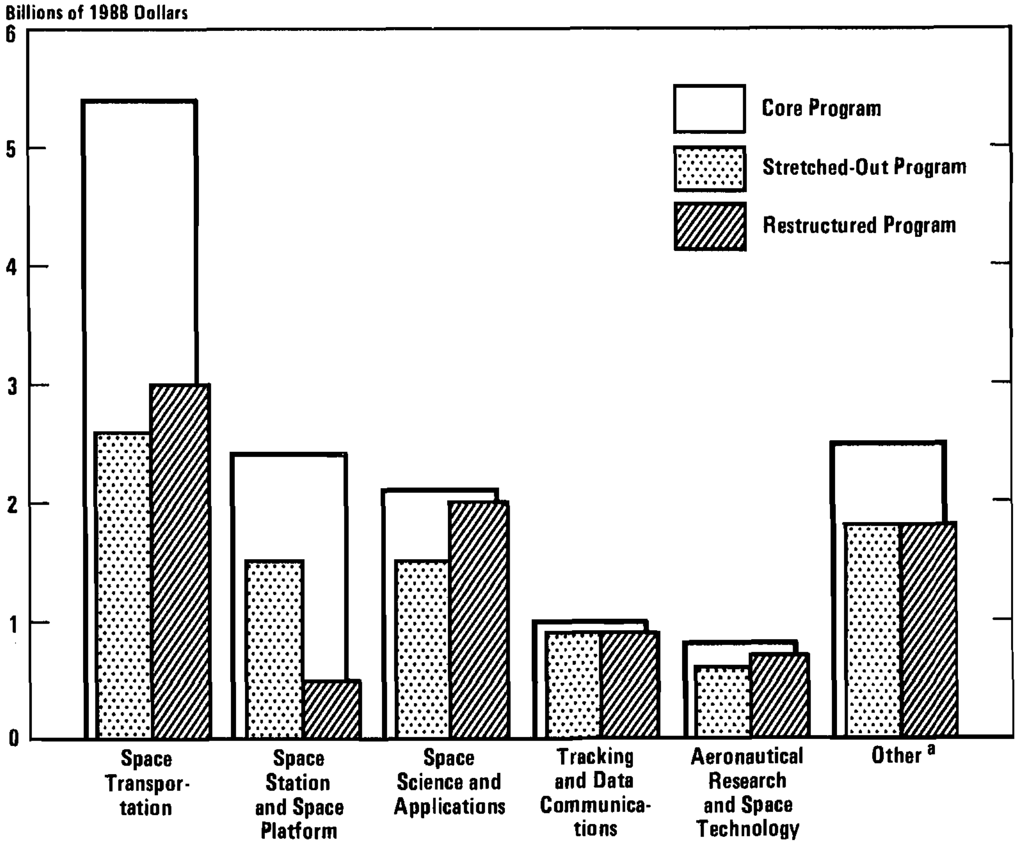
Stretching out the core program would entail delaying the space station into the next century, lowering the level of space transportation operational activity and funding, restricting investment in the transportation system to modify the shuttle orbiter fleet, and moving forward in space science only as quickly as current real dollar funding would permit. Figure 6 includes a breakdown of the annual NASA budget during the 1990s under these assumptions. The dilemma of devising a broad outline for stretching out the NASA program for the 1990s in the context of a no-growth budget is that the scale of new investment required for the space station and the cost of operating and maintaining the transportation system leave little funding to exploit these assets for science, exploration, or commerce. These activities, however, are at least as central a purpose of the civilian space program as the development and demonstration of technology associated with developing and operating the station or the shuttle.

Stretching out the core program would leave the United States behind the Soviet Union in manned space flight. But a permanently manned space station could, nonetheless, be achieved by 2005. However, manned exploration of the solar system, such as a return to the Moon or a Mars mission, could not be pursued. The United States would still be among the leading space-faring nations in unmanned space applications and explorations, but would have made no significant advances in space processing or other commercial activities that require a human presence, unless the private sector pursues these activities at a level now unforeseen and without federal subsidy.

The level of risk accompanying this strategy is high since the transportation system would be placed under stress by the station project and other demands, and the paucity of funding for a replacement system would leave the program unprepared if the shuttle system needed to be replaced early in the next century. The problem of the program bucking against funding constraints would be continually present as overruns in the station program, or additional problems with the shuttle, would require either cuts in other activities or delays beyond 2005 to complete the space station.

Infrastructure Under a Stretched-Out Program. The estimate for the average annual expenditure on infrastructure development and operation for 1989 through 2000 is $8.8 billion for the core program. The current NASA budget is only $9.0 billion; therefore, any budget-constrained option requires major cutbacks in this area. In a stretched-out program, space transportation would be cut back. The space station would be restricted to an annual expenditure of $1.5 billion--a $1

Figure 6.
The Core Program and Budget-Constrained Options Compared (Annual Averages 1989-2000)




SOURCE: Congressional Budget Office estimates based on NASA data.

[a] Research and Program Management, Construction of Facilities, Technology Utilization, Commercial Programs, Safety and Quality Assurance.

billion reduction from its average annual requirements from 1989 through 2000 in the core program, and almost $2 billion below the core program's annual estimate for the space station for the peak years from 1993 through 1995.

Space transportation operating requirements during the 1990s average $3.3 billion annually if the core program levels include only shuttle operations, expendable launch vehicle operations, upperstage rocket procurement, and limited shuttle modifications. A stretched-out program would have lower operational requirements than the core program, allowing operational savings. If the stretched-out program required only half of the flight activity of the core program, savings of perhaps $750 million annually could be realized. This level of reduction assumes that the cost of an additional shuttle flight is $100 million and that five flights could be saved annually.12/ Additional savings of $250 million could be obtained by a 50 percent cut in expendable launch vehicles. Space transportation investment would be restricted to the marginal shuttle improvements traditionally included in the shuttle production and capability account. Prominent proposed infrastructure additions found in the core program (such as the Advanced Solid Rocket Motor, Shuttle C, and the orbital transfer and maneuvering vehicles) would be eliminated. A significant implication of the stretched-out budget is its effect on existing and improved manned transportation in the second half of the 1990s. No provision is made to maintain orbiter production as the core program does, nor is any significant investment in a replacement for the shuttle permitted.

