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Space Station Engineering and Technology Development

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Space Station Engineering and Technology Development

Report of the ad hoc Committee on
Space Station Engineering and
Technology Development

Aeronautics and Space Engineering Board

Commission on Engineering and Technical Systems

National Research Council

NATIONAL ACADEMY PRESS
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Preface

At the request of the National Aeronautics and Space Administration (NASA), the National Research Council's Aeronautics and Space Engineering Board (ASEB) undertook a study of NASA's evolving space station program. The study, "Space Station Engineering and Technology Development," was carried out by an ad hoc committee of the ASEB. It was directed at a review of program planning with focus on engineering and technical development related to the initial operational configuration and the near-term evolution of the space station. The ad hoc committee also gave attention to technical management matters.

The committee members, who have industry, university, and government experience, were briefed by NASA staff members involved in the space station program. The deliberations and findings of the committee are discussed in this report.

The document contains an executive summary, a section on historical information, and a brief review of the current program plan. This material is included to provide background information for persons not familiar with the space station program. The work of the ad hoc committee is reflected in the last two sections of the report. These sections deal with system and engineering development status and program issues.

Acknowledgements

The ad hoc committee recognizes the pressures that NASA personnel were under during the period of this review. The formative stage of development of the space station program put an added burden on the NASA staff involved in committee and panel briefings, where engineeri and technical discussions were open and frank. The ad hoc committee expresses its appreciation to the many NASA representatives from headquarters and field centers who prepared and handled the briefings

Special thanks are due Richard Carlisle of NASA for his assistanc with presentation content. Without his help, the work of the committee would have been more difficult and less productive.

Contents

Executive Summary

ASSIGNMENT

The National Aeronautics and Space Administration (NASA) requested the Aeronautics and Space Engineering Board (ASEB) of the National Research Council to assemble a group experienced in engineering and technology management to review NASA's space space station program. Members of the group were not to be directly involved in the program. In response the ASEB formed the Committee on Space Station Engineering and Technology Development. The committee was asked to review NASA's program of engineering and technology development for the initial space station, including such factors as on-orbit maintenance, operational autonomy, and the nature of the research and technology to be conducted in space. NASA asked the committee to pay particular attention to planning for the evolution of the space station into a more versatile system.

When the study was under way, however, it became evident that the research and technology development to be conducted in space would not receive priority consideration by NASA or the committee because detailed consideration was premature. Thus, with NASA's concurrence the committee did not address these subjects.

After deliberation, the committee focused on assessing NASA's planned technical program and its approach to developing the technical foundation for the evolving space station. The objectives of the space station program are to provide for a permanent manned presence in orbit, the capability for scientists to conduct studies of the earth's environment and other subjects from orbit, the use of space for research and technology and product development and production, activities to advance space exploration, and station growth. The mission, operational requirements, development schedule, and cost assumptions were to have been outside the scope of the study, but because they affect the engineering and technical aspects of the program, the committee did give these matters some attention. The committee and NASA recognized that the space station program is just beginning and that many key engineering and management decisions have not been made. NASA intended the committee to assist in identifying critical issues, many of which could be resolved by NASA early in the course of program development.

This report is based on the data presented to the committee, discussions with experts presenting the data, and the committee's assessment of this information.

ACTIVITY

The committee held its first meeting in March 1984 in Washington, D.C. NASA briefed it on the operational and engineering philosophy behind the effort directed at defining space station requirements, configuration analyses, technology program content and issues, and program evolution and management. The committee then formed one panel to address work assigned to NASA's Marshall Space Flight Center (MSFC) and its associated centers and another to consider work assigned to NASA's Johnson Space Center (JSC) and associated centers. The committee and its panels also identified technical policy and management issues to help guide the study.

In April the MSFC panel was briefed on space operations, structures and materials, propulsion and fluids, engineering, and station stabilization and control. In May, the JSC panel was briefed on environmental control, human factors, life support, thermal control, data management, communications, electric power, and systems operations, and the full committee was briefed on other selected aspects of the program: systems engineering activity, reference configurations, evolutionary designs, user requirements, mission definition, and program management.

1984 In August, a special panel of the committee met with NASA representatives in Washington, D.C., to review plans for developing solar thermodynamic electric power generation technology. In a workshop at the National Academy of Sciences Study Center at Woods Hole, Massachusetts, NASA brought the committee up to date on the activities of the space station program. Panels met to address issues of technical and management policy, and a draft of this report was developed.

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

The committee concluded that there is an adequate national technical base to support development of the space station. However, high near-term performance benefits and long-term cost savings can be realized if certain selected advanced technologies, those relating to solar thermodynamic electric power generation, closures of life support systems, and automation, are pursued. Additional benefits could accrue from using independent research and development work by contractors funded by the Department of Defense and from creating a plan for an integrated technology development program that relates technology developments for the initial station to those for the evolving, more versatile station.

The committee considers onboard mission control possible and desirable and onboard maintenance capability required. NASA has proposed to use development hardware as operational equipment on the station to reduce costs. The committee believes this is possible but that the proposal requires careful analysis. The committee has some concern about cost definition, assessment and control, and management system complexity.

The issues and the committee's recommendations are summarized here. The more significant are designated by solid circles (●). However, all of the following issues and others discussed in the report warrant special consideration by NASA program management.

Technical issues: the committee recommends that NASA

● accelerate the development of a solar thermodynamic electric power system to assess whether this technology could support the initial space station. Concurrently, NASA should develop an integrated plan for converting the station from photovoltaic to solar thermodynamic power. This action would minimize the complexity and cost of increasing the generating capacity as the station's missions multiply. The effects of rotating machines on the stringent pointing requirements of the space station, however, must be carefully examined.

● continue to develop a control system that is stable under a wide range of conditions and provides active or passive ways to damp the vibration of appendages on the structural stack of the evolving station. Ground-based analyses and simulations cannot adequately predict the dynamic response of large flexible structures in space. Control logic will probably have to be adjusted in actual operation, which will require measuring responses in space and an adaptable control and stabilization system.

● achieve a significant measure of life support system closure for initial operations, using the state of the art. A reasonable degree of water and oxygen recycling will reduce resupply requirements and associated costs of operational support and crew time.

o support the development of technology to allow early incorporation of hydrogen-oxygen thrusters for control, stabilization, and orbit adjustment. Although hydrogen and oxygen require long-term cryogenic storage, they are less polluting than organic fuel. Hydrogen and oxygen are nontoxic, noncorrosive chemicals already in use on the space station.

o reexamine activity in advanced development of communications. Existing technology is capable of handling almost all projected requirements for the initial station. Funds used for advanced development of communications may be better invested in areas where technology is not as developed.

- o define procedures and safety requirements for extra-vehicular activity missions, designate performance bounds and design constraints, and provide suits that require no preconditioning (prebreathing) before they are put on. These actions will allow safer, more responsive extra-vehicular activity.

- o pursue research on microfiltration, the control of bacteriological matter and the identification of microbial buildup in closed, inhabited space station units. This knowledge is critical to long missions or emergency operations with an enlarged crew. Control of contamination is also important for the design of modules for plant and animal experiments onboard the space station.

- o use existing technology where possible, for example in control-moment gyros and wind-unwind joints where fluid or electric power are to be transfered. Unless new developments are required to accomplish a task, the use of proven technology will reduce time and resource requirements as well as technical risk.

- create plans that relate technology development programs for the initial station to evolving requirements. Periodically updated, these plans will help focus supporting developments and avoid design commitments that could make modifications to the station impossible or very expensive. The plans will also help identify the technology developments with high potential value for station growth.

- become familiar with and use research and development programs supported by the Defense Department that are pertinent to the space station definition and development program. This action will help ensure the early application of important technology developments at minimum cost.

Policy issues: the committee recommends that NASA

- centralize mission control functions on the space station to minimize the need for support from ground-based command and control. Onboard responses to emergencies should be quicker, and the need for ground-based operational support for routine operations should be less, reducing costs.

?
will be there either way

- design for onboard maintenance, including the detection of system malfunctions and assessments of corrective action. NASA should also define maintenance and logistics requirements. This information is needed early so that it can be considered when systems, subsystems, and components are designed and when operations are planned.

- o determine beforehand the requirements for maintaining major subsystems on the ground for trouble shooting problems arising in orbit and for systems development to assist station growth. The plan to fly subsystem hardware previously used in ground testing (protoflights) is sound as long as resources on the ground are sufficient to support mission malfunction analyses and evolutionary development.

- o consider carefully the degree and type of hardware commonality to pursue. For components and possibly subsystems, the use of common hardware is likely to be beneficial. For major elements, where performance, operations, or other design factors are more important, a requirement for commonality will be counterproductive.

- prepare test protocol and instrumentation plans for system tests in orbit. Many systems will be mated for the first time in orbit, and the process should be a natural outgrowth of prelaunch protocol. Consideration should also be given to judicious use of the instrumented space station and its components for validating design and performance and for assessing problems during assembly and operation.

- o consider the congressional mandate on automation and assume leadership in addressing areas of automation applicable to the space station. However, NASA should not develop automation beyond space station requirements. The work should be focused on functions that are repetitive and well understood, especially mission control and status functions to unload the crew and increase time for tasks requiring human judgment.

Management issues: the committee recommends that NASA

- establish a clear, firm philosophy of design, development, and operation in which the station is a standard facility providing a basic support like a utility. The space station should not be designed to accommodate every requirement of a user or mission. Users should provide any unique equipment they need to accommodate to the basic services.

- decide now on a philosophy and key measures related to significant cost, schedule, and performance factors for the program. Firm specifications will provide a consistent set of guidelines for the many program participants and reduce the complexity of the effort to engineer and integrate the system.

- reaffirm the commitment to the concept of designing to cost and be more explicit in defining the terms of reference for its implementation. If design-to-cost is to be a program constraint, cost targets need to be identified for major systems and elements and a common basis for costing identified.

- review the statements on and commitments to life-cycle-cost goals and controls to assess their appropriateness and usefulness. If the concept of life-cycle cost is to be retained, a term such as "annual operating cost" that represents this cost should be defined so that the cost can be understood and calculated. A statement that NASA will use life-cycle costs for program judgments is not sufficient. Specific identification of guidelines for station life and costing are required for meaningful comparative performance analyses.

- establish a single office for controlling and directing the program with ready access to the NASA administrator when required. Such focusing of program and contract management and of technical authority will provide timely reporting and direction and provide a cleaner line of responsibility and authority. This action will help make program management, control, and reporting to higher-level authority more effective.

- review the proposed procedure to control changes with a view to limiting decision nodes, flow paths, and complexity. NASA should develop a procedure that is clear, consistent, and intolerant of unneeded change. Long processes of review and approval add confusion, time, and cost to the program.

- continue to seek foreign participation and help resolve the security problems that prevent Defense Department participation in the space station program. Program participation by both foreign groups and the Defense Department is considered important to the interests of the nation. Appropriate use of the space station by both will maximize benefits from an important national asset.

- advise the Defense Department of actions related to the accommodation of classified defense experiments and prepare to initiate action to involve the department in the space station definition effort, including permanent representation in NASA while the national policy on DOD involvement in the program is being resolved. Active DOD participation will depend on the ability to accommodate and safeguard defense projects. Direct participation in program definition by responsible DOD representatives should help ensure effective utilization of resources.

1

Introduction

HISTORICAL BACKGROUND

The National Aeronautics and Space Administration (NASA) has been concerned with manned space stations since the early 1960s. Many studies of station use, design, operation, and crew requirements have been funded by the agency and others.* Indeed, a manned space station was considered the logical program to follow Project Mercury, the first U.S. manned space flight effort in the 1960s. Project Mercury carried a single astronaut; it was followed by projects Gemini (crew of two, two weeks in orbit, and rendezvous missions) and Apollo (crew of three, two crew members to the lunar surface).

While major attention and effort was directed at the manned lunar mission through the 1960s, the topic of space station design and use continued to receive attention. This led to a series of NASA space station studies in 1969.

In the early 1970s, NASA developed a limited space station, Skylab (crew of three). Using Apollo spacecraft and launch vehicle components and the Apollo spacecraft to ferry the crew to and from the station, Skylab was launched in May 1973. It performed three separate manned missions of 28, 59, and 84 days. Manned operations terminated in early 1974, and Skylab eventually reentered the Earth's atmosphere and was destroyed.

A decision to develop a space shuttle was made in 1973. It was recognized that a space transportation system was required for a space station, should one be developed. The Shuttle flew its first orbital mission with a crew of two in 1981; it is now capable of handling a crew of seven.

*Space Stations: A Historical Perspective. J. H. Logsdon, National Air and Space Museum, Washington, D.C.; Space Station Policy, Planning and Utilization. AIAA/NASA Symposium, 1983; and selected papers (Appendix A).

To support renewed interest in a space station, NASA established the Space Station Task Force in 1983 and directed it to identify program concepts through analyses of mission requirements, configurations and systems, technology developments and needs, and management and acquisition approaches. The concept of the space station evolved from this work (see Figure 1-1). Figure 1-2 illustrates the station's infrastructure. The functional elements of the space station include

-- Laboratory(s) (for science, applications, and technology)
-- Permanent observatory(s) (space and earth)
-- Transportation (crew, station elements, and logistics)
-- Servicing facility (for free flyers and platforms)
-- Communications and data processing
-- Manufacturing facility(s) (development and production)
-- Assembly facility(s)
-- Storage depot(s)

The major elements of the space station would be permanent, habitable, and automated modules in low earth orbit. There would be one or more automated free-flying platforms (for commercial, application, and scientific work) operating near the station. The station would serve as habitat, utility core, laboratory, and service station. The Shuttle would carry the components into orbit, help assemble the station, and service it on a nominal 90 day cycle with fresh crews, supplies, and equipment. Transportation between the station and the free-flying platforms would be provided by an automated space tug, the orbital maneuvering vehicle.

The initial station is envisioned to have a crew of six to eight and a power level of about 75 kW. Eventually, it would become the operations base for an orbital transfer vehicle capable of transporting payloads to high earth orbits. For platforms operating in polar orbits, the orbital maneuvering vehicle would operate from the Shuttle flying in polar orbit.

The program concept was approved for detailed study and preliminary specification by President Reagan in early 1984. An artist's drawing of an initial station, to be operational in 1991 or 1992, is shown in Figure 1-3.

The initial space station is expected to operate in an inclined orbit of about 28° with unmanned coorbiting platforms. The station's capabilities are expected to grow through modifications and additions to accommodate a crew of 12 to 18 and to generate about 300 kW of electric power by the year 2000. Figure 1-4 shows a possible future station. Just what the system will look like in its initial and expanded configurations is not yet certain. The configuration selected for detailed design will evolve from further in-house and contracted studies.

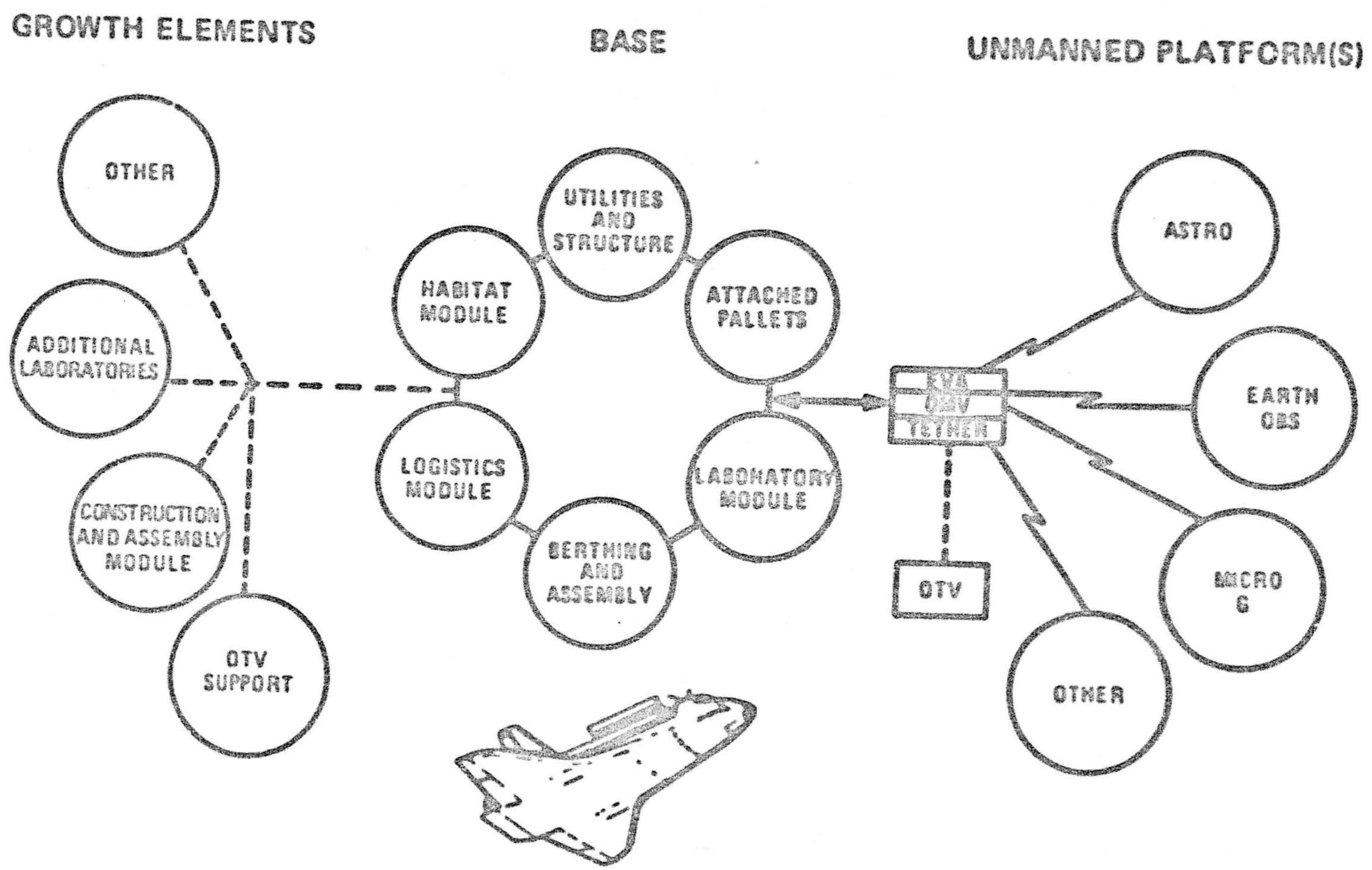


FIGURE 1-1 Space station cluster concept.

