United States General Accounting Office

GAO

Report to the Chairman, Committee on Science, Space, and Technology, House of Representatives

March 1991

SPACE STATION

NASA's Search for Design, Cost, and Schedule Stability Continues

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General Accounting Office
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National Security and
International Affairs Division

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March 1, 1991

The Honorable George E. Brown, Jr.
Chairman, Committee on Science,
Space, and Technology
House of Representatives

Dear Mr. Chairman:

As requested by the former Chairman, we reviewed the National Aeronautics and Space Administration's (NASA) space station program. Specifically, we evaluated (1) annual changes in the space station's design, estimated cost, and schedule since 1985; (2) the annual budget requests and resulting congressional funding for the space station for fiscal years 1985-91; and (3) the impact of NASA's 1989 program review on the space station's cost and capabilities.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days after its issue date. At that time we will send copies to the NASA Administrator and appropriate congressional committees. We will also make copies available to others.

Please contact me at (202) 275-5140 if you or your staff have any questions concerning this report. Major contributors to this report are listed in appendix II.

Sincerely yours,

Mark E. Gebicke

Mark E. Gebicke
Director, NASA Issues

Executive Summary

Purpose

In 1984 the National Aeronautics and Space Administration (NASA) instituted a program to assemble a research station in space. Since that time major changes in the space station's design, cost, and schedule have occurred. As a result of these changes and the apparent instability of the program, the former Chairman, House Committee on Science, Space, and Technology, asked GAO to provide information on

- annual changes in the space station's design, estimated cost, and schedule since 1985;
- the annual budget requests and resulting congressional funding for the space station for fiscal years 1985-91; and
- the impact of NASA's 1989 program review on the space station's cost and capabilities.

Background

In January 1984 President Reagan directed NASA to build a permanently occupied space station within a decade and invited international participation. The station is being designed to enable scientists to conduct research in materials and life sciences, including processing materials, monitoring the earth's environment, and developing new technologies.

The European Space Agency, Japan, and Canada plan to provide major elements, such as laboratory modules, and share the station's cost and use. NASA is still designing the U.S. portion of the space station. The hardware components are to be manufactured and then delivered and assembled on orbit by shuttle crews from March 1995 to August 1999.

Results in Brief

NASA has often changed the space station's design and cost estimate and postponed its assembly schedule. These changes have occurred partly because of conflicts between engineering technology and station capabilities, which NASA maintains is normal for any program making a transition from general design to development. Rising cost estimates and reductions in planned budget increases have also contributed to the changes. Recent directives from the Congress and recommendations from the Advisory Committee on the Future of the U.S. Space Program will likely result in further changes to the station's design, cost, and schedule.

As required by the fiscal year 1988 Authorization Act, NASA reports the space station's direct and related costs in its Capital Development Plan. However, the estimates in the plan do not include the costs for the entire assembly period or the first year of steady operations and are not

expressed in then-year dollars (the estimated purchasing power in the years that expenditures will occur). By fiscal year 1991, the space station's capabilities had declined somewhat from the conceptual design proposed in 1984. However, the space station's estimated U.S. direct cost had increased from $8 billion to $12.3 billion in 1984 dollars, or $11 billion to $18.5 billion in then-year dollars, and final assembly had been delayed to mid-1999. Furthermore, when related space station costs, such as ground facilities, personnel, shuttle flights, and operations, are included in the fiscal year 1991 estimate, the cost rises to $38.3 billion in then-year dollars. These estimates exclude the cost of international elements.

Annual space station research and development funding has climbed from $150 million in fiscal year 1985 to nearly $2 billion in fiscal year 1991. However, these appropriated increases were less than the amounts NASA requested.

To stabilize the space station's design and schedule it at achievable funding levels, NASA conducted a program review in 1989 that resulted in several design and schedule changes. Although NASA predicted that these changes would substantially reduce the station's near-term development cost, its estimates did not consider the cost of contractor proposals under negotiation as of November 1990. Therefore, estimated savings may not be as large as anticipated.

Principal Findings

Space Station's Design, Cost, and Schedule Have Changed

NASA's initial $8 billion estimate, in constant 1984 dollars, for the direct cost to permanently occupy the space station by 1994 was tentative, since it was based on a conceptual design. NASA maintained that a more precise estimate could not be made until it selected a specific configuration and the contractors' preliminary designs were completed. Yet, even at this early stage, when the cost estimate was at its lowest, the Congress was concerned about the program's affordability. The fiscal year 1988 Appropriations Conference Report therefore directed NASA to consider designing the station so that the laboratory modules could be used early in the assembly sequence. If fiscal constraints precluded assembling the entire station, the Congress wanted to ensure that the U.S. living quarters module would not be the U.S.'s primary contribution to

the station. If this occurred, the United States could become a housekeeper and transporter for other countries that might become the primary beneficiaries of the predominantly U.S.-financed space station.

In fiscal year 1987 NASA expanded the space station's capabilities by including some components that would be provided by other countries. However, in preparing its fiscal year 1988 budget submission, NASA completed a detailed cost study and decided that the expanded-capability configuration was not affordable. Therefore, it divided the configuration into two development phases. The estimated cost increased from $8 billion to $12.2 billion in 1984 dollars, or $17.7 billion in then-year dollars, for developing the first phase. NASA also delayed the assembly completion date from 1994 to early 1997.

NASA delayed the assembly completion date to mid-1999 to accommodate budget reductions in fiscal years 1990 and 1991. Even though the assembly schedule was delayed, design changes reduced the space station's estimated cost from $13 billion to $12.3 billion in 1984 dollars between fiscal years 1990 and 1991. However, when related space station costs, such as ground facilities, personnel, shuttle flights, and operations, are included, the cost estimate rises from $31.2 billion to $38.3 billion in then-year dollars, primarily due to the increased operating cost to support users. NASA estimates that the cost to operate the station will be about $2.8 billion in the year 2001, which is the first full year of steady operations. However, the estimate excludes some costs from other NASA organizations, such as shuttle flights.

The space station's design, cost, and schedule are likely to change once again due to a directive contained in the fiscal year 1991 Appropriations Conference Report to redesign the station as a series of self-sufficient phases and stay within a maximum annual funding limit of $2.6 billion. NASA expects to present its redesign plans to the Congress by early April 1991. The Advisory Committee on the Future of the U.S. Space Program recommended in December 1990 that NASA take sufficient time to redesign and reschedule the space station to reduce its cost and complexity.

Space Station's Funding Has Increased Substantially

As with any new research and development program, NASA has requested large funding increases for the space station since fiscal year 1985. Faced with severe fiscal constraints, the Office of Management and Budget and the Congress provided increases that were not as large as NASA had requested. Annual space station funding has grown from $150 million for fiscal year 1985 to $1.9 billion for fiscal year 1991.

In its annual appropriations to NASA, the Congress frequently delayed obligating a portion of the funds. According to NASA officials, these delays did not materially affect the station's design or schedule. However, for fiscal year 1988, a combination of factors delayed the award of contracts for the space station's detailed design and development phases: a congressional reduction of almost 49 percent to NASA's budget request; a delay in obligating over 57 percent of the appropriation until June 1, 1988; and, at the direction of the House Appropriations Committee, a delay in obligating fiscal year 1987 funding.

The fiscal year 1991 Appropriations Conference Report limited the growth of annual appropriations for the space station to a maximum of 10 percent per year. The 10-percent limit and the $2.6 billion cap would provide NASA with a maximum of $11.4 billion for fiscal years 1991-95, which is $2.4 billion less than NASA requested for that period.

NASA's 1989 Program Review Changed Space Station's Cost and Schedule

NASA's 1989 program review addressed space station budget, technical, and schedule concerns. The resulting changes, which did not affect the overall design or capabilities, accommodated a 15-percent reduction to NASA's budget requests for fiscal years 1990 and 1991. The changes also reduced power, weight, and maintenance requirements and uncertainties in the assembly schedule. However, these benefits were offset by an 18-month delay in the assembly schedule, minor limitations to station users, and increases in construction and operating costs.

Matter for Congressional Consideration

The Congress may wish to consider requiring the NASA Administrator to expand the Capital Development Plan to

- disclose the space station's total direct and related cost estimates for assembly and the operating cost estimate for at least the first full year of steady operations and
- provide all cost information in both then-year and constant dollars.

Agency Comments

As requested, GAO did not ask NASA to comment officially on this report. However, GAO discussed the information presented in a draft of the report with NASA program officials. The officials generally concurred with GAO's findings.

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Abbreviations

GAO	General Accounting Office
NASA	National Aeronautics and Space Administration
OMB	Office of Management and Budget

Introduction

In January 1984 President Reagan directed the National Aeronautics and Space Administration (NASA) to build a permanently occupied space station within a decade and invited international participation. Currently, 9 of the 13 nations represented by the European Space Agency will provide a laboratory module, a co-orbiting satellite, and an earth observation satellite in polar orbit;[1] Canada will provide a mobile manipulator arm;[2] and Japan will provide another laboratory module.

