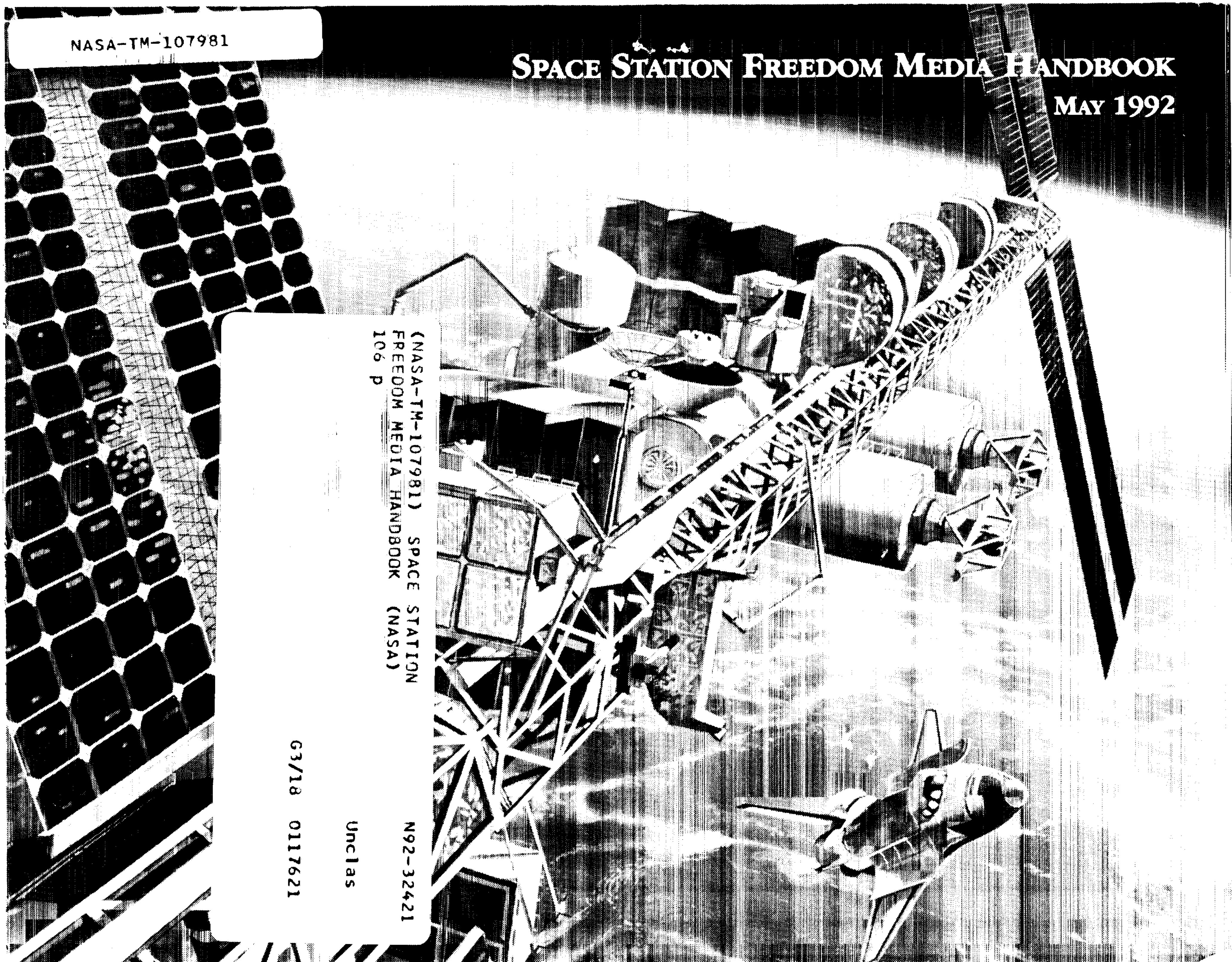
SPACE STATION FREEDOM MEDIA HANDBOOK

MAY 1992



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PREFACE

Since the initial publication of this Media Handbook in April of 1989, there has been a tremendous amount of program activity resulting in considerable changes.

On October 3, 1991, the NASA Headquarters Office of Space Systems Development was broken out of the existing Office of Space Flight organization, headed by Dr. William Lenoir, in response to the recommendations by the Advisory Committee on the Future of the U.S. Space Program. The new office, with Arnold Aldrich as the new Associate Administrator, will manage the Space Station Freedom Program, the National Launch System and other developmental projects and studies.

The Deputy Associate Administrator, Richard H. Kohrs remains as Director of the Space Station Freedom Program, a position he has held since June 5, 1989. Robert W. Moorehead remains Director, Programs and Operations at the Reston, Virginia program office, a position he has held since September 28, 1989.

1991 was a watershed year for Space Station Freedom. On May 15, the House appropriations subcommittee for Housing, Veterans and Independent Agencies voted to eliminate space station funding. On June 6, 1991, the House of Representatives overturned the subcommittee vote, restoring full funding for the program, and in September 1991, the Senate went along with the House and voted to uphold station funding.

This activity was the culmination of a process that had started in the fall of 1990. Due to a FY91 budget shortfall and Congressional direction to reduce outyear spending, a design assessment known as "restructuring" was started in October 1990. On March 21, 1991, NASA delivered the "restructuring" report to Congress outlining an extensive redesign of Space Station Freedom. This Handbook reflects that design and describes what each NASA Center and contractor is doing in support of the program.

Our international partners also had some personnel changes. Jean-Marie Luton was elected the European Space Agency Director General effective October 1, 1990. Canada formed the Canadian Space Agency (CSA) on December 4, 1990. The CSA President is Dr. Larkin Kerwin. On November 1, 1989, Mr. Masato Yamano became President of the National Space Development Agency of Japan.

On December 6, 1991, Professor Luciano Guerriero, President of the Italian Space Agency (ASI), signed a memorandum of understanding with the NASA Administrator to provide two Mini Pressurized Logistics Modules for the program.

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The Case for Space Station Freedom: A Statement of Purpose

Why a Space Station?

All seven space stations in history—one American, six Soviet—have been built and lofted to orbit for one basic purpose: to enable exploration. The space station NASA is building for the 1990s is first and foremost a means to that end.

Space Station Freedom embodies ideas first cast into the 20th century, on three different continents, by the founding fathers of modern rocketry: Oberth, Tsiolkovsky and Goddard. It fulfills the guiding principles written into the preamble of the National Aeronautics and Space Act of 1958, the law which created NASA and charged it to expand human knowledge, improve airplanes and spacecraft, and learn how to fly equipment, supplies and, most importantly, life from the planet Earth, in space. NASA's charter was to learn what technical and scientific benefits could be gained on the new ocean of space, to cooperate with other nations, and to marshal America's technical, industrial and scientific talents to explore the space frontier.

NASA's space station is, as President George Bush said, a "critical next step in all our space endeavors." Skimming along 250 miles above the cloudtops of Earth, Space Station Freedom is essential for advancing the human exploration of space. Continued progress in the human exploration of space requires the development of a permanently manned space station for multi-year studies of human adaptation, testing of life support systems and experience in building, maintaining and operating a large manned space system. Freedom also will serve as a permanent Earth-orbiting laboratory. It will allow humans the time and capability to routinely study, develop and employ the resources and potential of space. Aboard Freedom, scientists and engineers will do work and research in the microgravity environment of space for prolonged periods of time.

Freedom's mission is three-fold. First, it will provide a permanent outpost where we will learn to live and work productively in space. Freedom will be an orbiting research base with essential resources of volume, power, data handling, and communications to accommodate experiments for long-duration studies of human physiology and well-being in space, research that is required before the nation can embark on achievable, long-range human exploration goals. We need years of experience in space, not just days or weeks or even months. Second, Freedom will provide an advanced research laboratory to explore space and employ its resources for the benefit of humanity. Space Station Freedom will be a permanent, multi-purpose research laboratory and outpost in space unsurpassed in equipment and capabilities with the constant presence of a hands-on crew for learning how to use the unique microgravity environment of space, enabling the study of new materials, new medicines and new technologies. And finally, Freedom will provide the opportunity to learn to build, operate and maintain systems in space. Space Station Freedom will be an engineering testbed, located in low Earth orbit where we will perfect our ability to live and function, to allow development of the systems, the logistics, the knowledge and the talents required for the full-scale utilization and exploration of space.

The Next Logical Step

Of all the challenges inherent in space flight, perhaps the most difficult is rising up out of our planet's gravity well. And one of the earliest precepts in NASA's philosophy of space operations was the realization that most of the risk and much of the cost associated with space flight is tied to climbing out of this well and reaching Earth orbit. That is why a space station has been seen—for decades—as a logical development in the enterprise of space travel. A space station will allow the U.S. and its international partners to end what the 1986 report of the National Commission on Space called "our visitor status in space." No longer limited to brief sorties, the U.S. will be able to capitalize on the expense and risk of leaving the Earth and maximize the four absolutely critical spacefaring resources: time in orbit, power, volume and crew.

The Waypoints of Exploration

During the Age of Discovery, explorers capitalized on past experience and built upon the voyages of those who went before them. In American history, the frontiers moved steadily westward as explorers crossed each of the natural barriers in turn, and the waypoints of exploration moved westward with them. On the space frontier, the first natural waypoint is low Earth orbit, the modern equivalent to the river junction, the oasis, the island or the railhead of old. Earth orbit is a natural center of activity for space travelers, a resting place before moving on across the deep ocean of space.

Earth orbit is the logical place to build a permanent outpost, to try new things, to learn about space after an arduous trip across the gravity barrier. Still within the sheltering arms of Earth's magnetic field, which offers protection from the harsh radiation of deep space, it is close to the home planet, a relatively easy vantage point from which to depart in the event of an emergency. There is no better location in all of the Solar System than low Earth orbit to perfect our ability to live and function in this new environment, to allow development of the systems, the logistics, the knowledge and the talents required for the full-scale utilization and exploration of space. An orbital station is the natural extension of America's spacefaring enterprise, a fertile and accessible waypoint along an outbound trail, a logical next step in our travels above the skies of Earth.

Why Now?

Space Station Freedom is a sound design, the product of years of planning and preparation. It builds upon the momentum and experience of 30 years of U.S. manned space flight experience. To stop now would be to lose that momentum, to steer U.S. manned space flight to a technological dead end just as the conditions are ripe for a fundamental next step in space travel.

That next step represents an investment in the future. The investment NASA is proposing is one which stretches well into the next century, and one which will only become more difficult to realize in practical terms, and more costly the longer we wait. Leadership abandoned is leadership lost, in other words, and that would be a high price to pay over the long-term for the short-term gain of less than one-tenth of one-percent of the U.S. government's annual budget.

The issue, however, goes even deeper than that. It goes to the heart of how a great nation chooses to invest in its own future, of the kind of legacy the present generation plans to leave for those who will follow. It goes to the heart of accepting a challenge and acknowledging risk versus gain.

If we are to achieve anything of lasting significance in space, we must be willing to experiment, to learn from our mistakes and our successes, and to move on to the next challenge. Space Station Freedom is about expanding the human presence in space. If we wish to achieve that goal, now or in the future, then we should proceed.

Richard H. Kohrs
Director, Space Station Freedom

Historical Perspective

The concept of the space station goes back at least to 1869 when Edward Everett Hale mentioned the "Brick Moon," a 200 ft. (60 m.) 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 foresaw space travel in the late 1800s. By the turn of the century, scholars such as Konstantin Tsiolkovsky were laying the foundations of space travel to orbital stations.

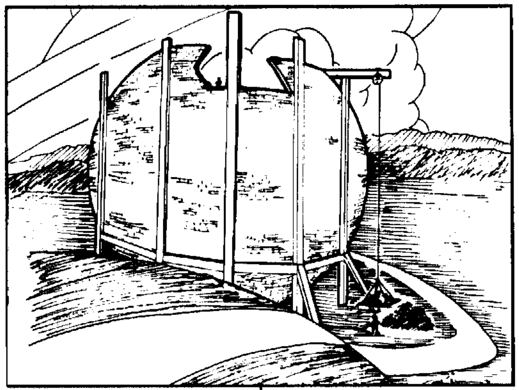
The modern space station concept dates back to 1923, when the Romanian-born Hermann Oberth published his serious theoretical treatise on the possibilities of large, liquid-fueled rockets. "Die Rakete zu den Planet-enraumen" ("The Rocket to Interplanetary Space") was the opening shot in a debate about 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 testbed 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 and over again—What would you want? What do you need? The answers flowed in, and NASA scientists 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 was all of these things, how much crew time should be devoted to each?

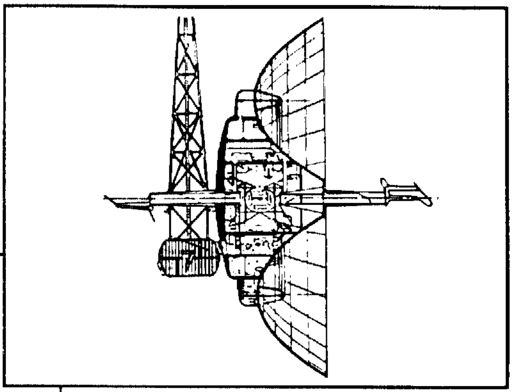
In the sixties, working quietly in the shadow of the gigantic Apollo/Saturn

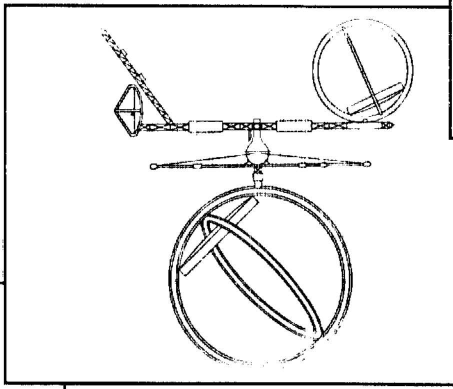
INTRODUCTION

The Early Concepts

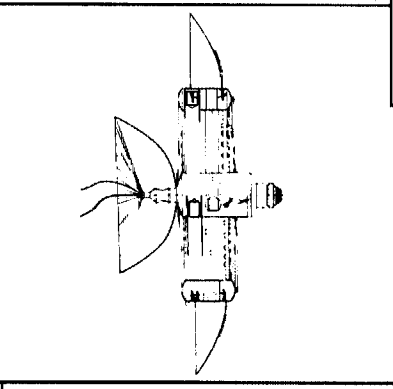
> *"The Earth is the cradle of the mind, but you cannot live in the cradle forever."*
>
> *–Konstantin Tsiolkovsky*

1940s
Harry E. Russ
and
Ralph A. Smith

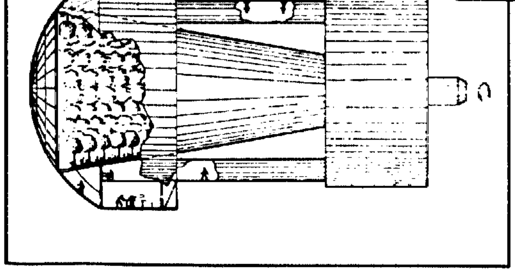




1930s
Hermann Oberth

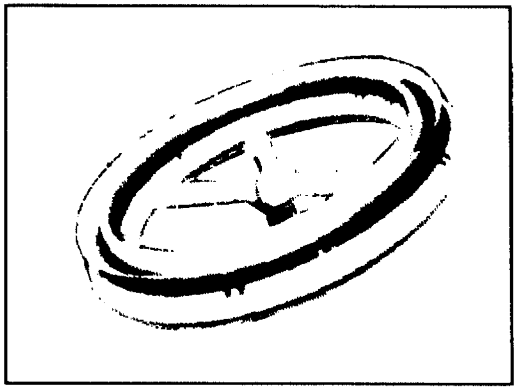


1920s
Hermann Noordung

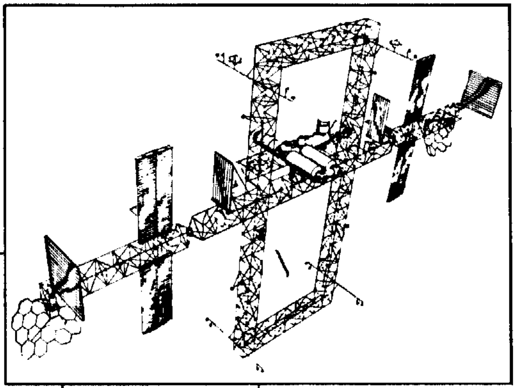


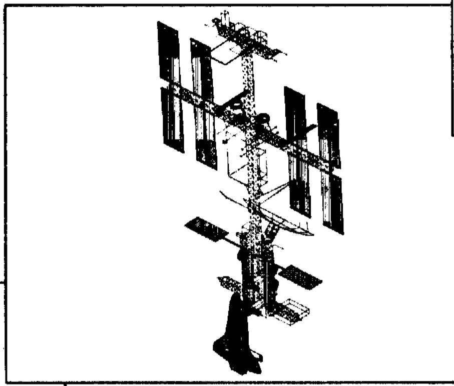
1900s
Konstantin Tsiolkovsky

1950s
Wernher von Braun
and
Chesley Bonestell

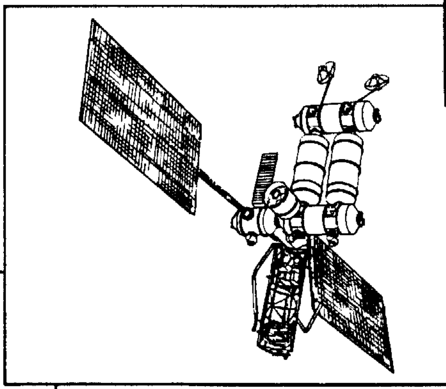


Late 1980s
Dual Keel

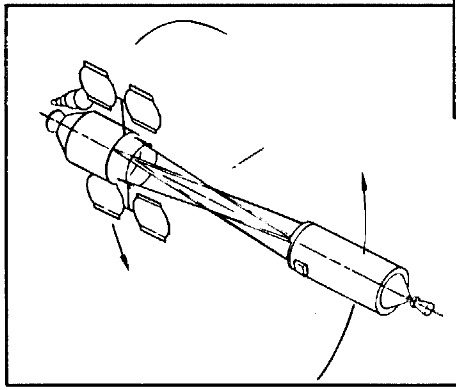




Early 1980s
Power Tower



1970s
Core Station



1960s
Spin/No Spin

> *"It is difficult to say what is impossible; for the dream of yesterday, is the hope of today and the reality of tomorrow."*
>
> *–Robert H. Goddard*

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 reusable spacecraft would shuttle between Earth and the space station. Hence, the name "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.

