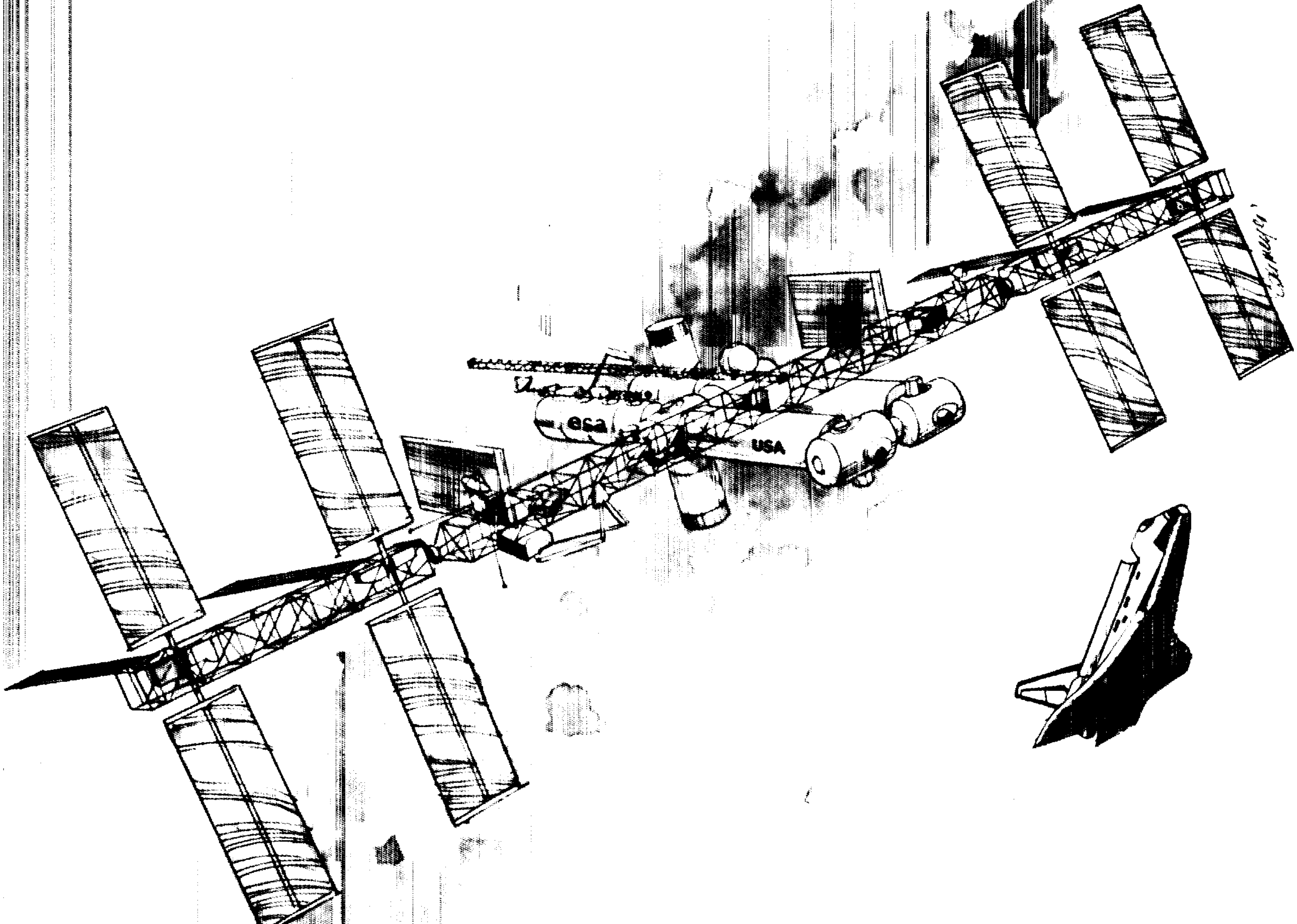
SPACE STATION FREEDOM MEDIA HANDBOOK



April 1989

(NASA-TM-102901) SPACE STATION FREEDOM MEDIA HANDBOOK (NASA) 113 p CSCL 22B

N90-23460

Unclas
G3/18 0260402

For more copies of this Handbook see your local NASA Center's Public Affairs Officer or contact the Technical & Administrative Services Corporation (TADCORPS)

600 Maryland Ave. SW #200
Washington, D.C. 20024
202/554-8677

Preface

For the past six years, the space station program has been working toward that day in 1995 when the space shuttle fleet will begin launching elements of Space Station Freedom into orbit. As the design and development of Space Station Freedom begins, it is important for the media to understand the work going on at the NASA Centers and at the contractors' plants. This booklet is intended to portray that work and to explain, in lay terms, the roles, responsibilities and tasks required to build Space Station Freedom's elements, systems, and components.

New ground facilities are also required for Space Station Freedom as are new and advanced technology projects that support the development effort. This booklet is organized by NASA Center in order to provide a local angle for the media. The reader will acquire historical, utilization, development, international, and futuristic perspectives as well as a better understanding of the hardware and software that will make up Space Station Freedom.

The booklet is intended to be a useful and handy reference guide for the Space Station Freedom program, one that is easy to read and yet small enough to keep in your briefcase or at your desk, as NASA enters the space station era of spaceflight.

This document is in the public domain -- you may use any and all information and art without permission, and you may request additional publications or quality photos from the contacts listed in the Appendices.

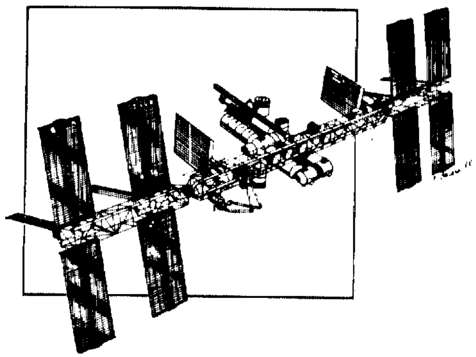
Additional copies in reasonable quantities may be ordered from this office. Corrections, additions and updated graphics may also be sent to this office for later editions.

Mark Hess
Public Affairs Officer
Office of Space Station
NASA Headquarters
Washington, D.C. 20546-0001
202/453-4164

Table of Contents

INTRODUCTION

Historical Perspective



The concept of the space station goes back at least to 1869 when Edward Everett Hale mentioned the "Brick Moon," a 60 meter-diameter satellite for a crew of 37 to help navigate ships at sea, in the Atlantic Monthly. Novelists like H.G. Wells and Jules Verne forsaw space travel in the late 1800's. By the turn of the century, scholars such as Konstantin Tsiolkovsky were laying the foundations of space travel to orbital stations.

The modern space station concept dates back to 1923, when the Romanian-born Hermann Oberth published his serious theoretical treatise on the possibilities of large, liquid-fueled rockets. Die Rakete zu den Planetenraumen (The Rocket to Interplanetary Space) was the opening shot in a debate about the meaning of the space station that was to last for more than six decades. Oberth envisioned a voyage to Mars, and perceived that a refueling depot in outer space (or "weltraumstation") would serve as a staging point for the journey. He quickly realized that a station in space could do many other things which would further justify its construction.

In the twenties, other visionaries, mostly Germans, joined Oberth in his advocacy of this unheard-of-technology. A space station was, at this time, symbolic of a wide range of Earth-orbital activity, such as astronomy, meteorology, cartography, and military reconnaissance. The word "weltraumstation" was a shorthand description for the entire gamut of orbital spaceflight technology.

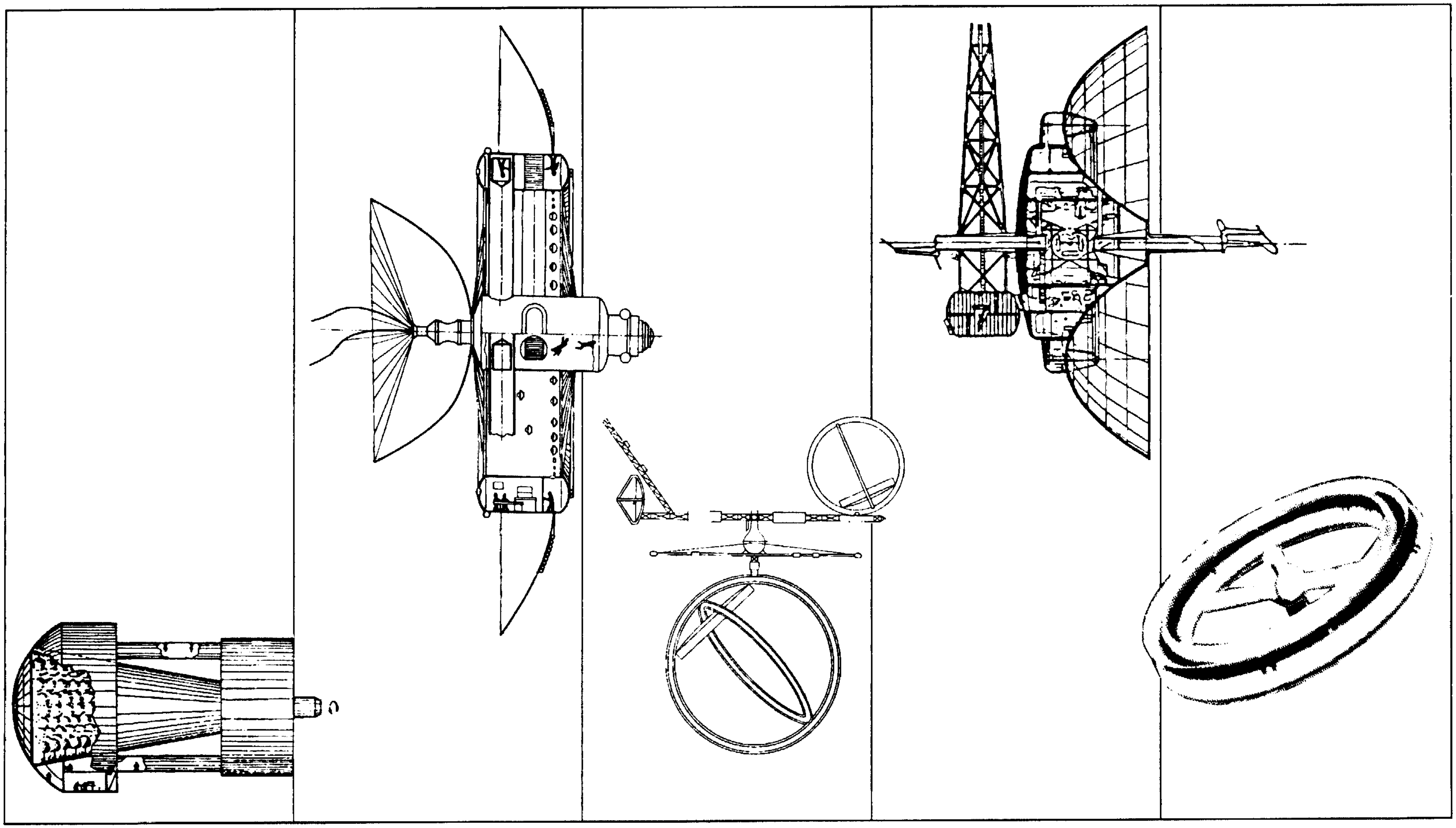
Wernher von Braun was one such young enthusiast. A protege of Oberth, he rose in the thirties to become the premier rocket designer-engineer of his time. Unfortunately, the cost of building a rocket--the first logical step into space--was so high that the only patron available was the state of Nazi Germany. Von Braun saw the V2 as an intermediate step towards the much grander vision of a manned mission to Mars. He and other visionaries such as Krafft Ehricke left Germany at war's end to work for the United States. Thus, serious space station thinking came to the United States in 1945.

In the fifties, many groups began to think of the immediate and practical uses of space--both civilian and military. Von Braun was in the forefront of the space race, but he dreamed of a space station in permanent Earth-orbit that would satisfy a wide range of scientific, economic, and political objectives--and serve as a base for future missions to the Moon and to Mars. He postulated that to get to that step, the United States should first build a small test bed orbital laboratory. Others agreed in principle, and the debate continued: How long should such an orbital laboratory last? What was its primary function--to test man, or technology, or both? How many crew? Would it be resupplied? What altitude and inclination? Should it be built in space, or on the ground and deployed in space?

NASA, created in 1958, became the forum for the space station debate. In 1960, space station advocates from every part of the fledgling space industry gathered in Los Angeles for a Manned Space Station Symposium where they agreed that the space station was a logical goal but disagreed on what it was, where it should be put, and how to build it.

In 1961, President Kennedy decided that the Moon was a target worthy of the American spirit and heritage. A lunar landing has an advantage over a space station: everyone could agree on the definition of landing on the Moon, but few could agree on the definition of a space station. This disagreement was healthy. It forced station designers and advocates to think about what they could do, the cost of design, and what was necessary. What were the requirements for a space station? How could they best be met? The requirements review process started informally in 1963 and continued for 23 years. NASA officials asked the scientific, engineering, and business communities over

The Early Concepts



1900's Konstantin Tsiolkovsky	1920's Hermann Noordung	1930's Hermann Oberth	1940's Harry E. Russ and Ralph A. Smith	1950's Werner von Braun Chesley Bonestell

Historical Perspective

and over again--What would you want? What do you need? The answers flowed in, and NASA scientist and engineers puzzled over how to organize these wants and needs into an orderly, logical sequence of activity. Was the station a laboratory, observatory, industrial plant, launching platform, or drydock? If it were all of these things, how much crew time should be devoted to each?

In the sixties, working quietly in the shadow of the gigantic Apollo/Saturn program, space station designers and planners began to come to grips with the tough questions of safety, hardware, money, and manpower. Working from 1964 through 1966, they settled on the modular approach: a pay-as-you-go program that offered something to everyone. With incremental funding, NASA managers could provide an incremental space station. Yet cost remained a problem. Design costs were always eclipsed by operations costs. The longer a station stayed up in space, the more it would cost to operate and resupply.

In 1967 and 1968, NASA planners started looking at an advanced logistics vehicle concept for the space station. They already had a dependable transportation system (Saturn) to launch station modules. What they needed was a relatively inexpensive way to resupply the station. This reuseable spacecraft would shuttle between Earth and the space station. Hence, the word "shuttle" was selected in the summer of 1968.

NASA officials felt that the station/shuttle combination served everybody's needs well.

The station had always been a logical step into space. The problem was that not everyone in the country agreed that developing space technology was a logical thing to do. The station program was caught in the shifting tides of politics and culture. Furthermore, the station and the shuttle began to be perceived as two separate entities, which had not been anyone's original intention. In 1970, plans to launch modules via Saturn technology were canceled, and station designers were told to scale down their modules to fit inside the shuttle, which would now do double duty as launch and resupply vehicle.

Thus, in 1972, in the approval of a reusable space transportation system, the space station concept itself was approved. The transportation segment, called the Space Shuttle, would be developed first. The space station itself would await the future. But before the Shuttle could be developed and made operational for a space station, the Saturn would be used as both a launch vehicle and the spacecraft for America's first space station: Skylab.

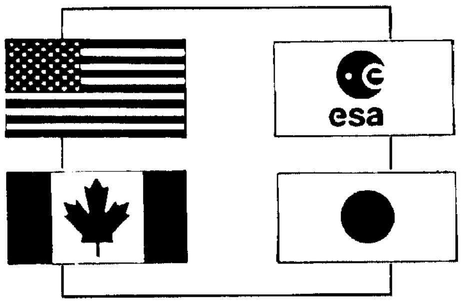
The Skylab was launched in 1973 and performed the first American experiments in long duration, manned spaceflight. Even though Skylab had a short life and was not equipped for resupply of key expendable items, it did foreshadow the promise of a permanently-manned laboratory in space. The Skylab effort proved that humans could live and work in space for extended durations, and more than 100 different experiments in life and materials science, earth and solar observation were conducted successfully.

When the first Space Shuttle flew, in April of 1981, once again the space station was considered the next logical step in manned spaceflight. In May of 1982, a Space Station Task Force was formed, and a year later they had an initial space station concept. Cabinet-level departments and agencies studied the concept, and in January of 1984, President Reagan committed the nation to the goal of developing a permanently manned space station within a decade.

The Space Station Program Office was established in April of that year, and in April of 1985, eight contractors were selected to do a detailed definition of the space station. In March of 1986, the Systems Requirements Review settled on a dual keel configuration for the space station, affording a better microgravity environment, more capacity for attached payloads, and better location for the servicing bay than a single transverse boom The U.S. reduced the number of their laboratory modules to one when the Europeans and Japanese decided to provide one each.

Although the definition and preliminary design phase ended in January 1987, the remainder of the year was spent conducting cost analysis, review of technical design issues, developing procurement packages, reviewing science requirements, developing operations concepts, and reporting to Congress and Commissions. The Development Contracts were announced in December 1987. These efforts resulted in the Baseline Configuration that is discussed in this document.

An International Perspective



Formal international agreement among the dozen nations to participate in the Space Station Freedom program took place in Washington on September 29, 1988, the very day Shuttle Discovery returned the U.S. and the free world to business in space after a 32-month pause.

In his 1984 State of the Union Address, when President Ronald Reagan directed NASA to develop a permanently manned space station, he also stressed international participation. "NASA will invite other countries to participate, " he declared, "so we can strengthen peace, build prosperity and expand freedom for all who share our goals."

Japan, Canada and the 13 nations involved with the European Space Agency (ESA) soon expressed interest in order to augment their own unmanned space efforts. Most of these nations have already discussed utilization requirements of a prospective space station as early as 1982, so the announcement came as no surprise.

Right after the State of the Union Address, negotiations began on cooperation in the space station definition and preliminary design phase. By the spring of 1985, ESA, Japan and Canada had signed memoranda of understanding to share in the benefits and risks of an international space station devoted to the peaceful uses of space.

A year later, in mid-1986, the four partners had achieved program-level agreement on flight hardware contributions. Then they began formal negotiations on detailed design, development, operations and utilization of the space station. These negotiations were successfully concluded in June of 1988 with both multilateral intergovernmental agreements and bilateral memoranda of understanding signed in Washington on September 29. The four partners agreed to dube the station "Freedom."

Thus, Space Station Freedom is an international endeavor. International cooperation is traditional in NASA programs, and a key objective of the U.S. civil space program is the promotion of international cooperation in space.

Canada specializes in remote sensing, space science, technology development and communications in its space efforts. Building upon the Remote Manipulator System which has served the Space Shuttle for most of this decade, Canada chose to develop a Mobile Servicing System for Space Station Freedom.

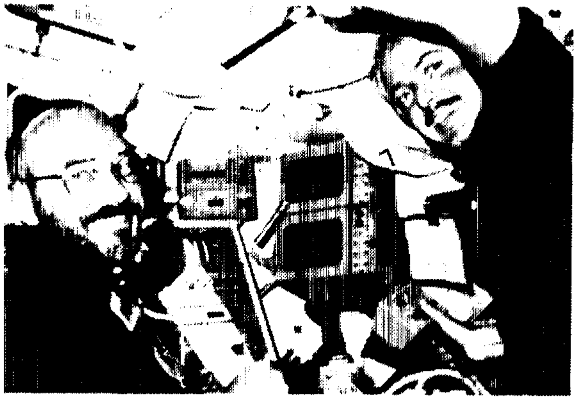
Program management for Canada's space station activities resides in the National Research Council of Canada. The Ministry of State for Science and Technology is the executive agency for Canada's space station participation.

Building on their experience with Spacelab aboard the Shuttle, ESA plans to build an attached pressurized module, a polar platform and a man-tended free flyer for the program. Already ESA is forming user communities for the station, and the member nations are planning to develop a new expendable launch vehicle (Ariane 5) and a reusable manned spacecraft, Hermes. The European Council of Science Ministers affirmed space station program participation in Rome in January of 1985 and reaffirmed it in November of 1987 at The Hauge.

Japan's contribution centers around the development and commercial use of the Japanese Experiment Module. A relative newcomer to space activity, Japan seeks advances in scientific observation, communications, materials processing, life sciences and technology development.

Based upon a $7 billion international contribution to the Space Station Freedom program, the partners will share in the utilization and in the operations costs according to formula: the U.S. has a 71.4 percent share, ESA and Japan 12.8 percent each, and Canada 3 percent.

A Utilization Perspective



The United States has begun the development of Space Station Freedom in cooperation with Japan, Canada, and the European Space Agency. The planned early uses of the station encompass a broad spectrum of research disciplines including life sciences, material sciences, astrophysics, earth sciences, planetary sciences, and commercial applications. A "user" is any individual, group or agency responsible for the development or operation of a payload, experiment, instrument, or mission utilizing a component of the program.

Based upon the needs expressed by many potential users over the past six years, plus reviews by scientific panels, independent boards and commissions, the initial requirements have been established. The program objectives have been finalized, and formal plans and documents are in the work to allocate and accommodate a broad mix of experiments and investigations in all disciplines. It is NASA's intention to utilize the station's unique environment and capabilities to the fullest extent possible for the conduct of science, the development of new technologies, and the support of the user communities, and to enable human exploration of the solar system.

The official NASA program objectives program are to:

- Establish mankind's ability to live and work in space
- Establish a permanently manned space station in Earth orbit by 1996
- Stimulate technologies of national importance (especially automation and robotics) by using them to provide space station capabilities
- Promote substantial international cooperation participation in space
- Create and expand opportunities for private-sector activity in space
- Provide for the evolution of the space station to meet future needs and challenges

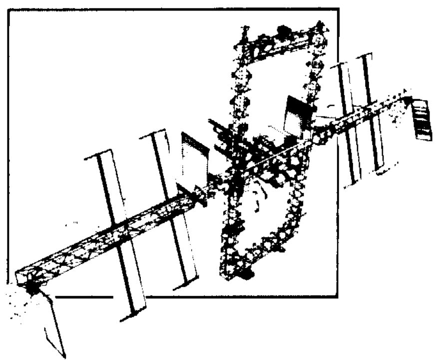
NASA and eight other federal agencies have drafted an important document regarding the research management of the station. The "Space Station Science and Applications Utilization Plan for U.S. Users" recognizes that the station will support three broad areas of activities: scientific research, technological development and commercial enterprise.

Since the beginning of the space era, the United States alone has invested more than $200 billion in space efforts, and the spin-offs for scientists and consumers have already proven well worth the investment. It has been estimated that this investment has been returned to the U.S. economy seven-fold. Partnerships among government agencies, private corporations and academic research centers have proven invaluable for the U.S. experience, and may be of value and interest to the international science community.

When Space Station Freedom is completely assembled, a broad spectrum of research in all the disciplines of life sciences, materials sciences, astrophysics, earth sciences and planetary sciences will be conducted. This will be accomplished with both manned and unmanned elements. The manned facility in a low Earth orbit will consist of four pressurized modules. Three of these modules--one each from the U.S., Europe and Japan--will serve as laboratories. The U.S. laboratory is designed to handle projects that need a stable microgravity environment for materials research as well as R&D in basic physics, chemistry and biology. The European and Japanese modules are designed primarily for research in fluid physics, life sciences and materials processing. The fourth module provides a habitation area for rest, recreation and health for the entire crew.

The unmanned elements of the program include free-flying platforms in polar or high-inclination orbit as well as attached payloads on the space station truss. The platforms will initially be used for earth observations in a variety of climatology and oceanographic studies. In summary, there will be a variety of manned, man-tended and unmanned user opportunities for science in, on, and around the space station.

A Futuristic Perspective



Background
Evolution planning for the long-term use of Space Station Freedom has been part of the program since Phase A. At the very start, NASA's Administrator called for the design of a "station we can buy by the yard," suggesting add-ons, developments and enhancements. The Space Station Task Force included a "Year 2000" concept that showed growth of the preliminary design, and Phase B contractor studies included system requirements for evolution of the station. Early in the program, two Space Station Evolution Workshops were held in Williamsburg, Virginia to explore station development. By 1985, it was decided that NASA Headquarters Office of Space Station should manage the evolutionary growth activities. NASA's Office of Exploration requested the Office of Space Station to look at the impacts of accommodating exploration missions. By 1987 the National Research Council Committee on Space Station endorsed the baseline configuration and urged NASA to continue to study "alternative evolutionary paths." A Presidential Directive on National Space Policy, issued on February 11, 1988, clearly states that Space Station Freedom" will allow evolution in keeping with the needs of station users and the long-term goals of the U.S."

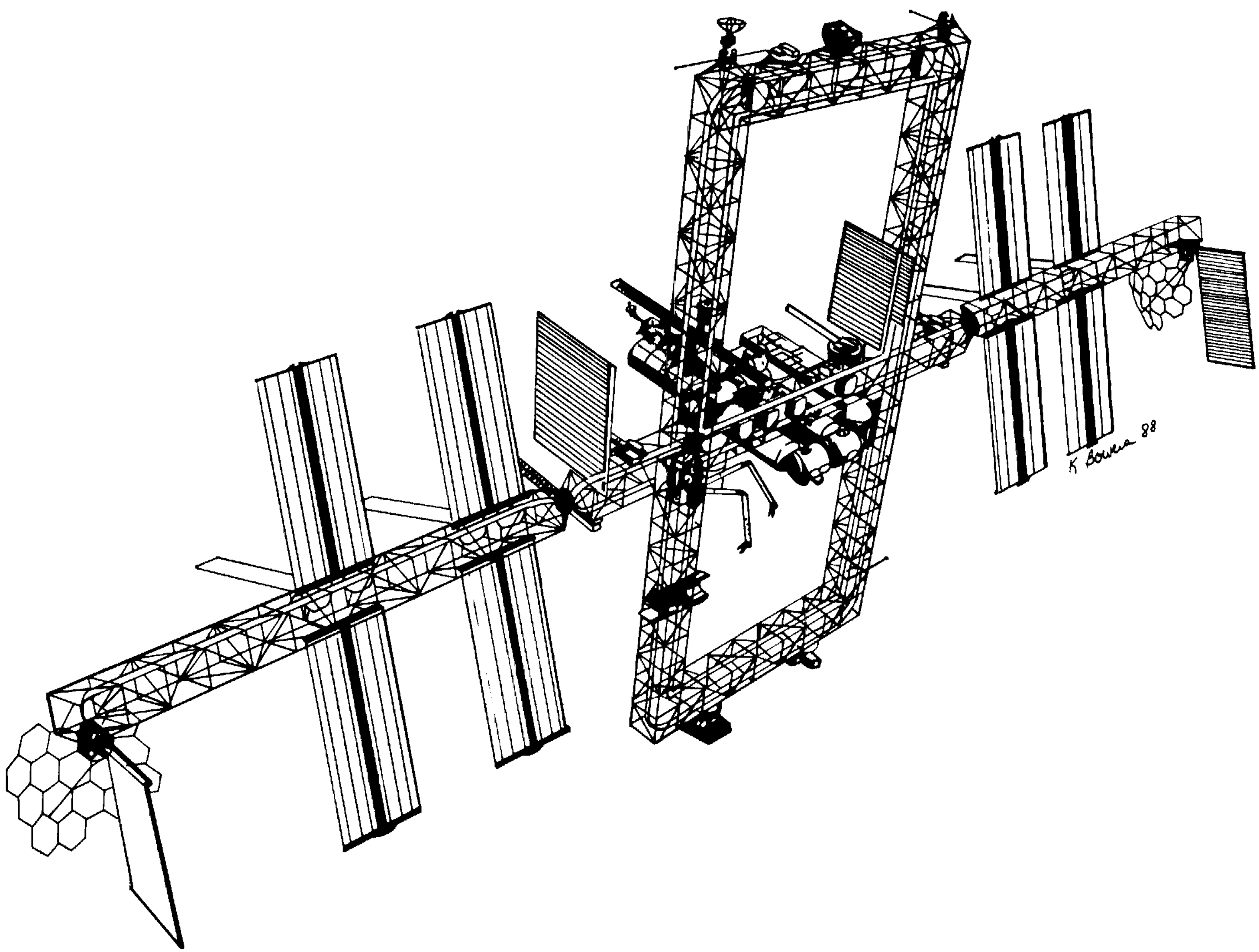
Hooks and Scars
From an engineering standpoint, these evolutionary changes will be accommodated by "hooks and scars." A "hook" is aerospace jargon for a design feature for the addition or update of computer software at some future time. Similarly, a "scar" is jargon for a design feature to add or update hardware at some future time.

Future Configuration
Although no decision has been made this far in advance, Space Station Freedom is being considered for enhancement sometime after the 20th assembly flight, planned for early 1998. The long transverse boom will be enhanced by two vertical keels about 105 meters long, and two 45-meter horizontal trusses at top and bottom. This "dual keel" configuration will add greater stability to the manned base, provide for many additional attached payloads and will offer a wide field of view for scientific instruments. Also included is a solar dynamic electric power system with an additional 50 kW.
The Mobile Servicing Center (MSC) will be enhanced to handle heavier payloads.

Lunar and Mars Mission Support
NASA scientists and technicians are developing scenarios on how Space Station Freedom can support other explorations. The dual keel configuration lends itself naturally to the function of a transportation node where spacecraft can be assembled, fueled and checked out for manned missions to the Moon or Mars. Subsequently, such a spacecraft could be berthed, refueled and repaired at the station upon its return. Space Station Freedom could conduct much-needed research in bioregenerative life support systems and artificial intelligence.
The station could define the limits of human endurance for long duration manned spaceflights in a weightless and hostile environment. The dual keel further lends itself to experimentation and as a quarantine facility before lunar and Martian samples are returned to Earth. Consequently, as space policy shifts, Congressional intent emerges, user demands change, and humans find new projects for outer space exploration, Space Station Freedom is presently designed for evolution to meet these and yet unheard-of uses for a 30-year, multi-purpose facility in low-earth orbit. Various growth concepts are shown in the next page.

Program Responsibilities
The Strategic Plans and Program Division (SPPD) of the Office of Space Station determines requirements and manages the Transition Definition program at Level I. The SPPD maintains the "Space Station Evolution Technical and Management Plan." Level II in Reston, Virginia manages the program including provision for the hooks and scars.
The Langley Evolution Definition Office chairs the NASA-wide Evolution Working Group (EWG) which provides interagency communication and coordination of station evolution, planning and interfaces with the baseline Work Packages.

Evolutionary Growth Option



Management

The Space Station Freedom program uses a three-tiered management structure. The three levels are as follows: Level I, the Office of the Associate Administrator for the Office of Space Station (OSS) at NASA Headquarters in Washington, D.C.; Level II, the Space Station Program Office in nearby Reston, Virginia; and Level III, the four NASA field Center project offices. This structure is shown on the next page.

The Associate Administrator for the Office of Space Station at NASA Headquarters, Level I, is responsible for the overall management and strategic planning of the program. Principal management responsibilities include policy direction, budget formulation, external affairs, and Space Station Freedom evolution. The Associate Administrator establishes and controls Level I technical and management requirements, milestones, and budget allocations and forecasts. Coordination of external affairs with both legislative and executive branches, user communities, and international partners, as well as internal units of NASA Headquarters that support the program, also falls under the jurisdiction of the Level I Office of the Associate Administrator.

There are six divisions in Level I: Information Systems, Resources and Administration, Policy, Operations, Utilization, and Strategic Plans and Programs. Level I is responsible for defining and controlling the program requirements, schedule, milestones and resources.

The Space Station Program Office (SSPO), Level II, is responsible for development of the space station, the operational capability of flight and ground systems, and the control of internal and external interfaces. Principal responsibilities include systems engineering and analysis, program planning and resource control for both development and operations phases, configuration management, and integration of elements and payloads into an operating system. This office is headed by the Director of the Space Station Program, who is responsible for the day-to-day management. The Jet Propulsion Laboratory (JPL) provides an independent program requirements and assessment function, attached to this NASA Program Office.

There are four offices and five groups in Level II: Safety/Product Assurance, Program Support, Program Integration, and Program Requirements and Assessment. The groups include Program Control, Program Information Systems Services, Program Utilization and Operations, Program Systems Engineering and Integration, and International Programs.

In addition, there are two supporting offices from other NASA organizations: the accounting office and procurement office.

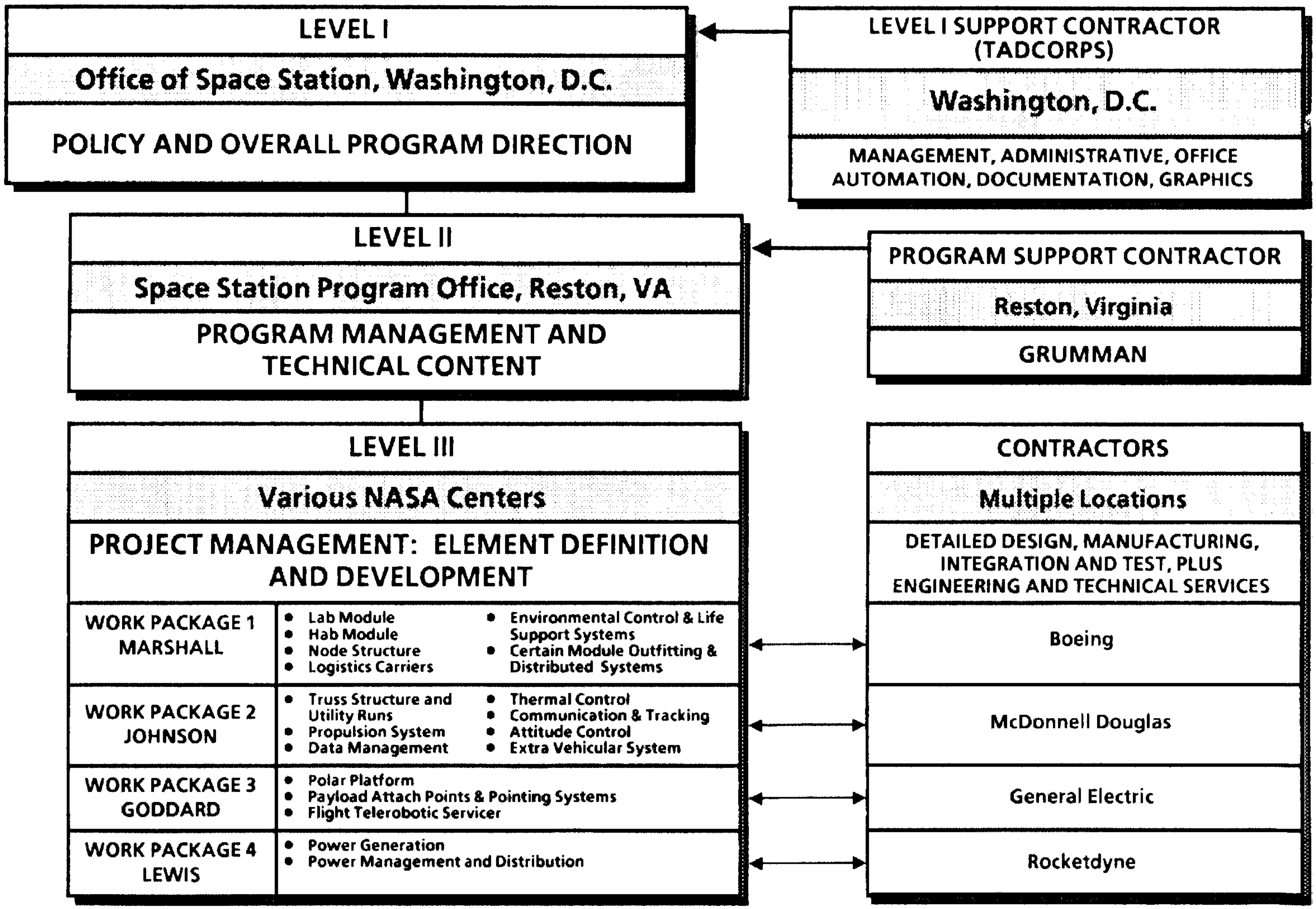
Level III consists of the four Work Package Centers and their contractors which are responsible for Design, Development, Testing and Evaluation (DDT&E); operation of hardware and software systems; and element, evolution, and engineering support. A Space Station Project Office is located at each of these Work Package Centers. The project managers of these offices report to the Director of the Space Station Program.

The management structure of these Centers is discussed later in this Handbook under each of the NASA Center descriptions.

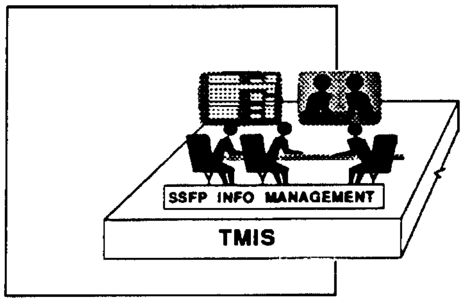
A Space Station Management Council assists the Associate Administrator in overseeing the program and advises on management, programmatic and institutional matters. This management council is composed of the Associate Administrator for Space Station and the Deputy; the Director of the Space Station Freedom Program and the Deputy; and the Center Directors of the following NASA Centers: Marshall Space Flight Center, Johnson Space Center, Goddard Space Flight Center, Lewis Research Center, Kennedy Space Center, Langley Research Center, and the Jet Propulsion Laboratory.

Other advisory boards, groups, and committees are appointed as necessary and as the program situation dictates.

Management


LEVEL I
Office of Space Station, Washington, D.C.
POLICY AND OVERALL PROGRAM DIRECTION
LEVEL I SUPPORT CONTRACTOR (TADCORPS)
Washington, D.C.
MANAGEMENT, ADMINISTRATIVE, OFFICE AUTOMATION, DOCUMENTATION, GRAPHICS
LEVEL II
Space Station Program Office, Reston, VA
PROGRAM MANAGEMENT AND TECHNICAL CONTENT
PROGRAM SUPPORT CONTRACTOR
Reston, Virginia
GRUMMAN
LEVEL III
Various NASA Centers
PROJECT MANAGEMENT: ELEMENT DEFINITION AND DEVELOPMENT
WORK PACKAGE 1 MARSHALL
• Lab Module • Hab Module • Node Structure • Logistics Carriers • Environmental Control & Life Support Systems • Certain Module Outfitting & Distributed Systems
WORK PACKAGE 2 JOHNSON
• Truss Structure and Utility Runs • Propulsion System • Data Management • Thermal Control • Communication & Tracking • Attitude Control • Extra Vehicular System
WORK PACKAGE 3 GODDARD
• Polar Platform • Payload Attach Points & Pointing Systems • Flight Telerobotic Servicer
WORK PACKAGE 4 LEWIS
• Power Generation • Power Management and Distribution
CONTRACTORS
Multiple Locations
DETAILED DESIGN, MANUFACTURING, INTEGRATION AND TEST, PLUS ENGINEERING AND TECHNICAL SERVICES
Boeing
McDonnell Douglas
General Electric
Rocketdyne

Management Support and Information Systems Contracts



Office of Space Station (OSS) Support Contractor
On March 29, 1988, the Technical and Administrative Services Corporation (TADCORPS) won the recompetition for the Management and Administrative Services Contract for the Office of Space Station (Level 1) in Washington, D.C.. The TADCORPS staff has been supporting the program continously since the original Space Station Task Force in 1983.

TADCORPS provides a broad range of support services to all of the OSS Divisions and staff. This support includes official Space Station Freedom Level I documentation including all formal presentations and briefings to Congress and other government agencies, institutions, professional associations, and public organizations, support for conferences, workshops and symposia, development of non-TMIS PC applications and data bases, technical writing and editing, and technical support to all the Divisions. TADCORPS also augments Level I with office automation services, computer graphic and photographic services, and special papers and reports. This contract employees approximately 22 people and is valued at $6.4 million over 5 years.

Space Station Freedom Program Office Support Contractor (SSFPO)
In July of 1987, The Grumman Corporation won the competitive procurement to be the program support contractor (PSC) for the Space Station Freedom Program Office (Level II) in Reston, Virginia.

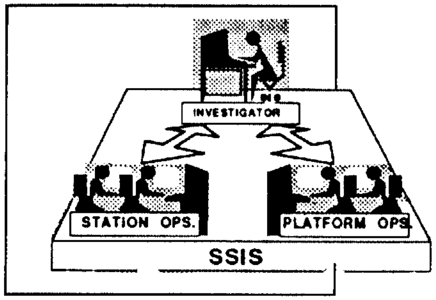
The Grumman team supports the SSFPO in program control and management, information systems, operations, program requirements and assessment, utilization, systems engineering, safety, reliability, quality assurance and international integration. The PSC also develops test requirements for verification, assembly and overall integration of space station components. This contract currently employees 640 people with growth to about 1300 in the mid 1990's and would exceed $1 billion over 10 years.

Information Systems Contracts
Information systems will be used by the program to collect, transport, and make available quantities of diverse information to a wide variety of program participants. The three interrelated systems that together comprise the Information System are: The Technical and Management Information Systems (TMIS), The Space Station Information System (SSIS) and the Software Support Environment (SSE). These systems will support both the development and operational phases of the program as described below.

Technical and Management Information System (TMIS)
The Space Station Freedom Program Office (Level II) implemented TMIS in 1988. TMIS is a system which acquires, organizes, controls, and uses vast amounts of technical and management data in order to maximize the effectiveness and efficiency of technical and management processes. The system is designed to handle a continuing stream of data and maintain its usability over the lifetime of the station. In order to increase the cost effectiveness of the station's design, development, and operations, TMIS integrates engineering data drawings, cost data, payload/accommodation data, planning data, and schedules.

TMIS includes the hardware, software, services, and people which allow program participants to exchange accurate information in a timely manner. With this system, the Program Office is able to control technical quality, cost, and schedule across all space station developers. TMIS will serve as the primary mechanism for the routine interchange of data among the Program Office, Work Package Centers, program support contractor, international partners, and development contractors throughout the life of the program. Since the program is so dynamic, there will be many changes in areas such as participants, locations, computing requirements. TMIS is designed to accommodate these changes. The Boeing contract for TMIS currently employees 250 people including subcontractors and is valued at $330Million.

Management Support and Information Systems Contracts



Space Station Information System (SSIS)

The SSIS will be an extensive collection of heterogeneous hardware (computers, networks, facilities) and software, whose primary purpose is to carry data to and from a space-based source and a ground-based user. The data source could be a scientific instrument on the manned base or on a platform; it could be a piece of on-board equipment (such as a space station subsystem); or even an on-board crew member. The ground-based user could be an experimenter operating from his home institution; or an operator based in a spacecraft control facility. The data itself might be: scientific data; housekeeping data used to monitor equipment health and safety; a database query; or even audio and video data forming part of a space-ground or ground-ground teleconference. Most of these dataflows will also occur, simultaneously, from ground to space.

The collection of hardware and facility elements involved in this process is large and varied. Some of these elements are new and NASA unique or extended versions of existing capabilities. Some elements are outside of the Space Station Freedom Program (and even NASA) control, such as user facilities. However, being connected to SSIS and using its services, they can be considered to be SSIS constituent elements.

There is no single SSIS contractor. Most of the current work for the manned base is under the Work Package II contractor McDonnell Douglas and their subcontractor for the on-board Data Management System (DMS), IBM.

The way in which users are connected to, and interact with, the system is fundamentally different from previous missions. These differences are captured in three new terms: teleoperations, teleanalysis, and telescience.

Teleoperations

The teleoperations concept is often described as the ability for a user to interact with their payload as if that payload were in a laboratory "next door". The realization of this concept imposes some stringent requirements on the intervening data systems:

- They must provide constant, standard interfaces so that the payload/user interface looks the same regardless of whether the payload is on a testbench in the manufacturer's facility, in an integration facility at the launch site, or in orbit attached to the station or a platform.
- They must provide data transparency with minimum interference or required knowledge of the data networks regardless of the data content.
- They must transport data with minimum delay so that the investigator can interactively change the course of an observation based on current information.
- They must provide all of the above regardless of the customer's physical location: at his home institution, at a NASA facility, or at an international location.

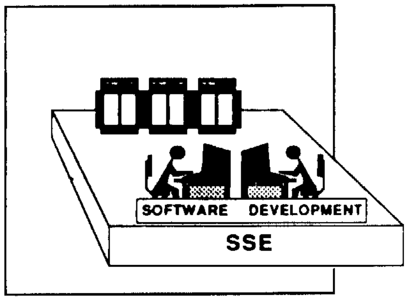
Teleanalysis

Teleanalysis extends the concept to the ground processing of payload (and other) data. It includes the ability to locate useful data in distributed databases and archives, to extract and receive subsets regardless of their physical location and finally, to combine and reprocess datasets (possibly from different investigations) to produce new datasets of increased utility.

Telescience

The combination of teleoperations and teleanalysis yields telescience - a mode of investigation in which telecommunications resources are used for the most effective division of functions among ground facilities, and between ground and space. Realization of all aspects of the telescience concept will require the cooperation and integration of a multitude of resources, including other information systems such as the Science and Applications Information System (SAIS) and the Earth Observing System Data and Information System (EosDIS). However, the foundation for these broader concepts, and the vital connection between investigator and payload, are provided by SSIS.

Management Support and Information Systems Contracts



Software Support Environment (SSE)
In July of 1987, Lockheed Missles & Space Co. won the competition for the SSE contract. The primary goal of the SSE is to minimize the cost and risk traditionally associated with large, complex software development efforts, and the subsequent sustaining engineering and maintenance of that software. The primary approach of the SSE in meeting this goal is to provide a complete and consistent support environment for the development and maintenance of Space Station Freedom Program mission software.

The support environment consists of several components: Software engineering tools; hardware tools; operating system interfaces; software development rules and procedures; and, software standards. The common computer language specified for operational space station software is Ada.

The focus of development for the SSE itself is the SSE Development Facility (SSEDF). This facility is dedicated to the specification, development, maintenance and distribution of all of the SSE components listed above. Essentially, the SSEDF is an "SSE factory" - it produces no mission software itself. The SSEDF will be responsible for life-cycle maintenance and configuration management of the evolving hardware and software tool set.

A Software Production Facility (SPF) is a physical computer system which hosts a subset of the SSE-defined software tools and procedures. The SPF can be used, in a local environment, to develop mission software according to the standards, methodologies and guidelines provided by the SSE. SPFs will be located primarily at the sites of the implementation contractors who will be doing the bulk of the software development, however, a SPF can be located wherever mission software is being developed.

A typical implementation center consists of a group of SPFs at contractor sites remote from the NASA Center controlling that Work Package. Typically one of the SPFs will be designated to integrate and test software from multiple SPFs. The output is software integrated at the Work Package level.

Since the Work Package Centers are distributed, a final level of integration is required to produce program level integrated software systems - this is the job of the Multi-System Integration Facility (MSIF). The MSIF will integrate and test mission software from all sources - Work Package Centers, individual SPFs at other sites, and in some cases, software from non-SSE sources.