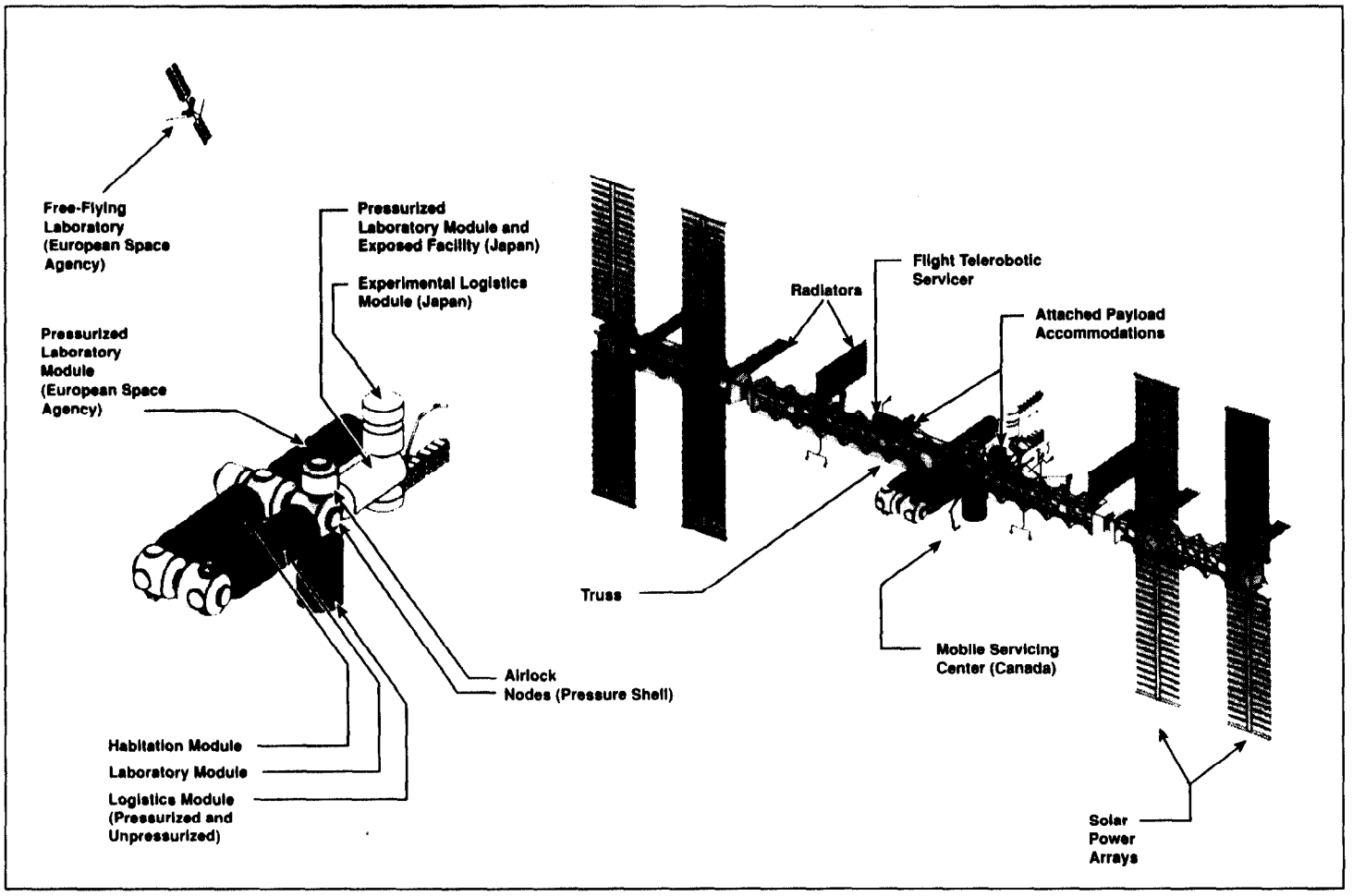
The primary research objectives of the space station are advances in materials and life sciences, the two areas that can most benefit from the station's extensive capabilities and from human supervision and interaction. Studies will concern basic research in physics, chemistry, and life sciences, including processing materials, monitoring the earth's environment, and developing new technologies.

The space station's most significant feature is the continuing presence of its crews. The potential of crew members to interact with instruments and respond to the unexpected is considered essential. Figure 1.1 shows the space station configuration as of December 1990, including the elements being provided by foreign countries.

[1]This polar satellite and the U.S. polar satellite have been transferred from the space station program to the space science program.

[2]The Mobile Remote Manipulator is a large tele-operated robotic arm—the station equivalent of the Shuttle Remote Arm—that can access critical areas on the exterior of the station and will be controlled from inside the station by the crew.

Figure 1.1: Space Station Configuration



Source: NASA.

NASA has divided the space station program into five phases. During phase A (concept), NASA reviewed various concepts for the space station configuration. Once a configuration was selected, definition studies were initiated in phase B (definition and preliminary design). Phase B ended when the phase C/D contracts were awarded. NASA is currently in phase C (detailed design). Once the design passes a critical design review, phase D (development) will start, and the manufacture and assembly of space station components will begin. Unlike other spacecraft that are completely assembled on earth, the space station will be assembled on orbit. Phase E (operations) will overlap with development and last throughout the station's expected 30-year life.

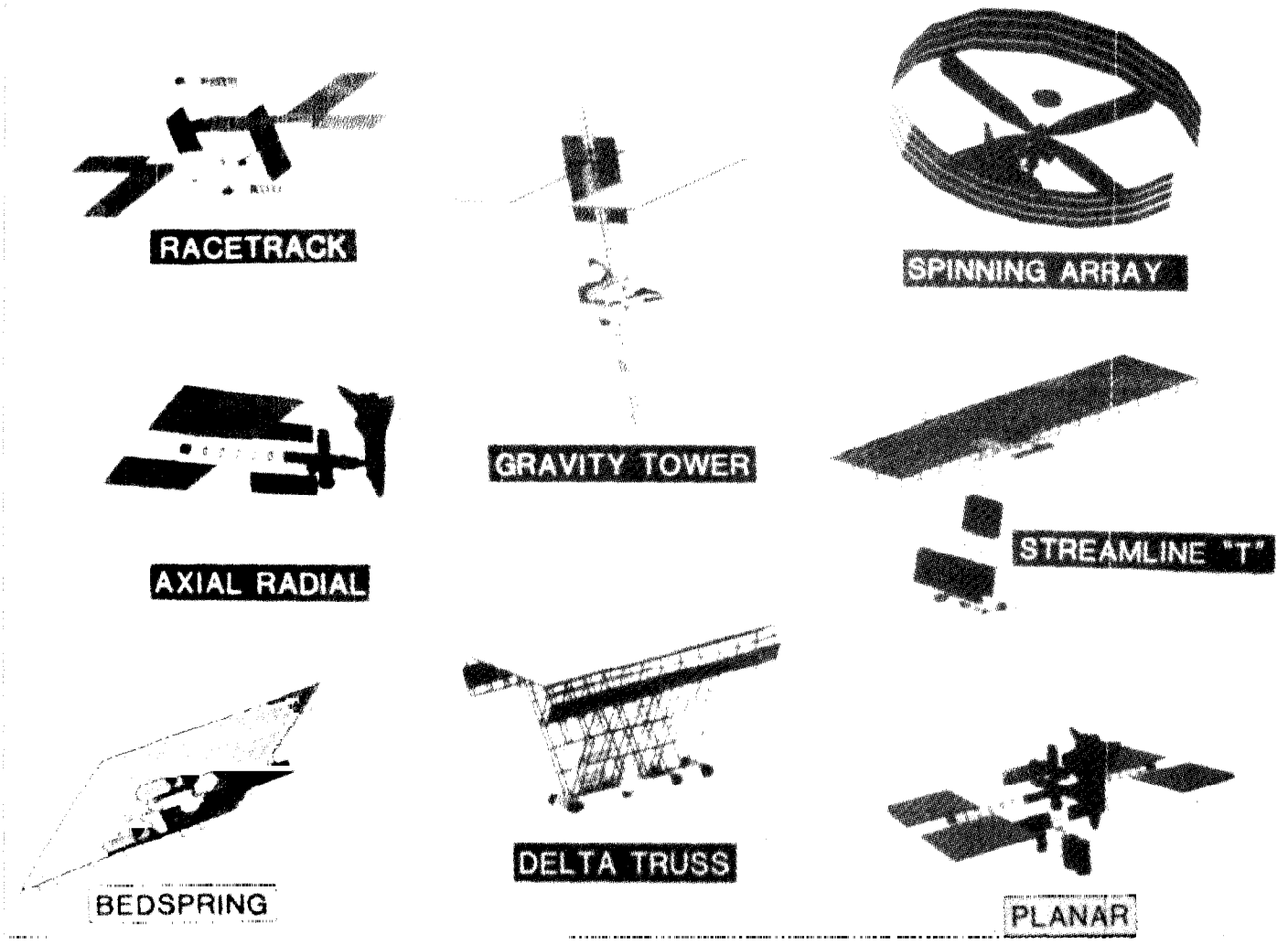
Early Space Station History

Within 2 years of its inception in 1958, NASA began to study the possibility of and required technology for a permanently occupied space station. Space station planning and review of requirements continued in the background of the Apollo program until the Space Task Group, formed in 1969, formally included the space station concept in the nation's space program.