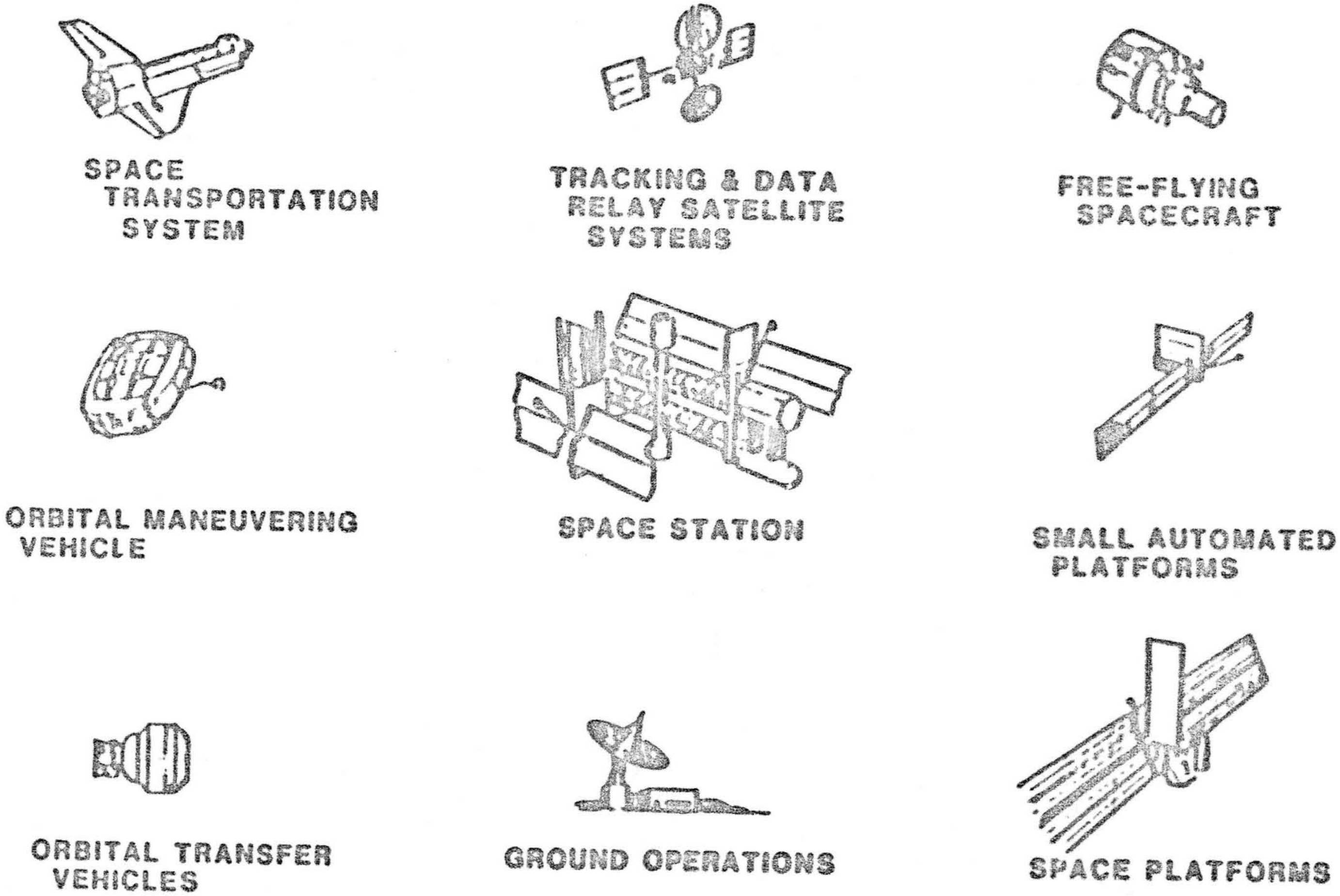


FIGURE 1-2 Space station infrastructure.

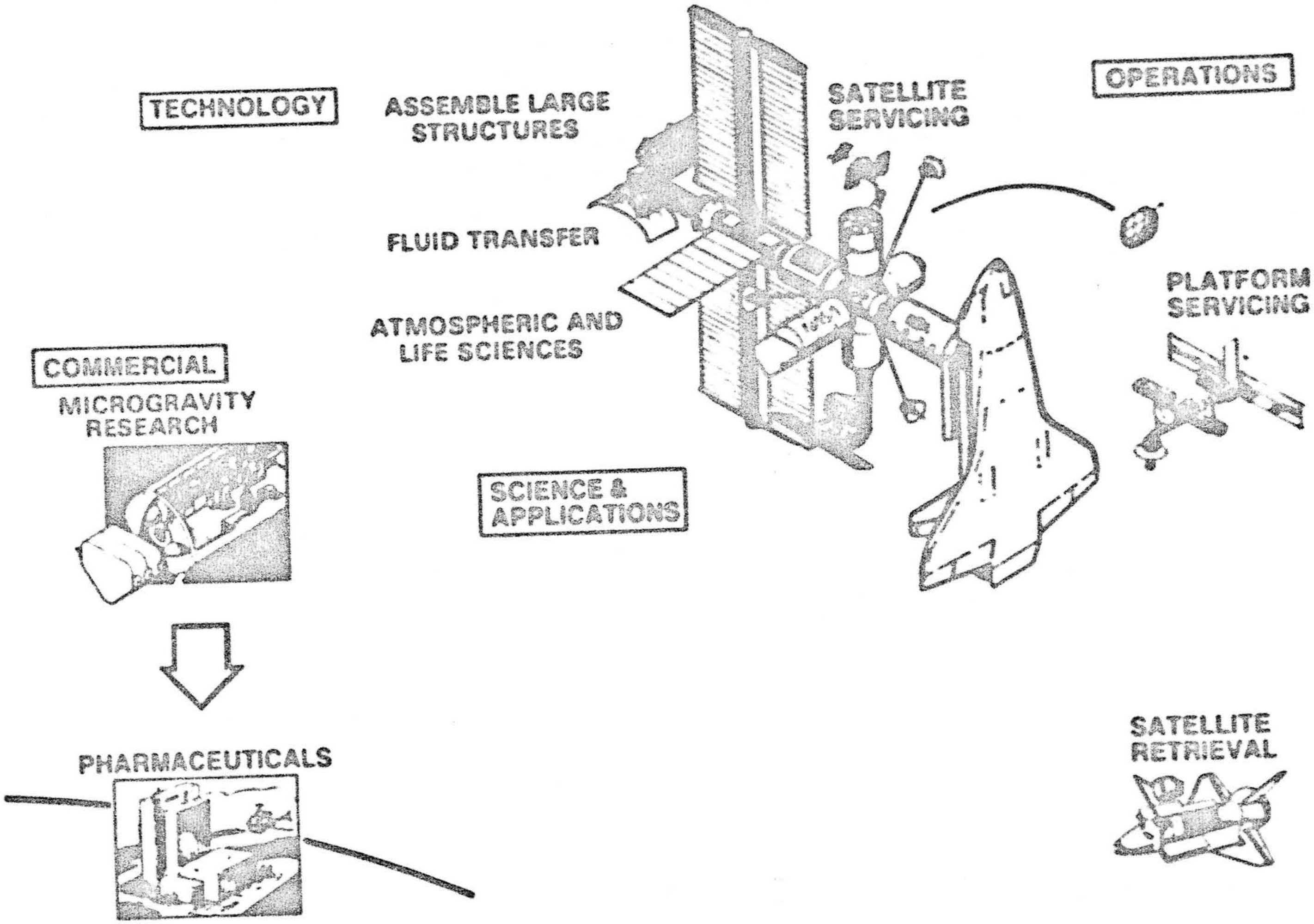
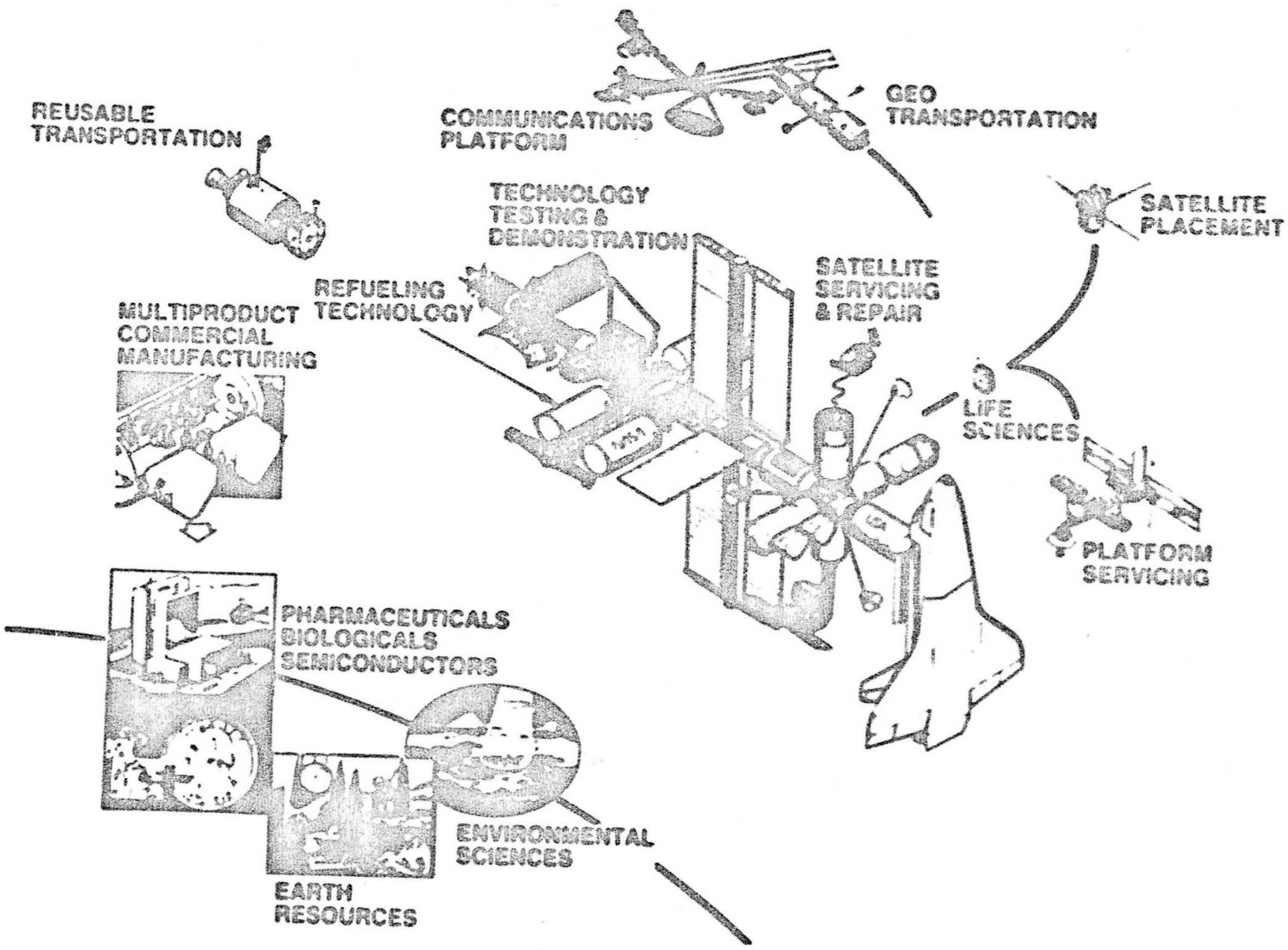


FIGURE 1-3 Initial space station.


REUSABLE TRANSPORTATION
COMMUNICATIONS PLATFORM
GEO TRANSPORTATION
TECHNOLOGY TESTING & DEMONSTRATION
SATELLITE PLACEMENT
REFUELING TECHNOLOGY
SATELLITE SERVICING & REPAIR
MULTIPRODUCT COMMERCIAL MANUFACTURING
LIFE SCIENCES
PLATFORM SERVICING
PHARMACEUTICALS
BIOLOGICALS
SEMICONDUCTORS
ENVIRONMENTAL SCIENCES
EARTH RESOURCES

ASEB INVOLVEMENT

In November 1982, NASA's Office of Aeronautics and Space Technology (OAST) initiated discussions with the Aeronautics and Space Engineering Board (ASEB) on space station technology program planning. At a meeting of the board in March 1983, various design and development questions were raised by OAST to which the ASEB responded. Following a general dialogue on the subject at a June 1983 ASEB meeting, NASA concluded that the overview process was of value and should continue. Of interest were the direction of the space station program and the technologies that needed to be developed. However, no action was taken on the matter at that time.

Committee Charge and Activity

Late in 1983, with the strong possibility that the space station would move from general study to design and hardware development, NASA, through OAST and its new Space Station Task Force, requested the ASEB to conduct a more thorough review of the program, concentrating on plans for engineering and technology development. In response the ASEB formed the Committee on Space Station Engineering and Technology Development, which was approved by the National Research Council on March 15, 1984.

The committee's major function was identified as the review of ongoing and planned NASA programs for research and technology development and of engineering approaches to the evolving program. The review was to consider

- -- technology for support of an initial station;
- -- an enhanced technology program that would support a more advanced space station;
- -- on-orbit maintenance;
- -- technology pertinent to the long-term evolution of the station; and
- -- the nature of research and technology development to be conducted in space and of related R&T facilities.*

Initially, the committee organized two panels, one concentrated on technical areas assigned to the Marshall Space Flight Center (MSFC) and associated NASA centers and the other assigned to the work of the Johnson Space Center (JSC) and associated NASA centers. Later, three other panels were formed to address the technology of solar thermodynamic electric power generation and program and management issues. The members of these panels are listed in Appendix B.

*Soon after the study was under way it became evident that it was premature to consider this subject in detail, thus the committee did not address the subject of in-space R&T.

The committee held three meetings and the panels held one meeting each. The first meeting of the committee was devoted to organization, the development of information, and a preliminary identification of issues. The second meeting was a review of panel findings and a preliminary identification of the committee's program findings. The final meeting was a workshop in which NASA provided the committee updated information on the status of selected developments in technology and the status and substance of NASA's space station definition and request for proposals on concept definition and preliminary design (Phase B). In addition, the committee discussed critical technical policy and management issues related to the program and developed the final working draft of this report.

Appendix C lists the subjects and NASA presenters for each of the meetings of the committee and its panels.

THIS REPORT

The findings of the committee, based on materials presented, and discussions held, are the subject of this report. The report is expected to be one of a series of studies requested by NASA for continued ASEB review of its space station engineering and technology development effort.

The committee conducted its study during a dynamic period. Many program matters were being resolved--organization and management, mission models, system descriptions and specifications, selection of preferred configurations, relations between NASA and industry, and preparation of the request for industry proposals for concept analysis and preliminary design. Both NASA and the ASEB understood this situation before the study was begun; the fluidity was considered an asset because it would allow time for the findings to affect program formulation.

Many key engineering and technology decisions are yet to be made. The committee believes that some of the issues reported here will be resolved in the normal course of program development; others may well require special action by NASA.

2

Current Program Plan

PLANS AND COSTS

The space station program, approved by the President and Congress for initial study, is estimated to cost some $8 billion for design, development, and flight of an initial station in the 1991-1992 time period. With growth and related infrastructure development, the program is projected to cost some $20 billion to the year 2000. Launch, support, and operational costs are not included in these estimates. In addition, the costs of payloads and their support requirements and the contribution of other countries being encouraged to take active roles in the program are not included.

The space station program is to pursue these objectives: a permanent manned presence on orbit, a manned capability for conducting science and studies of the earth's environment from orbit, utilization and commercialization of the space environment for research and technology and product development and production, enhancing space exploration capability, and providing growth capability for the station itself.

In pursuit of these objectives, the National Aeronautics and Space Administration (NASA) has identified and implemented generic and focused technology development programs in FY 1984. Extended plans are in development for FY 1985 and beyond. Studies of major station elements and components are under way. In addition, effort directed at Phase B (concept definition and preliminary design) was initiated with the release of the Phase B request for proposals (RFP) to industry in September 1984.

The RFP calls for a 9-month definition effort, starting in early 1985, followed by a 9-month preliminary design activity. The Phase C/D (final design, development, and production) effort is scheduled to start in 1987. Present plans call for a preliminary design review in 1988, a critical design review in 1989, and first flight of station elements in 1991. The initial operating configuration (IOC) would be assembled and in operation by 1992.

Funding for the study phase of the program is $150 million in FY 1985 and projected to be $280 million in FY 1986 and $250 million in FY 1987.

ORGANIZATIONAL ASSIGNMENTS

The NASA organization responsible for definition and implementation of the program consists of a Space Station Office at NASA Headquarters (Level A), a Space Station Program Office (Level B) at the NASA Johnson Space Center, and program support groups (Level C) at various NASA field centers. Level A is responsible for top-level policy, funding, and authorization activities, and Level B, for overall technical management of the program including systems engineering and integration (SE&I). There will be no industry prime contractor. Level B, the technical management office, will act as the prime contractor for the effort. This office will be described in more detail in the following section of the report. Level C activity, called work packages, is divided among the field centers, Figure 2-1, and is outlined in the following section, Program Development. The centers will be responsible for contracting for work in their assigned areas of responsibility and interface with and support the Level B and other Level C activity in their areas of technical specialty.

PROGRAM DEVELOPMENT

The conceptual design of the space station, at the time of this review, was being defined in-house, and NASA field centers program assignments had been made (Figure 2-1) and included:

Johnson Space Center (JSC): JSC's responsibilities include definition and design of the structure to which the elements of the space station will be attached and installation and integration of systems on the structure. JSC is also responsible for interfaces between the space station and the Shuttle and for station assembly, attitude control, thermal control, communications, data management, life support systems, and equipping of the habitability module for crew ward room and galley.

Marshall Space Flight Center (MSFC): Definition and design of common pressurized, inhabitable modules for laboratories, habitation, operations, and logistics is the responsibility of MSFC. The common modules will have provisions for data distribution, power, thermal control, and communications. Other responsibilities include onboard environmental control, the propulsive systems for the orbital maneuvering vehicle, and equipping of laboratory and logistic modules.

Lewis Research Center (LeRC): Definition and design of the electrical power generation, conditioning, and storage systems is LeRC's responsibility.

WP-01-MSFC	WP-02-JSC	WP-03-GSFC	WP-04-LeRC
• SE&I Support - ECLSS analysis - Logistics analysis - OMV/OTV interface analysis - Common module Commonality analysis - Propulsion analysis - Reboost analysis - Laboratory analysis	• SE&I Support - Growth analysis - Data management system analysis - Communications/tracking analysis - Loads analysis - Thermal analysis - Control analysis - Assembly sequence definition - STS proximity Operational berthing analysis - Crew interface analysis - Resource integration analysis	• SE&I Support - Platform configuration and commonality analysis - Platforms/satellites servicing analysis - Attached payloads analysis - Laboratory analysis - Station/platform interface analysis	• SE&I Support - Power system analysis
Hardware/Software • Common module - Structure - Distribution for: DMS Power ECLSS Thermal Communications • ECLS system • Propulsion system • Laboratory module outfitting (1) • Logistics module outfitting (2 or 3) • OMV/OTV accommodations • Applications software	Hardware/Software • Assembly structure - Truss - Module interconnect - Airlock - STS berthing - Power, Therm., Gimbals • Manipulators • Resources integration • Thermal control system • EVA system and airlock outfitting • Guidance, navigation and control system • Communications/tracking system • Data management system • Habitat module outfitting • STS interface • Applications software	Hardware/Software • Platforms • Attached payload accommodations • Platform and free-flyer servicing accommodations • Laboratory module outfitting (1) • Applications software	Hardware/Software • Power system - Generation - Conditioning - Storage • Applications software

NOTE: The upper portion depicts the supporting analysis work and the lower portion identifies actual end-item deliverables in Phase C/D. Both portions constitute a set of WP (work package) responsibilities for the Definition and Preliminary Design Phase.