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 produced 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 United States reduced the number of its laboratory modules to one when the Europeans and Japanese decided to provide one each.

The definition and preliminary design phase ended in January 1987, followed by cost analysis and a review of technical design issues. The Development Contracts were announced in December 1987. These efforts resulted in the Baseline Configuration, which was the basis for the April 1989 Media Handbook. Since then, the program has undergone several reviews which have resulted in the configuration discussed in this document. As part of its appropriation for Fiscal Year 1991, the Congress directed NASA to redesign the space station and to reduce development funding for the project by about $6 billion for years 1991–1996. NASA completed the "restructuring" of the space station program in the spring of 1991 and directed development contractors to incorporate design changes to make the station cheaper, smaller, easier to assemble and require fewer Space Shuttle missions to assemble.

In November of 1991, the Program conducted an integrated Preliminary Design Review (PDR) of the "restructure" man-tended configuration. A PDR of the permanently manned configuration is planned for 1992. Critical Design Reviews (CDR) of space station components and systems also are scheduled to start in 1992, culminating with an integrated CDR of the man-tended phase in early 1993. Completion of the CDR will mark a major milestone in the Freedom program as it signals the end of the design phase and the start of the major manufacturing phase.

In addition, the Committee on the Future of the U.S. Space Program made several recommendations pertaining to the Space Station Program.

Now that these difficult reviews and changes have been completed, the program can continue on schedule to a First Element Launch in early 1996.

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. to manned spaceflight 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."

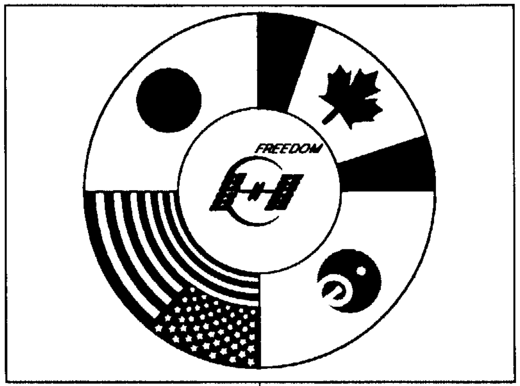
Japan, Canada and nine of the 13 nations involved with the European Space Agency (ESA) soon expressed interest in order to augment their own unmanned space efforts. Most of these nations had already discussed utilization requirements of a prospective space station as early as 1982, so the announcement 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 each had signed a 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. Signatories of the agreements were the U.S., Japan, Canada and nine of the 13 ESA member countries (Belgium, Denmark, France, Italy, the Federal Republic of Germany, the Netherlands, Norway, Spain and the United Kingdom).

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.

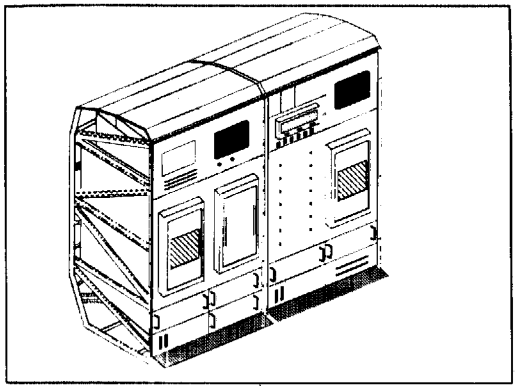


Building upon the Remote Manipulator System which has served the Space Shuttle for more than a decade, Canada chose to develop a Mobile Servicing System for Space Station Freedom.

Program management for Canada's space station activities is the responsibility of the Canadian Space Agency (CSA). The CSA was created in December 1990 to centralize and better coordinate Canadian space efforts. It is under the auspices of the ministry of industry, science and technology.

Building on their experience with Spacelab aboard the Shuttle, ESA plans to build an attached pressurized module 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 Hague.

Japan's contribution centers on 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 sci-



ences, and technology development.

Based upon an $8 billion international contribution to the Space Station Freedom program, the partners will share in the utilization and in the operations costs according to the following 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 seven 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 being prepared 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 science research, 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 are to:

- establish a permanently manned multipurpose facility in low Earth orbit (LEO) in the 1990s;
- enhance and evolve mankind's ability to live and work safely in space;
- stimulate technologies of national importance by using them to provide Space Station Freedom capabilities;
- provide long-term, cost-effective operation and utilization of continually improving facilities for scientific, technological, commercial and operational activities enabled or enhanced by the presence of man in space;
- promote substantial international cooperation in space;
- create and expand opportunities for private-sector activity in space;
- provide for the evolution of the Space Station Freedom to meet future needs and challenges;
- foster public knowledge and understanding of the role of habitable space system capabilities in the evolution of human experience outside the Earth's atmosphere.

When Space Station Freedom is completely assembled, a broad spectrum of research in all the disciplines of life sciences, materials sciences, astrophysics, Earth science, and planetary sciences will be conducted. This will be accomplished with both manned and unmanned elements. The manned facility in a low Earth orbit (180-240 n.m.) 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 research and development 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.

In addition, payloads can be attached to the transverse boom, external to the pressurized modules. Utility ports provide power and data resources.

The ESA will provide the Columbus Free-Flying Laboratory. This unmanned pressurized laboratory will provide a long-term research environment, of up to six months, free of manmade disturbances.

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

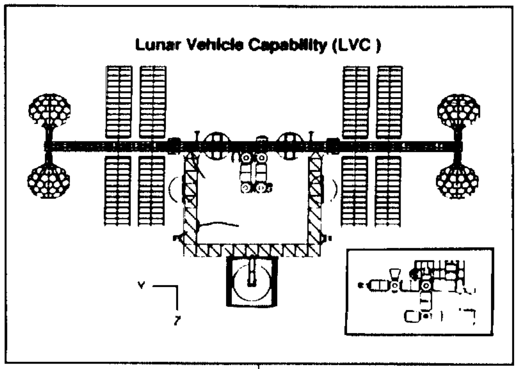
Evolution planning for the long-term use of Space Station Freedom has been part of the program since its beginning. At the very start, NASA's Administrator called for the design of a "station we can buy by the yard," suggesting add-ons, developments and enhancements. The Space Station Task Force included 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 the 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 study "alternative evolutionary paths."

On July 20, 1989, the twentieth anniversary of the Apollo 11 lunar landing, President Bush charted a new course for the human exploration of space when he challenged America to "go back to the moon, back to the future. And this time to stay. And...a journey into tomorrow...a manned mission to Mars." The new "Space Exploration Initiative" (SEI) included the evolutionary growth of the space station to support lunar and Mars flight. The Advanced Studies Program managed by NASA Headquarters and implemented by Langley Research Center continues to examine requirements, concepts, and options for space station evolution.

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 enable upgrade of hardware at some future time, analogous to the space on a car's dash that allows you to add a radio at a later time.

Future Configuration

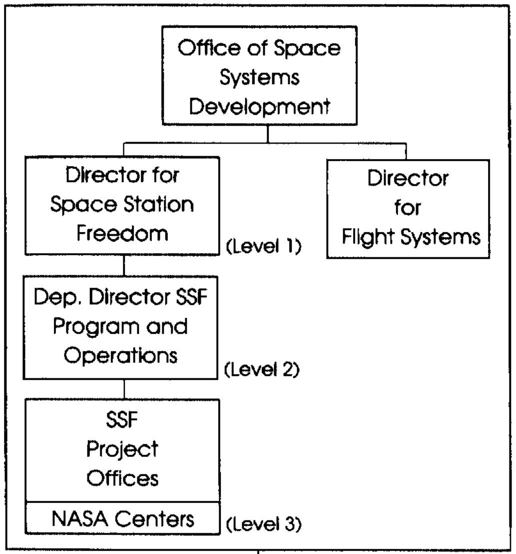
Freedom's development beyond Permanently Manned Capability (PMC), achieved by the year 2000, will be characterized by upgrades in three broad areas: increased resources, new functional capabilities and incorporation of new technologies. Increased resources will reduce time-sharing and increase schedule flexibility, permitting enhanced scientific and technical utilization of Freedom. Included among the planned additions for example, is a fourth photovoltaic array module to increase Freedom's power level to 75 kilowatts (kW). New functional capabilities will improve the station's operational characteristics. For example, improved Communications and Tracking (C&T) capabilities can support communications with next-generation satellites. Upgrading Freedom's systems with advanced technologies will result in reduced operations costs, increased productivity and increased crew safety. For example, crew time availability will be increased because advanced automation and robotics (A&R) can perform tasks that otherwise would be conducted by astronauts.



Lunar and Mars Mission Support

As a critical research laboratory in support of the SEI, Freedom will provide facilities for life sciences research that will enable mankind to live permanently in Earth orbit, go back to the moon and on to Mars. It is essential that scientists better understand how extended exposure to the near zero-gravity environment affects people before we embark on long-duration space trips. The development of techniques to counter the effects of near weightlessness is a key goal of life sciences research on Freedom. The opportunity to examine microorganisms, plants and animals over several generations in a low-gravity space environment is unprecedented. Similarly, human-factors research will examine the physiological and psychological conditions needed to maintain a productive crew over a long period of time. The full life sciences research program will also include studies in operational medicine, biomedical research, space biology, exobiology and biospheric research. The program retains the flexibility to evolve the configuration to serve as a "node" or staging base for manned lunar missions.

Space Station Freedom will serve as a testbed for technologies needed for SEI applications, including closed-loop life support systems and automated fault detection and repair systems.



Management

The Space Station Freedom program uses a three-tiered management structure. The three levels are as follows: Level I, the Associate Administrator for the Office of Space Systems Development at NASA Headquarters in Washington, D.C.; Level II, the Deputy Director, Program & Operations in nearby Reston, Virginia; and Level III, the NASA field centers' Space Station Freedom Project Offices. This structure is shown above and in more detail on the next page.

The Director of the Space Station Freedom Program is responsible for the overall management and strategic planning of the program. Principal management responsibilities include policy direction, budget formulation, engineering operations, external affairs and Space Station Freedom evolution. The Director 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 Director.

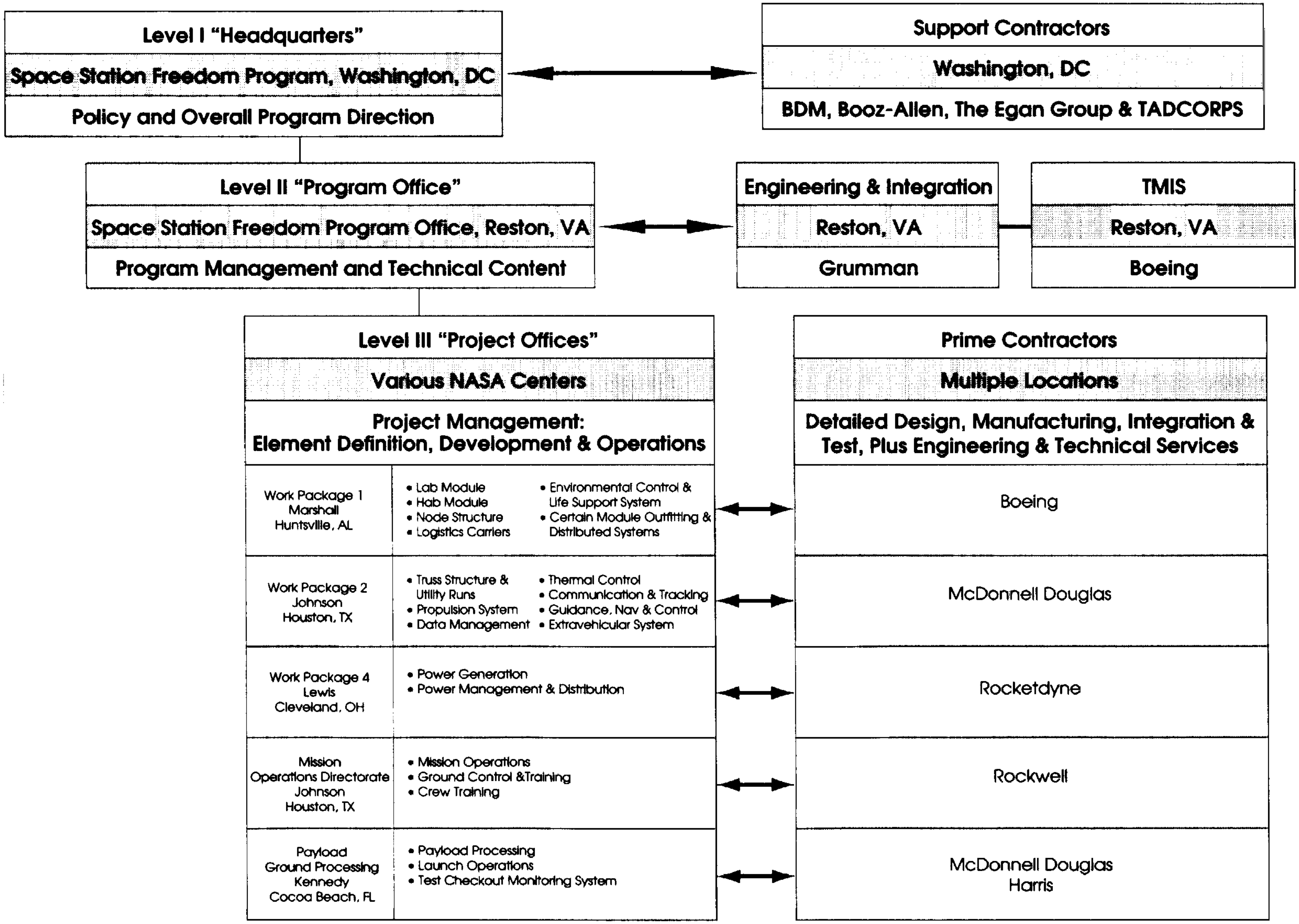
There are four divisions in Level I: Policy and Plans, Engineering, Operations and Utilization and Resources. Level I is responsible for defining and controlling the program requirements, schedule, milestones and resources.

Level II, located in a separate facility in Reston, 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 Deputy Director, Programs and Operations, who is responsible for the day-to-day management.

Level II offices include: International Programs, Management Integration, Business Management, Information Systems Integration, Systems Engineering and Integration, and Utilization and Operations. In addition, there are two supporting offices from other NASA organizations: the accounting office and procurement office. System and element integration functions are the responsibility of the Level II Integration Office. Support is provided for element integration by a field office located at the Marshall Space Flight Center in Huntsville, Alabama.