The Space Transportation System, or space shuttle, was initially included as part of the space station concept. However, due to budget constraints, NASA could obtain approval to develop only the shuttle. After the Columbia made the first shuttle flight in 1981, NASA was ready to begin the space station program as the next logical step for the U.S. space program. Since then the space shuttle has remained critical to the station's concept. Currently, only the shuttle can transport crews and thus is essential to the station's assembly and operation.

In 1982 the NASA Administrator convened a Space Station Task Force to define preliminary requirements and develop possible designs for the overall structure and to develop a station management plan. During this initial concept phase, the task force contracted with eight U.S. aerospace firms to define user requirements. The potential station users included participants from academia, industry, and the scientific community who would perform various experiments on the space station. In 1983 the Concept Development Group was formed within the task force, primarily to define space station design configuration concepts. This group assembled eight configuration candidates shown in figure 1.2.

Figure 1.2: Early Space Station Configuration Candidate Concepts



Source: NASA.

Program Management

Space Station Freedom's program management is divided into the following three levels:

- Level I is responsible for policy and overall program management. It is headed by the Director of the Space Station Program at NASA headquarters in Washington, D.C.

- Level II oversees the program's direction, technical content, and day-to-day management. It is headed by the Deputy Director of the Space Station Program in Reston, Virginia.
- Level III consists of four work package centers that oversee four prime contractors. Major systems are being designed and developed at the four work package centers: the Johnson Space Center in Houston, Texas; the Marshall Space Flight Center in Huntsville, Alabama; the Lewis Research Center in Cleveland, Ohio; and the Goddard Space Flight Center in Greenbelt, Maryland. Each center manages one of the four prime contractors. A space station project office is located at each of the centers, and the project managers of these offices report to the Deputy Director of the Space Station Program in Reston, Virginia.

Objectives, Scope, and Methodology

The former Chairman, House Committee on Science, Space, and Technology, requested that we review NASA's space station program to obtain information on

- annual changes in the space station's design, estimated cost, and schedule since 1985;
- the annual budget requests and resulting congressional funding for the space station for fiscal years 1985-91; and
- the impact of NASA's 1989 program review on the space station's cost and capabilities.

We reviewed NASA studies and briefings, our prior reports, and other relevant documents to obtain information on the annual changes in the space station's design, estimated cost, and schedule. We discussed these changes with NASA officials at all three program management levels and at the Langley Research Center. We attempted to obtain cost information on the space station elements that are to be provided by international participants through NASA's Space Station Program Office. However, Canada did not respond to NASA's request for cost information, and the European Space Agency and Japan provided information that was not comparable due to the different categories and scope of the cost estimates.

To obtain information on the station's annual research and development budgets, we reviewed NASA documents and congressional hearings, acts, resolutions, and reports. We also obtained NASA's views concerning congressional funding delays and reductions.

To identify the effects of NASA's 1989 program review changes on cost and station capabilities, we met with officials at the four work package centers, other agency officials, and representatives of the contractors that are responsible for developing the space station.

We relied on NASA's estimates and budget documents for development cost and annual budget information and for the cost impact of the 1989 program changes. We did not independently assess the reliability of these figures.

We performed our review from July 1990 through January 1991 in accordance with generally accepted government auditing standards.

Changes in the Space Station's Design, Estimated Cost, and Schedule

Since the program began in 1984, NASA has often changed the space station's design, refigured its cost, and postponed its assembly completion. These changes reflect NASA's continual efforts to adapt to changes in user and technological requirements, space shuttle capabilities, congressional funding, and international contributions. NASA expected that basic configuration changes to the space station's design would occur in the early years of the program, since it is a research and development program. NASA presented the results of its design and cost studies in the justification for its fiscal year 1988 budget. Since then, the basic design and estimated cost have been more stable. However, schedule delays continue to be made to accommodate technical concerns and reductions to planned budget increases.

As required by the fiscal year 1988 Authorization Act, NASA presents the space station's direct and related costs in a Capital Development Plan. However, the act did not require the plan to provide estimates for all direct and related costs in then-year dollars[1] or cover the entire assembly period and the first full year of steady operations. In 1984 NASA estimated the space station's direct cost at $8 billion in 1984 dollars ($11 billion in then-year dollars). For fiscal year 1991, the estimated cost for a somewhat less capable space station than initially proposed has increased to $18.5 billion in then-year dollars ($12.3 billion in 1984 dollars). However, these estimates do not include related space station costs, such as ground facilities, personnel, shuttle flights, and operations. When these related costs are included, NASA's then-year dollar estimate increases to $38.3 billion.[2] Also, NASA estimates that operating costs in then-year dollars will be $2.8 billion in the year 2001, which is the first year of steady operations. These estimates, as well as the station's design and schedule, are likely to change again due to recent design and assembly changes and an annual budget limitation of $2.6 billion, as directed by the fiscal year 1991 Appropriations Conference Report. Since the Capital Development Plan does not present the station's cost in then-year dollars for the entire assembly period and the first full year of steady operations, it does not reflect the estimated future appropriation needs or the funding impact of design changes on potential future funding needs.

[1]Then-year dollars reflect the estimated purchasing power of the dollar in the year that an expenditure will occur. These estimates show the Congress and others the amounts that may have to be appropriated to complete a project.

[2]None of these cost estimates includes the international contributions.

Space Station Design, Cost, and Schedule Changes Continue

The major design, cost, and schedule changes for the complete assembly of the U.S. portion of the space station are summarized in table 2.1. In the paragraphs that follow, the changes are discussed in terms of the fiscal year budget that was submitted to the Congress and discussed in hearings before the start of the fiscal year. NASA officials stated that it is important to note that NASA prepares these budgets 2 years before a fiscal year begins. For example, the fiscal year 1989 budget was developed during 1987 and submitted to the Congress in January 1988, even though the fiscal year would not begin until October 1988.

Table 2.1: Design, Estimated Cost, and Schedule Changes for the U.S. Portion of the Space Station

Dollars in billions

	Fiscal year budget						
Design	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
Configuration	[a]	Power Tower	Dual Keel	Phase I	Phase I	Phase I	Phase I
Number of laboratory modules	2	2	1[b]	1	1	1	1
Number of habitation modules	1	2	1[b]	1	1	1	1
Number of logistics modules							
Pressurized	2	1	2	3	3	3	3
Unpressurized	0	0	0	2	2	2	2
Number of U.S. crew members	6-8	6-8	6[c]	6	6	6	6
Power generation (in kilowatts)							
Total	75	75	75	75	75	75	75
Allocation for users	[d]	[d]	[d]	50	45	45	30
Number of satellites							
Polar-orbiting	1	1	1	1	1	1	0[e]
Co-orbiting with the station	1	1	1	0	0	0	0
Number of service facilities	1	1	1	0	0	0	0
Estimated cost							
1984 dollars	$8.0	$8.1	$8.3	$12.2	$12.8	$13.0	$12.3
Then-year dollars	$11.0	$11.4	$12.2	$17.7	$19.0	$19.0	$18.5
Schedule							
First launch	03/92	04/92	01/93	03/94	03/95	03/95	03/95
Man-tended capability	10/92	04/93	01/94	03/95	03/96	11/95	06/96
Permanently manned capability	1994	1994	1994	04/95	04/96	04/96	03/97
Assembly completion	[d]	[d]	[d]	03/97	03/98	02/98	08/99
Number of shuttle flights[f]	[d]	[d]	[d]	16	19	20	29

[a]The Concept Development Group had developed eight early space station design configuration candidates.

[b]Although the number of U.S. modules decreased, total volume available to the U.S. station crew did not change dramatically.

[c]Beginning in fiscal year 1987, NASA baselined a standard crew size of eight; however, two spaces could be used by international partners.

[d]Not available.

[e]This polar-orbiting satellite for earth observation was transferred from the space station program to the space science program.

[f]The increase in the total number of space shuttle flights is primarily due to an increase in the number of logistics and operations flights required for assembly schedule delays.

Fiscal Year 1985 Budget

During fiscal year 1985 budget hearings, the NASA Administrator stated that the space station could be in place within a decade at a development cost of approximately $8 billion in 1984 dollars ($11 billion in then-year dollars). This figure was an estimate of the cost to design, fabricate, and assemble the station. However, at that time a station configuration design had not yet been chosen from the eight configuration candidates. NASA maintained that it could not develop a reliable cost estimate until it conducted preliminary design studies. NASA also expected foreign countries to participate in the program and provide additional station hardware. The cost of the hardware was expected to add to the $8 billion estimate.