The core program's spending for the space station rises to a peak during the 1990s and then declines. One approach to stretching out the current program is to view the space station funding as a residual after providing for other NASA activities. This approach would smooth out the spending pattern by pacing the program to fit within a constant level of annual new spending authority. If the program re-

12. This assumption is reasonable if the Space Transportation System were "downscaled" well in advance of the canceled flights. NASA recently estimated the cost of each additional shuttle flight to be $45 million. This cost is estimated for an additional flight in a system expected to fly 8 to 14 times a year. Stretching-out the program downscales this system during the 1990s to five to seven flights annually and anticipates an additional $50 million saving per canceled flight. The savings of $100 million per flight are consistent with NASA's average variable cost estimate for a shuttle flight ($84 million, in 1982 dollars) before the Challenger accident.

quired increases in spending in a given year, then this approach would require the Congress to carry forward a significant amount of budget authority to accommodate future increased outlay requirements. If the stretched-out program restricts transportation to $2.6 billion per year and allows space science and applications, space research and technology, tracking and data communications, and all other parts of NASA's program to be maintained at their 1988 levels, then the residual funding for the space station is $1.5 billion annually.

Space Science and Applications, and Space Research and Technology. Both space science and applications and space research and technology would be decreased in a stretched-out program relative to the core program. Major projects in the core program--such as the two additional orbiting observatories, the Environmental Observation System, and the next round of planetary missions--would be slowed down or indefinitely deferred. Funds targeted for projects using the space station in the mid-1990s could be reprogrammed, however, and used for these other ends. Space research and technology would generally slow down, relative to the core program, by deferring major manned initiatives into the indefinite future.

## Restructuring the Core Program

The essential theme of a restructured core program would be the deemphasis of manned activities. Savings relative to the core program would be realized in space transportation, and the space station program would be terminated. Increases in funding for a man-tended space platform and spacelab flights would partially offset these savings, however. To meet the budget constraints imposed by the current NASA baseline, space science and applications and research and technology funds would be restricted relative to the core program. But spending on space science and applications would still benefit, relative to the stretched-out program, because it would receive part of the savings that result from canceling the space station. Activities in both areas--research and technology and space science--would be steered away from the manned program toward an expansion of unmanned activities.

Restructuring the NASA program by de-emphasizing manned activities would represent a fundamental change in the U.S. civilian space strategy. Expanding human activity to the Moon and eventually to Mars would no longer be the implicit goals of the program. Manned activities would be confined to the shuttle and tending orbital platforms, if such facilities were judged to be useful. The United States would not contest the Soviet lead in long-duration space flight. But the program could maintain, and perhaps expand, the U.S. lead in automated space science and applications. The risk implied by such a program is less that it would not perform within its cost and schedule parameters, as that the overall results would be inadequate to meet national space goals.

Restructuring the Infrastructure Program. The core program devotes significant resources to developing, supporting, and maintaining a permanently manned space station during the 1990s. If this goal is forgone, an annual $1.5 billion that was to be devoted to the space station program in the stretched-out program would be freed for alternative uses. The restructured program allocates one-third of these savings to activities and facilities that would partially fill the gap left by the space station program, particularly in the materials processing area. Another $0.4 billion of the space station savings would be directed toward space transportation to cover expendable launch vehicle use, near the annual levels included in the core program, and developing an orbital maneuvering vehicle with automated servicing capability, capable of working with or without the shuttle. The additional funding granted to space transportation relative to the option of stretching out the core program would be to support the higher launch demand arising from platform servicing and space science, both of which would require more launch capability since they would receive more resources to develop missions than in the stretched-out program.

Available shuttle capability, a minimum of five flights annually, would be devoted to laboratory activities requiring man. All of the major cuts in transportation development included in the stretched-out program would be adopted in a restructured program, with the exception of funding development for automated in-space vehicles.

Infrastructure investment in on-orbit facilities would be more focused, but less ambitious, than under options that included the space station. Investments could be made in adding to the capacity of the shuttle mid-deck (the area where astronauts perform experiments on an average shuttle flight), in flying additional spacelab flights, or in buying or leasing a pressurized man-tended freeflyer, such as the proposed Commercial Developed Space Facility. Using space platforms, and extending shuttle flights and expanding their capacity to function as an orbiting laboratory, would implicitly lower the program goals in the manned spaceflight area. Such a program could provide a substantial capability to perform research on processing materials, but with neither the capacity nor the power envisioned for the space station. These substitutes for the space station would not allow learning about human space flight of long duration, nor would they represent a transportation way station for future manned missions to the Moon or Mars. But these goals would not be relevant to this option.

Space Science and Applications and Space Research and Technology. The space science and applications program would receive additional funding under a restructured program relative to the stretched-out program, since the budget pressure of a large, continuing investment like that for the space station would be decreased. The physics and astronomy, and planetary exploration programs would be relatively unaffected by the loss of the space station. The environmental observation program would require rethinking, in that the polar platform is conceived as the first spacecraft carrying the instruments for the environmental observation system. The growth of the life sciences component of space science and applications included in the core program would be unnecessary and could be reduced, since ambitious manned missions are not envisaged for this option. Growth in the processing of materials area would still be necessary to support the activities undertaken on the shuttle and man-tended platforms.

Space research and technology could receive additional funding under a restructured program, and, like the space science and applications program, could redirect its efforts toward unmanned rather than manned missions.

CHAPTER IV

# EVALUATING CIVILIAN SPACE POLICY OPTIONS

The options before the Congress in civilian space policy require widely different resource commitments over the next decade. This chapter evaluates these options in light of the rationales traditionally used to support space activity. The Congress faces a crucial choice regarding the future of the U.S. space program. If it seeks international leadership--particularly in manned exploration of the solar system--then it must allow for as much as a threefold increase in the National Aeronautics and Space Administration's spending over the next decade. If it seeks to maintain NASA's spending at the 1988 level, it must forgo preeminence in space and direct NASA to exercise more limited leadership in particular areas and, ultimately, redirect its activities away from manned to unmanned ventures.