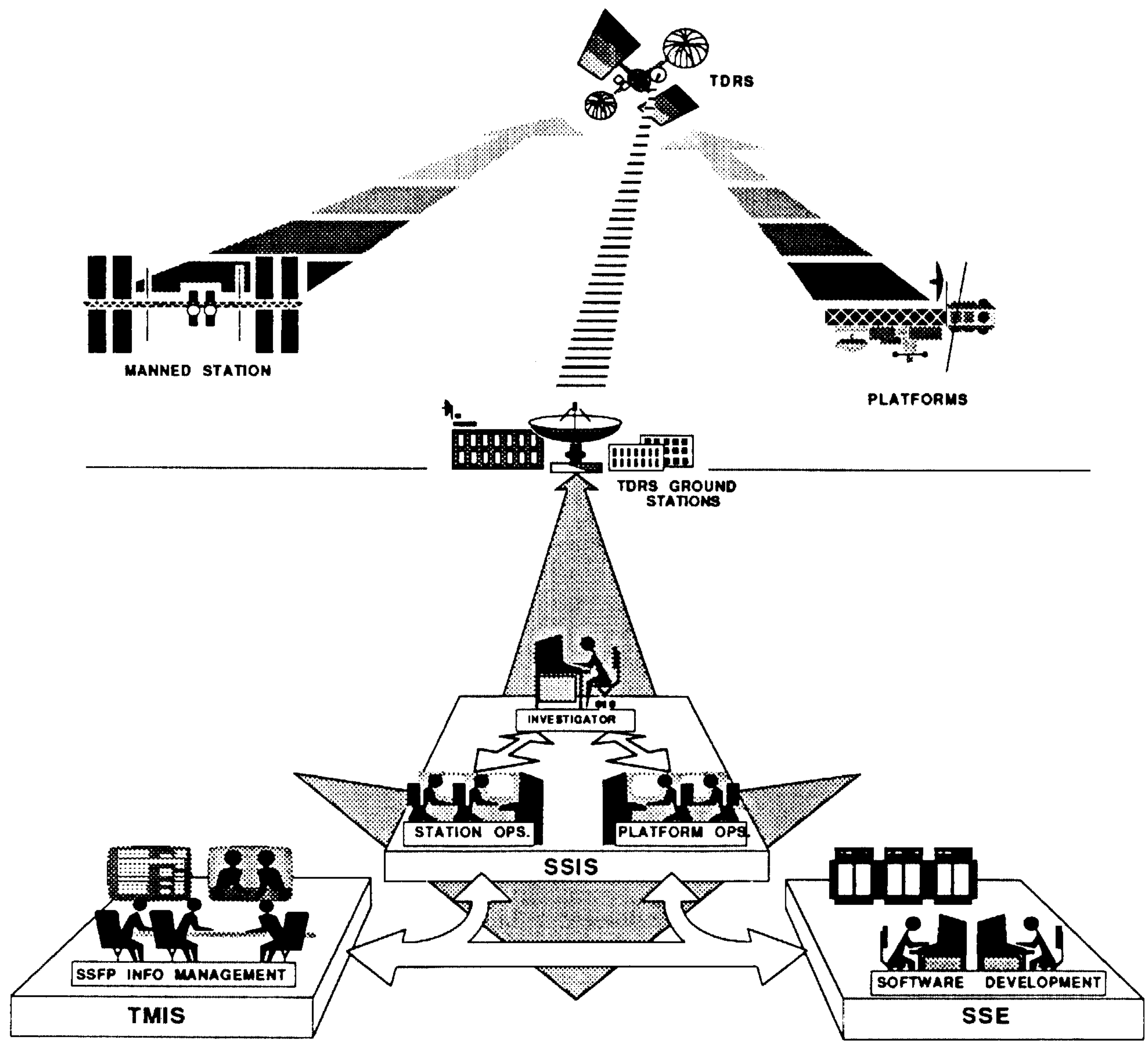
Lockheed currently has about 200 people including subcontractors working on SSE. The contract is valued at $242 million over six years with options for 3 more years.

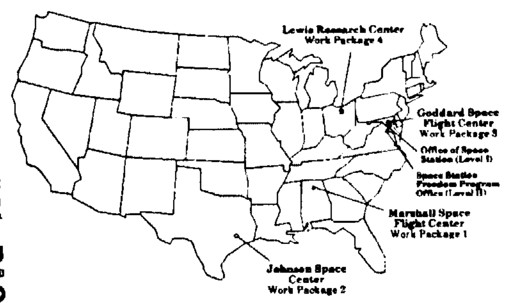
Integration of Information Systems
TMIS, SSIS, and SSE operate in harmony. Software developed and tested using SSE can be transferred to the space station elements via SSIS both before launch and during operations. SSIS and TMIS will both store information that will be necessary during flight operations. Data of critical importance, such as checklists and procedures, will be stored on-board within SSIS for rapid access. Backup data, such as drawings and design documentation, will be kept in TMIS where it can be accessed as needed either by crewmembers or ground controllers as well as designers of new capabilities.

TMIS is the repository of design knowledge however, detailed information on software will reside within SSE. The relationship between TMIS and SSE is being defined more specifically. Reports on the software engineering process will be sent from SSE to the TMIS for management review; schedules, plans and high-level design data will flow from TMIS to SSE as functions are allocated for software development.

SSIS will provide the standards and protocols that allow SSE and TMIS information to flow to and from operational users regardless of their location.

Management Support and Information Systems Contracts





ORIGINAL PAGE IS
OF POOR QUALITY

In 1986, General Samuel Phillips, former Apollo Program Director, chaired a committee to review the station's overall management structure and work package responsibilities. The Phillips Committee recommendations were structured to maintain contractor accountability is essential to cost control, and it demands clearly definable, deliverable items that can be integrated and checked out independently. It also requires the assignment of the entire design and development responsibility for each deliverable item to a single contractor.

Futher review, in the fall of 1986, resulted in a refinement to the field Centers' development responsibilities which has been recommended by the Phillips Committee.

The Work Package Centers are responsible for:

(1) design, development, testing,and evaluation;

(2) operation of hardware and software systems; and

(3) integration of element evolution, engineering support, and user operations

Work Package 1
The Marshall Space Flight Center in Huntsville, Alabama and its prime contractor, Boeing Aerospace will design and manufacture: the astronaut's living quarters - the Habitation Module; the U.S. Laboratory Module; the logistics elements; the resource node structures connecting the modules; the Environmental Control and Life Support System; and the Thermal Control and audio-video systems located within the pressurized modules. It also is responsible for the technical direction of the Work Package 2 contractor for the design and development of the engine elements of the propulsion system. In addition, MSFC is responsible for operations capability development associated with Freedom Station payload operations and planning.

Work Package 2
The Johnson Space Center in Houston, Texas and its prime contractor, McDonnell Douglas Astronautics Company, will manufacture: the integrated truss assembly; the propulsion assembly; the mobile transporter system; the outfitting of the resource node structures provided by Work Package 1; the EVA system; the external Thermal Control system; the attachment systems for the Space Shuttle and experiments packages; the Guidance, Navigation and Control System; the Communications and Tracking System; the Data Management System; and the airlocks. It is also responsible for the technical direction of the Work Package 1 contractor for the design and development of all man systems. In addition JSC is responsible for flight crews, crew training and crew emergency return definition, and for operation capability development associated with operations planning.

Work Package 3
The Goddard Space Flight Center in Greenbelt, Maryland and its prime contractor, the Astro-Space Division of General Electric Company, will manufacture: the servicing facility, the flight telerobotic servicer, the accommodations for attached payloads, and the U.S. unmanned free-flyer platforms.

Work Package 4
The Lewis Research Center in Cleveland, Ohio and its prime contractor, the Rocketdyne Division of Rockwell International, will manufacture the Electrical Power Systems.

The above Work Package Centers will be supported by the other NASA Centers in fulfilling their responsibilities. For example, the Ames Research Center (ARC) will provide supporting research and technology to Work Package 2 in the areas of human factors and the EVA system.

A listing of the contractors involved in the program can be found in Appendix A.

Program Phases

PHASE - A Concept Phase (Requirements & Architecture) From Authorization of the SSTF (5/82) to Award of the Phase B Contracts (4/85)

Concepts for a space station go back to the last century. Within NASA, conceptual studies and workshops go back to the early 1960's. Since the 1972 decision to develop the Shuttle first and launch Skylab in 1973, the Space Station program as described in this booklet was to be delayed until May of 1982, when NASA Administrator James Beggs authorized the Space Station Task Force (SSTF). In addition to organizing a new project and office, the SSTF conducted three major activities: 1) A major effort to define realistic missions that were enabled by or materially benefitted from the permanent presence of man in space. Studies were conducted by NASA advisory boards, in-house panels, and by industry under contract to NASA. Additional studies were undertaken by the international community. 2) Definition studies to define system requirements and interfaces, supporting systems and trade studies, a preliminary system design, and detailed plans for the development phase. And 3) advanced development activities. From August 1982 to April 1983, NASA funded the studies called "Space Station Needs, Attributes, and Architectural Options." In addition, a Mission Requirements Working Group was established to direct the industry studies and to integrate in-house activities and special studies such as the Space Science Board and Space Applications Board studies. This group was supported by three Mission Area Panels: 1) Science and Applications; 2) Commercial; and 3) Technology Development. The Working Group also maintained liaison with the international community who performed similar studies. Using the results of these studies and input from the various groups, NASA briefed the President and Cabinet in December 1983. In January 1984 the President directed NASA to build the space station within a decade.

1984 was the year for formulating the overall NASA management structure, reviewing requirements, conducting independent user and science community assessments, and developing a reference configuration that the Phase B contractors could bid against. President Reagan re-affirmed the space station program in the January 1985 State of the Union address. The first half of 1985 involved obtaining international participation and commitment for the program.

PHASE - B Definition and Preliminary Design Phase From Award of Phase B Contracts (4/85) to Award of Phase C/D Contracts (12/87)

In April of 1985, Phase B commenced with the four NASA Work Package Centers each awarding parallel definition contracts for their respective responsibilities. The eight definition contractors defined the system requirements, developed supporting technologies and technology-development plans, performed supporting systems and trade studies, developed preliminary designs and defined system interfaces and developed plans, cost estimates and schedules for the Phase C/D activities.

The Phase B definition studies were initiated in April 1985 and ended in January 1987. The contracts were awarded to the following:

• MSFC	(Work Package 1)	Boeing Aerospace Martin Marietta
• JSC	(Work Package 2)	McDonnell Douglas Rockwell International
• GSFC	(Work Package 3)	General Electric
• LeRC	(Work Package 4)	Rocketdyne TRW

The results of the definition studies were synthesized and integrated in to the Phase C/D Requests for Proposals (RFPs) released by each Work Package Center in April, 1987.

Also in the spring of 1985, NASA signed bilateral Memoranda of Understanding (MOUs) with Canada, ESA and Japan that provided a framework for cooperation on the space station during Phase B.

The user requirements were being reviewed and refined by various groups, committees and workshops. The results updated the Mission Requirements Data Base, and in June, 1985, the "Functional Requirements Envelope" was established to augment the Phase B RFPs.

By March 1986, the program reached a major milestone called the Systems Requirements Review (SRR) a traditional programmatic point that

PHASE - B Continued
From 4/85 to 12/87

marks the point at which the basic characteristics of the space station have been decided. This SRR process focused on technical decisions that, in May of 1986, established the baseline configuration called the "Dual Keel."

As a result of the Challenger accident in January of 1986, NASA went through an exhaustive evaluation period during which, among other Shuttle topics, management of major programs, such as space station, was examined. The NASA Management Study, led by ex-Apollo Program Manager General Samuel Phillips, made management, programmatic and organizational recommendations, many of which were implemented. Among these were the three levels of management; 1) the Headquarters Office of Space Station, 2) Space Station Program Office, later located in Reston, Virginia, and 3) individual Space Station Project Offices at those NASA Centers primarily involved with the program. The space station work was then allocated to those Centers in "Work Packages" that reflected the Center's expertise.

In August and September 1986, the program was subjected to an intense review by a specially constituted Critical Evaluation Task Force (CETF) which reaffirmed the soundness of the Dual Keel baseline configuration established at the SRR, but added resource nodes at the end of the Laboratory and Habitation Modules and revised the assembly sequence accordingly.

About this same time, the Operations Task Force was organized to focus operations planning by conducting a systemmatic assessment of station operations. This major effort involving over 150 people from the NASA Centers and contractors, took over a year and produced a major report that considered various options for achieving operations goals.

In 1987, a number of reviews by various independent groups and committees including the National Research Council (NRC) were conducted. The NRC, chaired by ex-NASA Administrator Dr. Robert Seamans, concluded in September that the program was a formidable challenge to NASA as the architect and program manager, but the commitment to the space station is, and must be, national in character. The NRC also endorsed the revised baseline configuration (what is now called Space Station Freedom) and stated that the nation's long-term goals in space should be clarified before committing to the evolutionary Block 2, or "Dual Keel" configuration.

PHASE - B Continued
From 4/85 to 12/87

Also published in September 1987 was the report by a specially constituted Space Station Science operations Study Team. This team of 60 key individuals examined science opportunities, operations, planning and management and concluded with a set of recommendations. The recommendations were considered and affected the Phase C work.

That year, 1987, was also a significant procurement period for the program. In addition to the four Work Packages, three separate and competitive procurements were conducted to support detailed design and development. The following contracts were awarded in 1987:

May	Technical & Management Information System (TMIS) - Boeing
June	Software Support Environment (SSE) - Lockheed
July	Program Support Contract (PSC) - Grumman
December	Space Station Design, Development & On-Orbit Verification

- -- Boeing (Work Package 1 Prime)
- -- McDonnell Douglas (Work Package 2 Prime)
- -- General Electric (Work Package 3 Prime)
- -- Rocketdyne (Work Package 4 Prime)

The contracts awarded in December were for Phase C and D. With these contracts in place, Phase B ended and Phase C - Detailed Design began.

Program Phases

PHASE - C Detailed Design From the Award of Phase C/D Contracts (12/87) to the Critical Design Review (1992)

Although many people use the term "Phase C/D", meaning both the design (C) and development (D) phases together, they are really two separate and distinct activities. The term C/D is used primarily because the same contractor generally does both the design and development including the manufacturing. Therefore, the contracts for these two major groups of activities are typically awarded together. However, in classical systems engineering, the detailed design takes the results of Phase B to the point of preparing detailed engineering drawings and specifications for hardware and software, which are design activities. However, nothing is actually built in Phase C except perhaps some test or prototype articles. Once the design passes a Critical Design Review, the design is "frozen" and handed off to the Development Phase D where actual manufacturing begins.

Phase C began with the announcements of the phase C/D contract awards in December of 1987, and due to adjustments in funding levels, analysis of program costs and adjustments in contractor work, schedules and responsibilities, the design phase got off to a busy start. The major engineering activity for 1988 was the Program Requirements Review (PRR) which proceeded on schedule. The PRR provides a critical review and assessment of the Level I requirements stated in the Program Requirements Document (PRD), and necessary Level III requirements to assure complete and consistent specification of program requirements, including: those whose satisfaction necessitates resources or capabilities outside direct control of the Space Station Freedom program; traceable satisfaction of high level requirements and constraints on the program; and elimination of requirements for which there is no need.

The Level I Office of Space Station review was completed in May 1988; the Level II Space Station Program Office review was completed in June 1988; and the Level III Work Package Centers review was completed in November 1988. Also, 1988 was the year for finalizing the details of the Work Package prime contractors once the program funding levels were determined and money appropriated. This allowed prime contractors to determine when they could get their subcontractors on-board and begin staffing up to their work assignments.

PHASE - C Continued

During the last half of 1988, the negotiations of international agreements regarding Phase C/D/E were completed and signed on September 29, 1988, the same day as the Discovery launch. This event culminated the efforts of the international partners and the U.S. to determine how they would work together to develop and operate Space Station Freedom.

Various committees and workshops occurred during 1988 to continue the review of requirements from all disciplines including the sciences, advanced technology and commercialization opportunities.

Another 1988 activity involved a major effort to determine the optimum launch and assembly sequence to provide an earlier man-tended capability. As a result of these studies it is planned for the U.S. Laboratory to be launched as early as the fourth launch in 1995 and that permanent manned capability can be achieved by late 1996. Completion of all the international elements would occur in early 1998. All of 1988 was filled with preparation of reports required by Congress on various topics. Major reports were delivered at the average rate of one per month.

Phase C activities planned for the fall and winter of 1988 included fulfillment of the required staffing, facility construction planning, development of an associate contractor relationship that will simplify the program integration process, and releasing two more Requests for Proposals (RFPs); one on the Test Control and Monitor System (TCMS) in September and one for the Flight Telerobotic Servicer in November.

Activities planned for 1989, 1990 and 1991 focus on preparing for the Initial System Preliminary Design, the Preliminary Design Reviews for the Man-Tended Capability and Permanently Manned Capability and, finally, a series of Critical Design Reviews.

PHASE - D Development (Manufacturing) From Critical Design Review (1992) to Assembly Complete (1998)

The development phase will be accomplished in four steps: 1) Equipment manufacture, test, and qualification; 2) Integration of all equipment in a central facility for integration, test, and verification; 3) Software integration and certification; and 4) Launch package integration. The manufacture of the various components of the space station will begin following the Critical Design Review.

The flight elements are vital parts of an orbital complex that must provide a safe and useable operational environment over the long term. They will be designed, developed, fabricated, and assembled in high-quality aerospace development centers by experienced people following proven procedures. Many of these centers and personnel have experience with the Shuttle and Apollo programs. Existing capital equipment, tooling, and production test equipment will be utilized extensively in order to minimize costs. Standard manufacturing processes will be employed to assume a dependable, high quality product.

The manufacturing of equipment will be performed at various locations. For example, the modules will be manufactured in Huntsville, Ala.; the truss assembly in Huntington Beach, Cal.; the power supply in Canoga Park, Cal.; and the payload attachment hardware in King of Prussia, Pa.

The Laboratory Module, for example, is comprised of several subsystems. The structure includes the pressure shell assembly, hatch and window assemblies. There are racks which will be used to house experiments, payloads, and consumables. The Environmental Control and Life Support System (ECLSS), the Thermal Control System (TCS), Electrical Power System (EPS), Audio and Video Systems and Data Management System (DMS) are also subsystems of the Laboratory Module. Some of these components will be manufactured by Boeing's subcontractors and other Work Package contractors at various locations throughout the U.S. These components, together with those built by Boeing at Huntsville, will be assembled into the U.S. Laboratory. The assembly and acceptance testing of the U.S. Lab, as with the Habitation Module and Logistics Elements, will take place in Huntsville.

PHASE - D Continued

Unlike other space programs where the total spacecraft is assembled at the manufacturers, assembly of space station elements must occur on-orbit and will, therefore, require training of astronaut crews in near zero gravity conditions to practice performing the delicate and complex assembly maneuvers safely and efficiently. Such training will be performed in large water immersion facilities such as the Neutral Buoyancy Laboratory at JSC and a similar facility at MSFC. The astronauts will be working under water with structural mock-ups of the flight hardware that will simulate their spatial mass and inertia characteristics to gain experience in handling these elements prior to actual assembly on-orbit.

Another facility, the Multi-Systems Integration Facility (MSIF), will integrate program software to ensure that developer systems are integrated, tested, and certified as flight ready. This facility will be located in Houston, Texas.

Prior to launch, all components are sent to the Space Station Processing Facility (SSPF) at KSC. Here, the entire system is assembled and thoroughly tested. Tests are performed to verify that flight software and hardware are compatible and correctly installed.

First Element Launch (FEL) is scheduled for early 1995. Four major launches and Space Station Freedom will have Man-Tended Capability near the end of 1995.

By Flight 11, scheduled for the end of 1996, the space station attains Permanently Manned Capability, but Phase D is not complete until assembly is complete. That comes with Flight 20, scheduled for early 1998.

Program Phases

PHASE - E Operations (Overlaps Phase D) From First Element Launch 1995 To End of Life (2025?)

Operation of a permanently manned station must satisfy a wide variety of payload users, ground operators in many types of facilities, and a crew living and working for long periods of time in near weightlessness. Onboard the station, an eight member crew will be divided into four-member teams and will follow predetermined plans for experiments and station operations. The crew will work a nominal six-day week with the seventh a common day off for all shift members. Each team will have some combination of three functional specialists: station operators, station scientists, and payload scientists. This specialization provides a core group of career astronaut scientists with research scientists to operate specific payloads.

Planning for the space station operations and utilization is designed to maximize the use of on-board resources. Operations planning for the long, medium, and short range is centrally managed to account for system and user demands, ensuring an integrated schedule is available at each stage of payload development, checkout, and flight. Below this level, detailed planning is distributed to the actual users, and to operators of the space station. This arrangement provides these groups with the flexibility to meet rapidly changing conditions and to accommodate unexpected payload research opportunities during flight.

The Space Station Control Center (SSCC) at the Johnson Space Center will perform station systems management and interact with a Payload Operations Integration Center (POIC) at the Marshall Space Flight Center which will work with users either individually or through user-provided operations centers. Predefined allocations will govern distribution of available resources among both U.S. and overseas users of the manned base. An execution plan for payload operations will provide for experiments the crew will conduct, autonomous experiments, and those operated remotely via the station's information system by investigators in laboratories on Earth. Experiment scheduling will be according to requirements for resources such as crew time and power.

PHASE - E Continued

Payload integration will also use a distributed operations concept. Users will be able to integrate their experiments into racks and onto pallets at multiple user-operated sites certified by NASA. These sites will allow users to check payload hardware and software interfaces for proper operation before the payloads are transported to the launch site.

Logistics operations for the manned base will be concentrated at KSC. With the space station in orbit for 30 years, maintenance and servicing will be performed routinely. Station design provides for Orbit Replaceable Units (ORUs), which a crew member can remove and replace inside the pressurized volume or during an EVA. Critical replacement units will be stored on board, and others will be on the ground ready for transport in logistics elements as needed.

Five or six Shuttle flights a year are required to keep the station alive and well, and to satisfy all logistics requirements.

The United States polar platform system and payload operations will be conducted from a Platform Support Center (PSC) at the Goddard Space Flight Center. Users will be able to interact with payloads either directly from the Platform Support Center or from remote user centers. Logistics operations will be concentrated at the Vandenberg Air Force Base.

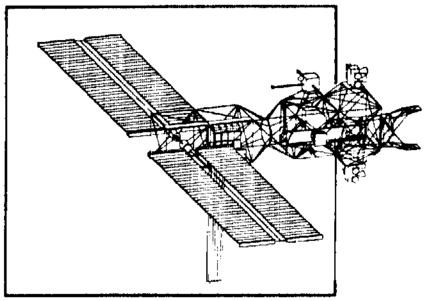
Phase E includes the enhancement of the revised baseline configuration in the Dual Keel. To provide the extra power needed for an enhanced, evolving station, solar dynamic system will be added to the photovoltaic electrical system. Various hooks and scars -- built in during the initial phases -- will carry state of the art hardware and software components as they are discovered, tested and proven, to carry Space Station Freedom well into the 21st Century.

Milestones

	CY87–CY99
PHASE C/D CONTRACT START DATE (CSD)	DEC 87
PROGRAM REQUIREMENTS REVIEW (PRR)	2ND QTR 88
CONTRACT DEFINITIZATION DATE	3RD QTR 88
PRELIMINARY DESIGN REVIEW (PDR-MTC)	3RD QTR 90
PRELIMINARY DESIGN REVIEW (PDR-PMC)	3RD QTR 91
CRITICAL DESIGN REVIEW (CDR-MTC)	2ND QTR 92
CRITICAL DESIGN REVIEW (CDR-PMC)	3RD QTR 93
PAYLOAD OPERATIONS INTEGRATION CENTER	4TH QTR 93
SPACE STATION CONTROL CENTER ORD	1ST QTR 94
DESIGN CERTIFICATION REVIEW (DCR-MTC)	2ND QTR 94
OPERATION PREPARATION REVIEW (OPR)	3RD QTR 94
SPACE STATION PROCESSING FACILITY ORD	3RD QTR 94
OPERATIONS READINESS REVIEW (ORR)	4TH QTR 94
FIRST FLIGHT READINESS REVIEW (FFRR)	1ST QTR 95
FIRST ELEMENT LAUNCH (FEL)	1ST QTR 95
DESIGN CERTIFICATION REVIEW (DCR-PMC)	2ND QTR 95
US POLAR PLATFORM LAUNCH VAFB	4TH QTR 95
MAN-TENDED CAPABILITY (MTC)	4TH QTR 95
PERMANENTLY MANNED CAPABILITY (PMC)	4TH QTR 96
JAPANESE MODULE LAUNCH	2ND QTR 97
EUROPEAN SPACE AGENCY MODULE LAUNCH	3RD QTR 97
ASSEMBLY COMPLETE PHASE 1	1ST QTR 98

PROGRAM MILESTONE — ALL PROGRAM MILESTONES UNDER REVIEW

Assembly



Space Station Freedom weighs about half a million pounds and is a too large and heavy to be placed into orbit by one launch vehicle. Based upon the Shuttle's performance and payload bay physical limitations, the current planning calls for approximately 20 Shuttle flights to get all of the elements, systems, and support equipment to low earth orbit. This assembly process will take about four years. The sequence in which these flights occur and packaging of selected parts is dependent on many factors. Early planning of the assembly sequence was based on various criteria such as utilization, manning, safety, power, and microgravity levels.

The following is a brief description of the Space Station Freedom's major assembly milestones. The Manned Base assembly sequence of twenty Space Shuttle flights has four major milestones as described below. These events are planned to be accomplished close to the completion of the 1st, 4th, 13th and 20th shuttle flights. The launch and deployment of the United States and ESA Polar Orbiting Platforms by ELVs are major assembly milestones independent of the Manned Base assembly sequence.

First Element Launch (FEL)
The first cargo will consist of a set of integrated Space Station Freedom components to provide a fully functional spacecraft as the "cornerstone" for the fully assembled Manned Base. This "cornerstone" will be the starboard end of the Manned Base and includes a power module with solar panels and radiators, S-Band communications pallet with antenna, a reaction control system and tank farm, the mobile transporter, an assembly work platform, and associated truss and alpha joint structures. This integrated assembly will provide its own power and heat rejection, adequate orbital life, communications with the ground, and the capability to rendezvous and dock with the Space Shuttle for the subsequent assembly flights.

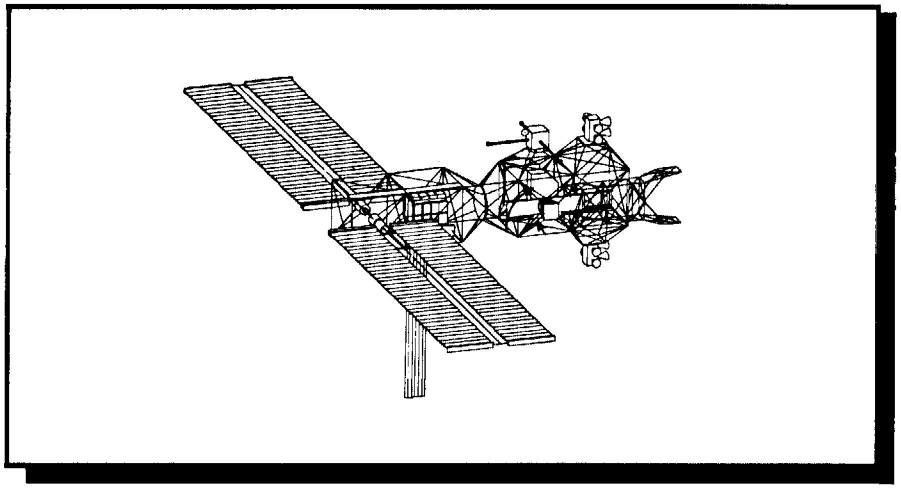
Man-Tended Capability (MTC)
Upon completion of the 4th assembly flight, added structure will extend to the approximate center of the Manned Base and include the starboard thermal control system, the Flight Telerobotic Servicer and shelter, a control moment gyro pallet, propulsion thrusters, power and fluid management distribution pallets, a TDRS antenna, the aft starboard node, the first phase Mobile Servicing Center, a pressurized docking module, module support structure, and the U.S. Laboratory Module outfitted to accommodate experiments. These added components and elements will provide the Manned Base with an early man-tended capability until PMC. The conduct of science and technology development in the U.S. Lab Module will be tended by astronauts on succeeding Shuttle assembly flights.

Permanently Manned Capability (PMC)
Upon completion of perhaps the 11th assembly flight, the complementing port side structure and components will have been added including the inboard power module with solar panels and radiator, tank farm, reaction control module, and logistics modules, attached payloads and equipment from the extended duration orbiter flights, aft and forward nodes with cupolas, airlocks and the Habitation Module.

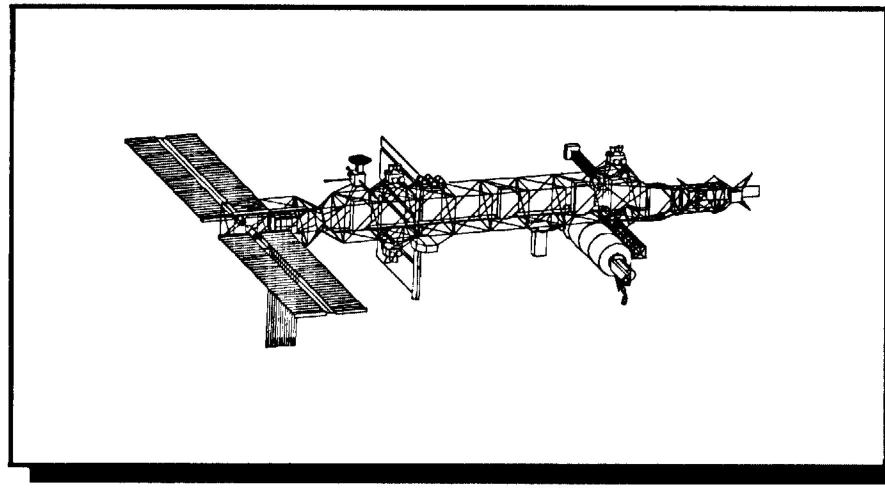
Initial crew size will be at least four persons and will grow to eight when the international modules are attached. The crew will have the capability to live and work comfortably and safely in pressurized volumes indefinitely, and be able to perform full space station-based EVAs. PMC will mark the beginning of full scale Manned Base operations on a day-to-day basis.

Assembly Complete
Upon complete assembly of the Manned Base, the Space Station Freedom Program will be a fully international space operation. The Japanese Experiment Module and the ESA Laboratory Module will be attached, and the Canadian Mobile Servicing Center will be in full operation. The crew will be fully integrated and composed of members from the four partners. Day-to-day operations will be centrally planned and coordinated through the Space Station Control Center and Payload Operations Integration Center, but execution of such activities will be initiated and controlled from remote partner payload operation centers as well as from on-board the Manned Base.

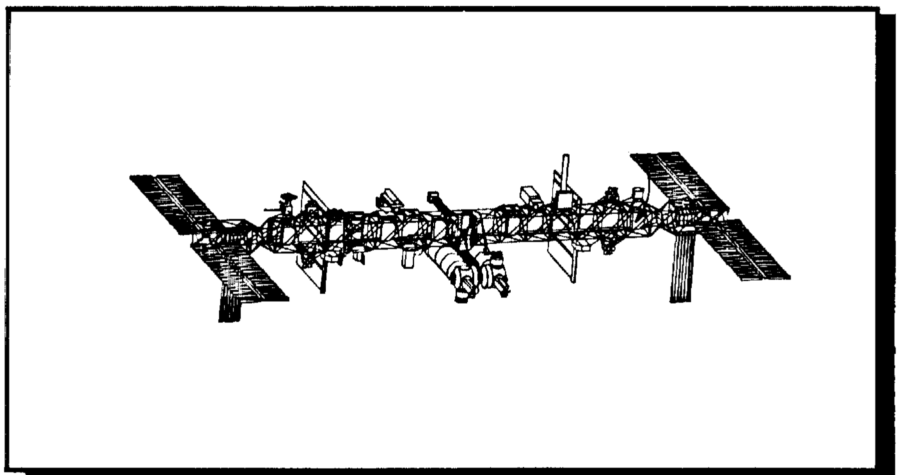
Assembly Sequence



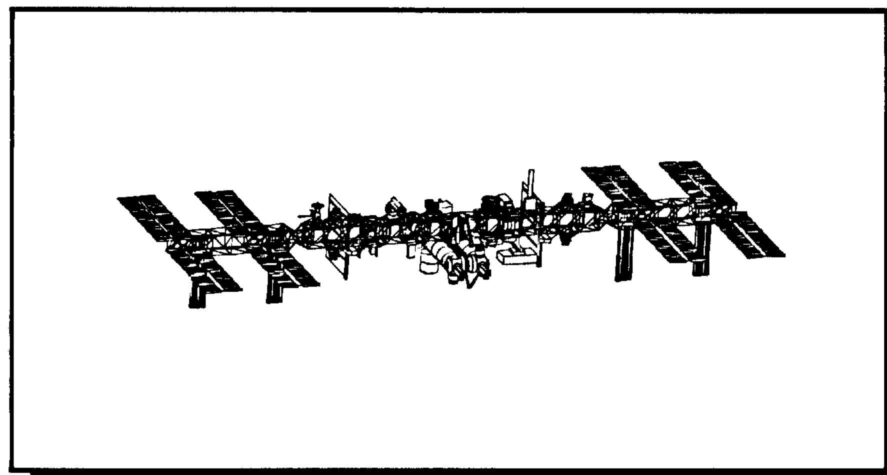
First Element Launch



Man-Tended Capability

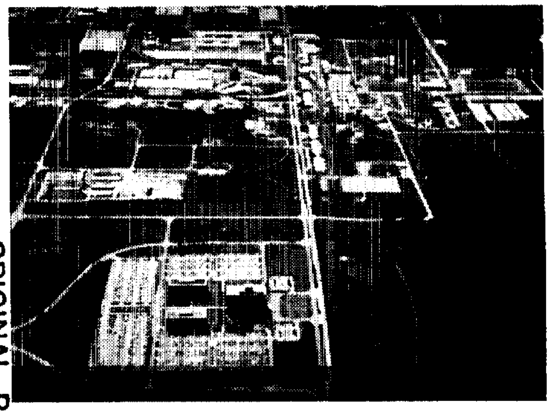


Permanently Manned Capability



Assembly Complete

Traditional Center Roles and Responsibilities



The Marshall Space Flight Center in Huntsville, Alabama, was established on July 1, 1960 through the transfer to NASA of part of the U.S. Army Ballistic Missile Agency. The Center was named in honor of General George C. Marshall, the Army Chief of Staff during World War II, Secretary of State, and Nobel Prize Winner for his world-renowned "Marshall Plan." Rocket pioneer Dr. Wernher von Braun was the Center's first director.

Marshall is well-prepared for its Freedom Station responsibilities, having managed America's first space station, Skylab, which was launched in 1973. In addition to having overall program management of Skylab, Marshall was responsible for much of Skylab's hardware and science experiment development and for the integration of the hardware and experiments into Skylab.

Marshall is also NASA's lead center for Spacelab, a Space Shuttle-based, short-stay space station that is serving as a stepping stone to the permanently-manned Freedom Station. Marshall developed selected Spacelab hardware and provided technical and programmatic monitoring of the international Spacelab development effort. The Center is also responsible for managing many Spacelab missions that include developing mission plans, integrating payloads, training payload crews, and controlling payload operations. Marshall is the home of NASA's Payload Operations Control Center (POCC) from which Spacelab and other major science missions are controlled.

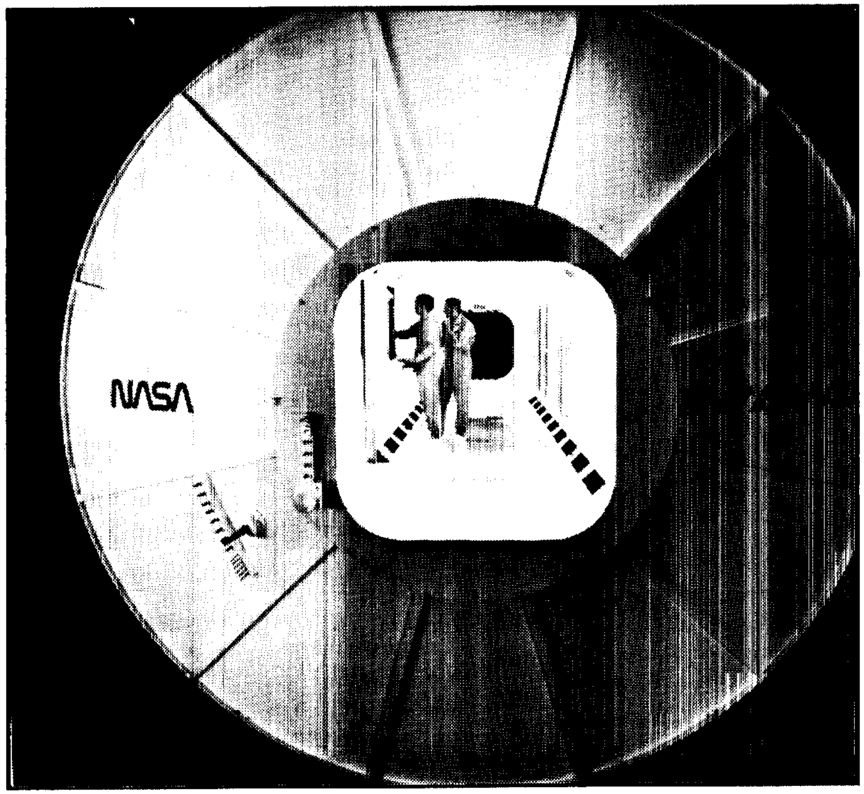
The Marshall Center has managed many successful space projects since its creation nearly three decades ago. It provided the Redstone rocket that put Alan Shepard into space in 1961. It developed the Saturn family of rockets that boosted man to the Moon in 1969. Saturns were also used in 1973 and 1974 to launch Skylab as well as Skylab crews, and in 1975 to carry the Apollo spacecraft into Earth orbit for the historic link-up with the Russian Soyuz spacecraft.

Marshall payloads have included the three Pegasus (1965), micrometeoroid detection satellites; the Lunar Roving Vehicle (1971) for use on the lunar surface; and the High Energy Astronomy Observatories launched in 1977, 1978 and 1979 to study stars and star-like objects.

In helping to reach the nation's present and future goals in space, the Center is working on more projects today than at any time in its history. In addition to its Space Station Freedom and Spacelab roles, Marshall provides the Space Shuttle main engines, the external tank, and solid rocket boosters for each Shuttle mission. Marshall is NASA's lead center for the Hubble Space Telescope, scheduled for launch in December 1989.

Other current Marshall projects include the Advanced Solid Rocket Motor (ASRM); the Advanced X-Ray Astrophysics Facility (AXAF); the Orbital Maneuvering Vehicle (OMV); the Inertial Upper State (IUS); the Transfer Orbit Stage (TOS); and the Tethered Satellite System.

The Marshall Center is working to develop an unmanned cargo-carrying version of the Space Shuttle. This Shuttle-C (for cargo) could triple the lift capability of the current Shuttle system. Other future-oriented programs include studies focusing on missions to Mars, a return to the Moon and establishment of bases on both bodies, and a series of Earth-observing experiments and space-based facilities to help us protect our environment and more fully understand the planet on which we live. Marshall facilities in Huntsville include structural and test firing facilities for large space systems, unique and specialized laboratories for a wide variety of studies, and facilities for assembling and testing large space hardware. It also operates the Michoud Assembly Facility in New Orleans, Slidell Computer Complex in Louisianna, and tests Space Shuttle main engines at the Stennis Space Center in Mississippi.

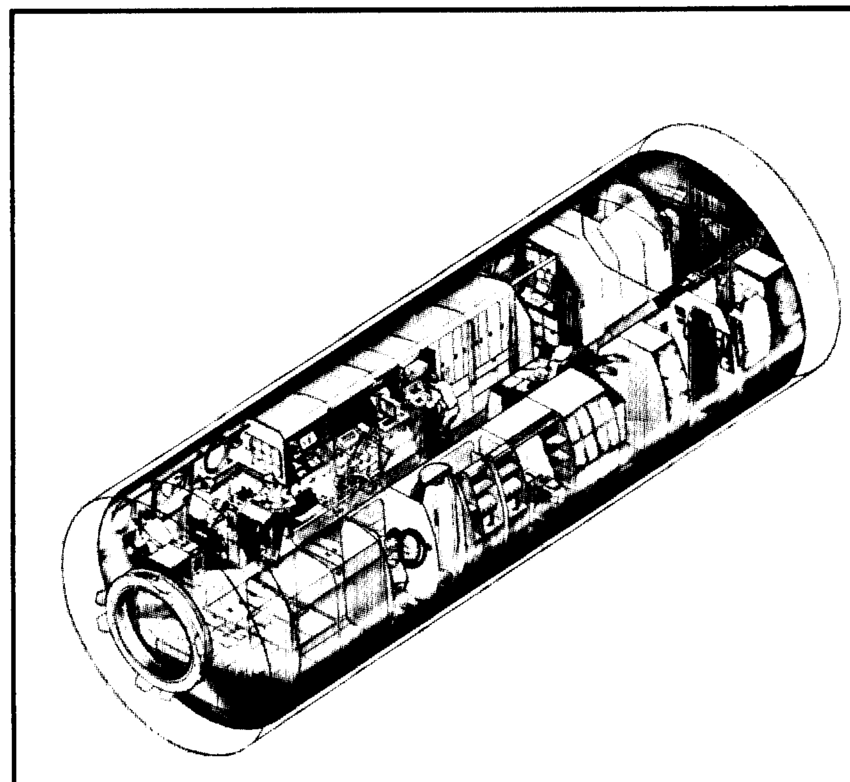


U.S. Laboratory Module

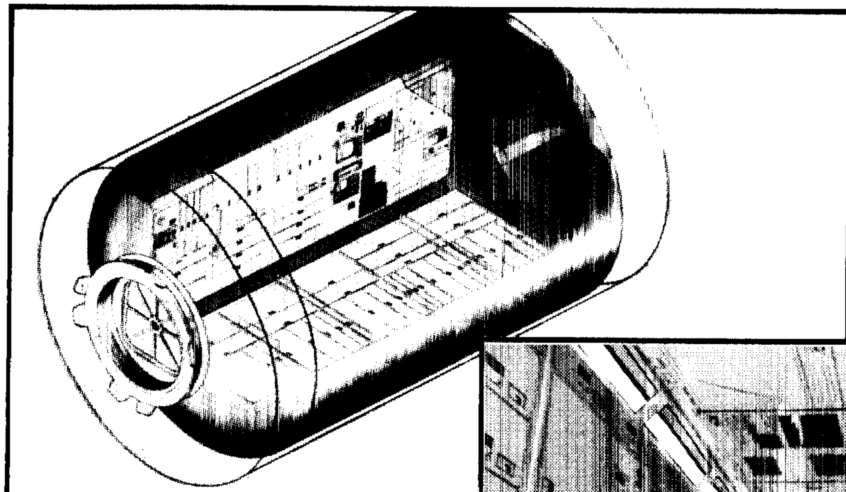
Marshall is responsible for the U.S. Laboratory Module, capable of supporting multi-discipline payloads, including materials research, development and processing, life sciences research, and other space science investigations in a pressurized area. User-provided equipment in the module includes furnaces for growing semiconductor crystals, electrokinetic devices for separating pharmaceuticals, support equipment for low-gravity experiments, and a centrifuge for variable gravity experiments in life sciences.

Marshall is responsible for the Habitation Module for eating, sleeping, personal hygiene, waste management, recreation, health maintenance and other habitation functions requiring pressurized space. The same size as the U.S. Laboratory, the Habitation Module is able to accommodate up to eight astronauts. These astronauts will be able to exercise in the Habitation Module, and they will be able to monitor their health through vital signs, x-rays, and blood samples.

Habitation Module

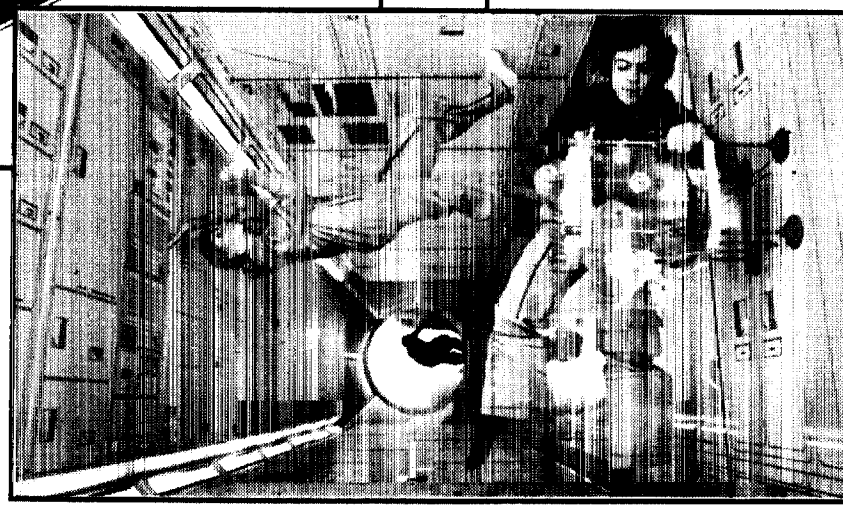


Space Station Freedom Unique Activities



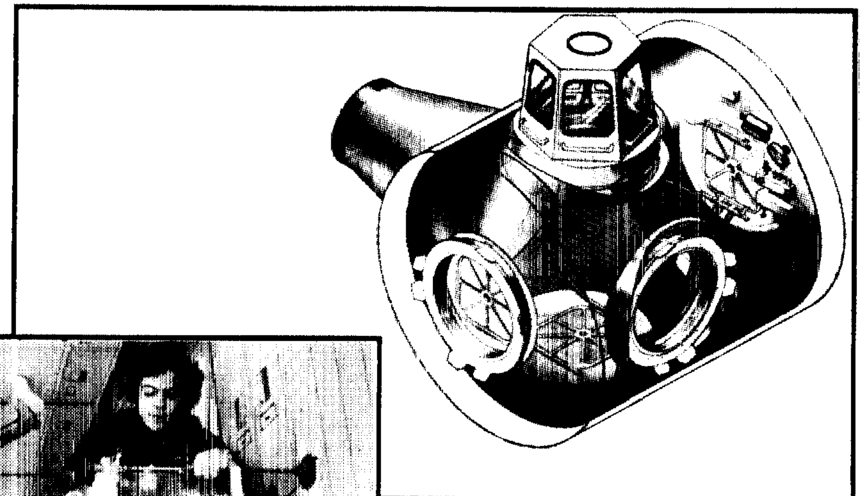
Logistics Elements

Marshall is responsible for the logistics elements required for the transport of cargo to and from the station for resupply of items required for crew, station and payloads; and for the on-orbit storage of these cargos. A key element will be the Pressurized Logistics Carrier to carry items used inside the station modules. Other elements include Unpressurized Logistics Carriers for the transport of spares for the exterior of the station, fluids, propellants, and dry cargo.



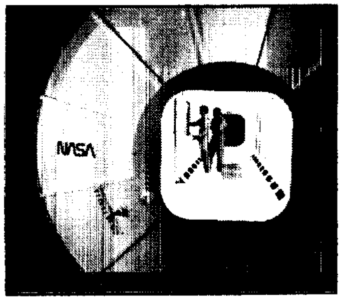
Environmental Control & Life Support, Internal Thermal Control and Audio/Video Systems

Marshall is responsible for the Environmental Control and Life Support System (ECLSS). The ECLSS provides a shirt-sleeve environment for the astronauts in all the pressurized modules of Space Station Freedom. A key feature of the ECLSS is the regenerative design in the air revitalization and water reclamation systems. Freedom Station's internal thermal control and audio/video systems are also provided by Marshall.



Resource Node Structure

Marshall is responsible for the structure of the Resource Nodes, required to interconnect the primary pressurized elements of the manned portion of Space Station Freedom. Resource Nodes also house key control functions. Marshall provides the Resource Node structures, berthing mechanisms, racks, the ECLSS system, internal thermal control, and internal audio and video communication systems.



U.S. Laboratory Module

The U.S. Laboratory Module is a pressurized cylinder, about 13.5 meters (44 feet) long and 4.22 meters (14 feet) in diameter, located below the lower face of the transverse boom and attached perpendicular and just to the right of center on the boom. It provides a shirt-sleeve environment for astronauts engaged in research and experimentation. The U.S. Laboratory Module will be located at the station's center of gravity, primarily for microgravity research payloads.

Purpose

The U.S. Laboratory Module is a core element dedicated to multidiscipline payloads within a pressurized habitable volume. Principal types of activity include:

- materials research and development most sensitive to acceleration;
- research in basic science requiring long duration of extremely low acceleration levels;
- life science research relating to adaptation to long exposure to microgravity;
- control and monitoring of user-attached pressurized payloads and selected external attached payloads;
- control and monitoring of user-attached pressurized payloads and selected external attached payloads; and
- the intravehicular activity (IVA) including maintenance and servicing of orbital replacement units (ORUs), instruments, and equipment requiring workbench support in a pressurized volume

The laboratory is pressurized to sea level pressure (14.7psi) and is able to accommodate up to 46 cubic meters (28 double racks) of payloads and payload support equipment located along the port and starboard walls of the lab. Along the floor and ceiling are the environmental control and life support system (ECLSS) components, other distributed system components, lab outfitting equipment and storage lockers. The life sciences centrifuge provides artificial gravity for living specimens.