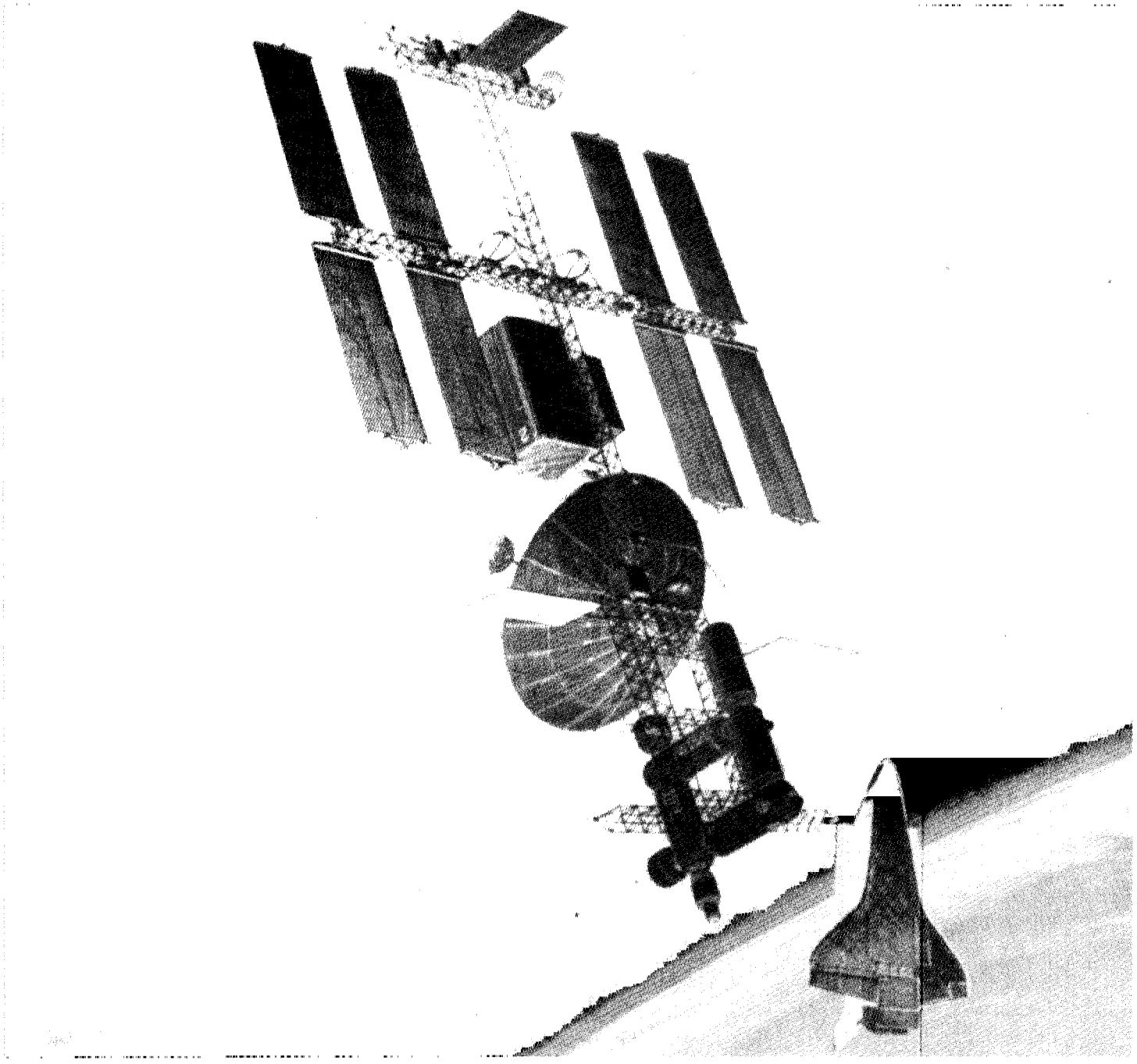
The first assembly milestone for the space station—its first launch—was scheduled for the first quarter of 1992, and the space station was to be permanently occupied by 1994, a goal set by President Reagan. NASA planned to have six to eight crew members occupy the station during the initiation of the program. However, due to the potentially prohibitive $8 billion price tag, the Congress directed NASA to study the option of incorporating an early man-tended capability[3] in the assembly sequence. The man-tended capability would occur before the launch of the U.S. habitation module and the international elements. In the event that budget constraints temporarily precluded funding the next stage, the station could still be used, although with reduced capabilities. Alternatively, if the U.S. laboratory module was assembled after the other elements, the United States could become a housekeeper and transporter for foreign countries because of funding constraints. Those countries could then become the primary beneficiaries of the predominantly U.S.-funded space station.

Fiscal Year 1986 Budget Changes

After a 1984 review of the eight configuration candidates, NASA selected the Power Tower design as the configuration that would serve as a reference for further definition studies. The design was used during fiscal year 1986 budget deliberations. The Power Tower (see fig. 2.1) was generally considered to be the configuration that could best provide simultaneous views of the earth, the sun, and space and an inherent flight stability while orbiting. In April 1985 NASA awarded contracts to eight companies to begin preliminary definition and design work on the Power Tower configuration.

[3]Man-tended capability would allow shuttle crews to use the station's laboratory module early in the station's assembly sequence.

Figure 2.1: Power Tower Configuration



Source: NASA.

The Power Tower configuration consisted of a single vertical structure over 400 feet long with five pressurized modules—two laboratory, one logistics, and two habitation—arranged in a racetrack pattern at the bottom of the structure. The module design incorporated two airlocks, which enable the transfer of crew and equipment between pressurized and unpressurized zones. Solar collectors, or arrays, mounted at the upper end of the structure were to provide 75 kilowatts of electrical power. NASA originally planned for the arrays to provide only 37.5 kilowatts of power, but advocates of the science community insisted that this would not leave enough power for experiments once housekeeping requirements were met.

The Power Tower would also repair and maintain free-flying vehicles and other satellites in a servicing garage positioned on the truss. In addition to the station base, two free-flying satellites—one in a polar orbit and the other co-orbiting with the station base—were included.

The original $8 billion cost estimate for the space station remained essentially unchanged in fiscal year 1986, since the definition and preliminary design phase was not yet completed. Similarly, NASA still planned to meet the President Reagan's 1994 goal to permanently occupy the station. However, NASA had not established the exact number of shuttle flights that would be needed to assemble the space station.

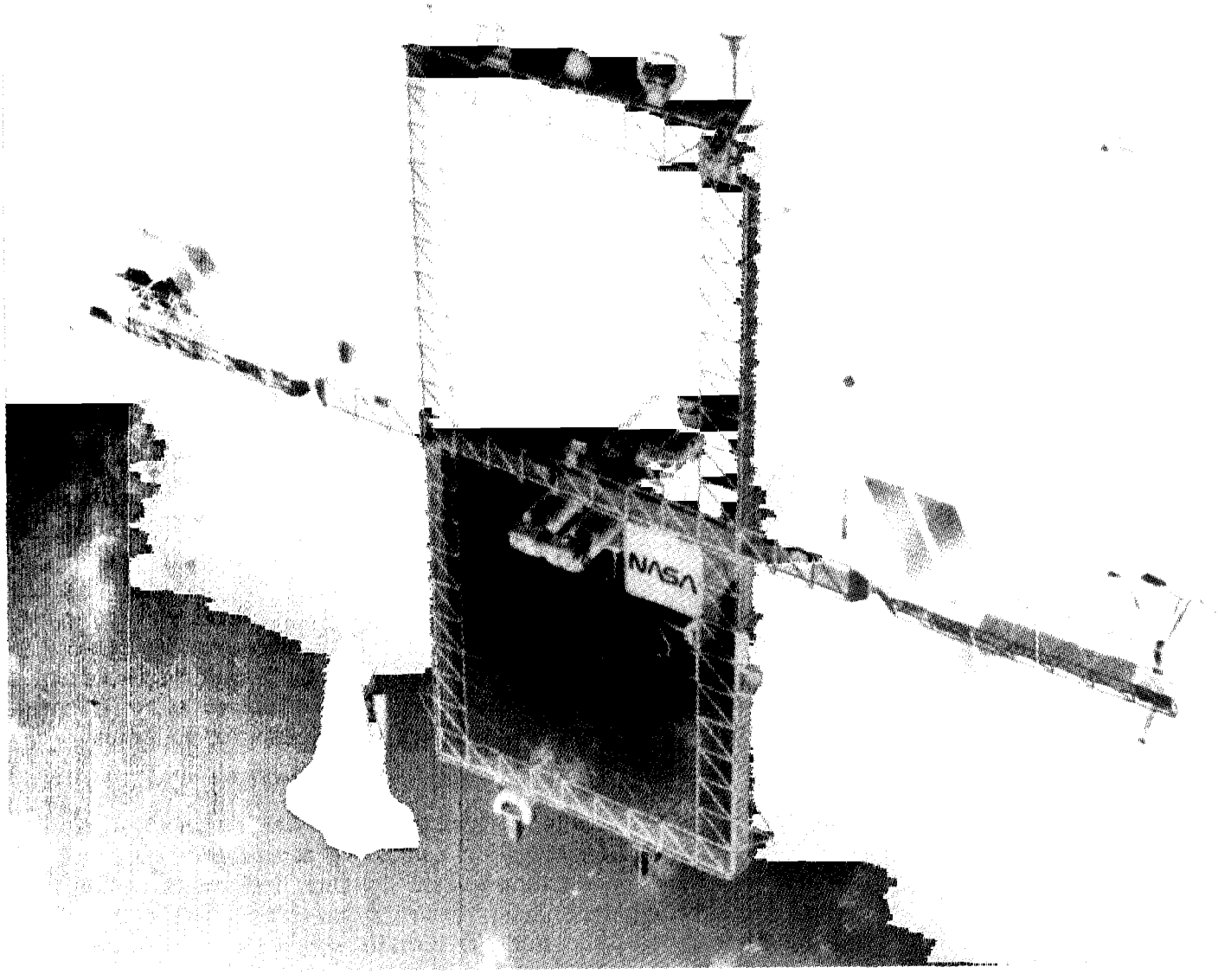
Fiscal Year 1987 Budget Changes

During 1985 the Power Tower came under serious scrutiny as the space station users' views became more prevalent in contractor design work. The users contended that the laboratory modules should be placed at the center of gravity (not at the bottom of the structure, as in the Power Tower) to obtain a more advantageous environment for materials processing experiments.