Should the Congress choose to support the core program, the United States is likely to be a leading space-faring nation in the late 1990s. Along with this leadership, the U.S. economy at large could benefit from spin-offs of NASA technology and research and development programs. At a minimum, the stage would have been set for future new commercial endeavors, although the prospects for new successful commercial activities in space are unknown.

It is impossible to determine, however, whether the increased benefits of a more ambitious program would be commensurate with the increased cost and risk. The most aggressive new initiative, the *Ride Report*'s "Humans to Mars," would raise the NASA budget from its level of $9 billion in 1988 to $33 billion in 2000, 50 percent above the $22 billion spent in 1965, the peak Apollo year, and twice the core program's $16.4 billion estimate for 2000.

Alternatively, NASA's program could be redesigned to fit the baseline budget, which holds future funding at 1988 levels. Adopting either of the two constrained budget options described in Chapter III would require the United States to relinquish the possibility of leadership in manned space flight at least for the immediate future, along with the direct and indirect economic possibilities of such leadership. The first option, stretching out the core program, would leave open the possibility of accelerating the program if the Congress chose to provide increased resources in the future. But it would also be likely to spread NASA's resources thinly over too many different areas, deferring several projects and accomplishing few. A restructured core program that fits the baseline budget (constant 1988-level funding), by de-emphasizing manned activities in favor of automated pay-loads, is likely to be more productive in terms of international space leadership and as a contributor to the economy, because it concentrates resources in fewer areas. It does not, however, provide the infrastructure that would be necessary for ambitious manned missions, such as those to the Moon or to Mars, in case the Congress should change its mind about the direction of the space program.

A difficulty in choosing among these alternative programs is that cost, or at least its order of magnitude, is more easily measured and foreseen than benefits. The types of benefits that might accrue include those that have justified past space policy: satisfying the inclination toward expanding human presence beyond the Earth, maintaining international leadership, and achieving economic benefits (both general and those specific to certain industries). The first two types of benefits are intangible, and therefore unmeasurable. Regarding the third, enough is known to evaluate the options relative to one another, but not to compare the benefits of civilian space spending with the possible results of other science and technology options or the general benefits to society from other types of federal spending.

## MANIFEST DESTINY AND INTERNATIONAL LEADERSHIP

Advocates of space exploration argue that it is the manifest destiny of the human race to explore and populate the solar system. They argue that the international prestige and national security of the United States are enhanced by space leadership that includes not only technical competence, but also, as stated in the *Ride Report*, "the active demonstration of those capabilities."1/

The manifest destiny case is certainly beyond the scope of this analysis in that it is clearly an issue related to values. A recent editorial stated that "Mars will be developed because it is there, just as America was."2/ However, even if that argument is accepted, the timing of human expansion is an open question. The issue of space leadership and its benefit to the United States, independent of its economic benefit, can be more concretely addressed.

The genesis of NASA and the civil space program was the contest for leadership between the United States and the Soviet Union. The military rivalry between the two superpowers produced rockets capable of placing satellites in Earth orbit, as well as delivering nuclear weapons. As the United States and the Soviet Union vied for successive first achievements in manned space flight, eventually racing to land a man on the Moon, the competition in the civilian space arena assumed ever larger proportions as an indicator of the relative merit of two radically different social systems.3/ Currently, the competition between the United States and the Soviet Union in civilian space continues to have implications in the international arena, but less so than during the 1960s.

The question that must be asked of the leadership standard is how much "international prestige and standing" is obtained by asserting leadership in civilian space and, if leadership is a goal of public policy, what is the cost of international prestige purchased by an aggressive civilian space program? Leadership as a space-faring nation could provide the United States with more international prestige than a stronger national defense, universal catastrophic health care, a superconducting super collider, or a smaller public-sector deficit. Unfortunately, the reverse can be asserted with equal certainty, since leadership is a perceptual issue when stripped of its economic components.

1. National Aeronautics and Space Administration, *Leadership and America's Future in Space* (August 1987), p. 12.

2. "Why Russia Does Better," *The Economist* (October 3, 1987), p. 15.

3. Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age* (New York: Basic Books, 1985), and John S. Lewis and Ruth A. Lewis, *Space Resources Breaking the Bonds of Earth* (New York: Columbia University Press, 1987), Chapter 2.

Thus, the first two points in support of expanding the civilian space effort rest on value judgments.

While the ultimate value of leadership in civilian space cannot be measured, the degree to which the various options for the NASA program are likely to provide "space firsts," or the highest quality of space activities and facilities, can be evaluated. Not surprisingly, the more resources that are devoted to space, the more leadership is gained. But even assuming large increases in the NASA budget above the core program, the United States might still have to focus its efforts on specific areas rather than trying to achieve leadership across the board. At the other extreme is the question of which of the budget-constrained strategies--stretching out or restructuring the core program--would be likely to contribute more to leadership, albeit on a smaller scale.

As leadership is a comparative standard, a general point should be made concerning the relative capabilities of U.S. adversaries and allies alike. During the Apollo era, the United States and the Soviet Union were the only contestants in the "space race." Any advantage either nation enjoyed by virtue of its pioneering status has now diminished, since space technology has spread to other advanced nations that are willing to pursue research in basic science, technology, and commerce in space. The implication is that the "latecomers" will rapidly close the gap with the leaders, at a cost significantly lower than that borne by the leaders in establishing the initial position of strength.4/ The cost of the new initiatives illustrates this point: the cost of restoring a leadership position, arguably not as dramatic as the leadership created by the Apollo program, requires a NASA budget in excess of $30 billion by the year 2000, more than $8 billion higher than was necessary in 1965, when the height of the Apollo effort was reached. In short, U.S. space leadership will prove increasingly difficult--and costly--to reassert and maintain.

4. Kenneth S. Pedersen, "Changes and Challenges," in Molly K. Macaley, ed., *Economics and Technology in U.S. Space Policy* (Washington, D.C.: Resources for the Future, 1987), pp. 173-199.