Level III consists of the three Work Package Centers the Kennedy Space Center and the Mission Operations Directorate at the Johnson Space Center. The project managers of these offices report to the Director of the Space Station Program. The Johnson Space Center Mission Operations Directorate is responsible for the training of the Space Station Freedom crew and ground controllers, and for the around-the-clock operational support of the space station. The Kennedy Space Center is responsible for the processing of payloads for the flight to Freedom onboard the Shuttle. This includes the required assembly, servicing integration and testing of payload hardware and software, and the requisite operations associated with a Shuttle launch. Contractors are responsible for Design, Development, Testing and Evaluation (DDT&E); operation of hardware and software systems; and element, evolution and engineering support.

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



Level I “Headquarters”
Space Station Freedom Program, Washington, DC
Policy and Overall Program Direction

Support Contractors
Washington, DC
BDM, Booz-Allen, The Egan Group & TADCORPS

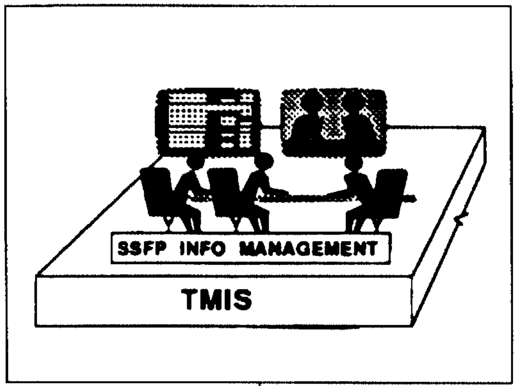
Level II “Program Office”
Space Station Freedom Program Office, Reston, VA
Program Management and Technical Content

Engineering & Integration
Reston, VA
Grumman

TMIS
Reston, VA
Boeing

Level III “Project Offices” **Various NASA Centers** **Project Management: Element Definition, Development & Operations**		**Prime Contractors** **Multiple Locations** **Detailed Design, Manufacturing, Integration & Test, Plus Engineering & Technical Services**
Work Package 1 Marshall Huntsville, AL	• Lab Module • Hab Module • Node Structure • Logistics Carriers • Environmental Control & Life Support System • Certain Module Outfitting & Distributed Systems	Boeing
Work Package 2 Johnson Houston, TX	• Truss Structure & Utility Runs • Propulsion System • Data Management • Thermal Control • Communication & Tracking • Guidance, Nav & Control • Extravehicular System	McDonnell Douglas
Work Package 4 Lewis Cleveland, OH	• Power Generation • Power Management & Distribution	Rocketdyne
Mission Operations Directorate Johnson Houston, TX	• Mission Operations • Ground Control &Training • Crew Training	Rockwell
Payload Ground Processing Kennedy Cocoa Beach, FL	• Payload Processing • Launch Operations • Test Checkout Monitoring System	McDonnell Douglas Harris

NASA Space Station Freedom Program Organization: Space Station Freedom program uses a three-tiered management structure.



Management Support and Information Systems Contracts

Space Station Support Contractors

TADCORPS has been supporting the program continuously since the original Space Station Task Force in 1983. TADCORPS provides a broad range of support services to all of the Space Station Freedom divisions and staff including official Space Station Freedom Level I documentation, all formal presentations and briefings to Congress, other government agencies, institutions, professional associations and public organizations, support for conferences, workshops and symposia, computer graphics and photographic services, technical writing and editing and technical project support.

Booz-Allen & Hamilton, Inc. has supported the Director, Space Station Freedom since 1986 with technical and policy analyses, engineering assessments and trade studies, program alternatives and operation and economic analyses.

BDM International supports the Director, Space Station Engineering with technical services concerning growth of the baseline station into its follow-on evolutionary phases.

The Egan Group provides general policy support for all issues related to commercial utilization of Space Station Freedom.

Space Station Freedom Engineering and Integration Contractor

In July of 1987, The Grumman Corporation won the competition to be the Program Support Contractor for the Space Station Freedom Program Office (Level II). Today, Grumman's role as the Space Station Engineering and Integration Contractor for NASA is to provide program-level systems engineering and integration, program management and technical support for Space Station Freedom across the NASA Centers, work package contractors and international partners. In addition to systems engineering and integration, Grumman is involved in the space station's program control, information systems, operations and utilization, safety, program requirements and assessment, quality assurance, and configuration management.

Headquarters for Grumman's Space Station Program Support division is in Reston, Virginia, near Washington, DC. Additional Grumman Space Station offices are at NASA Centers involved in the program. This contract currently employs nearly 900 people and will 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 System (TMIS), the Space Station Operational Data System (ODS) 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 Level II Office and Boeing Computer Services implemented TMIS in 1988. TMIS is a system which acquires, organizes, controls and uses vast amounts of technical and management information 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 Level II 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 information among the Program Office, Work Package Centers, program support contractors, international partners and development contractors throughout the life of the program. This is designed to accommodate the dynamic changes in the program. The Boeing contract for TMIS currently employs approximately 280 people including subcontractors and is valued at $330 million.

Space Station Operational Data System (ODS)

The ODS 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; it could be a piece of onboard equipment (such as a space station subsystem); or even an onboard crewmember. 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. Most of these dataflows will also occur, simultaneously, from space to ground.

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 ODS and using its services, they can be considered to be ODS constituent elements.

There is no single ODS contractor. Most of the work for the manned base is under the Work Package II contractor, McDonnell Douglas, and their subcontractors for the onboard Data Management System (DMS), Honeywell and IBM. The ground portion of ODS is provided in part by IBM, Loral, Grumman and others.

Telescience

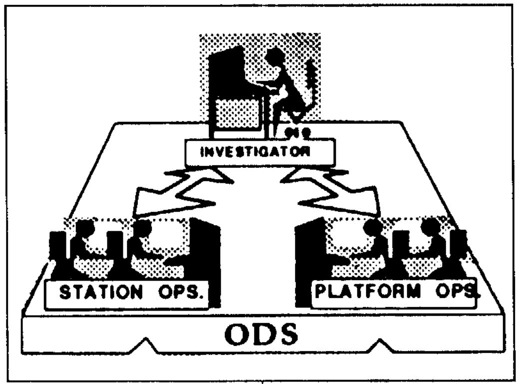
The combination of teleoperations and teleanalysis yields telescience—a mode of investigation in which telecommunications resources are used for the most effective division of functions among ground facilities, and between ground and space. Realization of all aspects of the telescience concept will require the cooperation and integration of a multitude of resources, including other information systems. However, the foundation for these broader concepts, and the vital connection between investigator and payload, are provided by ODS.

Software Support Environment (SSE)

In July of 1987, Lockheed Missiles & 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.

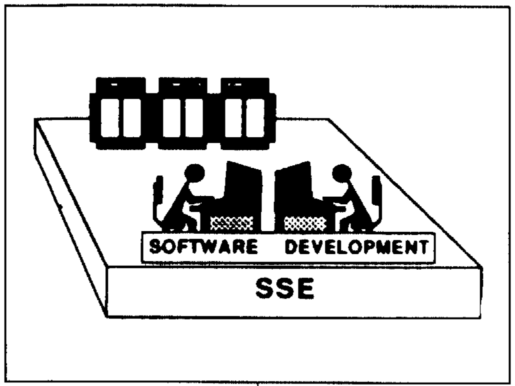
The support environment consists of several components: software engineering tools; hardware tools; operating system interfaces; software development rules and procedures; and, software standards. The common computer language specified for operational space station software is Ada.

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, an 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.

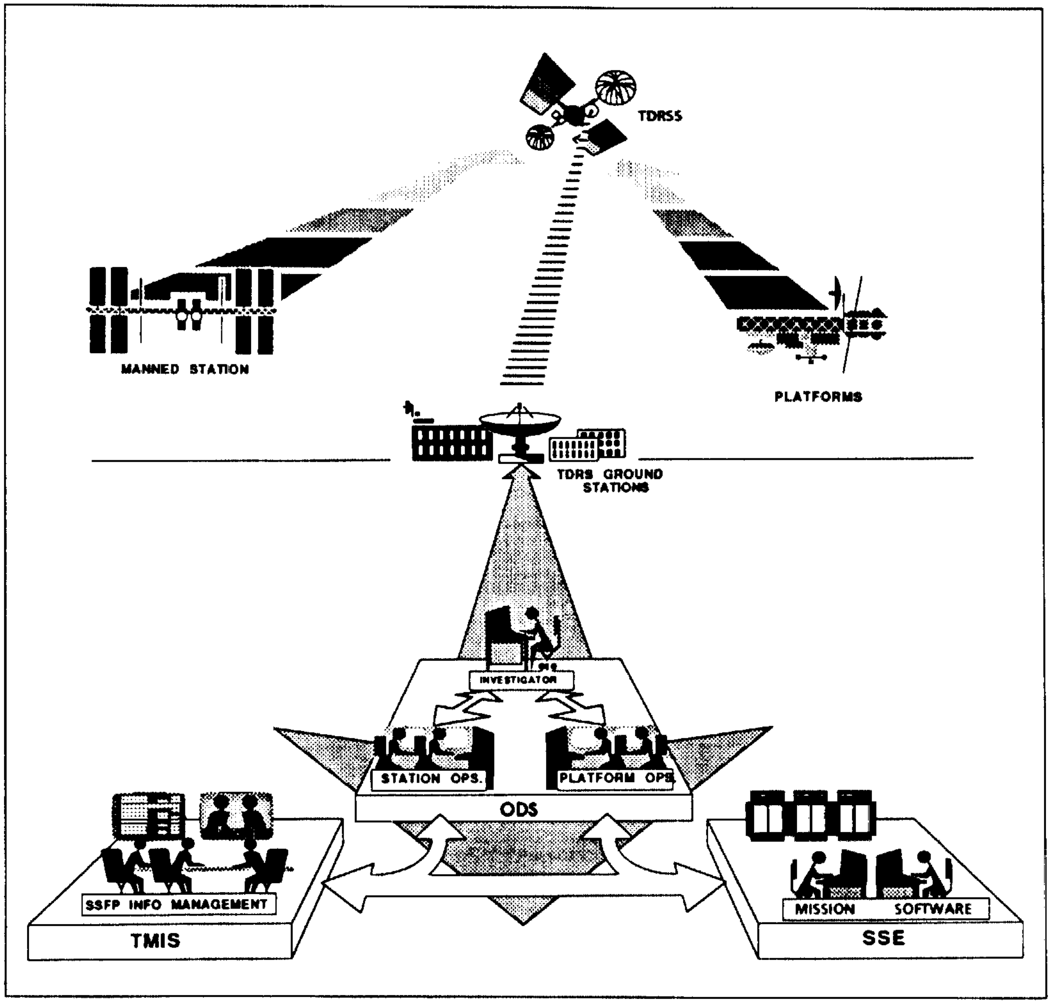
Lockheed currently has about 200 people including subcontractors working on SSE. The contract is valued at $242 million over six years with options for three more years.

Integration of Information Systems

TMIS, ODS and SSE operate in harmony. Software developed and tested using SSE can be transferred to the space station elements via ODS both before launch and during operations. ODS 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 onboard within ODS 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 TMIS for management review; schedules, plans and high-level design data will flow from TMIS to SSE as functions are allocated for software development.

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



Work Packages

In 1987, NASA let competitive procurements for the major space station contractor work called "Work Packages." Four NASA Centers were selected to manage the contractor work.

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 (MSFC) in Huntsville, Alabama, and its prime contractor, Boeing Defense & Space Group will design and manufacture 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. In addition, MSFC is responsible for operations capability development associated with Freedom Station payload operations and planning, laboratory-support and ground-support equipment.

Work Package 2

The Johnson Space Center (JSC) in Houston, Texas, and its prime contractor, McDonnell Douglas Space Systems 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 Extra-Vehicular Activity (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; the airlocks; crew health care systems (CHeCS); and user accommodations. It is also responsible for the technical direction of the Work Package 1 contractor for the design and development of all manned systems.

Mission Operations Project Office (MOPO)

The MOPO, also located at JSC, is responsible for:

- Operational capability development for the Space Station Control Center (SSCC) and associated operations support systems,
- Operational capability development for the Space Station Training Facility (SSTF) and associated training support systems,
- Flight crew and ground controller training,
- Integrated planning of real-time operations and utilization activities,
- Integration of SSF and Shuttle real-time operations,
- Management of space systems operations, and
- Overall operational command and control.

Work Package 3

The Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, and its prime contractor, GE Astro-Space, originally intended to manufacture: the servicing facility, the flight telerobotic servicer, the accommodations for attached payloads, and the U.S. unmanned free-flyer platforms. However, in 1991, these elements were either terminated or transferred to other NASA organizations and this work package was dissolved.

Work Package 4

The Lewis Research Center (LeRC) in Cleveland, Ohio, and its prime contractor, the Rocketdyne Division of Rockwell International, will design and manufacture the Electrical Power Systems.

Kennedy Space Center (KSC)

Although not a Work Package Center, KSC is responsible for:

- Launch sites,
- Launch site common ground support equipment,
- Launch site facilities to support prelaunch/post-landing processing, payload processing, and logistics,
- Management and operations of integrated logistics systems, and
- Space Station Processing Facility (SSPF).

These areas of responsibility are more thoroughly discussed in the KSC section.

The above Work Package Centers will be supported by other NASA Centers in fulfilling their responsibilities.

Assured Crew Return Vehicle (ACRV)

The ACRV is a separate but related support program to Space Station Freedom. The program is managed by the ACRV Project Office in the New Initiatives Office at JSC.

History of Assured Crew Return

Since the beginning of the manned space program, NASA has been dedicated to an Assured Crew Return Capability (ACRC). During the Mercury and Gemini programs, the first orbit's trajectory assured the return of the capsule into the atmosphere. The early Apollo missions to the moon were flown in a "free return" trajectory, where the capsule could circle the moon and return home automatically, and the Lunar Module proved its value as an emergency vehicle on the Apollo 13 mission. The Skylab missions had an Apollo capsule docked at the station whenever crewmembers were aboard (a method the former Soviet Union—now Commonwealth of Independent States—uses at its MIR space station.) The Space Shuttle assures crew return by providing a level of redundancy for critical systems that is equal to or greater than that designed for any other space vehicle.

ACRV and Space Station Freedom

The commitment of NASA to ACRV continues today in the era of Space Station Freedom. Permanent low-Earth orbit facilities such as Space Station Freedom and the Soviet space station MIR have special needs to assure crew return because, unlike other manned vehicles, permanent orbiting facilities cannot inherently return their crew to Earth. Just as MIR and Skylab had dedicated space-based return vehicles standing by, NASA is currently developing an ACRV which would always be docked at the station to assure return for the entire crew. While the space station, in conjunction with the Shuttle, is capable of handling many emergency situations on its own, NASA has found at least three situations where an ACRV is essential:

- Medical Emergency: If one of the crew suffers a severe injury or illness which exceeds the capability of the space station's medical facilities, and the Space Shuttle cannot arrive in time to transport the crewmember;
- Station Catastrophe: If, while the Shuttle is away from the station, some catastrophic event or accident occurs which requires the crew to evacuate immediately;
- Shuttle Problems: If a problem occurs in the Space Shuttle program which requires the Shuttle to suspend flight for a period of time, meaning it is not available to resupply or transport the station crew.

ACRV System Concept

The ACRV, essentially a "lifeboat" for space station, will be a simply designed, reliable, on-orbit vehicle that will always be available for immediate use. The vehicle will be slightly larger than the Apollo capsule, weigh about 10,000 pounds, and will fit in the Shuttle payload bay, so that either the Shuttle or an expendable launch vehicle will be capable of delivering it to the station. The ACRV will be capable of life support, de-orbit, reentry, and landing.

The other elements of ACRV will work under the concept of "embedded" operations, meaning that the ACRV will use existing ground support facilities and existing international search and rescue (SAR) forces. Under this concept, the required new ground equipment to support the ACRV will be kept to a minimum, and the use of proven existing hardware and software will minimize the cost and maximize the reliability of ACRV operations.

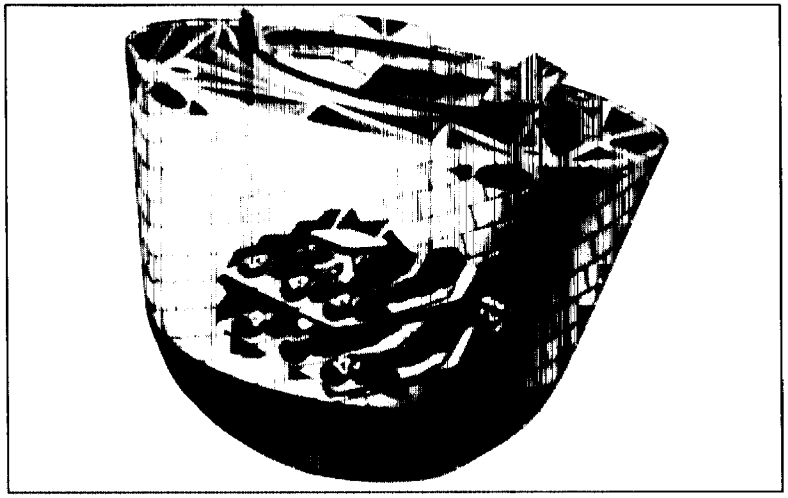
Preliminary NASA and independent contractor studies show that a properly designed and integrated ACRV system can provide assured crew return capability for all reasonable scenarios, at reasonable cost, using today's technology.

