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Report to the Honorable
John W. Warner, U.S. Senate

May 1993

SPACE STATION

Information on National Security Applications and Cost

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National Security and
International Affairs Division

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May 18, 1993

The Honorable John W. Warner
United States Senate

Dear Senator Warner:

This report responds to your request that we (1) provide information on the potential use of Space Station Freedom by the Department of Defense (DOD) for national security purposes; (2) update the information provided in our May 1, 1991, testimony on the total cost of the National Aeronautics and Space Administration's (NASA) space station program; and (3) identify other existing and planned space stations. NASA is in the process of evaluating alternatives to its current space station design in an attempt to reduce the overall costs of the program. As you requested, this report addresses the space station's existing design and does not reflect the revisions that are expected to be announced next month.

Results in Brief

DOD has no formal requirement for a manned space station for national security purposes. In fact, for many of DOD's space research needs, the facilities of Space Station Freedom would be less suitable than those currently available on the space shuttle. Some research that DOD currently conducts on the shuttle, particularly that which would benefit from extended stays in orbit, could be enhanced by the capabilities of the space station. However, certain shuttle upgrades might satisfy additional DOD research needs.

In March 1993, NASA revised its cost estimate for the station to $31.3 billion. At the same time, NASA stretched the schedule for having permanent occupants in the space station to 2000. The $31.3 billion estimate, like previous estimates, excluded substantial budgetary resources required to successfully complete development and support the station over its planned 30-year life. Additional funding necessary to support and outfit the station for permanent occupancy would be another $11.7 billion. Further, at least $78 billion would be required to bring the facility to its full planned capability and maintain, supply, and operate the station after permanent occupancy was achieved. When these costs are included, the space station funding requirements through 2027 would be at least $121 billion.

The only existing space station is Russia's Mir. It is thought to be beyond its design life; however, it continues in use, and major upgrades are planned in 1994 to add remote sensing and atmospheric studies capabilities. In the longer term, Russia plans to build a more capable space station, Mir 2; details about the program are uncertain.

Background

The United States, Canada, Japan, and the European Space Agency each plan to provide Space Station Freedom elements and crew members. Over its expected 30-year lifetime, Space Station Freedom is to provide pressurized laboratories that allow researchers to interact with experiments in a "shirt sleeve" environment over extended periods of time.

Disciplines that NASA expects to benefit from the space station are life sciences, microgravity research, and technology development. Life sciences activities will focus on basic biological processes of cells, plants, animals, and humans. Microgravity research will study fluids, combustion, materials, biotechnology, and fundamental physics to increase the understanding of gravity-dependent phenomena. Technology development will investigate how microgravity, radiation, and other aspects of the environment affect the functioning of space systems. DOD currently conducts research in each of these areas and also in earth observation, space environment monitoring, and the role of the "military man in space."

DOD experiments that require a pressurized environment or human interaction are flown in the mid-deck locker area of the space shuttle. On a much smaller scale, this environment is similar to that to be provided by the laboratories of Space Station Freedom. DOD researchers have found the mid-deck area of the shuttle to be well-suited for testing and evaluating technology. In that environment, DOD can conduct proof-of-concept testing relatively inexpensively because the experiments do not have to operate autonomously in the harsh environment of outer space. Since 1989, at least 12 different DOD organizations have flown 62 experiments on the space shuttle's mid-deck, representing more than 20 percent of the shuttle's mid-deck capacity by weight.

The space station would provide another facility for those DOD experiments that require a pressurized environment or direct human interaction. A September 1988 space station intergovernmental agreement among the international partners allows the space station to be used for national security purposes. The agreement stresses the civil nature of the space station and states that the station is to be used for peaceful

purposes. However, each international partner determines whether the proposed uses of its laboratory are for peaceful purposes.

DOD Has Not Identified Any Requirements for the Space Station

In March 1988, the Secretary of Defense prepared a report at the request of the Senate and House Armed Services Committees on the potential use of the space station.[1] The report concluded that DOD had no requirements for major payloads that would use or uniquely require the space station. Nevertheless, the report noted that, depending upon its design, a manned space station could be useful for researching potential military applications such as:

- direct observation for purposes of battle management, surveillance, weather support, and monitoring naval activities;
- development of systems to identify, collect, and remove space debris;
- on-orbit maintenance and repair of satellite systems;
- development of techniques for assembly of satellite systems on orbit;
- detection of missiles launched from land, sea, and airborne platforms; and
- development and testing of technology, such as electrical power for space systems.