## The Core Program

The consensus of a number of recent studies is that the core program will maintain the U.S. position as a leader among space-faring nations. The NASA Advisory Council assesses the leadership potential of the core program for the late 1990s as follows: "In absolute terms, the U.S. civilian space program will be larger (with the possible exception of the Soviet Union), more comprehensive, and more technologically advanced than any other." But, the report continues, the size of the U.S. lead will be less than in the past as foreign programs increase their effort.5/

The *Ride Report* measures the space leadership potential of national programs against a progressive continuum of "leadership stages" from "pioneering" through two intermediate operational stages to "commercial viability." By this standard, the core program is adequate to provide leadership in the late 1990s. The core program represents a leadership position, as defined by the *Ride Report*, by advancing the U.S. program in those areas related to the infrastructure investment program--high Earth orbit, low Earth orbit, and supporting technologies and transportation. Core program missions in planetary exploration, physics and astronomy, and environmental observation would also be consistent with leadership as defined by the *Ride Report*.6/ On the other hand, by the report's measure, the core program is lacking in that it does not provide a strong enough foundation to move forward in the future, particularly where manned exploration is concerned.

## New Initiatives

The basis of the proposals to provide NASA with substantial new objectives and the resources to obtain them is the claim that the United States is losing its leadership position. Given that, it is not surprising that all of the new initiatives reassert the U.S. position as the preeminent space-faring nation. According to the *Ride Report*, adopting

5. NASA Advisory Council, *International Space Policy for the 1990s and Beyond* (October 1987), p. 16.

6. National Aeronautic and Space Administration, *Leadership and America's Future in Space*, pp. 15-19.

either the lunar outpost or the Mars mission goals would reassert U.S. leadership in manned space activity. The "Mission to Planet Earth," alone or in combination with either of the manned exploration missions, would push forward the U.S. program in activities and supporting technologies in Earth's orbit. The reports of the National Commission on Space and the American Institute of Aeronautics and Astronautics propose similar activities and would therefore provide similar advances.7/

## Budget-Constrained Options

Neither stretching out the core program nor restructuring it would place a high priority on leadership. Were the Congress to choose either, it would implicitly place a low value on leadership in space as a national benefit, and reject the proposition that the civil space program should be a higher national priority. Nevertheless, each of the baseline options has distinctly different leadership implications.

A stretched-out program is less likely to produce any tangible leadership results than a restructured program by virtue of its diffusion of resources over many different areas. In the current fiscal environment, the pressure to provide funds simultaneously to operate existing infrastructure, the shuttle system (inclusive of its spacelab and scientific instrument pallets), and the Hubble Space Telescope, and to build new infrastructure (the space station) is likely to result in underfunding those operations already under way. Pressure to build the large projects would result in lower priorities for small science and limited mission spacecraft, at a time when many analysts have suggested the program could enhance its productivity by reemphasizing this type of mission.8/

The restructured program would probably permit more progress and leadership in the areas where program resources were focused. For example, research and technology development could be reoriented toward a leadership strategy in unmanned, automated systems.

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7. National Commission on Space, *Pioneering the Space Frontier* (New York: Bantam Books, 1986), p. 30. See also American Institute of Aeronautics and Astronautics, *The Civil Space Program: An Investment in America* (Washington, D.C.: AIAA, 1987), p. 25.

8. NASA Advisory Council, *The Crisis in Space and Earth Science* (1986), Chapter I.

Space science activities would be planned around unmanned technologies and ultimately benefit from the refocused research and technology program. The manned portion of the program, using the spacelab and perhaps a periodically manned, free-flying laboratory could be aggressively pursued and well funded, thereby providing a potential for leadership in processing materials in space. But leadership in manned operations in low Earth orbit or manned exploration of the solar system would be abandoned.

## ECONOMIC BENEFITS

Advocates of the civilian space program point to several types of economic benefits associated with the NASA program. First, NASA provides the public good of increased scientific and technical knowledge and contributes to national security in areas such as space transportation. Second, in the process of undertaking research and development, NASA encourages private firms to increase their independent spending, thereby increasing the level of such spending economywide and contributing to economic growth. This process may work through spin-offs of products or techniques, or less directly by increasing the economy's supply of scientific and technical talent.

A final type of economic benefit of the NASA program noted by supporters is its potential to create new space industries. This more explicit industrial policy rationale has in the past focused on the satellite communications industry and land remote sensing (a form of sophisticated satellite photography). Current areas in which NASA is directly involved in encouraging commercial activities include processing materials in space and private-sector provision of space infrastructure.

### Public Goods

General advances in science and technology are usually classified by economists as "public goods." An essential characteristic of a public good is that it contributes to social welfare but that this contribution cannot be fully captured by private investors in the form of profit. As a consequence, private firms lack the incentive to produce the good, and it remains underproduced unless the government intervenes. Such public goods certainly include the knowledge gained about the universe and its origins, or about the history of the Earth and the solar system through planetary exploration and environmental and solid Earth observation programs. The federal government provides the public good of scientific knowledge through a variety of activities, including the National Science Foundation and the National Institutes of Health. As there is usually not a private market standard against which to value the public good of scientific and technical knowledge, a comparison of the costs of each mission is often substituted as an alternative, however incomplete such a comparison may be.

## Economic Growth and Civilian Space Expenditures

The argument that current federal space expenditures enhance the nation's technology base and that of specific U.S. industries is more easily defined and analyzed than the other points made in support of expanding the NASA program. Advocates of a more aggressive space program argue that it is vital to the technological standing of U.S. industry. For example, the American Institute of Aeronautics and Astronautics states that "throughout our short two hundred years the chief source of new wealth has been the new technology derived from research and development," and that "investments in the civil space program . . . bring a high return in future revenues and jobs." Moreover, in this view, "a vigorous civil space program is a key element in economic competitiveness."9/

Economists agree with the larger point in the advocates' case, but they may have reservations about how expenditures for the NASA program fit into the picture.10/ While research and development may not have been the most important element of economic growth throughout the history of the United States--natural resources, investment, and education were as important--research and development

9. American Institute of Aeronautics and Astronautics, *Civil Space Program: An Investment in America*, p. 1.

10. Comptroller General of the United States, *NASA Report May Overstate the Economic Benefits of Research and Development Spending* (General Accounting Office, October 18, 1977).

has assumed a very prominent position in U.S. economic growth since the end of the Second World War.11/

Moreover, the federal government has played an important role in undertaking, funding, and indirectly stimulating private research and development.12/ Since 1953, the federal share of total research and development has risen from 54 percent to 65 percent in 1965 and fallen to 46 percent in 1984. Most of this change can be explained by the fall in civilian space spending in the aftermath of the Apollo program.13/ The effect of federal research and development spending on private spending in the same area is generally seen as mildly stimulative. Recent studies (conducted under a variety of different methodologies and different time periods) estimate that a $1 change in such federal spending produces a change in related private spending ranging from minus 8 cents to plus 56 cents.14/ While NASA's independent effect cannot be evaluated, NASA is the most significant federal research and development agent after the Department of Defense. The private marketplace undervalues science and technology, because individual firms cannot fully capture the benefits of research and development in their balance sheets. The federal government's encouragement of private-sector research and development, therefore, benefits society as a whole.