As a result, NASA formally replaced the Power Tower with a Dual Keel design configuration in May 1986 and used that configuration in the fiscal year 1987 space station budget. The Dual Keel design (see fig. 2.2) included a rectangular-shaped truss with two vertical keels that added strength to the structure and increased the surface area for attached payloads. The modules were moved to the center of gravity, which improved the conditions for scientific experiments with materials. The module pattern was also changed from a racetrack pattern to a parallel pattern. The parallel modules were connected by nodes and tunnels that increased interior volume by 30 percent. This arrangement also increased safety and permitted ease of access from one module to

another, since an astronaut would no longer have to go the entire way around the previous racetrack layout to reach another module.

Figure 2.2: Dual Keel Configuration



Source: NASA.

NASA expanded the space station's capabilities by including the international elements in the Dual Keel design. However, the U.S. modules were changed as a result of this addition. Previously, the U.S. self-contained

space station had two laboratory and two habitation modules. The U.S. modules were then reduced to one laboratory and one habitation module but were designed to be longer than the previous modules so that the volume would not change substantially. Further, the U.S. share of laboratory volume increased when the Japanese and European modules were added and the U.S. received a 46-percent usage allocation of these modules. However, with the addition of two international crew members, the previously planned 6- to 8-member U.S. crew was limited to 6. During congressional hearings NASA continued to present the $8 billion estimate but stated that the estimate might increase or decrease by a small amount when definition studies, initiated in April 1985, were completed at the end of the year. However, when the studies were completed, the then-year dollar estimate had increased approximately $1 billion, from $11.4 billion to $12.2 billion.

Solar dynamic power, which uses mirrors to collect the sun's energy and transform it indirectly into electrical power, was added to supplement the power generation of the solar arrays. With the addition of solar dynamic power, the number and size of solar arrays was reduced, thus decreasing the drag on the station. However, solar dynamic power involves higher development costs, since it has never been used in space. As a result, the first launch was slipped from April 1992 to January 1993, but NASA still planned to be able to permanently occupy the station by 1994.

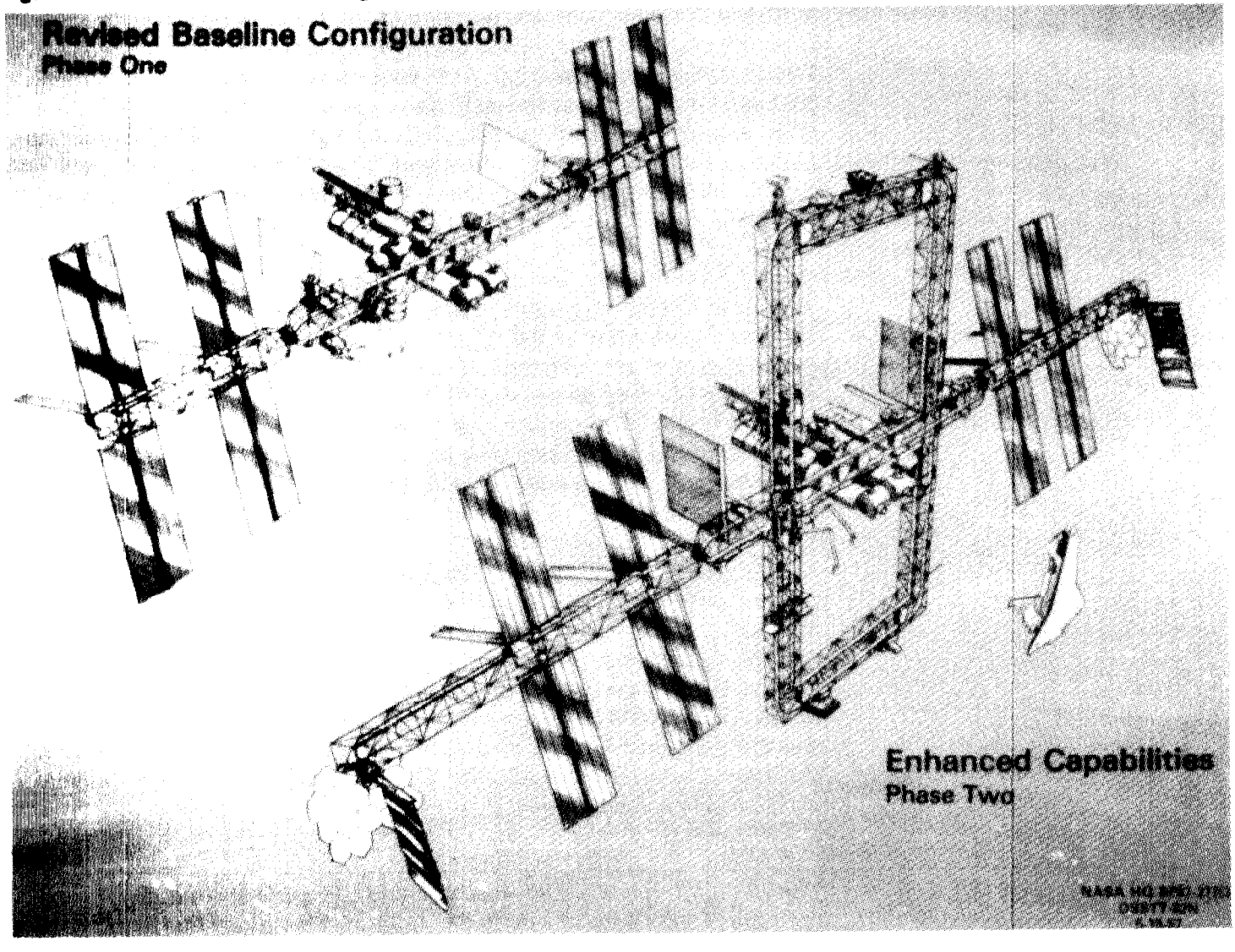
In congressional hearings NASA discussed the study on the man-tended phase that the Congress requested in fiscal year 1985. The study assumed that the early man-tended phase would operate for 3 to 5 years and then progress to assembly completion. NASA did not recommend this approach, since the type of experiments that could be done in the man-tended phase could be done on Spacelab. Also, the man-tended approach was more expensive in the long term, partly due to the cost of operating the space station for users during the 3 to 5 years before resumption of the assembly sequence.

Fiscal Year 1988 Budget Changes

The $8 billion space station cost estimate changed substantially during the time of NASA's fiscal year 1988 budget deliberations due in part to a major cost review. The review concluded that the estimated direct cost for the Dual Keel configuration would increase to $14.5 billion in 1984 dollars. President Reagan's goal of permanently occupying the space station in 1994 slipped to 1995, and assembly completion slipped to early 1997.

Recognizing that this cost was not affordable, NASA conducted a study to identify configuration options that would reduce development costs. NASA evaluated the results of the study and decided to divide the Dual Keel design into two development phases (see fig. 2.3).

Figure 2.3: Phase I and Phase II Configurations



Source: NASA.

Phase I, known as the revised baseline configuration, included a single horizontal boom, the U.S. laboratory and habitation modules, accommodation of attached payloads, the U.S. and European polar platforms, 75 kilowatts of photovoltaic power,[4] European and Japanese laboratory modules, the Canadian Mobile Servicing Center, and provisions for evolution. Phase II, known as the enhanced configuration, had greater capabilities, including an additional 50 kilowatts of power from the solar dynamic system, additional accommodation of attached payload on dual keels and upper and lower booms, the satellite servicing facility, and the U.S. co-orbiting laboratory satellite.

The National Research Council[5] conducted a review of the Phase I and Phase II space station design options. In September 1987 the Council reported that the Phase I design was a compromise among reasonably understood but sometimes conflicting user requirements and should be adopted. The report also stated a commitment of adequate and predictable funding during more than one administration should accompany a decision to deploy a permanently occupied international space station. However, the report also identified several problems, including those discussed below.

- The space station program was in a state of flux, and uncertainties surrounded NASA's cost estimates of between $21 billion and $25 billion in 1984 dollars, including direct and related space station costs.
- Space station costs could absorb a major portion of NASA's budget if increased attention is not given to estimating and controlling operating costs.
- Deploying the space station with the post-Challenger space shuttle, although feasible, would be difficult and risky.
- National long-term space goals are ambiguous.

In its fiscal year 1988 budget request, NASA estimated Phase I direct costs at $12.2 billion in 1984 dollars ($17.7 billion in then-year dollars). From fiscal years 1988 to 1991, NASA's development cost estimates had covered only Phase I. The estimates excluded the $600 million for design definition costs that were previously included in the $8 billion estimate.

[4]Photovoltaic power uses solar cells to collect sunlight and convert it directly to electricity.