ACRV Schedule

The ACRV is in the system definition phase (also known as Phase B) which will be completed in FY93. Phase B involves developing a preliminary design for an ACRV system, as well as detailed costing and scheduling. Upon completion of Phase B, NASA is expecting to begin full-scale development in FY94. The development phase will provide the ACRV in time to support the Permanently Manned Capability in 1999.

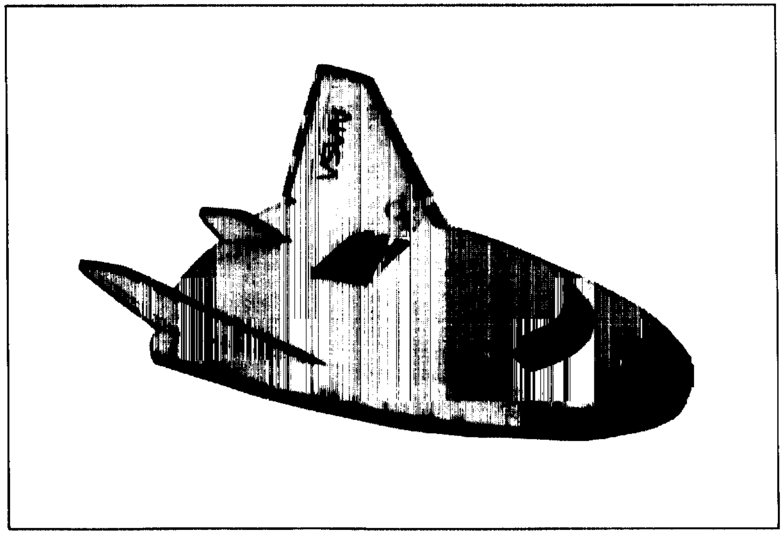
Candidate ACRV Concepts

Scram Vehicle

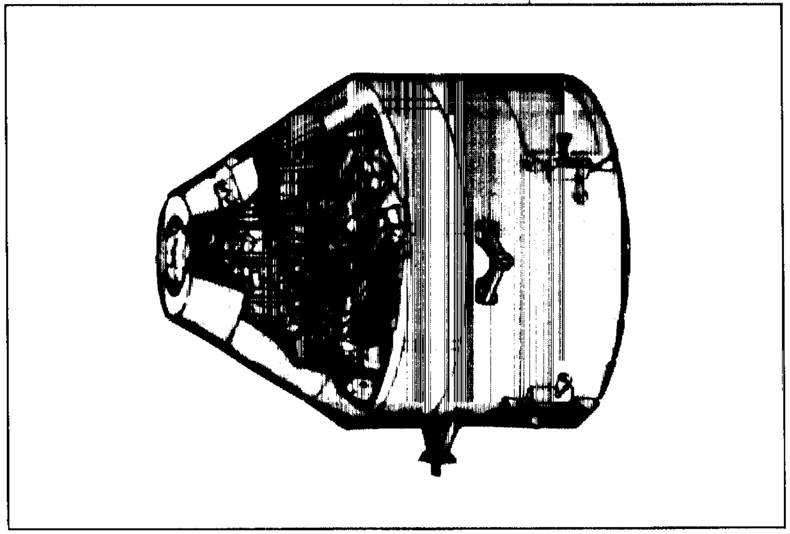


Discoverer Shaped Vehicle

Mid-L/D Vehicle



Apollo-Derived Vehicle



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 1960s. The 1972 decision to develop the Shuttle first delayed the Space Station Program 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 benefited from the permanent presence of humans in space. 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 which 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 reaffirmed 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 and RCA
- LeRC (Work Package 4): Rocketdyne, TRW

The results of the definition studies were synthesized and integrated into 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 marks the point where 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 was the establishment of three levels of management: 1) the Headquarters Office of Space Station; 2) the 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 effect, this was a shift from the former "Lead Center" concept to a Level II program office located at Headquarters.

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.

Meanwhile, the Operations Task Force was organized to focus operations planning by conducting a systematic assessment of station operations. This major effort produced a 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.

In September 1987 the Space Station Science Operations Study Team examined science opportunities, operations, planning and management and concluded with a set of effective recommendations that were considered for Phase C work.

That year, 1987, was also a significant procurement period for the program. In addition to the four Work Packages, three separate, competitive procurements were conducted to support detailed design and development. The contracts awarded in 1987 are listed on page 20.

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.

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.

Due to adjustments in funding levels, analysis of program costs and adjustments

Contracts Awarded in 1987

May 1987
  Technical & Management Information System (TMIS): Boeing

June 1987
  Software Support Environment (SSE): Lockheed

July 1987
  Program Support Contract (PSC): Grumman

December 1987
  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)

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.

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 made and money was appropriated. This allowed prime contractors to determine when they could get their subcontractors onboard and begin staffing up for their work assignments.

During the last half of 1988, the negotiations of international agreements regarding Phase C/D/E were completed and the agreements were signed on September 29, 1988, the same day as the STS-26 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. 1988 was also 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 concluded in the fall and winter of 1988 included fulfillment of the required staffing, facility construction planning, development of an associate contractor relationship that would simplify the program integration process and release of 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.

During 1989, the program was faced with severe budget cuts. A Configuration Budget Review (CBR) Team was formed in July to develop preliminary options for presentation to space station management and the international partners. Three separate Level I/II Control Boards were convened to analyze the options and recommendations. These three Control Boards were held in August, September and October 1989. The results of this "rephasing" were briefed to Congress and were implemented by changes to the Program Requirements Document. These results maintained the first element launch in March 1995, but delayed the assembly/complete milestone 18 months, while making some significant system and subsystem changes. The CBR kept the station element design essentially the same.

In January 1990, the External Maintenance Task Team (EMTT) was formed to address concerns regarding the amount of extravehicular activity (EVA) required to maintain the station. The EMTT was co-chaired by Dr. William F. Fisher, astronaut, and Mr. Charles Price, Chief of the Robotics Systems Development Branch at NASA's Johnson Space Center. They were given the authority to review all aspects of Space Station Freedom external maintenance and repair. They conducted a seven-month investigation, concluding that about 3,200 hours of EVA, annually, would be needed to maintain the station, but made several recommendations which, if implemented, could reduce EVA to 500 hours annually.

To address the findings and recommendations of the EMTT, a complementary program-wide team was formed in June 1990 called the External Maintenance Solutions Team (EMST). The EMST was chaired by Dr. William E. Simon of JSC and was chartered to develop solutions to the problems regarding Space Station Freedom external maintenance identified by the EMTT. The EMST's two-month study concluded that about 3,500 hours of EVA would be required annually, but this could be reduced to about 485 hours by implementing their solutions.

In June 1990, the Level II Resources "Turbo Team" was formed to reduce the weight of the station and the housekeeping power requirements.

Throughout 1990, Preliminary Design Reviews (PDRs) were held. In all, over 80 separate design reviews were conducted during the year. The preliminary design of nearly every major component, subsystem and system was reviewed. This culminated with the Integrated System PDR (ISPDR) in November–December of 1990. This resulted in a baseline station design which was accepted by all program participants.

A 1991 fiscal year budget shortfall of more than $550 million, along with Congressional direction to significantly reduce out-year spending, prompted NASA to initiate an assessment of the Space Station Freedom Program. This effort, known as restructuring, was initiated in October 1990 and culminated with a report to Congress in March 1991.

The Advisory Committee on the Future of the U.S. Space Program (the Augustine Committee) made several recommendations pertaining the Space Station Freedom in its December 1990 Report.

As a result of these reviews and recommendations, Space Station Freedom was extensively redesigned. The new design is cheaper, smaller, easier to assemble in orbit and will require fewer Shuttle flights to build.

The U.S. Laboratory and Habitation Modules are 40 percent shorter and can be outfitted and verified on the ground. The truss is now pre-integrated and can be tested with all subsystems before launch. This significantly reduces EVA time needed to build and maintain the station.

During November 1991, the Man-tended Configuration Preliminary Design Review was conducted. This review focused on the major programmatic interfaces between the three different work packages, the International Partners and the station's hardware and software elements. This major milestone confirmed the validity and maturity of the design and was a complete program success.

Phase D

Development (Manufacturing) after Critical Design Review (1993)

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 usable 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 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, Alabama; the truss assembly in Huntington Beach, California; and the power supply in Canoga Park, California.

The Laboratory Module, for example, comprises several subsystems. The structure includes the pressure shell assembly, hatches and rack support hardware. There are racks that 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. Unlike other space programs where the total spacecraft is assembled on the ground, 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 at a similar facility at MSFC. The astronauts will be working under water with structural mockups of the flight hardware that will simulate their spatial mass and inertia characteristics to gain experience in handling these elements prior to on-orbit actual assembly.

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

The program development has distinct phases. The initial phase calls for the first element launch to occur in the first quarter of 1996. Man-tended capability (MTC) will be met in the second quarter of 1997. The MTC phase culminates with the permanently manned capability (PMC) of the station with at least a 4-person crew in 2000. Seventeen Shuttle flights with four Advanced Solid Rocket Motors (ASRM) flights will be needed to complete the initial phase. On the eighteenth flight, the centrifuge will be added. An Assured Crew Return Vehicle (ACRV), capable of returning space station crew members to Earth in an emergency, will be in place prior to permanent staffing of the station. During the initial phase substantial accommodations will be available to microgravity materials and life sciences researchers.

The Follow-on Phase will result in further enhancements consistent with national policy.

Phase E

Operations (Overlaps Phase D) from First Element Launch 1996 to End of Life

Six Shuttle flights will be needed for station assembly to achieve MTC. Following MTC, four Shuttle flights per year are scheduled for station assembly and maintenance. There also will be three utilization flights per year during MTC operations. During these utilization flights, the Shuttle will dock at the station for 13 days or more. A crew of up to seven will be onboard the Shuttle. Four of the crew will devote their time to support space station user activities. During this period experiments requiring human intervention will be conducted. Experiments that require quiescent operation for an extended period can be left onboard the station to operate while the station is unattended. The crew will have been trained in the handling of the experiments and their results.

Following PMC the station will be permanently staffed by at least a four person crew, two of whom will be dedicated to supporting space station user activities.

Planning for the space station operations and utilization is designed to maximize the use of onboard 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.

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 international 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.

Payload integration also will 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 at least 30 years, maintenance and servicing will be performed routinely. Station design provides for Orbital Replacement Units (ORUs), which a crewmember can remove and replace inside the pressurized volume, or by robotics or EVA for externally mounted payloads. Critical replacement units will be stored onboard, and others will be on the ground ready for transport in logistics elements as needed.

Program Milestone	Calendar Year													
	CY87	CY88	CY89	CY90	CY91	CY92	CY93	CY94	CY95	CY96	CY97	CY98	CY99	CY00
Phase C/D Contract Start Date (CSD)	● Dec 87													
Program Requirements Review (PRR) Completed		● July 88												
International Agreement Signed		● Sept 88												
Preliminary Design Review (PDR)				● Dec. 90										
Man-Tended Capability (MTC) Phase PDR					● Oct. 91									
MTC Critical Design Review (MTC-CDR)							○ 2nd Qtr 93							
MTC Design Certification Review (MTC-DCR)									○ 3rd Qtr 95					
Permanently Manned Capability Critical Design Review (PMC-CDR)									○ 4th Qtr 95					
First Element Launch (FEL)										○ 1st Qtr 96				
MTC											○ 2nd Qtr 97			
Japanese Experiment Module (JEM) Launch												○ 2nd Qtr 98		
ESA Attached Pressurized Module (APM) Launch												○ 3rd Qtr 98		
PMC														○ 2000

○ Planned Program Milestone ● Completed Program Milestone

Key program milestones for Phase C/D and E.

Assembly

Space Station Freedom weighs over a half million pounds and will require multiple launches for its assembly in orbit. Based upon the Shuttle's performance and payload bay physical characteristics, the current planning calls for 17 Shuttle flights including four ASRM flights to get all of the elements, systems and support equipment to Earth orbit. On the eighteenth flight, the centrifuge will be added. This assembly process will take about four years. The sequence in which these flights occur and the 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.

A brief description of Space Station Freedom's major assembly milestones is presented below. There are three major milestones which are planned to be accomplished at the completion of the first, sixth and seventeenth Shuttle flights.

- The First Element Launch (FEL)
- Man-Tended Capability (MTC)
- Permanently Manned Capability (PMC)

While the station is being assembled, there will be three flights per year to support user activities. These flights will begin following MTC.

First Element Launch (FEL)

The first station cargo, called Mission Build (MB-1) carried by the Shuttle will consist of a set of integrated components to provide a "cornerstone" on which to assemble the station. This cornerstone will be the starboard side of the station and includes a solar power module, an unpressurized berthing mechanism, the Mobile Transporter, two pre-integrated truss (PIT) segments, an alpha rotary joint assembly, and starboard integrated equipment assembly (IEA). These pre-integrated truss segments will be built and checked out on Earth. They will then be connected, on-orbit, by astronauts and the Shuttle's Remote Manipulator System (RMS). The Space Shuttle will rendezvous and berth with this cornerstone assembly on subsequent assembly flights.

Second Assembly Flight (MB-2)

The second assembly flight will deliver the third PIT segment and two propulsion modules. The electrical power system (EPS) will be activated, attitude control and reboost capability will become operational, and the S-band portion of the communications and tracking (C&T) system will be activated.

Third Assembly Flight (MB-3)

The third assembly flight will transport another PIT segment with a Thermal Control System (TCS) radiator, UHF and Ku-Band portions of the C&T system and the Canadian-provided Space Station Remote Manipulator System (SSRMS).

Fourth Assembly Flight (MB-4)

The fourth assembly flight will deliver another PIT segment, crew and equipment transfer aids (CETAs) and additional equipment.

Fifth Assembly Flight (MB-5)

The fifth assembly flight will deliver the port node and racks, a pressurized docking adapter and the cupola including a workstation. On this flight a pressurized berthing location will be established for future use; the central TCS will be activated; and the station will be capable of command and control activities.

Man-Tended Capability (MTC)

The sixth Shuttle flight will carry the U.S. Laboratory Module and racks. At this point, the station includes propulsion modules, a TDRS antenna, thermal control, guidance, navigation and control apparatus, the aft port node, the pressurized docking adapter, the Mobile Servicing System, a cupola and the U.S. Laboratory Module outfitted to accommodate experiments. These added components and elements will provide the station with an early man-tended capability until PMC. Payloads which can function unattended until the next scheduled assembly flight will be accommodated at this time. (See the figure on page 24.)

Seventh Assembly Flight (MB-7)

The seventh assembly flight will add an airlock, pressurized docking adapter, the Canadian Special Purpose Dexterous Manipulator (SPDM) and Mobile Servicing System Maintenance Depot (MMD).

Eighth Assembly Flight (MB-8)

This flight will add another pre-integrated truss section with Thermal Control System and UHF antenna.

Ninth Assembly Flight (MB-9)

Another truss section with three dry cargo berthing mechanisms and two propulsion modules of reduced capacity will be added..

Tenth Assembly Flight (MB-10)

The flight will add still another truss section along with the port photovoltaic power module with alpha joint assembly and power module platforms.

Eleventh Assembly Flight (MB-11)

The Shuttle will bring up the starboard node and outboard photovoltaic power module spacer.

Twelfth Assembly Flight (MB-12)

The Shuttle will lift the Japanese Experiment Module, DC to DC conversion units and heat exchangers.

Thirteenth Assembly Flight (MB-13)

The Shuttle will place the ESA Attached Pressurized Laboratory in orbit along with its DC to DC conversion units and heat exchanger.

Fourteenth Assembly Flight (MB-14)

The Shuttle will bring up the last truss section with starboard photovoltaic power module.

Fifteenth Assembly Flight (MB-15)

The Shuttle will bring up the JEM Exposed Facility and Experiment Logistics Module's Pressurized Section and Exposed Section.