During the 1960s, the connection between economic competitiveness and civilian space spending was argued largely in terms of spin-offs. Products like the integrated circuit, used in the Apollo program, found broad application throughout the economy. This government spending on science and technology also increased the pool of scientists and engineers. In the short run, the supply of

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11. Angus Maddison, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, vol. XXV (June 1987), pp. 649-698.

12. Congressional Budget Office, *Using Federal R&D to Promote Commercial Innovation* (April 1988).

13. Nathan Rosenberg, "A Historical Overview of the Evolution of Federal Investment in Research and Development Since World War II," paper commissioned for a workshop, "The Federal Role In Research and Development" (November 21-23, 1985), p. 16.

14. Nestor E. Terlecki, "Measuring Economic Effects of Federal Research and Development Expenditures: Recent History with Special Emphasis on R&D Performed in Industry," paper commissioned for a workshop on "The Federal Role in Research and Development" (November 21-23, 1985), pp. 23-25.

scientists and engineers is relatively fixed. Increases in the demand for these workers, therefore, initially lead to increases in their salaries. Over a number of years, higher salaries draw more people of higher quality into these professions.

These indirect effects certainly occur and are positively correlated with the level of private research and development spending, and technical change. The NASA program has long recognized this potential and has sought to promote it actively through its technology utilization program. But the evolution of the larger NASA program during the 1970s toward infrastructure investment and away from basic technology development may have diminished the flow of spinoffs. NASA's concentration on infrastructure, therefore, may involve utilizing technology rather than creating it. Nevertheless, aggressive increases in space spending, particularly in the basic research and technology program, will undoubtedly result in technologies that can be applied in the private sector.

The economic rationale for more resources for the space program has increasingly emphasized a direct industrial policy role for NASA. As an agent of industrial policy, NASA, in conjunction with private firms, sets out to develop specific products, processes, or technologies with precise market objectives. The core program's space station initiative is frequently justified as an infrastructure investment that will allow U.S. firms to increase their market share in areas such as pharmaceuticals and materials used to manufacture electronic components. The Administration's space policy of 1988 added an emphasis on private-sector investment in infrastructure that would receive a variety of direct and indirect supports from the government. These supports include deferred launch payments, technical cooperation, and, most important, a government commitment to play the role of "anchor tenant," in essence creating a demand for the product financed and operated by private capital.15/

15. Congressional Research Service, *Civilian Space Policy under the Reagan Administration: Potential Impact of the January 1988 Directive*, Report No. 88-237SPR (March 1988), pp. 18-21.

## Economic Benefits and NASA Program Options

Were the broad options for the civilian space program to be evaluated solely against narrow economic concerns, much as a private investor evaluates investment opportunities, two points would stand out. First, the set of options open to the investor are far broader than those in the civilian space area; and second, the uncertainty of returns in scientific enterprises, particularly in civilian space, makes it difficult to distinguish among space policy options. The comparison of options that follows can provide only a broad characterization of the likely returns of the program options. The evaluations are based on intentions rather than the possibility of success.

The Core Program. The core program will increase the output of scientific public goods by the civilian space program, stimulate private research and development through spin-offs (most likely those associated with the space station), and open the possibility of new space-based businesses in the private sector.

The provision of public goods in the area of science and technology depends on substantial increases in the level of spending. The effectiveness of this spending is, as noted earlier, a major test for the strategy of infrastructure investment. Each major investment project--the space shuttle, the space station, the Great Observatories, the Environmental Observation System, and the new generation of planetary probes--must produce a greater scientific return than the previous generation of space science in order to justify the high levels of investment necessary to bring the current generation into operation.

The core program's indirect effect on the larger economy is likely to be closely associated with the space station. Spin-offs are inherently unpredictable, but the direction of new expenditures indicates where they might be created. The most technically challenging aspects of the space station include its self-contained environmental system and various applications of robotics and automation. Expenditures in space transportation would be large but tied to the shuttle system. In critical areas like data processing, therefore, the stream of technical benefits is likely to flow from the larger economy to NASA rather than from NASA to the economy.

The most uncertain economic benefit of the core program is its influence on new space-based industries. Procurement of services from the private sector for government use will occur in the areas of the expendable launch vehicles and infrastructure to support the processing of materials. In the case of the former, NASA demand will reinforce demand from the Department of Defense, establishing a foundation that will help U.S. producers to compete in the global launch services market.16/ A potential exists to create new space-based processing activities, but these possibilities are generally viewed by the scientific community as occurring in the next century, and then only after a period of basic research and technology development that includes the early years of space station operation.17/

NASA has historically maintained an interest in satellite applications with commercial potential. The core program, however, does not include significant support for these areas consistent with Administration policy. Thus, the core program can be expected to contribute little to the technology base and economic health of the communications satellite and land remote sensing industries.

New Initiatives. Since the new initiatives build on the core program, their economic value lies in the economic benefits they create beyond those attributable to the core activities. In the area of public goods, higher spending should deliver more results--for example, a more aggressive planetary exploration program--but probably at a diminished rate for each new dollar of spending. The value attached to manned exploration and presence in space is paramount in this case, since most of the new initiatives involve new manned space activity. An exception is the aggressive development of an environmental observation and monitoring system that holds the promise of substantial improvement in delivering the public goods of monitoring pollution and forecasting weather.