FIGURE 2-1 Work package summary definition.

Goddard Space Flight Center (GSFC): GSFC is responsible for the definition and design of the automated free-flying platforms and the service, maintenance, and repair of these and other free-flying spacecraft. In addition, the definition and development of payloads to be attached internally and externally to the space station and the outfitting of pressurized modules for science and applications is to be handled by this center.

Kennedy Space Center (KSC): Definition and design in support of preflight and launch operations and logistic-support activities are KSC responsibilities.

JSC, MSFC, and LeRC responsibilities include the development of test beds to assist in the acceleration of major component and subsystem technology development and eventually for flight hardware design and development support and flight readiness testing. The actual flight system design, development, and test work will be carried out by contractors. Figure 2-2 identifies these test bed program assignments.

The Langley Research Center (LaRC) has been given the task of working with the JSC Space Station Program Office to help define the growth station and its advanced technology development requirements. Another LaRC assignment is to address and identify design features to be incorporated in the initial station to facilitate station growth.

REFERENCE CONFIGURATION

NASA has identified a reference space station configuration in its Phase B RFP. The reference configuration was arrived at through evaluations of such factors as: control, stabilization, operational flexibility, and ease of station erection. The candidate configurations, illustrated in Figure 2-3, were selected for detailed examination considering: IOC cost, maintainability, operations flexibility, user accommodation, growth, number of Shuttle launches, life-cycle costs, and complexity. As a result of analysis, the power tower, described in more detail in Appendix D, was selected as the Phase B IOC reference configuration with the following projected capabilities:

	IOC	Growth
-- Power to bus	75 kW	300 kW
-- Heat rejection	75 kW+	300 kW+
-- Balance/controllability (normal and degraded modes)	X	X
-- Simultaneous viewing of earth, space solar, and stellar payloads	X	X
-- Scientific airlock and windows with earth, solar, and stellar viewing	X	X

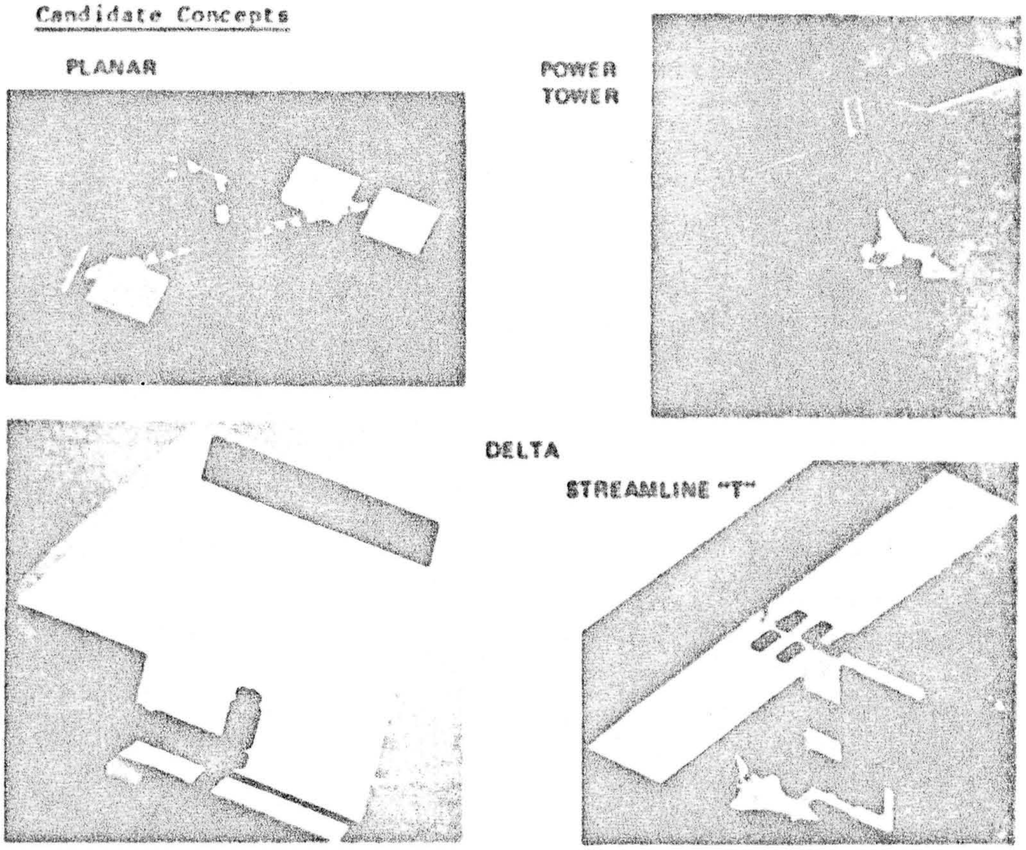
	IOC	Growth
-- Large structures construction and payloads/platforms servicing	X	X
-- Tethering of spacecraft	X	X
-- Orbital transfer vehicle basing	-	X
-- Growth elements	-	X
-- Polar platform (commonality with SS)	Abt. 10 kW	Abt. 20-25 kW
-- Co-orbiting platform (commonality with SS)	Abt. 10 kW	Abt. 20-25 kW

Test Bed System	Lead Center	Core Team	Support
Data management	JSC	ARC, GSFC, JPL KSC, LaRC, MSFC, NSTL	
Regenerative life support	MSFC	ARC, JSC	
Power	LeRC	JSC, MSFC	JPL
Thermal management	JSC	GSFC, LeRC, MSFC	
Attitude control and stabilization	JSC	MSFC, JPL	
Auxiliary propulsion	MSFC	JSC, LeRC, JPL	LaRC
Space operations, mechanisms	JSC	MSFC, LeRC, JPL	LaRC

JPL - Jet Propulsion Laboratory
ARC - Ames Research Center
NSTL - National Space Technology Laboratories

FIGURE 2-2 Test bed program assignments.

Candidate Concepts



Principal Characteristics

	Planar	Power Tower	Delta	Streamline T
Orientation				
• Earth-fixed		X		X
• Quasi-inertial			X	
• Both	X			
Solar Array Concept				
• Fixed			X	X
• Fixed, tiltable				X
• Gimbaled	X	X		
Structure				
• Module-to-module	X			
• Truss spine		X		
• Large area truss			X	X

FIGURE 2-3 Candidate concepts and their principal characteristics.

3

Program Status

To place the study findings in perspective, a brief overview of selected information provided to the ad hoc committee by National Aeronautics and Space Administration (NASA) program managers is presented here with committee commentary based on the presentation material (Appendix C) and committee deliberations. Addressed are technology development, user requirements, mission evolution, systems analyses, systems engineering and integration, contracting, and costs.

TECHNOLOGY DEVELOPMENT

The analytical work to date on such matters as structural configurations and dynamics, thermal control, and life support indicates that gross analytical tools are in hand, but refinement in some areas is required for higher confidence in the analyses.

Space station electric power generation studies have addressed solar photovoltaic, energy storage, solar thermodynamic, and nuclear electric power generation systems and system trades. Initial studies show solar thermodynamic (Rankine, Brayton, or Stirling) followed by solar modular (GaAs concentrating) systems to be more promising than conventional photovoltaic systems for the initial operating configuration (IOC), but particularly for the growth station. The solar thermodynamic system is of special interest because of significant reductions in projected area and obscuration, direct generation of alternating current, and more efficient operation. However, until recently NASA's program managers did not support aggressive technology development due to the assessed technical development schedule risks for IOC. Nuclear (static thermionic) systems could be of interest in the long term, but environmental and political issues constrain serious consideration for the station. However, the Department of Defense and NASA are pursuing technical development of nuclear systems for space power generation, albeit of too large a size.

It is reasonably certain that hard docking will be avoided. Berthing (soft docking) concepts have not been examined in detail but will be used. Model tests will develop an appreciation for design and operational problems and help identify docking hardware commonality between operating elements of the station.

Automation and autonomy will be used to augment crew capability through an appropriate balance between the crew's higher order skills and automation. The level of autonomy for IOC is not expected to be great but will build up with time.

The present mission model calls for a large amount of fluid transfer and handling from the ground to the station and the station to free-flying orbital transfer vehicles. Fluid transfer mechanization, measurement, contamination avoidance, and safety are important technical developments. A space flight experiment on the Shuttle to study these problems is planned for the 1988-1989 time period. The data come late for initiation of the hardware development program, but are phased to support the orbital transfer vehicles. Funding has constrained the schedule, which is now difficult to accelerate.

Thermal control technology development for two phase heat pipes has progressed far enough to allow this type of heat rejection system to be developed for the IOC. Shuttle flight experiments will be run to validate the concept in the 1985 to 1988 time period.

First and second generation life support system developments can be scaled to the size required for the space station. A test bed program, operated concurrently with Phase B work, will provide design data for the Phase C/D (final design/construction and operations) effort. The life support area does not present difficult issues. However, significant reductions in fluid supply and crew support for filtration system maintenance can be realized through partial closing of fluid and gas loops and automating subsystem management.

Space suit problems are: ease of initiation and termination of extra vehicular activity; closing the life support system to reduce external contamination; improvement of hand manipulation; and operational flexibility including onboard maintenance, repair, and resupply. This later requirement is new and important from logistics and resupply considerations.

Human productivity contributes to the effectiveness of the kinds of missions and lengths of stay time (90 days) planned for the space station. Studies considering the complete spectrum of anticipated crew activity--internal and external vehicular activity, machine interface, food, habitation, and support--are included in the technology program. Special attention must be given to medical and psychological factors.

Guidelines, standards, and requirements for crew-machine integration exist. However, they need to be upgraded for the space station. Plans call for this to be accomplished in FY 1985, in time to support

Phase B definition and design effort. A related test bed activity will support guideline and hardware development and crew training.

There are no significant technological constraints in the areas of life support, habitation, and human relations that cannot be satisfied with technology development.

Data management system studies are under way within NASA and at contractors. The major technology issues relate to integration, verification, and fault tolerance capability, as well as station maintainability and servicability. It is estimated that there will be about a 26 megabit capacity in the data system. Half of the capacity will be used for management functions and the other half for application functions. There are no technical show stoppers in this area. However, technology advances can provide improvements in data system performance, speed, and operational flexibility. A set of system design guidelines would assist in the focusing of new developments.

A distributed data system with common/standard interface units is planned to handle the complex data flow on the space station for management of operational as well as user data. These units will allow the distributed, special function units to communicate and independently display data. Special function units will be used to handle commands and pass through data to control stations.

The concept is to provide common services to all elements of the space station. Each data generator will have its own (distributed) system and software that ties into the data distribution system.

NASA plans to procure major system software elements from vendors and perform the systems software integration task in-house.

A test bed is considered critical to the development, operational support, and training associated with the data management system and is being developed by NASA.

Most of the communication system requirements identified are essentially within the state-of-the-art. Proposed technology development work reflects far-out needs. The committee does not consider the work to be of immediate value to the station.

USER REQUIREMENTS

Space station missions have been under study for several years. Some missions represent active (funded) programs, others just concepts. These mission studies have been used to scope space station operation and support requirements.

The mission requirements thus obtained are known to be overstated, but are used by NASA to allow for accommodation of future international and commercial payloads.

By late summer of 1984, some 111 missions and 158 unique support parameters had been identified, i.e., power (levels and duration), weight, volume, and support services. These data allowed development of operational and functional scenarios and related station and crew support requirements. However, the missions identified are not approved by NASA or the user community.

Because the missions (payloads) contain unknowns, the philosophy followed is to design for general accommodation, not specific payload requirements. Insight into payload requirements is provided through extensive contract activity and contacts between NASA and user groups. The Langley Research Center has the task of developing and maintaining the mission model and integrating and defining payload accommodation and support requirements. The NASA Office of Space Sciences and Applications has also mounted a special advisory effort to explicitly identify missions and support requirements in the sciences and applications areas.

MISSION EVOLUTION

The Langley Research Center updates the mission model every few months. The model consists of individual payloads grouped into mission sets by common support and service requirements, i.e., space, weight, time, extra vehicular activity (EVA), power, and other support requirements and integrates them to represent reasonable, achievable operational capability. The model had not been expanded to include international and commercial missions at the time of this review.

Studies to develop the definition of laboratory modules for life science, materials, and research and technology development (R&T) activity in space are planned. Although most of the projected space R&T work has been generated within NASA and reflects university and industry interests, there are efforts ongoing to improve the R&T model.

The space station program operating/growth scenario is projected to be: IOC, the addition of international payloads, the addition of commercial payloads, then growth in capability and services. The initial foreign involvement in the space station is assessed to be in the period between the IOC in 1992 and the year 2000.

SYSTEMS ANALYSES AND DESIGN

The general rule is that technology for the IOC be ready for full-scale development by 1987 to ensure that the technology selected for Phase C/D will be qualified for an operational 1991-1992 station. The critical technologies have been identified through NASA-supported mission, system, and subsystem studies. However, a firm set of system specifications is still to be defined and technology development activity coalesced and focused.

Because of the early state of definition of missions, current space station program and technology development plans represent best estimates, not plans based on firm system specifications. The Space Station Program Office (SSPO), with the Phase C participants, has the responsibility for developing these mission plans and system specifications.

The prime structure for the space station is projected to be aluminum. NASA stated that little composite material will be needed because the Shuttle, with respect to space station payloads, is volume not weight limited. In addition, aluminum is better understood and less expensive than composites, although composites are stiffer, lighter weight, and have lower coefficients of expansion. Composites may have their major use in secondary and erectable/extendable structures and can be expected to be used for structural members of the large modules.

A major design consideration is on-orbit maintenance, both scheduled and unscheduled. It is proposed to design for minimum disruption of noncritical functions and no disruption of critical functions.

Contracted studies address not only station design but such matters as the servicing of satellites, construction of large structures, and the design of orbital maneuvering vehicles and orbital transfer vehicles. Technology issues and development needs will be identified in these contracted studies as well as in the Phase B contracts.

An SSPO objective is to define, specify, and integrate all system requirements as completely as possible. In this regard, NASA is taking on more responsibility than it has in past programs. NASA itself will be the systems integrator and manager. The job is a large one requiring levels of activity, skills, and people that NASA may find difficult to assemble in-house without significant industrial assistance.

SYSTEMS ENGINEERING AND INTEGRATION

As noted earlier, the Space Station Task Force that managed the definition and request for proposal effort has been replaced with a permanent Space Station Office (SSO) at NASA Headquarters, directed by an Associate Administrator. SSO reports to the Administrator of NASA and has Level A program responsibility (e.g., policy, plans, budgets, and administration and congressional interfaces). Level B program responsibility rests with the newly formed Space Station Program Office (SSPO) located at the Johnson Space Center. This office, supported by a number of special offices, includes a Systems Engineering and Integration (SE&I) office. The SSPO and SE&I organizations are shown in Figures 3-1 and 3-2.

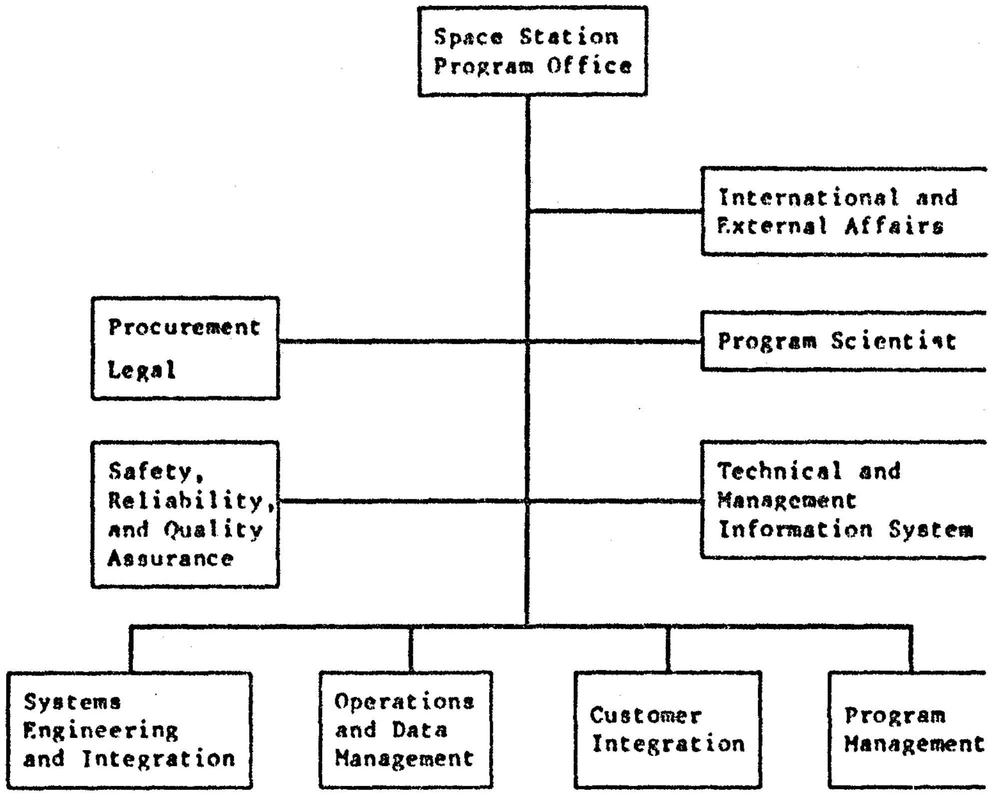


FIGURE 3-1 Space Station Program Office, JSC--Level B.

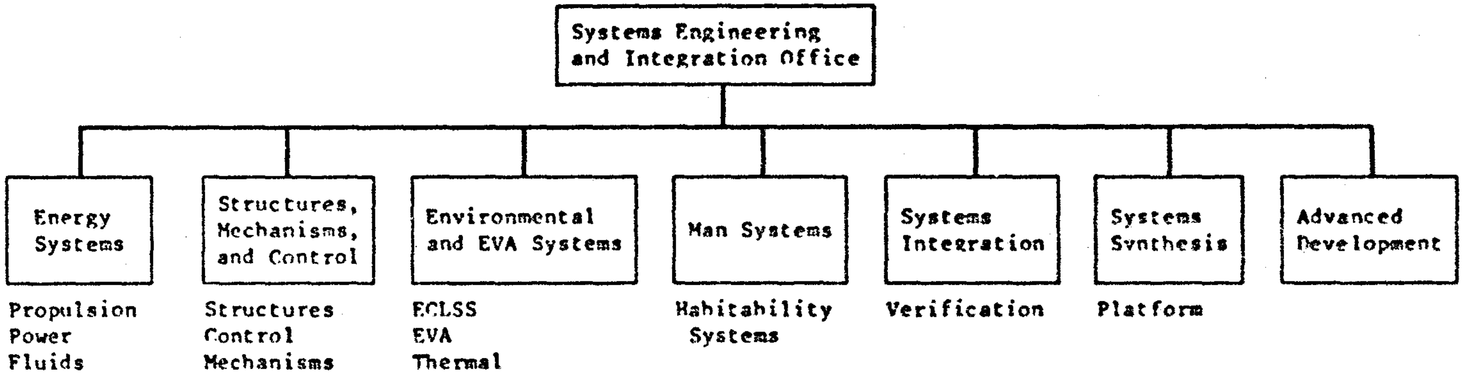


FIGURE 3-2 Systems Engineering and Integration Office, SSPO.