Sixteenth Assembly Flight (MB-16)

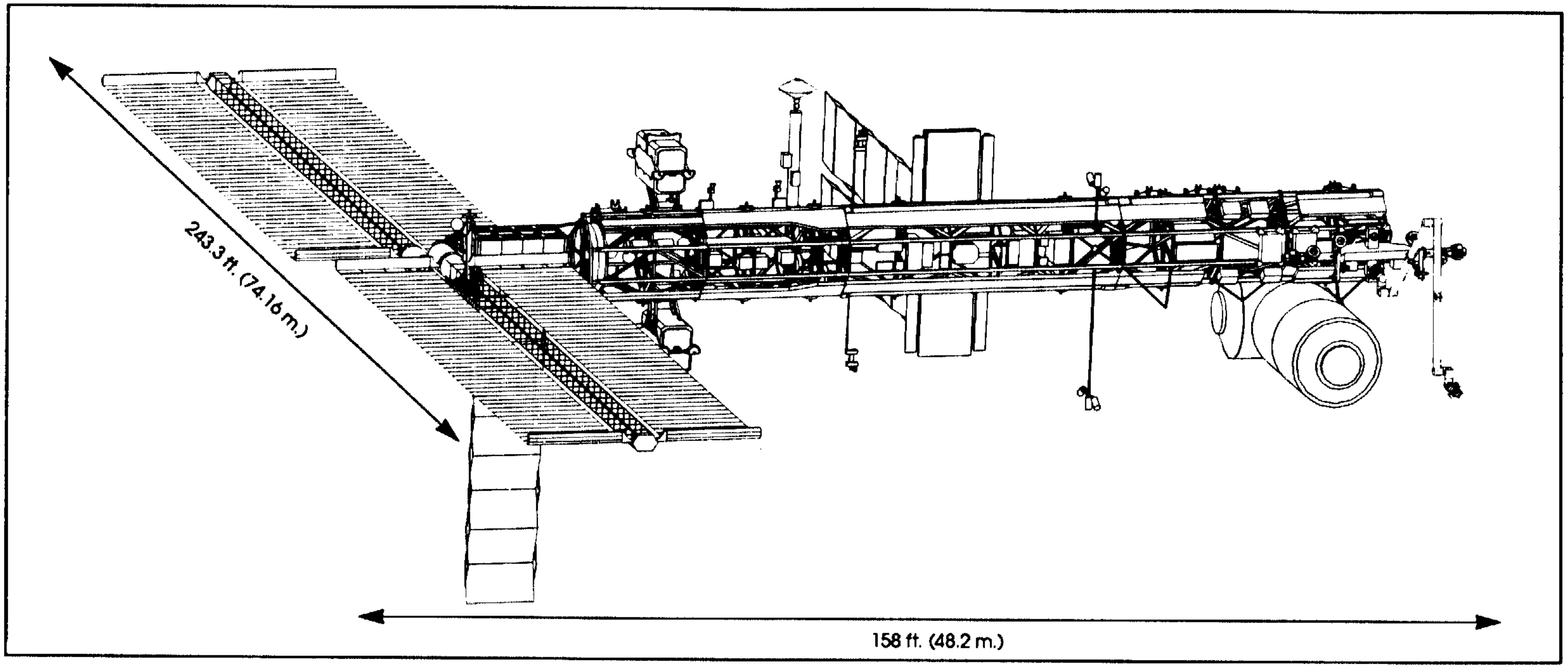
The Shuttle will bring up the U.S. Habitation Module and system racks, containing fully-functional life support, data management and manned systems.

Permanently Manned Capability (PMC)

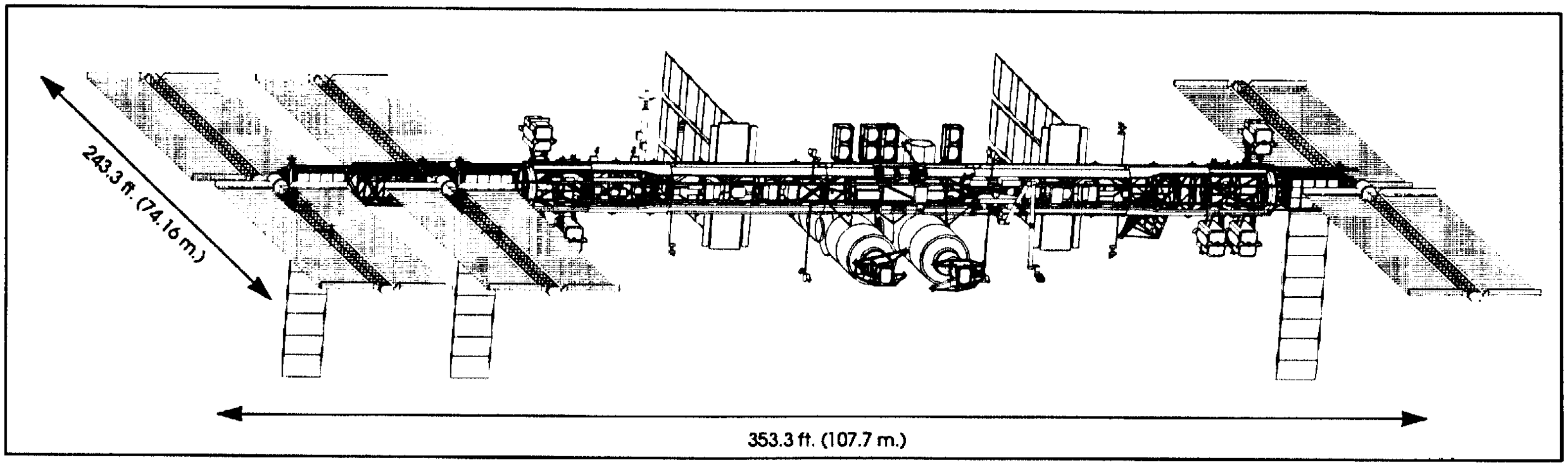
On the seventeenth flight, the Shuttle will bring up the Assured Crew Return Vehicle that will allow for the station to be permanently manned with an emergency escape capability. The centrifuge and Node 3 will follow on the eighteenth Shuttle flight.

Configuration Capabilities

	Man Tended Capability 1997	Permanently Manned Capability 2000
Power	18.75 kW - 1 PV module	56.25 kW - 3 PV modules
Module length	27 ft. - 1 microgravity lab	27 ft. - 1 lab, 1 hab
U.S. lab user racks (ISPRs)	12	12
User research power	11 kW	30 kW
Logistic module capacity	MPLM – 8 racks	PLM - 20 racks
Command uplink	70 kbps	70 kbps
Data downlink	43 Mbps	43 Mbps
Gravity level	1µg	1 µg
Attached payload accommodations	2 ports	4 ports
U.S. assembly and logistics flights	6	17
Permanent crew size	0	4 expandable to 8
Dedicated crew for research	4 (while on station)	2 (continuous)
Utilization flights (MTC to PMC)	8	N/A
Truss	4 segments built and checked out on ground	7 segments built and checked out on ground
Length (total)	158 ft.	353
Pressurized resource nodes	1	2
International hardware: Canada	Mobile Servicing System (simplified)	Mobile Servicing System
Japan	none	JEM – 10 ISPRs
Europe	none	APM – 20 ISPRs
Life Support	Shuttle supported	regenerative water loop
Propulsion	2 downsized modules	4 modules
Pressurized docking adapter	1	2
Airlock	0	1
Assured Crew Return Vehicle	0 – use Shuttle	1



Configuration shown at Man-tended Capability



Configuration shown at Permanently Manned Capability

Space Station Freedom Budget History

(Millions)

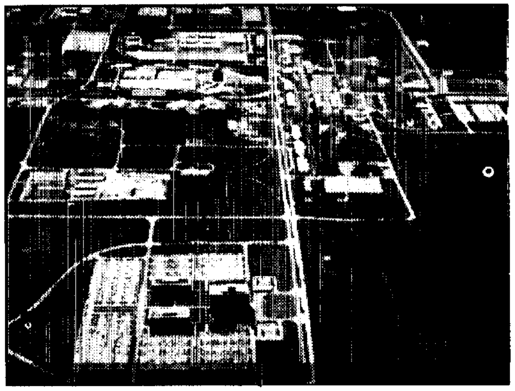
Year	NASA Requested	Appropriated	% NASA Budget	% Federal Budget
1985	150	155	2.1	.014
1986	230	200	2.6	.019
1987	410	420	3.9	.038
1988	767	393	4.4	.033
1989	967	900	8.4	.069
1990	2050	1750	14.2	.128
1991	2451	1900	13.7	.125
1992	2029	2029	14.1	.129

Space Station Freedom's budget as a function of NASA's and the entire Federal Budget

Specifications of Space Station Freedom (PMC)[1]

Element	Shape	Length (ft/m)	Width/Diameter (ft/m)	Weight (Tons/Kg)
Truss Assembly & Equipment	Hexagon	216.0 / 65.9	12 x 16 / 3.7 x 4.9	160.6 / 146,000
U.S. Laboratory Module	Cylinder	27.4 / 8.4	14.5 / 4.4	17.1 / 15,545
Habitation Module	Cylinder	27.4 / 8.4	14.5 / 4.4	17.8 / 16,182
Columbus APM	Cylinder	38.7 / 11.8	14.7 / 4.5	18.7 / 17,000
Japanese Module[2]	Cylinder	56.0 / 17.0	13.8 / 4.2	36.1 / 32,818
Resource Node[3]	Cylinder	17.0 / 5.2	14.5 / 4.4	25.9 / 23,545
Solar Panels[4]	Rectangle	112.0 / 34.0	39.0 /11.9	8.7 / 7,909
Other (airlock, pressurized docking adapters)				24.7 / 22,431
Approx. Total Weight and Length of Station		353.0 / 107.6		309.6 / 281,430
Columbus Free-Flyer	Cylinder	39.4 / 12.0	14.7 / 4.5	20.1 / 18,200

[1] All specifications are approximate and subject to change and generally include user allocations.
[2] Includes Exposed Facility and Experiment Logistics Module.
[3] Dimensions are for one resource node; weight is total of two resource nodes and cupola.
[4] Shape and dimensions are for the Solar Array Wings; weight includes six of the Array Wings but not the truss.



Traditional Center Roles and Responsibilities

The Marshall Space Flight Center in Huntsville, Alabama, was established 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 micrometeoroid detection satellites (1965); 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 was NASA's lead Center for the development of the Hubble Space Telescope (HST), which was launched in June 1990. GSFC now has lead for operations of the HST.

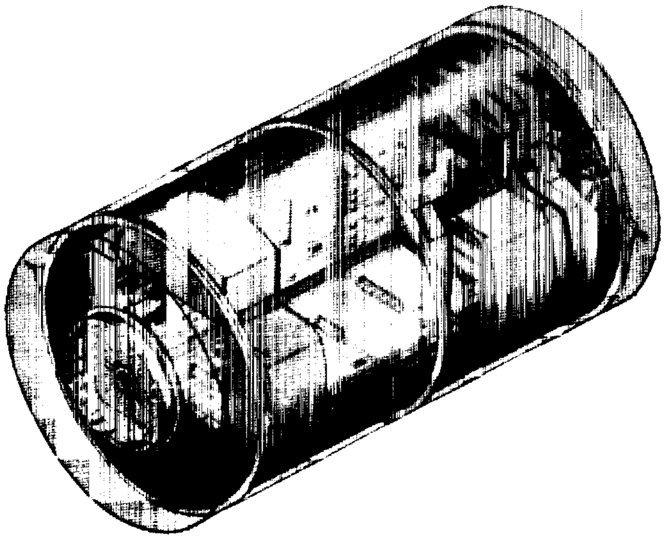
Other current Marshall projects include the Advanced Solid Rocket Motor (ASRM); the Advanced X-Ray Astrophysics Facility (AXAF); the Inertial Upper Stage (IUS); the Transfer Orbit Stage (TOS); and the Tethered Satellite System.

The Marshall Center is working to develop a heavy lift launch vehicle, a new launch system, with joint participation with the U.S. Air Force. 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 Louisiana, and tests Space Shuttle main engines at the Stennis Space Center in Mississippi.

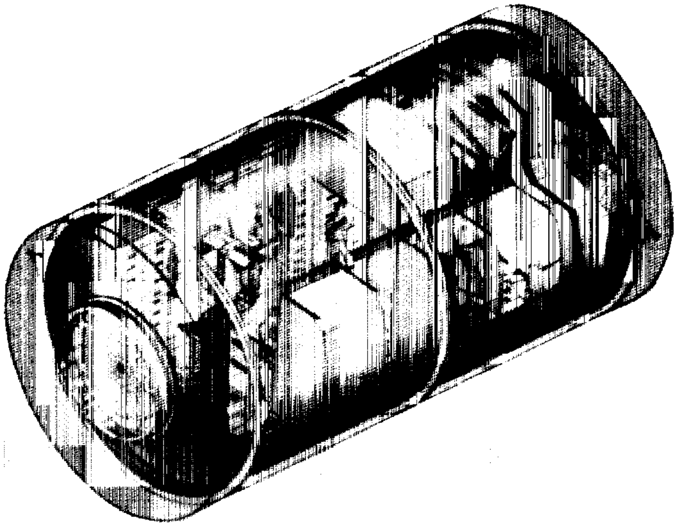
Space Station Freedom Unique Activities

U.S. Laboratory Module

Marshall is responsible for the U.S. Laboratory Module, capable of supporting multidiscipline payloads, including materials research, development and processing, life sciences research and other space science investigations in a shirt-sleeve pressurized volume. The U.S. Laboratory Module supports payloads provided by the scientific community, such as furnaces for growing semiconductor crystals, electrokinetic devices for separating pharmaceuticals, support equipment for low-gravity experiments and life sciences gravitational biology and space physiology.



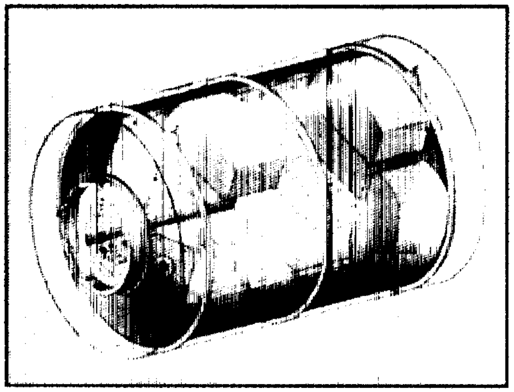
Length: 27.44 ft. (8.36 m.) outside
Diameter: 14.50 ft. (4.42 m.) outside
Weight: 34,200 lbs. (15,513 kg.)



Length: 27.44 ft. (8.36 m.) outside
Diameter: 14.50 ft. (4.42 m.) outside
Weight: 35,600 lbs. (16,148 kg.)

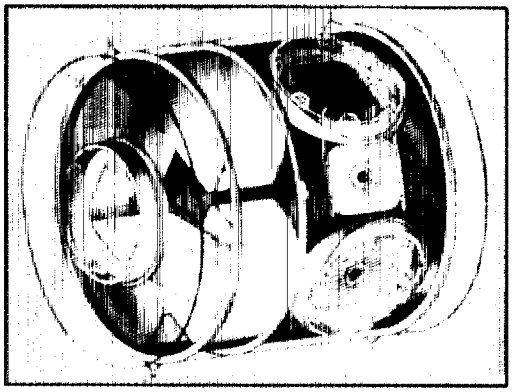
Habitation Module

Marshall is responsible for the Habitation Module which includes facilities for eating, sleeping, personal hygiene, waste management, recreation and other habitation functions requiring pressurized space. The same size as the U.S. Laboratory, the Habitation Module is able to accommodate up to four astronauts at PMC. In addition, the Habitation Module and the U.S. Laboratory Module provide housekeeping functions, i.e., power distribution, heat rejection, audio/video for crew and payloads.



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 customers; and for the on-orbit storage of these cargoes. A key element will be the Mini Pressurized Logistics Carrier (built by Italy under direction of Marshall) at MTC and the Pressurized Logistics Carrier at PMC to carry items used inside the pressurized modules. Other elements include Unpressurized Logistics Carriers for the transport of spares, fluids, propellants and dry cargo, used outside the pressurized modules.



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 and support experiments. Marshall provides the resource node structures, berthing mechanisms, racks, the ECLSS system, fluid management system, internal thermal control, internal audio and video communication systems and manned-systems subsystems, components and hardware. After PMC, the 2.5 m. centrifuge will be located in the endcone of Node 3. It will also house the habitats and systems.

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 water reclamation system. Freedom Station's internal thermal control and audio/video systems are also provided by Marshall.

Elements and Systems

U.S. Laboratory Module

The U.S. Laboratory Module is a pressurized cylinder, about 27.44 ft. (8.2 m.) long and 14.5 ft. (4.42 m.) in diameter, located below the lower face of the transverse boom and attached perpendicular and just to the left of center on the boom. It provides a shirt-sleeve environment for crewmembers engaged in research and experimentation. This location accommodates the microgravity research needs.