Structure

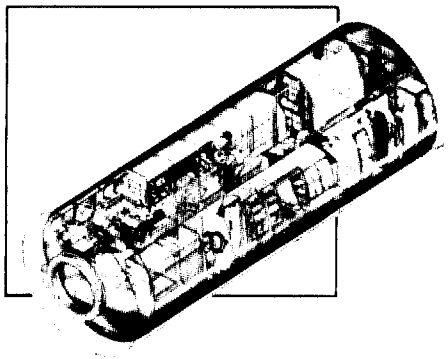
The U.S. Laboratory Module consists of two basic structures and a number of layers. The primary structure consists of a pressurized shell, and a meteoroid shield. Sandwiched between these two layers is multilayer insulation for thermal protection. The exterior will also have attached point viewports and grappling fixtures.

The secondary structure consists of mounting hardware which provides rigidity for attaching equipment racks and other equipment to the pressurized shell. Utility lines are also mounted to this secondary structure.

Design

The U.S. Laboratory Module uses a common design that is the prime building block for all the pressurized modules, based upon proven materials and processes. The approach results in a commonality of parts, assemblies, components and subsystems, leading to simplified manufacturing processes, a reduction in spares, and ease of maintenance. Design commonality also means that about 80% of the hardware needed for the station's two-fault tolerant life support systems will be common in the U.S. Laboratory, the Habitation Module, the Pressurized Logistics Carrier and the Resource Nodes. Furthermore, commonality of design and architectural continuity adds to a sense of familiar surroundings for the crew. A pleasing environment helps to promote crew productivity and a feeling of well-being.

The modular design consistent throughout the station means that some components can be moved from one module to another, or to the nodes, as the station evolves and needs change. Designed with the user in mind, the U.S. Laboratory Module is segmented by work activity. For example, crystal growers need power, vacuum, thermal control and purge gas in close proximity. Life scientists need a glovebox, centrifuge, equipment washer and specimens readily available. Lightweight composite experiment racks are designed to tilt down for servicing, replacement, cleaning and transfer to the Shuttle or to other modules.



The Habitation Module

The United States provides the living quarters for use by all the astronauts. The Habitation Module is an environmentally protected enclosure intended for long duration crew activity and habitation functions like eating, sleeping, exercise, relaxation, medical operations and some work activities. It is the same size as the U.S. Laboratory Module and provides the same shirt-sleeve environment. The Habitation Module is located parallel and next to the U.S. Laboratory Module in the cluster of pressurized modules that make up the manned base.

Isolated somewhat from the other modules, the Habitation Module is part of the safe haven and emergency provisions for the crew. It has internal audio and video, data and information handling, and utility distribution and control. The floor and ceiling are used for stowage, equipment and provisions for crew and daily operations.

The interior of the Habitation Module is outfitted for cooking, sleeping, personal hygiene and other human needs. At one end are vertical sleep restraints and emergency provisions. At the other end, where module-to-module berthing is located, are the galley and wardroom. The galley is equipped with an oven, refrigerator/freezer, trash compactor, hand and dish washer, and water supply. The wardroom, equipped with windows for looking out into space, is an area for entertainment, eating and monitoring of energy and life support systems. The middle of the Habitation Module is devoted to health and hygiene. Exercise and medical equipment is located on one side, and laundry, bathroom and shower are located on the other side.

Special attention is devoted to the Habitation Module in order to assure a "crew friendly" environment. Materials and techniques learned from airplane cabin technology will keep noise levels at about 50 decibels--as quiet as a whisper. Each crew member will have a private, dedicated compartment for sleep, rest, quiet reading or just privacy. This dedicated area of at least 50 cubic feet for each of the eight astronauts will be sufficient for a change of clothes and limited stowage of personal effects for 90 to 100-day missions.

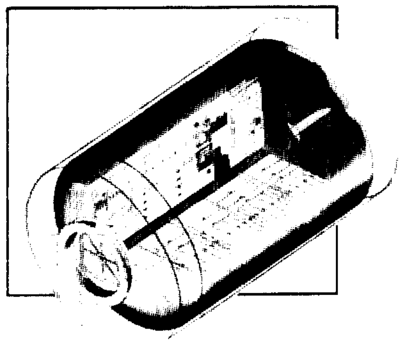
Yet, the Habitation Module is also a work area. Work stations in this module include those dedicated to station operations, payload and experiment operations, proximity and maintenance operations, and crew health care.

The Health Maintenance Facility includes test and diagnostic instruments, a patient restraint, medical provisions to care for or stabilize an injury or illness, exercise equipment and an environmental health subsystem. The last mentioned includes instruments for micro-biological, toxicological, radiation,and accoustics measurements. A computerized health care system keeps track of medical supplies, crew condition and check-up schedules.

The Habitation Module is designed for eight crew members. The tabletop panels adjust to provide various seating arrangements for the entire crew for meals, meetings, games, relaxation, or teleconferencing. Of course, since work schedules are expected to be scattered, four members of the crew may be eating supper while four others are eating breakfast.

The exterior and shells for meteoroid and radiation protection are similar to those of the U.S. Laboratory Module. Thus, the "Hab and Lab" Modules are made from the same materials and same basic designs, resulting in commonality and an estimated 20% cost savings.

While there is no "up" or "down" in weightless space, the Habitation Module does resemble a ultramodern, earth-bound kitchen, den, laundry and entertainment center. The notable exception is the vertical sleep restraint system in place of bunkbeds. See the JSC section for more on outfitting the Habitation Module.



Logistics Elements

Logistics elements are cargo cannisters attached to the station truss or to a module. They are designed to be replaced rather than refilled, containing either dry or fluid material, propellant, and experiments or specimens. The combination of cargoes will vary for each flight to and from the station, depending on the needs of the crew, payloads and platforms.

Basically, Space Station Freedom requires two kinds of logistics elements: pressurized and unpressurized. Both are needed in the transport of equipment, supplies and fluids to the station, and to return experiment results, equipment and waste products back to Earth. These cylindrical carriers provide the logistics for the ground-to-orbit, on-orbit supply and storage, and return-to-ground requirements of the station. They are designed to fit in the cargo bay of the Space Shuttle.

Pressurized Logistics Carrier (PLC)

The basic purpose of the PLC is to provide ready, on-orbit access to cargo without extravehicular activity. That means the PLC is a habitable environment, providing a benign, temporary storage facility for cargo. Thus, the PLC contains all the electrical, thermal and air pressure requirements of an inhabited module. It will transport cargo, including life science (e.g., plants, etc.) specimens, requiring a pressurized environment and then transports equipment, products, plants, biological specimens and waste from the station. The interchangeable racks contain consumables, spare parts, experiment parts, and orbital replacement units (ORUs). The ORUs are modular components of the station that can be easily removed and replaced.

Unpressurized Logistics Carriers (ULCs)

Other ORUs, payloads and equipment do not need a pressurized environment. Therefore, several unpressurized logistics carriers will be berthed at station ports. Typical contents in the ULCs include dry cargo; ORUs for station, payloads and platforms; payloads and experiments for the station and platforms; and fluids for the crew, payloads and the ECLSS.

Depending on the particular logistics resupply requirements for that flight, fresh logistics elements may be exchanged for expended ones. The newly arrived logistics elements will be transferred to the station, hooked up and checked out before the returning element is removed from the station and loaded into the Shuttle cargo bay for the return trip to Earth.

The exact designs, sizes and positions for the various logistics carriers have not been decided. At present, a Pressurized Logistics Carrier will be located on the nadir of the station--that is, in the direction of the Earth. It will be approximately 14 feet in diameter; its length depends on the amount of cargo that will need to be pressurized and readily available. The PLC, structured like the nodes and modules for commonality of manufacture and design, will be cylindrical with conical ends. It will have attachment mechanisms to berth with both the station and the Shuttle. It will be berthed at either Node 1 or Node 2.

The Unpressurized Logistics Carriers will also berth at station ports, but out on the truss. The diameter of the ULCs will, of course, be no wider than the Shuttle's cargo bay, and their lengths may vary. Certainly, one of the ULCs will contain dry cargo; another fluids and another propellant. As the station evolves, additional carriers will be required for enhancements to the power or thermal systems, longer duration missions, and, possibly, the refueling and resupply of spacecraft that stop off at Space Station Freedom on a mission to Mars and beyond.

Presently, three PLCs and four ULCs are being built at Marshall. The PLCs feature a portable, automated inventory system using handheld bar code readers, plus a lightweight plug door and a roller floor to reduce ground handling. The ULCs are designed to accept square carriers and nearly 60 different combinations of carrier racks.

Elements and Systems

Environmental Control and Life Support System (ECLSS)
Marshall is responsible for the Environmental Control and Life Support System (ECLSS) which is divided into seven distinct subsystems:

1. temperature and humidity control,
2. atmosphere control and supply,
3. atmosphere revitalization,
4. water recovery and management,
5. fire detection and suppression,
6. waste management, and
7. support for extravehicular activity.

Primarily, the ECLSS provides a habitable environment for crew and biological experiment specimens.

The ECLSS represents a breakthrough in closed-loop life support, necessary for long duration missions to Mars and beyond. Water is recycled through the collection of H_2O in both air and liquids, such as urine and sweat. The ECLSS produces potable water, even from urine, although such water is labeled "hygiene quality" for washing and cleansing. Carbon dioxide is collected in one of two ways, both of them producing more potable water. The CO_2 collected can yield either water and carbon (the Bosch method) or water and methane (the Sabatier method.) Waste products are containerized and returned to Earth. There shall be no overboard dumping of solids or liquids.

The only vital chemical for life, missing, is nitrogen which must be shipped and stored. Nevertheless, the hardware for the ECLSS is distributed throughout the pressurized modules to assure sea-level pressure, temperature, humidity, and air composition; as well as potable and hygiene water, and fire detection/ suppression equipment. For redundancy, repressurization and fire fighting equipment are located in both the Habitation and U.S. Laboratory Modules. Design challenges for the remainder of this decade included the ability of the ECLSS to maintain microbial and chemical system cleanliness during extended duration and multiple reuses of potable and hygiene water supplies.

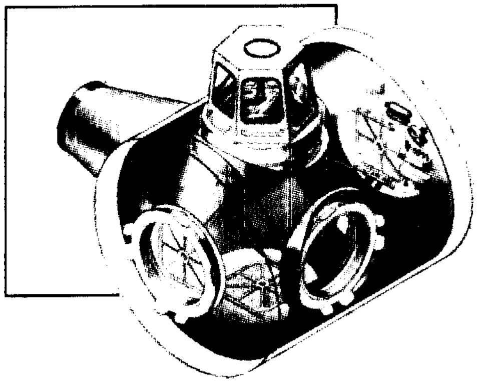
The ECLSS will collect, process, and dispense water as required, to meet the needs of the crew and any other users. It will pretreat waste water in order to prevent chemical breakdown and the growth of microbes. Post-treatment systems and a water quality monitoring system will ensure that the water provided to users is of sufficient quality.

Waste management is another important function of the ECLSS. Waste products (e.g., metabolic waste, food/packaging, regenerative process effluents, hard copy waste, etc.) will be collected and processed for conversions to useful products or returned to Earth. Venting of gases shall be strictly controlled so as to avoid contamination or degradation of the exterior shells of modules, not to mention exposed payloads out on the truss.

The ECLSS will provide support for servicing the Extravehicular Mobility Unit (EMU), the Extravehicular Excursion Unit, and the EVA systems. It will provide the depressurization and repressurization of the two airlocks and the hyperbaric chamber. An interface will exist between the ECLSS and the Thermal Control System (TCS) for the removal of heat from the atmosphere of the pressurized elements.

Commonality is stressed as the ECLSS is built into each of the U.S. Laboratory and Habitation Modules, nodes and the pressurized logistics carrier. It is estimated that four-fifths of all the hardware that is installed for the ECLSS in Space Station Freedom is identical. This commonality reduces manufacturing costs, lightens the load for spare parts, and makes repairs simpler and quicker. In the event of an accident or malfunction, the ECLSS is built with redundant life-critical hardware in both U.S. modules to satisfy safe-haven requirements.

The ECLSS represents design challenges not seen on previous space programs. The requirements for closed loop air and water systems extend human duration in space and reduce resupply flights significantly.



Resource Node Structure
Resource Nodes are required to interconnect the primary pressurized elements of Space Station Freedom. As such, these nodes also house key controls for operations.

A resource node is a pressurized volume and an environmentally controlled enclosure. It is also a center for Space Station Freedom command, control, and operations. Distributed subsystems are located and controlled here at workstations. Each of the four Resource Nodes, located at each end of the U.S. Laboratory and Habitation Modules, provides a pressurized passageway to and from the modules and an interface to the Space Shuttle.

Built like the other pressurized modules, the four nodes will be smaller, about 17 feet long and 14 feet in diameter, designed to reduce the amount of EVA time required to assemble the station.

Node 1 is the spacecraft control center for both unmanned flight and man-tended operations. Located between the U.S. Laboratory and ESA's Columbus Module, Node 1 may also contain some components of the propulsion subsystem and attaches to the hyperbaric airlock, the Pressurized Logistics Carrier, and Node 2.

Node 2 may become the man-tended command and control station, located between the Habitation Module and the Japanese Experiment Module (JEM). It provides spacecraft and station back-up command and control workstations.

Node 3 is likely the primary command and central station for the pressurized modules, located at the forward end of the U.S. Laboratory Module. Node 3 is expected to contain the control mechanisms for the distributed utility systems, a control station for proximity operations, and a back-up central station for the Mobile Servicing System (MSS).

Node 4, connected to Node 3 and the forward end of the Habitation Module, features a Cupola, designed for proximity operations and berthing of the Space Shuttle. Node 4 provides the prime command and control for the Mobile Servicing System.

Each of the four Nodes are designed and outfitted by Johnson Space Center but are built at Marshall Space Flight Center. Each node is a pressurized, environmentally controlled element designed to perform a variety of activities:

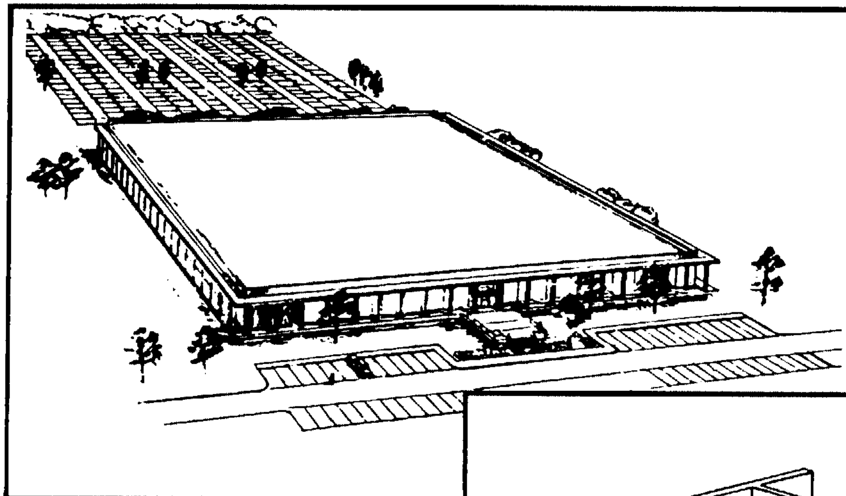
- passage of crew and equipment
- station command and control functions
- external view for berthing and proximity operation
- IVA control and monitoring electronics for the MSS and FTS
- residence for station distributed systems
- residence for supporting utility systems equipment
- limited station storage
- limited user payload operation

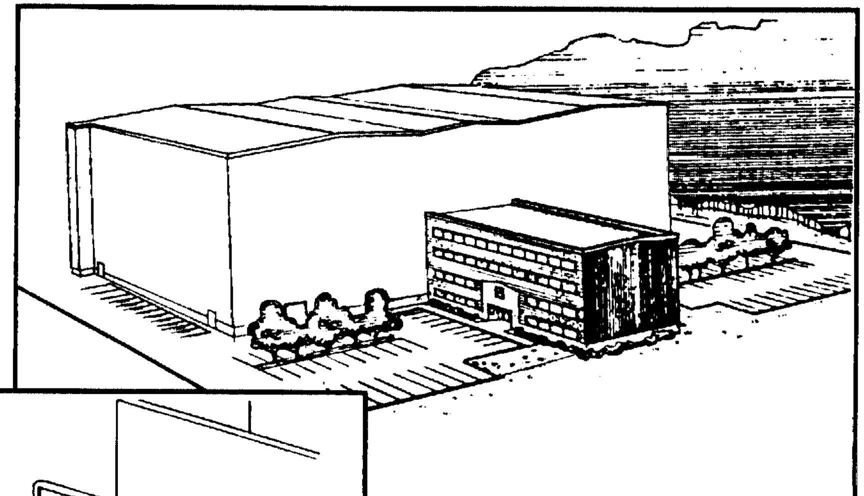
Contingency access to the nodes shall be provided as soon as each is added to the station assembly.

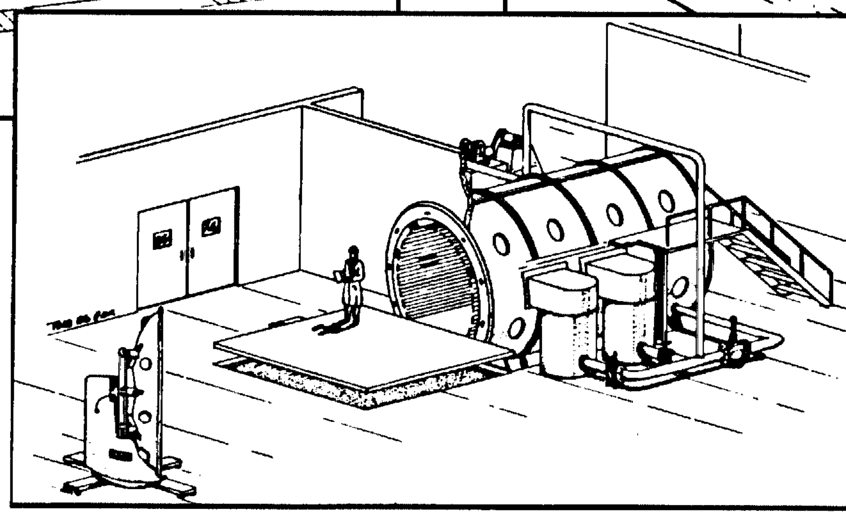
The final configuration of the four nodes has not been determined. Nevertheless, in the design stage, the Resource Node and Airlock System promises many tested and innovative features. Berthing mechanisms with flexible bellows and gimbals will provide better tolerance in the assembly phase. Subsystems will be mounted in the end cones for volumetric efficiency. The Cupola is being designed for maximum viewing with both portable and installed command and control consoles.

Baseline requirements call for a nadir (earth-facing) and zenith (stellar-facing) Cupola. It must be able to dock an Orbital Maneuvering Vehicle (OMV) and accommodate two large astronauts. A Cupola cover can extend and retract for meteoroid protection.

Facilities







Payload Operations Integration Center

The Payload Operations Integration Center (POIC) will be used to "manage" or "control" real-time research operations, interfacing with the Space Station Control Center in Houston, Texas and various user facilities in other communities. As a control central point for payload operations, the POIC will integrate science operation centers and will house computer systems for mission planning system and analytical tools.

Engineering Support Center

The Engineering Support Center (ESC), an adjunct to the Huntsville Operations Support Center (HOSC), will provide Work Package 1 engineering support for real-time operations. The ESC serves as a control point for requests from the SSCS and the POIC for engineering support to operations. It also supports the engineering flight evaluation and anomaly resolution for Space Station Freedom.

Payload Training Facility

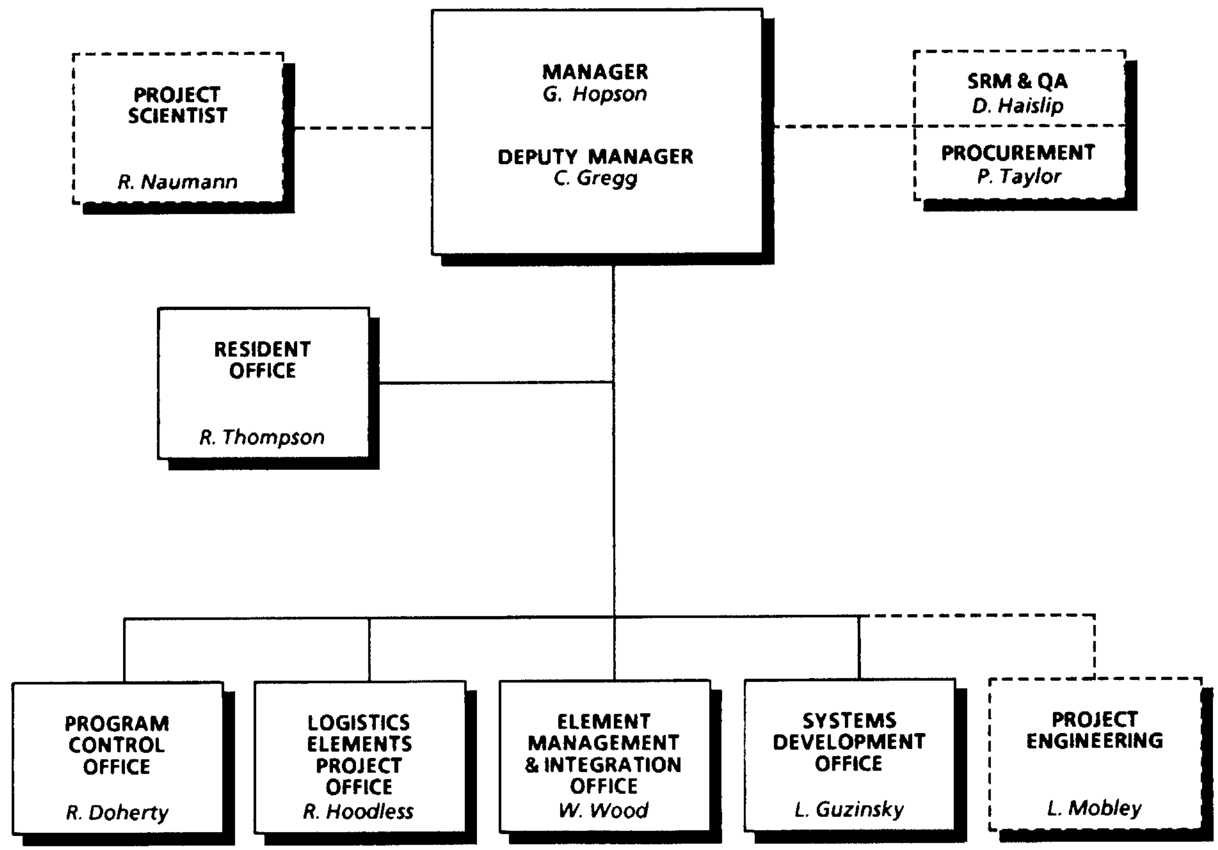
The Payload Training Facility (PTF) will provide for the development, maintenance and verification of payload operations training, including the hardware and software to support the training of payload crew, Payload Operations Integration Center personnel, experimenters and users. The PTF will provide both space station data as well as training.

Space Station Freedom Organization

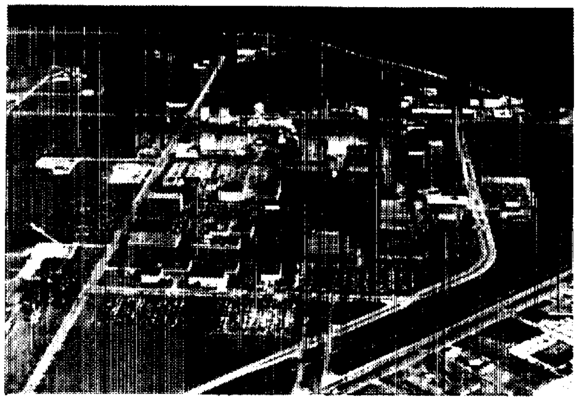
The Marshall Space Flight Center (MSFC) in Huntsville, Alabama been designated as the Work Package 1 Center. Work Package 1 includes the design and manufacture of the astronaut's living quarters, known as the Habitation Module; the U.S. Laboratory Module; logistics elements, used for resupply and storage; node structures connecting the modules; the Environmental Control and Life Support System; and the thermal control and audio/video systems located within the pressurized modules.

MSFC has established the Level III Space Station Freedom Projects Office to manage and direct the various design, development and operational activities needed to successfully complete the Work Package 1 assignment.

A unique aspect of this organization is its emphasis upon Environmental Control and Life Support Systems in spaceflight. Preparing accommodations for a crew of eight for 90-day stretches is vastly complex, but to develop the world's first closed-loop life support system is a real challenge for Marshall Space Flight Center, preparing the U.S. for longer duration missions to Mars and beyond.



Traditional Center Roles and Responsibilities



The history of the Johnson Space Center began in 1961 when it was announced that the new Manned Spacecraft Center would be established on a 1020-acre tract near Houston, Texas. The land, originally Humble Oil and Refining Company property that had been donated to Rice University, was transferred to the government by the university. Construction of facilities was begun in 1962 and the majority of buildings were completed by 1965. The name of the Center was changed to the Lyndon B. Johnson Space Center in 1974.

The Johnson Space Center is located in Harris County, Texas, on a 1620-acre tract near Clear Lake. The site is approximately halfway between Houston and Galveston.

JSC participated with other NASA installations in the Mercury, Gemini, and Apollo space programs which culminated in the first manned lunar landing in July 1969. The Skylab space station, controlled from JSC, provided the base for numerous scientific projects including the evaluation of manufacturing methods in space, the study of energy radiation from the Sun, and the study of the capability for space monitoring of the environment and resources on Earth. JSC participated in the joint U.S.-U.S.S.R. (Apollo-Soyuz) space mission in 1975, which has highlighted international cooperation in space to date. With the adoption of a national goal for development of a space transportation system, JSC has played a major role in this area. JSC serves as both the development center for the Space Shuttle and the Operations center for the evolving transportation system. Activities in the development of the Shuttle have included the successful completion of a number of research goals. The development of the power extension package will utilize deployable solar arrays, which are expected to triple the on-orbit stay time and double the available power compared to initial concepts. JSC has also demonstrated the feasibility of a three-man vehicle launched by the Shuttle which can potentially perform a wide variety of construction and service operations that would exploit the capabilities of man in space. Also, an analysis has been made by JSC of deployment, erection, fabrication, and assembly of very large structures in space.

Research and development activities at JSC related to manned space flight include the following.

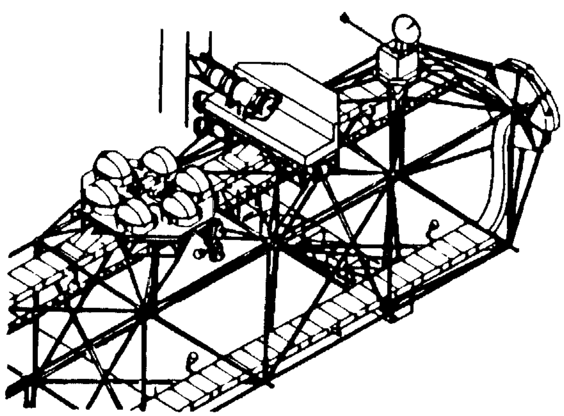
1. The design, manufacture, testing, qualification, and delivery of systems such as space suits, extravehicular activity systems, crew provisions, and crew support equipment.

2. The development of instrumentation, data management systems, and ground checkout systems used on manned spacecraft.

3. The analysis, development, and evaluation of spacecraft structures, materials, and thermal protection systems.

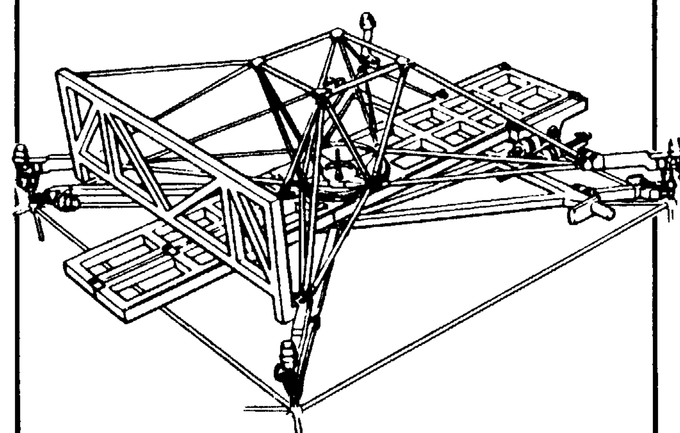
In addition to its role in the development of the Space Shuttle, JSC is involved in a wide range of research and technology activities in other areas. In lunar and planetary science, JSC scientists have led in the investigation of the ancient lunar crust. The tie of lunar and planetary studies to Earth has been strengthened. A new model has been developed for the origin of the Earth's continents. The environmental effects of space transportation are also being studied, from the standpoint both of the effects of launch and landing on the Earth environment and of the effects of the space environment on vehicles or structures in space. In the area of life sciences, research is being conducted to understand the effects of weightless spaceflight on the human body and to apply spaceflight-developed procedures and equipment to the solution of problems on Earth. JSC also functions as the lead organization for agricultural remote sensing. Other Earth observation responsibilities of JSC include soil moisture mapping, multicrop research, water mapping, forestry applications, and resources inventory with the State of Texas.

Space Station Freedom Unique Activities



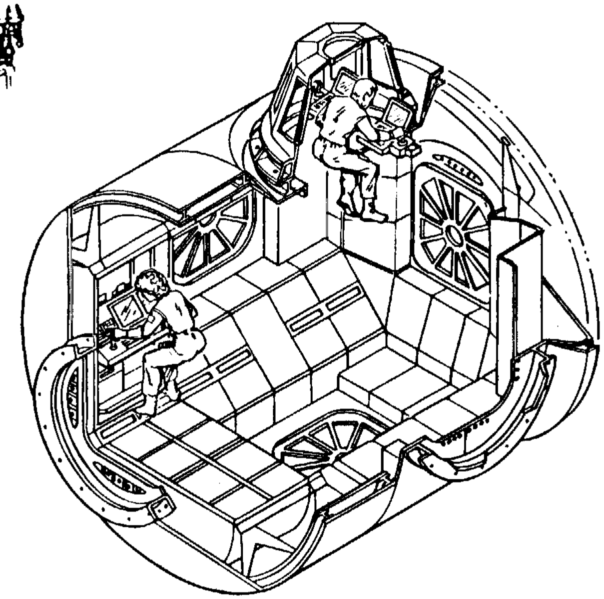
Integrated Truss Assembly

The integrated truss assembly provides the framework for the core base of the station. The transverse boom is 155 meters (508 feet) in length. It serves as the attachment point for the solar power arrays, as well as other systems, including experiments. It facilitates the movement of crew and equipment, and provides for distributed systems.



Mobile Transporter

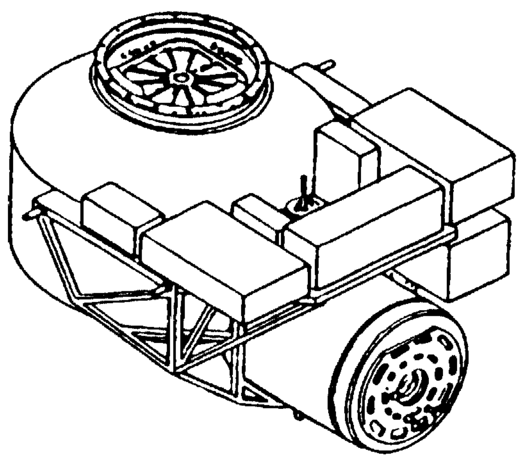
The mobile transporter will enable the Canadian supplied Mobile Servicing Centre (MSC) to move along the truss. It provides the translation, rotation, and plane change mobility required by the MSC to support transportation, assembly, and payload operations.



Resource Nodes - Design and Outfitting

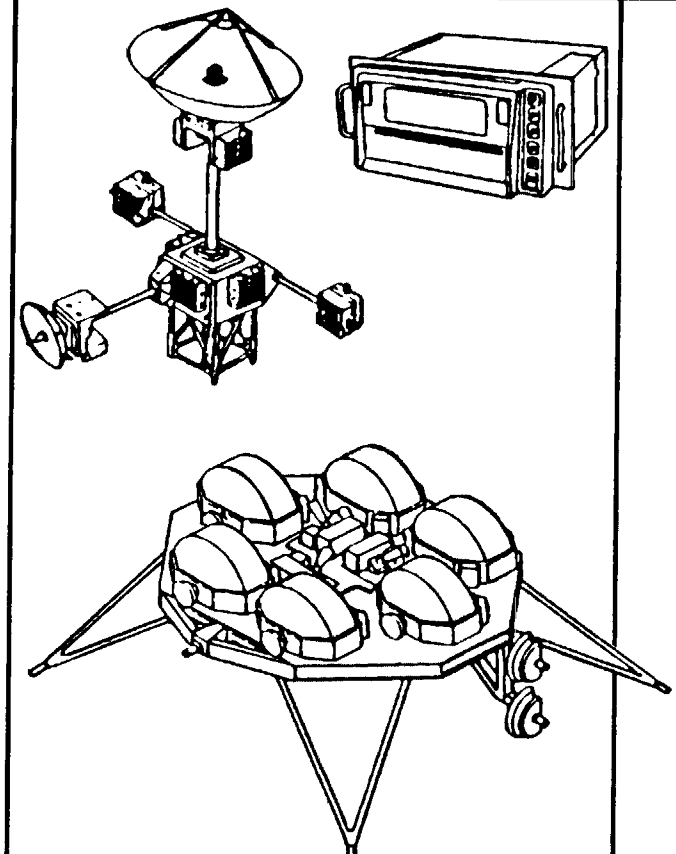
The four resource nodes, located at each end of the Habitation and U.S. Laboratory Modules, are small pressurized cylinders approximately 17 feet long and 14 feet in diameter. They are designed and outfitted to serve as command and control centers and as passageways to and from the various modules. A cupola will be attached to each of two nodes.

Space Station Freedom Unique Activities



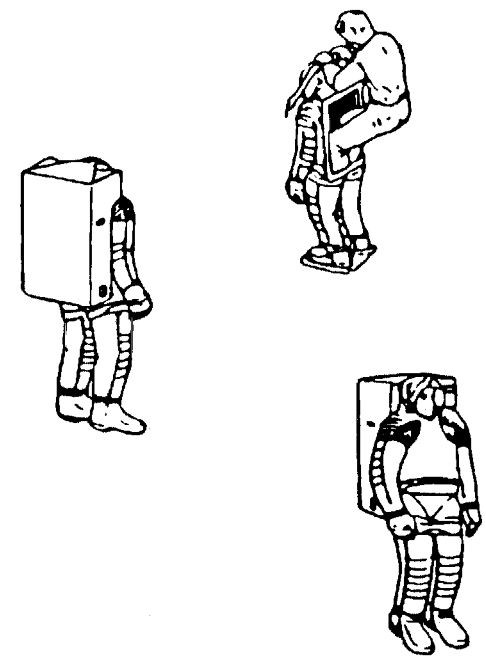
Airlocks

There are two types of airlocks planned for Space Station Freedom. There will be two standard airlocks and one hyperbaric airlock. The airlocks attached to a node, enable the transfer of crew and equipment between pressurized and unpressurized zones. The hyperbaric airlock has the capability for the treatment of decompression sickness.



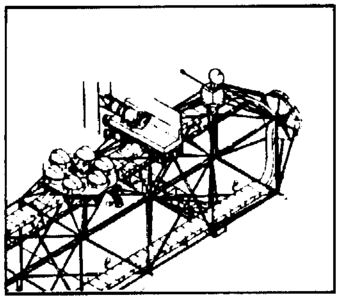
Distributed Systems

There are a variety of systems which are fundamental to the operation of the space station in a safe and effective manner. They are the propulsion, data management, communications and tracking, guidance, navigation and control, thermal control, fluid management, mechanical, and electrical power systems.



Man Systems

Man Systems provide the crew with a safe environment and the necessities of life. Man Systems includes the health care system, hygiene system, crew quarters, galley, wardroom, food management, lighting, workstations, EVA system, flight crew integration and training, restraints and mobility aids, housekeeping/trash management, portable emergency provisions, operational and personal equipment, and stowage.



Integrated Truss Assembly
The truss assembly will give structural stiffness and dimensional stability to the entire space station. It also will provide the structure for integration and installation of all the elements and systems, including the modules, that make up the space station's manned base, or core.

The integrated truss assembly for Space Station Freedom is the structural framework of tubular beams and columns which stiffen and stabilize the core base of the station. It has provisions for mounting and attaching modules, logistics carriers, external experiments, solar power arrays, and both Earth and astronomical viewing instruments. The truss also provides corridors and distributed systems for crew and equipment movement, and external lighting.

The transverse boom, including solar arrays at each end, measures 155 meters (508 feet). The center section of 360 feet consists of a sequence of 5-meter (16.4 ft) cubic bays to secure the station elements and systems. It is erected in space, composed of longerons, battens and diagonal struts to form a latticework for structural stiffness and stability.

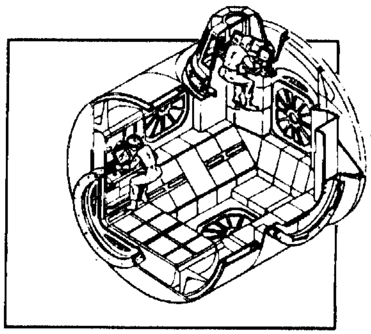
Because of extreme temperatures as the station goes from the heat of the sun to the cold of the umbra, the tubular members are built of a composite material which reacts differently to heat and cold. A candidate material is an aluminum clad graphite epoxy which is lightweight and relatively stronger and stiffer than metal. Engineers at JSC weave graphite fibers through a convergence plate and into an aluminum tube. A second, smaller tube holds the strands together until resin can be injected around the fibers to form a structural member, ready for covering, corner fitting, launch, and assembly.

Mobile Transporter System
The primary function of the Mobile Transporter (MT) is to provide the Canadian-supplied Mobile Servicing Center (MSC) with mobility. It also provides the capability for movement of supplies, materials, and personnel independent of the MSC. The Mobile Transporter combined with the MSC comprises the Mobile Servicing System (MSS). The MT will will ride along rails mounted on truss providing mobility for the MSC. The MT will generate its own utilities and data, or will throughput station-distributed utilities and data. The base of the MT will measure approximately 4.9 x 6.1 meters (16 x 20 feet). The height has not yet been determined.

The MSC will consist of a base structure mounted on the MT, a Remote Manipulator System (RMS), similar to the one on the orbiter, an Astronaut Positioning System, and a Special Purpose Dextrous Manipulator (SPDM) that acts as the "hands" of the system. The Astronaut Positioning System will be similar to the RMS, except that it will have additional restraints designed to interface with a suited astronaut. The SPDM will be designed to changeout space station orbital replacement units and attached payloads.

Mechanical System
The mechanical system consists of the solar alpha rotary joint, the thermal radiator rotary joint, umbilical mechanisms, and special end-effectors. The solar alpha rotary joint supports the outboard transverse booms and provides controlled rotation to point the power generation equipment towards the sun, while transferring power and data across this rotating interface. The thermal radiator rotary joint supports the control radiator panels and provides controlled rotation for aligning the panel edges to the sun. It transfers liquid/gaseous ammonia between the station and the panels. The umbilical mechanisms facilitate utility transfer between the station and the unpressurized logistics carrier, the mobile transporter, and the platform. Special end-effectors are provided for construction, assembly, maintenance, and repair. They are compatible with the other station manipulator systems.

Elements and Systems



Resource Node Design and Outfitting
The JSC is responsible for the design and outfitting of the resource nodes. The four resource nodes, located at each end of the Habitation and U.S. Laboratory modules, are designed to reduce the amount of EVA time required to assemble the station. The nodes are small, pressurized cylinders,approximately 14 feet in diameter and 17 feet long, that serve as command and control centers, and as pressurized passageways to and from the various modules. They, like the modules, have a primary and a secondary structure and contain accommodations for distributed systems. Certain nodes also contain berthing mechanisms for the temporary attachment of either the space shuttle or the logistics modules.

Node 1 serves as a control center for the Communication and Tracking System, Data Management System, Guidance, Navigation and Control System, Propulsion System, Electrical Power System, Thermal Radiator Rotation, and the hyperbaric airlock. It is located between the Columbus (ESA) and U.S. Laboratory modules and attaches to the hyperbaric airlock and Node 2.

Node 2 provides redundant control for the Propulsion System, Electrical Power System, Thermal Radiator Rotation, and the Communication and Tracking System. It also serves as the airlock control station. It is located between the JEM and the Habitation module.

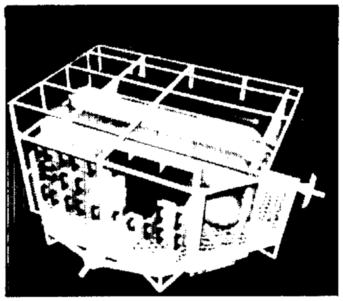
Node 3 is the primary command and control station for the pressurized areas of the station. It is located at the forward end of the U.S. Laboratory Module. It provides: the accommodation for a cupola interface and for a secondary docking port interface; a backup command and control station for the Mobile Servicing Centre and the Flight Telerobotic Servicer; backup guidance and navigation control; a secondary proximity operation for pressurized attached payload equipment.

Node 4 is attached to the forward end of the Habitation module and is connected to Node 3. It serves as the primary docking port for the space shuttle, the primary control center for proximity operations, and the primary command and control center for the Mobile Servicing Center and the Flight Telerobotic Servicer. It also provides accommodations for interfacing with the cupola.

Nodes 3 and Node 4 will be scarred for future growth. That is, both will contain the necessary hardware provisions to enhance the nodes as the station evolves.

Cupolas
There are two cupolas. One will be attached to resource Node 3 and the other to Node 4. One will face towards the earth while the other will face towards space. They facilitate the control of proximity operations and can be used simultaneously by two crewmembers with a work station available for each. From the cupola, they have a 360° field of view in azimuth and a complete hemispheric field of view in elevation. A restraint system enables the crewmembers to easily rotate for viewing through any of the 8 windows. The workstations can also be rotated to move to an optimum position for use by a crewmember. The workstations have a keyboard, two hand controllers, and a trackball. The following systems can be controlled by a crewmember in the cupola: the station manipulators (except the JEM manipulator), the mobile transporter, the telerobotic servicer, OMV piloting, external video cameras and lights and internal video monitors, international and external voice communications, and systems control functions via access to the DMS. When not in use the cupolas will be within a retractable, protective cover.

Airlocks
There are two types of airlocks: the hyperbaric airlock, and the airlock. The hyperbaric airlock provides an effective and safe means for the transfer of crew and equipment between pressurized and unpressurized zones and provides a capability for the treatment of decompression sickness. The airlock is a separate element attached to a node by berthing/docking mechanisms. The airlock serves the same function with the exception of the capability to treat decompression sickness.



Utility Distribution System
In order to minimize EVA installation time, the number of joints, and fluid connector leakage potential, a unique concept of a rollout utility tray has been proposed. A 10-foot inside diameter (14.5-foot outside diameter) aluminum frame spool will provide a large bend radius. This will allow tray preintegration of long runs of stiff, yet lightweight, power cables and multi-insulation wrapped heat rejection and transport lines. During assembly, EVA crew members snap the trays into support fittings prebonded every 16.4 feet to the batten struts and make connections at distribution points. Aluminum covers provide protection from ultraviolet radiation, atomic oxygen, and meteroid-debris impact.

Fluid Management System (FMS)
The FMS handles the distribution of nitrogen, water, and waste fluids throughout the station. The integrated nitrogen system (INS) includes all of the hardware and software required to resupply, transfer, store, condition, distribute, control and monitor nitrogen for the station.

The nitrogen logistics resupply subsystem includes the tankage, mounting hardware, condition, thermal control, transfer, monitoring and control hardware necessary to deliver the fluid to the station. It is located on the truss, as well as the tankage and associated equipment to store the nitrogen.

The nitrogen distribution subsystem which transfers nitrogen from the resupply subsystem to the storage tanks and from the storage tanks to the user interface, is also located on the truss. The nitrogren distribution subsystem consists of two parts:

- One part transfers nitrogen to the ECLSS and the integrated waste fluid system, and interfaces with the internal distribution systems located in Nodes 1 and 2, and
- The other part transfers nitrogen to the integrated water system (IWS) and the laboratories.

The integrated water system (IWS) is conceptually similar to the integrated nitrogen system. The storage system, located in the nodes, accepts water from the Space Shuttle orbiter's cargo bay, from the NSTS water scavenging system, and from the ECLSS.

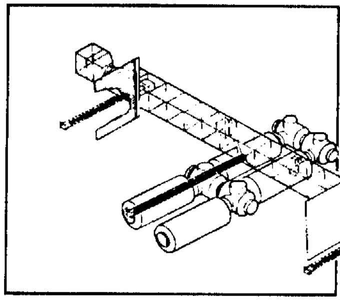
The integrated water fluid system (IWFS) consists of a collection/distribution subsystem, and a storage subsystem. These subsystems will contain all hardware and software required to provide fluid transfer, storage, conditioning, disposal, control, and monitoring to accommodate gas mixtures and water. The collection/distribution subsystem receives fluid discarded by the users and transfers them to the storage subsystem.

Thermal Control System (TCS)
The TCS is an integrated system which will maintain structures, systems, subsystems, equipment, and payloads within required temperature ranges. Twenty-five heat acquisition devices (HADs) will be used initially to collect waste heat from Habitation and Laboratory modules, resource nodes, and payload accommodation equipment. The heat will be transported by means of an ammonia/water loop from the HADs to a radiator located on the transverse boom. The radiator will be a 15.2m (50 ft) square which will be mounted on a rotary joint which permits the radiator to be turned away from the radiant heat of the Sun.

The external thermal system provides cooling and heat rejection to control temperatures of electronics and other space station hardware located outside the modules and node.

For truss attached payloads, thermal acquisition is provided at the payload attachment interface. Separate Attached Payload Accommodation Equipment (APAE) thermal loops transport waste heat to the central thermal bus heat exchangers. The APAE loop design is based upon a two-phase ammonia system. For pressurized payloads attached directly to nodes, thermal acquisition is through central thermal bus interface heat exchangers attached externally to the payload.

Elements and Systems



Propulsion Assembly
The function of the propulsion assembly is to maintain the proper altitude, avoid collisions, and to provide backup attitude control. The propulsion assembly will provide thrust for orbital maintenance and 3-axis thrust for attitude stabilization and reorientation. Three-axis thrust will be used to desaturate the Control Momentum Gyroscopes, which are the primary attitude actuators of the Stabilization and Control System. The propulsion system consists of four propulsion modules, a tank farm, and a fuel distribution system. Each module contains fuel tanks, plumbing and valving, a fuel pump, and two types of jet actuators (hot gas and resistojets). The resistojets, used for vernier control, are fueled by waste fluids and produce a pound of thrust. The hot gas actuators are fueled by a hydrogen-oxygen mixture and produce 25 to 40 pounds of thrust.

Communication and Tracking (C&T)
This system provides for the transmission, reception, multiplexing, distribution and signal processing of telemetry, commands, user data, science data, computer data, and tracking data. C&T also provides for the raising, lowering and pointing of antennae on the station. C&T is comprised of six subsystems:

1) space to space,
2) space to ground,
3) audio,
4) video,
5) tracking, and
6) control and monitoring.

The space-to-space subsystem provides communications with: astronauts performing EVA, the Space Shuttle, the Orbiting Maneuvering Vehicle, the Mobile Servicing Center, the Flight Telerobotic Servicer, and any compatible free-flying platforms in the vicinity of the manned base. Simultaneous communication can be carried out with up to four vehicles.

The space-to-ground subsystem provides near continuous communications between the station and ground data networks through the TDRSS.

The audio subsystem provides all of the voice communications on the space station. It is similar to a standard telephone system and permits voice communication between the crew inside the pressurized modules, the EVA crew, the crew of other manned vehicles, and compatible ground systems.

The video subsystem provides all of the internal and external video capabilities on the space station by means of remotely controlled cameras. It includes closed circuit TV, storage, retrieval, compression, graphics, and special effects capabilities.

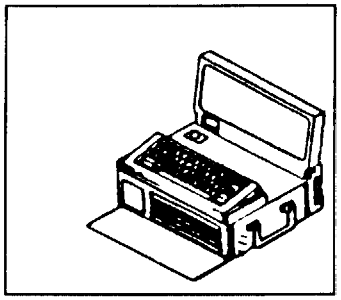
The tracking subsystem consists of a Global Positioning System (GPS) receiver/ processor with provisions to accommodate future laser docking and radar requirements.