[5]The National Research Council was established by the National Academy of Sciences. The Academy, by authority of the charter granted to it by the Congress in 1863, has a mandate to advise the federal government on scientific and technical matters.

The first launch of Phase I slipped to March 1994, and assembly completion was delayed until March 1997. On the basis of the Phase I configuration, NASA awarded contracts for the detailed design of Phase I in December 1987. The station's detailed design phase is scheduled to continue until a critical design review is completed in early 1992.

Fiscal Year 1989 Budget Changes

NASA made no major changes to the revised baseline configuration for fiscal year 1989. Due to a congressional cut of about 49 percent to NASA's fiscal year 1988 President's budget and the associated Office of Management and Budget (OMB) reduction of about 48 percent to the requested budget for 1989, NASA pushed the entire assembly schedule back 1 year, slipping the first launch to March 1995 and the assembly completion to March 1998. According to NASA, the schedule delays were a major reason for the estimated increase in development cost from $12.2 billion to $12.8 billion in 1984 dollars ($17.7 billion to $19 billion in then-year dollars).

Fiscal Year 1990 Budget Changes

The space station's configuration, estimated cost, and assembly schedule did not change significantly for the fiscal year 1990 budget deliberations. However, NASA's fiscal year 1990 budget request included a proposed ceiling of $13 billion (in 1984 dollars) on the program's development cost through assembly completion. NASA believed the ceiling, concurrent with multiyear funding, was necessary to control costs and provide funding stability. NASA officials do not view the ceiling as a problem because recent cost estimates have been below the ceiling. Furthermore, NASA spent about $2.4 billion on development in fiscal years 1985-90.

Fiscal Year 1991 Budget Changes

NASA conducted a major program review of the space station in late 1989 to reduce future funding needs and schedule risks and address a number of engineering problems. This review resulted in design changes and an additional 18-month slip in the assembly completion date from February 1998 to August 1999. Although engineering changes were made, the overall configuration was maintained. From 1988 to 1990, the number of shuttle flights needed to complete the assembly sequence increased from 16 to 20. However, in 1991 the number increased from 20 to 29, also due largely to the program review.

In addition to the design and schedule changes, NASA transferred the earth observation satellite platform in polar orbit and its related launch

cost (estimated at about $900 million) from the space station program to the science program. This transfer, design deletions, and schedule deferrals reduced the station's estimated cost from $13 billion to $12.3 billion in 1984 dollars ($19 billion to $18.5 billion in then-year dollars). Also, the power available for experiments decreased from 45 to 30 kilowatts due in part to unexpectedly large habitability requirements.

Fiscal Year 1992 Budget Changes

In the fiscal year 1991 Appropriations Conference Report, the conferees directed NASA to change the station's design and assembly plan again. To lower costs, NASA is to redesign the station as a series of self-sufficient phases, beginning with an orbiting laboratory from which shuttle astronauts could do short-term research. NASA's redesign plans, which are expected to be completed by early April 1991, will likely result in further revisions to the space station's design, cost, and schedule. Further, the Advisory Committee on the Future of the U.S. Space Program in December 1990 recommended that NASA take sufficient time to redesign and reschedule the space station to reduce its cost and complexity.

Current Reports on Costs Do Not Include Adequate Information

NASA's space station cost estimates have historically been expressed in constant 1984 dollars. A constant dollar estimate is a good management tool for analyzing actual program content changes without the influence of inflation. These figures, however, do not reflect all space station-related costs or account for inflation over time.

The Congress has been concerned about the space station's rising cost estimates, the need for a balanced civilian space program, and the importance of operating costs in design trade-off decisions.

These concerns are reflected in NASA's fiscal year 1988 Authorization Act. The act required NASA to establish goals that (1) the space station's total development cost would not exceed 25 percent of NASA's total budget and (2) direct operating costs, except those costs associated with space station utilization, would not exceed 10 percent of NASA's total budget. To monitor the achievement of these goals, the act also required NASA to develop a Capital Development Plan, to be submitted with the President's annual budget request, outlining the design, cost, and schedule of the proposed space station. The Capital Development Plan identifies direct and related costs and operating costs. However, the Authorization Act does not require the plan to show these costs in then-year dollars for the entire assembly period or the first year of steady operations. The recent fiscal year 1991 Appropriations Conference

Report also raised affordability concerns and placed an annual $2.6 billion cap on the space station program.

Not All Direct and Related Cost Estimates Have Been Reported

To obtain a more complete picture of space station cost estimates, both direct and other related costs must be considered. Table 2.2 shows NASA's estimate of these costs through assembly completion.

Table 2.2: Space Station Direct and Related Cost Estimates Through Assembly Completion

Then-year dollars in millions

	Fiscal year	
Cost category	**1990**	**1991**
Research and development		
Direct	$19,013	$18,541
Definition	600	600
Flight Telerobotic Servicer	260	819
Other research and development	325	260
Operations cost to support users[a]	7,003	12,802
Subtotal	**$27,201**	**$33,022**
Shuttle flights	1,473	2,471
Transport capability development	389	355
Polar platform launch	211	0
Personnel	1,394	1,963
Communications and tracking	391	162
Construction of facilities	184	367
Total	**$31,243**	**$38,340**

[a]Once a man-tended capability is achieved during the assembly sequence, users will be able to use the station while the shuttle is docked at the station.

According to NASA, the space station's direct cost for fiscal year 1991 in then-year dollars is estimated to be $18.5 billion but increases to $38.3 billion when other major related costs are included. Examples of other major items that are not currently included in the space station program are medical monitoring equipment needed to certify that crews can inhabit the space station for the expected 90 to 180 days, an emergency vehicle for returning crews to earth, and a specimen transportation handling system.

These and other space-station related items could add over $1.5 billion to the $38.3 billion estimate. Program officials indicated that a program reserve is available to cover such costs. However, most of the reserve is

needed to cover hardware development, which is where most research and development programs experience the largest cost increases.

Total space station cost estimates are also useful in analyzing program changes. For example, NASA's 1989 program review reduced the station's estimated direct costs in then-year dollars from $19 billion to $18.5 billion for fiscal years 1990 and 1991 (see table 2.1). However, when space station-related costs are included, the total then-year dollar estimate increases from $31.2 billion to $38.3 billion. The decrease in direct costs was largely due to the transfer of the $892 million polar platform to NASA's science program and the deletion of a planned new space suit. These decreases were offset by the additional operations cost needed to support users during an 18-month delay in the station's planned completion.

We have reported[6] that NASA could improve the way in which it reports program costs to the Congress. In January 1990 we recommended that Project Status Reports, which are submitted on all major NASA projects except for the space station, be modified to include total estimates in then-year dollars to complete a project.

Annual Operating Costs

NASA estimated the space station's annual operating cost at $2.8 billion in year 2001 dollars—the first full year of steady operations—excluding some costs such as shuttle flights. This estimate exceeds the $2.6 billion limit on annual space station funding specified in the fiscal year 1991 Appropriations Conference Report. Also, the $2.8 billion estimate may exceed 10 percent of NASA's total budget, the ceiling stated as a goal in the fiscal year 1988 Authorization Act.

Conclusions

As required by the fiscal year 1988 Authorization Act, NASA reports space station direct, related, and operating cost estimates annually in its Capital Development Plan. However, the plan's cost estimates do not include the total cost for the assembly period and the first full year of steady operations and are not expressed in then-year dollars.

[6]NASA Project Status Reports: Congressional Requirements Can Be Met, but Reliability Must Be Ensured (GAO/NSIAD-90-40, Jan. 23, 1990); NASA Issues (GAO/OCG-89-15TR, Nov. 1988); Space Station: NASA Efforts to Establish a Design-To-Life-Cycle Cost Process (GAO/NSIAD-88-147, May 5, 1988); Space Station: National Aeronautics and Space Administration's 1987 Cost Estimate (GAO/NSIAD-87-180FS, July 21, 1987); and Need for the National Aeronautics and Space Administration to Provide the Congress More Complete Cost Information on Its Projects (GAO/PSAD-81-7, Nov. 26, 1980).

We recognize that NASA has provided then-year dollar estimates of space station cost estimates to OMB and, on request, to Members of Congress and their staffs. However, if this information were routinely included in NASA's Capital Development Plan, Congress would be able to better assess the future affordability of the space station.

The plan's current reporting practice of using constant dollars is a useful analytical tool, but it does not fully reflect future appropriation needs and the full impact of design and schedule changes. Similarly, providing future-year operating costs in then-year dollars would aid the Congress in assessing NASA's potential for continually meeting the goal not to exceed 10 percent of its total budget for operating costs and in assessing the impact of design trade-off decisions. Also, comparing the operating cost estimates in two or more annual plans could aid the Congress in assessing the impact of NASA's design decisions, such as those made during the 1989 program review, on operating costs. According to NASA officials, providing this information to the Congress would not be difficult and can be made available if requested.

Matter for Congressional Consideration

The Congress may wish to consider requiring the NASA Administrator to expand the Capital Development Plan to

- disclose the space station's total direct and related cost estimates for assembly and the operating cost estimate for at least the first full year of steady operations and
- provide all cost information in both then-year and constant dollars.