Among the initiatives that would require a major increase in funding, the most promising areas for economic benefits--a lunar base or a Mars mission during the 1990s--are also the least predictable.

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16. For discussion of the role of government demand in the global launch market, see Congressional Budget Office, *Setting Space Transportation Policy for the 1990s* (October 1986), Chapter IV.

17. National Research Council, *Industrial Applications of the Microgravity Environment* (May 1988), p. 3.

New initiatives of this type would require substantial increases in the basic research and technology budget above the core program levels. Advances in materials, power systems, electronics, robotics, and computation would be among the areas focused on in developing technology. But it is impossible to foresee in which, if any, of these areas a spin-off comparable to the integrated circuit might occur.

The creation of new space-based industries is not a focus of any of the new initiatives per se. The increase in the demand for launch and in-space services required to carry out any of the initiatives would create new commercial prospects. It could also even lower the cost of getting into and operating in space sufficiently to induce new independent commercial activity. More visionary new industrial possibilities involving the use of space resources for fuel and oxygen would certainly be opened by the manned initiatives.

Budget-Constrained Options. The budget-constrained options spend far less on space than the core program or any of the new initiative packages; accordingly, they would deliver fewer benefits. The variables differentiating the stretched-out from the restructured program in the leadership area also apply in considering economic benefits. The spreading of resources made necessary by stretching out the core program would increase the cost of each project, if only because fixed costs are borne over a greater number of years. Moreover, infrastructure investments would not be used productively because operating funds would be limited. The restructured program would not have these problems.

A smaller civilian space effort cannot be expected to deliver the benefits of a program three times its size. But the alternatives confronting the Congress are broader than a larger or smaller space program. In the science and technology area alone, large projects such as the superconducting super collider or increases in the budget of the National Science Foundation may be superior alternatives to spending more on space. Broadening the scope of choices beyond science to a variety of other options, many of which provide public goods and commercial spin-offs to the larger economy and encourage the creation of new commercial enterprises, further complicates matters. The uncertainties surrounding many of the benefits of the civilian space effort prevent comparing it definitively with the array of other spending options open to the Congress. Within the context of the space program alone, however, it is clear that the greatest contrast in budget requirements occurs in the comparison of ambitious manned space initiatives, which require substantial increases in funding if they are to be undertaken in the near future, with the more modest funding demands of unmanned, robotic space exploration and research programs. Choices among the options presented in this study depend to a large extent on the goals of U.S. space policy.

# CHAPTER V

# INCREASING THE EFFECTIVENESS OF NASA's SPENDING

The tension between the National Aeronautics and Space Administration program and its budget is likely to be present regardless of the levels of appropriations provided or the ambitiousness of the agency's goals. A number of proposals have been put forward to increase the effectiveness of NASA's spending. Some are under active consideration and represent positions supported by the agency, such as increased international cooperation in large-scale science missions, and cooperation with the Department of Defense in developing new space transportation systems. Others are related to the budget process and include advanced appropriations for large infrastructure projects like the space station. Finally, a set of proposals has surfaced calling for broader private-sector investment in space infrastructure, in some cases combined with a restructuring of NASA that would divest it of operational responsibility for the infrastructure it develops.

## International Cooperation and Coordination

Cost sharing with an international partner can lower the cost to the United States of a given mission and its benefits. The magnitude of this saving depends on the nature of the cooperative venture and the partners involved. Assuming no changes in mission characteristics or international differences in the production cost of space hardware and services, and no significant duplication of expenses in administration or planning and coordination, the cost of a mission will not be increased by cooperation. As a practical matter, these circumstances may not be present and, as some have argued, international cooperation may actually increase mission costs. Nevertheless, if pure scientific results are the objective of the mission, a commodity unaffected by joint ownership, the United States will increase the return to its investment through cost sharing even if total cost per mission increases as a result of coordination problems, technology disparities, and the like.

The core program includes both large and small international cooperative ventures, from coordination of separate spacecraft observations in the solar physics program to the space station partnership involving the United States and 13 partners. The projected cost of a manned mission to Mars has led to proposals to join with the Soviet Union in such an enterprise. Proposals made to intensify and expand the observation of Earth also call for international cooperation.

Cooperative ventures might also affect the magnitude and distribution of benefits. In the case of pure science missions undertaken with Japan, Canada, or the European Space Agency--political allies of roughly equal technical competence--the benefits of such missions are largely unaffected by international cooperation. Sharing scientific results with partners does not diminish the value of these results to the United States. As the type of mission moves toward space applications with commercial potential, economic rivalry assumes a more prominent role. In this case, the results of a specific mission may be translated into an economic gain for a pioneer that cannot be achieved by latecomers.

More complicated is the issue of international cooperation in the design, development, and shared operation of infrastructure. The space station is to be such a cooperative venture among the European Space Agency, Canada, Japan, and the United States. The issues of concern for the United States in this area are:

- The distribution of operating costs and facilities among the partners;

- The fear that international partners will reap economic gain by investing in using the space station in areas like materials processing while the United States continues to invest in infrastructure; and

- The need to reconcile the budget process and U.S. commitments to joint ventures with its allies.

The first two issues are under consideration at NASA. The Congress's direction to NASA continues to stress the themes of shared costs and preparation to take early advantage of the nation's investment in a space station by supporting science applications programs. The growing maturity of both the European Space Agency and Japan in space technology has led to significant commitments to future infrastructure investment in manned and unmanned transportation systems and space platforms. During the 1990s, the European Space Agency programs will probably experience the same pressures of simultaneously supporting costly infrastructure projects and smaller applications and scientific missions that are present in the U.S. program. The United States will, therefore, not be the only partner to deal with this problem.

The need to harmonize the budget process and the negotiation of international partnerships such as the space station is evident. On the one hand, the United States suffers a loss of prestige when the Administration negotiates agreements to which the Congress is not fully committed. On the other hand, it is questionable whether international negotiations should be a factor in the Congress's decision to commit itself to a program that it has yet to accept on its own merits. One possibility is to refrain from international negotiations on joint ventures until the Congress has appropriated a significant portion of funding for a project. In the case of projects like the space station, the authorization for international negotiations could be tied to advance appropriations included by the Administration in the fiscal year 1989 budget request.