The control and monitoring subsystem manages all C&T resources and distributes the C&T data.

Guidance, Navigation & Control (GN&C)
The GN&C performs two main functions: to control the manned base orbit and to control traffic around the space station.

Periodically, the manned base portion of Space Station Freedom will decay in orbit. The GN &C, operated by sensors, star trackers and gyroscopes, will signal the propulsion assembly for a reboost for proper altitude and attitude. This system also supports the pivoting of the solar arrays and thermal radiator on the transverse boom to maximize the capture of the solar rays.

Traffic management around the station is also critical. The GN&C controls all incoming, outgoing and station keeping traffic; it also controls berthing and docking operations for the Space Shuttle. Finally, the GN&C monitors the trajectories of vehicles and objects that may intersect the orbit of the manned base and platforms. Such objects include meteoroids, some the size of a car, which are extremely rare in space. The more common micrometeoroids, ranging in size from a grain of sand to a marble and traveling at thousands of miles per hour, are too small to be tracked on radar.



Data Management System (DMS)
The DMS is an onboard computer system with two main functions. First, the DMS includes all the hardware and software necessary for data processing and local communications among the onboard elements, systems and payloads. Secondly, the DMS provides an interface between human and machine for the operation and control of Space Station Freedom.

The DMS provides database access, command and control, data transmission, data processing and handling, and human computer interfaces for the users and subsystems as well as interface for the onboard information systems of the international elements. It enables users and subsystems to initiate on-line capabilities such as command generation, data handling, graphics, health monitoring, planning, scheduling and training activities, display of performance and trend data, and monitoring of properly interfaced payloads.

The Data Management System provides a family of compatible computers ranging from a single board computer suitable for use as an embedded controller, to a general purpose processor suitable for hosting system application software. Each processor has a compatible set, or subset, of the DMS operating systems tailored to its specific application. The DMS also includes a common assembly called the Multipurpose Application Console (MPAC).

The MPAC is the electronic core of the space station workstations. It provides access into operational monitoring, training, testing, cautions and warning display, and crew operations. Some of the MPACs are fixed in place, while others are portable.

The information and data management services provided will include data storage processing and handling presentation, and onboard networking services adequate to accommodate most user requirements.

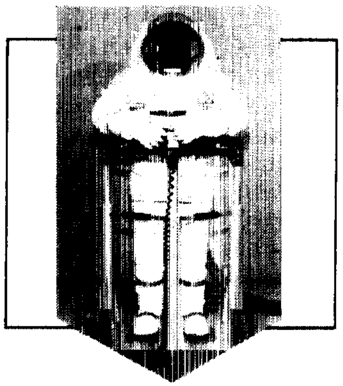
The Data Management System interfaces will be capable of supporting both Operations/Administrative (O/A) traffic and payload traffic on a near continuous basis. O/A traffic can take priority over payload traffic in the event of emergencies or link failure which restricts link performance. Specifically, the Data Management System will exhibit the following features:

1) Support the control of all onboard subsystems such as electrical power, thermal control, data management, communications, attitude control and orbit altitude maintenance of the station and platforms.
2) Support normal, systems-management functions that ensure the station and platform systems continue to operate normally in a desired configuration. This function will be accessible by a ground controller or onboard crew members.
3) Provide for onboard distribution of data between subsystems, payloads, and payload support equipment over DMS networks.
4) Support real-time command and control. Commanding can be initiated by the system the crew, ground operations, or other payloads.
5) Support the provision of orbit-position data of a selected reference point, attitude data, and navigation information.
6) Provide the capability and warning and advisory information necessary to safely override, or inhibit manually, any automated functions.

The DMS will provide a self-monitoring capability that will reduce recurring operations cost, reduce the crew and ground time devoted to configuration management, allow crew and ground controllers to quickly determine the health and status of all systems, and automatically give appropriate notification when checks should be made.

There will be three primary configuration management functions: (1) hardware configuration management of space station elements, (2) software configuration management of station space elements, and (3) both system and customer data configuration management in the Data Management System.

Elements and Systems



Man Systems

Johnson Space Center is responsible for managing the design, development, test and engineering of manned systems for the Habitation, U.S. Laboratory and Logistics modules. The manned systems include crew quarters restraints and mobility aids, health care, operational and personal equipment, portable emergency provisions, workstations, galley food management, personal hygiene, lighting, wardroom, stowage, and housekeeping/trash management. The Man Systems utilize a group of modular elements or "Functional Units" which enable partial or entire systems to be removed, replaced, and relocated as desired and at the time desired.

The Habitation Module provides the living environment for eight crewmembers. Specifically it contains the crew quarters, galley, wardroom, general workstation, personal hygiene facility, crew emergency healthcare system, exercisers, and stowage.

The crew quarters, perceived as a low activity area, are grouped at one end to minimize traffic and equipment operation disturbances while the crewmembers are resting. In addition, stowage racks are located between crew quarters and adjacent facilities to act as activity buffers and aid in sound absorption. The galley/wardroom is located at the opposite end of the module because of the high level of activity associated with meal preparations, consumption, and clean up. The personal hygiene facilities are located centrally to minimize the overlap of crew activities between the galley/ wardroom and crew quarter area.

The layout of the module is designed to provide the most habitable and productive environment possible given the restricted available volume.

The space station will provide private quarters for each of the eight crewmembers. Each crew quarter will serve as a bedroom, den, and living room, albeit on a smaller scale. At least 50 cubic feet will be provided within each compartment for sleeping. The crew quarter will provide stowage space for clothing and personal effects, a sleep restraint, a portable workstation linked to the space station data management system, audio/visual recording and playback equipment, and a communications panel.

The interior decor of each crew quarter is made up of acoustical fabric panels, which are modular and easily removed. This allows crew members to personalize their quarters with colors and textures of their choice.

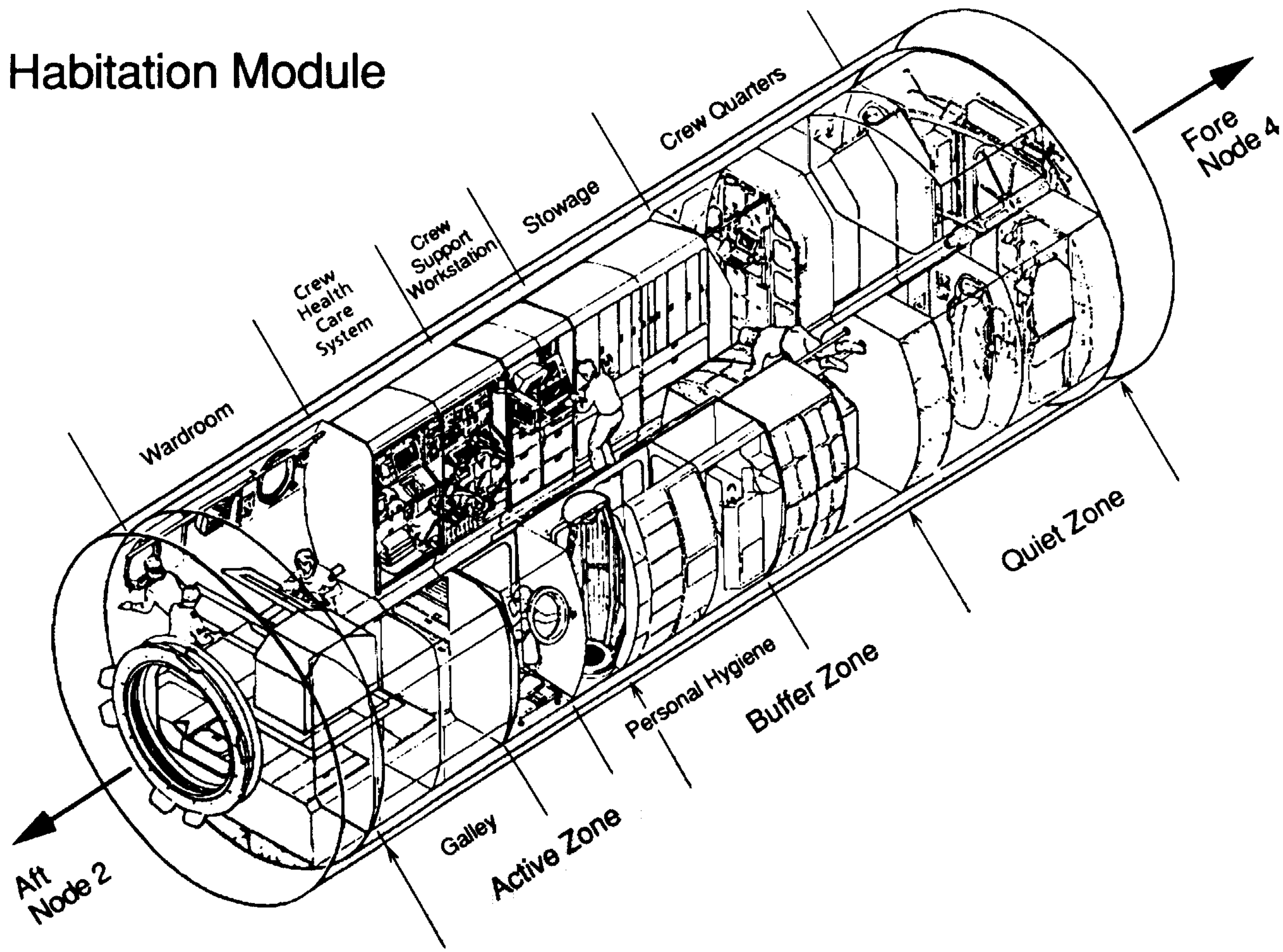
Food preparation and stowage on the space station will be handled in the galley, or kitchen, located across from the wardroom area. Here the crew will be able to cook and dispense their daily meals using the galley's microwave and convection ovens, liquid/beverage dispensers and deployable preparation counters. After the crew is finished eating, the galley will also handle the clean-up with its trash collection/compaction unit, dishwasher, and handwasher.

The galley provides bulk stowage for a 14-day supply of ambient, cold and frozen food stock. To make more efficient use of crew time, an integrated menu selection and inventory management system keeps track of the food used from the stock and tells the crew when it's time to resupply.

The space station crew will need a place to eat their meals, have meetings and just relax. For these reasons a wardroom area has been set across from the galley. The wardroom will provide seating for up to eight crew members and support everything from meals to teleconferencing.

The current concept features an integrated wardroom table and entertainment unit. The center bay is occupied by a single rack from which six of the eight worksurfaces are cantillevered. The remaining two worksurfaces are separate independent units that can be positioned anywhere in the Habitation Module via their compression posts. The rack also holds the monitor, playback equipment and 25 cubic feet of stowage. The entire wardroom can col-

Habitation Module



lapse into one rack space and then deploy to fit two to eight crewmembers. With extra independent worksurfaces, the wardroom area can accommodate up to 12 people.

The integrated workstation system incorporates all on-board computer-based workstations. It has operating displays and controls, and will interface with the Data Management System. The detailed workstation system design is presently under study.

The crew hygiene system being proposed for the Space Station Freedom is composed of the entire body shower subsystem, the waste management subsystem and a partial body hygiene/grooming compartment. The mechanical, electrical, and human engineering aspects of the design of these subsystems must incorporate state-of-the-art technology. A research laboratory has been established at JSC to support all the development efforts and tests necessary for providing a personal hygiene system.

The Space Station Crew Health Care System is an in-flight medical subsystem designed to maintain the health of the crew and provide treatment for illnesses and traumas that may be encountered during a mission. The subsystem is also responsible for monitoring the station's environment and assessing its impact on the crew's health. The Crew Health Care System is located in the Habitation Module and includes exercise equipment for crew conditioning, an analytical and microbiology lab, a restraint system for patient examination and treatment, a hyperbaric chamber, and a medical database.

The purpose of the Health Care System is to ensure the safety of the crew and the mission by dealing with minor accidents or illnesses immediately, and thereby eliminating the necessity of early mission termination or emergency rescue. If a major emergency does arise, the Health Care System can provide a margin of safety by stabilizing injured or sick crew before transfer to Earth. The system also plays a major role in the prevention of accidents and illnesses by maintaining and monitoring the health of the crew and their environment. A computerized system will be used to keep track of crew condition, schedule check-ups, and track medical supplies. The system will also be linked to centers on the ground to increase the power and flexibility of the medical team. Photography and imagery systems will again be an integral part of the space station program. Photographic systems provide film imagery from modified, off-the-shelf hardware. They will consist of still photography cameras in the 35mm, 70mm, and 5-inch film format sizes and motion picture photography in the 16mm format size. The 35mm still and 16mm motion picture cameras will be used primarily for interior photography. All the systems will have typical characteristics and features of commercially available hardware.

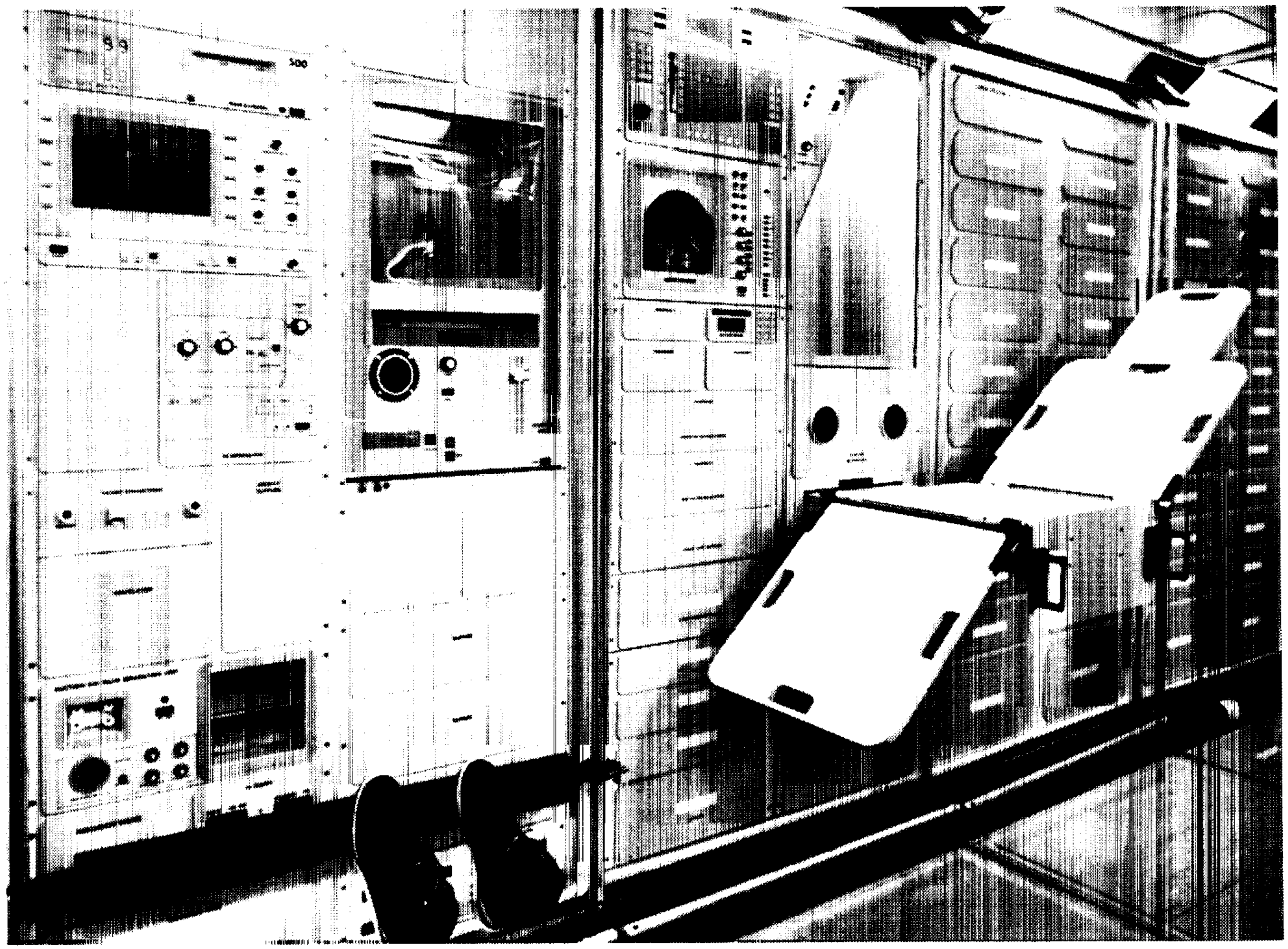
In addition to the film imagery, an electronic still camera system will be provided to support the necessity to return near photographic, high resolution quality data to the ground in a timely manner. The system will take the form of a hand-held camera in which the images are recorded electronically on memory media and then down-linked through a playback/ interface unit to the ground.

Attachment Systems
Devices are needed for Space Shuttle docking at the manned base. Johnson Space Center is responsible for these attachment systems, plus those needed for logistics supply modules. Devices to attach experiment packages and external hardware to the truss structure are also handled by JSC.

EVA System
The EVA system enables crewmembers to assemble, maintain, repair, inspect, and service the station and user systems. Until the Mobile Transporter is in place, assembly of the transverse boom is accomplished by extravehicular activity (EVA). The Johnson Space Center is responsible for EVA systems, including the extravehicular mobility unit (EMU), better known as the spacesuit, associated life support equipment, and support equipment. Inherent in the spacesuit are communication systems, a physiological monitoring system, and an autonomous life support system. The EVA system also includes mobility aides such as handrails, slide mechanisms, tethers, lighting, tools, and other support equipment.

Flight Crew Integration
JSC is responsible for providing the flight crew requirements across all space station systems and elements, as well as the standardization

Crew Health Care System



Elements and Systems

definition of crew interfaces for all systems and elements.

The flight crew's training includes: space station distributed systems, such as power and life support, on-orbit operations, man systems; mobile servicing systems, on-orbit maintenance, ESA/JEM module systems, and EVA operations. Initially a classroom environment serves as the training forum, including workbooks, personal computers, and a computer assisted instructional trainer. Visits to factories, other NASA centers, and countries of participating partners for additional training, follow.

The final aspect of the training program includes interfacing with both the Payload Operations Integration Center (POIC) and the Engineering Support Center (ESC).

As an illustration of how these various training programs and facilities will interact to support station operations, consider the following hypothetical scenario:

Career U.S. astronauts (station operators and scientists) who have been assigned to the manned base will commence with a series of training classes aimed at providing them with the proficiency necessary to operate the distributed systems on the station. This process will take about six months, conducted on a part-time basis, and will commence 24 months prior to launch. This training will occur at the SSTF or at other facilities at Johnson Space Center.

Once a crew is assigned to a flight increment, they will begin a training regimen which will last approximately 18 months (i.e., will begin 18 months prior to launch). Payload Scientists will be added at this point to make up the complete increment crew complement.

The first six months of increment-specific training will be accomplished as a team at the various user facilities associated with the team's projected flight increments. (Each team will be on-orbit for the duration of two increments.) Each individual payload investigator will be responsible for the training which the crew will receive while at a specific location. Scheduling coordination for the crew while taking part in this training will be the responsibility of the SSTCB located at JSC.

The following six months of training will generally be based at the POIC or thePayload Training Facility (PTF) where the crew can work with the investigator's personnel and with PTF training people versed in the payload problems which have occurred on previous flight increments. At this point the crew will spend increasing time on individual experiments (including brief return trips to the laboratories). More and more time will be spent operating groups of experiments, which could be discipline groupings, or other sets of payloads which have some functional affinity. Increasingly, the crew will operate in concert with the personnel who will be in the POIC and the relevant DOC/ROCs during their flight increments. About six months before their flight, the crew begins to train in earnest in the PTF with a selected complement of experiments. These sessions are conducted on an integrated basis with the POIC and the applicable ROC/DOCs whenever possible. During this time the station operators and station scientists work on the skills they will require for EVAs planned during their increments, and will maintain their proficiency with MSCS and other manned base systems tasks they will have onboard.

Three months before flight, the crew moves to JSC where their training continues in the SSTF and other JSC facilities. The concentration now is on ensuring that the crew comes together as a team, and that an affinity is also developing between the crew and the support personnel who will be on the ground during the first few weeks of their flight increment. It is at this point that the non-NASA crewmembers will receive the habit-ability training they require. During this period, all of the crew will work to maintain the systems skills they will need.

Beginning approximately ten weeks before launch, a small number of integrated simulations will be scheduled with a portion of SSSC personnel, along with personnel from the POIC and the users' ROC /DOCs. These simulations will be designed to ensure that the team building process has occurred properly and that the training for the increment about to launch is properly completed. Finally, after launch, "on-the-job" training and proficiency maintenance will occur throughout the duration of both increments.

Operational Activities

A typical day's activity for the manned base will be analogous to the operation of a multi-functional research and development complex on Earth. The major difference, of course, will be its location (in space and physically separated from its support facilities), including the unique requirements it places on those who maintain and use it. Typical operations activities for the manned base and unmanned platforms include: operations and utilization planning (determining who uses which resources and for what purposes, and planning for long term systems evolution); logistics operations support (the prelaunch activities associated with preparing the crew, consumables, and user instruments for launch to either the manned base or a platform, plus postlanding activities upon return); space operations (activities which transpire in orbit); and space operations support (ground-based activities which support or control manned base and platform on-orbit operations).

During real-time operations, the Space Station Control Center (SSCC) (led by its FlightDirector) is charged with maintaining manned base systems in working order and providing for the general health and welfare of the crew. SSCC responsibilities will include: space systems performance monitoring, resource availability assessments and projections, oversight of and support for increment changes, systems and user operations replanning, systems maintenance, housekeeping templates, crew safety assurance, extravehicular activity (EVA) scheduling and support, trajectory and altitude maintenance, and command and control zone operations support (in conjunction with the STS Mission Control Center).

In the interests of system safety and clear communications paths to the station crew, the SSCC will perform overall management and control of the air-to-ground data and voice links, and will be responsible for coordination of space station systems flight data file uplinks to the crew (including checklists and crew timelines). The Payload Operations and Integration Center at MSFC (POIC) will be responsible for coordinating specific user operations of the data and voice links for payload operations, consistent with SSCC operations guidelines and constraints.

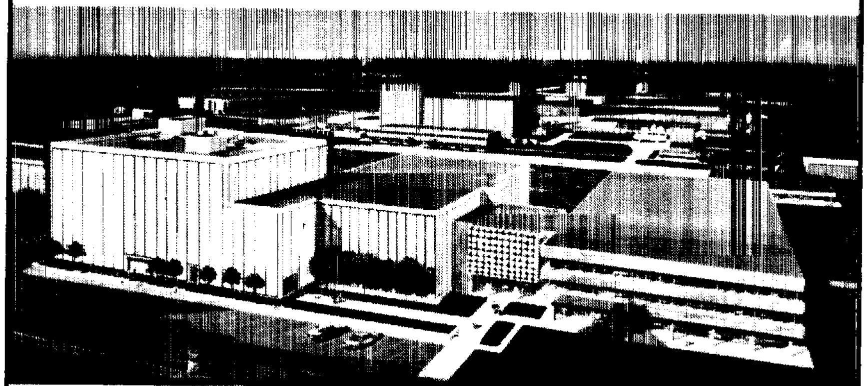
The SSCC is also responsible for integration of all systems upgrade and sustaining engineering operations support provided by the various Engineering Support Centers (both domestic and partner-supplied).

The SSCC will provide active support to the crew for at least one shift per day, with a minimum level of support consistent with safety requirements of the remainder of the time. Extensive use of automated monitoring capabilities will help to keep personnel requirements to a minimum.

Other systems inputs are provided to the SSCC for logistics support requirements, and by the Platform Control Center (PCC) for any transfer operations scheduling requirements for servicing of the Co-Orbiting Platform (COP). These inputs are integrated into the real-time replanning effort, along with the user resource templates provided by the POIC to maximize systems performance, crew effectiveness, and user operations returns.

JSC will provide an ongoing engineering support capability for sustaining the performance of systems acquired during the designing and fabrication program phases. This will include the provision of personnel and technical analysis capabilities to support routine space systems sustaining engineering activities, as well as "on call" support to the station execute teams for analysis of unanticipated situations onboard station elements.

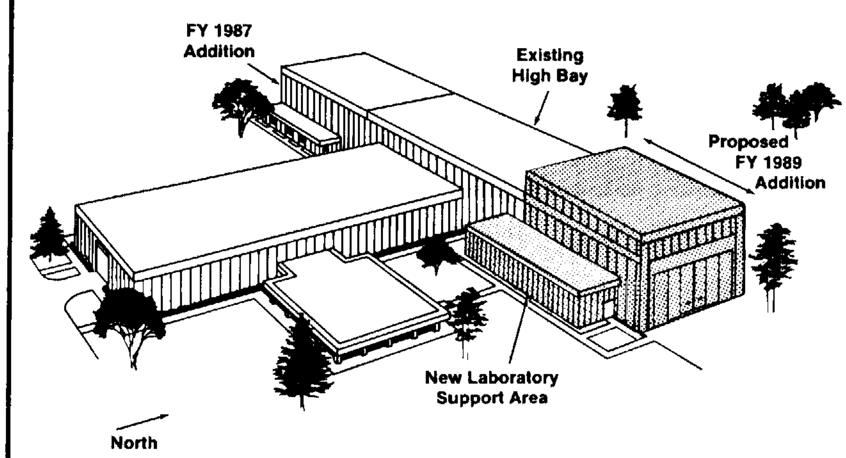
Space systems sustaining engineering includes systems maintenance engineering (engineering required to keep baselined space systems operating at peak performance); systems design engineering (engineering analyses performed in support of design modifications); and payload integration engineering (engineering in support of user payload operations and integration).



Space Station Control Center (SSCC)

The SSCC will provide for continuous real-time Space Station Freedom control and support, Manned Base Systems Integration/Support, Flight Activities Integration/Support, Flight Crew and Ground Support Personnel Integrated Training, Operations Planning and Preparation Support, Ground Applications Software Development and Operations Concept and Procedures Verification.

A five-story addition will be constructed at the southwest corner of the existing Mission Control Center (MCC). The addition will consist of approximately 106,000 square feet of floor for space station operations support and data processing/storage. The SSCC and MCC will share common skills, personnel, equipment, communications, and data. The facility will be fully operational approximately one year prior to launch of the first element, in order to conduct simulations.



Space Systems Automated Integration and Assembly Facility (SSAIAF)

The SSAIAF will provide an area for high-fidelity dynamics simulation testing of manual and automated construction techniques and hardware, component attachment methods, and verification/inspection techniques for on-orbit space station structural assembly tasks and similar applications. It will provide required space for a large stationary simulator. A three-story laboratory is required for a technician work and staging area.

A 47,000 square-foot addition will be constructed at the east end of the Systems Integration and Mockup Laboratory of Building 9. The addition consists of a 21,000 square-foot high-bay area and a 26,000 square-foot, three story, laboratory support area.

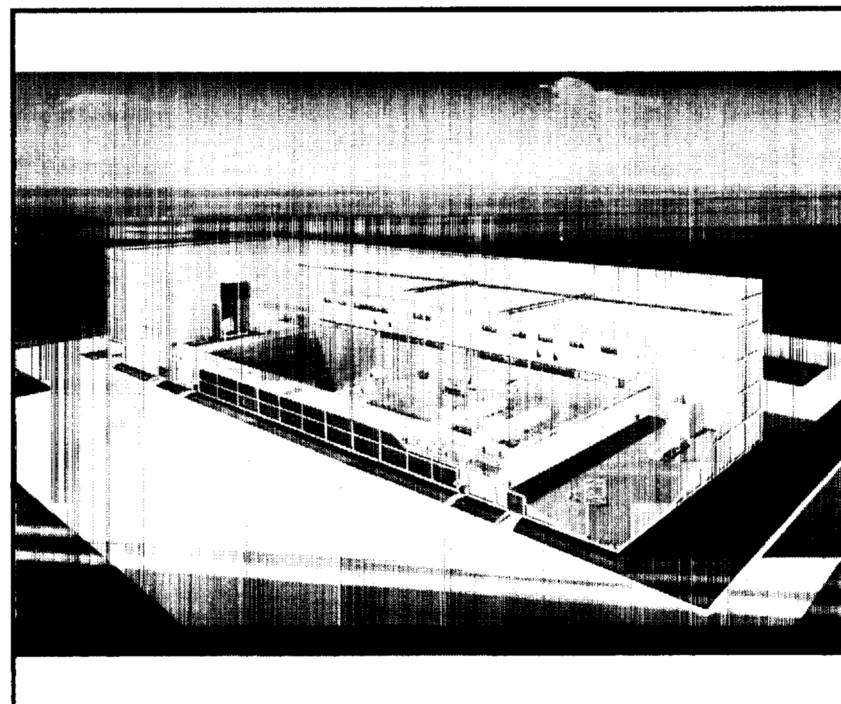
Space Station Training Facility (SSTF)

This planned facility supports Ground Training Applications Software Development; Manned Base Training for Crew and Ground Support Personnel; Integrated Operations Training for Systems and Payloads; Flight and Ground Procedures Verification; Flight Software Verification; and Space Station Information System Network simulation. A three-story addition will be constructed on the south side of the existing south-wing high bay of building 5. The addition will include approximately 23,200 square feet of floorspace. A variety of trainers needed for the unique Space Station systems will be housed in the facility.

The NBL will be a large neutral buoyancy simulation facility which will provide the mandatory capability to support EVA activities associated with the large-scale on-orbit construction, verification, crew training, and mission operations. Products are Engineering Evaluations, Procedures Verifications, EVA Training, and Real-Time Mission Support.

The NBL building houses a pool which is 225 feet long, 125 feet wide, and 60 feet deep. The pool holds 12.6 million gallons of water. Two separate pressure suit exercises can be conducted simultaneously.

Neutral Buoyancy Laboratory (NBL)

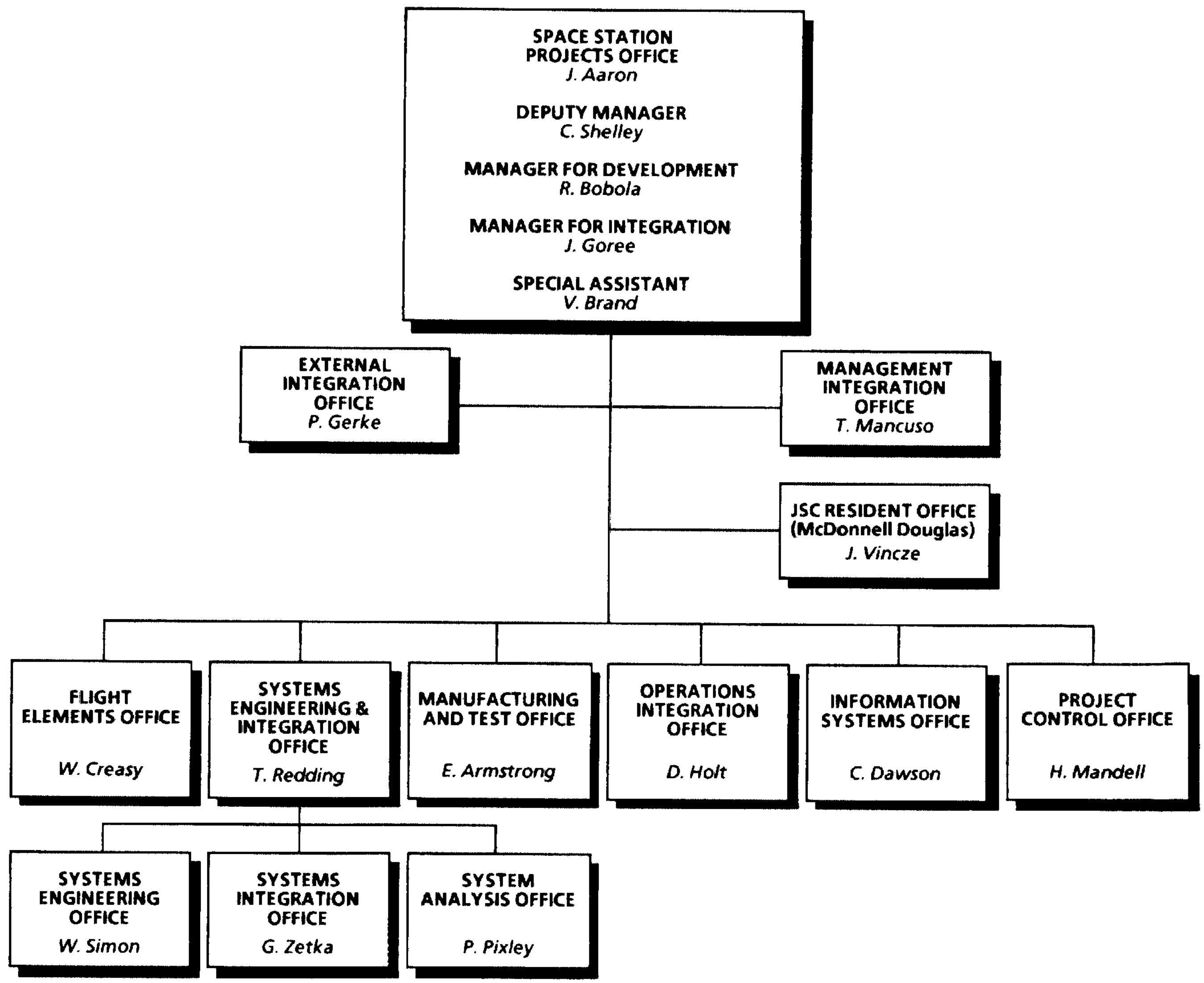


Space Station Freedom Projects Office

The Johnson Space Center is responsible for the design, development, verification, assembly and delivery of the Work Package 2 flight elements and systems. This includes the integrated truss assembly, propulsion assembly, mobile transporter, resource node design and outfitting, external thermal control, data management, operations management, communications and tracking, extravehicular systems, guidance, navigation and control systems, and the airlocks. JSC is also responsible for the attachment systems, the STS for its periodic visits, the flight crews, crew training and crew emergency return definition, and for operational capability development associated with operations planning. JSC will provide technical direction to the the Work Package 1 contractor for the design and development of all manned space subsystems.

Johnson Space Center has established the Level III Space Station Freedom Projects office to manage and direct the various design, development, assembly, and training activities. This organization reports to the Space Station Freedom Program Office in Reston, Virginia.

The Space Station Freedom Projects Office will develop a capability to conduct all career flight crew training. Experience has shown that integrated training, involving the flight crew and ground controllers using combined system and experiment trainers, is essential to mission success. The integrated training architecture will include the Space Station Control Center, and ultimately the Payload Operations and Integration Center when the station becomes permanently manned.



Traditional Center Roles and Responsibilities

The Goddard Space Flight Center was established in 1959 at Greenbelt, Maryland. It was NASA's first major scientific laboratory devoted entirely to the exploration of space. Named after Dr. Robert Hutchings Goddard, the man recognized as the "Father of American Rocketry," the Center continues its commitment to scientific research and development for space exploration. Goddard has one of the world's leading groups of scientists, engineers and administrative managers devoted to research in space, Earth sciences and applications. It employs more scientists than any other NASA Center. It also is the only national laboratory that can develop, design, fabricate, test, launch and analyze space science missions using all its own resources.

Today, Goddard scientists, engineers and technicians are working on advanced missions to support both terrestrial and astronomical research. The spacecraft they build and the scientific research they conduct are expanding our knowledge of the Earth, the solar system, and the universe. Goddard plays an important role in many of our nation's most challenging space missions. Goddard manages the worldwide tracking and communications network that support these missions. The network currently consists of ten ground stations, the Network Control Center, and the Tracking and Data Relay Satellite System (TDRSS). This network will also support Space Station Freedom.

The Goddard Space Flight Center has supported all of this country's major space programs including the manned programs such as: Mercury, Gemini, Apollo, Skylab and Shuttle and many unmanned programs such as TIROS, NIMBUS, LANDSAT, the Orbiting Astronomical Observatory, the International Ultraviolet Explorer and many others. Goddard also manages the Delta launch vehicle program. Goddard continues to support new space missions in their areas of expertise such as the Hubble Space Telescope (HST), the Cosmic Background Explorer (COBE) and various space platforms planned for the 1990's such as the Gamma Ray Observatory (GRO), and Upper Atmospheric Research Satellite (UARS).

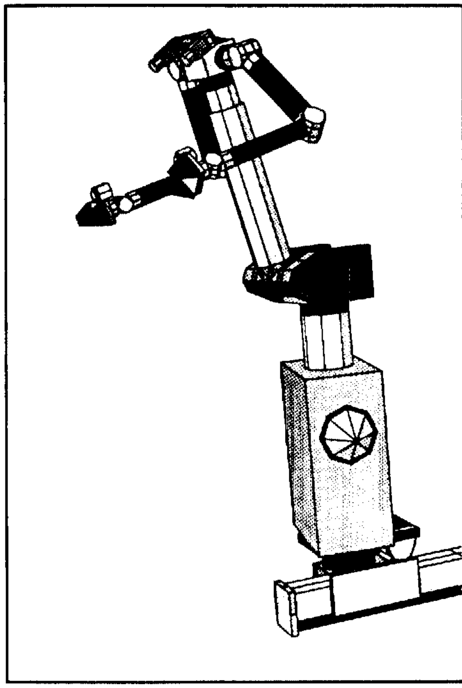
The fundamental mission of the Goddard Space Flight Center is the expansion of knowledge of the Earth, its environment, the solar system, and the universe through the conduct of scientific research and the management, development, and use of near-Earth space systems. Goddard is a collection of specialized laboratories committed to excellence in challenging areas of research and development to ensure that the Nation and NASA maintains leadership in space science and technology. Goddard has diverse skills in science, engineering, operations, and management disciplines to provide the capability for integrating internal and external resources in effective mission management and implementation of NASA programs. Goddard's science role is to provide NASA's principal leadership and competence in space and Earth sciences; advancing scientific understanding, disseminating knowledge, and ensuring quality guidance and support to NASA's space research, technology, and flight programs.

Goddard's engineering role is to excel in research, engineering, development, and application of technology for sensors, instruments, spacecraft, and complete information systems for space flight and ground system use.

Goddard serves as the NASA focal point for the planning and execution of near-Earth spaceflight projects for science and applications research. Goddard manages these projects in the most productive manner possible, achieving maximum returns on the resources invested. Goddard also provides a launch range and research airport at the Wallops Flight Facility on Virginia's eastern shore for suborbital rocket, balloon, and aeronautical missions. Goddard is a team of some 3,700 civil service employees and 8,100 contractors; about 12,000 people working for the expansion of knowledge of the Earth.

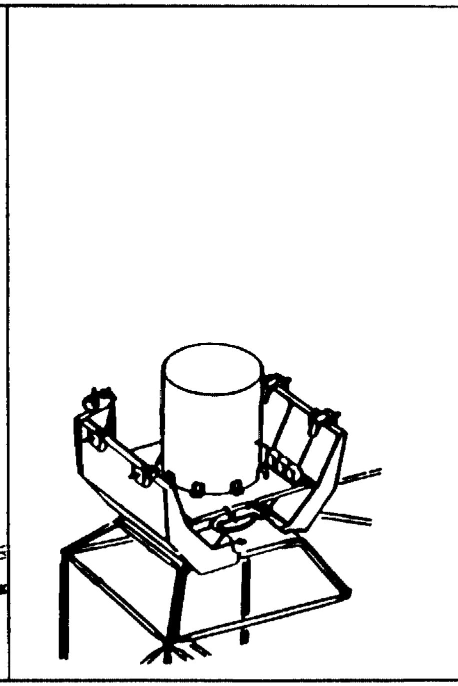
Space Station Freedom Unique Activities

Flight Telerobotic Servicer (FTS)



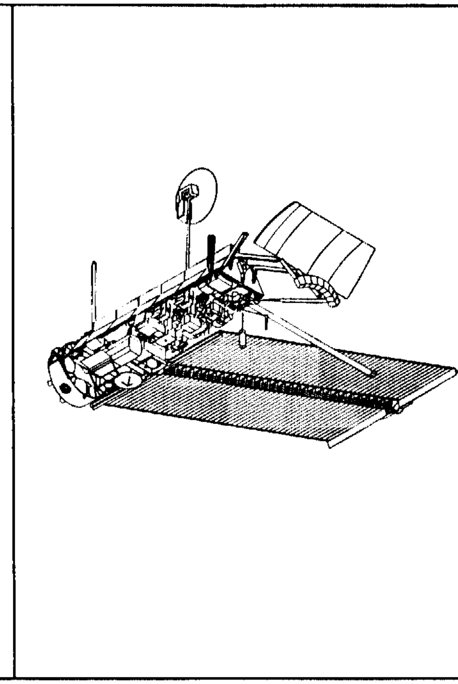
Goddard is responsible for development and implementation of the FTS, including the selection of appropriate technology, conducting Shuttle demonstration flights, delivering the flight element and providing a ground based training and evaluation capability. Goddard works with other NASA Centers conducting research in automation and robotics and evolutionary growth.

Attached Payload Accommodations



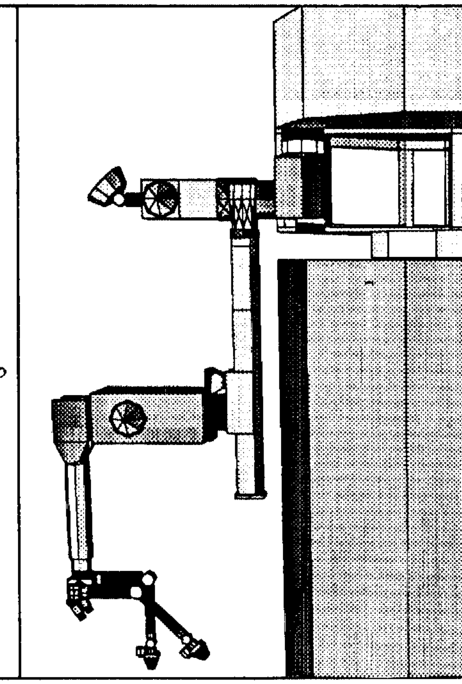
Goddard is responsible for accommodating various scientific, commercial and technology development instruments and experiments, providing utilities such as power, thermal control, data system interfaces, pointing and stability; providing attachment fixtures and other equipment necessary to properly place and operate the payloads and provide attitude determination.

Unmanned Free Flying Platforms

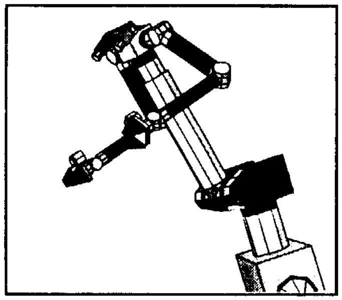


Goddard is responsible for managing the detailed design, development, test, and evaluation of the U.S.platforms that are not attached to the station but fly freely in their own orbits. The initial U.S. polar platform will support the Earth Observing System (Eos) mission. Another U.S. platform, co-orbiting with the space station in the late 1990's, will serve additional scientific users from various disciplines.

Assembly, Maintenance and Servicing



Goddard is responsible for developing the servicing system architecture for all flight vehicles and attached payloads to optimize station performance for user operations. Goddard works with the user community to determine requirements that impact design and evaluates capabilities such as replacement, replenishment, retrieval, storage, assembly, test and verification of intended operation.



Flight Telerobotic Servicer Program
The Flight Telerobotic Servicer (FTS) is the result of discussions between NASA and the Congress on how the Space Station Freedom program could best be utilized to enhance the technologies of robotics and machine intelligence. Mandated by Congress in the conference report accompanying NASA's FY 1986 appropriations bill, the FTS is an outgrowth of the Automation and Robotics (A&R) initiative of the project's Definition and Preliminary Design Phase ("Phase B").

The FTS is a telerobotic device capable of precise manipulations in space. It will operate with a mix of direct teleoperation and supervisory control by astronauts. It will be used to assist in assembly and servicing operations. The FTS will improve the efficiency and safety of operations. Initially intended for relatively simple tasks, the FTS capabilities will evolve over time to accommodate increasingly sophisticated operations. Invaluable not only for station operations, the FTS will have wide application in orbits beyond the reach of the present manned space transportation system.

The Goddard Space Flight Center's Space Station Freedom Projects organizaton is accountable for the development and implementation of the FTS. Technical and management activities at GSFC are continuing to focus and drive the implementation of the FTS program in response to the A&R objectives of the Space Station Freedom program. Other NASA Centers support Goddard in implementing the FTS program.

Early in space station planning, NASA initiated a study to determine the most effective manner of applying A&R technologies both to enhance Freedom and to provide the desired development impetus. The NASA Advanced Technology Advisory Committee (ATAC), established by NASA at the direction of Congress, evaluated the recommendations of universities, aerospace and automation related industries and government laboratories, integrating them into a comprehensive set of recommendations for further study by Phase B contractors. These recommendations may be summarized as follows:

- Automation and robotics should be a significant element of the Space Station Freedom program.
- Initially, the station should be designed to accommodate evolution and growth in automation and robotics.
- Initially, the station should utilize significant elements of automation and robotics technology.
- Criteria for the incorporation of A&R technology should be developed and promulgated.
- Verification of the performance of automated equipment should be stressed, including terrestrial and space demonstrations to validate technology for station use.
- Maximum use should be made of technology developed for industry and government.
- The techniques of automation should be used to enhance NASA's management capability.
- NASA should provide the measures and assessments to verify the inclusion of automation and robotics in the space station program.

During the course of Phase B Study, the ATAC continued to monitor the implementation of these recommendations. As a result of the efforts to date, functions which would benefit from application of robotic technologies have been identified and robotic concepts have been evaluated.

Space Station Freedom Unique Activities

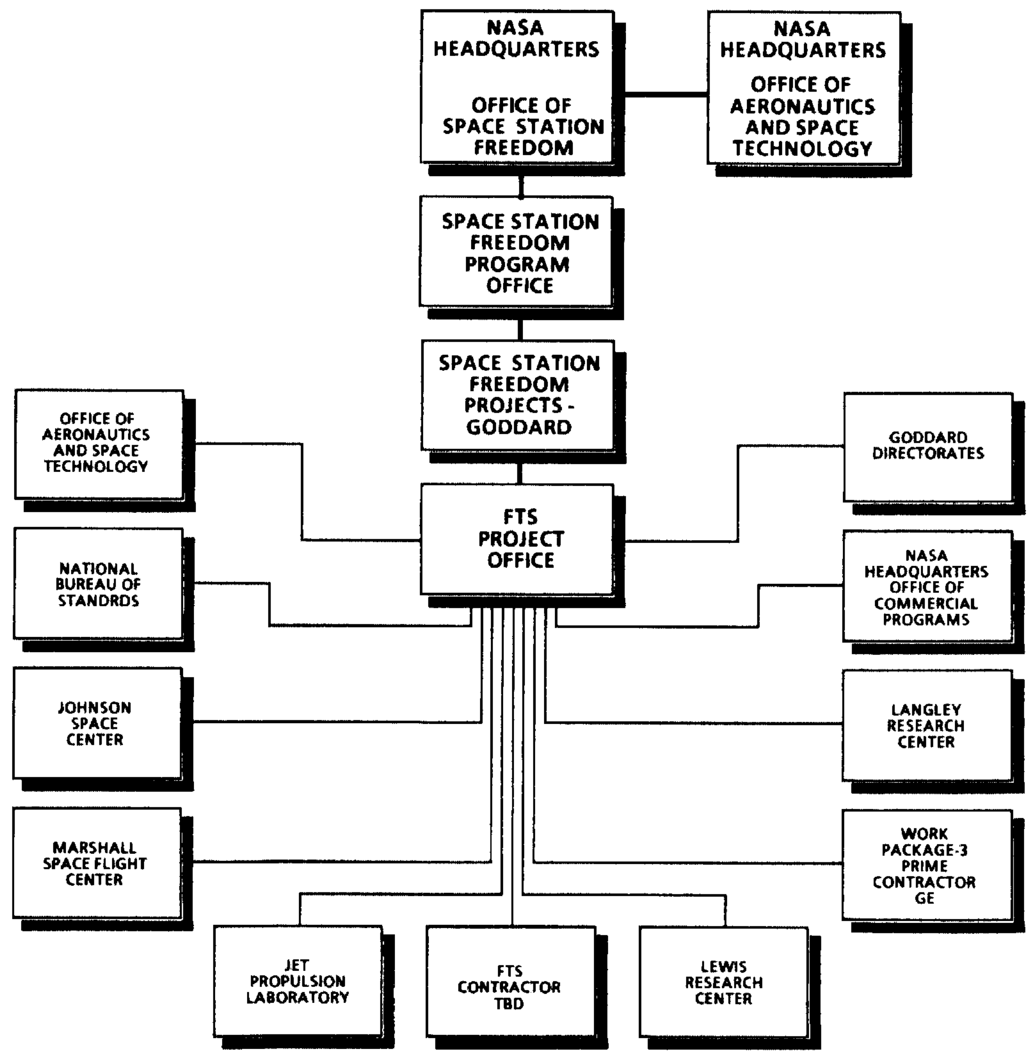
The FTS program will be implemented by establishing and coordinating four major elements:

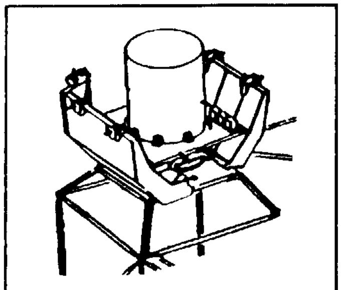
- A Technology element to select, modify, and transfer evolving technology and to identify requirements for new technology.
- A Flight Demonstration element to conduct demonstration flight(s) on the NSTS prior to station assembly for verification of design and operations concepts.
- A Freedom Flight System element to deliver, operate, and evolve an FTS for use by the Space Station Freedom program.
- A Ground System element to provide continuing capability to evaluate and implement advanced robotic technology and to assist training operations and FTS on-orbit performance evaluation.