A NASA program directors group, the Management Council, has been established to advise SSO. The Management Council consists of Level A and B program directors and the directors of the NASA field centers involved in the space station program. The Level C program directors, at the field centers, report to SSPO but are also responsible to their field center directors.

SSPO will integrate and control all program technical activity. Systems engineering will be the responsibility of Level B supported by Level C centers and their contractors.

Configuration control boards will control Levels B and C change activity at appropriate A, B, and C program levels.

The program is developing a broad base of new technology and maturing selected technologies through an advanced development program. Final substantiation of the newly developed technologies will be made early in the Phase C design effort.

Program plans down through Level C hardware are being developed to provide an early assessment of schedule and costs. Early cost projections are high. Cost reduction targets will be identified through in-house studies of costs for hardware design, development, and testing and through support contractor work that will project program plans and cost estimates.

CONTRACTING

The 18-month Phase B contracts, to be let by the Level C centers, have two parts. Within the first 9 months, decisions on baseline systems and subsystems will be made. The final 9-month effort will focus on preliminary design and technology development in preparation for the definition of the in-house and contracted Phase C/D final design, development, construction, test, and operational activity.

The Phase B contractors will work with NASA on the development and application of the technology development (software and hardware) test beds. Additional NASA-sponsored studies, notably data management and life support studies, support the test bed program.

The methods for exchange of information between contractors has not been identified. The general view is to keep the data within NASA, with NASA "mixing and matching" Phase B and other contract results and distributing the data as considered appropriate.

NASA, though generally aware of pertinent Department of Defense technology, has not actively integrated these data into NASA's program.

COSTS

There is not yet a good cost analysis tied to specific configurations and capabilities. Gross costs estimates for space station system hardware represent one-fourth of the cost of the IOC. Other major estimated costs relate to system integration and support.

Cost sensitivity analyses show that it is difficult to reduce space station costs without major changes in program capability or changing NASA's approach to development and flight qualification. Reducing capability may not result in large cost savings. The full cost of the space station program through the year 2000 has not been identified. The estimates of $8 billion for IOC and $20 billion through the year 2000 are for design and development of the system and do not cover launch costs, operations, program support, or payload costs.

NASA has concluded that protoflighting (flying development test hardware) will reduce program costs in the order of $1.8 billion for flight hardware procurement and testing. Care will be needed to assure that the hardware used for flight is appropriately qualified and does not require replacement in test beds for the solving of flight problems or for further system development work.

Free-flying platform system requirements have not been resolved. Platform cost analyses have progressed but are not fully developed. It is assumed that platform costs can be reduced through the use of common station systems and subsystems. However, this may not be possible due to requirement differences.

If the Europeans, Japanese, or others join the program, their investment is independent of the U.S. investment. The U.S. program plan is such that there will be an operational space station even if there is no foreign involvement.

One complete analysis of costs had been made at the time of this study and was being examined to identify major cost factors and ways to reduce costs. Cost reduction actions have been identified and estimates made of associated cost savings that need careful attention if the $8 billion limit for IOC is to be realized.

4

Program Issues

The committee, in its review of the engineering and technology development program for the space station, identified broad technical and policy factors that warrant National Aeronautics and Space Administration (NASA) program management consideration. These issues, related to technical, policy, and management factors, are described in this section of the report. Recommendations for NASA consideration are included.

TECHNICAL FACTORS

The committee examined technology issues considered critical to the development of the initial operating configuration (IOC) and the growth station. Discussed here are technical matters related to: electric power, control and stabilization, environmental control and life support, onboard propulsion and fluids, communications and tracking, extra vehicular activity, human productivity, mission operations and station autonomy, space operations, maintenance, automation and on-orbit operations, onboard test instrumentation, biological contamination, structures, materials, mechanisms, and thermal control.

Electric Power

A key element of the space station is its electric power generating system. Early designs specified photovoltaic arrays and a storage system of batteries or fuel cells. However, the initial requirement for 75 kW will grow as the station evolves. The level of electric power for station growth may approach 300 to 400 kW.

NASA space station studies have addressed electric energy storage and electric power generation through solar photovoltaic, solar thermodynamic, and nuclear systems. These studies show that solar modular-photovoltaic (GaAs concentrating) systems are better than solar photovoltaic but that solar thermodynamic (Brayton, Rankine, and Stirling) systems are more promising for station application, especially for the long term.

The solar thermodynamic systems are most promising due to high system efficiencies; reduced projected area; reduced obscuration of lines of sight; and simplified power distribution, control, and storage compared with the photovoltaic systems. However, the need for research and technology development and the lack of flight experience create schedule and program cost risks for IOC application. Therefore, it would not be prudent to base the IOC design totally on their use. Fortunately, this decision does not have to be made until 1987, the date for Phase C design decisions.

To maximize the probability of meeting current IOC cost and schedule commitments, NASA proposed to be conservative and to use the solar photovoltaic system for IOC.

The ad hoc committee's panel that reviewed NASA's solar thermodynamic program in August 1984 found that for solar thermodynamic systems required technical developments are not high risk if advanced development is funded now. The most difficult problem relates to the solar energy receivers. There is a reasonable probability that the technology could be developed and applied with little impact on the IOC date. Because of this potential, NASA has identified $18 million to support technology development for solar thermodynamic systems.

To help resolve the issue of power system selection, NASA should quantify the risks for the competitive systems (photovoltaic versus solar thermodynamic). This selection process, in part, will require mission studies to address how the systems are assembled, used, and maintained; how they fail; how failures are identified; and how the systems are repaired. One factor of possible concern, not explored by NASA, is the level and effects the gyroscopic forces and vibration, generated by such systems, on space station control and pointing precision. This issue may require space flight experiments to provide operational design data if structural response characteristics cannot be determined accurately enough before flight.

Mission planning indicates that the space station will need additional power within a few years after initial operation. The development of a road map for upgrading the power system from 75 kW, along with the related work on thermal control, is an essential part of a successful overall program. In addition to development of a solar thermodynamic system for the IOC, the road map should address transition from solar photovoltaic to solar thermodynamic systems. Without early analyses and appropriate technology development commitment, it is not believed that transition will occur with proper time phasing and minimum cost impact.

The committee recommends that:

- NASA continue vigorous solar thermodynamic system technology development and lay out a road map for changeover and/or initial application of such a system as part of the IOC design and development effort. The agency should proceed to narrow its electric power generating system options through technology development, design, hardware test, and trade-off analyses, and, as quickly as possible, focus final design/development to reduce risks and costs.

If the solar thermodynamic system is not ready for IOC, some components such as the power system support truss and the central power tower should be designed to accommodate transition, including the addition of an alternating current power distribution and control system and other required changes.

Although nuclear power was not discussed by the committee, concern was expressed over the fact that the subject was not under active review. Safety is a serious consideration, but the potential benefits appear great enough (i.e., space requirements, logistics, reliability, power levels) to warrant a comprehensive assessment, especially for the growth station. A decision on the long-term course of action could follow.

Control and Stabilization

The technology applied to control and stabilization and orbit maintenance of the space station rests on several decades of technology development and continued NASA effort on theoretical development. Design work shows that the size and flexibility of the current space station concept dictates the need for further technical advances to satisfy system performance and reliability. Of particular interest are automated control and stabilization techniques for application to practical station arrangements including sensors to be used in angular orientation and structural deformation and motion control systems.

Obviously, the control system for the IOC should be designed to account for the changing configuration of the space station, a large flexible structure whose mass, mass distribution, and moment characteristics will vary with time. Control concepts and analytical tools, sensors and actuators, and computer hardware and software are needed for designing and developing control systems. It is reasonably clear that the control and damping (active and passive) systems should be based on adaptive concepts, both discrete and distributed depending on the dynamic modes to be controlled.

In preliminary control and stabilization analysis, the space station structure was assumed to be relatively stiff. There is little question that this class of analysis will not be adequate for system design, and there is no way to test the full system prior to assembly on orbit. It would be prudent to have the control and stabilization technology developed sufficiently to allow a design that has a range of dynamic responses that can accommodate the probable range of station structural flexibility.

Several levels of structural representation are desirable. A first-order analysis is needed to provide physical insight into vibration modes without getting involved in large computer programs. For example, the DISCOS (a modeling tool of large capacity) developed by NASA's Goddard Space Flight Center is currently not practical for design purposes because of the excessive computing time required and the questionable value of analytical results due to input uncertainties.

Development of on-orbit sensing of structural static deflections and dynamic motions and the possibility of rewriting control laws based on identification of modes in orbit was discussed. The changing of codes in orbit can be a high-risk action for a manned system. The approach that should be taken is to design the software and control system with sufficient control-algorithm flexibility to cover the range of expected parameters. This flexibility should be such that required control system changes reside in the onboard data base.

Control and stabilization during the initial construction phase of the station presents unique challenges. The full sensor and actuator complements will not be in place. The initial configuration may not have the benefit of gravity gradient stabilization. These conditions need to be factored into the design.

Recent technology program reviews indicated that support for control and stabilization work was to be reduced. It appears to the committee that this may increase IOC risk.

The committee recommends that:

- NASA mature the technology required for the control and stabilization of large flexible space station systems with changing inertia and moment properties.

and that:

- NASA restore funds to the technology development program for work on active control and stabilization of large, flexible systems with distributed sensors and controls.

Environmental Control and Life Support

There is considerable technology background in the life support area at the NASA Johnson Space and Ames Research Centers and in industry. Life support systems incorporating recovery of water and oxygen have been tested in bread-board configurations. Some subsystems are in their third or fourth generation of technology development.

Design factors relating to life support system consumables are well known. One person can consume about 15,000 pounds of water per year for drinking, cooking, washing, and hygiene. About 85 percent of the water is used for washing and hygiene. To reduce resupply, some closure of the water system and some reclamation of oxygen from water or carbon dioxide is very desirable.

Water recovery for drinking purposes is straightforward if the water is recovered from vapor in the atmosphere. Reclamation of wash water for general reuse is relatively simple, but producing potable water (for drinking and cooking) from reclaimed wash water or urine requires further development.

Both distillation and filtration of wash water appear feasible and should be pursued as a first-order priority to satisfy stringent needs (8 pounds/day of water for drinking and food preparation; 41 pounds/day for hygiene and clothes washing).

The recovery of drinking water from the cabin air or as a by-product of metabolic oxygen recovery is also important. Implementation can be delayed somewhat beyond IOC. The water recovery system must be designed in a manner to allow the acceptance of water from multiple sources. The technology is evolving. The current technology for obtaining water as noted above and from fuel cell by-products is moving to filtration and distillation and eventually will go to integration with closed systems for reduction of carbon dioxide to produce oxygen.

Systems that collect, concentrate, and reduce carbon dioxide have been developed and tested. Collected and concentrated carbon dioxide can be used as propellant for attitude control systems. One key advantage of such systems would be a reduction of the crew-intensive task of changing lithium hydroxide carbon dioxide scrubbers and their attendant resupply.

The first-priority environmental control and life support system elements that require further study prior to choices for the station are: the Sabatier and Bosch reduction processes for water purification; solid polymer and static feed electrolysis techniques for oxygen generation; and the molecular sieve, solid amine water desorption and the electrochemical depolarized cell as alternatives to lithium hydroxide desorption canisters for concentrating cabin atmosphere carbon dioxide.

The strategy should be to move from an initial open system to a partly closed system with carbon dioxide removal and multifiltration of wash water and condensate. The follow-on closed system would include oxygen generation and would recycle urine and flush water with the removal of ammonia.*

*J. B. Hall, S. J. Pickett, and K. H. Sage, "Manned Space Station Environmental Control and Life Support System Computer-Aided Technology Assessment Program," SAE technical paper #840957, 1984.

Microbial contamination is an area of increasing concern as life support system closure increases. Work is needed on the measurement and control of trace and microbial contamination in closed systems. Biological contamination is discussed later.

Test bed facilities for environmental control and life support systems are planned and well integrated between the Johnson and Ames centers. Test beds will support Phase B activity and test data should be available to support final space station design and development work. These test beds will help resolve the environmental control and life support system problems addressed here.

For the IOC, the primary need in the environmental control and life support systems area appears to be early decisions on the degree of closure for the water and oxygen systems. More attention must be given to emergency conditions and operations; for example, if a problem occurs during a crew change with double staffing aboard, the life support system must be able to accommodate the increased load until relief is provided.

Funding for the environmental control and life support system program appears to be adequate, but the program needs to be examined to assure adequate coverage of the matters addressed.

Onboard Propulsion and Fluids

Based on actions taken to limit funding for technology development related to propulsion and fluids, NASA has made the decision to utilize state-of-the-art technology for the IOC, i.e., storable propellant (hydrazine) reaction controls or resistojets for space station control. These systems will provide adequate performance. But, some tasks may require more control propellant than reasonable hydrazine systems can provide. It would be prudent to consider bipropellants. Hydrogen and oxygen could be generated in gaseous form from water for these small thrusters. This would provide commonality and improved performance at the expense of power.

Advanced development efforts will focus on propulsion system component life, where a design goal of 10,000 hours (burn-time) has been set. To date, demonstrations of component life fall far short (one or two orders of magnitude) of this goal.

Because life is more important than performance, trade studies should determine the sensitivity of propulsion unit life to reductions in specific impulse and chamber temperature and pressure. Advanced development work on resistojets should focus on propellant selection and system durability.

Several propulsion-related issues deserve attention in the development program: contamination, maintenance, safety, and resupply of consumables. Effluents from the Shuttle control system degrade viewing for instruments, although it is not clear how serious or pervasive this problem is. Effort to assess contamination potentials should be undertaken so that, if required, program adjustments can be made.

Even if the 10,000-hour burn-time component life goal is achieved, it will be necessary to allow for inspection, maintenance, and replacement of propulsion system components. Attention should be given to accommodating these needs in the design of the attitude control and stabilization systems.

Component life and operational tests should provide information for safety-related procedures, inspection, and maintenance. Examination of broader system safety issues is imperative.

The committee was informed that advanced development dealing with fluid management of cryogenic fluids has been deferred. This raises two questions. First: Is the generic technology program sufficient to provide technology options for high specific impulse propulsion and cryogenic fluid management for space station growth? Second: What impact does curtailment of this technology development have on the design development and operation of orbiting maneuvering vehicles (OMV) and orbiting transfer vehicles (OTV)? Initially, the OMV, part of the IOC system, will use hydrazine as a propellant. An OMV burning hydrazine heightens concern over contamination. The OTV, a separate and later development, may very well require cryogenic hydrogen and oxygen.

For the reference space station, the OMV is serviced in the vicinity of the radiator array. The matter of radiator contamination should be examined, since radiator coating materials can be adversely affected by contamination. Furthermore, the selection of hydrazine to fuel the OMV raises questions of handling and transfer of a toxic substance. These questions were not being addressed in the technology development program.

Use of cryogenic hydrogen and oxygen for propulsion in the IOC configuration (including the OMV) could have several significant advantages, but requires technology development related to long-term cryogenic storage and maintenance of propellants free from contaminants. Hydrogen/oxygen systems can eliminate the need to store and handle toxic and highly corrosive materials, can eliminate a potential contaminant source, and can greatly simplify the consumable resupply problem (with significant long-term cost advantages). But, long-term storage of cryogenics, as noted, is a serious problem. Since it is almost certain that the OTV will use cryogenic hydrogen and oxygen for its propellant, management and storage of large quantities of cryogenic fluid will be required on the station in the event the OTV operates from the station. Thus, it may be prudent to consider the appropriate technology development and use of cryogenic hydrogen and oxygen for propulsion on the IOC and OMV, perhaps even at the expense of deferral of the IOC date.

The ad hoc committee recommends that:

- NASA review its position and technology programs related to cryogenic fluid management and utilization in the space station with a view to its early application.

Communications and Tracking

The review of the projected communication and tracking technology programs for the space station in May 1984 concluded that the programs were embarking on advanced developments that were not required for the space station. A near-term system definition study is needed to determine what, if any, technology development needs exist.

The committee believes that essentially all the elements of the system have been developed elsewhere. At most, some selective component repackaging may be required, and there may be areas in need of selective technology development.

Some of the proposed tasks illustrate the committee's concern about technology development program overkill:

-- A near-field test facility was proposed for the Johnson Space Center. A good far-field range 2500 feet long is available at Johnson, and the Lewis Research Center has a near-field facility. These would be sufficient to test a 10-foot-diameter antenna at 12 GHz, providing a 0.6° beam and 49-dB gain, about as narrow a beam as one would use on a space station. As an alternative, at 60 GHz, a 0.6° beam would require an antenna 2 feet in diameter, and a range length of only 480 feet for testing.

-- Work was proposed on improved solid state and laser devices, but no evidence was presented that such improvements are needed for IOC or the growth station in the near term.

-- Work was proposed on a system to automatically identify nearby satellites by comparing video images with a library of possible shapes. It would seem far simpler to use an audible alarm, triggered by any vehicle coming within a preselected radar range and depend on the crew to visually identify the vehicle.

The committee believes that in areas such as communications, for which adequate solutions are available using existing technology, state-of-the-art approaches should be used to the greatest extent possible. It is essential that the space station system be defined at an early date to assist in this selection process so that any required developments in communications and tracking can be identified and proceed.

Extra Vehicular Activity

Space suit problems revolve around eliminating or reducing the need for prebreathing prior to extra vehicular activity (EVA), ease of donning and removing the suit, reducing maintenance and refurbishment, closing the life support system to reduce contamination from leakage and vapor exhaust, improved hand manipulation, and operational flexibility.

Bends can occur if air pressure is reduced by 50 percent (or less on occasion) without prebreathing of an oxygen-enriched atmosphere. Thus, a suit at an operating pressure of 8 pounds per square inch (psi) is required to eliminate prebreathing for a wearer coming from a standard atmosphere of 14.7 psi.

A program is in place to develop an 8-psi suit. This program, initiated to develop a new suit for the Shuttle, is now considered part of the space station effort. The technology status for development of suit components and alternates is good.

Astronaut work required to bend suit joints can be reduced by the application of constant volume joints. The most troublesome element of the suit is the glove. Glove improvement, end effector, and power tool studies are warranted.