Annual Funding Delays and Future Budget Guidance

The Congress has frequently expressed reservations about the affordability of the space station since the program's inception in 1984. Despite these reservations, the Congress has provided substantial funding increases. According to NASA officials, annual funding often needs to be increased for new research and development programs such as the space station. However, NASA has not received as much funding as it requested, which has affected the space station's schedule. In addition, the Congress has also frequently delayed the obligation of a portion of appropriated funds until later in the fiscal year. According to NASA officials, these funding delays have generally not presented a major problem, but the continuous adjustments to NASA's planned funding increases have contributed to program instability, as evidenced by frequent and costly schedule slippages and redesign efforts. Also, NASA work package center and contractor officials have reportedly experienced planning and staffing problems. However, the Congress has recently provided detailed guidance for future space station funding. NASA's plan for accommodating this congressional guidance is expected to be presented in April 1991.

Space Station Appropriations Have Increased Substantially

Annual appropriations for the space station have increased significantly since fiscal year 1985. Table 3.1 shows that during fiscal years 1985-91, appropriations for the space station program totaled $5.7 billion.

Table 3.1: Space Station Research and Development Appropriations

Dollars in millions

		Change from previous year	
Fiscal year	**Appropriation**	**Amount**	**Percent**
1985	$150.0		
1986	200.3	$50.3	33.5
1987	410.0[a]	209.7	104.7
1988	392.3[b]	−17.7	−4.3
1989	900.0	507.7	129.4
1990	1,749.6	849.6	94.4
1991	1,900.0	150.4	8.6
Total	**$5,702.2**		

[a]This amount excludes $10 million that resulted from an agency reprogramming effort.

[b]A congressionally directed realignment, which transferred some research and development funds into the research and program management account, changed the original appropriation from $425 million to $392.3 million.

Revisions to NASA's Planned Budget Growth Have Been Significant

Although the Congress has provided the space station program with substantial funding increases, it has repeatedly cautioned NASA about future years' fiscal constraints. In response to NASA's proposed funding increases, the Congress and OMB substantially reduced NASA's planned budget growth for the space station. Table 3.2 shows NASA's space station funding proposals for fiscal years 1985-91 and the changes made to the proposals by the President and the Congress. Since fiscal year 1985, annual space station funding has generally increased but not as much as NASA has requested.

Table 3.2: Space Station Program Budget Request Adjustments

Dollars in millions

Fiscal year	NASA's request	President's changes to NASA budget		Congress' changes to President's budget		Total changes from NASA's requested budget to amount appropriated	
		Amount	Percent	Amount	Percent	Amount	Percent
1985	$235.0	−$85.0	−36.2	0	0	−$85.0	−36.2
1986	280.0	−50.0	−17.9	−$29.7	−12.9	−79.7	−28.5
1987	600.0	−190.0	−31.7	0	0	−190.0	−31.7
1988	1,055.0	−288.0	−27.3	−374.7	−48.9	−662.7	−62.8
1989	1,872.0	−904.6	−48.3	−67.4	−7.0	−972.0	−51.9
1990	2,130.2	−80.0	−3.8	−300.6	−14.7	−380.6	−17.9
1991	2,693.0	−242.0	−9.0	−551.0	−22.5	−793.0	−29.4

Each year OMB has reduced NASA's planned budget growth for the space station. The differences between OMB and NASA funding levels were particularly large in fiscal years 1985-89, reaching a high of over 48 percent in 1989. However, NASA officials stated that in several cases, OMB reductions were appropriate and agreed to by NASA because they reflected the congressional reductions made in the prior fiscal year budget. For example, NASA submitted its fiscal year 1989 budget to OMB before the Congress had passed the fiscal year 1988 appropriation act. The OMB reduction to NASA's fiscal year 1989 requested budget primarily reflected the congressional reductions to NASA's fiscal year 1988 appropriations.

Except for fiscal years 1985 and 1987, the Congress further reduced the requested budgets, by as much as 48.9 percent in 1988. According to a NASA official, the large 1988 congressional budget reduction resulted from the delay of the detailed design and development phase of the station program. This official also stated that the delay stemmed from congressional concerns about the lack of agreement on an appropriate

station design, public criticism of the design, an increase in the cost estimate, and an overall lack of control of the program.

Adjustments to NASA's planned funding have contributed to program instability. In anticipation of congressional funding reductions, NASA conducted a program review in 1989 and reduced its fiscal year 1991 request to $2.7 billion. NASA's request was reduced to $2.5 billion in the President's budget. NASA was still in the process of negotiating contract program changes made as a result of the program review when the Congress further reduced the program by about 22 percent.

Congressional Concerns Delayed Some Appropriated Funds From Obligation

As shown in table 3.3, portions of the space station appropriations were delayed from obligation until a specified date.

Table 3.3: Space Station Appropriations and Amounts Delayed From Obligation

Dollars in millions

		Delayed from obligation[a]		
Fiscal year	Appropriation	Amount	Percent	Release date
1985	$150.0	$57.5	38.3	04/01/85
1986	200.3	0	0	[b]
1987	410.0	150.0	36.6	[c]
1988	392.3	225.0	57.4	06/01/88
1989	900.0	515.0	57.2	05/15/89
1990	1,749.6	750.4	42.9	06/01/90
1991	1,900.0	1,260.0	66.3	02/03/91[d]

[a]The directives for these delays appeared in various acts, conference reports, and committee reports.

[b]Not applicable.

[c]No date was specified in the appropriation act, conference report, or committee report.

[d]As of this date, $1.6 million was released; however, due to the extension of the reporting requirements for the space station redesign and assembly plan, the remainder is expected to be released in April 1991.

The reasons for the delays have differed. For example, in fiscal year 1987, $150 million of appropriated funds was delayed until NASA's design and assembly plan incorporated several requirements before providing space station living quarters. These requirements included a minimum of 37.5 kilowatts of power, a fully equipped materials processing

laboratory, early attached and pressurized payloads, and accommodation of life sciences to include essential animal facilities. NASA's design and assembly plan was to be approved before the request for proposals for the detailed design and development was issued. Also, in fiscal year 1991, the fiscal year 1991 Appropriations Conference Report directed the delay of $1.26 billion of space station appropriations pending completion of NASA's redesign and assembly plan. NASA has received an extension of the 90-day redesign reporting requirements until early April 1991.

Generally, NASA officials did not view these funding delays as a major problem because the station's annual appropriations usually increase each year and are available for obligation for 2 years. However, for fiscal year 1988, a combination of factors delayed the award of contracts for detailed design and development: the congressional budget reduction of almost 49 percent; a delay of over 57 percent of the $392.3 million appropriation; and, at the direction of the House Committee on Appropriations, a delay in obligating fiscal year 1987 funding.

Funding Uncertainties Have Affected Recruitment and Retention of Personnel

According to NASA and contractor officials working on the space station, past funding cuts and continued funding uncertainties have adversely affected the program. The space station program has experienced difficulties in planning and staffing at a time when it should be finishing final station design and preparing for production.

Some NASA center and contractor officials said they had problems in recruiting and retaining experienced, skilled engineers and other technicians because of the program's funding uncertainties and the perception that the Congress does not support the program. One contractor had expected an attrition rate of 3.4 percent but experienced a rate of 6.2 percent. Other center and contractor managers that had not yet experienced such problems expected to if funding uncertainties continue. One contractor, however, noted that funding uncertainties were natural to the space industry and that although attrition was significant among new engineers, it decreased among senior employees.

Officials from all four work package centers and contractors stated that, despite the frustration of frequent budget reductions to planned requested increases, morale was remarkably high, which they attributed to enthusiasm for the space station and belief in its value. However, officials did note some degree of burnout among their staffs and wondered whether it would increase if budget reductions continue.

The Congress Recently Provided Funding Guidance

The fiscal year 1991 Appropriations Conference Report provides fiscal and programming guidance for the space station program. In cautioning NASA that the funding crisis is only beginning, the conferees directed NASA to develop the station in self-sufficient phases. The incremental development would be funded at an annual growth rate of not more than 10 percent a year, starting with the $1.9 billion appropriated in fiscal year 1991. The conferees also directed that NASA limit the use of annual appropriations to $2.6 billion per year. The 10-percent growth rate and $2.6 billion funding cap will provide NASA with a maximum of $11.4 billion for fiscal years 1991-95. To comply with this directive, NASA must reduce its current 5-year $13.8 billion space station budget estimate for fiscal years 1991-95 by a minimum of about $2.4 billion. Also, NASA officials stated that the issue of whether the $2.6 billion cap includes inflation has not been settled.

A report by the Advisory Committee on the Future of the U.S. Space Program recently addressed the affordability of the space station. The Committee recommended that the station be redesigned to reduce its cost and complexity. The Committee suggested that NASA take whatever time is required for a thorough reassessment and the establishment of a design that will receive stable, long-term funding support.

Design and Schedule Changes Based on NASA's 1989 Program Review

To stabilize the space station's design and schedule at achievable funding levels, NASA reviewed the space station program in 1989. The review resulted in about 38 design and schedule changes that did not significantly alter the station's overall design or capabilities. Power, weight, and maintenance requirements were reduced to meet engineering constraints, and uncertainties in the assembly schedule were reduced by switching to more proven technologies. These benefits, however, were offset by an 18-month delay in the assembly schedule; minor limitations to space station users; and increases in construction, development, and operating costs. Although NASA estimated that the changes would substantially reduce the station's near-term development cost, its estimate did not include the potentially higher cost of contractor proposals still being negotiated as of January 1991.