Because the design of Space Station Freedom has changed over time,[2] certain applications cited in DOD's 1988 report may no longer be relevant.

DOD still has no formal requirement for the space station, but it appears likely that DOD researchers would use it for some types of experiments. However, DOD has no experiments planned for the space station at this time and some DOD researchers maintain that it is too early to do so. If the space station is built, DOD researchers would consider the relative costs of accomplishing their research on that facility in comparison to other platforms such as unmanned systems or the shuttle.[3]

[1] A Report to the Committees on Armed Services of the Senate and the House of Representatives on Potential Department of Defense Use of the Permanently Manned Space Station, Office of the Secretary of Defense, Mar. 1, 1988.

[2] Questions Remain on the Costs, Uses, and Risks of the Redesigned Space Station, (GAO/T-NSIAD-91-26, May 1, 1991).

[3] NASA is currently studying strategies for future access to space. Options under consideration include retaining the shuttle as the primary means of access to low earth orbit at least through 2005 and perhaps through 2030.

Much of DOD's Shuttle-Based Research Could Not Be Done on Station

Characteristics of the current space station design make it less suitable than the shuttle for many of the activities DOD currently conducts on the shuttle. Some types of DOD shuttle-based research might benefit from the capabilities of the space station, especially research that requires more time than currently available during the normal duration of a shuttle flight. However, given NASA's plans to upgrade the shuttle to extend flight duration to nearly a month, coupled with increased research capacity available when the Spacehab module is flown in the shuttle bay, DOD researchers would have increased research capability available even without the space station.

Space Station Would Not Be Suitable for Certain DOD Uses

Much of the DOD research presently done on the space shuttle would not be possible on the space station because the station lacks suitable windows for "direct view" experiments. Direct view experiments, which have accounted for about half of DOD's mid-deck experiments, involve astronauts directly observing the earth or phenomena taking place outside of the shuttle. The following DOD experiments illustrate some of the types of test and evaluation activities that have used or will use the shuttle windows:

- The Army's "Battlefield Laser Acquisition Sensor Test" investigated the concept of conducting communications between ground personnel and orbiting spacecraft. Sensors placed on the shuttle windows successfully locked onto ground-based lasers as the shuttle passed overhead. To the military, such a capability would be useful for covert communications with troops, ships, or even downed pilots.
- In "Terra Scout," the skills of an Army imagery analyst were used to investigate the human/machine interface with remote sensing devices. This research may aid in the development of more powerful and versatile sensors.
- The Navy's "Military Application of Ship Tracks" experiment will analyze ship track signatures to determine their intelligence potential in identifying threats to the fleet.
- The Auroral and Interactions Photography Experiment sponsored by the Air Force will quantify emissions induced by the space environment on spacecraft surfaces. This type of data could be useful for identifying and tracking spacecraft.

Unlike the windows of the shuttle, the windows of the existing space station design would not be useful for direct view experiments. Early space station designs included windows in the U.S. laboratory module that

were suitably located for the type of direct view experiments that DOD conducts. However, the windows were deleted during an earlier space station redesign exercise to save money and weight. The windows included in the current space station design are not located where they would be useful for direct view experiments. These windows are intended for crew recreation and operational activities, and not for research. However, one of the three space station design options under consideration may include windows suitable for direct view experiments. It should be noted that neither the windows specified for the space station nor those of the shuttle are of high optical quality. DOD researchers have noted that improving the optical quality of the windows would enhance direct view research.

DOD officials pointed out other aspects of the space station that could limit DOD's interest in using it. For example, the presence of foreign nationals on the space station would limit DOD's interest in using it for classified purposes. The shuttle, on the other hand, has been used on eight dedicated DOD flights, some of which included classified research.

Space Station Capabilities Could Enhance Some DOD Research

Certain types of research that DOD currently conducts on the space shuttle may benefit from the capabilities of the space station. Three recent experiments flown illustrate the kinds of research that DOD could adapt for the space station laboratories:

- The Army conducted the "Microcapsules in Space" experiment to demonstrate that better pharmaceutical microcapsules could be designed in the microgravity of space. The test was considered a success in that the capsules were more perfectly formed and contained fewer impurities than those produced in the earth's gravity. For the military, these superior microcapsules might be useful for inoculating troops and treating wounds on the battlefield.
- The Army conducted its "Space Tissue Loss" experiment to study bone and muscle cell degradation that occurs while in orbit. This research has potential military relevance in treating battlefield trauma, such as bone fractures.
- The Strategic Defense Initiative Organization sponsored the "Cosmic Radiation Effects and Activation Monitor" experiment to measure the radiation environment of low-earth orbit in order to help engineers design more effective radiation shields for electronic equipment in spacecraft.