Purpose

The U.S. Laboratory Module is dedicated to accommodating 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 sciences research relating to long duration exposure to microgravity;
- control and monitoring of user-provided pressurized payloads and selected external attached payloads;
- the intravehicular activity (IVA) including maintenance and servicing of orbital replacement units (ORUs), instruments, and equipment requiring workbench support in a pressurized volume.

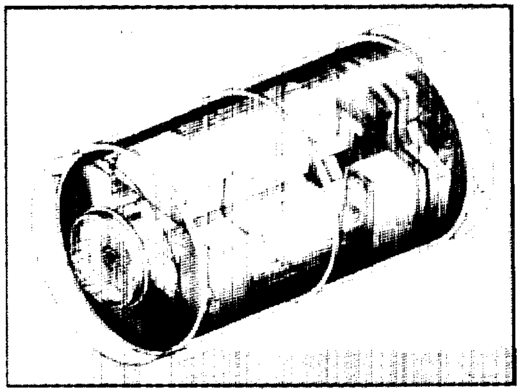
The Laboratory Module has an atmospheric pressure of 10.2 psi at MTC and 14.7 psi at PMC. The lower pressure enables the astronauts to spend less time prebreathing before performing the EVA activities which will be needed during the construction of the station. The higher pressure is equivalent to sea level pressure.

It has 24 racks of which 12 are standard payload racks. The remaining 12 rack positions accommodate such systems as the environmental control and life support system (ECLSS), thermal control system (TCS), manned systems and electrical power system (EPS).

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 systems, leading to simplified manufacturing processes, a reduction in spares and ease of maintenance. Design commonality also means that about 80 percent of the hardware needed for the station's life support systems will be common in the U.S. Laboratory Module, the Habitation Module, the Pressurized Logistics Module and the Resource Nodes. Furthermore, commonality of design and architectural continuity adds to a sense of familiar surroundings for the crew. A pleasing environment enhances crew productivity and a feeling of well being.

The modular design of the station means that some components can be moved from one module to another, or to the Resource Nodes, as the station evolves and needs change. Designed with the user in mind, the Laboratory Module is segmented by work activity. For example, materials science payloads and supporting equipment are co-located. Material scientists need glove boxes, ultra pure water and fluid handling tools. Life sciences payloads are also co-located. Life scientists also need special equipment. Outfitting racks are designed to tilt down for servicing, replacement, cleaning and transfer to other modules.



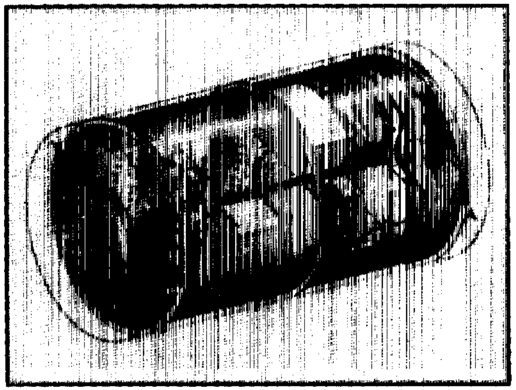
Structure

The U.S. Laboratory Module consists of primary and secondary structures. 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 attachment points and grappling fixtures.

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

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, relaxation 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.

The Habitation Module 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 of the module are the galley and wardroom. The galley is equipped with an oven, refrigerator/freezer, trash compactor, hand washer and water supply. The wardroom, equipped with windows, is an area for entertainment, eating and meetings. The middle of the Habitation Module is devoted to hygiene with a bathroom and shower.

Special attention is devoted to the Habitation Module to ensure a "crew friendly" environment. Knowledge, materials and techniques learned from previous space flights and airplane cabin technology will keep noise levels at about 50 decibels—as quiet as a whisper. The crew will sleep in attached sleeping bags in the aisle of the module after PMC.

The Habitation Module is designed for four crewmembers. The tabletop panels adjust to provide various seating arrangements for the entire crew for meals, meetings, games, relaxation or teleconferencing. Because work schedules are expected to be scattered, two members of the crew may be eating supper while two 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 percent cost savings.

While there is no up or down in weightless space, the Habitation Module does resemble an ultramodern, Earthbound kitchen, den and entertainment center. The notable exception is the vertical sleep restraint system in place of bunk beds. See the JSC section for more on outfitting the Habitation Module.

Logistics Elements

Logistics elements are cargo canisters attached to the station truss or to a node. They are designed to be exchanged rather than refilled, containing either dry or fluid material. The combination of cargoes will vary for each flight to and from the station, depending on requirements of the crew, station and customers.

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 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 Carriers (PLCs)

The basic purpose of the PLCs is to provide ready, on-orbit access to cargo without extravehicular activity. That means a PLC is a habitable environment, providing a benign, temporary storage facility for cargo. Thus, a PLC contains all the electrical, thermal, and air quality requirements of an inhabited module. It will transport cargo requiring a pressurized environment to the station, and then transport equipment, products, biological products 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 are used in an unpressurized 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, an arriving logistics element containing resupplies may be exchanged with a berthed logistics element that has been packed with equipment no longer needed, experiment results, trash, etc., and readied for return to Earth. 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.

A Pressurized Logistics Carrier will be located on the nadir of the station—that is, in the direction of the Earth. The PLC, structured like the nodes and modules for commonality of manufacture and design, will be cylindrical with conical ends. It will be berthed at either Node 1 or Node 2.

The ULCs will berth 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. The ULCs will contain dry cargo, gases and fluids. 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.

PLCs and ULCs are being built at Marshall. The PLCs feature a portable inventory system plus a lightweight plug door, and a roller floor to reduce ground handling time. The ULCs are designed to accommodate modularized fluids and modularized dry cargo in many combinations.

Mini Pressurized Logistics Modules

The Italian Space Agency (ASI) will design and develop two Mini Pressurized Logistics Modules for the Space Station Freedom program under a memorandum of understanding (MOU) signed with NASA on December 6, 1991.

The Mini Pressurized Logistics Modules (MPLM) are capable of transporting user payloads and resupply items in a pressurized environment to the station and returning necessary items to the ground. The MPLMs will be capable of remaining at the Space Station Freedom until the arrival of the next pressurized logistics module. The MPLMs will be used to transport user payload racks on the utilization flights, during the MTC period. The first MPLM is currently scheduled to be transported to the station by the Shuttle in May 1997 and the second in August 1997. Each MPLM will accommodate seven racks. After PMC, the MPLMs will be augmented by the larger PLMs.

The Italian aerospace firm Alenia Spazio will build the modules. Boeing Defense and Space Group in Huntsville, Alabama, will act on behalf of NASA as the systems engineering and integration manager.

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. Available at PMC, the ECLSS produces a potable grade of water, even from urine, for drinking, washing and cleansing. Carbon dioxide is collected and vented to space. Waste products are containerized and returned to Earth. There shall be no overboard dumping of solids or liquids. Because of leakage and process losses, all quantities of oxygen, nitrogen and water must be resupplied from Earth.

The hardware for the ECLSS is distributed throughout the pressurized modules to assure sea-level pressure, temperature, humidity and air composition; as well as water, and fire detection/suppression equipment. For redundancy, repressurization and fire fighting equipment are located in both the Habitation and Laboratory Modules. Design challenges for the remainder of this decade include the ability of the ECLSS to maintain microbial and chemical system cleanliness during extended duration missions and multiple reuses of 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 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 airlock. 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. 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 the U.S. modules.

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, they 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. The two resource nodes, located at the ends of the U.S. Laboratory and Habitation Modules, provide a pressurized passageway to and from the modules and an interface to the Space Shuttle.

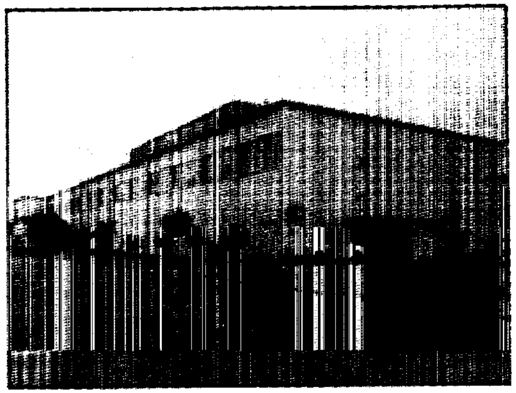
Built like the other pressurized modules, the nodes will be smaller, about 17 feet (5.2 meters) long and 14.5 feet (4.42 meters) in diameter. They will reduce the amount of EVA time required to assemble the station. The nodes are designed and built by Marshall Space Flight Center and outfitted by Johnson Space 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,
- residence for station distributed systems,
- limited station storage,
- residence for supporting utility systems equipment,
- limited user payload operation,
- residence for the centrifuge, and
- residence for the Crew Health Care System.

The first node to be launched, Node 2, is located between the U.S. Laboratory Module and the Japanese Experiment Module (JEM). It contains the primary command control workstation and provides integrated avionics racks to perform data management, thermal control, communications and tracking and electrical power monitoring and control. Node 2 provides ports for the airlock, pressurized logistics module, cupola and Node 1. Node 2 is available at MTC.

The second node to be launched, Node 1 is attached to the starboard port of Node 2 and provides ports for the Habitation Module, the Columbus Laboratory, the Pressurized Logistics Module and the Assured Crew Return Vehicle. It contains the secondary command control workstation and other integrated avionics racks which distribute electrical power, data management, audio/video and communications and tracking resources.

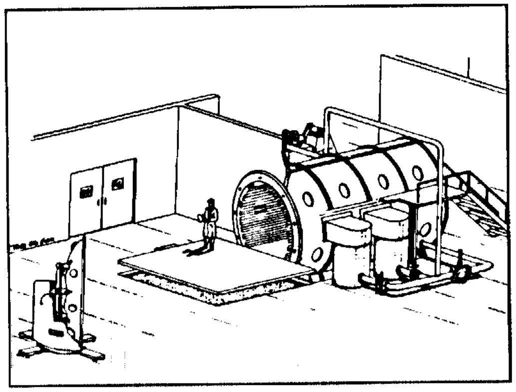
The cupola is being designed for maximum viewing with both portable and installed command and control consoles. It will be attached to the outboard port of a resource node. It can be used for observations during shuttle berthing and attached payload servicing. It will accommodate two astronauts. A cupola cover can extend to provide micrometeoroid and debris protection.



Facilities

Payload Operations Integration Center

The Payload Operations Integration Center (POIC) will be used to manage or control realtime 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 realtime operation, the 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 realtime operations. The ESC serves as a control point for requests from the SSCC and the POIC for engineering support to operations. It also supports the engineering flight evaluation and anomaly resolution for Space Station Freedom.

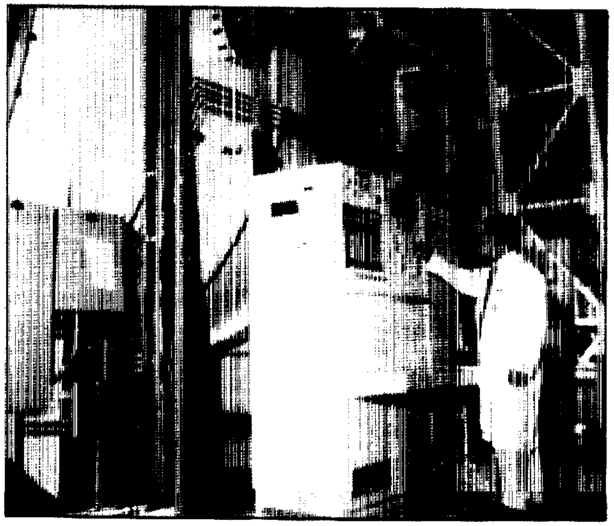
Payload Training Complex

The Payload Training Complex (PTC) 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.

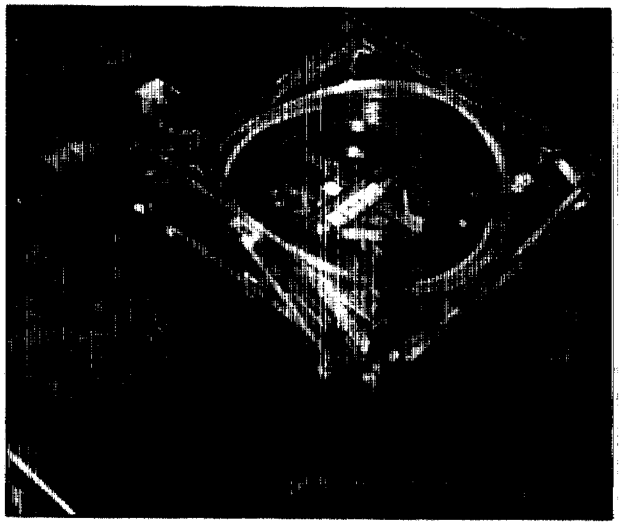
Node Hatch Test Article

Module Structural Test

ECLSS Testbed



Node Structure Berthing Plate



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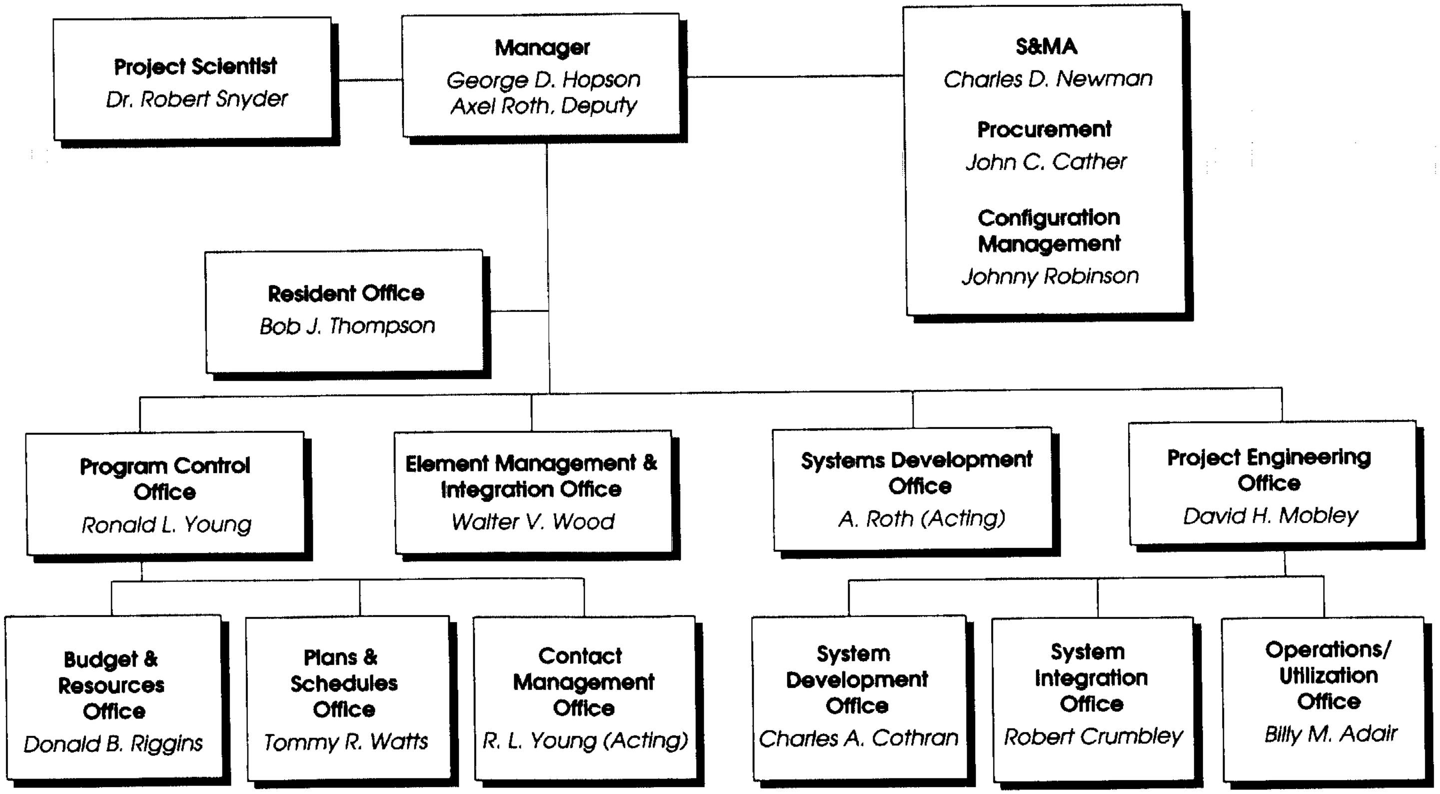
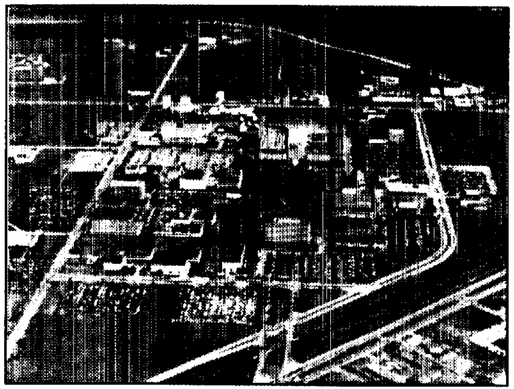
Space Station Freedom Organization

The Marshall Space Flight Center (MSFC) in Huntsville, Alabama has 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 Internal 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 four 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 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 what is now 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 basis 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.