In the suit program, extended range and duration, universal fit, and lower cost are of special value. In the longer term, it is desirable to have plug-in support subsystems for ease of onboard servicing, maintenance, and component replacement.

A flexible, routine EVA capability will be important for IOC assembly and operation. Thus, a no-prebreathing, 8-psi suit with improved gloves and/or end effectors are important developments for the program. NASA needs to assure aggressive development of this technology.

Human Productivity

Human productivity in space is affected by such factors as: food, clothing, habitability, hygiene, medical support, and man-machine operational interfaces. Background is available from studies and operational experiences in polar exploration, submarines, and, to a degree, long-duration aircraft flights. However, it is difficult for space station designers and architects to accept current habitability specifications for design.

The Ames Research Center has organized an activity to focus on space station human factors. It will draw on aviation technology with attention to crew-machine interface, operations, and training. The Johnson

Space Center is pursuing issues of food, recreation, and privacy, important for long-duration, isolated missions.

A human productivity test bed is under development that will be used for hardware design and development, and crew training. Examination of such matters as food, personal hygiene, and habitat design, as well as long-duration closed environment, will be possible. This work is important.

The existing guidelines, standards, and requirements for crew-machine integration should be upgraded and made applicable to the space :ation. Plans call for this to be accomplished in FY 1985, in tis to support Phase B design activity.

For long-term manned flights, continuing medical problems include cardiovascular deconditioning, calcium loss, and closed environment microbial contamination.

Funding for FY 1985 has been reduced, but the generic programs are believed to be adequate until development requirements become more focused. It is expected that technology development effort will need to increase to support the design of future systems.

Mission Operations and Station Autonomy

The committee believes that the space station architecture should be configured to allow early transfer of ground-based mission command and control center functions to the space station. This should, as is planned, be part of the system design. The committee believes that early evolution to an almost autonomous station (if related studies support this position) will reduce the need for, and high cost of, ground-based mission command and control center operation. This capability should be developed consistent with the overall philosophy of automated diagnostics in support of station and experiment operation, service, and maintenance. The development of this onboard capability will, in the opinion of the committee, in the long term allow quicker decisions and action and reduce operational costs.

Situations could develop where ground support is needed. Thus, some minimal capability to support emergency situations may be a requirement. Examination of this matter should be part of the Phase B study program.

The requirement for achieving space station autonomy will be bound up in the nature of the design of the mission control center onboard the space station. This center will essentially replace the ground-based mission control center. Specification of the operational philosophy and architecture of the spaceborne mission control center is a pacing item for the IOC. An extensive effort will be required to introduce the elements of system compaction and automation to achieve this objective. As has been stated, it is believed that program costs can be reduced by a reduction of ground-support activity and an increase in in-space autonomy. Thus, this design feature is of great importance.

The committee recommends that:

- NASA act to assess and have the mission control functions, to the degree practical, carried out onboard the space station for IOC including having repetitive, well-understood mission control functions automated.

Part of this autonomy issue involves EVA. For EVA, the development of a high-pressure (8-psi) space suit with ease of hand manipulation is essential to exercising the manned activities contemplated.

To support on-orbit operations, a series of specific instruments and mechanisms must be developed. These include attitude sensors, sensors for precise relative positioning (both center of mass and orientation) to support rendezvous, activators for attitude control, docking and berthing, and near-space-station traffic control.

In general, these problems are understood by NASA and effort is under way to provide technology options. However, at present options have not been prioritized due to the need to resolve conceptual design questions.

Space Operations

A major decision relates to whether the space structures will be erectable (assembled) or deployable (extendable). The construction philosophy will influence technology development in support of structural subsystems, EVA requirements, and maintenance and repair of components.

Consideration should be given to the impact that crew safety will have on the overall station design. EVA trade-off analyses need to evaluate the use of automation to reduce extended periods of EVA.

The space station construction phase will present a higher-risk environment than the operational phase. Acceptable levels of risk should be defined. The Phase B contractors will address the broad issue of crew safety, including onboard resupply, EVA service, and crew operations. These need to be compared with guidelines that NASA defines.

The area of on-orbit operations includes satellite servicing, maintenance, rendezvous, and berthing. The original on-orbit assembly of the space station and other large space structures will require such capabilities, which in turn demand advances in engineering design and in supporting technology.

An on-orbit operations philosophy must consider such questions as the kinds of satellite servicing and repair to be provided, i.e., will it be a "shirt sleeve" or a vacuum environment? The specification of the operating environment impacts other developments: space suits, service shelter modules, and supporting equipments. The level at which satellites will be repaired--module, card, or component--will also have an impact on the design of the satellites themselves.

The committee recommends that:

- NASA specify early the operational mode(s) of on-orbit servicing and maintenance to assist in definition and design choices for on-orbit services.

Program documentation does not indicate that EVA safety has been given adequate consideration. Questions relate to the rescue of astronauts in the event of the malfunction of an operational support unit and equipment contamination associated with the spillage of hydrazine fuel or station effluents.

The committee recommends that:

- NASA define at an early date EVA operational procedures and safety requirements specifying performance bounds and design constraints.

Maintenance

The maintenance philosophy and the design of structures, critical systems, and subsystems should be based on the assumptions that: the space station will be a permanent evolutionary system, crew time will be critical, and systems will be fail safe (long life systems where failures result in switching to operational components) rather than have a safe life (very low probability of failure and scheduled change out of systems within a designated time period).

Based on these assumptions, the committee recommends that NASA integrate and state the following logic in the space station design/operations maintenance philosophy:

-- Establish ease of maintenance as a design review criterion.
-- Adopt condition maintenance rather than periodic replacement of components.
-- Establish maximum levels of acceptable system degradation to be tolerated without corrective maintenance.
-- Maximize the number of maintenance tasks that can be accomplished in a shirt-sleeve environment as opposed to EVA.
-- Match the definition of replaceable units to diagnostic capability. Consider smaller replaceable units as onboard diagnostic capability develops with time.

-- Trade the use of redundancy against design complexity and logistic costs to minimize costs considering such matters as down time, aborts, and Shuttle flights. Consider redundancy management techniques that provide multiple redundancy at the card level in avionic systems.
-- Design the space station to accommodate gradual introduction of artificial intelligence for use in diagnosing system malfunctions.
-- Develop clear guidelines for replaceable elements, i.e., functions, sealed (perhaps), and minimum number of connectors/connections.

Automation

Congress has suggested that NASA take a lead role in the developmen of a national automation technology development effort. The committee believes that NASA should take such a lead role in the areas of automation that are particularly important to space station development. While the space-station-oriented work will not satisfy all national interests in the area of automation, the committee believes that NASA, while concentrating on its space station task, will be supporting the development of new technology pertinent to the broad subject of automation. Thus, NASA will make a major contribution to the national interest in the execution of their program.

For the space station, a long-term, progressive application of automation should be planned and implemented. The division of tasks between crew and computer is not yet well defined but would be a part of this effort.

The crew should be used for physical and mental duties not practical to automate and used for monitoring and management for those functions that can be automated. This will leave the crew as much time as possible for productive work.

Automation will grow and could be implemented on a time-phased basis along the following lines:

-- situation and system condition displays (e.g., flight attitude and system parameters);
-- situation and system condition analysis (e.g., orbital error or system malfunction);
-- operational and system expert advice; and
-- operational and maintenance functions performed automatically.

The committee recommends that:

- NASA recognize and incorporate in the space station program Congress' interest in automation technology and take a leadership role in the areas of automation applicable to the space station.

On-Orbit Operations

On-orbit operations include satellite servicing; maintenance, repair, and the assembly/construction of the space station and other large space structures; orbital launch and transfer operations; and EVA activity. Operational techniques in support include: tethering, rendezvous, stationkeeping, and berthing. Berthing could be automatic or crew-aided.

The breadth of work is reflected in this partial list of crew activities: the maneuvering of orbital vehicles, servicing of the space station and its modules, mobile manipulator operation, fuel storage and refueling activity, logistics support, EVA support, and satellite/platform tethering and servicing.

These matters were not reviewed in depth by the committee, so no judgment is made as to the adequacy of attention directed to these and related activities. However, NASA needs to assure that they receive detailed attention.

Onboard Test Instrumentation

Considerable agency attention has been directed toward the development of ground-based test beds for subsystem design and verification. Where there is a need for complete space station system tests, the tests will have to be made in orbit. It is also possible that if problems arise, such instrumentation could be used for diagnostic purposes. Consequently, in the design process careful attention needs to be given to the test protocol and instrumentation requirements for this purpose. The requisite instrumentation should be placed onboard during the construction phase of the station, where appropriate, for in-flight operational tests and diagnostics in the event problems develop.

The committee recommends that:

- NASA make preparations during the design phase for on-orbit system tests to obtain required in situ performance and operational data. The planning should include test protocol and instrument requirements for design and performance measurements for such matters as structural response, thermal characteristics, and the tailoring of stabilization and control response characteristics.

Biological Contamination

An important consideration for the environmental control and life support system is the monitoring and control of biological contamination--among the crew, and between the crew and animals, plants, or other biological matter. This is anticipated to become increasingly important as the degree of life support system closure increases. Spacelab techniques for air filtration into and out of animal cages and laminar flow work stations may be adequate for one-week flights, but may need augmentation for long-life station use with partial or fully closed life support systems. Conservative approaches call for a biological barrier between biological work stations and material and areas normally used by humans. However, barriers should be designed into the station only if justified. To date, there is insufficient information on microbial buildup and transfer in closed systems for extended periods of operation to establish the need for biological barriers.

The committee recommends that:

- NASA pursue research on means for controlling bacteriological matter, on microfiltration, and on the identification of tolerable levels of microbial buildup in closed systems with human operators.

Environmental control experience with nuclear submarines as well as Skylab and the Shuttle obviously should be brought to bear on these problems.

Structures

A key space station issue for both structural and control system design is the adequacy of analysis techniques, that is, the degree of structural representation required to analyze structure/control system coupling. The complete structure cannot be tested on the ground in the full space environment including zero gravity.

NASA is fully aware of this problem. However, there are design approaches that can minimize the risks associated with the limitations of analytical and modeling techniques. Due to the nonlinear stiffness damping, and distortion characteristics of most space station configurations, as has been noted, the basic structural stack should have a control system with large stability margins and active and/or passive means for damping appendage vibration modes. Active as opposed to passive damping techniques may be required since the ability to analytically characterize or determine the inherent damping of representative space station structures through testing on the ground are limited.

NASA representatives stated that space station element weight would not be critical because the Shuttle that transports station elements into orbit would be volume rather than weight limited. Therefore, increased weight can be traded for reduced cost or complexity of station elements. This philosophy is questionable considering the aspects of the space station that are influenced by weight and inertia loads. Sensitive systems include station control and stabilization, stationkeeping, and reboost. Increased weight will require increased energy for these functions with logistic implications.

Ground rules for erectable versus deployable structures might reduce the technology programs needed to support station design and development. It is believed that erectable structures may be less complex, more easily maintained and repaired, and will have higher stiffness in partially erected stages. It would appear that erectable structures should be favored and deployable structures used where EVA is considered impractical.

Materials

NASA stated that the station modules would be fabricated from aluminum. This may be proper for modules, but it is believed that large beam or truss structures could be made of composite materials for their stiffness, mass, and low thermal expansion. Because of these characteristics, it is probable that the modules will use some composites for structural components.

Coating material mass loss associated with oxidation due to atomic-oxygen in low orbits was a concern noted by NASA. Shuttle experiments indicate that mass loss rates are high for some materials: pure carbon, mylar, kapton, polyurethane paint, kevlar, and the metal osmium. However, there are coating materials that show little, if any, mass loss: teflon, quartz, fused silica, tin oxide, indium tin oxide, and gold. In general, mass loss rates for carbon-rich and unoxidized materials is much higher than for fully oxidized materials. Due to the range of materials available this does not appear to be a critical problem.

The question of space charging was not discussed with the committee. This needs to be considered in the selection of coating materials.

Mechanisms

The technology exists to provide long life control moment gyros of the size needed for the space station. Some units have been operated for over 10 years, having accumulated over 300 component years of operation without mechanical failure. This experience includes constant speed rotors, variable speed rotors, and moving gimbals.

Mechanisms of the type needed for solar array positioning and operation have demonstrated long life capability. Dual spin satellites and three-axis controlled vehicles with movable solar arrays and antennas have demonstrated long life. The space station should consider the proven wind-unwind type of bearing design as well as the continuous rotation bearings being proposed. Limited rotation system will simplify fluid and electric power transfer across joints.

Some concern over lubricants was expressed. There are three types of commercially available lubricants--oil, grease, and dry film--for space use. They have exhibited long-term stability and sustained performance. The concern with lubricants is high mass loss and contamination. Experience has shown that proper design of labyrinth seals, vent paths, and lubricant reservoirs can solve these problems.

It was the view of the committee that significant technology exists, in the Department of Defense (DOD) and industry, to handle mechanism design problems. NASA needs to tie more closely to this technology base.

Thermal Control

On the space station, heat from instruments, equipment, and other sources will be removed through the use of thermal buses (heat pipes) that collect and transport unwanted heat to external radiators.

Cold plates to cool instruments and equipment are being developed at the Johnson Space and Goddard Space Flight Centers. Two-phase fluid thermal buses to collect and transport the heat are under study. Compared with single-phase systems, two-phase systems have lower pumping, and thus power requirements, by as much as 5 kW for a representative IOC. If a two-phase system is chosen, on-orbit tests will be required to examine performance in zero gravity. Such tests are planned in the Shuttle, but results may come late for design purposes.

Technology programs covering the major elements of the thermal control system are comprehensive and appear to be adequately funded for FY 1985. However, flight experiment plans related to fluid boiling and condensation and work on refurbishment/replacement of radiator coatings have been deleted from the program, and as noted flight experiments come too late to be compatible with the space station design schedule. In the current program, the technology development flight tests of two-phase cold plates, buses and radiators, and construction/erection techniques are planned for 1987-1988.

Considering the large effect that the thermal control system has on station design, it appears prudent to accelerate the flight test work to provide more timely data.

The committee also suggested that NASA study distributed thermal control systems (a distributed system may be more practical for station growth) compared with the centralized system currently planned. The dissipation of the large heat loads associated with station growth, and thermal controls for orbiting platforms also need to be addressed.

The extent to which the space station thermal systems can be applied to platforms (commonality) is questionable. Differences in orbital characteristics and in design requirements may make systems tailored to the station unsuitable for platforms.

POLICY FACTORS

Although the ad hoc committee's major interests were directed at the engineering and technology deve..pments, policy matters, both technical and managerial, have a direct bearing on these subjects and require program management attention. These matters are addressed here under the headings "Technology Policy" and "Management Policy."

Technology Policy

The committee's technology policy deliberation identified several issues related to technology evolution, data management, and protoflighting.

Technology Evolution

Since space station development will continue beyond IOC, technology development plans (road maps) that couple development for key IOC technologies and technologies for station evolution should be developed and maintained. The road maps will serve to define the timing and interaction between these developments and assist in program planning for maximizing performance and minimizing costs.

DOD research and development programs including those of the Strategic Defense Initiative Program have many elements common to the space station. NASA could profit from closer attention to this work. Some examples are very-large-scale integrated circuits, command and control procedures, and large-scale data processing and computing. It is considered essential that NASA take this work into account in the development of the space station.

The committee recommends that:

- NASA take steps to become and stay familiar and knowledgeable with the research and development in DOD programs pertinent to the space station and factor this technology into its technology development and space station definition and development plans.

Data Management

In the area of data management, NASA is pursuing a software architecture strategy that recognizes needs for: system autonomy, unique operational requirements, man-machine interface languages, application software for system and user, and distributed systems both in space and on the ground.

The distributed system concept is believed to be the proper approach to data handling and is not considered a technology issue. Industry can provide the electronic hardware. The status of circuit technology will control package size to be used but will not limit the speed or capacity below anticipated requirements. However, response to failures must be defined early to help define redundancy concepts and hardware requirements.

The space station data management architecture is being studied by two contractors (TRW and McDonnell-Douglas Aircraft Corporation). Their work over the next two years will assist in the definition of the data management system. It is believed that this dual effort will further complicate the data management system selection and integration process. The results of this work are to be transferred through NASA to the individual Phase B contractors. The Phase B contractors will be working in parallel with the data management system contractors.

In this process, NASA functions as a "third" contractor to provide data-management-system direction to the Phase B contractors. NASA will be taking on a complex effort in assuming systems engineering, integration, and management roles.

This complex interface is an operational/design challenge even for a major contractor who has had extensive experience in developing distributed systems in a common software development environment. It is suggested that NASA simplify interfaces and allow its contractors a more active role in this area.

Protoflighting

Protoflighting is intended to reduce program cost by using the same hardware in two modes: ground-based test and flight. While flight hardware for key operating subsystems would be tested on the ground, the all-up space station could not be tested prior to assembly and operation in orbit.

In earlier space programs, the availability of flight system prototypes for testing, downstream diagnostics, troubleshooting, and system development has proven to be of considerable value. A possible consequence of protoflighting is the loss of this ground-based capability for diagnosing flight problems and development hardware for station growth.

If NASA's proposed action means flying hardware used in ground tests, the committee agrees with the concept as long as it does not result in removing hardware from the ground needed for trouble shooting and evolution. If this is the case, the committee is concerned.

The committee believes, with regard to protoflight, that NASA should analyze the kinds of space station system changes that could be required, assess the difficulty and cost of accomplishing these in orbit, and assess the need for maintaining ground-based test equipments to support IOC operations and station evolution.

The committee recommends that:

- NASA determine the ground-based system/subsystem requirements in support of major subsystem analyses, in the event of flight failures, and for future development.

In some cases ground-based prototype mockups will be adequate. But in some areas, flight system duplication will be important, i.e., avionic-related hardware, where developmental work is critically dependent on hardware fidelity.

Management Policy

The areas of management policy that the committee believes warrant NASA program attention relate to: mission and system specification, program constraints, management controls, system integration, and foreign and Department of Defense involvement.

Mission and Systems Specification

Clear limits on system design had not been established for the space station. Without a clear notion of such parameters as shape, size, and capability of the space station, contractor participants will select their own baseline specification for analytical purposes. These specifications may or may not coincide with NASA's. With each study participant setting conditions, there is a high probability that the elements of the station will not match. The NASA job of system integration and management will be made unnecessarily difficult.

The lack of a specific design base/framework has made it difficult to focus the technology development supporting the program. For example, the committee was briefed on a budget exercise to reduce technology development costs. In the absence of a design base, such pro-

program adjustments are difficult to assess and can increase technical risk.

NASA can improve program focus, even before precise specifications are developed in Phase B, by setting a gross design envelope, which addresses such things as power, volume, weight, and stability. Contractors need this information for preliminary design. Users need the information for experiment design. NASA needs the information to reduce the difficulty of controlling and assessing space station system design and integration.