Each of these experiments was conducted on the shuttle over a period of days. The space station would offer the opportunity to conduct the research for much longer periods, thus permitting the use of much greater sample sizes and more iterations to increase researchers' confidence in the validity of their work. In addition, in research such as "Microcapsules in Space," the additional time would permit the production of far greater quantities of pharmaceuticals.

Shuttle Upgrades Could Enhance Its Usefulness for DOD Research

If DOD were to require greater research capabilities than those previously available, shuttle upgrades might meet its needs. For example, experiments that would benefit from longer time in space could be flown for up to 16 days on "extended duration" missions made possible by recent upgrades to the shuttle orbiters. By 1999, "long duration orbiters" could allow flights of up to 28 days—about 3 times as long as current flights. To date, DOD researchers have not proposed experiments requiring either extended duration or long duration shuttle flights.

If DOD had a need for more laboratory space, it could take advantage of the additional capability provided by Spacehab. Scheduled for its first flight in June 1993, Spacehab is a module that can be placed in the shuttle's cargo bay to increase the volume of laboratory space beyond that available in the mid-deck. Spacehab is privately built and owned and intended to provide commercial access to space research. Presently, DOD has no plans to lease lockers on the facility because the cost is much greater than flying experiments on the shuttle's mid-deck.

The shuttle's usefulness for DOD's direct view research could be enhanced by upgrading the orbiter's windows. In the past, DOD expressed interest in having the shuttle windows upgraded to high optical quality glass. According to NASA officials, the total cost would have been roughly $5 million to replace panes in the overhead windows of the three shuttle orbiters that existed at that time. To date, however, the windows have not been upgraded.

Space Station Cost Estimate

In May 1991, we testified that NASA's estimate of $30 billion did not include some cost elements attributable to the space station program. First, it did not include at least $10 billion in program cost attributable to the program prior to permanent occupancy. Second, it did not include at least $78 billion in funding required after permanent occupancy. When these

costs were considered, the space station estimate was at least $118 billion. We cautioned in our testimony that the remaining technical challenges and risks associated with the program could also be understated. We noted that some cost elements were still undefined and significant cost growth could occur during hardware development.[4]

In testimony before the Congress on March 2, 1993, NASA acknowledged substantial new cost growth for research and development of the space station program through permanent occupancy. The preliminary results of a program cost assessment review team attributed the program cost growth to

- an inability to meet the management challenges that had been incorporated into the program as a result of the 1991 restructure;
- an inability to achieve productivity gains assumed in contractors' and subcontractors' bids and projections;
- an overall lack of space station design maturity, which resulted in underestimating costs;
- change orders issued by NASA to its contractors;
- unanticipated increases in contractors' overhead rates; and
- the need to begin funding spare parts that require a long lead-time.

NASA pointed out that the data supporting the fiscal year 1991 redesign cost estimate were incomplete and costs became higher than anticipated. For example, the avionics and software designs and verification requirements and implementation plans were not fully developed, and the avionics themselves were more complex and expensive than anticipated.

When we testified on NASA's original $30 billion station estimate in May 1991, we pointed out that the cost of other planned elements, such as an assured crew return vehicle, a centrifuge facility, science experiments, and additional shuttle costs, would add about $10 billion, bringing total costs to $40 billion. Today, based on revised NASA figures, these elements are estimated to cost about $11.7 billion. Together with NASA's revised estimate of $31.3 billion, the total cost of the current program to permanent occupancy in 2000 is estimated at $43 billion. Table 1 provides a breakdown of the current cost elements that make up the space station program and the annual appropriations that will be required to support those elements. It covers both NASA's latest estimate of $31.3 billion and

[4]For a more detailed discussion see Questions Remain on the Costs, Uses, and Risks of the Redesigned Space Station (GAO/T-NSIAD-91-26, May 1, 1991).

those additional items we believe are also attributable to the space station program through 2000.