As can be seen from the figure at the right, many other NASA, government and industry organizations are participating in the FTS program, each contributing in their areas of Center or organizational expertise.

The FTS program will provide an early demonstration of the FTS capabilities onboard the Shuttle sometime in 1991. The results of that demonstration and research being conducted on the ground at the NASA Centers and contractors will be transferred into the actual flight article that will be used to assemble Space Station Freedom beginning in 1995. The role of the FTS will evolve with Space Station Freedom over time, taking on different tasks and roles consistent with the assembly, servicing, maintenance and operations activities.

FTS MANAGEMENT STRUCTURE AND RELATIONSHIPS





Attached Payload Accommodations
Goddard is responsible for accommodating many and various scientific, commercial, and technology development instruments and experiments. The term "payload" is used to mean the total complement of specific instruments, space equipment, support hardware, software, and consumables required to accomplish a discrete activity in space. A payload, then, may be large or small, simple or complex and serve just one or many experimenters, investigators or users. Payloads can be mounted inside the pressurized volume of Space Station Freedom or outside on the structural members or truss. The outside ones are called attached payloads.

Like experiments or processes in a laboratory or factory on Earth, Space Station Freedom payloads will need power, thermal control, command control, and data systems.

They also need, in many cases, periodic monitoring, maintenance and perhaps repair. In some cases, the payloads may even produce a product that needs to be "harvested" or retrieved and brought back to Earth.

Some payloads may want to "look" at outer space while others may want to "look" at Earth or point towards a particular star, all at the same time. This will require special pointing requirements and a special system to allow for very accurate and stable pointing.

When one considers the potential for thousands of different possible experiments and operations over the useful lifetime of the space station, the challenging role Goddard has in accommodating all of the potential users becomes more apparent as does the potential for conflict over station resources.

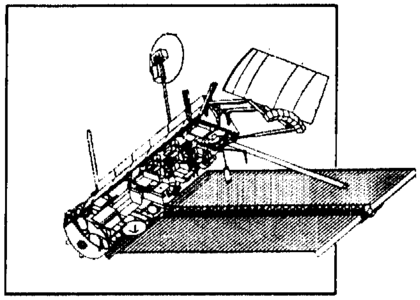
The attached payloads will initially be scientific in nature and sponsored by the NASA Office of Space Science and Applications. The disciplines include Solar System Exploration, Space Physics and Earth Science and Applications. These various disciplines endeavor to understand the origin and fundamental laws of the universe, and the solar system; to establish the scientific and technical foundation upon which to undertake both manned and unmanned explorations of the Solar System, and to specifically provide a greater understanding of the Earth, its immediate environment and the Sun. Goddard Space Station Freedom personnel will work with the sponsors and users of attached payloads to determine how their requirements can be accommodated by both design and operations. The user requirements include the following:

- Information - onboard and on the ground
- Transportation - from the Shuttle to the manned base
- Operations Planning - including integration, test and operation
- External Storage - outside the pressurized volume
- Servicing - for assembly, replacement, replenishment and storage.
- Verification - integration test & verification of payload with attached payload accommodation equipment.

Goddard Space Station Freedom personnel will work with the designers and users to identify and discuss the accommodation issues in such areas as:

- Crew size - how many and how much time
- Microgravity - how little and how variable
- Available power - how much and where
- Volume - how much and where
- Experimental compatibility - between fundamentally conflicting experiments
- Payload orientation - with respect to the Earth, stars and Sun
- Attach points - on the transverse boom
- Distributed payloads - parts that are distributed to various points.

Elements and Systems



Free-Flying Platforms

Platforms are unmanned modular spacecraft designed to carry and support science, technology and commercial payloads that require exposure to space or that cannot be attached to Space Station Freedom's manned base for one reason or another. They provide facilities for a broad range of users to conduct long term independent missions and investigations. There are two such platforms associated with the Space Station Freedom's initial capabilities. One platform is in polar orbit and is the responsibility of the United States. The other is a polar orbiting platform that is the responsibility of ESA.

Goddard will manage the detailed design development, test and evaluation of the U.S. polar platform now planned to be used by the Earth Observing System Program which is also managed by Goddard. The Eos program is also part of the Mission-to-Earth Program which also includes many of the 1992 International Space Year scientific activities.

The first U.S. polar orbiting platform is intended for continued viewing of the Earth and is placed in a north-south orbit, thereby allowing the sensors to view the entire Earth rotating under the platform. By syncronizing the altitude (and therefore the orbital period) with the Earth's rotation and inclination of the sun, the scientists can be sure their sensors look at the desired locations on the Earth in morning and afternoon sunlight rather than darkness. This orbit is called sun-syncronous and is 705 kilometers (438 statute miles) and inclined 98.7 degrees to the equator. To achieve this, the polar platform must be launched from Vandenberg Air Force Base in California. Present planning leans toward the use of a Titan IV expendable launch vehicle.

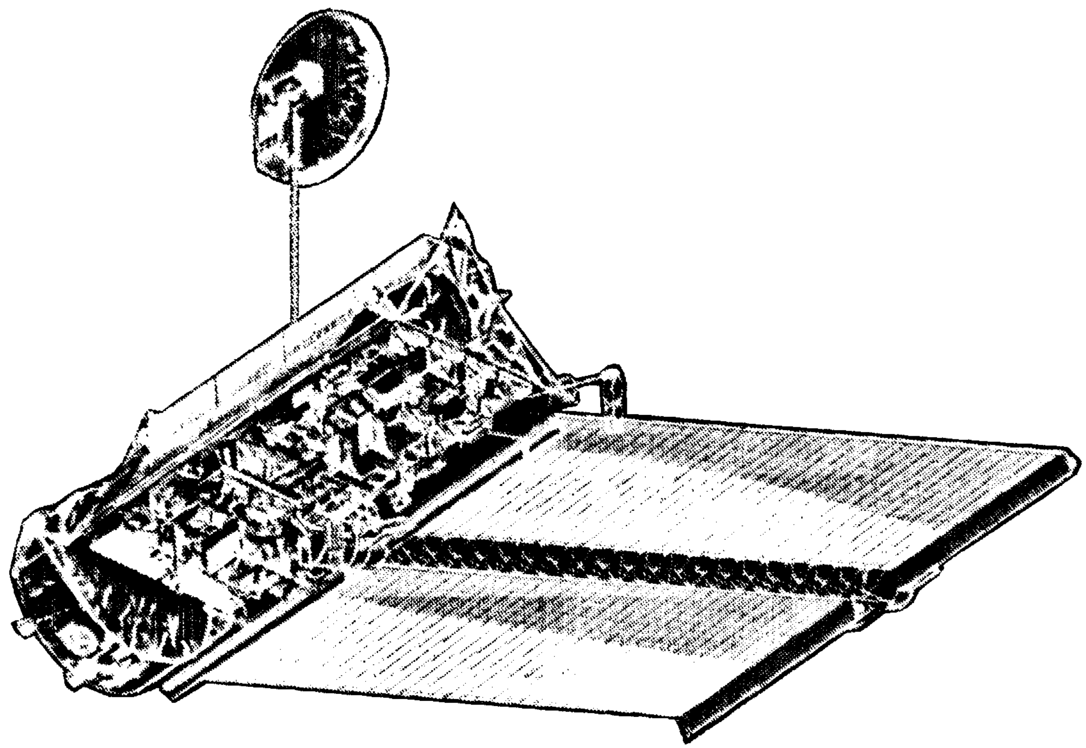
The principal goal of the Earth science and applications discipline, which will be the primary user of this polar platform, is to obtain a scientific understanding of the entire Earth system on a global scale by determining how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all may be expected to continue to evolve on all time scales. To attain these objectives, the Eos program will be carried out in conjunction with the National Oceanic and Atmospheric Administration's (NOAA) weather monitoring program.

The Eos system includes a complement of instruments on the platform which will greatly enhance the scientific communities' ability to gather remotely sensed data on the Earth's land masses, its oceans, atmosphere and ice sheets. This data can be recorded on-board and played back to the ground via the TDRS network or direct broadcast to a ground station.

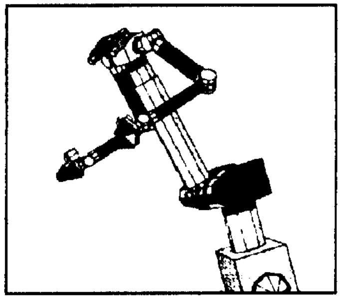
The basic design of the U.S. platforms provides for a significant degree of commonality between both polar and co-orbiting platforms and the manned base. These design studies also look at potential instrument commonalities between NASA, ESA and Japanese platforms. Commonality implies common interfaces for all users. This should make logistics simpler, repairs more efficient and costs lower.

The platforms are designed to be serviced in different ways: by the Shuttle, by rendezvous with a servicing carrier and by robots on a servicing carrier.

An artist's view of the polar orbiting platform with an Eos payload is shown under the Elements and Systems section.



U.S. Polar Platform - Earth Observing System (Eos)



Flight Telerobotic Servicer (FTS)

The Need

The crew will need assistance in assembling, servicing, inspecting and maintaining Space Station Freedom and all of its payloads and systems. While some extra vehicular activity (EVA) will still be required, it is more risky and expensive (in both time and dollars) than if an intelligent robot could perform some of those functions. One way to get the various jobs done is to put the astronaut's intelligence inside the station and put his or her hands and arms outside. In effect, this is what a "telerobot" accomplishes. The term "telerobot" refers to a hybrid capability for the robot to operate either under direct control of a human operator (tele-operation) or to carry out tasks by itself according to some computer rules, knowledge and sensory information but providing the ability for the human to intervene. Another way to get the job done is to provide the robot with some intelligence of its own for certain types of jobs. In effect, this is a "smart robot." The concept of the Flight Telerobotic Servicer provides a useful, reliable and safe tool to assist the crew in performing a broad range of routine tasks on both the station and the Orbiter.

Design Concept

The FTS project will soon be evaluating competing approaches offered by industry. In preparing for this evaluation, GSFC engineers developed their own design concept to the same requirements being studied by the competing Phase B contractors. What follows is a description of this "in-house" design concept. The actual FTS, to be built by the successful contractor, is likely to differ substantially from this description. The FTS is an unique element of Space Station Freedom, unique to spaceflight and unique to the robotics world. The FTS is a robot which is also a spacecraft, and it must be designed and built accordingly. The FTS must work in a much less structured world than an industrial robot. The FTS will be required to perform many varied tasks with varying degrees of precision throughout its expected lifetime. These tasks will increase in complexity; therefore, the system must be capable of substantial growth and evolution.

The telerobot is composed of three major subassemblies: the main body, the arm positioning system and the manipulator arm assembly.

The Main Body

The main body contains all the major electronic components of the telerobot, as well as the grapple fixture by which the telerobot is picked up by one of the large manipulator arms, e.g., the Remote Manipulator System (RMS). The main body also contains the attachment grapple (or foot) by which the telerobot is securely fixed at the worksite.

One of the features of the main body of the telerobot is that it is free to rotate about its central core and the attachment foot. This freedom to rotate allows the thermal radiators that cover three sides of the main body to be oriented for optimum heat rejection at the worksite. Main body rotation with respect to the attachment foot allows the operator of the large manipulator arm another degree of freedom to help orient the FTS foot for proper mating to the worksite attachment point.

The Arm Positioning System

The next major component of the telerobot is the arm positioning system that consists of two, linearly driven, tubular sections connected through an offset rotational joint. The lower section is free to rotate simultaneously with respect to both the main body and the attachment foot. The manipulator arms are free to rotate ± 180 degrees with respect to the upper section. Five degrees of freedom are obtained to position the arms relative to the telerobot main body and attachment location. There are a number of advantages to the arm positioning system: it extends the reach of the telerobot without extending the length of the manipulator arms; it allows the arms to be positioned squarely to a task so that the teleoperator interfaces with the task in a natural manner;

and it allows the telerobot to reach out over objects which may come between the attachment fixture and the location of the task.

The Manipulator Arm Assembly
The final component of the telerobot is the manipulator arm assembly that is mounted to the end of the positioning system. It consists of the shoulder assembly that rotates ± 180 degrees about the end of the positioning system, and two, 7-degree of freedom manipulators mounted to each end of the shoulder assembly. The manipulators are 1.524 meters (5 feet) long and are configured with a shoulder, elbow, and wrist.

In addition to the telerobot, the FTS includes two workstation designs: a stowable workstation in the Shuttle's aft flight deck and one that will be located inside Freedom.

Design Drivers
During the analysis of the requirements and task capabilities, the Goddard study team identified the following major design drivers for the FTS:

- Thermal Environment
- Independent Operation
- Manipulator Stability and Positioning
- Safety
- Mobility
- Evolution
- One-G Operation
- Human Interface

The key challenges for each of these design drivers are as follows:

- Thermal Environment - The thermal environment created by space introduces unique problems in an area that is only a minor concern for terrestrial robots. In space, the only way of dissipating heat is by radiation or conduction. For several reasons, radiation was the selected method. The peak operating power is in the 1 to 2 kilowatt range including all the motors, computers, video equipment and batteries. The combined effect of all the necessary design choices produced a thermal design that is independent of Freedom that will permit indefinite operation of FTS under most conditions.

- Independent Operation - The FTS must be capable of limited operation independent of hard-wired utilities for power, data, and video from the manned base. As a result, a large battery and an RF communications system was included in the design. The FTS can never be totally independent of the space station because it always needs a firm structural attachment when working. However, the requirement for independent operation gives the FTS a tremendous amount of flexibility, allowing it to work in areas where no utility ports are located.

- Manipulator Positioning and Stability - Studies of the size of the Shuttle payload bay and Freedom's truss and required work indicate that the ideal reach envelope of the telerobot would be 5 meters (16 feet). If the telerobot is to work in these locations, it must be able to cover these types of distances. This requires a trade-off of distance vs. dexterity. A local mobility system and an arm positioning system delivers the arms to the tasks.

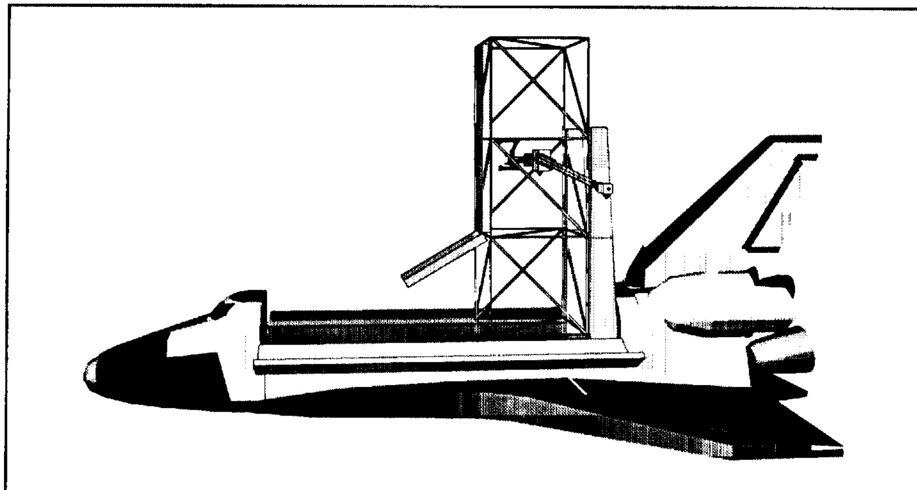
- Safety - Safety is of primary importance in the design of the FTS. The Phase B study approach was to set up a watchdog safety subsystem that consists of redundant radiation-hardened computers and associated sensors in the telerobot to monitor all aspects of the telerobot's operations and health. The workstation has a computer that acts as a global safety monitor for workstation operations as well as the telerobot safety subsystem. Whenever any anomalous condition is detected, the safety computers will stop all movement of the telerobot.

- Mobility - The local mobility sytem that is part of the in-house concept is a portable rail that can ride out to the worksite with the telerobot to provide lateral movement. The portable rail, together with the arm positioning system, allows the manipulator arms to be positioned with 6 degrees of freedom at the worksite.

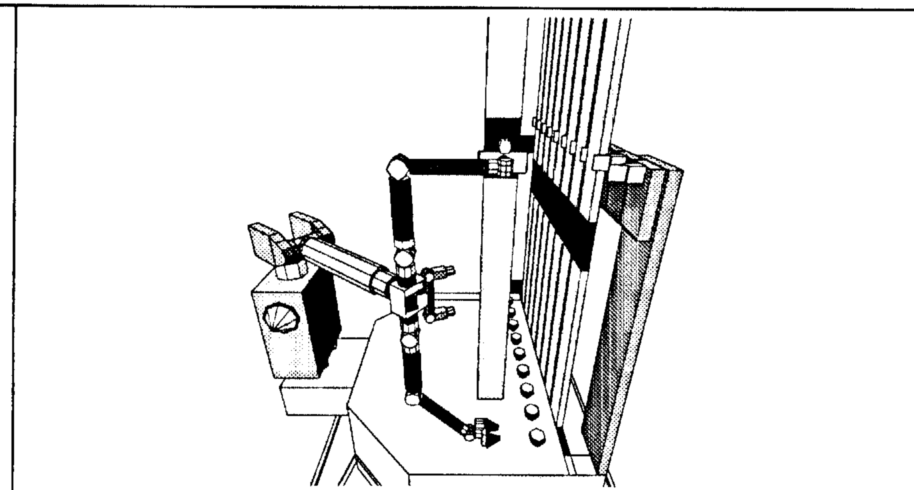
- Evolution - The FTS must be able to evolve towards greater autonomous operation which will be accomplished through the incorporation of advanced hardware and software items as they become available. The FTS must be designed to easily accept these changes.

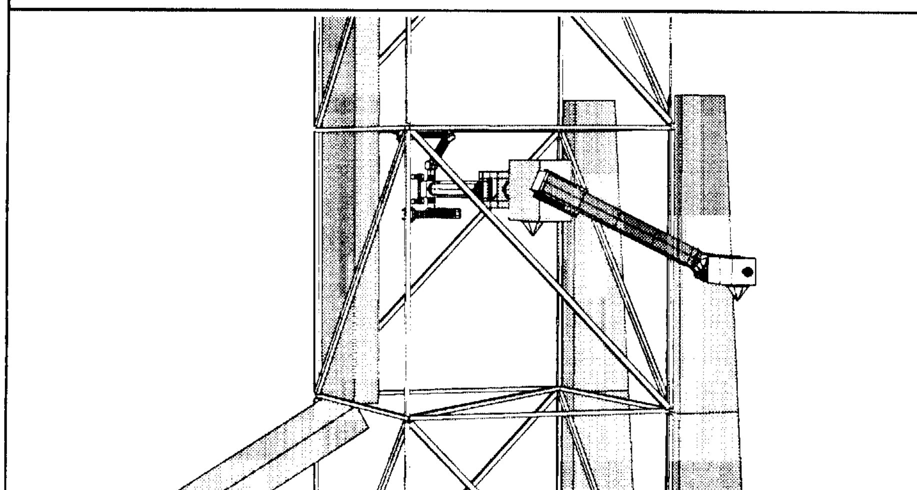
Elements and Systems

FTS assembling the truss in the orbiter

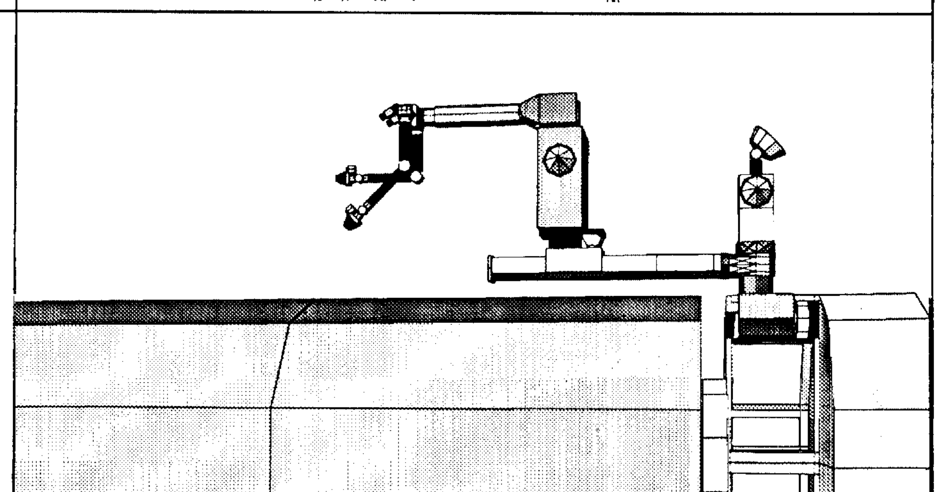


FTS installing a radiator

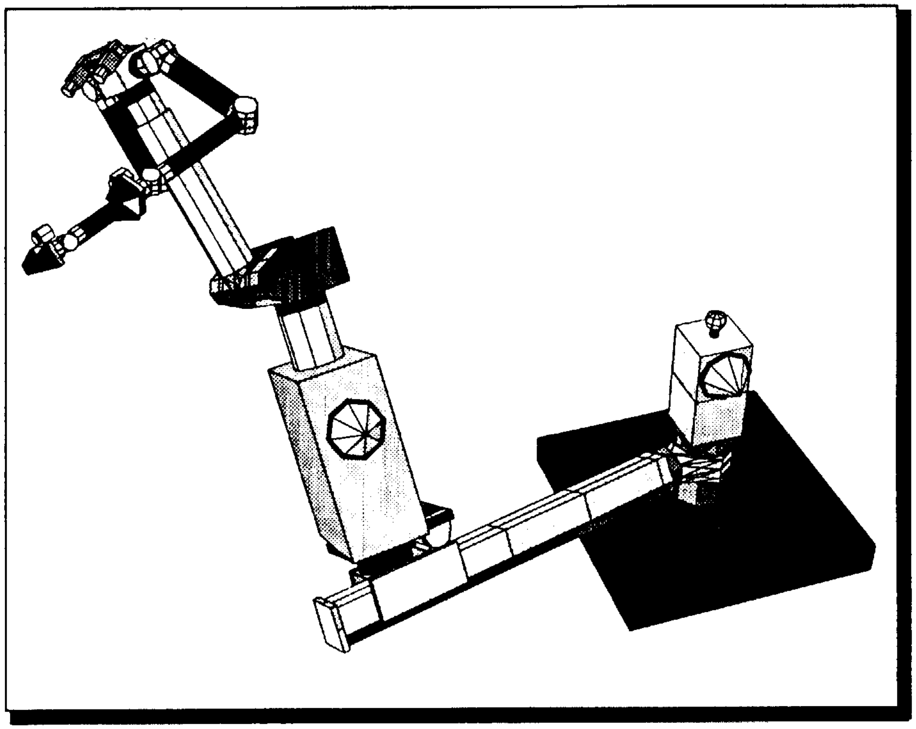




FTS working on the truss

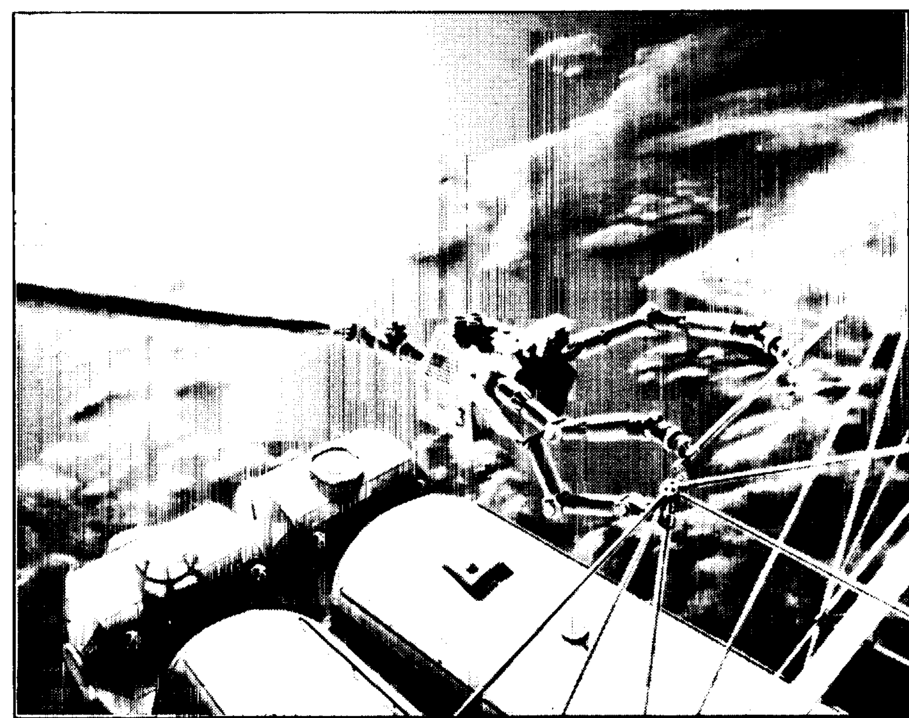


FTS servicing another spacecraft



The Resultant FTS from Goddard's Study

A conceptual telerobot assembling a truss



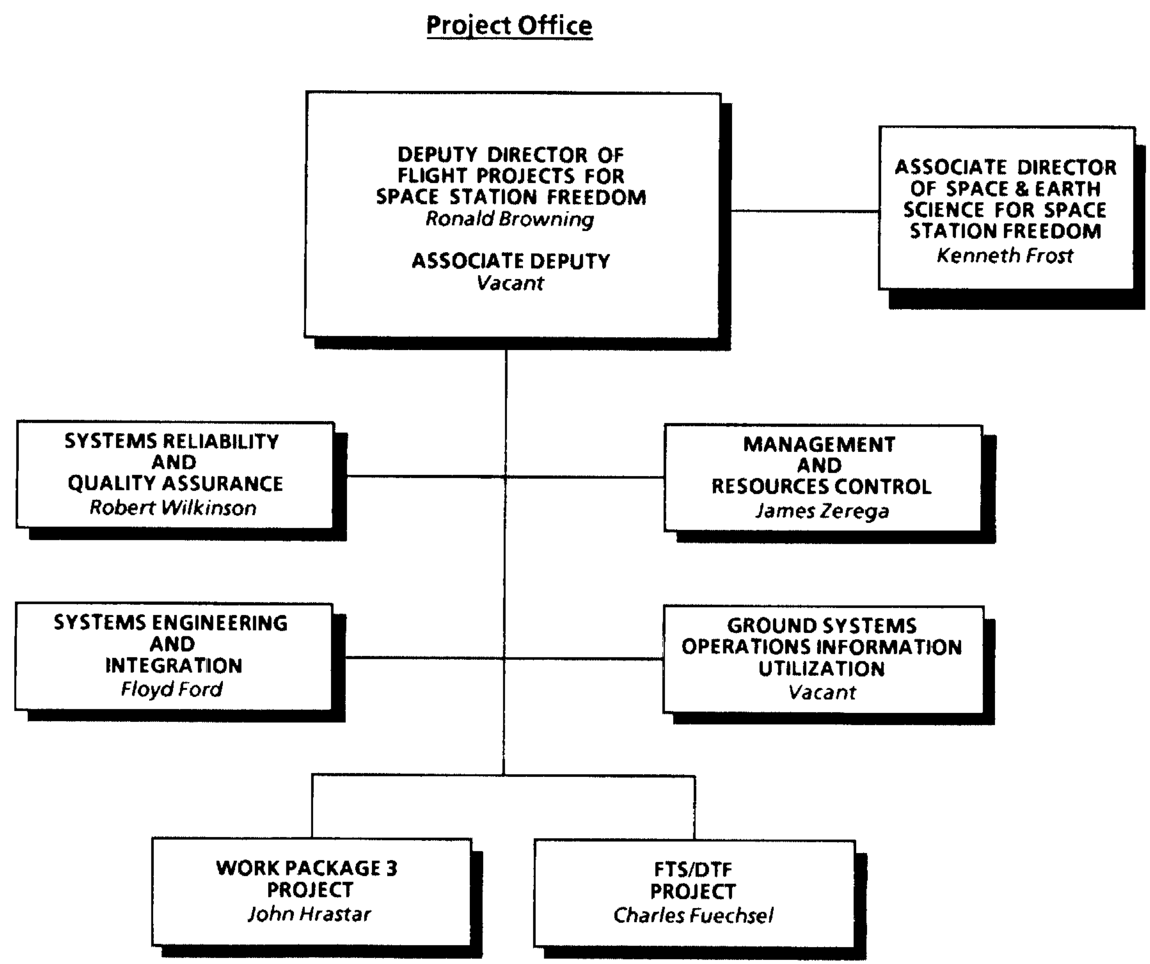
Space Station Freedom Organization

NASA's Goddard Space Flight Center, Greenbelt, Md., is responsible for development of several of Space Station Freedom's elements and systems including the free-flying platforms, attached payload accommodations, and for planning NASA's role in servicing accommodations in support of the user payloads and satellites. Goddard is also responsible for developing the Flight Telerobotic Servicer.

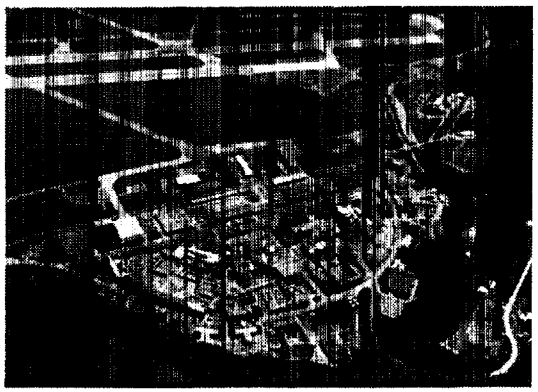
As the Work Package 3 Center, Goddard has established the Level III Space Station Freedom Projects organization to manage and direct its various development, scientific, engineering, and support activities. This organization reports to the Space Station Freedom Program office in Reston.

A unique aspect of this organization is its responsibility to the various scientific, engineering and commercial communities that intend to utilize the station's resources. This organization represents the needs of the users by ensuring sufficient power to their experiments or payloads and a place for them on the station's truss, a physical environment that supports their experiments, robotics and crew services for their experiments, communications with their experiments, and most importantly, their experiment data.

This organization currently includes approximately 100 civil servants. There are an additional 70 people working on related activities in other Goddard organizations on such areas as advanced development, robotics, and testing of prototype flight hardware.



Traditional Center Roles and Responsibilities



The Lewis Research Center was established in 1941 at Cleveland, Ohio adjacent to the airport. It was one of three centers operated by the National Advisory Committee for Aeronautics (NACA) nationwide. The center was named for George W. Lewis, NACA's Director of Research from 1924 to 1947. The Center developed an international reputation for its research on jet propulsion systems in the new jet age.

Lewis' original objective was aeronautics propulsion research. The Engine Research Laboratory, as it was first called, was responsible for creating technology to improve aircraft engines and components, studying fuels and combustion, and performing fundamental research in those areas of physics, chemistry, and metallurgy relevant to propulsion.

In October 1958, the NACA Centers became the nucleus of the National Aeronautics and Space Administration (NASA). Today, Lewis scientists, engineers, technicians and support personnel number about 2,700 people and occupy 100 buildings and 500 specialized R&D facilities spread out over 360 acres. In addition to offices and laboratories for almost every kind of physical research such as fluid mechanics, physics, materials, fuels, combustion, thermodynamics, lubrication, heat transfer, and electronics, Lewis has a variety of engineering test cells for experiments with components such as compressors, pumps, conductors, turbines, nozzles, and controls.

A number of large facilities can simulate the operating environment for a complete system: altitude chambers for aircraft engines, large supersonic wind tunnels, space simulation chambers for electric rockets or spacecraft, and a 420-foot-deep zero-gravity facility. Some problems are amenable to detection and solution only in the complete system and at essentially full scale.

The combination of basic research in pertinent disciplines and generic technologies with applied research on components and complete systems has helped Lewis become one of the most productive centers in its field in the world.

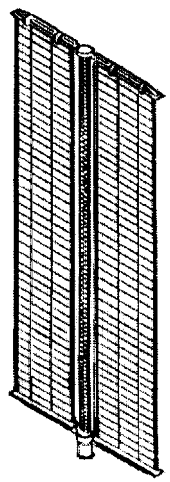
Whereas Lewis has continued their traditional work in aircraft propulsion, they have utilized their expertise in space propulsion, space power and satellite communications. They have also applied this fundamental knowledge to terrestrial applications such as solar and wind energy, automotive propulsion, advanced technology batteries, fuel cells, and biomedical engineering. Some of the unique facilities supporting programs and basic research include the following:

- Propulsion Systems Laboratories
- 8-by 6-foot Transonic/Supersonic Wind Tunnel and 9-by 15-foot V/STOL Subsonic Wind Tunnel
- 10- by 10-foot Supersonic Wind Tunnel
- Icing Research Tunnel
- Engine Research Building
- High Pressure Facility
- Vertical Lift Facility
- Electric Propulsion Laboratory
- Rocket Engine Test Facility
- Zero-Gravity Facility
- Energy Conversion Laboratory
- Power Systems Facility
- Materials and Structures Laboratory
- Materials Processing Laboratory
- Basic Materials Laboratory
- Central Process Air System
- Research Analysis Center
- Flight Research Building (Hangar)
- Technical Services Building
- Plum Brook Space Power Facility

The new Power Systems Facility will test the Space Station Freedom Power System. Lewis is responsible for the end-to-end electric power system architecture for the station including solar arrays, batteries, and common power distribution components to the platforms.

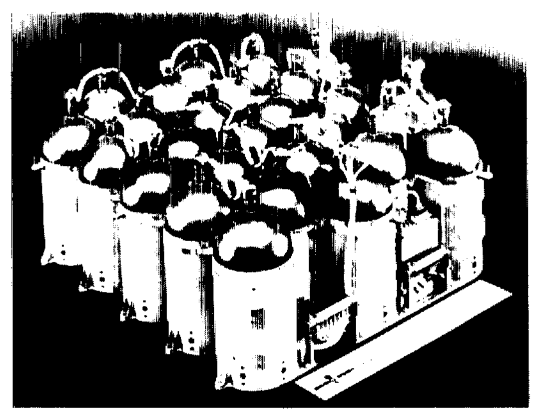
Contemporary and future programs at Lewis will continue to develop technologies important to the Nation.

Space Station Freedom Unique Activities (Summary)



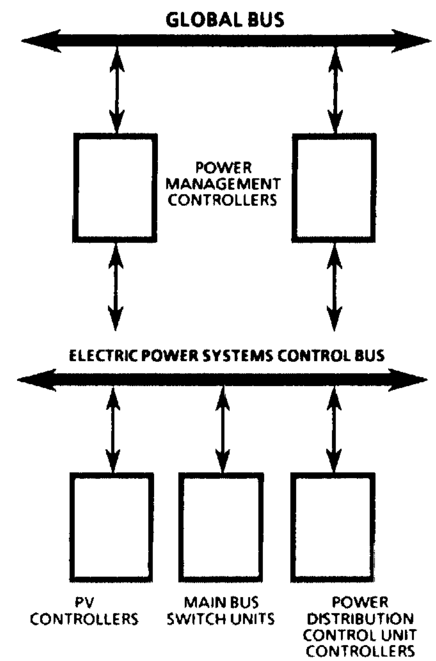
Solar Arrays

A series of eight solar array wings will be utilized to provide electric power aboard the space station during its early years. Each 34- by 108-foot wing consists of two blanket assemblies, each covered with 14,592 solar cells. The modules are located on the transverse boom, outboard of the truss element alpha gimbals. Each one consists of an integrated equipment assembly (radiator panels, energy storage, DC electronics thermal control assemblies and AC power) and truss members.



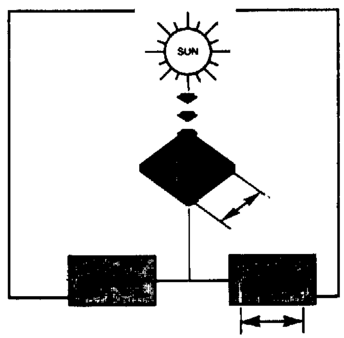
Batteries

The energy obtained from the sunlight will be stored in Nickel-Hydrogen batteries for later use when the station is in the Earth's shadow. A battery pack is made up of 30 Ni-H2 cells, wiring harness, and mechanical/thermal support components. On discharge, this operates near 28 volts which allows the flexibility to connect several packs in series to obtain a high voltage system for the space station and platforms, and lower voltage for the platforms or other station applications.



Power Management And Distribution (PMAD)

The 20 kHz Primary PMAD system is designed specific-ally to meet aerospace system requirements. The system is based upon rapid semiconductor switching, low stored reactive energy, and cycle by cycle control of energy flow which allows the tailoring of voltage levels. The PMAD system will deliver controlled power to many scattered and different user loads. The high frequency AC power system was selected to provide higher efficiency, lower cost, and improved safety.



Electrical Power System (EPS)

NASA's Lewis Research Center is responsible for the end-to-end electric power system architecture for the space station and for providing the solar arrays, batteries, and common power distribution components to the U.S. Polar Platform. The EPS consists of power generation, energy storage, and power distribution subsystems.

The EPS provides all user and housekeeping electrical power and is capable of expansion as the station grows. Initially, the EPS will generate 37.5 kw, which will increase to a baseline value of 75kw. Nickel Hydrogen (Ni-H2) batteries store the direct current (DC) power generated by the solar panels for use when the station is in the shadow of the Earth. The DC will be converted to AC for primary distribution. The EPS provides 20kHz, 208 volts, single phase sine wave, utility grade power to station elements. The power is then converted ti 129 volt DC and distributed to users.

The most important design choice for the space station EPS was the selection of the power generation and storage system. The possible options are all photovoltaic (PV), all solar dynamic (SD) and hybrid (a combination of PV and SD).

Photovoltaic (PV)

A PV system has solar arrays for power generation, and chemical energy storage (batteries) to store excess solar array energy during periods of sunlight, and provide power during periods of shade. A PV system is generally characterized by low development cost and high recurring cost (due to maturity of solar array development and high cost of solar cells and panels); low efficiency-approximately 10 percent; and high drag from the large solar array panel area required to capture sufficient sunlight to meet required user power levels.

Initially, power for the space station will be provided by eight flexible, deployable solar array wings. This configuration minimizes the complexity of the assembly process by taking advantage of the technology demonstrated on Space Shuttle Flight STS 41 B. Each 32- by 108-foot wing consists of two blanket assemblies covered with solar cells. These are stowed in blanket boxes which are attached to a deployment canister. Each pair of blankets is to be deployed and supported by a coilable, continuous longeron mast. A tension mechanism will supply tension to the blanket as it reaches complete extension. The entire wing will be tied structurally to the transverse boom by means of the beta gimbal assembly. In order to provide the power needed during the period of space station assembly, two solar wings and other elements of the power system are scheduled to be carried up on each of the first two space station assembly flights. These four wings will provide 37.5 kW of power. The remaining four panels will be delivered on orbit after the permanently-manned configuration is reached.

Batteries

Ni-H2 batteries will store the energy produced by the solar arrays. A battery pack is made up of 23 Ni-H2 cells, wiring harness, and mechanical/thermal support components. On discharge, this operates near 28volts which allows the flexibility to connect several packs in series to obtain a high voltage system for the space station, or use of single packs as a candidate for other low voltage applications. Ni-H2 batteries offer minimum weight and high reliability. During the eclipse periods, power is supplied by these batteries.

Solar Dynamic (SD)

Solar dynamic systems use solar radiation to heat a working fluid in a closed loop. The fluid transfers work to a turbine which drives an alternator, converting thermal energy to mechanical energy to electrical energy. Heat is added to the fluid in a heat receiver which absorbs focused solar radiation from a sun-tracking concentrator with a reflective surface. The receiver and concentrator are oversized to allow excess thermal energy to be stored in a melting salt as the heat of fusion when the system is in the sun. During solar eclipse, some of the salt solidifies, releasing heat to the working fluid which continuously powers the turbo alternator. Radiators are required by

Elements and Systems

solar dynamic systems to reject the waste cycle heat to space. Solar dynamic systems are characterized by higher development costs (because they have never flown in space before) but lower recurring costs; slower performance degradation due to aging; much higher efficiency than PV systems, and much lower drag. Extensive trade studies were conducted comparing PV, SD, and hybrid EPS options during the Phase B effort. Although the hybrid option was judged to be superior to either all-PV or all-SD options, the all-PV system was selected for development initially because of low initial cost.

As the space station grows and the demand for electric power increases, a solar dynamic system may be installed as a complementary system to the photovoltaic power module. This technology, far different from the photovoltaic system, converts the Sun's rays into heat for the production of power. Heat is collected in a receiver which is located near the focal point of a large parabolic mirror. Power is then generated exactly the same way as on an earthbound power station: by heating a fluid, which in turn rotates a turbine. Since a heat/gas-driven turbine is a much more efficient power converter than a sunlight-driven solar cell, the mirror (the assembly with the largest area in the solar dynamic system) would have to be only one-third the area of a solar array to generate the same amount of power to from the Sun's light.

There are several different engines that can be used for the generation of power within the solar dynamic system. They are similar in that they are "closed cycle," i.e., they recycle the working fluid. These engines are usually known by the names of their inventor. For use on Space Station, the Brayton Cycle engine has been selected.

The energy storage device used for a solar dynamic power system is superior to a photovoltaic system because heat is stored rather than electricity. Heat is cheaper and far more simple to store for subsequent use. Storage can be accomplished by taking advantage of the heat, of fusion of inorganic salts. On the sunny side of the Earth, heat is absorbed by the salt and it melts. On the dark (cold) side the salt freezes and gives up its heat to the working fluid of the engine, ensuring continuous operation.

Primary Power Distribution

The 20 kHz Power Management and Distribution (PMAD) system is designed specifically to meet aerospace system requirements. The system is based upon rapid semiconductor switching, low stored reactive energy, and cycle by cycle control of energy flow which allows the tailoring of voltage levels. The high frequency AC power system was selected to provide higher efficiency, lower cost, and improved safety.

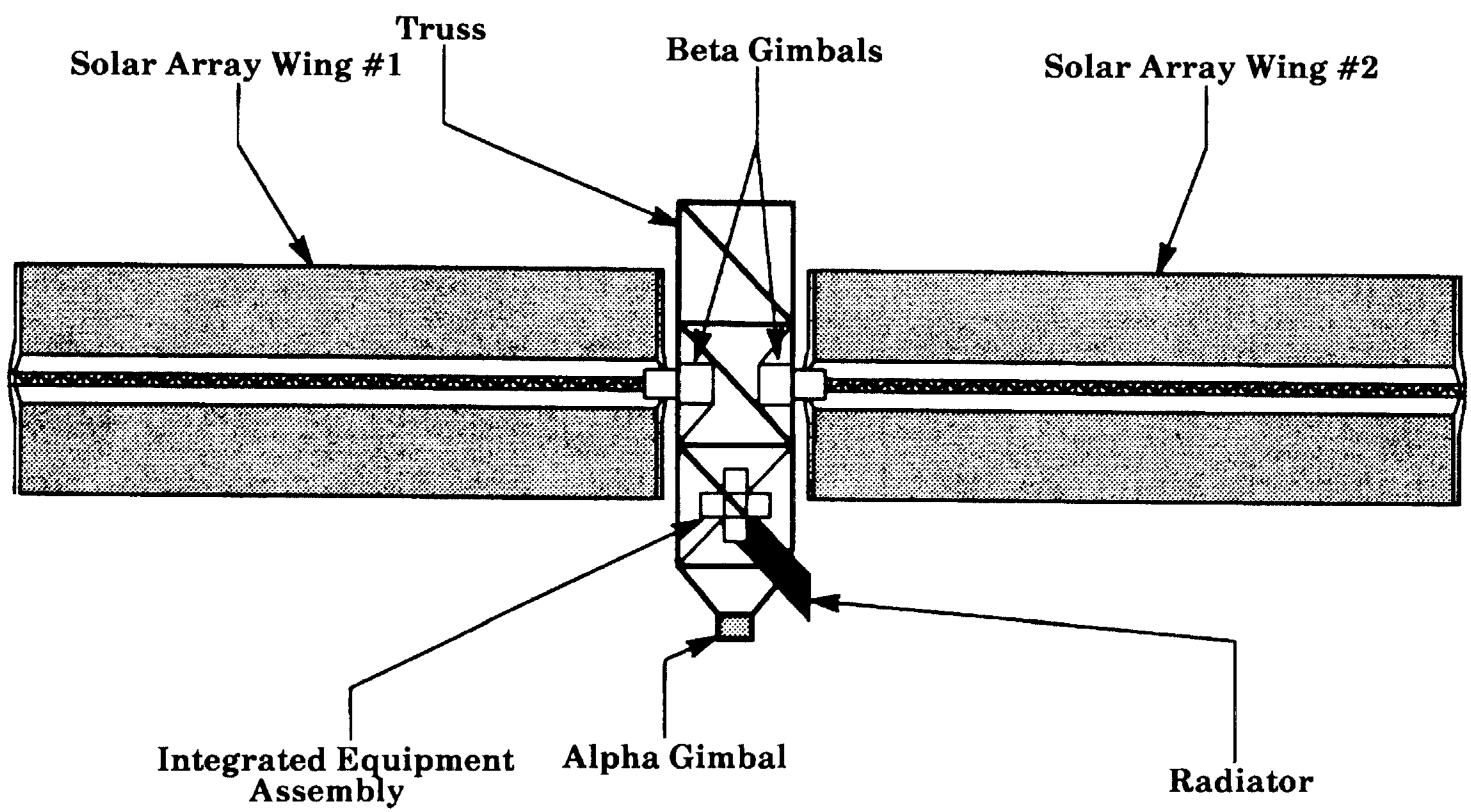
The overall distribution equipment will include cables, load converters, transformers, regula tors, switches and other standard electrical equipment. The overall distribution subsystem will be composed of equipment necessary to process, control, and distribute power to other station subsystems, elements, and attached payloads.

The most significant PMAD design decision was the selection of the primary distribution system frequency. Both DC and AC options were considered, and both high frequency (typically 20 kHz) and low frequency (typically 400 Hz) AC options were considered. DC Primary distribution was not selected because it had much higher weight and cost than either of the AC options.