Program Constraints

As currently defined, the program has no identifiable, dominant constraints such as cost, schedule, or performance.* For the success of the program it is essential that these parameters have fixed values or at least a limited range of values. The values and relative importance of these parameters should be identified for each phase of the program.

Without program constraints, program participants--particularly contractors--will be confused as to the guidelines to use. Questions could be: Is the $8 billion figure a constraint? Is this a design-to-cost program? Is the IOC date, 1992, a constraint? Is there a single or a combination of performance parameter constraint?

If not provided, the participating contractors will set constraints themselves to guide their analyses. In all probability the values selected by individual contractors will not be compatible. Such action, in combination with individual selection of mission and system specifications, will magnify the difficulty of the NASA program management and integration task.

The committee believes that any program, with the possible exception of basic research, should have anchors related to cost, schedule, and/or performance. In most programs, constraints tend to be a combination of two or more of these factors. Apollo was constrained by: performance--"Man on the Moon . . . " and schedule--" . . . by the end of the decade."

An additional cost issue relates to projection of total program cost. The simple fact is that the Administration and Congress, as the program evolves, will want to know the cost of the program. At present the figures of $8 billion and $20 billion are used to cover IOC and development (for the space station alone) through 2000. NASA will need to begin to develop cost estimates for related effort, i.e., launch, operations, support, and payloads.

*Since the writing of this report, cost has been identified (in the RFP) as a program constraint.

For the space station, a performance constraint has been tacitly established: provide a permanent, evolvable, inhabited facility for research, technology development, application, and commercial use in low earth orbit. To be effective, this constraint needs to be amplified in terms related to capacities, support, and services. The committee believes that at least one other constraint is needed, i.e., on orbit by 1992, but not later than 1995; or a cost for certain capability not to exceed a specific dollar level.

Another committee concern is lack of guidance for design-to-cost. It should be remembered that design-to-cost normally refers to a product production cost. For the space station, a design-to-cost will include design, development and production costs. Therefore, special consideration must be given to definition of the term design-to-cost. The draft request for proposal (RFP) for Phase B does not identify or allocate cost by program element. If design-to-cost is to be a cornerstone of the space station, NASA will have to provide a more detailed definition of the term and require contractors to establish and enforce related design-to-cost goals and methods.

A related matter is life-cycle cost. The Phase B proposals state that life-cycle costs will be controlled. However, for the space station program, "life cycle" is an ambiguous term. The station, by definition, is modified, added to, and extended in terms of capacity and performance. Indeed, what is the life cycle of the station?

In order to guide trade-offs between initial design and long-term costs, some simple, quantifiable measure of postdeployment cost would be useful. Possibly a yearly operational cost under a specific set of conditions would be a more useful reference than life-cycle cost. Clearly, it is not sufficient to state, as in the draft Phase B RFP, that "life-cycle cost will be controlled."

In view of the foregoing, the committee recommends that NASA:

- decide now on program constraints, get administration/congressional approval of them, publicize them, and once established, stick to them.

- review its commitment and approach to design-to-cost and, if appropriate, refine and state its design-to-cost goals and approach and take the necessary implementing actions.

- review its statements and commitments to the application of life-cycle cost. In the opinion of the committee, life-cycle cost, except in the broadest sense of the term, is not an appropriate parameter for space station design analyses, considering hardware design, development, and operations. Hardware and annual operating costs might be a better choice of parameters.

Management Controls

The assignment of space station effort in four major work packages to different NASA centers (supported by one or more teams of contractors) introduces complexity in program management. Exacerbating this is the distribution of systems engineering and integration (SE&I) functions among the centers and the long-term nature of the program. Clearly, there is a need for rigorous program management and change control. There is a potential for cost growth and schedule slippage if a tight change control mechanism is not established early.

The management process proposed by NASA is complex with many decision nodes and iterative loops. A program of the size and complexity of the space station will be difficult to manage under these conditions. At the time of this review there were no clear system design limits; there was no clear and unequivocal centralized program authority; there was a cumbersome management system; there was a distributed, potentially ineffective change-control process; and there was a distributed SE&I activity.

The committee believes that the space station should be considered and treated as a facility--a laboratory, a factory, a test facility, a habitat. It should be designed to provide a well-characterized standard enviornment: utilities, interfaces, services, logistical support, and crew accommodations. It must be easily used by customers, but customers should not dictate design beyond limits of affordability. What is called for is a fixed capability with standard interfaces and procedures to meet most anticipated needs.

It is the opinion of the committee, as has been discussed, that management controls, as well as technology selection and design, should flow from known design, development, and operational constraints. If, philosophically, the space station program is thought of as a standard facility, the program definition and development task will be simplified compared with trying to satisfy long-term, undefinable customer forecasts (as appears to be the case). Neither technology, design, nor management can be adequately focused until a facility design philosophy is identified and documented.

The committee recommends that NASA:

- establish, now, a clear design, development, and operational philosophy that includes a standard facility concept.

- establish, as soon as possible, specifications for a core utilities capability with standard interfaces and operational and logistical support limits and be intolerant of change.

- review its proposed change control procedures and revise them so that they are reasonable, clear, consistent, and rigorous with minimum interfaces. They must be designed to outlast individuals and organizations.

System Integration

NASA is organizing to do the space station system prime program management and system manager/integration function in-house. NASA may be underestimating the complexity of the task and the capability required to perform it.

NASA has performed as system integrator previously--witness management of scientific satellite programs. Generally, the science satellite programs were assigned to a single center that had total control. But, the diversity and complexity of the space station program is much greater. The Apollo program approached the complexity of the projected space station program, but the space station will be more complex due to mission, growth, logistics, and lifetime. The Apollo program employed systems support contractors (Bell Com and Boeing).

The management philosophy for the space station program, as the committee perceives it, involves five centers operating with relative autonomy under the overall program leadership of a lead center--the Johnson Space Center. It is not apparent that there is a clear line of authority for the program. Although the title Program Office is mentioned, there does not appear to be, as yet, a Program Office in the usual definition of the term. Neither has the committee discerned a Program Director--that is, a single individual with specific, clear responsibility and authority to manage the total program including all major contract activity. It seems, in fact, that there are several program directors with varying responsibilities and authorities within NASA's field centers associated with the major subsystems. In the view of the committee, this complicates the program management and integration task.

It appears that each center will conduct its own research and development program; have its own change and configuration control procedures; and have its own cost, schedule, and performance goals and measurement systems. This will include, in assigned areas, a large amount of autonomy and their own contracting authority with contractors rewards and penalties that may differ for the same contractors working for different centers.

In principle, with the proper centralized management, authority, skills, and resources, including data, physical aids, and people, the management/integration task could be done effectively. But of concern is whether NASA will be able to assign the proper critical masses of people and skills to do the job.

The committee envisions a management system where responsibility and authority are assigned to an individual in a single office that is equipped with facilities and staff to do the demanding management job. In view of the present confederated management system, the committee raises the question, will NASA be able to move, as the program evolves, to the type of management system the committee judges to be more appropriate?

The committee believes that NASA would be well advised to reexamine its management plan. Several alternative approaches are possible: a prime contractor, a federally contracted development center, or an integrating contractor.

A prime contractor with total system performance responsibility would have the possible disadvantages of NASA committing to a single contractor for a long time period and adding cost to the program. In addition, the contractor would be paid from program funds, whereas NASA in-house management is paid from institutional funds.

A federally contracted development center such as Aerospace or MITRE would have the possible drawback of not having the depth or experience to perform the task, and it might prove difficult to assemble the required experienced personnel. The assignment-of-cost issue arises here too.

An integrating contractor who would accept a hardware-exclusion clause (will not undertake related hardware design or construction) is the method that the Air Force has used for intercontinental ballistic missiles (ICBMs). In this Air Force work, for example, TRW has been the integrating contractor, under the control of the Ballistic Missile Office (BMO), formerly the Ballistic Missile Division. TRW has supervised associate contractors and performed the integration task as an extension of the BMO. This arrangement has generally worked well for the Air Force, is currently employed on the Peacekeeper program, and will probably be used on the strategic ICBM program. The committee believes that NASA should, in its management system review, consider the BMO modus operandi for the space station program. If similar action is indicated, early attention would be desirable because of the time involved in bringing a contractor into the program.

As would be the case for the other management alternatives noted, the cost of an integrating contractor would be charged to the program budget, not the NASA personnel and management budget. Nonetheless, the committee believes that contracting for system management support would be prudent. OMB Circular A-76 ("Performance of Commercial Activities," August 1983) could be invoked to support this action. The circular enunciates a policy of contracting where possible. It is believed that the out-of-house effort could be justified operationally and financially.

The committee further believes that NASA should consider the establishment, as soon as possible, of a central space station program office headed by a director with total programmatic and technical authority. It is important that the director have direct access to the administrator of NASA, independent of where the office is established.

It is the committee's recommendation that NASA:

- reassess its approach to program management and integration, directing attention to establishing a space station program manager who will have full, complete responsibility and authority over the entire program--over all NASA and contractor elements associated with the program--and will have direct access to the Administrator.

Foreign and Department of Defense Involvement

NASA has stated as a matter of policy and has actively pursued foreign government involvement in the space station program. DOD involvement, if any, is not resolved. The committee's concern is that if DOD does become involved in the program as a matter of national policy and interest, classified work (national or for that matter international) will not be compatible unless certain actions are taken during the design phase of the program.

Although not a mission requirement, the committee believes that the space station program is ideally suited for DOD experiments. The problem is the DOD-program-related experiments will be classified and will need to be conducted under stringent security.

Involvement of our allies and trading partners in the space station program has been stated as a national objective and is highly desirable. Through this action, program content can be enlarged. Foreign investment serves foreign policy interests, and foreign participation in the program portrays the United States as a world technical leader whose hand is extended in friendship.

But, if the space station is to accommodate DOD experimental work, security requirements have to be resolved. Foreign involvement requires an open program. DOD involvement requires a closed environment. The committee believes that this incompatibility can be resolved through system and data flow isolation, which with careful design will require a minimum expenditure of funds. The committee does recognize, however, that DOD participation will raise questions and could deter some foreign involvement in the program.

The committee recommends that:

- NASA continue to actively pursue foreign government involvement in the space station program.

- NASA help resolve the national position regarding DOD involvement in the space station program through the Administration and Congress.

It is further recommended that NASA take action to ensure an abil to accommodate DOD experiments until the DOD involvement question is resolved. Thus:

- NASA should consider accommodation requirements during definition and design activity. Accommodation would involve provisions for isolation of experiment compartments, data bases, data handling, and communications. Other probable needs are high power levels, large computational capability, and high pointing accuracy.

- NASA should make DOD (particularly the Director of the Strategic Defense Initiative Program) aware of NASA actions and prepare to arrange for adequate permanent DOD representation in the space station program.

CLOSING COMMENTS

The ad hoc committee has reviewed NASA's ongoing and planned research and technology development programs and engineering approacl pertinent to the evolving space station program.

The committee carried out its study in the formative period of th space station program. During the study period, the program offices at NASA headquarters and its centers were organized and in the proce of being staffed, and an RFP for space station definition and preliminary design studies, Phase B, was developed and released to industry with awards scheduled for April 1985.

It is the hope of the committee that its deliberations are useful to NASA in the conduct of this important national program.

Appendixes

A. Space Station References--Selected Listing
B. Ad Hoc Committee Panels
C. Presentations to Ad Hoc Committee and Panels
D. Reference Configuration
E. Reports Provided to Ad Hoc Committee

APPENDIX A

Space Station References--Selected Listing

George Low, "Manned Space Flight," in NASA, NASA-Industry Program Plans Conference, July 1960.

The early Langley studies are summarized in Langley Research Center, Report on the Research and Technological Problems of Manned Rotating Spacecraft, NASA Technical Note D-1054, August 1962.

Douglas Missile and Space Systems Division, Douglas Aircraft Co., "Report on the Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential," Report SM-48822, January 1966.

Studies during the 1960s at LRC, MSC, and MSFC are summarized in Langley Research Center, Compilation of Papers Presented at the Space Station Technology Symposium, February 11-13, 1969.

William Normyle, "NASA Aims at 100-Man Station," Aviation Week and Space Technology, February 24, 1969.

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Frederick I. Ordway III, "The History, Evolution, and Benefits of the Space Station Concept," presented to the XIII International Congress of the History of Science, August 1971.

Jack C. Heberling, "The Management Approach to the NASA Space Station Definition of Studies of the Manned Spacecraft Center," NASA Technical Memorandum X-58090, June 1972.

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U.S. Senate, Committee on Aeronautical and Space Sciences, NASA Authorization for FY 1977, Hearings.

NASA, Lyndon B. Johnson Space Center, Space Operations Center: A Concept Analysis, November 29, 1979.

NASA's attempts to gain support for this large program are described in John Lodsdon, "The Policy Process and Large Scale Space Efforts," Space Humanization Series, Vol. 1, No. 1 (1979).

W. David Compton and Charles D. Benson, Living and Working in Space: The History of Skylab (Washington: NASA SP-4208, 1982).

Office of Technology Assessment, U.S. Congress, Salyut--Soviet Steps Toward Permanent Human Presence in Space, TM, December 1983.

NASA, "Space Station Advanced Development Program," July 2, 1984.

APPENDIX B

Ad Hoc Committee Panels

- <u>MSFC Program Panel</u>

	Subjects
Artur Mager, Chairman	
Kenneth F. Holtby	Structures and materials
Walter B. Olstad	Propulsion and fluids
James T. Rose	Space operations
Alton D. Slay	Engineering approach
Byron D. Tapley	Stabilization and control

- <u>JSC Program Panel</u>

John V. Harrington, Chairman	
Lawrence R. Greenwood	Environmental control
Richard W. Hesselbacher	Data management, systems operations
Sidney Metzger	Communications
Richard W. Hesselbacher	Electric power
Clarence A. Syvertson	Thermal control
Laurence R. Young	Human factors, life support

- <u>Program Issues Panel</u>

  Kenneth F. Holtby, Chairman
  Lawrence R. Greenwood
  John V. Harrington
  Artur Mager
  Byron D. Tapley
  Laurence R. Young

- <u>Solar Thermodynamic Panel</u>

  Joseph F. Shea, Chairman
  Richard W. Hesselbacher
  Walter B. Olstad

- <u>Management Issues Panel</u>

  Alton D. Slay, Chairman
  Robert A. Frosch
  Richard W. Hesselbacher
  Sidney Metzger
  Walter B. Olstad
  Clarence A. Syvertson

APPENDIX C

Presentations to
Ad Hoc Committee and Panels

Committee Meeting; March 21-22, 1984

Program Overview	J. Hodge
Space Station Utilization	L. Tilton
Ground Rules and Assumptions for Design	R. Frietag
Configurations, Major System Trades, and Technology Needs	L. Powell
Space Station Management	J. Hodge
Supporting Technology Program--Current and Projected Work	R. Carlisle

MSFC Panel Meeting; April 24-25, 1984

Engineering Approach	J. Cole
Satellite Servicing Efforts	R. Middleton
Space Station Maintenance/Repair	A. Quinn
S/S Technology/Advanced Development	F. Vinz
Automatic Rendezvous and Docking Work Summary	J. Michael
Structures and Mechanisms Advanced Development	C. Cornelius
Materials and Structures S/S Support in OAST Base R&T	M. Card
Deployable Structures Technology	E. Engler
Structural Dynamics	R. Jewell
S/S Propulsion and Fluids Advanced Development Program	R. Richmond
S/S Auxiliary Propulsion	F. Berkopec
S/S Fluid Management Technology Status	L. Hastings
S/S Attitude Control and Stabilization Advanced Development Program	H. Buchanan
S/S Control Technology	A. Tolivar

JSC Panel Meeting; May 10-11, 1984

S/S Engineering Approach	A. Louviere
Systems/Operations	R. Hook
Systems Analysis	L. DeRyder
Power/Propulsion Systems Analysis	P. Finnegan
Proximity Operations/Berthing Docking	K. Cox
Automation	R. Turner
Fluid Transfer	R. Taeuber
Thermal Control	W. Ellis
ECLSS	F. Samonski
EVA	R. Mayo
Human Productivity	D. Travis, A. Chambers
Data Management	E. Chevers
Communications and Tracking	R. Dietz, K. Krishen
Electrical Power--Generation, Distribution, and Storage	R. Bechtel, H. Schwartz W. Chandler

Committee Meeting; May 22-23, 1984

Program and SEI Status	N. Hutchison
SE&I	B. Redd
Reference Configuration(s)	B. Redd
Evolutionary Designs	B. Pritchard
User Requirements	B. Pritchard (D. Gerke)
Technology Missions	D. Russell
Science and Application Missions	B. Roberts
Commerical Missions	J. Moore
Program Management	N. Hutchison

Solar Dynamics Panel Meeting; August 3, 1984

Solar Dynamic Power Impact on Space Station System Design	M. Craig
Power Generation State-of-the-Art	H. Schwartz
SD Development History and System Concepts	J. Deyo
Solar Collector Technology	R. English
Receiver Technology	J. Deyo
Critical Technical Issues	J. Deyo
Technology Program Augmentation	J. Deyo
Summary	H. Schwartz

Committee Workshop; August 20-24, 1984

FY 1985 Technology Program	J. Romero W. Tumulty
Reference Configuration and Work Packages	A. Louviere

APPENDIX D

REFERENCE CONFIGURATION

SECTION C

STATEMENT OF WORK

ATTACHMENT C-5

REFERENCE CONFIGURATION DESCRIPTION

Taken from Space Station Definition and Preliminary Design Request for Proposal, September 15, 1984.

TABLE OF CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION.

Reference configurations for the Space Station manned core, the man-tended option and the unmanned platforms were derived to aid in the definition of system requirements, to assure the feasibility of acceptable customer accommodations, and to provide a basis for evaluation of contractor proposals. An overview of these configurations is presented in this section. A detailed presentation of the reference configuration design characteristics is contained in "Space Station Reference Configuration Description," JSC-19989, accession no. J8400076.

2.0 MANNED CORE REFERENCE CONFIGURATION.

The reference concept presented in this section is representative of a family of configurations which has been studied extensively by both NASA and industry. This family is characterized by a common set of elements which are assembled in various ways to meet a number of different design priorities. The elements are:

a. Pressurized modules.

b. Articulated solar-inertial power generation devices.

c. Assembly hardware which connects the modules and power devices and which supports externally mounted systems, payloads, and facilities.

The reference configuration described herein assembles these elements in such a way so as to maximize customer viewing opportunities and to provide versatility in station growth while meeting other customer and operational requirements and constraints. However, it is felt that significant improvements are possible due to the limited shelf life and depth of examination to this reference configuration. Therefore, the contractor is encouraged to examine other configurations within this family or propose modifications, large or small to the reference configuration. A configuration belonging to another conceptual family may be presented in an alternate proposal.