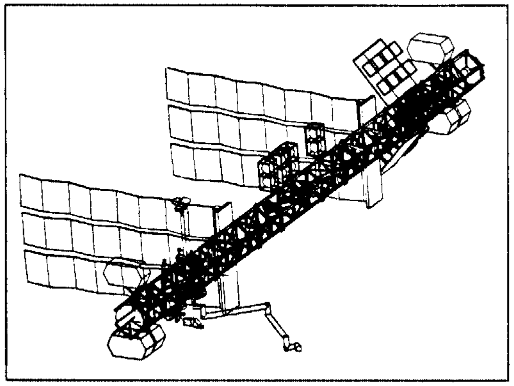
Research and development activities at JSC related to manned space flight include:

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; and,
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.

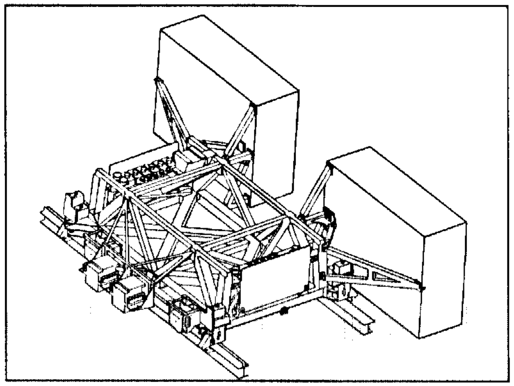
Other Earth observation responsibilities of JSC include soil moisture mapping, multicrop research, water mapping, forestry applications and resources inventory with the State of Texas.

Space Station Freedom Unique Activities



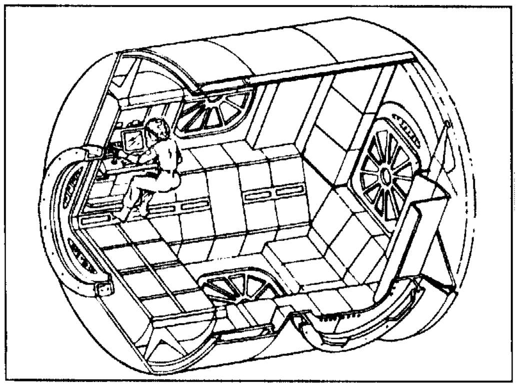
Integrated Truss Assembly

The pre-integrated truss assembly (ITA) provides the framework for the core base of the station. The ITA is 216 ft. (65.9 m.) in length measured from one alpha joint to the next. It serves as the attachment point for the pressurized modules, solar power arrays, as well as other systems, including experiments. It facilitates the movement of crew and equipment, and provides support for distributed systems.



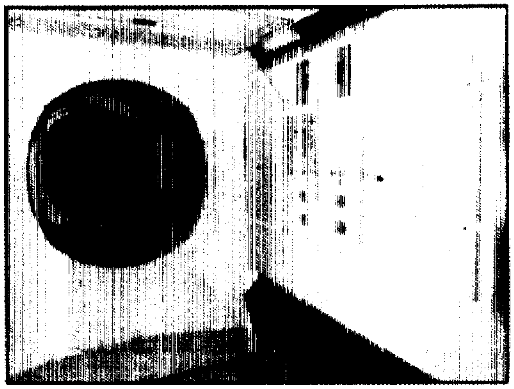
Mobile Transporter Element

The mobile transporter element will enable the Canadian-supplied Mobile Servicing Center (MSC) to move along the truss. It provides the translational mobility required by the MSC to support transportation, assembly, maintenance, servicing and payload operations.



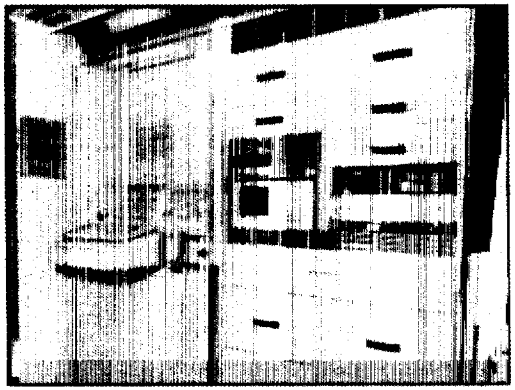
Resource Nodes - Design and Outfitting

The two resource nodes, located at the end of the Habitation and U.S. Laboratory Modules, are small pressurized cylinders approximately 17 ft. (5.2 m.) long and 14.5 ft. (4.42 m.) 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 Node 2.



Airlock

Space Station Freedom will have one hyperbaric airlock. The airlock attaches to a node and enables the transfer of crew and equipment between pressurized and unpressurized zones. The hyperbaric airlock also has the capability for the treatment of decompression sickness or air embolism.



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 data management, communications and tracking, guidance, navigation and control, thermal control, EVA, electrical power systems, environmental control and life support and manned systems.

Manned Systems

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

Elements and Systems

Integrated Truss Assembly (ITA)

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 pressurized modules that make up the space station's manned base, or core.

The pre-integrated truss assembly for Space Station Freedom is the structural framework that stiffens and stabilizes 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 for crew and equipment movement, and accommodation of distributed equipment including external lighting. The truss also includes the provision of utility distribution, module to truss structure, thermal guidance and control, communications and tracking and propulsion equipment.

The center section of the transverse boom (the integrated truss assembly) is 216 ft. (65.9 m.) in length, consisting of seven sections, with a 12 ft. x 16 ft. (3.7 m. x 4.9 m.) hexagonal-shaped cross section. The sections are assembled on the ground using anodized aluminum bulkheads, longerons and diagonals to form a truss. Systems equipment is preintegrated with the truss structure and launched in the Space Shuttle as a preassembled and verified section. These seven sections are launched separately and joined together in orbit during each flight to form the integrated truss assembly.

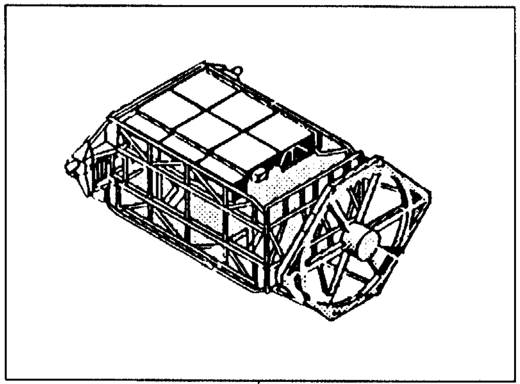
Utility Distribution System

The Utility Distribution System provides integrated distribution of the necessary utilities including power, data, video and fluids to locations throughout the SSF. For ease of EVA installation and maintenance and environmental protection, external utilities will be housed in rigid aluminum carriers that run the length of truss sections. Line routing between the carriers and equipment on the truss will be preinstalled and checked out on the ground. During assembly, EVA crewmembers will only be required to make connections at the ends of the segment carriers. The Utility Distribution System will also provide for all external illumination (lights).

Mobile Transporter Element (MTE)

The Mobile Transporter Element (MTE) provides mobility for the Canadian-supplied Mobile Servicing Center (MSC). The MTE combined with the Mobile Remote Servicer (MRS) comprises the MSC. The MTE is comprised of the Mobile Transporter (MT), the Transporter Energy Storage System (TESS), and the Trailing Umbilical System (TUS). The MTE will move along rails attached to the pre-integrated truss while supporting MSC operations. During translation, the MTE will provide the MRS with power from the MT batteries, TESS and data through the trailing umbilical, TUS. When rigidly attached to the truss, the MT will throughput station-distributed utilities and data through the Umbilical Mechanism Assembly (UMA) connected to a MSC utility port. The base of the MT will measure approximately 5 ft. x 8 ft. (1.5 m. x 2.5 m.). The height is approximately 2.5 ft. (.76 m.).

The MSC will consist of the MT, a base structure mounted on the MT, and a Space Station Remote Manipulator System (SSRMS) similar to the one on the Orbiter. Another Canadian-supplied element, the Special Purpose Dextrous Manipulator (SPDM), will be carried on the MSC. The SPDM acts as the "hands" of the system and will be designed to change out space station orbital replacement units and attached payloads.



Mechanical System

The mechanical systems consist of the Solar Alpha Rotary Joint; the Thermal Radiator Rotary Joint; the Thermal Radiator Beam Launch Restraints; the Capture Latch Assembly which is incorporated into the Segment to Segment Attach System, Propulsion Module Attach System, Cryogenic Attach System, and the Unpressurized Logistic Carrier Attach System; the Segment to Segment Structural Attach System; the Unpressurized Berthing Adapter extension, attach and locking systems; the Antenna Deploy/Support systems, (Ku band, ACS RF, and UHF); Trailing Umbilical System; Airlock and Pressurized Berthing Adapter Hatch Seals and mechanical systems; and the Umbilical Mechanism.

- The Solar Alpha Rotary Joint which supports the outboard transverse booms, provides controlled rotation to point the power generation panels toward the sun and transfers electrical power, data and video across the rotating interface.
- The Thermal Radiator Rotary Joint (TRRJ) which supports the radiator panels, controls their orientation and transfers electrical power, liquid/gaseous ammonia, and data across the rotating interface.
- The Thermal Radiator Beam Launch Restraint secures the radiator beam to the segment truss during launch and is released prior to radiator deployment. It is also used to restrain the radiators in the event the TRRJ is removed and replaced.
- The Capture Latch, which is common to all the attach systems, captures and draws the two mating components together, and restrains the repeatedly berthed (Propulsion Module, Cryo Pallet, and the Unpressurized Logistic Carrier) payloads to the SSF truss. It positions the truss segments so the Segment to Segment Structural Attach System can permanently join the segments.
- The Segment to Segment Structural Attach System is a motorized bolt that joins and preloads the truss segments and provides the structural load path between truss segments. In other applications, it structurally attaches, restrains or releases different components such as the UBA to MTE and the Radiator Launch Restraint System.
- The Unpressurized Berthing Adapter (UBA) extension, locking and attach systems extend the UBA and latch and structurally join it to the Mobile Transporter Element (MTE) thus providing the initial berthing interface between the Orbiter and SSF. This sequence is reversed when the Pressurized Berthing Adapter is attached to the SSF so the UBA can be returned to Earth.
- The Antenna Deploy/Support systems provide for deploying and attaching the various antenna systems (Ku-band, ACS RF and UHF) to the truss.
- The Trailing Umbilical System provides control data and video to the MTE through a fiber optic cable that extends or retracts as the MTE travels on its rails.
- The Airlock and PBA EVA hatch seals are similar in configuration. The mechanical systems restrain and position the hatches in the open or closed position and provide the preload to initiate a seal.
- The Umbilical Mechanisms provide power and data, or fluid transfer between the SSF and the Mobile Transporter, Propulsion Modules, Cryo Pallets, Unpressurized Logistics Carriers and also between the MTE and UBA.

Resource Node Design and Outfitting

The JSC is responsible for the design and outfitting of the two resource nodes. They are located at one end of the Habitation and U.S. Laboratory modules, and are designed to interconnect the pressurized modules. The nodes are small, pressurized cylinders, approximately 14.5 ft. (4.42 m.) in diameter and 17 ft. (5.2 m.) 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.

Node 1 serves as a backup control center for the Communication and Tracking System, Data Management System, Guidance, Navigation and Control System, Propulsion System, Electrical Power System and Thermal Radiator Rotation. It is located between the Columbus Attached Pressurized Module and the Habitation module and attaches to an ACRV and Node 2. It has one of the berthing locations for the Pressurized Logistics Module.

Node 2 provides primary command and control. It is located between the JEM and the U.S. Laboratory module. It also serves as a berthing location for the Pressurized Logistics Module and is attached to the airlock. Node 2 will also contain a pressurized berthing mechanism for the temporary attachment of the Space Shuttle during assembly.

Cupolas

There is one cupola planned for MTC and PMC which is attached to Node 2.

A second cupola will be added later. The cupola facilitates the control of proximity operations and can be used simultaneously by two crewmembers with a workstation available. 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 six side windows. The workstation 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, external video cameras and lights and internal video monitors, international and external voice communications and systems control functions via access to the DMS.

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 pressurized treatment of decompression sickness and air embolism. The airlock is a separate element attached to Node 2. The airlock also serves as the storage and service area for the EVA system hardware.

Thermal Control System (TCS)

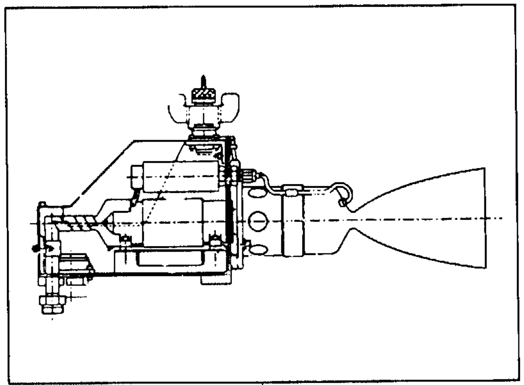
The TCS is a distributed cooling system that maintains core systems, elements and payloads within required temperature ranges. Most equipment located outside the pressurized elements is passively cooled using fins and special coatings to radiate heat to space. High power equipment outside, and all equipment inside the pressurized elements is actively cooled by a series of pumped fluid loops.

More specifically, heat buildup inside the pressurized modules is removed locally by that element's low and moderate temperature water loops using air to water heat exchangers and equipment coldplates. Each pressurized element then transfers the heat collected to an external system of two low and one moderate temperature loops.

These outside ammonia loops use evaporative cooling to efficiently gather heat from the pressurized elements and high power outside equipment. This heat, totalling up to 82.5 kW, is rejected by two large condensing radiator arrays measuring 75 ft. (22.8 m.) long by 38 ft. (11.6 m.) wide. Rotary joints point the arrays away from the sun to allow the waste heat to be radiated to space.

Propulsion Assembly

The propulsion assembly will provide thrust for orbital maintenance and three-axis thrust for backup attitude control and reorientation. Three-axis thrust can be used to desaturate the Control Momentum Gyroscopes (CMG), which are the primary attitude actuators of the Attitude Determination and Control System. The propulsion system consists of multiple propulsion modules. Each module is a self-contained hydrazine propulsion system consisting of propellant tanks, valving, plumbing and thrusters. The propulsion system may also later include resistojets which produce supplemental thrust using station waste gases.



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 pointing of antennae on the station. C&T is comprised of four subsystems:

1) assembly/contingency,
2) space to ground,
3) audio, and
4) video.

The assembly/contingency subsystem provides near continuous communications between the station and ground data networks through the Tracking and Data Relay Satellite System (TDRSS) for remote control and monitoring of the station.

The space-to-ground subsystem provides near continuous transmission of video and payload science data from the station through the TDRSS and ground networks.

The audio and video subsystems serve as the eyes, ears and voice of the space station. The audio subsystem provides audio communications between the crew inside the pressurized modules, the ground, the spacecraft and astronauts in extravehicular activity, for entertainment of the crew, and emergency communications. 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 and special monitoring capability for the experiments conducted onboard the space station. The audio and video subsystems utilize fiber-optic technology to maximize reliability, bandwidth and performance, while saving hundreds to thousands of pounds over conventional wiring techniques. MSFC has responsibility for the internal video subsystem; JSC has responsibility for the external subsystem.

Guidance, Navigation & Control (GN&C)

The GN&C performs two main functions: to stabilize the manned base in orbit and attitude and to monitor traffic around the space station.

Periodically, Space Station Freedom will decay in orbit. The GN&C, using its star trackers, gyroscopes and computers, will signal the propulsion assembly for a reboost to the proper altitude and attitude. This system also supports the pointing of the solar arrays, thermal radiators and antennas on the transverse boom.