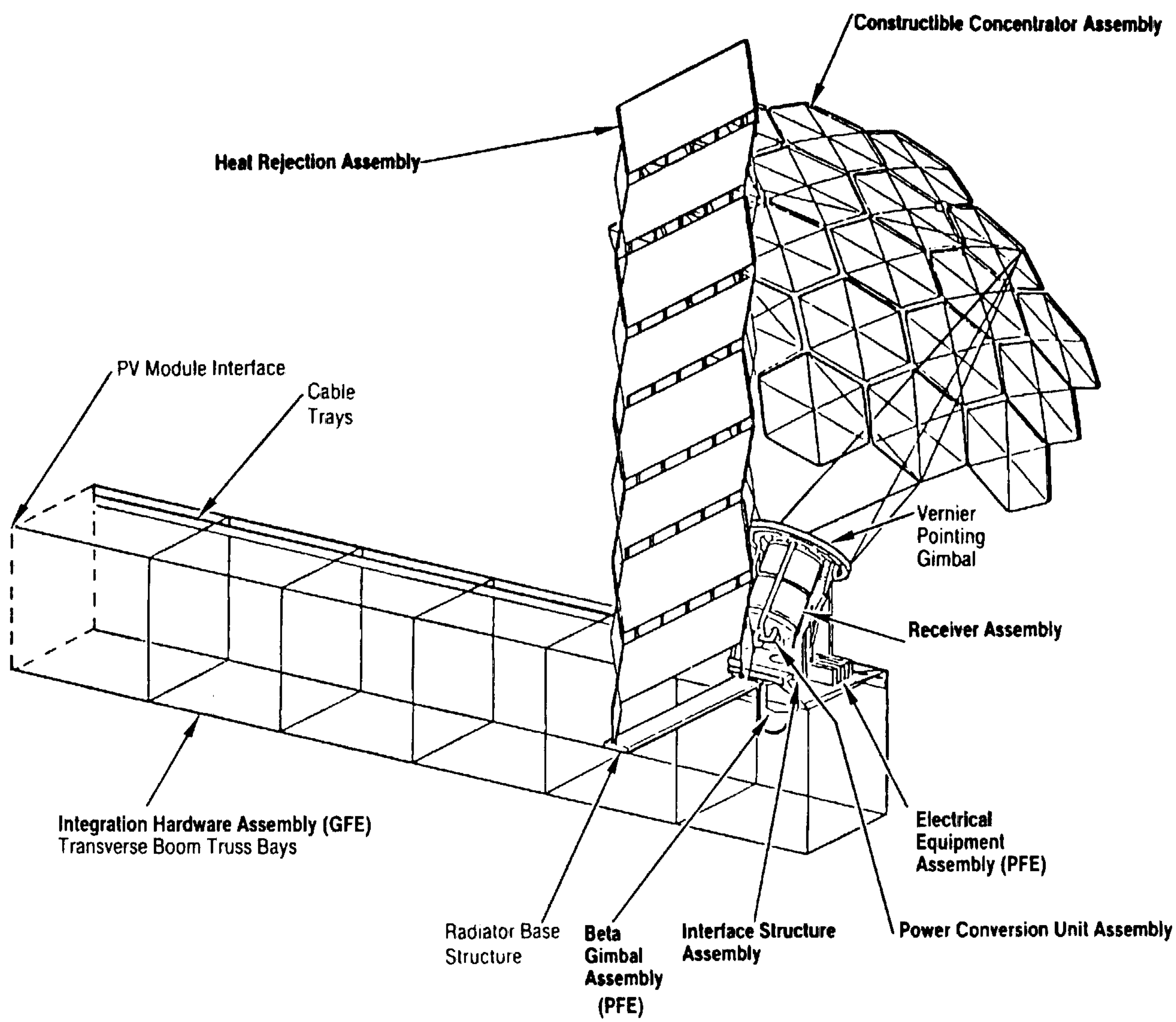
The performance of the candidate AC systems was relatively similar and the choice was difficult. All reactive components (i.e. inductors, capacitors, transformers) are much lighter for the 20 kHz system than for the 400 Hz system.

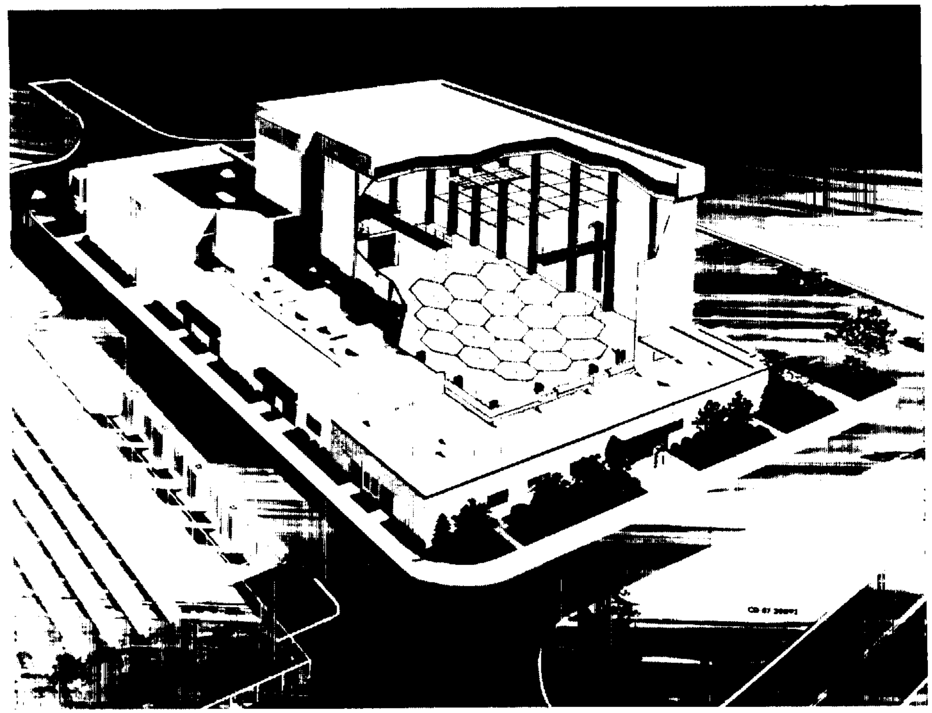
The major discriminator between 20 kHz and 400 Hz was electromagnetic interference (EMI). Space station experiments are sensitive to conducted and radiated EMI from a 400 Hz system, including all of the harmonics up to about 10 kHz. The weight of shielding and filtering required to reduce the EMI from all of these frequencies to acceptable levels in a 400 HZ system is prohibitive. The EMI in a 20 kHz system is expected to be a more tractable problem. In addition to EMI considerations, audible noise from a 400 Hz system may be objectionable to the crew. As a result of these considerations, 20 kHz was selected as the primary distribution frequency.

Space Station Photovoltaic Module



Evolutionary Solar Dynamic System





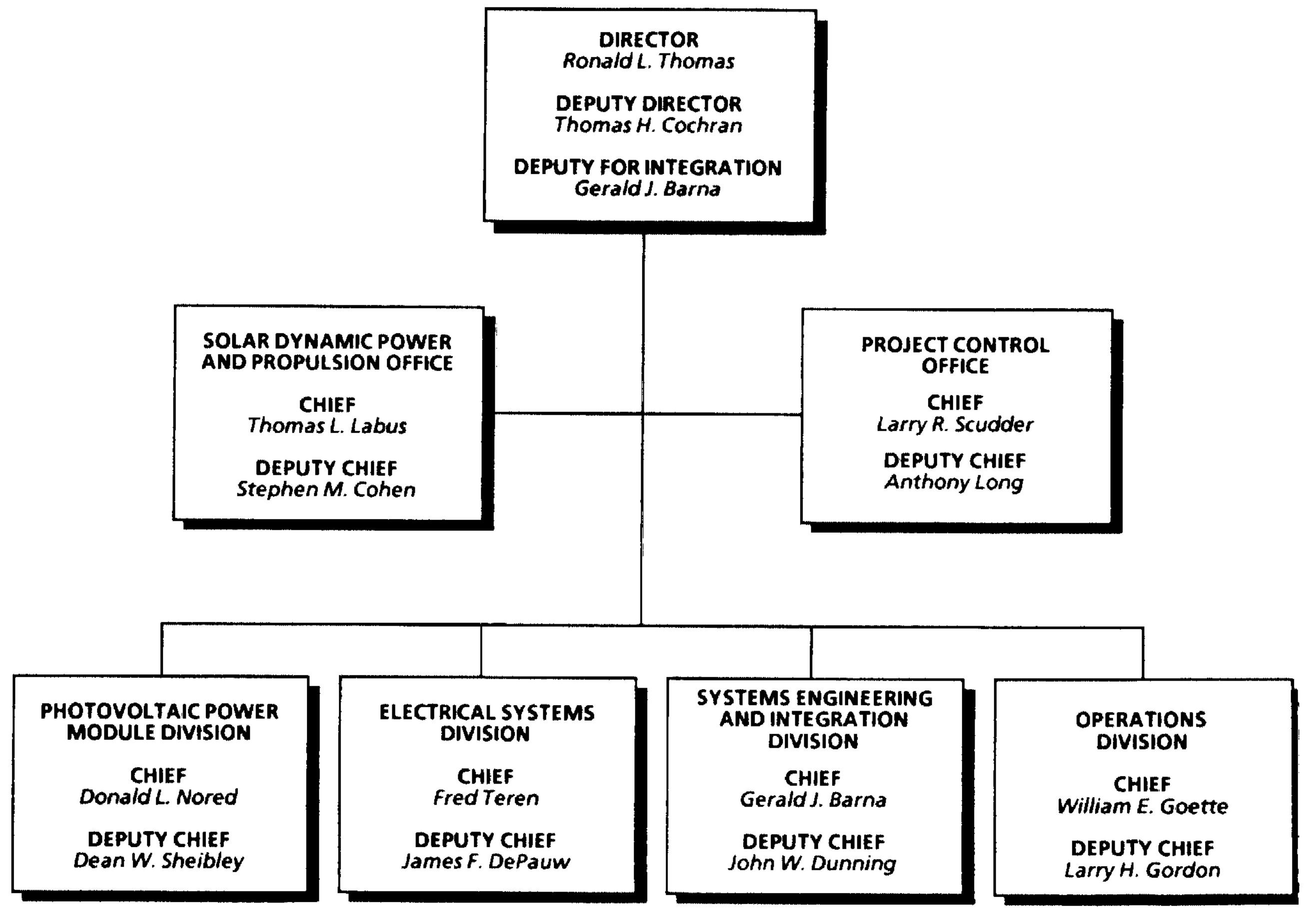
Power Systems Facility (PSF)
The PSF will provide the capability for development, testing and evaluation of prototype power systems hardware for the space station program. The facility will be used to test systems in support of both the baseline program and evolutionary growth phases, to simulate anomalies during flight, and support testing needs for future refinements. The PSF will have a total area of approximately 31,000 square feet and will include a high bay test area with Class 100,000 Clean Room capability, a loading-unloading-workshop area, laboratory rooms and support areas. Solar dynamic systems will be tested together with the power management and distribution system. Assembly and deployment tests, optical tests, and vibration tests of concentrating mirrors as large as 60 feet in diameter will be conducted in the clean high-bay area. The building site has been selected for its close proximity to the existing solar array field in recognition of the importance of using line lengths representative of the space station electrical power distribution system. Electrical transient interactions are very sensitive to line lengths and component separation as well as the detailed characteristics of the power source. While some studies will be done using the solar simulator, others will required use of the outside solar array powered by the sun.

Space Station Freedom Systems Directorate

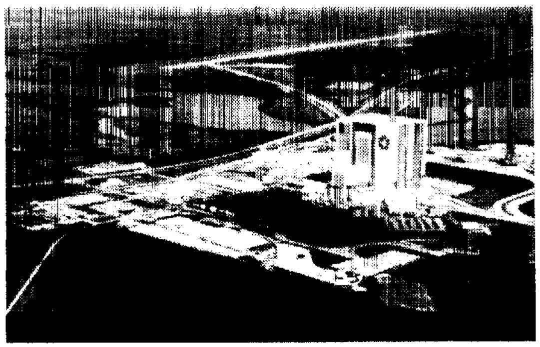
NASA's Lewis Research Center in Cleveland, Ohio is responsible for the Work Package 4 portion of the Space Station Freedom Program. The Space Station Systems Directorate is responsible for the design and development of the Electric Power System. In effect, this Directorate is the Space Station Freedom Electrical Power System Projects Office.

The Project Control Office's responsibilities include resources control, contracts, administrative services, configuration management and technical documentation. The Systems Engineering and Integration Division performs system engineering and analysis for the overall Electrical Power System. The Photovoltaic Power Module Division is responsible for all activities associated with the design, development, test and implementation of the photovoltaic systems. The Solar Dynamic Power and Propulsion Division is responsible for hooks and scars activities in solar dynamics and in supporting Work Package 2 in resistojet propulsion technology. The Electrical Systems Division has responsibility for the power management and distribution system development. The Operations Division manages all Directorate activities associated with Lewis space station power system facilities and in planning electric power system mission operations.

This organization currently includes approximately 200 civil servants. There are an additional 150 people in other Lewis organizations working on such areas as test and evaluation, construction and outfitting of the Power Systems Facility and power related research.



Traditional Center Roles and Missions



Carved out of virgin savannah and marsh in the early 1960s as the departure point for Project Apollo's manned explorations of the Moon, the John F. Kennedy Space Center (KSC) has primary responsibility for ground turnaround and support operations, pre-launch checkout and launch of the Space Shuttle and its payloads, including those of Space Station Freedom.

This responsibility extends to Space Transportation System (STS) operations, including the construction and maintenance of STS payload and flight element processing facilities, and the development of ground operations management, processing schedules and logistics, and their use in support of the STS and payloads. The construction of a Space Station Processing Facility is scheduled to begin in January of 1990.

Kennedy Space Center responsibility also extends to the facilities and ground operations at Vandenberg Air Force Base (VAFB) in California and designated contingency landing sites.

Shortly after President John F. Kennedy announced bold plans in 1961 to fly American astronauts to the Moon and return them safely by the end of the decade, Congress approved development of a strip of marsh and sandy scrub 34 miles long and five to ten miles wide on Florida's east coast, midway between Jacksonville and Miami. The "space coast" of Florida has long been determined ideal for launches and landings. The Atlantic Missile Range was built at Cape Canaveral, adjacent to the northern part of Merritt Island where KSC is now located. Later the Cape Canaveral peninsula became the Eastern Test Range where both Mercury and Gemini Spacecraft where launched. NASA began acquiring land across the Banana River from Cape Canaveral in 1962. By 1967, Complex 39 was operational, and the new space center was variously known as Cape Kennedy, Cape Canaveral, and the Cape.

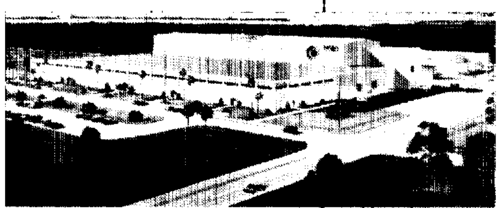
Complex 39 is strategically located next to a barge site and soon consisted of a variety of structures including a vehicle assembly building, processing facilities, press site, crawlways to various launch pads and the launch control center. The Vehicle Assembly Building (VAB) is described as the "heart" of Complex 39. This huge building, covering eight acres and standing 525 feet tall, is used for assembly, stacking and mating of rockets and orbiters. The Launch Control Center (LCC) is described as the "brain" of Complex 39. Launch, mission support and loading are controlled here.

Twelve manned and un-manned Saturn V/Apollo missions were launched from "the Cape" between 1967 and 1972, and in 1973 the Skylab space station was placed into high-circular orbit, followed by three-member crews aboard Saturns later that year to tend the station. The Saturn/Apollo era ended in 1975 with the launch of a Saturn IV/Apollo crew on a joint manned mission with the Soviet Union. Earlier, in 1972, KSC was selected as the primary launch and landing site for the Space Shuttle because of its existing facilities and structures.

A three-mile Shuttle Landing Facility and an Orbiter Processing Facility were built, and the Orbital Flight Test Program began at KSC in 1979. Within three years, KSC launched the STS four times. The Canadian-built Remote Manipulator System was tested, and both government-sponsored and commercial experiments were conducted in the payload bay on a Spacelab pallet.

The current phase, commencing in 1982, is called the STS Operational Period for KSC. The European-built Spacelab was flown within 18 months, plus a variety of observational, scientific and communications payloads. By 1983, KSC was involved with parallel processing of three Shuttle orbiters for the STS. Today KSC continues lead responsibility for Shuttle integration and rollout, cargo processing, launch pad operations and Shuttle recovery. With the launch of STS-26, the Discovery Orbiter, KSC resumes its primary role with the Space Shuttle and continues its launch capability of unmanned rockets as America prepares to enter the space station era.

Space Station Processing Facility (SSPF)



By March of 1994, Kennedy Space Center plans operational readiness for a $68.74 million Space Station Processing Facility (SSPF). Construction begins in January of 1990.

The SSPF will be a 264,000 square foot building designed especially for the processing of Space Station Freedom payloads to be launched by multiple Space Shuttles in the cargo bay.

Flight elements arrive at KSC by various means, including a C-5B, currently being modified by the U.S. Air Force to carry Shuttle payloads. A mobile transporter moves the hardware to the SSPF where it is removed from shipping containers, inspected and serviced in preparation for power-up testing, if necessary. Some flight elements, such as the basic truss structure, are "ship and shoot" items, requiring little KSC testing or processing. Other elements, such as pressurized modules, will require full functional testing at the SSPF. Specific processing steps are being selected from capabilities appropriate for each flight element.

Generally, each flight element follows a four-part handling in the SSPF. First, post shipment verification is conducted by inspecting the quantity and condition of each package. Accompanying data packages are reviewed, and problems or discrepancies are documented. The flight elements are serviced by filling, purging, sampling and leak-testing all fluid and gas containers. Ground support equipment is connected and the system is powered up to detect shipping damage or defects. Finally, the Interface Test, the most critical of all, is conducted.

Current planning indicates that each element will be tested for exact interface with all other pertinent elements by the use of simulation. The interface test includes functional verification of one work package to the others, then functional verification of the on-orbit configuration. Verification of critical interfaces, and verification of the on-orbit installation sequence are performed. Possible other tasks include verification of interfaces between the on-orbit station and the Orbiter flight decks, and verification of on-orbit assembly procedures involving the astronauts.

Subtasks of the Interface Test involve international partners, communications and software systems. Functional verification of the space station core systems and the Canadian, Japanese and European elements are required to assure compatibility and critical interfaces. Major concerns are fire detection and suppression, environmental control and life support systems, and auxiliary power.

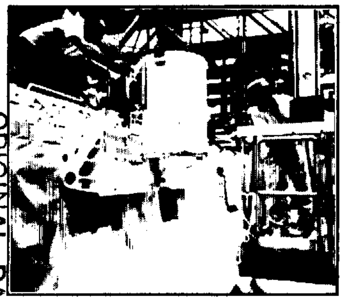
Two separate tests will verify the Space Station Information System (SSIS). One test will verify the compatibility of SSIS hardware and software, confirm SSIS operational procedures and validate the software for the Space Station Control Center which will command and monitor the core systems of the space station. Another test verifies the end-to-end interfaces between experiments and their Payload Operations Control Centers scattered throughout the nation and across the oceans at the international partner centers.

Finally, flight software load and verification are handled in the SSPF. Tests are performed to verify that flight software and hardware are compatible and correctly installed.

After all this testing, fluids and gases are prepared for flight, switches are reset, non-flight items are removed, and the flight elements are packaged for launch. Crew members may participate so they can determine the best methods of unpacking once they are aboard Space Station Freedom.

Upon return of the Shuttle from orbit, user payloads are removed at the SSPF and routed to international, governmental and private users. Logistics modules are refurbished and refilled for the next flight to the station. An estimated 20,000 orbital replacement line items will be handled at KSC for logistical purposes aboard the space station. Non-hazardous station elements will be processed at the SSPF. Such items as gaseous oxygen and hydrogen will be loaded on modules at the hazardous processing facility.

Space Station Freedom Unique Activities



Once the space station elements and systems are manufactured and tested by either the NASA Work Package Centers, their contractors or international partners, all roads lead to the Kennedy Space Center in Florida. The various shipments are off-loaded at KSC for receiving and inspection in the proposed Space Station Processing Facility (SSPF). There the space station elements, systems and user payloads to be launched by the Space Shuttle are inspected and monitored for damage or leaks. All structural and mechanical parts are reviewed for safety, verification and interface with elements or systems from other Centers and partners. Both hardware and software are verified for post-shipment health, fit and functionality. Pressure, temperature and humidity are evaluated, and some assembly may take place there before the payload is placed into a canister for transport.

Ground processing of logistics elements is critical to Space Station Freedom operations. Three types of logistics carriers are designed for the station, supplied and resupplied by the ground crew at KSC. A pressurized logistics module will carry hardware and consumables in a benign temporary storage facility, accessible in orbit without EVA equipment. A fluids pallet handles the resupply of consumables for the on-orbit Environmental Control and Life Support System, laboratories and satellite servicing. An unpressurized cargo pallet carries tools, equipment and supplies. Each of these is loaded into the canister for transportation and installation in the Shuttle cargo bay at KSC and off-loaded after return for refurbishing and resupply in the Space Station Processing Facility. Users are expected to provide payload-peculiar Ground Support Equipment (GSE) and technical data documentation. All international and domestic users must ensure interface compatibility of their equipment. Interface and verification of payload-to-station and station-to-Shuttle are required before canisters leave the Space Station Processing Facility.

Hazardous payloads, such as those containing fuel or power cells, are trucked to the Hazardous Processing Facility at KSC for servicing. Other station-related facilities include the Logistics Facility at KSC and the Payload Processing Facility at the Vandenburg Launch Site.

Eventually, the various space station payloads end up at the Vehicle Assembly Building (VAB) in Complex 39, the heart of KSC. The VAB covers eight full acres and stands 525 feet high, one of the largest buildings in the world. Here the solid rocket boosters are stacked and mated to the Space Shuttle orbiter. The environmentally controlled payload canisters arrive at the VAB on a 48-wheel, self-propelled truck, able to move forward, backward, sideways and diagonally. The cannister containing the payload is rotated to a vertical position and carried out to the launch pad.

The orbiter and attached rockets are moved to the launch pad in a vertical position. They are carried by a crawler with four double-track drives, each 10 feet high and 41 feet long. They travel along a roadway as broad as an eight-lane turnpike at about two miles per hour. The upright payload canister follows later, after the Shuttle propulsion and rockets are tested. At the launch pad, the Space Station Freedom payload is installed in the Orbiter as KSC personnel verify the interface before closeout.

Nominal postlanding processing follows roughly the same procedure in reverse. The Shuttle payload from Space Station Freedom is transported to the Space Station Processing Facility after the Orbiter has been inspected and the flight systems hardware removed. At the SSPF, Kennedy Space Center workers examine the payload and return the experiments or products to the users. The reusable flight systems hardware, such as spools, dispensers and pallets, are refurbished and tested for the next flight to Space Station Freedom.

Currently, STS flights to the station are scheduled over a period of four years, with elements being flown in a "phased construction" approach to space station assembly. Payload processing can begin from one year to six months before flight. At any one t ime, payloads for four separate flights can be processed.

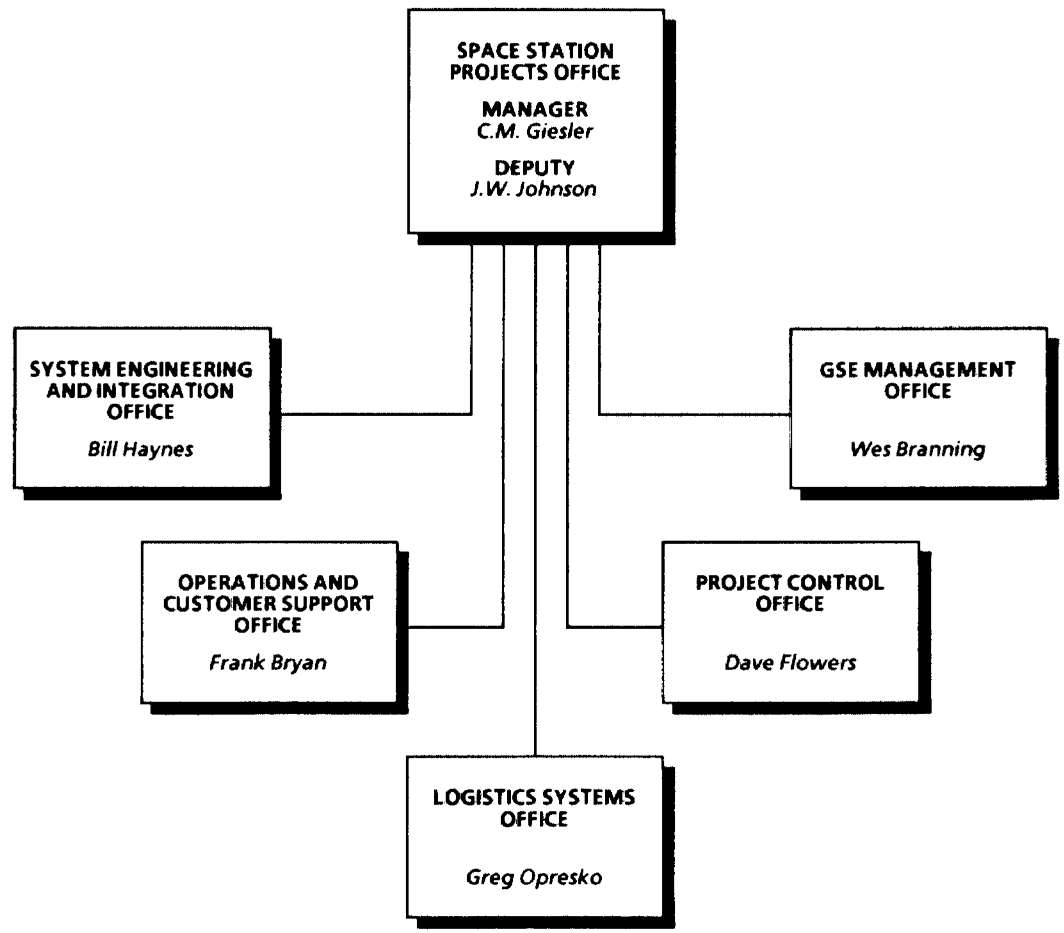
Space Station Freedom Projects Office

Until the Space Station Processing Facility (SSPF) is built at Kennedy Space Center, the KSC Space Station Projects Office is devoted to systems engineering and integration, ground support equipment management, operations and customer support, project control and logistics systems. The SSPO Manager reports to the Space Station Program Office in Reston, Virginia.

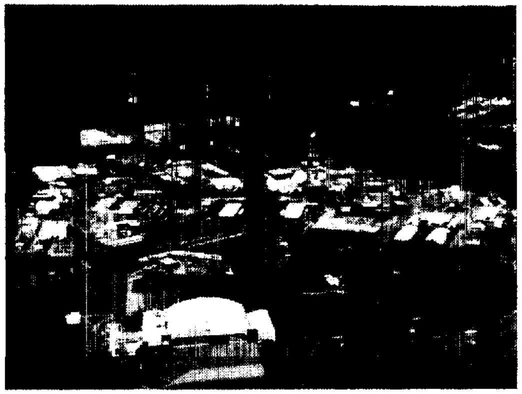
Because NASA has overall responsibility for the integration of both international and U.S. elements and systems with the National Space Transportation System, Kennedy will be the focal point for pre-launch and launch activities. Technicians from Japan, Canada and ESA will provide technical and hands-on support for the integration of international elements at the KSC Space Station Projects Office.

The KSC Space Station Freedom test teams will provide launch site final acceptance testing and certification of facilities at science and technology centers, if requested. Launch site testing is designed to verify major interfaces, provide confidence tests of critical systems, and verify end-to-end operations between the flight elements and ground control centers.

The KSC processing team is also responsible for the resupply of the fluids, supplies and hardware that require early access to the Orbiter cargo bay upon return. Less critical items, such as experiment racks and specimens are off-loaded at the SSPF and routed to users.



Traditional Center Roles and Responsibilities



The Langley Research Center was established in 1917 during World War I in the city of Hampton, Virginia, in the southeastern part of the state. Originally a part of the National Advisory Committee for Aeronautics, the Center was called the Langley Memorial Aeronautical Laboratory after Samuel P. Langley, a contemporary of the Wright brothers. The Center has grown to cover 787 acres and is considered one of the world's premier research facilities. Since those earliest days the Center has received five Collier Trophies, an annual trophy given for the greatest accomplishment in aeronautics and astronautics.

Langley's first wind tunnel began operation in 1921 and subsequently modernized versions helped pioneer the way to supersonic flight. Hundreds of aircraft, including vehicles like the X-15 have been tested in wind tunnels at Langley. In 1958, Langley became part of the newly formed National Aeronautics and Space Administration.

Today, the primary work at Langley is basic research in the fields of aeronautics and space technology, including aerodynamics, materials, structures, flight systems, information systems, acoustics, aeroelasticity, and atmospheric sciences. Approximately 60 percent of Langley's work is in aeronautical research to improve aircraft of the future. This research includes investigation of the full flight range, from low-speed general aviation and transport aircraft through high-speed hypersonic vehicles.

The National Aero-Space Plane is challenging researchers to expand the limits of several technologies. The plane is intended to be a fully reusable air and space vehicle that will take off horizontally from a conventional runway, accelerate to Mach 25 (25 times the speed of sound), and achieve low-Earth orbit.

Much of the aeronautical research at Langley concentrates on subsonic aircraft. Researchers are developing basic technology to improve their safety and efficiency. Studies of ways to improve engine performance, the fabrication of new composite materials, vortex flow, laminar flow, wind shear, and the application of supercomputers are being conducted. Air travel passengers in the next century will likely benefit from the current research programs being conducted at Langley.

Approximately 40 percent of the work at Langley supports our national space program. Langley was the home of the Mercury and Gemini manned spacecraft programs before the formation of the Johnson Space Center.

Five successful lunar orbiter missions to photograph candidate Apollo landing sites were managed by Langley, as were two unprecedented planetary landing Mars missions by the Viking spacecraft. Today, researchers conduct studies in atmospheric and Earth sciences, identify and develop technology for advanced Space Transportation Systems, conduct research in laser energy conversion techniques for space applications, and provide the focal point for conceptual design activities for both large space systems technology and space station activities.

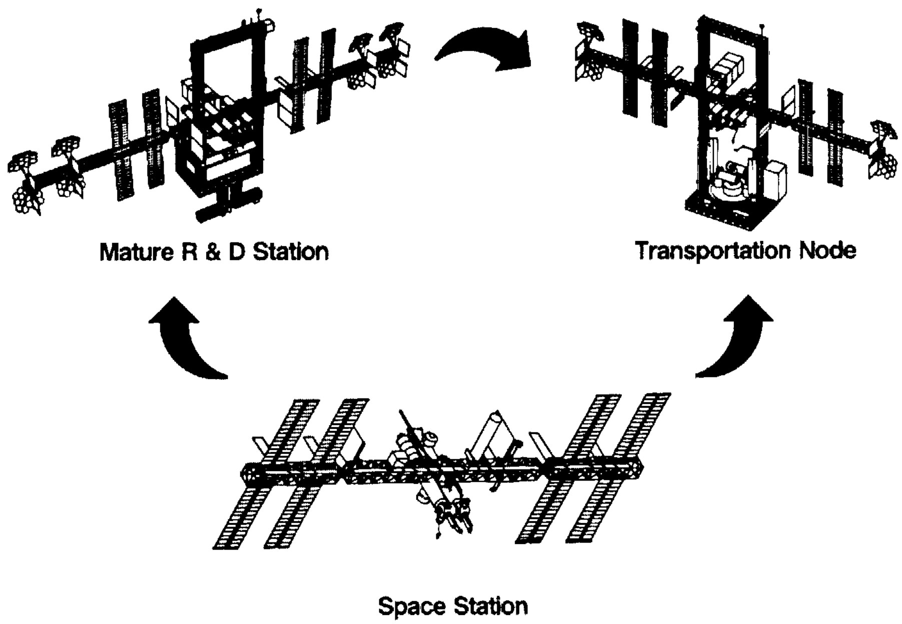
Langley researchers did extensive work on the Space Shuttle structure, aerodynamics, and thermal protection system. Several Space Shuttle payloads have been developed at Langley, including the Long-Duration Exposure Facility, filled with 57 experiments and deployed in orbit for several years.

ACCESS, Assembly Concept for Construction of Erectable Space Structure, was a Langley project to demonstrate that large structures can be assembled, tested, repaired and manipulated in Earth orbit. Conceptual designs and evolutionary definition studies for the space station are under way at Langley. Related studies investigate robotics and large space systems that may be built in Earth orbit within the next decade.

Langley has 2,800 employees and 1,950 contracts. The Center continues to pursue excellence in its quest for knowledge to keep the U.S. a leader in aeronautics and space technology.

Space Station Freedom Unique Activities

Space Station Evolution



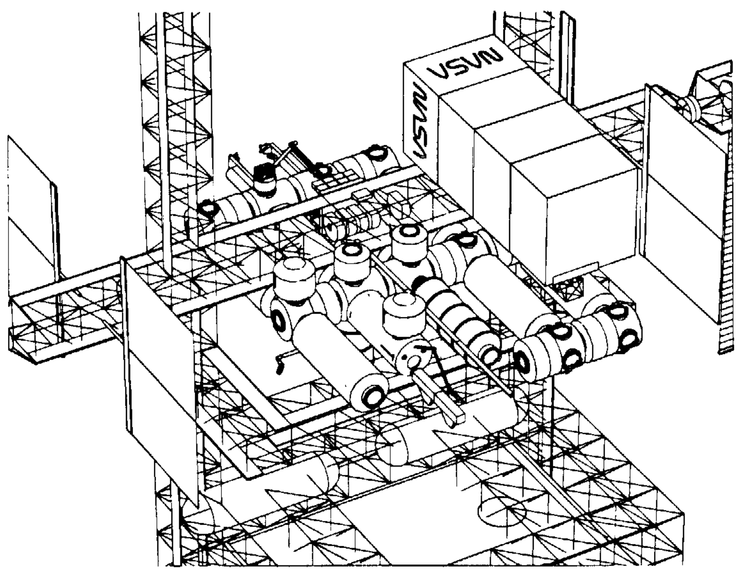
Langley is responsible for space station evolution to meet future needs such as increased research and development activities, support of a return to the Moon, or a manned expedition to Mars. This responsibility includes conducting mission, systems, and operations analyses; systems level planning of options/configurations; coordinating and integrating study results by others (including international partners and U.S. industry); chairing the evolution working group; and supporting advanced development program planning.

Technology User Representation

- Space structures
- Space environmental effects
- Power systems and thermal management
- Fluid management and propulsion systems
- Automation and robotics
- Sensor and information systems
- In-space systems
- Humans-in-space

Langley is responsible for representing the research and engineering community interested in using the space station for in-space technology development experimentation. This responsibility includes: conducting technology user accommodation analyses; representing NASA's Office of Aeronautics and Space Technology (OAST) on various space station users panels and working groups; serving as the focal point for OAST's In-Space Technology Experiments Program; identification and analysis of technology needs of the evolutionary space station for OAST; and managing the space station structural characterization experiment.

Mature Space Station - R&D Focus

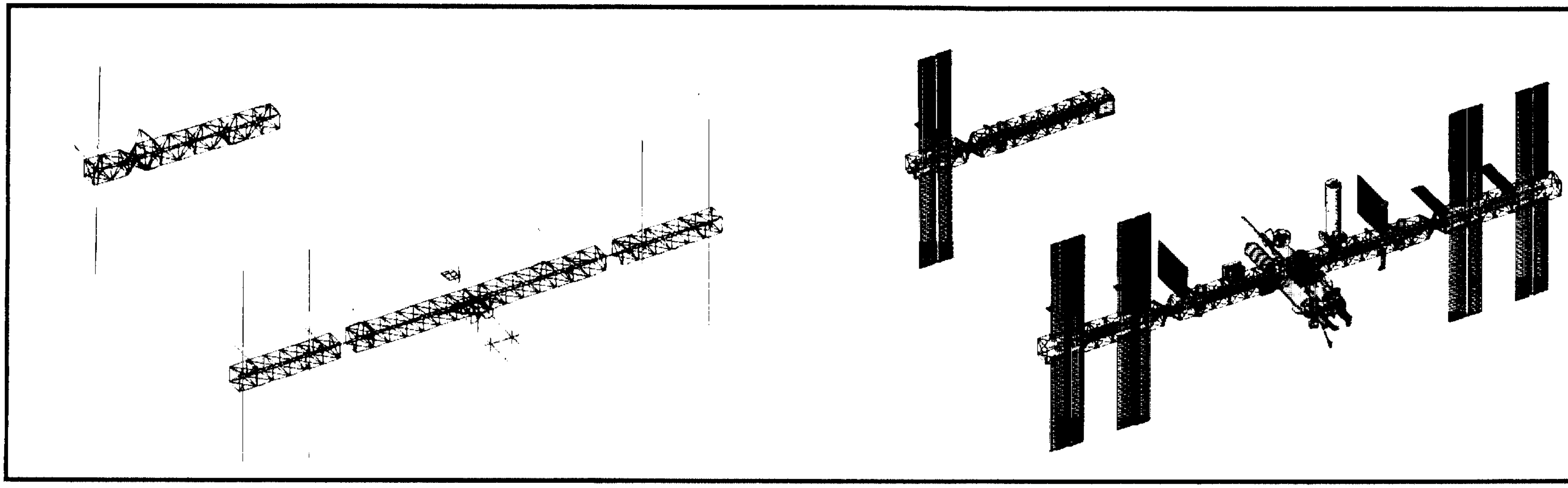


Science, technology, and commercial (R&D) accommodation	Crew User: 20 Total: 24 Power (kW) User: 170 Total: 275	4 U.S. labs: 1 European Space Agency lab (ESA) 1 Japanese Experiment Module (JEM) 3 HABS	Facilities 1 human life science: 1 animal & plant science; 2 materials processing or 1 materials processing, & a closed environmental life support system (CELSS) 3 attached press payloads 1 servicing bay (&Orbital Maneuvering Vehicle) 1 Orbital Transfer Vehicle hangar
New Initiatives accommodation	Crew User 17-20 Total: 21-24 Power (kW) User: 110-130 Total: 205-225	3 U.S. labs: 1 ESA lab 1 JEM 3 HABS	Facilities 1 assembly/servicing lab 1 human life science 1 CELSS 2 attached press payloads 1 assembly hangar 1 servicing bay (&Orbital Maneuvering Vehicle)

Space station resource requirements derived for mature operational phases of principal evolution options

To support initiatives such as the Humans to Mars and Lunar Base projects, the space station serves first as a facility for life science research and technology development and eventually as a transportation node for vehicle assembly and servicing. Another viable evolutionary path involves continued growth of the space station as a multipurpose research and development (R&D) faciltiy for science, technology, and commercial endeavors. For these options, mission and systems analyses have been conducted by Langley to determine primary resource requirements such as power, crew, and volume. For example, studies of multidiscipline, R&D growth at the space station involved analysis of a number of considerations, each of which emphasized a particular discipline on the space station (e.g.,microgravity research). Resource levels constrained by lift capabilities were determined utilizing transportation models with expendable and heavy lift launch vehicles as well as the Space Transportation System. These data, along with those from the transportation node analyses performed at Langley, comprise the foundation for evolutionary requirements derivation.

Technology User Representation



The space station structural characterization experiment begins with the first assembly flight.

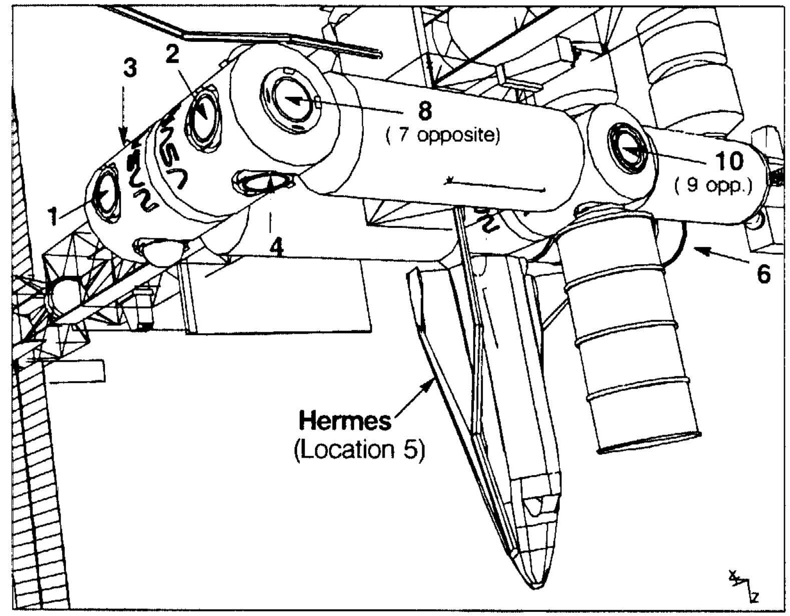
To insure that the space station will accommodate various user activities, Langley is responsible for representing the research and engineering community (industry, universities, and government) interested in in-space technology development experimentation. This experimentation includes: basic or applied research to improve understanding of phenomena and buildup of engineering data bases; technology development involving test/evaluation of prototype components and subsystems; and demonstrations involving proof of maturity and performance verification in integrated system context. Langley is responsible for conducting various use accommodation analyses such as determining support equipment outfitting needs. Langley represents OAST on various space station user panels and working groups including: user accommodation panel; attached payload/ platform accommodation working group; pressurized element payloads working group; payload manifest working group; design reference mission working group; user information systems working groups; utilization and operations review board; and utilization and operations information planning group.

Langley serves as the focal points for OAST's In-Space Technology Experiments Program for the definition and development of industry, university, and NASA in-space experiments.

The program includes experiments in space structures, space environmental effects, fluid management and propulsion systems, power systems and thermal management, automation and robotics, sensor and information systems, humans-in-space, and in-space systems. These experiments will initially fly on the STS or ELVs but will transition to the space station as it becomes available. One of these experiments, the Space Station Structural Characterization Experiment, is being managed by Langley. This experiment will instrument the space station and provide valuable engineering data to validate computer modeling codes and lay the basis for future large space systems including space station evolution.

SE&I Key Analysis Support Tasks

- **Critical Evaluation Task Force**
- **Phased Program Task Force**
- **Mixed Fleet Study**
- **Heavy Lift Launch Vehicle Study**
- **ESA Hermes Interface/Accommodation**
- **Space Station Transportation Study**
- **Station Keeping Platform Utilization for Space Station Assembly**
- **Industrial Space Facility Utilization Study**
- **Early Man-Tended Assembly Sequence Studies**
- **Enhanced-STS Space Station Assembly Sequence Study**
- **Space Station Microgravity Environment Analysis**



Hermes spaceplane docked at bottom of starboard aft node.

Langley conducted a number of key analysis tasks using the IDEAS^2 computer program capability in support of SE&I. These tasks have included support of the Critical Evaluation Task Force which reaffirmed the soundness of the baseline space station configuration subsequent to the Challenger accident and support of various transportation studies related to space station assembly sequence options.

One of these analysis tasks identified and assessed potential space station docking port locations to accommodate the European Space Agency's Hermes spaceplane. The Hermes vehicle will weigh approximately 21 metric tons with a length of 15.5 m and a wing span of approximately 10.5 m. The docking port is located in the rear with cold-gas thrusters used for the rendezvous phase.

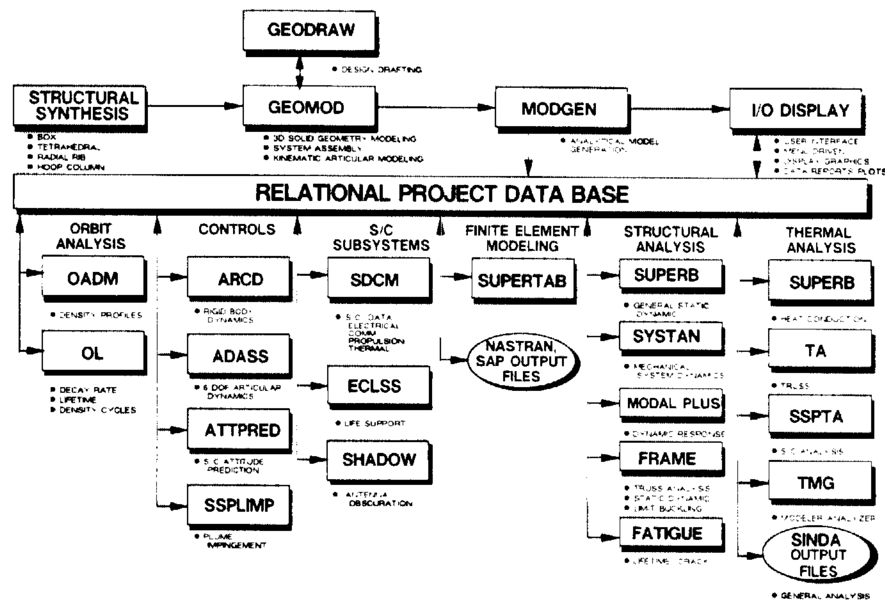
Ten potential docking port locations (shown above) were selected and evaluated with respect to several criteria, such as the clearance between the station's elements and Hermes, the complexity of approach rendezvous and proximity operations, the impact of Hermes on the flight characteristics of the space station, and the station's remote manipulator system access for final berthing operation via the grapple.

Two docking locations (front of the starboard forward node and front of the port forward node, i.e., locations 1 and 2, respectively) appeared to be the best all-around choice since there were no clearance problems. The approach path was unobstructed along the +X axis (i.e., along the station's velocity vector). Furthermore, no negative impact was found on the station's attitude and control. However, Hermes cannot use these locations while the Space Shuttle orbiter is docked (location 2 is the primary orbiter docking port), and the Hermes docking port must work with the Space Transportation System docking adapter.

ORIGINAL PAGE IS OF POOR QUALITY

IDEAS^2

Integrated Multidisciplinary Engineering Analysis Capability



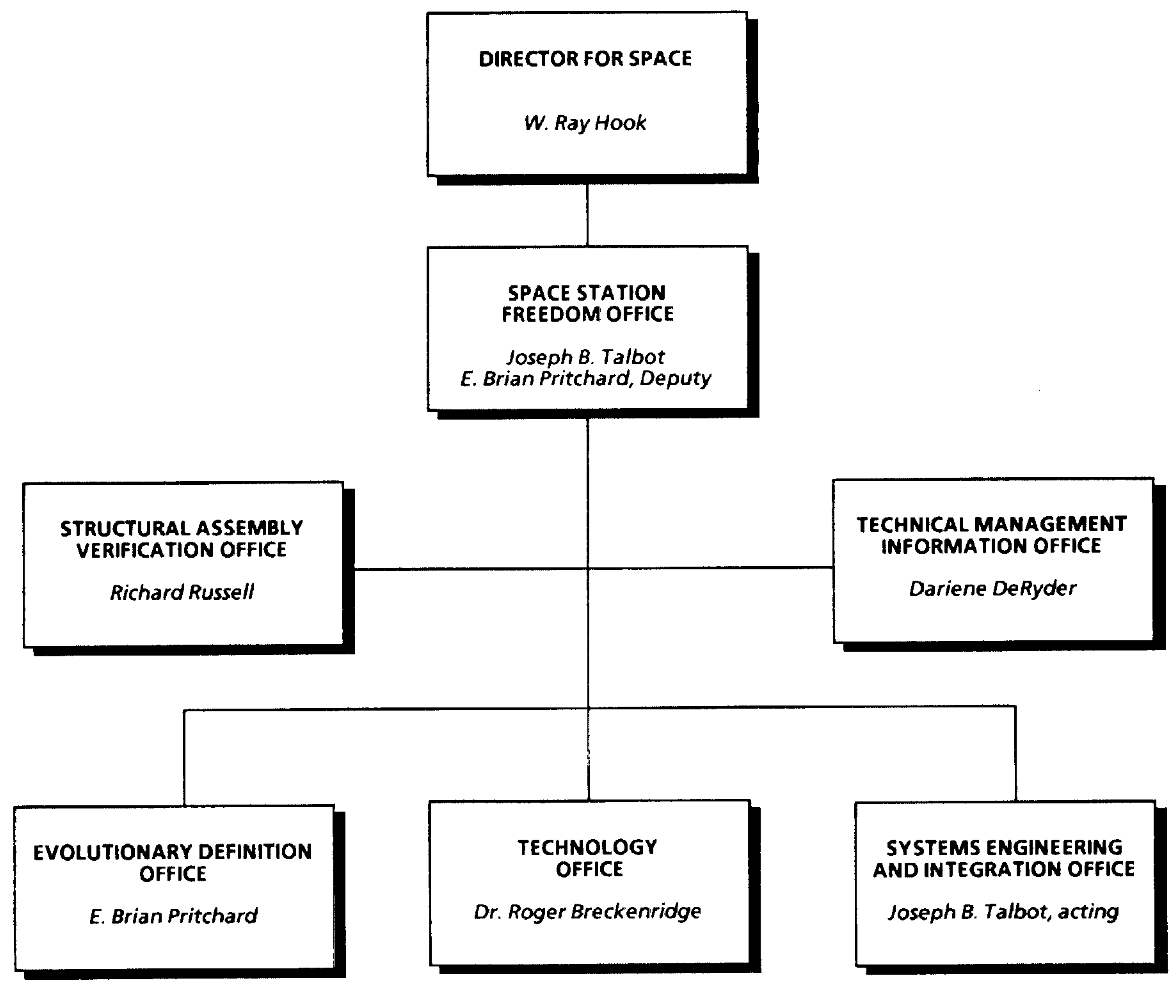
Langley expertise and involvement in systems analysis over the years has resulted in the development of a number of spacecraft computer-aided engineering (CAE) analytical tools to support advanced space system design, conceptualization engineering analysis, and performance prediction. Analytical tool products generated from this area of research have been applied to the Space Station Freedom System Engineering and Integration (SE&I) program to address the overall assessment and understanding of the interactive performance of various engineering and technology disciplines which make up such a complex spacecraft system configuration definition. The Interactive Design and Evaluation of Advanced Spacecraft (IDEAS^2) CAE system was developed to assess the design considerations to meet the mission goals and requirements by performing analytical simulations of spacecraft performance in the dynamic orbital environment of space. The IDEAS^2 computer software modules include structural synthesizers; orbital mechanics simulators; aerodynamic, gravity gradient and solar-pressure orbital environmental synthesizers; solid geometry and finite element modelers; on-orbit static, dynamic and structural analyzers; thermal analyzers; structural element design; sub-system design and database; performance, cost and reliability analysis algorithms. These multidisciplinary analytical tools are interfaced such that data from one module can be accessed by another module in an interactive process which provides the capability to evaluate spacecraft systems design concepts whose performance predictions include disciplinary interaction.