NASA's Review Objectives

Facing substantial budget cuts and questions on engineering limitations and user requirements, NASA's program managers conducted a major review of the space station program from July through December 1989. The primary objective of the review was to adjust the program to accommodate an anticipated reduction of about 20 percent to NASA's requested budget increase in fiscal years 1990 and 1991 while causing the least delay in assembly and the minimum limitations to the station's capabilities. However, the NASA Administrator and program managers also hoped to assess options for reducing the risks associated with launching, assembling, and operating the space station. They also wanted to stabilize the program and alter the program management structure for the transition to the phases beyond preliminary design. Since the design changes often involved several benefits, such as reduced power and launch weight requirements, we could identify only a few changes that were made as a direct result of the anticipated congressional reductions to NASA's fiscal year 1990 budget.

Program Changes

On the basis of its program review, NASA planned to delete, defer, or modify many of the station's systems and elements. When the station's fiscal year 1990 budget was reduced by about 15 percent, not the expected 20 percent, NASA was able to reinstate some of the items but, in the end, made at least 38 deletions, deferrals, and modifications. Even though these actions included 15 major changes, they did not significantly change the station's overall design or expected capabilities. However, NASA delayed all assembly milestones except the first launch date, scheduled for March 1995. The man-tended capability milestone was

delayed from November 1995 to June 1996, and assembly completion was delayed from February 1998 to August 1999—an 18-month delay.

NASA estimated that these revisions reduced the President's space station research and development budget by about $202 million for fiscal year 1990. The four work package centers' budget submissions estimated budget savings at $591.6 million and $962.5 million for fiscal years 1990 and 1991, respectively, and about $2.1 billion for fiscal years 1990 through 2000. However, these estimates may be overstated because contractor costs for making the changes have not yet been negotiated. As of January 1991, the four work package centers were still negotiating new contracts based on the changes. Three of the contractors' proposals indicated that costs would be higher than anticipated. According to center officials, the contractors have increased their costs partly because they now have a better idea of what the changes involve. NASA headquarters officials stated that program reserves are available to cover any increased costs that may result from the negotiations. Furthermore, these negotiations may need to be altered as a result of the current redesign effort.

Appendix I shows the changes to the station's power, launch weight, and cost associated with the 15 major program changes as of December 1989. The estimated savings resulting from the changes are based on the centers' estimates of the cost of the changes and their budget submissions.

Changes Due to Funding Considerations

To reduce its budgetary requirements, NASA delayed all assembly milestones except the launch date for the first element, scheduled for March 1995. The man-tended capability milestone was delayed from November 1995 to June 1996 and assembly completion from February 1998 to August 1999. To further reduce funding requirements, NASA made several other schedule and design changes. Some of these changes are described below.

- Elimination of a new space suit: NASA decided to discontinue development of a space suit to be used only with the space station, choosing instead to use a modified shuttle space suit. The change saved approximately $70.7 million in fiscal years 1990 and 1991. However, preliminary estimates indicate the change also increased the total operating cost because the shuttle space suits will add 7,701 more pounds to the launch weight. The change will also require 676 more hours of maintenance based on 52 extravehicular activities per year and necessitate

astronauts taking more time to adjust their body pressure before space walks.

- Deletion of solar dynamic power generator test: In fiscal years 1990 and 1991, this deletion saved an estimated $17 million and did not affect the station's capabilities because solar dynamic power is not necessary for the current size of the station.
- Delay of full electrical power: NASA deferred an increase in station power, from 37.5 kilowatts to the full 75 kilowatts, from February to November 1997. This change saved an estimated $22.1 million for fiscal years 1990 and 1991. However, the cost will escalate an additional $19.6 million through fiscal year 2000 primarily because of inflation.

Changes Due to Technical Reasons

NASA also made changes for technical reasons, which is normal for any program making a transition from general design to development. These changes addressed problems of technical risk, power, weight, and external maintenance and, according to NASA officials, would have been made regardless of budget constraints. Some of these changes are described below.

- Change in type of propulsion: According to program officials, NASA changed the space station's propulsion agent from a hydrogen/oxygen mixture to hydrazine to reduce the need for extravehicular maintenance, reduce schedule risks, and save 3 kilowatts of power. NASA estimated that the change would save about $40.3 million through fiscal year 2000. However, the hydrazine propulsion system will require the shuttle to carry almost 6,000 additional pounds for resupply. Subsequent to the program review, NASA identified a need to construct hazardous processing facilities, which include processing of the hydrazine propulsion modules. Preliminary estimates indicate that the facilities' cost will be $114.4 million.[1] The facilities will be located at Kennedy Space Center, Florida.
- Deferral of closed-loop environmental control life-support system: Because this new technology has high technical risks, NASA delayed it 32 months, from December 1996 to station completion in August 1999. The station's life-support system will therefore begin without an oxygen and water recycling system. This deferral saved a total of $6.9 million in fiscal years 1990 and 1991. However, through fiscal year 2000 the system is estimated to cost an additional $18 million, including $17 million for an oxygen carrier necessary for resupply before closing the loop. Therefore, by saving $6.9 million in the short term, NASA will incur an

[1]This estimate represents $20.7 million for construction and $93.7 million for outfitting.

additional operating expense of $18 million over the life of the program. In addition, the weight of the oxygen increases shuttle launch requirements by about 2,470 pounds every 90 days.

- Elimination of one airlock: On the basis of NASA's May 1989 technical review and the need to reduce launch weight, NASA decided to delete one of the two station airlocks. The remaining airlock will have redundant capabilities and spares, reducing the risk of any damage that would render it inoperable. Moreover, if the airlock should become inoperable, astronauts could make an emergency return to the station through a node. Deleting the airlock saved a total of approximately $23.1 million through fiscal year 2000.
- Elimination of alternating current power: The space station was to use an alternating current/direct current power system. As a result of the 1989 program review, the alternating current portion of the power system was changed to direct current, which resulted in an all direct current system. According to NASA officials, this change eliminated the risk associated with alternating current, increased power efficiency by 6 percent with only a moderate weight increase, and saved an estimated $61.9 million in fiscal years 1990 and 1991.

Other Costs of Program Changes

Some of the revisions made as a result of the 1989 program review will increase operating costs, but NASA officials could not determine the extent of that increase. In addition, the space station incurred nonrecoverable costs of approximately $43 million for items deleted from the program as well as approximately $51.2 million for the review.

NASA did not prepare an analysis that identified the net impact of the 1989 program review changes on operating costs. Rather, NASA officials told us that these and other changes were incorporated in a 1990 update of the station's estimated annual operating costs. This update estimated station operating costs at $2.8 billion in then-year dollars, or $1.5 billion in 1987 dollars, and was not substantially different from NASA's 1987 estimate.

Changes Resulting From NASA's 1989 Program Review

Dollars in millions

Element	Center[a]	Change: Power (in kilowatts)	Change: Assembly launch weight (in pounds)	Change: Cost FY 1990	Change: Cost FY 1991	Change: Cost FY 1990-2000
Deletions						
Lab support equipment	MSFC	−3.09	−6,306	−$8.0	−$18.0	−$79.0
Solar dynamic power generator system test	LeRC	[b]	[b]	−0.7	−16.3	−40.4
Second airlock	JSC	[c]	−2,503	[c]	[c]	−23.1
User ultra-pure water waste fluid and gas systems	MSFC	−2.11	−1,658	−3.4	−6.1	−24.3
Animal specimen transport logistics module	MSFC	−0.28	−2,030	−1.0	−3.0	−23.8
Substitutions						
Space station suit switched to space shuttle suit	JSC	[b]	7,701[d]	−25.4	−45.3	−345.4
Hydrogen/oxygen propulsion switched to hydrazine	JSC	−3.00	−1,200	−3.0	−15.8	−40.3
Alternating current switched to direct current power system	LeRC	[d]	1,300	−28.2	−33.7	−58.5
Active switched to passive thermal control system	JSC	0.5	650	2.9	−14.2	−50.4
Deferrals[e]						
Data management system elements	JSC	−5.86	−7,870	−19.3	−24.8	33.3
Communications and tracking elements	JSC	−0.56	−2,575	−52.6	−92.1	22.7
75-kilowatt power	LeRC	[b]	[b]	−5.6	−16.5	9.6
Payload pointing	GSFC	−1.80	−4,634	−7.1	−17.0	17.7
Closed-loop environmental control life-support system	MSFC	−2.76	62	−2.8	−4.1	18.0
Crew habitability	MSFC	−1.27	−5,088	−5.2	−6.8	2.1

[a]GSFC, Goddard Space Flight Center; JSC, Johnson Space Center; LeRC, Lewis Research Center; MSFC, Marshall Space Flight Center.

[b]Not applicable.

[c]Not available.

[d]Power efficiency improved 6 percent, but center officials could not convert this amount to kilowatts.

[e]Savings in power and weight for deferrals are temporary until assembly is completed.

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