The scale of enterprises like a Mars mission or establishing a lunar base has led a number of people to suggest cooperative ventures with the Soviet Union. The rationale supporting such efforts is similar to that supporting any cooperative scientific venture, but with significant caveats. National security considerations are present with regard to the transfer of technology. The leadership factor cuts in two ways in such a venture. Accomplishment would be shared between the contending political systems, but sustaining the cooperation necessary to undertake a Mars mission or establish a lunar base would bestow leadership benefits on all parties. The complexity of U.S.-Soviet relations opens the possibility of cooperative ventures being set back at any time. Thus, strategies that call for separate but coordinated activities may be preferable, even though they will limit the cost-sharing aspect of any venture.

## Cooperation Between Government Agencies

The history of cooperation between different government agencies in space policy is mixed.1/ NASA and the Department of Defense have alternated between cooperative and competitive relations. NASA and the National Oceanic and Atmospheric Administration cooperated in developing and operating the civil weather satellites system and, until 1983, the land remote sensing system. Recently, as interest in space applications has grown, other federal agencies have become involved in space policy, most notably the Department of Transportation in the regulation of private-sector launch companies, and the Department of Commerce in the more general promotion of commercial activities. This broadening of concern about space policy has, at times, led to disagreements about authority and responsibility. In the context of the effectiveness of NASA spending, the relationship with the Department of Defense remains the most critical.

The failure of the pre-Challenger shuttle-only space transportation policy should not obscure the rationale for coordination of Department of Defense and NASA space transportation policy and planning. The NASA core program is dominated by space transportation investment and operations. To the extent that expenditures are duplicated by or not coordinated with Department of Defense space transportation investment and operation, the effectiveness of civil space spending will be decreased. In its most evolved form, coordination could include the joint development of Earth-to-orbit transportation systems, and a combined national space transportation strategy that stresses efficient use and operation of federally developed and operated space transportation.

## Budget Process Issues

A basic tension between the budget process and the civil space program is the annual appropriation cycle and the many years it takes to develop and build a system like the shuttle or the space station. NASA, the system developer, tries to devise a plan that completes its project in a cost-effective way that can be incorporated into the agen-

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1. Recent issues are presented and discussed in Erasmus H. Kolman, *What Future for the United States in Space?* (September 1987), an occasional paper for the National Aeronautics and Space Administration, National Academy of Public Administration.

cy's longer-term budget plan. The Congress is concerned not only with the effectiveness of the NASA program, but also with the larger issue of fiscal and budgetary policy as a whole.

While the effectiveness of the NASA program may be enhanced by advance or multiyear appropriations, such appropriations may limit the Congress's flexibility in addressing larger budgetary issues by implicitly broadening the scope of expenditures that cannot be deferred or canceled at any point in time. Moreover, to the extent that a particular project within an agency, or an agency as a whole, establishes a special status granted by advance appropriations, the project or agency receives an implicit and unintended priority when larger fiscal problems lead the Congress to enact across-the-board spending cuts as required by the Balanced Budget and Emergency Deficit Control Reaffirmation Act of 1987 (Public Law 100-119) or as negotiated at the end of 1987.

The case for multiyear appropriations is usually made in terms of the efficiencies planners gain by having a stable budget outlook rather than having to "game" the appropriations process.2/ If insufficient funds are available to support an optimal schedule, the quality of the project may suffer, or its cost may increase. If more funds than necessary are appropriated, federal outlays may be higher than necessary and inefficiencies encouraged within the project. This argument is more forceful during a construction phase of a project than during its design, and it depends, in large part, on the ability of NASA to estimate accurately the cost of a mission.

Two additional arguments support multiyear appropriations for major NASA programs. First, in those projects where international partnerships are undertaken, advance funding commitments would enhance U.S. credibility and reliability as a partner. Such improvements in the U.S. image may be increasingly important, because the traditional allies have a widening set of choices, including partnership with the Soviet Union, or among themselves. Second, as the funding required by the core program illustrates, the NASA program has been

2. A different case for multiyear appropriations is made for production programs. In these programs, the argument is that reductions in unit cost are lost when the number of units procured is cut back, since the cost of capital facilities and other fixed costs are spread over fewer units. See Congressional Budget Office, *Effects of Weapons Procurement Stretch-Outs on Costs and Schedules* (November 1987).

characterized by many new starts that will require increased outlays in the future. Full funding for larger projects could generate a greater awareness in the Congress of the implications of apparently small new starts for future agencywide funding requirements.

## Broadening Private-Sector Involvement in Space

The debate concerning the space station, and the cost of building and operating the low-Earth-orbit infrastructure more generally, has included the argument that the federal government, principally NASA, should step aside and encourage direct private investment in space infrastructure. In its simplest form, the argument holds that NASA is an engineering bureaucracy that inefficiently designs and operates space infrastructure, at least where commercial users are concerned. NASA designers pursue the objective of the broadest possible capability at the expense of lower cost for a basic capability that would satisfy the majority of users, but not all possible users. As a consequence, the cost of getting into, and then operating in, space is much higher than it need be. Encouraging private investment in, and subsequent operation of, space infrastructure would lower these costs, according to this argument. Moreover, the federal government could get out from under the cost of building and then maintaining idle space infrastructure capacity by substituting service purchases and leasing arrangements for direct ownership and operation.

Advocates of increasing the private sector's ownership of space infrastructure contend that the consequences of NASA's ineffectiveness in the infrastructure area extend beyond just higher costs for the federal program. They argue that, by not permitting the cost of space activity to fall, a flood of viable commercial ventures--from space manufacturing to tourism--is held back. These commercial ventures would contribute to U.S. economic growth, and initiate a positive circle of increased space commercial activity and cost reduc-tion, since economies of scale would be realized in the transportation and on-orbit infrastructure that are necessary to meet the growing demand for space activity. For some observers, one desirable outcome of unleashing the private sector in this way would be to redirect NASA's effort away from the mundane business of operating transportation and on-orbit laboratory facilities toward the more exciting prospects of scientific exploration and discovery.