Space Station Freedom Organization

Project Office

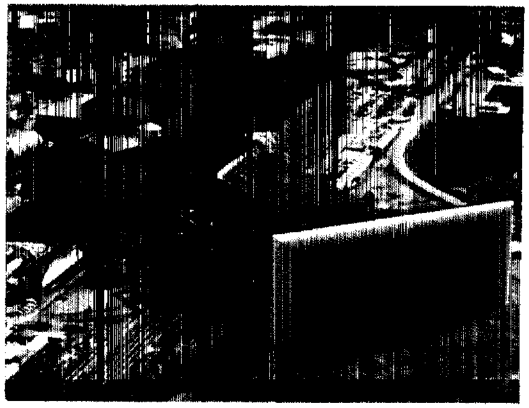
The Space Station Freedom Office is the focal point for Langley Research Center's involvement in the Agency-wide Space Station Freedom Program and is responsible for the implementation and coordination of Langley's direct support of their program. This office is NASA's lead office for the identification, definition, and evaluation of the evolutionary space station capabilities and for the identification of technology and advanced development required for long-term evolutionary development. The office represents the engineering community as technology users of the space station. It also advocates flight experiments on future Space Shuttle flights which contribute to space station technology use as well as flight experiments from technology programs which can contribute to both the initial operational capability and the evolutionary space station. The office also uses highly interactive computer-aided design tools to provide Langley's support to the NASA-wide in-house space station systems engineering and integration activity.

This organization currently includes approximately 30 civil servants. There are an additional 50 people in other Langley organizations working on supporting research, studies and analysis.



Traditional Center Roles and Responsibilities

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



Ames was founded in 1939 as an aircraft research laboratory by the National Advisory Committee for Aeronautics (NACA) and named for Dr. Joseph S. Ames, Chairman of NACA from 1927 to 1939 and former President of Johns Hopkins University. In 1958 Ames became part of NASA, along with other NACA installations and certain Department of Defense facilities. In 1981, NASA merged the Dryden Flight Research Center with Ames. The two installations are now referred to as Ames-Moffett and Ames-Dryden.

Ames-Moffett is located in the heart of "Silicon Valley" at the southern end of San Francisco Bay on about 422 acres of land adjacent to the U. S. Naval Air Station, Moffett Field, California.

Ames-Dryden, which is located in the high desert about 70 miles northeast of Los Angeles, occupies about 520 acres adjacent to Edwards Air Force Base. This facility was established in 1947 as a NACA flight research station at the U. S. Army Air Corps Test Facility, Muroc, California (now Edwards AFB). In 1959, the station became the NASA Flight Research Center, and in 1976 it was renamed the Dryden Flight Research Center in honor of D. Hugh Dryden, Chairman of the NACA from 1947 to 1958 and Deputy Administrator of NASA from 1958 to 1965.

Ames specializes in scientific research, exploration, and applications aimed toward creating new technology for the nation.

The Center's major program responsibilities are concentrated in:

- Computer Science and Applications
- Computational and Experimental Aerodynamics
- Flight Simulation
- Flight Research
- Rotorcraft and Powered Lift Technology
- Aeronautical and Space Human Factors
- Life Sciences
- Space Sciences
- Interplanetary Missions
- Airborne Science and Applications
- Infrared Astronomy

About 2,000 civil service employees and almost 2,000 contractor employees are employed at Ames.

Along with other NASA Centers, Ames significantly contributed to the Mercury, Gemini, and Apollo programs. The Center's achievements in atmospheric entry systems and heating, aerothermodynamics, and derivation of flight profiles contributed to the design of the Shuttle Orbiter and the materials of its thermal protection system. Ames-Dryden continues to handle the Shuttle landing operations as well as to manage flight research on virtually every new military fighter and experimental aircraft built in the United States.

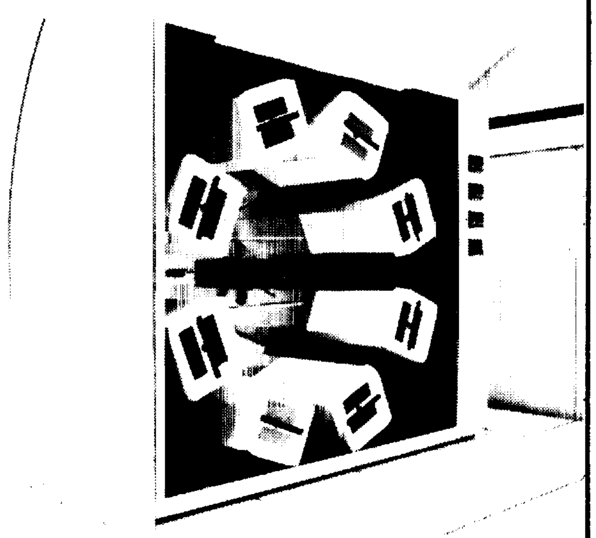
The Pioneer series of spacecraft, an Ames triumph, made the first trips through the Asteroid Belt and on to Jupiter and Saturn. The array of scientific experimental equipment carried in these spacecraft resulted in significant discoveries, culminating in June 1983 when Pioneer 10 completed history's first flight beyond the known solar system, still transmitting data, as it does today.

Ames has some of the most unique facilities including:

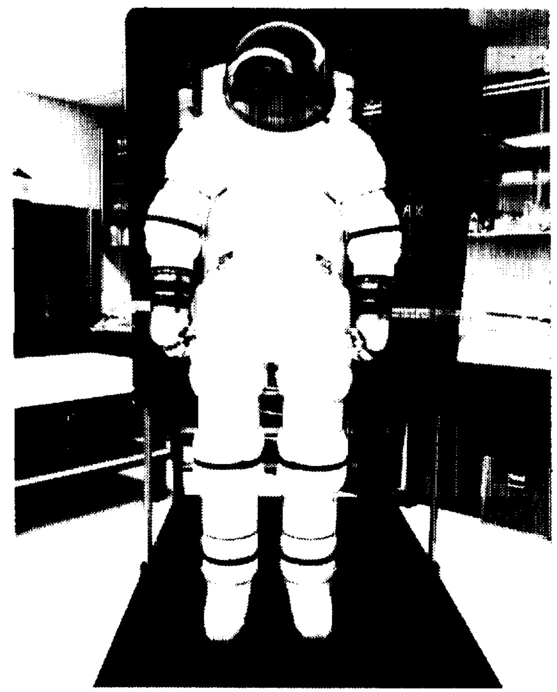
- Full scale wind tunnels, one of which is the largest in the world
- National Full-Scale Aerodynamics Complex (NAS supercomputer system)
- Ames' fleet of airborne laboratories that support the Airborne Sciences and Applications Program
- Vestibular Research Facility
- Piloted Flight Simulator Complex

New programs for the 1990's and beyond include the Space Infared Telescope Facility (SIRTF), and support of the Space Station Freedom.

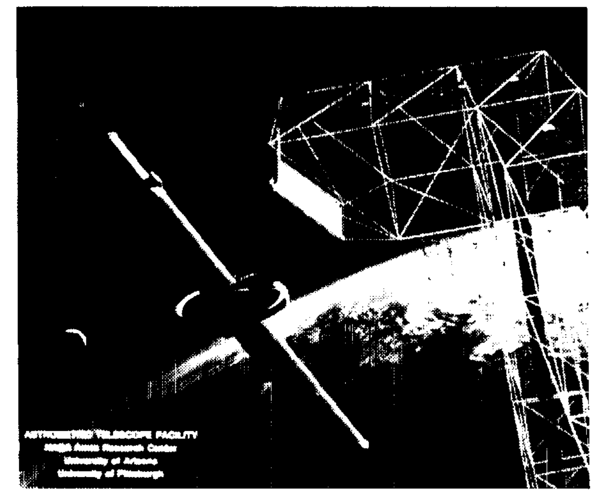
Space Station Freedom Unique Activities



Life Sciences Centrifuge
Ames will develop a centrifuge, a 1.8 meter circular device that rotates with approximately 6 specimen habitats around its circumference. Test subjects such as biology cells, tissues, small plants and animals, will be subjected to variable gravity conditions in the centrifuge. Observations of any changes in the test subjects will be performed by the crew.

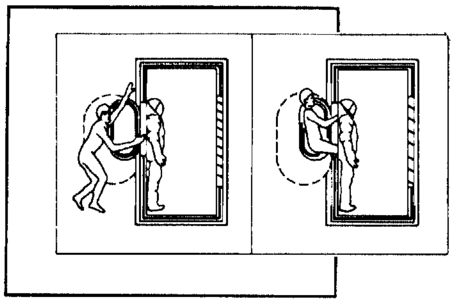


Advanced Space Suits
Ames developed the AX-5 Hard Suit, which is a candidate for use on the space station. The suit is highly reliable, requires little maintenance, and is more comfortable than the current suit. The suit can be put on or taken off in just a few seconds compared with several minutes for the current spacesuit. The new suit has an internal pressure of at least 8.3 psi which eliminates the possibility of the bends.



Astrometric Telescope
Ames will support the Astrometric Telescope Facility as an attached payload. It is a telescope which is designed to search out and detect planetary systems around nearby stars. The project interprets data by mathematical analysis to identify perturbations in the proper motions of the stars which may be caused by the presence of planets orbiting those stars.

Supporting Activities



The Ames Research Center provides a source of research and technology in support of the space station. The Center will also be a user of the space station, particularly in life sciences. It will support payload development, and space station operations. Ames is involved in several areas, including: human factors, autonomous systems, telescience, materials microgravity research, life sciences, centrifuge, spacesuit, controlled ecological life support system, polar orbiting platform, astrometric telescope facility, infrared astronomy, and the gas grain facility. As with any research endeavor, some of these projects will result in the development of hardware and software for use in the space station program while others will not.

Studies are being conducted on how the crew can most effectively interface with control and maneuvering systems. Autonomous systems being developed at ARC are computer based "expert" systems which emulate some forms of human intelligence. These advanced systems will handle routine operations on the space station to free the crew to concentrate on the operations and research that benefit from human adaptability, intuition, and creativity. A demonstration project is underway to show how expert technology can be applied to operate the space station's thermal control system. This is an evolutionary system on the premise that once expert systems have been used for thermal control they can be developed further to control the power system and the life support system. The goal is for a single integrated system to control all these systems. In addition, ARC is working on automated free-flying space robots that will have the intelligence to perform routine extravehicular activities unattended in space.

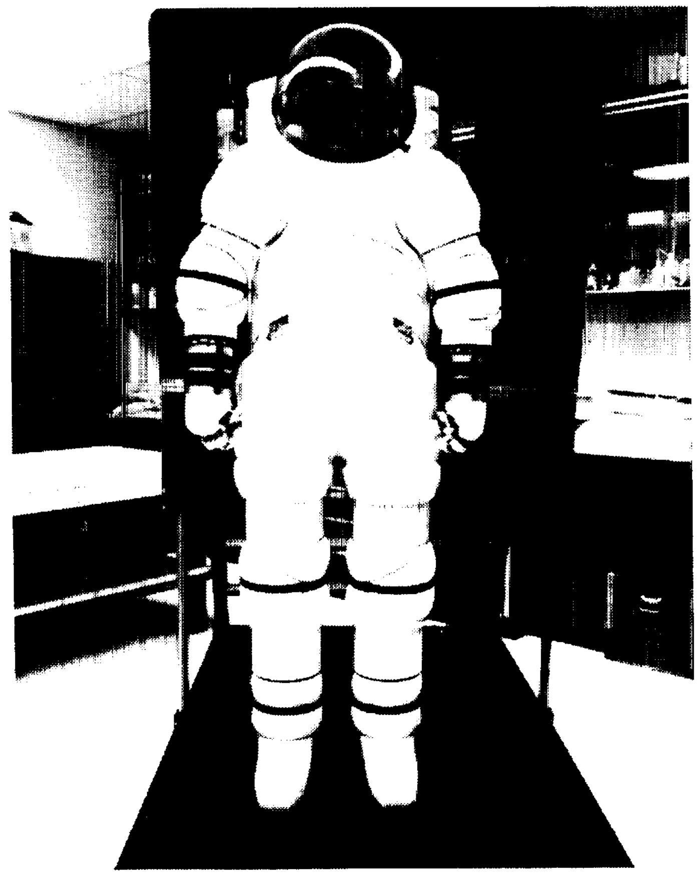
How materials behave under conditions of microgravity is an important area of research essential to the building and operation of the space station. Materials processing in space includes smolder-to-flame research to explore how fires develop under conditions of microgravity where convection, which brings oxygen to a fire, is inhibited. This research is aimed at developing fire safety procedures and control methods for use in the space station. The formation of droplets is being researched by another project which examines interactions between gas and fluids under conditions of microgravity. This is important to the space station in developing methods to handle and pump fluids in space.

How human beings might adapt to long terms of duty in space and subsequent return to Earth has been studied extensively at Ames for many years. These studies are continuing and are vitally importtant to the space station.

Ames has a number of unique Life Sciences research facilities which directly support the space station program. A Vestibular Research Facility allows scientists and medical researchers to investigate the important role of the vestibular organs in governing the effectiveness of humans in a microgravity environment. A Human Research Facility has been operating for a number of years. It was designed specifically for studies of physiological and psychological responses of humans under simulated conditions of weightlessness and confinement. The biological responses of animals and plants to microgravity conditions for extended periods in the space station will be investigated. A 1.8 meter centrifuge provides the variable gravitational conditions for the experiments to isolate the effects of spaceflight on test subjects such as biological cells, tissues, small plants and animals.

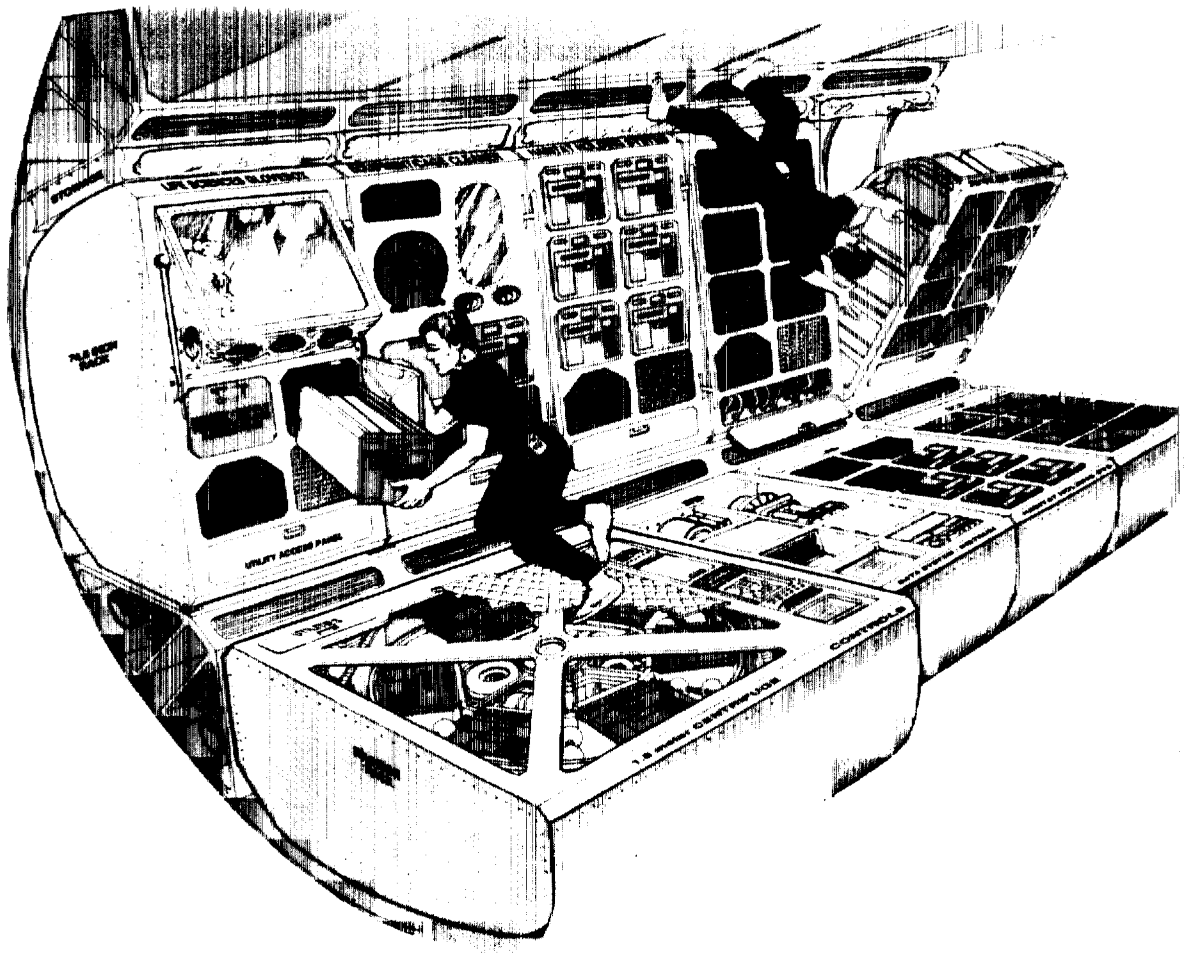
An advanced spacesuit, the AX-5 Hard Suit, which is a candidate for use on the space station, has been developed at Ames. The suit is made of aluminum and contains no fabric or soft parts that would be subjected to damage by atomic oxygen in the wake of spacecraft or by rocket propellants spilled into space. The suit has high reliability, has low maintenance needs, and enhances mobility and comfort for its wearer. It shields the wearer against radiation and impact from small meteorites and space debris. The suit maintains a constant internal pressure and volume, no matter how it is flexed. Its modular design allows easy replacement of parts and extension to fit astronauts of various sizes.

Ames AX-5 Hard Suit



Supporting Activities

Ames Life Science Research Activities



The suit is being evaluated by immersion in water to simulate weightlessness, and NASA astronauts are continuing these studies so that a suit can be decided upon before the space station is in orbit. The suit can be put on or taken off in just a few seconds compared with several minutes for the current spacesuit. The suit is entered through a hatch in the rear. The legs are put in first, followed by the upper part of the body. The new suit no longer requires an astronaut to spend several hours prebreathing pure oxygen to prevent the "bends" because its internal pressure is at least 8.3 psi and can be raised to normal atmospheric pressure of 14.7 psi if less mobility of the hands can be tolerated.

Food, water, and a breathable atmosphere are three elements essential for human survival. NASA's project for a Controlled Ecological Life Support System (CELSS) is aimed at developing a bioregenerative support system to generate oxygen, supply fresh food, and remove excessive carbon dioxide from the space station. Essentially, this is a recycling of air, water, and waste products using biological systems to do so. This system may be used as the growth of the station evolves. Ames is supporting CELSS with basic research. Environmental parameters such as temperature, light intensity, photoperiodicity, radiation, carbon dioxide levels, and oxygen production are being examined in detail, while comparing plant biomass yield, time to harvest, and percentage of edible plant biomass under varying environmental conditions. Plants being studied include wheat, soybeans lettuce, and potatoes.

An Earth Observing System is being set up as part of the space station program. There will be almost complete interchangeability among sensors carried by high-flying aircraft today and the space station and its platforms in the future. ARC's experience over many years in managing and supporting high flying aircraft equipped with remote sensors of various kinds is of great advantage to the planning of remote sensing instrumentation for the space station and its orbiting platforms, their management, and their operations on behalf of scientists of different disciplines.

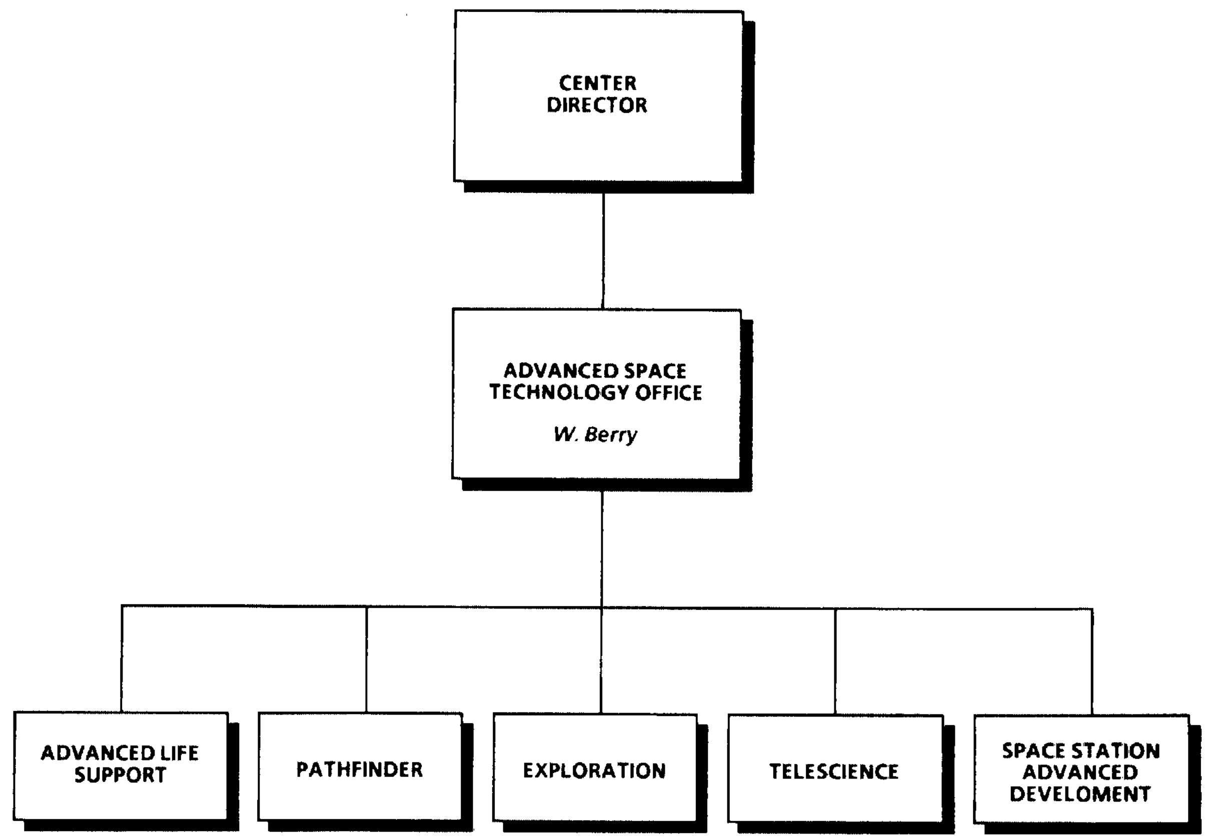
The Astrometric Telescope Facility is an attached payload project which is a telescope designed to search out and detect planetary systems around nearby stars. The project interprets data by mathematical analysis to identify perturbations in the proper motions of the stars which may be caused by the presence of planets orbiting those stars.

A Space Infrared Telescope Facility (SIRTF) is planned as a future NASA project for exploring deep space at infrared wavelengths. It requires a cryogenic fluid (liquid helium) to keep the detecting elements at a very low temperature for increased sensitivity. The supply of helium carried by SIRTF is used up during operation and will need to be replenished every $1^1/_2$ to 2 years when SIRTF is in orbit early in the next century. The space station can act as supply base and also as a maintenance base for SIRTF when the project is funded. Ames is studying ways in which the space station can support this advanced future project. ARC's Infrared Astronomy Project Office has initiated a flight demonstration program to develop and prove the technology required for efficient transfer of liquid helium in orbit. A technology demonstration project to be tried on a Shuttle flight will transfer liquid helium between two Dewer flasks in the STS bay while in space. This is aimed toward the design of an automated space supply vehicle which could operate from the space station to replenish the tanks of the SIRTF, as as alternative to using an orbital maneuvering vehicle (a space tug) to move SIRTF to the station for servicing.

A wide range of fundamental scientific problems involving interactions of small particles and clouds can be addressed by conducting microgravity experiments on the space station. NASA-ARC is developing an interdisciplinary fundamental research facility, the Gas Grain Simulation Facility (GGSF) to simulate and study fundamental chemical and physical processes such as formation, growth, nucleation, condensation, evaporation, and like processes, and mutual interactions among cloud crystals, dust grains and other particles in the absence or near absence of gravity. The facility will investigate how particles are affected by magnetic, electric, and acoustical fields.

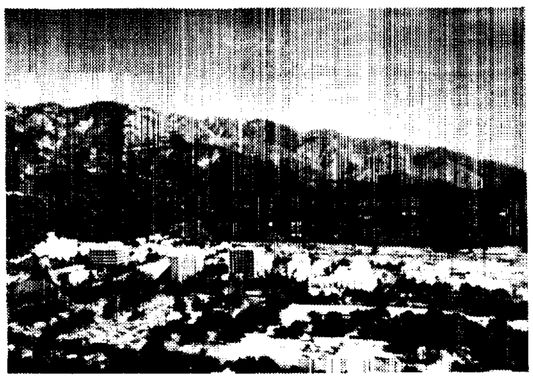
Such research is expected to provide better understanding of phenomena such as nuclear winter, species extinction following asteroid impact, the mechanics of Martian dust storms, the aerobiology of interstellar dust clouds, the formation of comets and planets from grains of a solar nebula, and the formation of stars from interstellar clouds.

Advanced Space Technology Office



The Advanced Space Technology Office has two major responsibilities. First it is responsible for coordinating the Center's overall activities with respect to the NASA Space Station Freedom program. This office is the focal point for the Center's participation in all aspects of the program. The office serves as the focus to space station for Ames Research Center's interests, and to provide to ARC directorates information regarding the opportunities in research technology development and utilization in the space station era. The office is also responsible for coordinating and directing new interdisciplinary multiorganization space research and technology programs and projects. These currently include programs in exploration, telescience, and Project Pathfinder.

Traditional Center Roles and Responsibilities



On December 3, 1958, two months after the National Aeronautics and Space Administration was created by Congress, the Jet Propulsion Laboratory in Pasadena, California was transferred from Army jurisdiction to NASA. Its primary mission evolved from pioneering rocket research through guided missile work to space projects. Every rocket that flies today shares the common heritage of pioneering research by Professor Theodore von Karman of the California Institute of Technology (Caltech). The Laboratory is still operated by Caltech under contract to NASA. It is a preeminent national laboratory with a budget of $892 million and a workforce of 5,465 people.

Today, JPL's principal responsibility is exploration of the solar system with automated spacecraft.

Because of the laboratory's expertise in rocket propulsion, JPL was selected to launch the nation's first satellite. On January 31, 1958, 66 days after receiving project approval, JPL launched the 14-kilogram (31-pound) Explorer 1. It transmitted until May 23, 1958, and discovered the Van Allen Radiation Belts that surround the Earth. JPL went on to lead the United States mission to explore the Moon and planets. Among the Laboratory's significant accomplishments are: The Ranger and Surveyor lunar projects; the Mariner missions to Mars, Venus, and Mercury; the Viking mission to Mars; the Infrared Astronomical Satellite; and the Voyager mission to Jupiter, Saturn and Uranus. The Voyager 2 encounter with Neptune on August 24, 1989, will mark the end of the first exciting reconnaissance phase of planetary exploration. At that point we will have visited all but one of the planets and many of their satellites.

To provide spacecraft tracking and communications for deep-space and earth orbit missions, JPL designed, built, and operates the Deep Space Network (DSN) of antennas for NASA. The antennas are clustered at sites at Goldstone, California near Madrid, Spain, and near Canberra, Australia. Those locations allow communication with spacecraft anywhere in the solar system. The Network Control Center and its supporting facilities are at JPL. The scientific community also uses DSN facilities for radar and radio-astronomy research.

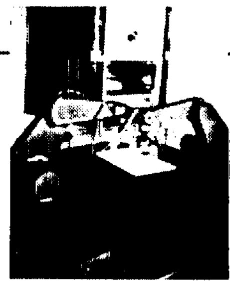
JPL is preparing for future planetary missions: Galileo to Jupiter, Ulysses to the Sun's poles, Magellan to Venus, and the Mars Observer. Galileo will be launched to Jupiter in October 1989 and will arrive in October 1995. It will drop an instrumented probe into Jupiter's atmosphere and orbit the planet for 20 months. Close observations and studies of Venus, Earth, the Moon, two asteroids, and interplanetary space will take place on the trip to Jupiter. Another mission, to map the surface of Venus with a new high-resolution radar is under way. The Magellan mission will be launched in April 1989 and will arrive at Venus in August 1990. Ulysses, a mission to explore both poles of the sun, will be launched in October 1991. The Mars Observer, scheduled for launch in 1992, will orbit Mars for a full Martian year gathering new data on geology and climate.

Other missions which are planned include: Comet Rendezvous Asteroid Flyby (CRAF), Cassini Mars Rover Sample Return, and Thousand Astronomical Units (TAU) as well as several spacecraft designed to study the Earth, oceans, wind and ozone layers. The Comet Rendevous Asteroid Flyby (CRAF) mission will fly by one or more asteroids and then will rendezvous and fly beside a short-period comet. The Cassini Project is studying a mission to Saturn that would orbit the planet and drop a probe into the atmosphere of Titan, Saturn's largest satellite. Together with the Johnson Space Center, JPL is studying a Mars Rover Sample Return mission that will collect soil samples and return them to Earth. The mission would be a precursor to manned Mars exploration.

JPL supports the Space Station Freedom program in several important technology development areas and program support which are discussed in the next pages.

JET PROPULSION LABORATORY

Supporting Activities



The Jet Propulsion Laboratory (JPL) supports the space station program in three areas: program requirements and assessment, automation and robotics, and attached payloads.

JPL took on a major role for NASA's space station project by establishing the project facilities in Reston, Va. and by leading the Program Requirements and assessment (PR&A) effort as a member of space station Level II management. The PR&A participates in program management, including leadership of the Program Plan effort, responsibility for the Program Requirements Document, and support for generating and revising the Program Approval Document. Other tasks include developing a cost-management process and conducting analyses and assessments.

NASA's interest in automation and robotics for the space station is represented by three main components: the Flight Telerobotic Servicer (FTS) for the baseline station, the evolution of the FTS, and the Office of Aeronautics and Space Technology (OAST) R&D program. JPL supports the the R&D effort.

The OAST Telerobotics R&D program has two major thrusts: a core technology research element, and a telerobotic technology testbed research and development effort. The core program is focused in five areas. They are:

- <u>Sensing and Perception</u>: Including machine vision hardware and software; "feel" sensing by force, torque, grasp and tactile sensing.
- <u>Task Planning and Reasoning</u>: The application of artificial intelligence to robotic tasks.
- <u>Operator Interface</u>: Design and analysis of controls and displays command.
- <u>Control Execution</u>: Research and development of hardware and control software to execute manipulation with robotic arms and end-effectors.
- <u>System Architecture and Integration</u>: Hardware and software technologies for integrating telerobotic systems.

The telerobotic testbed integrates and demonstrates the ability of these "core" telerobotic technologies to perform space assembly and servicing tasks when integrated into a telerobotic system. A series of demonstrations is scheduled to be implemented on this testbed through the year 2000. Several "core" technologies will be integrated to perform autonomous satellite servicing tasks, directed by machine vision and force sensing, and using 6-degree-of-freedom, dual arm manipulation. Teleoperator control technology will be then integrated with this autonomous system to create a telerobotic system, capable of trading control between teleoperated and autonomous modes, for demonstrating a variety of space assembly and servicing tasks.

As a next step the testbed plans to add two 7-degree-of-freedom, flight qualifiable, manipulator arms being developed by the NASA Langley Research Center and the Oak Ridge National Laboratories. End-effectors, developed by JPL, capable of sensing grasp force, will also be added to the demonstration, as will the software and control hardware adaptations to control them.

Future OAST demonstrations will consider the incorporation of mobility, laser sensing, and artificial intelligence-based planning. Later demonstrations are planned to include the ability to recognize and acquire unlabeled objects from a cluttered background, autonomous navigation, and the use of multiple cooperating robots. The testbed will be a national test facility and will support NASA Centers, private industry and universities.

The OSS and OAST have developed and are implementing a plan for the exploitation of the Telerobotic Program results. The plan includes the transfer of the technology from JPL to the design and construction of the FTS under the cognizance of the Goddard Space Flight Center. Thus, the FTS project, which is intended to aid in the assembly and maintenance of the station and to be used in servicing space station attached payloads and visiting spacecraft, will be in a position to take advantage of the most advanced technology available.

Space Station Freedom Organization

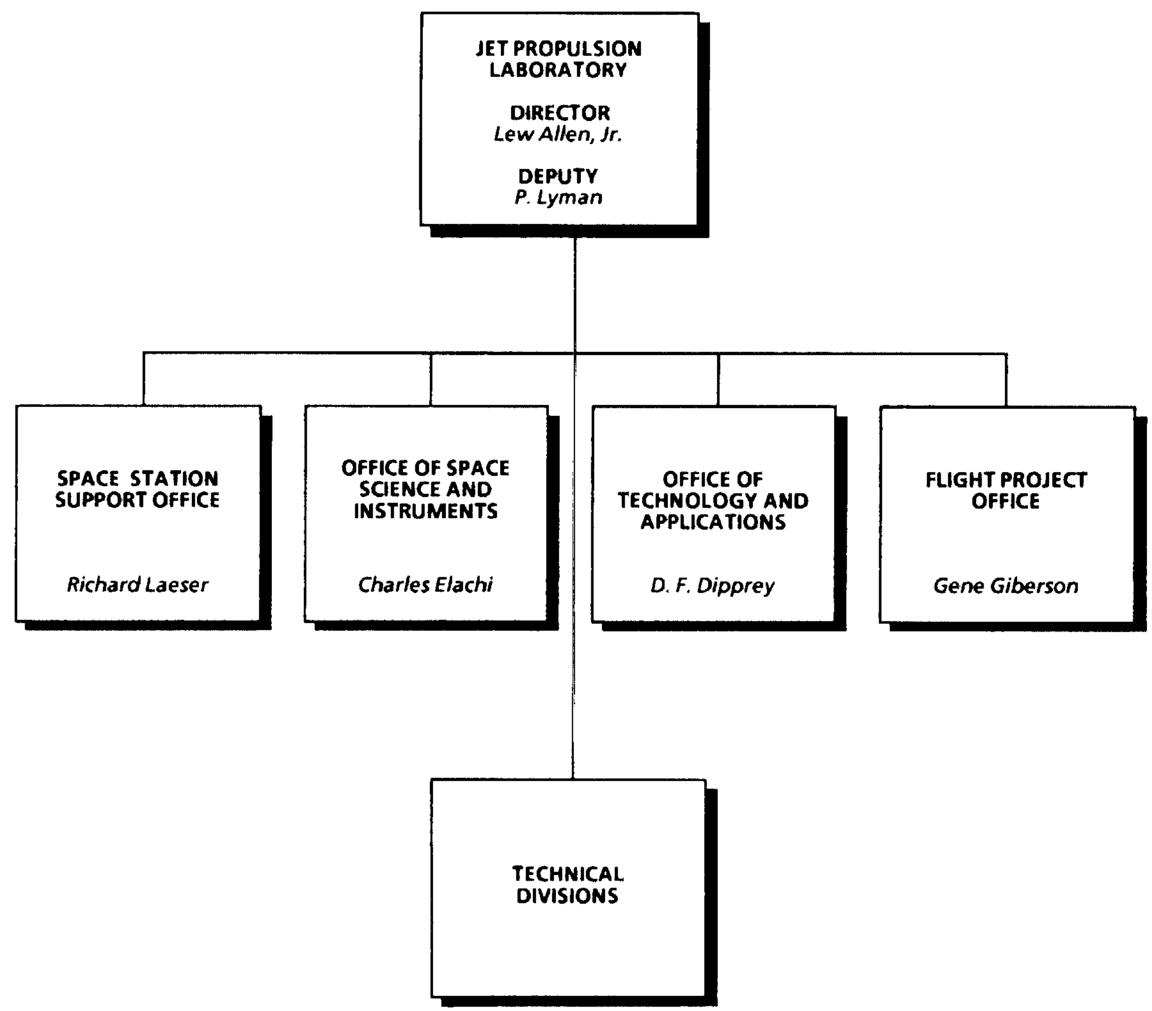
The Jet Propulsion Laboratory (JPL) carries out a range of support activities for on NASA's Space Station Freedom program.

The Space Station Support Office (SSSO) is part of the JPL Director's office. SSSO's responsibilities include providing detailees to the Office of the Space Station (OSS) to carry out temporary assignments and to provide a limited amount of policy study support to Level I. The SSSO's major responsibility is to manage and staff the Level II Program Requirements and Assessment Office (PR&A).

JPL's space station payload definition and development activities are centered in the Office of Space Science and Instruments. This currently involves the execution of studies of possible evolution-era payloads and missions in support of Level I, as well as the Office of Space Science and Applications (OSSA) supported definition and development.

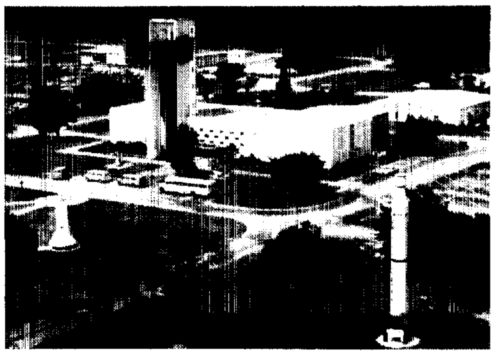
The Office of Technology and Applications also supports Level I with studies of possible evolution paths for telerobotics technology. This office is also responsible for leading the NASA Office of Aeronautics and Space Technology (OAST) Telerobotics Technology Program.

The Flight Projects Office is the focal point for Earth Observation System (EOS) mission and system level activities in support of OSSA's EOS Program, which is to be the ultimate user of the U.S. Polar Platform. Approximately 100 to 150 professionals are involved in space station activities at JPL.



JOHN C. STENNIS SPACE CENTER

Traditional Center Roles and Responsibilities



Formerly designated the National Space Technology Laboratories (NSTL), the Center was renamed the John C. Stennis Space Center by Executive Order signed by President Reagan on May 20, 1988.

In October 1961, the federal government announced its selection of a site in Hancock County, Mississippi, to locate the nation's test facility for static firing of the Saturn V rocket engines. The selection of this site for the Mississippi Test Facility, as NSTL was first named, was a logical and practical one. The area offered ample land for construction of the huge test facilities and had water access for shipping massive rocket stages and barge loads of propellants.

NSTL's first assignment was to flight certify all of the first and second stages of the Saturn V rocket for the Apollo program. The program began with a static test firing on April 23, 1966, and continued in the early 1970s. In all, 27 Saturn stages were tested and all performed successfully, including those used for Apollo 11, the first lunar landing mission.

A new chapter in NSTL's history was opened with the first test of a Space Shuttle Main Engine in June 1975. The main engine test program is expected to continue into the 1990s and beyond, supporting shuttle missions and the planned space station. NSTL's missions also expanded during the transition between the Apollo and Space Shuttle programs, when the installation evolved into a multi-agency, multi-discipline facility comprised of a number of federal and state agencies which are engaged in space and environmental programs and the national defense.

The current missions of the Stennis Space Center are to support the development of the Space Shuttle Main Engines; to conduct research and development in remote sensing and other space applications; and to manage the 13,480-acre installation and provide support services to resident agencies.

The Space Shuttle Main Engine test program has been underway since 1975. All the main engines used to power the orbiter during the first 8½ minutes of flight are tested here before an actual launch. Research and development engines designed for ground-testing purposes only are also tested continuously to refine and improve the performance of flight engines.

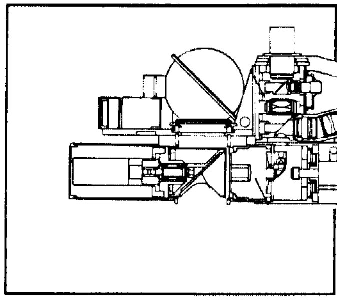
Another Stennis Space Center mission is to provide technical and institutional support to the 18 resident agencies and university elements located here. These federal and state agencies are primarily involved in environmental and oceanographic programs on national and international levels.

The Sciences and Technology Laboratory (STL) is the primary research and development organization of the Stennis Space Center. The laboratory was established in 1970 to develop new technology for observing the Earth and its resources. STL advances new remote data collection and analysis concepts, and provides a logical transition from basic research through applications development to commercialization of space remote sensing technology. Laboratory personnel develop and test airborne prototypes of advanced remote sensing instruments as proofs of concept for orbital instruments.

The STL is currently adapting remote sensor technology to support rocket engine testing and Shuttle launch and landing operations.

The STL is comprised of scientific and technical personnel working in such fields as mathematical modeling, forestry, geology, urban geography and archaeology. STL scientists have close ties with the academic and industrial remote sensing communities, enabling the laboratory to be fully attuned to current trends. Also, its co-location with other scientific and technical agencies fosters cooperative R&D activities. One goal of the laboratory is to develop advanced capabilities to remotely examine and predict changes in Earth processes, especially those caused by natural and human-induced disturbances. The STL also develops advanced data processing systems, comprised of state-of-art hardware and spatial data management and analysis software, to address complex scientific and administrative information extraction requirements.

Supporting Roles For Space Station Freedom



The John C. Stennis Space Center's (SSC) involvement in the Space Station Freedom program includes promoting commercial participation in remote sensing opportunities on board the station, performing user requirements and station utilization studies for Space Station Program Office working groups, and development of a payload simulator.

The Space Station Freedom assignments at Stennis Space Center are being carried out by the Science and Technology Laboratory, the installation's research and technology development organization.

Stennis Space Center has conducted NASA outreach activities designed to inform, stimulate, encourage and facilitate U.S. industrial participation in NASA programs. In this effort, an information base developed at Stennis Space Center is used to provide technical assessments to U.S. industry regarding commercial remote sensing opportunities on Space Station Freedom.

A major portion of Stennis Space Center's outreach activity and station planning was preparation for the Space Station Freedom Commercial Users Workshop held in Denver, Colorado in October 1988. Sponsored by NASA's Office of Space Station and the Office of Commercial Programs, the industry-oriented workshop was organized to define and encourage commercial activities and to elicit U.S. industry requirements in their anticipated utilization of Freedom.

One of the concepts proposed for Space Station Freedom is the Earth Observation Accommodation Facility. The advantage of such a facility on the station will be in providing a testbed where sensors may be placed, tested, refined, retested and ultimately customized for specific application. This facility has evolved from commercial space station user workshops, outreach activities, and contractor studies. Stennis Space Center will continue to conceptualize and detail the design of the facility to conform to existing baseline station parameters, user requirements, and hardware and assembly procedures.

Stennis Space Center has been assisting several station working groups with generic remote sensing accommodations analysis and in defining user requirements for workstations on Space Station Freedom. Node utilization studies are also being conducted by Stennis Space Center in support of the program.

The Space Station Freedom Payload Simulator is a software package written entirely in the Ada programming language that supports space station program activities. The simulator, developed and maintained at Stennis Space Center, presently resides on computer systems at the Johnson Space Center, Goddard Space Flight Center, and Stennis Space Center.

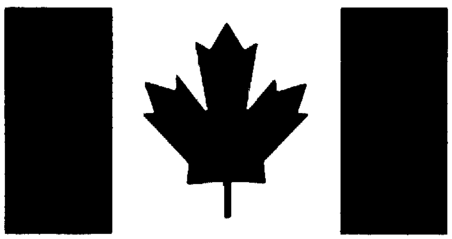
The simulator enables a principal investigator to acquire information and test specific conditions that are likely to occur during the actual operation of experiments.

The purpose of the payload simulator is to support the Space Station Freedom effort by providing tests of the network communication on the Data Management System (DMS) testbed at JSC, and the Platform Management System (PMS) at GSFC.

The simulator will support the implementation of the telescience concept in Space Station Freedom payload development and operations as well as provide a training tool for payload design and operation. Also, the payload simulator will provide NASA with information and experience in the development of software in Ada for real-time applications.

Potential users of the payload simulator services are other NASA program office Space Station Freedom activities, other U.S. government Space Station Freedom partners and support contractors, international Space Station Freedom participants, and U.S. commercial Space Station Freedom partners and participants.

Canada



At the "Shamrock Summit" in March 1986, Prime Minister Brian Mulroney and President Reagan agreed to meaningful, visible Canadian participation in the space station program. Canada intends to commit $1.2 billion on the program through the year 2000.

Canada will provide the Mobile Servicing Center (MSC) for Space Station Freedom. Together with a U.S. provided, rail-mounted, mobile transporter, which will move along the truss, the MSC and the transporter comprise the Mobile Servicing System (MSS). The MSS will play the main role in Space Station Freedom's assembly and maintenance, moving equipment and supplies around the station, releasing and capturing satellites, supporting EVA activities, and servicing instruments and other payloads attached to the station. It will also be used for docking the Shuttle Orbiter to the station and then loading and unloading materials from its cargo bay.

NASA considers the MSC as part of the station's critical path; an indespensible component in the assembly, performance and operation of Space Station Freedom.

The Mobile Servicing Center will be the next generation of Canadarm, currently being used on the Shuttle Orbiter. The MSC will be about the same size but will be about three times as strong.

The arm will be 17.6m (58 feet) long with a payload capacity of 100,000kg (110 tons). It will be voice controlled and utilize artificial intelligence. On-board cameras will provide the system with the visual data needed to recognize, automatically track, and handle a variety of objects.

A separate smaller robot, called the Special Purpose Dexterous Manipulator (SPDM), will have two arms, each two meters long, for more delicate jobs such as working on electrical circuits, fuel lines, and cooling systems. The SPDM will have exceptional mechanical dexterity and will be able to work alone or as a companion to the MSC. It will contain tactile sensors for "feeling" surfaces and carry a set of tools to enable it to perform many functions.