2.1 Configuration Overview.

Table C-5-I summarizes the characteristics of the manned core in both initial and growth phases of build-up. Layouts and isometric views of the reference configuration in these phases are presented in figures C-5-1 through C-5-4. Note that both photovoltaic and solar dynamic power generation systems are shown to demonstrate design options rather than to advocate a particular initial system selection or growth path.

2.2 Flight Mode Description.

The reference configuration is flown with a small pitch angle in the orbit plane such that no momentum, due to aerodynamic and gravity gradient

TABLE C-5-I.- MANNED CORE DESIGN CHARACTERISTICS

	INITIAL	GROWTH
ALTITUDE	500 KM (270 N. MI.)	500 KM (270 N. MI.)
INCLINATION	28.5°	28.5°
AVG. BUSS POWER	75 KW	300 KW
CREW SIZE	6	18
NO. PRESS. MODULES	5*	10

* HABITABILITY MODULE #1
HABITABILITY MODULE #2
LABORATORY MODULE #1
LABORATORY MODULE #2
LOGISTICS MODULE

(REFERENCE CONFIGURATION ONLY)

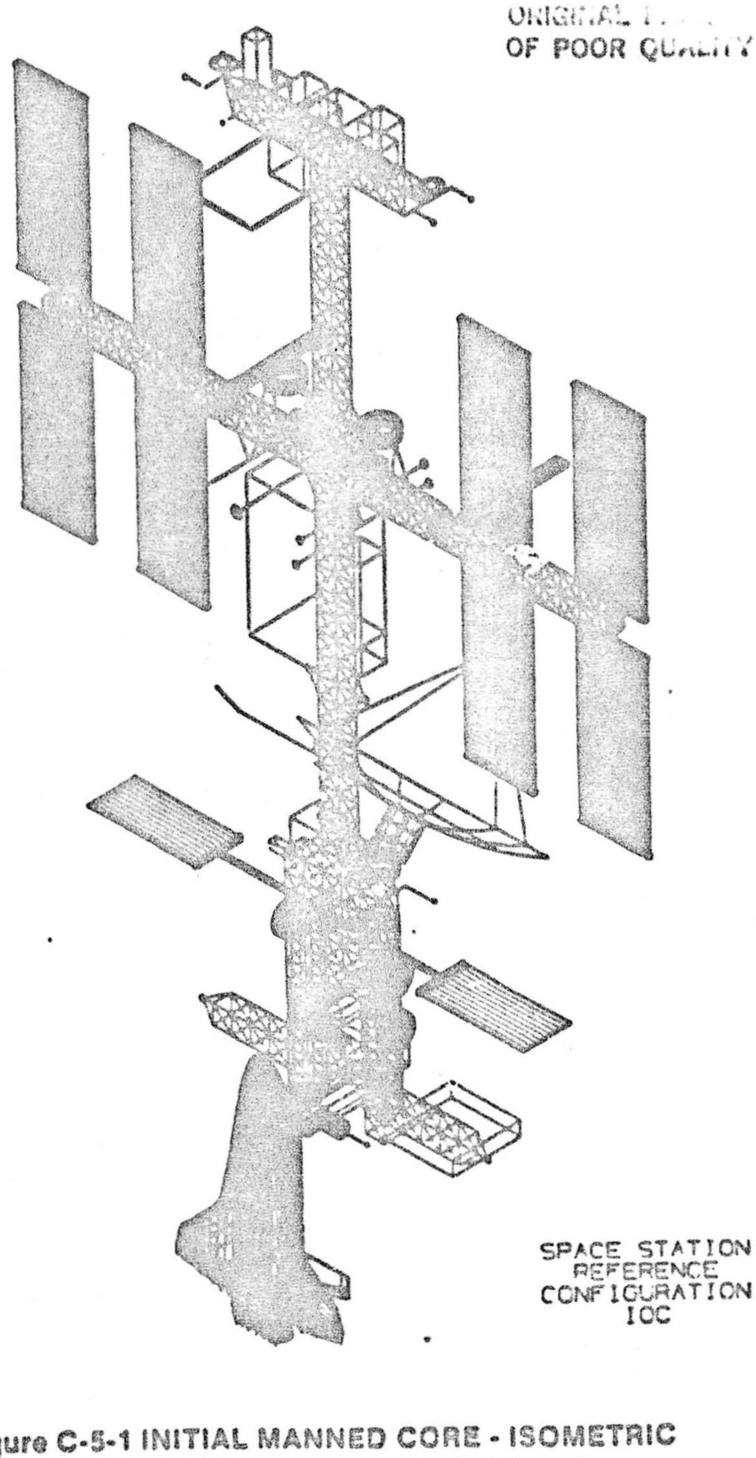
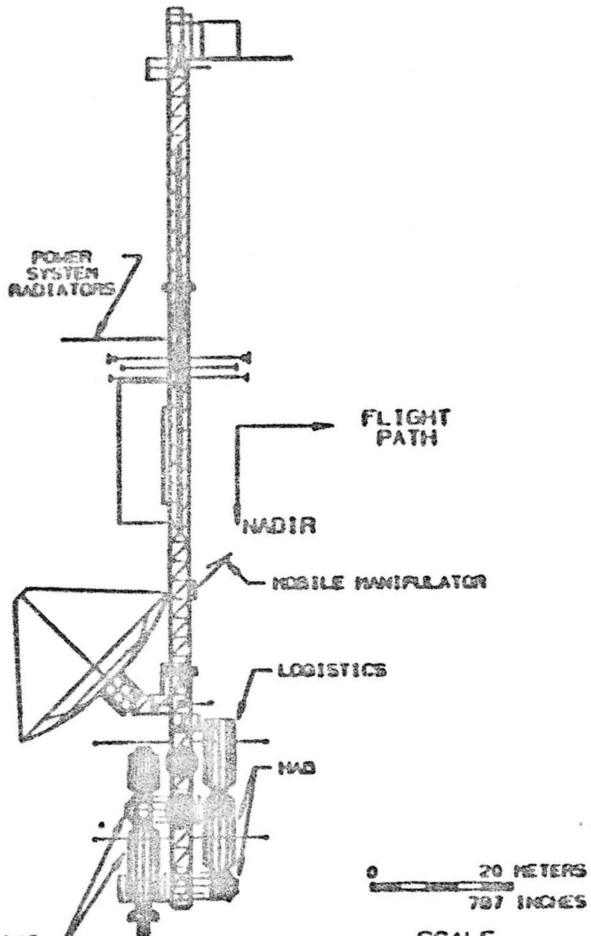
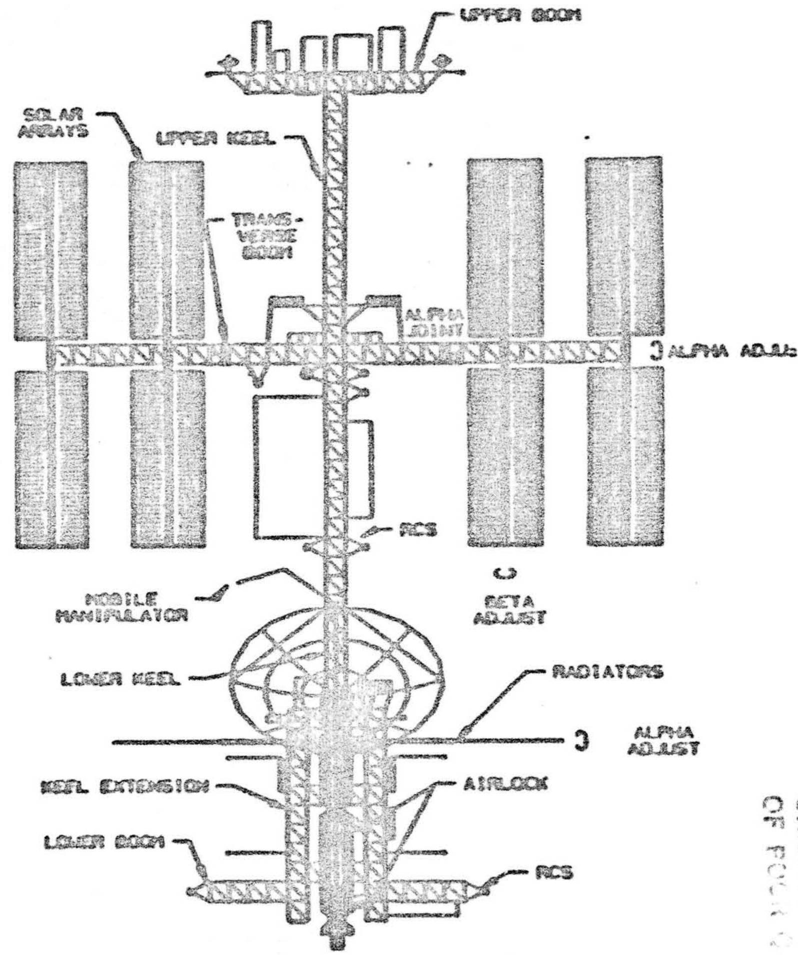


Figure C-5-1 INITIAL MANNED CORE - ISOMETRIC
(REFERENCE CONFIGURATION ONLY)



LEFT
SIDE VIEW



FRONT VIEW

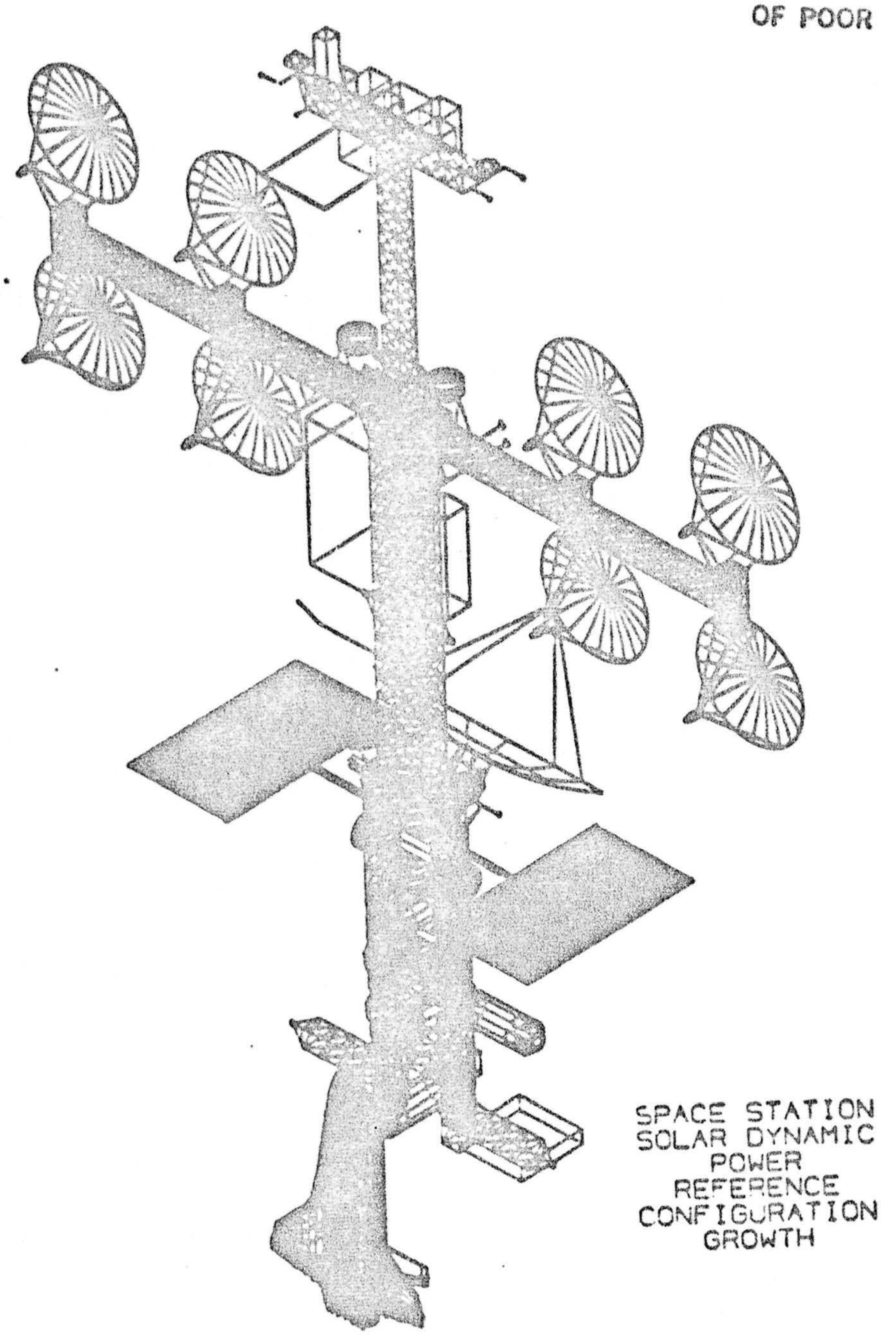
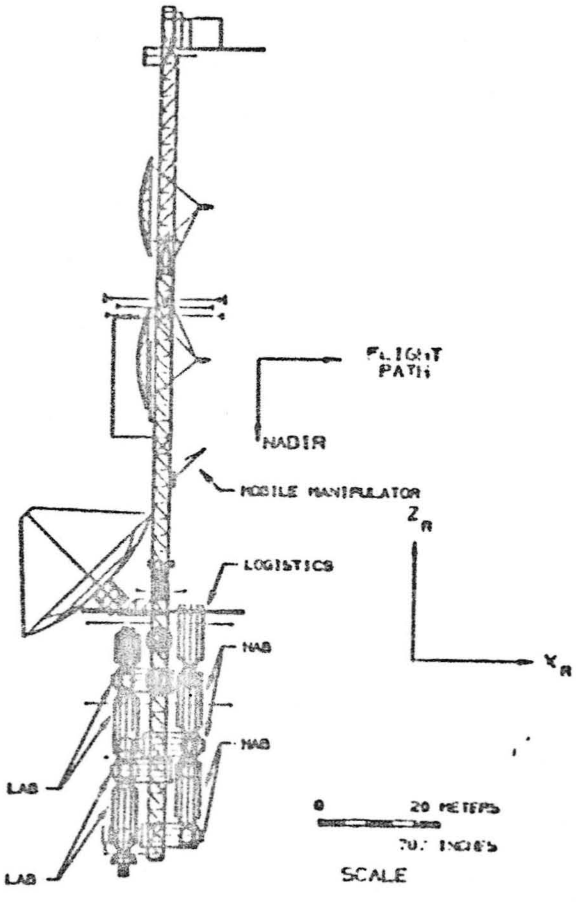
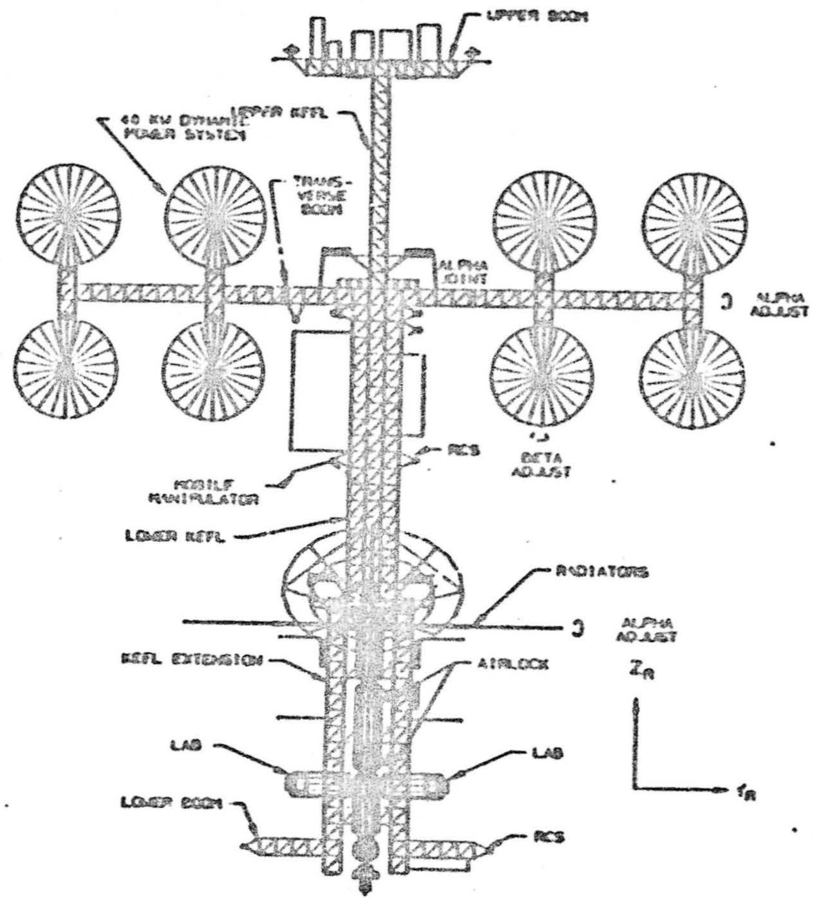


Figure C-5-3 GROWTH MANNED CORE - ISOMETRIC
(REFERENCE CONFIGURATION ONLY)



LEFT SIDE VIEW



FRONT VIEW

torques, are accumulated over an orbit. This flight mode is known as an average Torque Equilibrium Attitude (TEA) flight mode. The pitch attitude, which is maintained with CMG's, is adjusted to account for major changes in station mass properties. Momentum is accumulated on the roll and yaw axes by CMG's which are dumped periodically through the use of magnetic torquers and/or RCS thrusters.

2.3 Payload Accommodation.

Table C-5-II summarizes payload accommodations provided by the reference configuration. These accommodations include payload viewing, construction, servicing, and OMV/OTV support. Figure C-5-5 identifies these accommodations on a reference configuration layout.

2.4 Man-Tended Option.

Included in the family of configurations associated with the reference Space Station concept is an alternative (figure C-5-6) that delays the introduction of the manned habitat from 3 to 5 years following initial deployment of the basic Space Station. During this 3 to 5 year interval, the Space Station would function in a man-tended mode. Pursuant to Congressional directive, NASA is requiring offerors to include in their proposals how they would study this alternative configuration. The configuration should be examined from the standpoint of its inherent capability to fulfill requirements, considering basic operations in an automated mode, with intermittent manned operations as constrained by the NSTS as currently conceived. In addition, offerors selected for negotiations will be required to examine the DDT&E and life-cycle costs of this man-tended configuration, comparing them to the reference configuration.

3.0 UNMANNED PLATFORM REFERENCE CONFIGURATION.

The SSP reference configuration includes co-orbiting and polar-orbiting platforms with the characteristics summarized in table C-5-III. The platform reference configuration is presented in figures C-5-7 and C-5-8. The platform utilizes Space Station elements, subsystems, and components to the extent which is practical and cost effective. The capability for modular growth is incorporated in the design. While the platforms incorporate station elements, the ultimate platform design is not constrained to have a physical resemblance to the Space Station. A single, multipurpose platform design is presented, incorporating features that allow easy on-orbit interchange of instrument or processing module payloads at a standardized interface. Platform subsystems are also easily interchanged at standardized interfaces, so that the platform can remain permanently in orbit.