The central premises of the argument that broadening private-sector investment in space activity would energize the entire national effort deserve careful examination. If the private sector, freed of NASA's allegedly burdensome oversight, failed to develop space infrastructure more cheaply and effectively, then federal programs providing special incentives to private infrastructure investment might be necessary, leading to a more complicated, and perhaps costly, version, of the current procurement system that already involves private firms in contractual relations with NASA. If a flood of new marketable uses of the space environment proved not to be awaiting the spur of lower operating costs, then the government would remain the dominant user of space infrastructure, and economies of scale would not be forthcoming unless the government were to expand its activities.

There is little clear evidence that the private sector can in all cases design and undertake infrastructure investment more cheaply than NASA. The case against significant private-sector savings is stronger to the extent that the project involved includes sizable technical risk and retains an aspect of a research and development effort throughout its life. (For example, at what point does the shuttle system stop being a system in development and become an operating concern?) The private sector is more likely to provide lower costs if the technology is mature and well understood, as in the case of expendable launch vehicles.

The level of interdependence among missions and infrastructure elements requires a careful consideration of how privately provided infrastructure could be integrated with the other activities of the federal program. As the hiatus in shuttle flights has shown, the ripple effect of failure in a key element can extend, with tremendous costs, beyond the part of the program directly effected.

The second major premise of the larger role for the private sector in infrastructure is less supportable. Reviews of potential commercial uses of space tend to agree that such uses await additional basic research, an area where government support, directly through scientific research and indirectly through cost sharing, is critical.3/ Most of the private-sector interest in commercial activity in space remains in the mature satellite communications industry and in providing the capability to get to space and function there, rather than in delivering a good or a service to the marketplace. Unless a commercial demand exists for these space-based products and services, there will be no demand for the inputs necessary to produce them. Thus, even where costs may be lowered, it is unlikely that a flood of new commercial ventures will occur during the next decade.

3. For example, most reviews of the application of the microgravity environment in drug or electronic materials manufacturing suggest near-term prospects are not significant. See National Research Council, *Industrial Applications of the Microgravity Environment* (Washington, D.C.: National Academy Press, May 1988).

# APPENDIX

# SOURCES OF ESTIMATES FOR THE CORE PROGRAM

The Congressional Budget Office has derived the content, schedule, and estimated cost of the National Aeronautics and Space Administration's core program from a number of sources. Existing core program missions and infrastructure investments, and their general sequence, are more of a certainty than is the timing of wholly new development projects. Indeed, one way of controlling the growth of the NASA budget would be to slow down the pace of new activities and investments included in the NASA core program, rather than change the program's content.

The major elements of the core program are the rate of growth of NASA's infrastructure and the cost of operating the infrastructure. To estimate the costs of these major elements, CBO has used the limited experience in operating and maintaining the space transportation system (the shuttle orbiters and associated facilities) and the Tracking and Data Relay Satellite system, and estimates of space station operating costs. Extensive NASA, General Accounting Office, and National Research Council reviews of the space station program provide estimates of the cost and schedule for this major infrastructure project.1/ Schedule and cost estimates for the development and eventual operation of new space transportation are drawn from NASA and contractor program and planning materials.

The outlines of the space science and applications program included in the core program are taken from a recent overview report of the NASA Advisory Council that relied on a number of other, more specialized reports to provide cost and schedule estimates for mission development and operation in the major areas of the space science and

1. See National Aeronautics and Space Administration, "Space Station Capital Development Plan" (April 1988); General Accounting Office, *Space Station Cost Review* (April 1987); National Research Council, *Report of the Committee on the Space Station* (Washington, D.C.: National Academy Press, September 1987).

applications program.2/ The space science and applications program presented in the Advisory Council report has been delayed to account for the effect of the Challenger accident. A number of less significant parts of the NASA program (as measured by their share of the budget) are projected at the constant dollar levels found in the NASA fiscal year 1989 budget request. The annual program funding levels developed in this way are then used to estimate agency research and program management requirements based on the relationship between other program funding and research and program management funding between 1970 and 1988.

Taken as a whole, the core program presented in this analysis is similar to projections of future NASA activities developed by NASA, its Advisory Council committees, and industry, and is distinct from the five-year "runout" budget included with the NASA 1989 request. The runout budget for NASA includes the cost of programs currently approved by the Administration and projects NASA's required budget authority to be $11.7 billion (in 1988 dollars) by 1993. This study's higher core program level of $14.4 billion for that year reflects new program starts not included in the runout budget: in space science, the planetary and environmental observation missions; in space transportation, the Shuttle C (an unmanned cargo shuttle) and new shuttle orbiters; in the space station program, a crew emergency rescue vehicle; and in the institutional support program, associated increases in research and program management spending.

The NASA Advisory Council Task Force on International Relations in Space projects a "State of the U.S. Civil Space Program: 1995-2000" that is similar to the core program used in the analysis.3/ A National Research Council report projects a set of missions during the 1990s covering most of those in the core program.4/ The American Institute of Aeronautics and Astronautics--a professional society presenting a combination of industry, academic, and governmental views--describes a more ambitious program that includes all of the

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2. NASA Advisory Council, *The Crisis in Space and Earth Science* (November 1986).

3. NASA Advisory Council, Task Force on International Relations in Space, *International Space Policy for the 1990s and Beyond* (October 1987).

4. National Research Council, *Space Technology to Meet Future Needs* (Washington, D.C.: National Academy Press, 1987), Part I.

elements of the core program.5/ CSP Associates, a private consulting group, projects NASA activities and funding requirements that are somewhat lower than those included in the core program through 1998 but, like the core program, foresees funding requirements increasing rapidly into the mid-1990s.6/ NASA's *Leadership and America's Future in Space* (the *Ride Report*), includes a base program less ambitious than the core program by choosing to define new planetary missions, the Earth Observation System, and significant transportation investment currently proposed by NASA as supplemental, new initiatives.7/

5. American Institute of Aeronautics and Astronautics, *The Civil Space Program: An Investment in America* (Washington, D.C.: AIAA, December 1987).

6. CSP Associates, Inc., *NASA Programs, 1988-1998* (Boston: CSP Associates, December 1987).

7. National Aeronautics and Space Administration, *Leadership and America's Future in Space: A Report to the Administration* (August 1987), written by Sally K. Ride and referred to as the *Ride Report*.

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