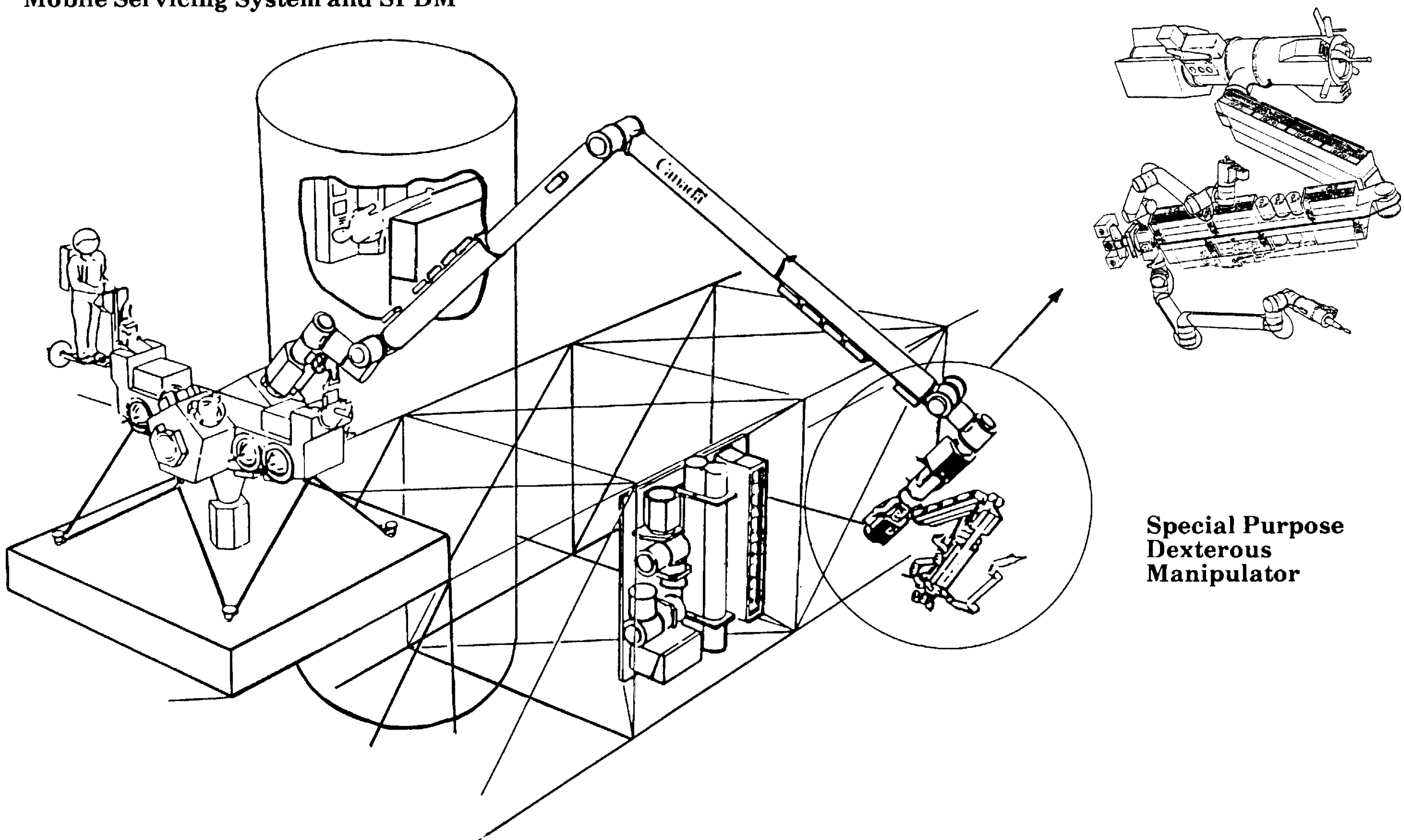
The MSC itself will consist of a remote manipulator system with special purpose dextrous manipulators, end-effectors, and servicing tools. This base structure will handle assembly, servicing, payloads, orbital replacement units, utilities, and thermal control. Crewmembers can operate the MSC from internal and external control stations.

In space, Canada will supply the Space Station Remote Manipulator System, the MSS Maintenance Depot (MMD), the special Purpose Dexterous Manipulator (SPDM), MSS work and control stations, a power management and distribution system and a data management system. On the ground, Canada will build a Manipulator Development and Simulation Facility (MDSF) and a mission operations facility and equipment.

Besides the creation and operation of hardware systems for the MSC, involving advanced technology, Canadian industry--especially the non-aerospace companies-- plans to make use of the weightless environment of space for the development of commercial products. The user development program will enable Canada to capture its share of the large anticipated market for products developed on Space Station Freedom.

Project management is handled by the Canadian Space Agency.

Mobile Servicing System and SPDM



Special Purpose Dexterous Manipulator

European Space Agency (ESA)

Columbus is the name of ESA's program to develop the three elements representing Europe's contribution to the space station.

The Columbus philosophy aims at providing an in-orbit and ground infrastructure compatible with European and international user needs from the mid-1990's onwards. The program also provides Europe, through international cooperation, with expertise in manned, man-assisted and fully automatic space operations, as a basis for future autonomous missions. The program also aims to ensure the establishment within Europe of the key technologies required for these various types of space flights. In this respect, the development of the Columbus space elements and associated ground infrastructure is closely linked to that of other ESA programs such as Ariane 5, Hermes and the European Data Relay Satellite.

The concept of Columbus was studied in the early 1980s as a follow-up to the successful Spacelab. The design, definition, and technology preparation phase was completed at the end of 1987. The development phase is planned over a duration of ten years (1988-1998) and will be completed by the initial launch of the following three elements:

Columbus Attached Laboratory
This laboratory which will be permanently attached to the station's manned base. It has a diameter of about 4m (13 feet), and will be used primarily for Materials Sciences, Fluid Physics and compatible Life Sciences missions.

The internal architecture of the laboratory provides a "shirt-sleeve" environment for the crew. The subsystems required to sustain the laboratory functions and to provide the necessary payload services and crew life support are accommodated under the floor and in standard equipment racks. All subfloor subsystem equipment and the standard racks can be exchanged on-orbit. Two viewports for external viewing and a scientific airlock for small experiments requiring exposure to the vacuum of space are provided.

The Columbus Attached Laboratory will be launched from the Kennedy Space Center (KSC) on a dedicated Shuttle flight, removed from the Shuttle Orbiter payload bay and berthed at Space Station Freedom's manned base.

Columbus Free-Flying Laboratory
This laboratory, also called the Free-Flyer, will be operated in a microgravity optimized orbit with 28.5° inclination, centered on the altitude of Space Station Freedom. It will accommodate automatic and remotely controlled payloads, primarily from the materials sciences and technology disciplines, together with its initial payload, and will be launched by an Ariane 5 from the Centre Spatial Guyanais (CSG) in Kourou, French Guiana.

It consists of a 2-segment pressurized module for the accommodation of payloads, and an unpressurized resource module which provides the main utilities and services required by the Free Flyer and its payloads. It is about 12m (40 ft) long and 4.4 m (14 ft) in diameter and weighs about 20,000 kg (44,000 lbs.)

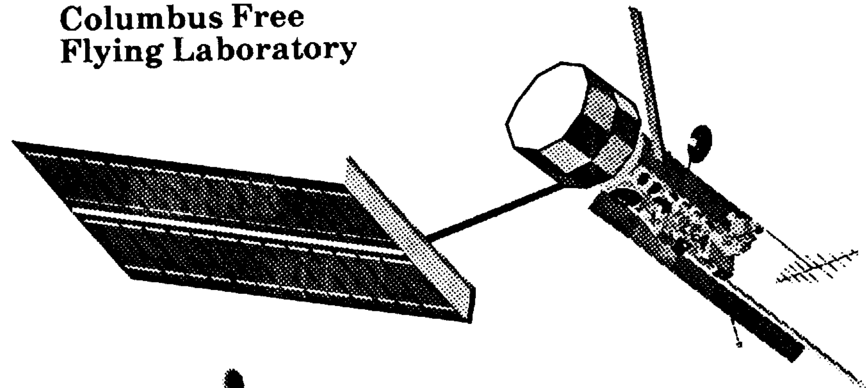
It will be routinely serviced in-orbit by Hermes at approximately 6-month intervals. Initially this servicing will be performed at Space Station Freedom, which the Free Flyer will also visit every 3-4 years for major external maintenance events.

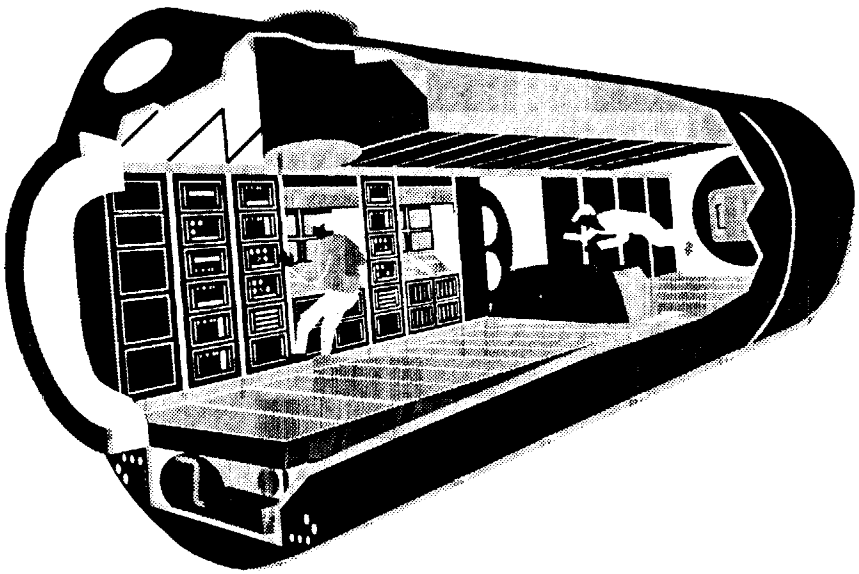
Columbus Polar Platform
The unmanned Polar Platform will be stationed in a highly inclined sun-synchronous polar orbit with a morning descending node and will be used primarily for Earth observation missions. The platform is planned to operate in conjunction with one or more additional platforms provided by NASA and/or other international partners, and will accommodate European and internationally provided payloads.

The platform is not serviceable and is designed to operate over a minimum of a four-year lifetime. The platform will accommodate between 1700 kg (773 lbs) and 2300kg (1045 lbs) of ESA and internationally provided payloads.

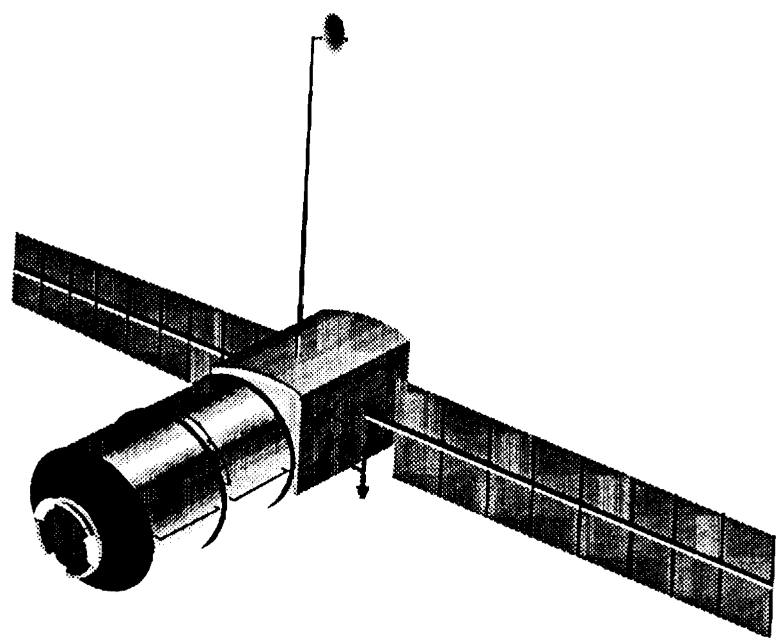
European Space Agency (ESA)

Columbus Free
Flying Laboratory





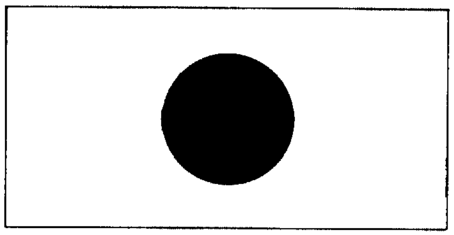
Columbus
Attached
Laboratory



Columbus
Polar
Platform

C-2

Japan



Japan initiated its space station program in 1985 in response to the United State's invitation to join the program. The Space Activities Commission's (SAC) Ad Hoc Committee on the Space Station concluded that Japan should take part in the phase B study of the program with its own experimental module. On the basis of the committee's conclusion, the Science and Technology Agency (STA) concluded the phase B memorandum of understanding (MOU) with NASA. Under the supervision of STA, the National Space Development Agency of Japan (NASDA), which is a quasi-governmental organization responsible for developing and implementing Japanese space activities, began the detailed definition and the preliminary design of the Japanese Experiment Module (JEM), which will be attached to the international space station. The JEM is a multipurpose laboratory and consists of a pressurized module, an exposed facility and an experiment logistics module.

Pressurized Module (PM)

The PM is an approximately 10 meter long tubular cylinder with an internal diameter of approximately 140 cubic meters. It has a pressurized volume of approximately 140 cubic meters. The PM can accommodate 23 equivalent standard racks. Materials processing experiments and life science experiments will be performed in the PM. The PM will also accommodate the capabilities of controlling and monitoring the experiments on the EF.

Exposed Facility (EF)

The EF is a box type working station composed of EF-1 and EF-2, both of which are connected by berthing mechanisms. Each part is 4 meters in length, 2.5 meters in height and 1.4 meters in width. It will be connected to the PM by a berthing mechanism, and can be mechanically disconnected on orbit. Some kinds of activities on the EF, such as an exchange of experimental equipment and materials and construction of large structures in space will require frequent crew access. However, by employing a local manipulator and an equipment airlock, both operated within the PM, this access can partially be accomplished while minimizing extravehicular activity. Scientific observation, communication experiments, scientific/engineering, and materials experiments will be conducted on the EF.

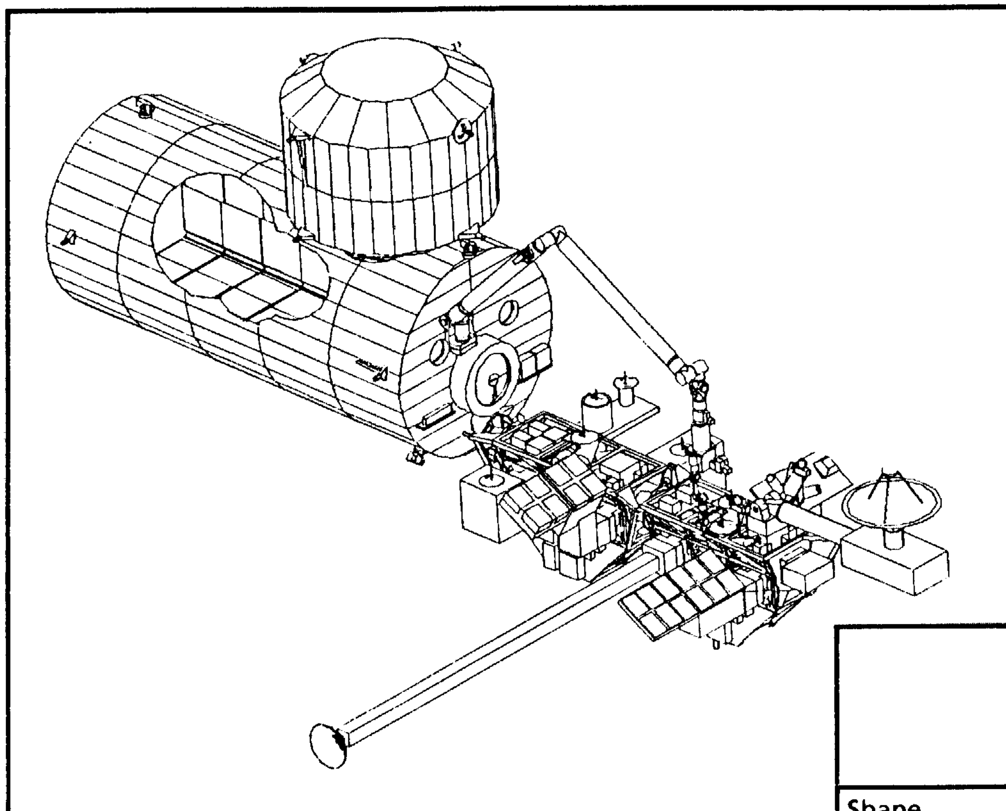
Experiment Logistics Module (ELM)

The ELM provides on-orbit storage volume and can transport JEM logistics supplies such as experiment specimens, gases and fluids, equipment for configuration change, and space parts for maintenance. The ELM will consist of two sections: a pressurized section and an exposed section. The pressurized section will store and transport JEM logistic supplies in a pressurized environment and have crew evacuation provisions for emergencies. It is designed to have a pressurized volume of approximately 40 cubic meters. It will provide crew survival conditions during emergency evacuation for rescue. The exposed section will store and transport JEM logistic supplies in an unpressurized environment.

The JEM will be launched on two Shuttle flights. The first flight will transport the PM and EF-1. The second flight will bring up the EF-2 and ELM.

Heading toward the space station era, Japan is promoting many space experiments. As to the Space Shuttle/Spacelab program, Japan is preparing the First Materials Processing Test (FMPT) project planned in 1991 and is participating in the International Microgravity Laboratory (IML) program. The Space Flyer Unit (SFU) is also being developed as a joint program among the Institute of Space and Institute of Space and Astronautical Science (ISAS), STA/NASDA and Ministry of International Trade and Industry (MITI) aiming at the launch in 1993. Many governmental agencies, universities and private companies are also promoting basic research and research support for space utilization in Japan.

Japanese Experiment Module



	Pressurized Module	Experiment Logistics Module		Exposed Facility
		Pressurized section	Exposed section	
Shape	Cylinder	Cylinder	Box	Box 2 unit
Size	4m Dia.	4m Dia.	4mX4m	2.5(H)X1.4m(W)
Length	10m	4m	2m	4m
Number of mission payloads	Payload Rack 10	Rack 8		Payload 10
Average power	Housekeeping 5kW Mission 20kW			
Data transfer rate	32 Mbps. (MAX., Optical LAN)			

Note: Values in this table are approximate.

APPENDIX A

Work Package Contractors

COMPANY	LOCATION	TYPE OF WORK	CURRENT STAFF	VALUE ($)
WORK PACKAGE 1				
Boeing Aerospace Co.	Huntsville, AL	Prime Contractor	730	$1,550M
Teledyne Brown Engineering	Huntsville, AL	Materials Processing Lab Outfitting, Payload Integration, Ground-Support Equipment	95	$158M
TRW, Inc.	Huntsville, AL	Systems Simulation and Training Software	14	$14M
Allied-Signal AiResearch	Torrance, CA	Thermal Control, Environmental Control, Life Support, Valves, Fire Detection, Technology Demonstrator	49	$39M
Lockheed Missles and Space Co.	Sunnyvale, CA	Life Sciences and Animal Research Facilities Outfitting	27	$164M
Hamilton Standard	Windsor Locks, CT	Urine Processor, Potable Water, Hygiene, Thermal, Technology Demonstrator	84	$39M
Arde	Norwood, NJ	ECLSS Tank Sets	10	$11M
Fairchild-Weston Systems	Syossett, NY	Internal Video	21	$25M
Astro International Corp.	League City, TX	ECLSS Processing Control Water Monitoring	17	$5M
Grumman Aerospace, Corp	Houston, TX	Design and Outfit Habitation Module	34	$54M
ILC Space Systems	Houston, TX	Galley, Laundry, Refrigerator, Trash, Storage	31	$50M
Life Systems	Cleveland, OH	CO_2 Reduction, O_2 Generator, Technology Demonstrator	49	$27M
Camus, Inc.	Houston , TX	Mockups, Trainers, Simulators, Flight Hardware	3	$2M
Harris Corp	Melbourne, Fl	Internal Audio	27	$35M
Perkin-Elmer	Pamona, CA	Atmosphere Composition Monitor	21	$16M
Ball Aerospace Co.	Boulder. CO	Fluid Subcarrier Tank Set	10	$14M
ILC Technology	Sunnyvale, CA	Interior Lighting	5	$15M
WORK PACKAGE 2				
McDonnell Douglas	Huntington Beach, CA	Prime Contractor	654	$3,300M
Motorola	AZ			
Sperry	AZ			
Astro Aerospace	Carpinteria, CA	Mobile Transporter (D&D)*	11	$50M
Emulex	CA			
Lockheed Missles & Space Co.	Sunnyvale, CA	Active Thermal Control System, EVA System, Rotary Mechanisms (D&D)*	153	$650M
Hamilton Standard	Windsor Locks, CT			
International Latex	Dover, DE			
Honeywell, Inc.	Clearwater, FL	Control System (D&D)*	55	$150M
McDonnell Douglas	Cape Canaveral, FL	Launch Integration and Support		
Honeywell, Inc.	Minneapolis, MN	Ring Laser Gyro		
McDonnell Douglas	St. Louis, MO	Corporate Support		

* (D&D) = Design and Development

Work Package Contractors (continued)

COMPANY	LOCATION	TYPE OF WORK	CURRENT STAFF	VALUE ($)
WORK PACKAGE 2 (Continued)				
General Electric	Camden, NJ	Communication & Tracking System	109	$400M
IBM	Owego, NY	Data Management System, Flight Hardware (D&D)*		
IBM	Houston, TX	Data Management System (D&D)*	148	$300M
Lockheed	Houston, TX	EVA System	89	
McDonnell Douglas	Houston, TX	Software Development Operations Planning, Flight Crew Integration, Airlock Testing		
Eagle Technical Services, Inc.	Webster, TX	Systems Engineering	16	$1.375M
WORK PACKAGE 3				
General Electric Co.	Valley Forge, PA	Prime Contractor	232	$900M
Teledyne Systems	CA			
TRW	Redondo Beach, CA			
WORK PACKAGE 4				
Rockwell International	Conoga Park, CA	Prime Contractor: System Integrator	320	$1.5B
Rocketdyne Div.		PMAD, Software		
Allied-Signal Aerospace Co.	Tempe, AZ	Closed Brayton cycle heat engine	9	$45M
Allied Signal Aerospace Co.	Torrance, CA	Solar Receiver	3	
Ford Aerospace	Palo Alto, CA	Batteries, DC source PMAD, consolidated EEE parts	157	$199M
General Dynamics	San Diego, CA	20KHz converters	27	$86M
Lockheed Missles and Space Co.	Sunnyvale, CA	Solar arrays	79	$211M
Harris Corp.	Melbourne, FL	Solar dynamic collector structure	6	$5M
LTV	Arlington, TX	Deployable radiator for SD system	8	$3M
Spectrolab Inc.	Sylmar, CA	Solar cells	7	$130M
Applied Solar Energy Corp.	City of Industry, CA	Solar cells	13	$69M
Whittaker-Yardney Corp.	Pawcatuck, CT	Battery cells	15	$17M
Gates Corp	Gainesville, FL	Battery cells	5	$27M

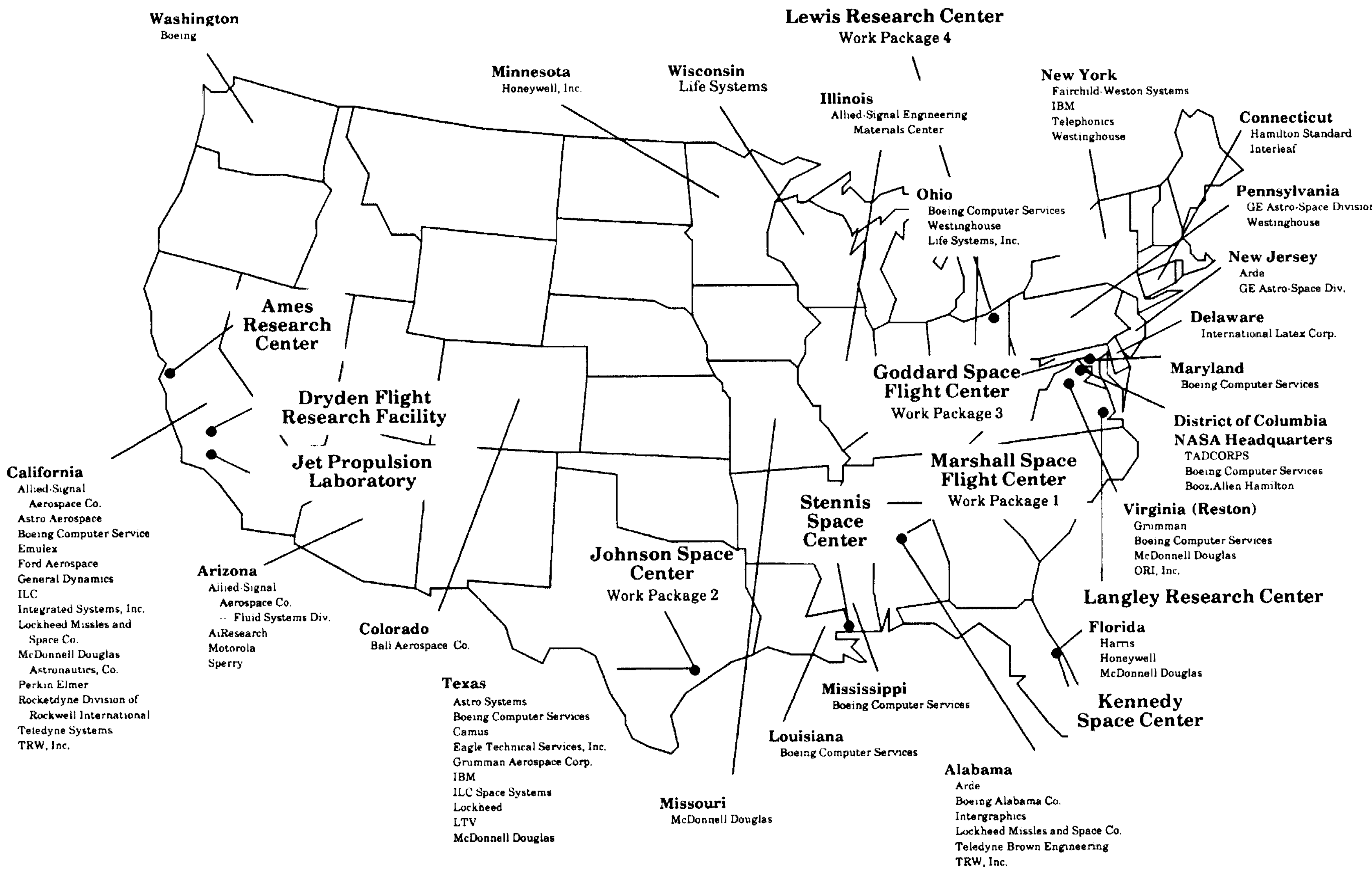
* (D&D) = Design and Development

APPENDIX A

Management Support and Information Systems Contractors

SUPPORT CONTRACT COMPANY	LOCATION	TYPE OF WORK	CURRENT STAFF	VALUE ($)
Technical and Management Information Systems				
Boeing Computer Services	Reston, VA	Prime Contractor for computer integration of TMIS	250 (including Prime and Subs)	$330M
Program Support Contractor				
Grumman Space Station Program Support Division	Reston, VA	Level II Program Support Contractor for the Space Station FreedomProgram Office. Providing support for program control, management, information systems, operations, utilization systems, engineering, SRM&QA and international integration	640	$1B (over 10 years)
Software Support Environment				
Lockheed Misses and Space Co.	Sunnyvale, CA	Provide a program-wide software support environment including architecture, design, acquisition,development, implementation, and maintenance	200 (including Prime and Subs)	$242 M (over 6 years)
Level I Support Contrator				
Technical and Administrative Services Corporation (TADCORPS)	Washington, D.C.	Provides OSS (Level I) with management and administrative support services including: Official Level I documentation, formal presentations, conferences, development of non-TMIS PC applications, technical writing and editing, and technical support to all Divisions	22	$6.3 M (over 5 years)

Geographic Locations of NASA and Contractors



APPENDIX B

Acronyms & Abbreviations

A&R	Automation & Robotics
ACS	Attitude Control System
AI	Artificial Intelligence
APAE	Attached Payload Accommodation Equipment
AXAF	Advanced X-Ray Astrophysics Facility
BCD	Baseline Configuration Document
C&T	Communictions & Tracking
CERV	Crew Emergency Return Vehicle
CMG	Control Momentum Gyroscope
COP	Co-Orbiting Platform
DMS	Data Management System
DOC	Discipline Operations Center
ECLSS	Environmental Control and Life Support System
EF	Exposed Facility
ELM	Experiment Logistics Module
ELV	Expendable Launch Vehicle
EOS	Earth Observing System
EPS	Electrical Power System
ESA	European Space Agency
ESC	Engineering Support Center
EVA	Extravehicular Activity
FEL	First Element Launch
FF	Free-Flyer
FMS	Fluid Management System
FTS	Flight Telerobotic Servicer
GEO	Geosynchronous Orbit (22,300 mi)
GN&C	Guidance, Navigation and Control
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HMF	Health Maintenance Facility
HQS	Headquarters (NASA)
ICD	Interface Control Document
IGA	Intergrovernmental Agreement
IOC	Initial Operational Capability
IVA	Intravehicular Activity
JEM	Japanese Experiment Module
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LCC	Life Cycle Costs
LCC	Launch Control Center
MCC	Mission Control Center
MOU	Memorandum of Understanding
MPAC	Multipurpose Application Console
MRMS	Mobile Remote Manipulator System
MS	Man System
MSC	Canadian Mobile Servicing Centre
MSFC	Marshall Space Flight Center
MSS	Mobile Servicing System
MTC	Man-Tended Capabilities
MTFF	Man-Tended Free-Flyer
NASA	National Aeronautics and Space Administration
NSTS	National Space Transportation System
NASDA	National Space and Development Agency (Japan)
OAST	NASA Office of Aeronautics and Space Technology
OMV	Orbital Maneuvering Vehicle
ORU	Orbital Replacement Unit
OSS	NASA Office of Space Station
OSSA	NASA Office of Space Science and Applications
PLC	Pressurized Logistics Carrier
PM	Pressurized Module
PMC	Permanently Manned Capability
PMS	Platform Management System
POIC	Payload Operations Integration Center
POP	Polar Orbiting Platform
PSC	Platform Support Center
PTF	Payload Training Facility
QA	Quality Assurance
RFP	Request for Proposal
RMS	Remote Manipulator System
ROC	Regional Operations Center
SE&I	Systems Engineering & Integration
SLC	Shuttle Launch Complex (VAFB)
SRR	Systems Requirements Review
SSC	John C. Stennis Space Center
SSCC	Space Station Control Center
SSE	Software Support Environment
SSIS	Space Station Information System
SSP	Space Station Program
SSPF	Space Station Processing Facility
SSFPO	Space Station Freedom Program Office
STS	Space Transportation System
TCS	Thermal Control System
TDRSS	Tracking and Data Relay Satellite System
TMIS	Technical Management and Information System
ULC	Unpressurized Logistics Carrier
USL	United States Laboratory
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
WBS	Work Breakdown Structure
WP	Work Package
WTR	Western Test Range

APPENDIX C

Glossary

ARTIFICIAL INTELLIGENCE (AI)
The use of computers to perform tasks (such as robotics, vision interpretation, problem solving, etc.) with a minimum of pre-programmed direction.

ATTACHED PAYLOADS
Payloads located on manned base truss outside the pressurized modules.

AUTOMATION
Mechanization of a process or system to proceed without human intervention.

BASELINE
A specification or product that has been reviewed, agreed upon, and that serves as the basis for further development and can be changed only through change control procedures.

BASELINE PROGRAM
The first phase of the space station program, during which permanently manned capability is achieved, and including on-orbit installation of the following components:
- Horizontal (transverse) boom
- Photovoltaic arrays generating 75 kW of power
- Flight Telerobotic Servicer
- Four pressurized modules (U.S. Lab & Habitation, ESA Columbus Lab, JEM)
- First increment of Mobile Servicing System
- Resource Nodes
- Two polar platforms (one U.S., one ESA)

CO-ORBITING PLATFORM (COP)
A platform, co-orbiting with the space station manned base, serviced by the Space Transportation System or an Orbital Maneuvering Vehicle. Provided in the reference evolutionary design of the space station program. Nominally, co-orbiting objects occupy different positions (right ascensions) in the same orbit.

COLUMBUS MODULE
The ESA-provided laboratory module that is part of the baseline space station program configuration.

COMMONALITY
The use of the same or similar hardware and software throughout the space station program to accomplish the same function, with the primary objective of reducing costs.

CONFIGURATION
(1) The arrangement of an information system as defined by the nature, number, and chief characteristics of its software and/or hardware functional units. (2) The requirements, design, and implementation that define a particular version of a system or system component. (3) The functional and/or physical characteristics of hardware/software as set forth in technical documentation and achieved in a product.

ELEMENT
One of the following components of the space station:

U.S.-PROVIDED ELEMENTS (PRESSURIZED)
- Habitation Module
- Laboratory Module
- Resource Nodes (four)
- Airlocks
- Hyperbaric Airlock
- Logistics Carrier

U.S.-PROVIDED ELEMENTS (UNPRESSURIZED)
- Truss Element
- Mobile Transporter (MSS Base)
- Flight Telerobotic Servicer (FTS)
- Attached Payload Accommodations Equipment
- Servicing Facility (Evolutionary Phase)
- Solar Power System
- Propulsion Assembly
- Unpressurized Logistics Carriers

INTERNATIONALLY PROVIDED ELEMENTS (PRESSURIZED)
- Columbus Module (ESA)
- JEM Laboratory and Exposed Facility (Japan)
- JEM Logistics Module (Japan)

INTERNATIONALLY PROVIDED ELEMENTS (UNPRESSURIZED)
- Mobile Servicing System (MSS) (Canada)
- MSS Maintenance Depot (Canada)
- Special Purpose Dexterous Manipulator (Canada)

Glossary

EVOLUTIONARY GROWTH PHASE
The second phase of the space station program, during which the following components might be added to the baseline configuration:
- Solar dynamic power system generating 50 kW of power
- Upper and lower booms
- Final increment of Mobile Servicing System
- Co-orbiting platform

EXPENDABLE LAUNCH VEHICLE (ELV)
A ground-launched propulsion vehicle, capable of placing a payload into Earth-orbit or Earth-escape trajectory, whose various stages are not designed for, nor intended for recovery and/or reuse.

EXPERT SYSTEMS
Software programs for solving problems in specific disciplines, composed of procedural rules for that discipline, a rule process, descriptive databases for that discipline, and a knowledge base provided by a human expert in that or a related disciplines. Examples of expert systems include programs that will translate complex, out-of-context statements from one foreign language to another, or that will diagnose and discriminate between diseases.

EXTRAVEHICULAR ACTIVITY (EVA)
Operations performed by crew members wearing life-support suits outside the habitable environment.

FIRST ELEMENT LAUNCH (FEL)
The first shuttle assembly flight of Space Station Freedom, including structure and those subsystems necessary to sustain the initial package until additional hardware is placed in orbit.

FLIGHT TELEROBOTIC SERVICER (FTS)
A device attached to a space station manipulator or the Orbital Maneuvering Vehicle which interfaces with the payloads located on the space station, or with payloads located on platforms or free-flyers in order to allow servicing to be performed on-site.

HOOK
Aerospace jargon for a design feature to accommodate the addition or upgrade of computer software at some future time.

INTEGRATION
The process of combining software and, hardware elements, networks, personnel, and procedures into an overall system.

INTERFACE
The point or area where a relationship exists between two or more parts, systems, programs, persons, or procedures wherein physical and functional compatibility is required.

INTERNATIONAL PARTNER
Any of the non-U.S. partners participating. and sharing in the design, development, and operation of the space station: National Research Council of Canada, National Space Development Agency (NASDA) of Japan, and the European Space Agency (ESA).

INTRAVEHICULAR ACTIVITIES (IVA)
Operations performed by crew members within the habitable environment.

JAPANESE EXPERIMENT MODULE (JEM)
The Japanese-provided laboratory module (including an Experiment Logistic Module) that is part of the baseline station configuration.

LEVEL 0
Office of the NASA Administrator at Headquarters.

LEVEL I
Management organization at the level of the NASA Associate Administrator for the Office of Space Station at NASA Headquarters.

LEVEL II
Management organization at the level of the NASA Space Station Program Office in Reston, Virginia.

LEVEL III
Management organization at the level of the NASA field center Space Station Project Offices.

LOGISTICS
The management, engineering, and support activities required to provide personnel, materials, consumables and expendables to the space station elements reliably.

LIFE CYCLE COST (LCC)
The entire cost of a program or project from inception to ultimate disposition. Estimating life cycle cost is important to understanding long term impacts of decision-making early in the lifetime of a program.

MANNED BASE
Major, manned core of the Space Station Freedom program providing permanent manned presence in space. The manned base includes all the U.S. and partner-provided manned elements, plus all the related systems and structure, except for co-orbiting platforms and free-flyers.

MAN-TENDED CAPABILITY (MTC)
The capability to operate the space station unmanned except for periodic visits by the Shuttle crew for servicing and maintenance.

MAN-TENDED FREE-FLYER (MTFF)
A spacecraft that may require servicing by the space station or an Orbital Maneuvering Vehicle but is not associated with one of the platforms. Free-flyers may have their own movement capability or require an Orbital Maneuvering Vehicle for orbit maneuvers.

MOBILE REMOTE MANIPULATOR SYSTEM (MRMS)
A large relocatable, tele-operated robotic manipulator which is provided by Canada. The station equivalent of the Shuttle Remote Manipulator System but which is mounted on a mobile transport mechanism. It will be able to access all critical areas on the exterior of the station and will be controlled by the crew from inside the pressurized modules and potentially during Extravehicular Activity or remotely from the Shuttle or Space Station Support Center.

MOBILE SERVICING SYSTEM (MSS)
The station's Mobile Remote Manipulator System facility, consisting of one or more Canadian-provided manipulator systems and a U.S.-provided transport mechanism, located on the truss structure for assembly, maintenance and external payload processing.

NATIONAL SPACE TRANSPORTATION SYSTEM (NSTS)
The Shuttle program and its supporting facilities.

ORBITAL MANEUVERING VEHICLE (OMV)
The unmanned propulsive stage used to ferry between the station or Shuttle and a platform or free-flyer. It will be used either to bring the spacecraft to the station or Shuttle for servicing or to perform servicing in-site via a smart front end. (Not part of the Space Station Freedom program but used by it.)

ORBITAL REPLACEMENT UNIT (ORU)
The lowest level of component or subsystem hardware and software that can be replaced in orbit.

PAYLOAD
An aggregate of instruments and software for performance of specific scientific or applications investigations or for commercial production. Payloads may be inside pressurized modules, attached to the space station structure, attached to a platform, or they may be free-flyers.

PERMANENTLY MANNED CAPABILITY (PMC)
The capability to operate the space station with a human crew on board, 24 hours a day, 365 days a year.

PLATFORM
An unmanned orbital element of the space station program that provides standard support services to payloads not attached to the space station.

POLAR ORBITING PLATFORM (POP)
An unmanned spacecraft in polar or near polar inclination operated from the ground and dependent on the space station program to provide services for a complement of payloads.

ROBOTICS
The technology and devices (sensors, effectors, and computers) for carrying out, under human or automatic control, physical tasks that would otherwise require human abilities. (See automation.)

SCAR
Aerospace jargon for design features to accommodate the addition or upgrade of hardware at some future time.

SOFTWARE SUPPORT ENVIRONMENT (SSE)
Computer hardware, networks, software,

Glossary

standards, and procedures forming an integrated whole. In the context of the space station program, the function of the Software Support Environment is to enhance the design, implementation, test, integration, and maintenance of the Space Station Information System software for the duration of the program.

SPACE STATION INFORMATION SYSTEM (SSIS)
Those hardware and software subsystems that interface with the sensors and effectors of the orbital space station elements and the data processing facilities of the various users. It is composed of both spaceborne and ground based subsystems.

SYSTEM
One of the following components of the space stations:
- Electrical Power System (EPS)
- Data Management System (DMS)
- Thermal Control System (TCS)
- Communications and Tracking System (C&T)
- Guidance, Navigation, and Control System (GN&C)
- Extravehicular Activity System (EVA)
- Environmental Control and Life Support System (ECLSS)
- Fluid Management System (FMS)
- Man Systems

SYSTEM INTEGRATION
The process of uniting the parts of the space station program into a complete and functioning space station with associated platforms. Results in the specific decisions (e.g., types of connectors to be used at an interface, modifications required as a result of a verification testing, etc.) required to accomplish this task.

SYSTEMS ENGINEERING
The process of analytically determining the optimal space station configuration and associated program elements from a combined initial, life cycle, user cost, and user performance perspective. Results in an integrated set of requirements and an allocated set of functions and resources for the total system and its interaction with all related factors throughout development and operations.

TECHNICAL AND MANAGEMENT IN FORMATION SYSTEM (TMIS)
An advanced network of compatible hardware and integrated software used to provide systematic technical and management information development and exchange between space station program personnel.

TELESCIENCE
Telescience identifies a mode of operation in which a distributed set of users can interact directly with their instruments, whether in space or ground facilities, with databases, data handling and processing facilities, and with each other. Telescience comprises the aspects of Teledesign, allowing remote inter-action with design databases, transfer of drawings, etc.; Teleoperations, involving interactive instrument control, as well as operational interaction with crew from remote locations; and Teleanalysis, wherein users interact with data sets and data processing facilities from remote locations.

USER
Any organization, group, or individual who uses or plans to use the space station or any other space station program facility for the operation of a payload or related mission.

WORK BREAKDOWN STRUCTURE (WBS)
A product-oriented, family-tree hierarchy which contains the levels of work required to be accomplished in order to achieve an objective. For a program, the WBS is developed by starting with the end objective of the program which is subdivided into projects which are each then further subdivided into systems, subsystems, assemblies, and components which are the logical and necessary steps to achieve each project objective. The total estimated cost for any item at any level is equal to the sum of the estimated costs for all items below it.

WORK PACKAGE (WP)
A WP is a complement of program activities which is assigned to a selected responsible NASA field installation. A WP describes the type and scope of activity to be performed at any level of detail and can include development of hardware, software, interfaces, systems operation, and system utilization operations.

NASA Public Affairs Points of Contact

NASA HEADQUARTERS
Mark Hess
Public Affairs Officer
NASA Headquarters
Code S
Washington, DC 20546
Phone: 202/453-4164
Fax: 202/426-6111

Debra Rahn
Public Affairs Officer
Code XI
NASA Headquarters
Washington, DC 20546
Phone: 202/453-8455
Fax: 202/453-2628

MARSHALL SPACE FLIGHT CENTER
Ed Medal
Public Affairs Office
Mail Stop CA10
Marshall Space Flight Center
Huntsville, AL 35812
Phone: 205/544-0034 (824)
Fax: 205/544-5852

JOHNSON SPACE CENTER
Billie Deason
Media Services
Mail Code AP3
Johnson Space Center
Houston, TX 77058
Phone: 713/483-8646 (525)
Fax: 713/483-2000

GODDARD SPACE FLIGHT CENTER
Mike Braukus
Public Affairs Office
Code 130
Goddard Space Flight Center
Greenbelt, MD
Phone: 301/286-5565 (888)
Fax: 301/286-8142

LEWIS RESEARCH CENTER
Mary Ann Peto
Public Affairs Office
Mail Code 3-11
Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216/433-2902 (297)

KENNEDY SPACE CENTER
Pat Phillips
Public Information Office
PA-PIB
Kennedy Space Center, FL 32899
Phone: 407/867-2468 (823)
Fax: 407/867-2692

LANGLEY RESEARCH CENTER
Jean Clough
Public Information
MS 115
Langley Research Center
Hampton, VA 23665
Phone: 804/865-3006 (928)
Fax: 804/865-4000

AMES RESEARCH CENTER
Pete Waller
Manager, Public Information
Mail Stop 204-12
Ames Research Center
Moffett Field, CA 94035
Phone: 415/694-5091 (464)
Fax: 415/694-3953

JET PROPULSION LABORATORY
Mary Beth Murrill
Public Information
MS 180-200
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
Phone: 818/354-5011 (792)
Fax: 818/354-4537

STENNIS SPACE CENTER
Mack Herring
Public Affairs Officer
Mail Code AB-10
John C. Stennis Space Center
Bay St. Louis, MS 39529
Phone: 601/688-3341 (494)
Fax: 601/688-3017

APPENDIX D

NASA Public Affairs Points of Contact

INTERNATIONAL PARTNERS

Wally Cherwinski
Canadian Space Agency
240 Sparks St.,
8th Floor West
Ottawa, Ontario K1A 1A1,
CANADA
Phone: 613/990-6122
Fax: 613/996-7887

Helge Aamotsbakken
Head of Public Relations Division
European Space Agency
Paris,
FRANCE
Phone: 9 011 33 1 42 73 7425
Fax: 42 73 7560

Mr. Masakazu Toshikage
First Secretary,
Embassy of Japan
2520 Massachusetts Ave., NW
Washington, DC 20008
Phone: 202/939-6922
Fax: 202/939-6788

PROGRAM SUPPORT CONTRACT

Larry Hamilton
Director, Public Affairs
Grumman Corporation
1000 Wilson Blvd., Suite 2100
Arlington, VA 22209-2280
Phone: 703/276-4929
Fax: 703/276-4955

Susan Pearce
Ford Aerospace
1235 Jefferson Davis Hwy
Suite 1300
Arlington, VA 22202
Phone: 703/685-5585
Fax: 703/685-5573

SOFTWARE SUPPORT ENVIRONMENT

Roger Beall
Public Relations Coordinator
Lockheed Missiles and Space Co.
Dept 2401, Bldg. 101
P.O. Box 3504
1111 Lockheed Way
San Diego, CA 94088-3504
Phone: 408/742-6688
Fax: 408/743-2239

TECHNICAL AND MANAGEMENT INFORMATION SYSTEM (TMIS)

John Alter
Director, Public Relations
Boeing Computer Services
7980 Boeing Ct.
Vienna, VA 22180
Phone: 703/821-6505
Fax: 703/821-6339

Contractor Points of Contact

WORK PACKAGE 1
Dave Suffia
Boeing Aerospace
MS 85-19
P.O. Box 3999
Seattle, WA 98124
Phone: 206/773-2816
Fax: 206/773-2113

Peri Widener
Boeing Alabama
Mail Stop JA49
P.O. Box 1470
Huntsville, AL 35807
Phone; 205/461-2803
Fax: 205/461-3070

WORK PACKAGE 2
Tom Williams
Public Relations
McDonnell Douglas Astro. co.
5301 Bolsa Ave.
Huntington Beach, CA 92647
Phone: 714/896-1300
Fax: 714/896-1313

Susan Flowers
Director of Communications
Headquarters
McDonnell Douglas Astronautics
P.O. Box 516, Dept. Y085
St. Louis, MO 63017
Phone: 314/233-9377
Fax: 314/777-1287

WORK PACKAGE 3
Carol Schmidt
Public Relations
GE Astro-Space Div.
Mail Stop 103, P.O. Box 800
Princeton, NJ 08543-0800
Phone: 609/426-3756
Fax: 609/426-2386

Montye Male
Public Relations Manager
TRW Electronics and Defense Sector
E2/9063
One Space Park
Redondo Beach, CA 90278
Phone: 213/812/4721
Fax: 213/535-5555

WORK PACKAGE 4
Pat Coulter
Director, Communications
Rocketdyne Div.
Rockwell International Corp.
6633 Canoga Ave.
Canoga Park, CA 91303
Phone: 818/710-2213
Fax: 818/710-2866

BOEING (TMIS)
John Alter
Director, Marketing Communications
Boeing Computer Services
7980 Boeing Ct.
Vienna, VA 22180
Phone: 703/821-6505

GRUMMAN (Program Support Contract)
Larry Hamilton
Director, Public Affairs
Grumman Corporation
1000 Wilson Blvd., Suite 2100
Arlington, VA 22209-2280
Phone: 703/276-4929

TADCORPS (Level 1)
Manfred von Ehrenfried
Executive Vice President
TADCORPS
600 Maryland, Ave, S.W., Suite 200
Washington, DC 20024
Phone: 202/554-8677
Fax : 202/863-0265