Table 1: GAO Estimate of Space Station Cost Through Fiscal Year 2000 - May 1993 Estimates (NASA Data Except Where Noted—In Billions of Then Year Dollars)

Cost Components	Prior	1994	1995	1996	1997	1998	1999	2000	Total
Research and Development									
Development	8.921	2.210	2.131	1.827	.892	.581	.342	.123	17.027
Operations		.030	.309	.843	1.688	1.919	1.858	1.902	8.549
Shuttle Modifications	.205	.089	.106	.107	.058	.060			.625
Flight Telerobotic Servicer	.283								.283
Program Definition	.612	.010							.622
Space Flight, Control and Data Communications									
Shuttle Transportation		.012	.031	.168	.230	.367	.350	.324	1.482
Communications & Data Systems	.033								.033
Construction of Facilities									
Construction of Facilities	.171	.031	.043	.044	.027	.019	.004		.339
Research and Program Management									
Civil Service Personnel	.909	.182	.190	.199	.208	.217	.228	.238	2.371
NASA Estimates	**11.134**	**2.564**	**2.810**	**3.188**	**3.103**	**3.163**	**2.782**	**2.587**	**31.331**
Additional Appropriations to Support Space Station Program									
Assured Return Vehicle[a]	.016		.366	.369	.332	.239	.200	.150	1.672
Centrifuge Facility[b]	.018	.021	.037	.084	.106	.133	.200	.200	.799
Science Experiments[b]	.064	.077	.155	.196	.221	.236	.300	.359	1.608
Additional Appropriations	.098	.098	.558	.649	.659	.608	.700	.709	4.079
Allocation of Additional Shuttle Costs									
Additional Shuttle Cost[c]						**2.524**	**2.541**	**2.567**	**7.632**
Grand Total	**11.232**	**2.662**	**3.368**	**3.837**	**3.762**	**6.295**	**6.023**	**5.863**	**43.042**

[a]NASA has estimated that about $1.7 billion would be required to produce an assured return vehicle for a permanently manned capability. The agency is currently studying the feasibility of developing a less costly return vehicle by modifying the Russian Soyuz-TM spacecraft. Ten million dollars is allocated under program definition for this purpose in fiscal year 1994. However, in the absence of any new development estimates we have maintained the $1.7 billion to account for this requirement.

[b]NASA's planning did not provide funding estimates for development of science experiments or the centrifuge beyond fiscal year 1998. Amounts for fiscal years 1999 and 2000 are notional estimates we developed based on continuing funding requirements and are subject to change when official NASA estimates are made available.

[c]Figures are based on NASA's estimates of 7 assembly or utilization flights per year at an average $413.5 million per flight less shuttle transportation costs already included in its $31.3 billion estimate. NASA's "average cost per flight" does not include any of the approximately $30.2 billion spent through 1992 to develop the shuttle, acquire reusable hardware and equipment, and construct and modify facilities. Nor does it include any of the more than $1 billion that NASA estimates will be needed annually for shuttle upgrades.

Not included in table 1 is an estimated $78 billion (uninflated) necessary to support the space station after the year 2000. This estimate consists of $54 billion to maintain, supply, and operate the station for 27 years at $2 billion annually, and about $24 billion necessary to bring the station to its full planned capability, provide shuttle transportation, conduct scientific research, and pay civil service salaries. Estimates of these out-year costs have not changed since we reported them in 1991. When these costs are considered, the total space station life-cycle cost estimate through 2027 is at least $121 billion.

NASA has objected to our including in the space station estimate the additional appropriations required to support development of an assured crew return vehicle, centrifuge facility, and science experiments and the allocation of additional shuttle costs. We have included NASA's arguments in prior reports and its position has not changed. In responding to our September 1992 report, [5] NASA took exception to including the estimated development cost of an assured crew return vehicle because less costly alternatives are being considered. NASA also claimed the inclusion of the centrifuge facility and science experiments was inappropriate because, in its opinion, they were analogous to cargo being flown on a cargo plane. We believe that until a decision is made on the developmental approach for the assured crew return vehicle, the estimate currently available should stand. Also, we disagree with NASA's cargo analogy. Since the centrifuge facility and the science experiments are being designed to meet the unique engineering requirements of the space station, they should be considered as part of that spacecraft's cost.

NASA also objects to allocating the average shuttle flight cost to the space station program. These objections were set out in NASA's response to our recommendation that it allocate this cost during the period that the space station is the predominant user of shuttle capabilities.[6] NASA's view was that most of the elements of the average cost per flight were fixed in that NASA is committed to six to eight shuttle flights annually through at least 2005, even if there is no space station program.