TABLE C-5-II.- MANNED CORE PAYLOAD ACCOMMODATIONS

- O SOLAR/STELLAR VIEWING
  - O MOUNTED AT UPPER END OF CENTRAL TRUSS
  - O CAPABILITY TO VIEW EARTH'S LIMB
- O EARTH VIEWING
  - O MOUNTED AT BOTTOM OF CENTRAL TRUSS
  - O CONTINUOUS VIEW OF EARTH LIMB TO LIMB
- O LARGE SPACE STRUCTURE CONSTRUCTION
  - O LOCATED AT BOTTOM OF CENTRAL TRUSS
  - O NEAR VICINITY FOR EVA, MATERIALS TRANSPORT FROM ORBITER
- O SATELLITE SERVICING
  - O MAINTENANCE, REPAIR, AND STORAGE ACCOMMODATIONS
  - O LOW CONTAMINATION STORAGE AND SERVICING
- O OMV/OTV SUPPORT
  - O SERVICING, MAINTENANCE, REPAIR, AND STORAGE ACCOMMODATI
  - O PROPELLANT NEAR C.G.

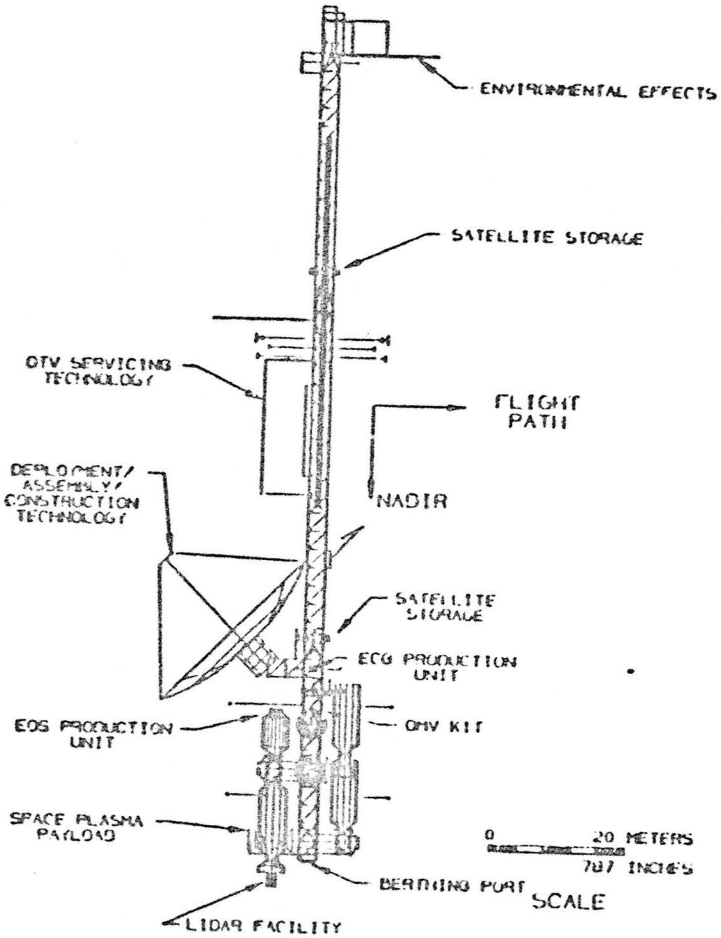
(REFERENCE CONFIGURATION ONLY)

TABLE C-5-III.- UNMANNED PLATFORM DESIGN CHARACTERISTICS

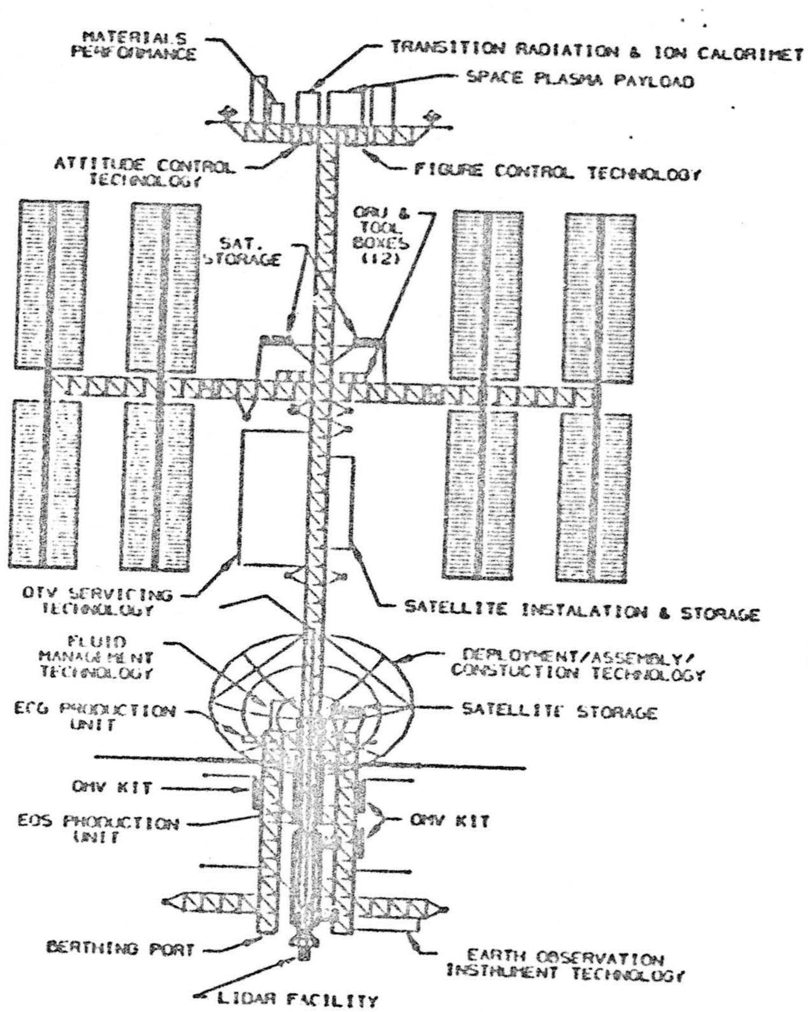
	INITIAL PLATFORM		GROWTH PLATFORM	
	CO-ORBIT	POLAR	CO-ORBIT	POLAR
ALTITUDE	500 KM (270 N. MI.)	700 KM (380 N. MI.)	500 KM (270 N. MI.)	700 KM (380 N. MI.)
INCLINATION	28.5°	98.2°	28.5°	98.2°
AVG. BUS POWER	8 KW *	8 KW *	23 KW *	23 KW *

* Includes 3 KW housekeeping power

(REFERENCE CONFIGURATION ONLY)



LEFT
SIDE VIEW



FRONT VIEW

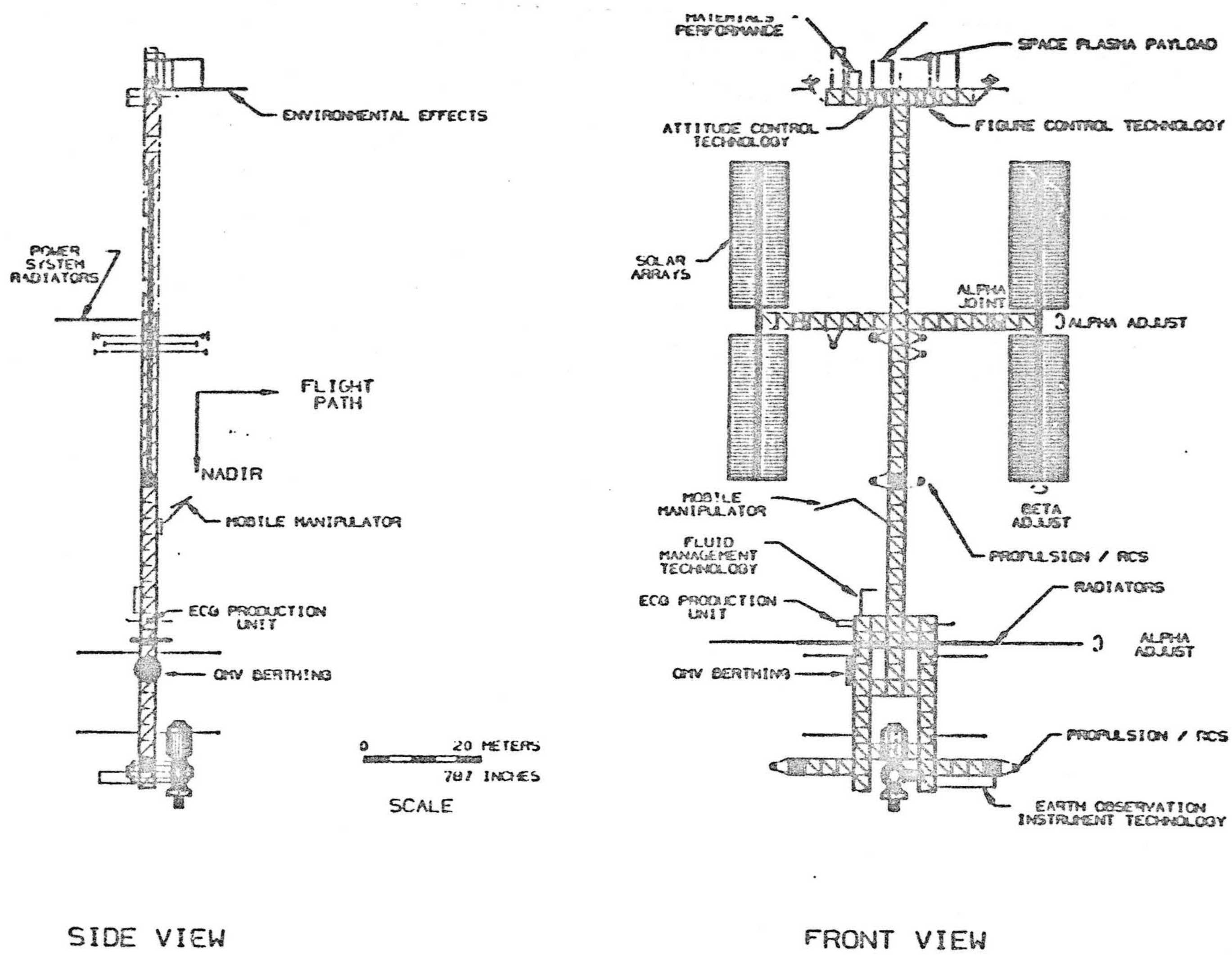
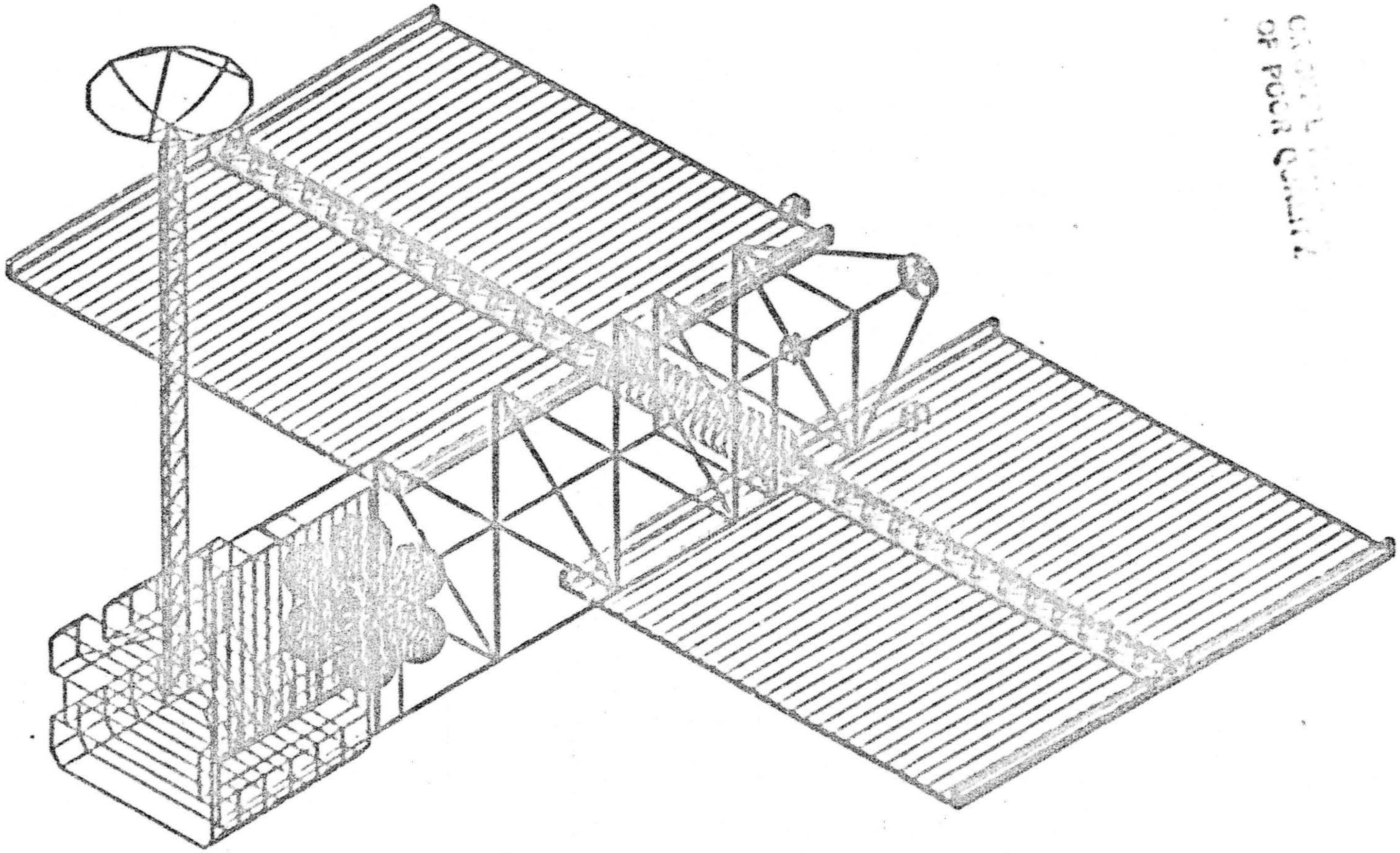


Figure C-5-6 MAN-TENDED CONFIGURATION (REFERENCE CONFIGURATION ONLY)



UNMANNED PLATFORM
LOW EARTH ORBIT
COORBITING SATELLITE

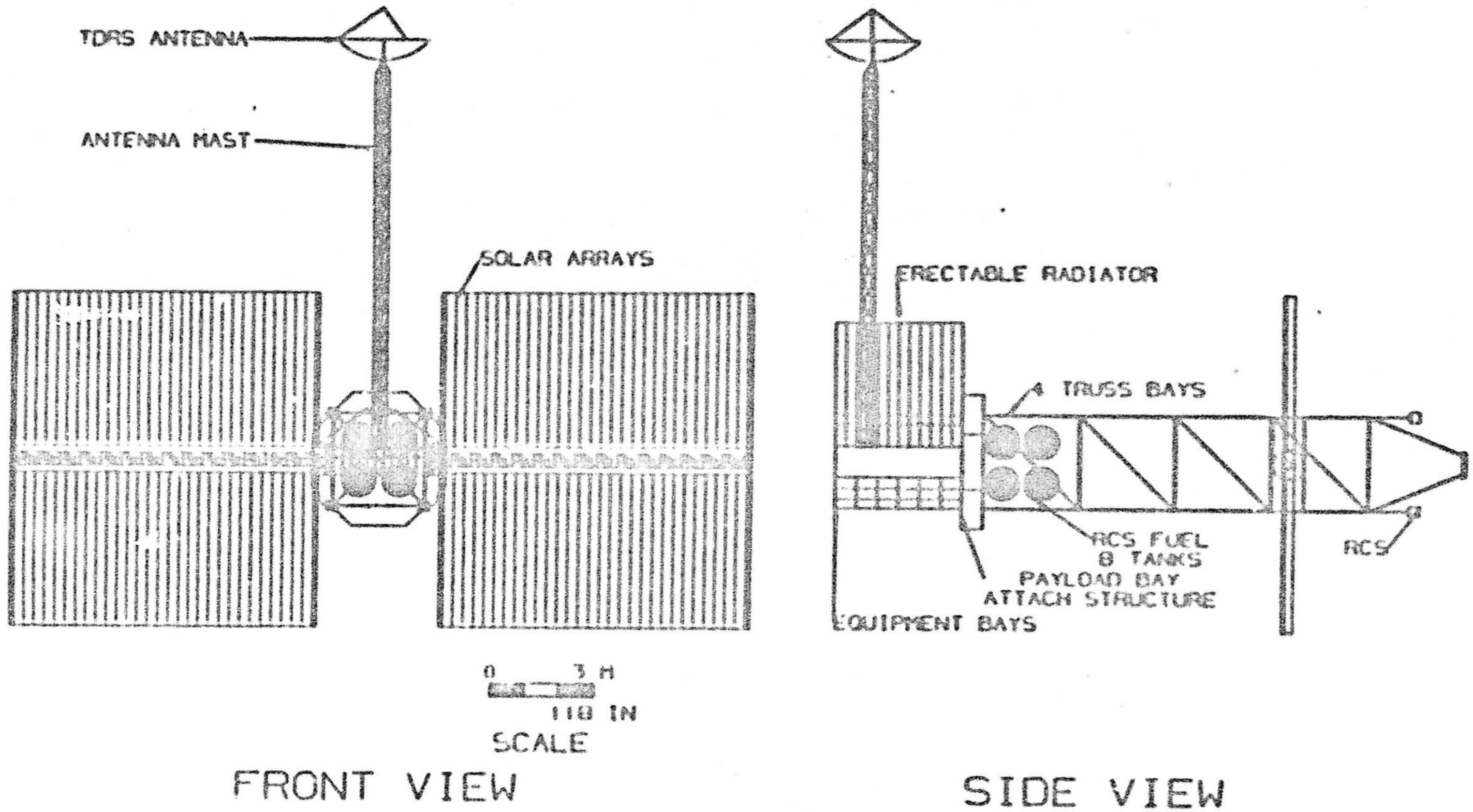


Figure C-5-8 UNMANNED PLATFORM - LAYOUT (REFERENCE CONFIGURATION ONLY)

APPENDIX E

Reports Provided to Ad Hoc Committee

- Practical Applications of a Space Station, Space Applications Board, NRC
- Space Station Advanced Development Program, NASA, July 2, 1984
- Space Station Mission Requirements Report, NASA (JSC, February 1984)
- Space Station Policy, Planning & Utilization, AIAA
- Space Station Technology 1983, NASA Workshop Report
- Space Station Technology Challenges, R. Carlisle, NASA Headquarters
- Second Interim Review--Satellite Servicing, Martin Marietta, March 22, 1984 at MSFC
- Mid Term Review--Satellite Servicing, TRW, March 22, 1984 at MSFC

END

DATE

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