NASA's practice is to allocate only the marginal cost of a shuttle flight to the space station program, that is, those additional costs, such as fuel and other consumables, that are incurred or avoided when a flight is added to

[5]NASA: Large Programs May Consume Increasing Share of Limited Future Budgets (GAO/NSIAD-92-278, Sept. 4, 1992).

[6]Space Transportation: The Content and Uses of Shuttle Cost Estimates (GAO/NSIAD-93-115, Jan. 28, 1993).

or deleted from the shuttle program. While this practice is appropriate for incremental changes to the flight manifest, it is not appropriate with regard to the space station.

NASA claims it will fly the shuttle with or without the space station, but this is based on the premise that only NASA and the administration make resource allocation decisions for NASA programs. If this were true, then shuttle costs could be viewed as substantially independent of the space station program. However, we believe the role of the Congress needs to be recognized and that sound congressional decision-making is best served by analyses recognizing that the duration and content of the shuttle program would become an open issue if the space station were abandoned. NASA's "fixed" costs are most certainly subject to congressional review and any significant flight rate reduction could reduce resource requirements and, ultimately, some of those costs.

NASA should also not use marginal cost exclusively during the time the shuttle is substantially dedicated to the space station because such heavy, prolonged use imposes an opportunity cost; that is, other uses of the shuttle must be foregone, or at least deferred. From this perspective, while it is entirely possible that even the average cost per flight may understate the decision-relevant cost of a shuttle flight, the average cost is still a more appropriate measure than the marginal cost.

Russia's Plans to Build a New Space Station Are Uncertain

The Russian Mir, launched in 1986, is the only space station currently in operation. Mir is modular in design, having a core module with six ports to which are docked modules that house the station's scientific and support equipment. Currently docked are Kvant, an astrophysics module; Kvant-2, a logistics module; and Kristall, a materials processing module. During lengthy stays in orbit, the longest of which was 366 days, cosmonaut teams have accumulated much information on the long-term effects of weightlessness on humans, and have performed considerable research in materials processing, astronomy, and earth remote sensing.

Mir is said to have surpassed its design life, and questions have been raised about its structural integrity. Nevertheless, the Russians continue to use the facility and, in fact, plan major upgrades in 1994. At that time, Russia plans to add two new modules—Spectre for atmospheric studies, and Priroda for remote sensing of the earth.

Russia's plans for Mir 2, a follow-on to the current station, have become a matter for speculation. Among those familiar with the Russian space program, there seems to be general agreement that the Russians will go ahead with a Mir 2 program; however, specifics are unclear. One expert on the Russian space program likened the uncertainty surrounding Mir 2 to that surrounding NASA's Space Station Freedom. Experts believe a launch time frame of 1997 is probable. The Russians hope that the current station will remain operable until that time. It appears likely that the new station's design would be a modification of the current one; however, it is expected to have more power and possibly a truss structure, similar to the current design of Freedom.

Scope and Methodology

In the course of our review, we focused on potential DOD research uses of the space station; however, we did not review non-defense uses. We interviewed:

- NASA officials responsible for planning and coordinating research on the space station and for estimating the costs of the space station;
- representatives of DOD organizations that may conduct research on the space station, including various components of the Army, Navy, Air Force, the Advanced Research Projects Agency, and the Strategic Defense Initiative Organization;[7]
- astronauts who have conducted research for DOD on the space shuttle;
- officials from the National Security Agency;
- State Department officials responsible for space treaties and agreements; and
- government and private experts on the Russian space program.

We reviewed:

- DOD studies on its use of space stations;
- space station agreements and space treaties;
- space station program documents; and
- DOD shuttle experiment plans.

We conducted our review from March to May 1993 in accordance with generally accepted government auditing standards. As requested, we did not obtain written DOD or NASA comments on a draft of this report. We obtained the views of responsible DOD and NASA officials and considered

[7]We identified these organizations through discussions with officials from the tri-services Space Test Program who arrange flight opportunities for DOD experiments.

them in preparing this report. Information on the total cost of the space station in this report has been provided to Congressman Tim Roemer[8] as part of his request for information related to the cost of the space station.

We are sending copies of this report to the NASA Administrator; the Secretary of Defense; the Director, Office of Management and Budget; appropriate congressional committees; and other interested parties upon request. If you or your staff have any questions, I can be reached at (202) 512-8412. Major contributors to this report are listed in appendix I.

Sincerely yours,

Donna M. Heivilin
Director, Defense Management
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[8]Space Station: Program Instability and Cost Growth Continue Pending Redesign (GAO/NSIAD-93-187, May 18, 1993).

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