Traffic management around the station will also become critical. The GN&C monitors all incoming, outgoing and station keeping traffic; it also supports berthing and docking operations for the Space Shuttle. Finally, the GN&C responds to the trajectories of vehicles and objects that intersect the orbit of the manned base by the executing of collision avoidance maneuvers.

The crew and experiment motions and drag on the large elements will cause the manned base to turn or shift its attitude. The GN&C system's ring laser gyroscopes and star trackers continuously monitor for these disturbances and counteract them by torquing one or more of the large spinning control moment gyroscopes, or by signaling the propulsion system for a controlled thrust.

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, it provides an interface between human and machine for the operation and control of Space Station Freedom.

The DMS provides database access, command and control, subsystem signal conditioning and conversion from analog to digital format, 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 online capabilities such as command generation, data handling, graphics, health monitoring, planning, scheduling, 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 subsystem interface and control Multiplexer/Demultiplexer assembly and the Multipurpose Application Console (MPAC). The MDM is the means by which the DMS interfaces with the various sensors and effectors on the station. It provides the interface between the sensors and effectors on one side and the DMS and MPAC on the other.

The MPAC is the electronic core of the space station workstations. It provides access into operational monitoring, training, testing, cautions and warning display, TV and crew operations.

The information and data management services provided will include data storage processing and handling time and frequency generation and distribution, 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 crewmembers.
3) Provide for onboard distribution of data between subsystems, payloads, and payload support equipment over DMS networks.
4) Support realtime command and control. Commanding can be initiated by the system, the crew and ground operations.
5) Support the provision of orbit-position data of a selected reference point, attitude data and navigation information.
6) Provide the caution 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 space station elements, and 3) both system and customer data configuration management in the Data Management System.

Manned Systems

JSC is responsible for managing the design, development, test and engineering of manned systems for the Habitation and U.S. Laboratory modules, nodes and cupolas. The Manned Systems include crew quarters restraints and mobility aids, health care, operational and personal equipment, portable emergency provisions, workstations, galley and food management, personal hygiene, lighting, wardroom, stowage and housekeeping/trash management. Manned 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 four crewmembers. Specifically it contains the crew quarters, galley, wardroom, personal hygiene facility and stowage.

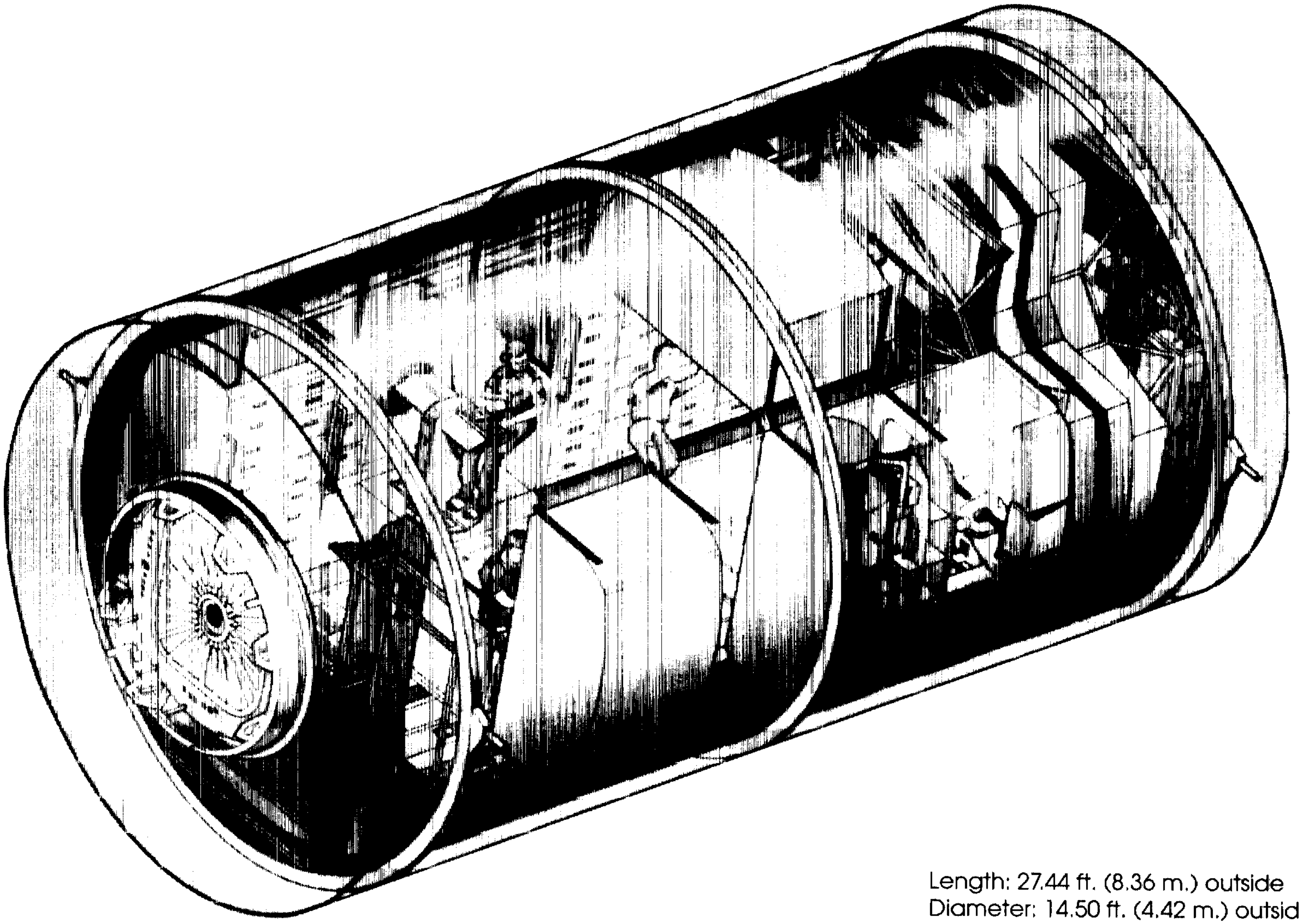
The layout of the module is designed to provide the most habitable and productive environment possible given the restricted available volume.

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 cleanup with its trash collection and 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 crewmembers 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 work surfaces are cantilevered. The remaining two work surfaces 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 collapse into one rack space and then deploy to fit two to eight crewmembers. With extra independent work surfaces, the wardroom area can accommodate up to 12 people.



Length: 27.44 ft. (8.36 m.) outside
Diameter: 14.50 ft. (4.42 m.) outside
Weight: 35,600 lbs. (16,148 kg.)

Habitation Module

The crew hygiene system being proposed for the Space Station Freedom is composed of the entire body shower subsystem and the waste management subsystem. 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 integrated workstation system incorporates all onboard 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 Health Care System is an inflight 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 comprised of the Health Maintenance Facility, the Exercise Countermeasure Facility and the Environmental Health System.

The Health Maintenance Facility includes test and diagnostic instruments, a patient restraint and medical provisions to care for, or stabilize, an injury or illness.

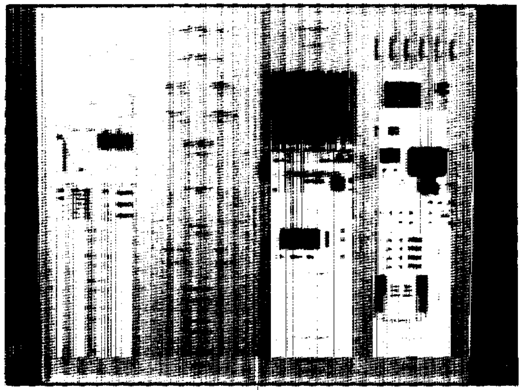
The Exercise Countermeasure Facility includes exercise equipment and monitoring equipment. The Environmental Health System includes instruments for microbiological, toxicological, water quality and radiation measurements.

The purpose of the Crew 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 Crew 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. The crew health care 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.

Attachment Systems

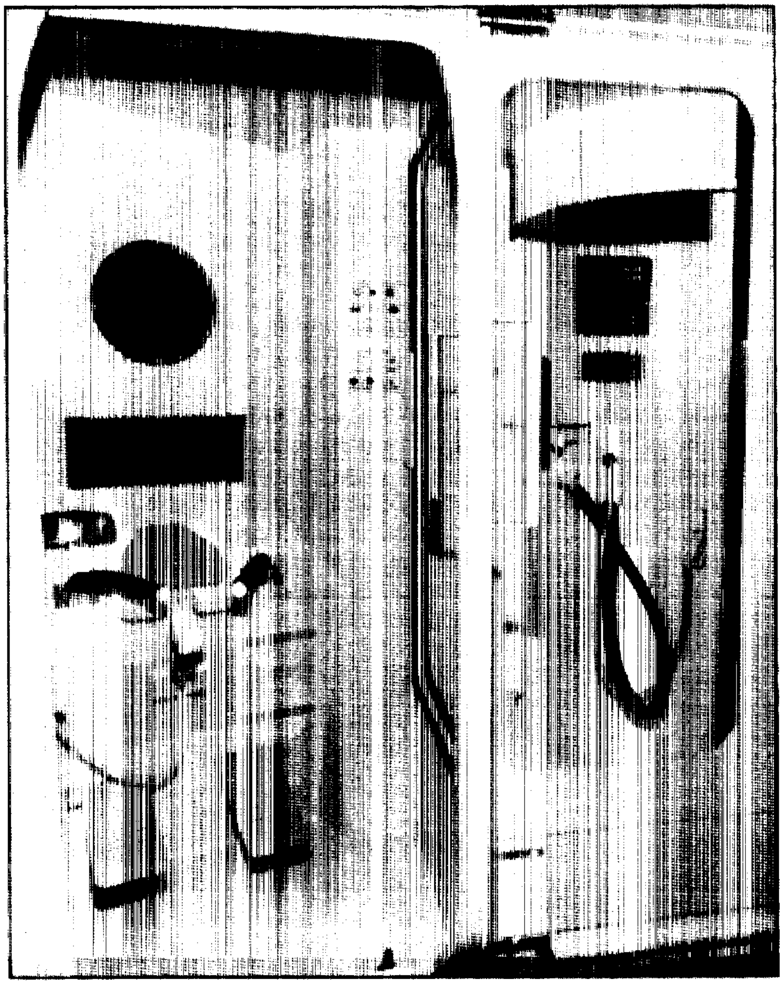
Devices are needed for Space Shuttle docking at the manned base. JSC is responsible for these attachment systems, plus those needed for logistics supply modules. Devices to attach experiment packages and external hardware to the truss structure are also handled by JSC.



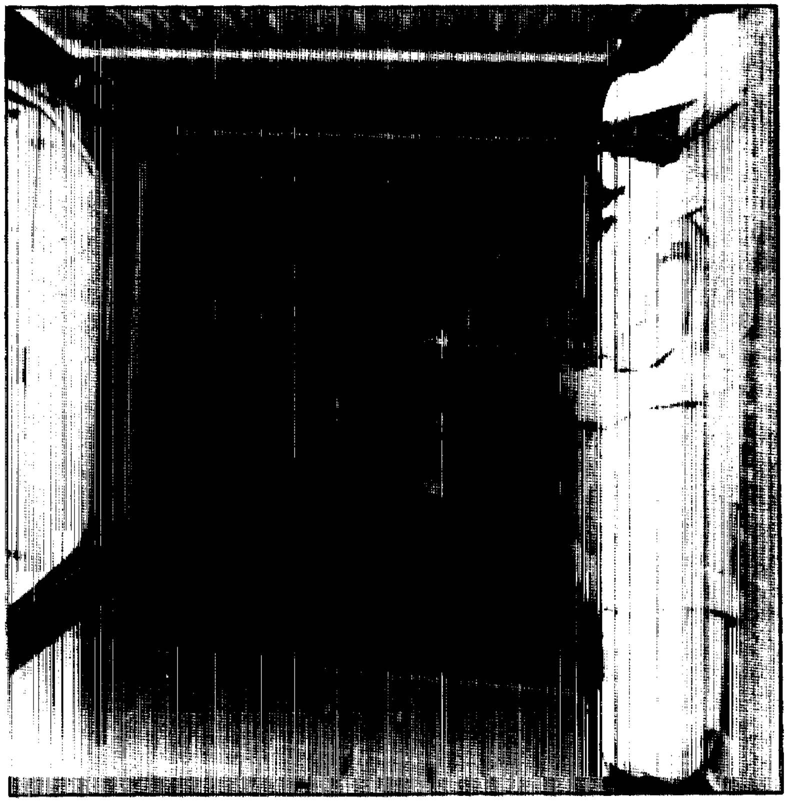
EVA System

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). JSC 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.

Crew Hygiene System



Sleep Restraint



Interior views of the Habitation Module

Crew and Ground Support Personnel Training

JSC is responsible for providing the U.S. systems training and a portion of the CSA MSS systems training for the SSF crew and JSC Ground Support Personnel (GSP).

Overall Space Station Training includes instruction in distributed systems, such as power and life support, module-unique systems, on-orbit operations, man systems, robotic systems, EVA operations and payload operations.

Training of the crew and GSP is accomplished through the completion of several training phases. GSP training is the responsibility of each NASA center or international partner (i.e., CSA, ESA, NASDA), while crew training responsibility is distributed across all space station partners (i.e., CSA, ESA, NASA, NASDA).

First, each student completes Basic Training. For the crew, Basic Training includes such subjects as science, space science and technology, general spacecraft system overview, and operations capabilities. Basic Training for the GSP includes such subjects as space systems overviews and space history. Much of this training, as well as other high level training, will be accomplished through the use of lectures, workbooks and computer based training.

All international partners provide Basic Training for their crewmembers and GSP. Upon the completion of Basic Training, the crewmembers from across the world will be brought together to receive International Integration Training, which is designed to ensure that each crewmember has the same skills. For example, crewmembers from CSA, ESA and NASDA will receive T-38 familiarization, water survival training and Space Shuttle familiarization at NASA.

Next the students receive Advanced Training. For the crew, this training includes instruction in space station systems, payload science, generic payload equipment and payloads that will remain on the station for extended periods of time. JSC is specifically responsible for the U.S. systems training. This training will occur in the Space Station Training Facility and the Space Station Mockup and Trainer Facility, as well as other JSC training facilities. The GSP will receive training specific to their discipline (e.g., life support, power, data management). Much of this type of training, as well as other detailed training, will be accomplished through the use of mockups, trainers and simulators.

The last phase of training, Increment Specific Training, will begin when the crew or GSP are assigned to an increment. During the PMC timeframe, this occurs approximately 18 months prior to launch for the crew and approximately three months for GSP.

For the crew, Increment Specific Training is divided into three six-month periods. During the first two six-month periods, instruction will include individual payload familiarization and operations, operation of combined suites of each partners' payloads, distributed systems, and module-unique systems and elements. Again, JSC is responsible for the distributed systems training.

During the final six-month period, instruction will include primary systems training at JSC. Minimal payload training will be conducted at JSC during this period. The crew will concentrate on systems training to ensure safety and operability of the Station once on orbit.

During the last three months before launch, the crew will be integrated with the SSCC mission controllers and with the POIC mission controllers to enable the crew to establish a working relationship with the ground controllers. Training sessions involving the crew and mission controllers are the responsibility of JSC.

Finally, after launch, emergency (fire, etc.) drills will be conducted to ensure crew safety. Additionally, the crew may ultimately have the capability to train onboard through the use of computer based training, videotapes, sessions with the ground, etc.

Operational Activities

A typical day's activity for the manned base will be analogous to the operation of a multifunctional 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 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 the manned base plus post-landing 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 realtime operations, the Space Station Control Center (SSCC), led by its Operations Director 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 Space Shuttle Mission Control Center.

In the interest 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 operations data file uplinks to the crew (including checklists and crew timelines). The Payload Operations and Integration Center (POIC) at MSFC 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 (ESCs), both domestic and partner-supplied.

Other systems inputs are provided to the SSCC for logistics support. These inputs are integrated into the realtime replanning effort, along with the user resource templates provided by the POIC to maximize systems performance, crew effectiveness and user operations returns.

JSC, with support from the ESCs, 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 analysis of unanticipated situations onboard SSF.

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).

Key SSCC Elements and Systems

Manned operations will be directed from the Space Station Operations Control Room (SSOCR) which is centrally located on the second floor of the SSCC. Prior to manned operations, the SSOCR will be used for integrated training, which is scheduled to begin in 1995.

Surrounding the SSOCR on the first, second and third floors are Space Station Support Rooms (SSSR) in which teams of experts will provide realtime operations support to mission controllers in the SSOCR.

The Operations Support Room (OSR) is also located on the second floor and will serve as the prime operations center for unmanned operations, as well as for training and operations support during manned operations.

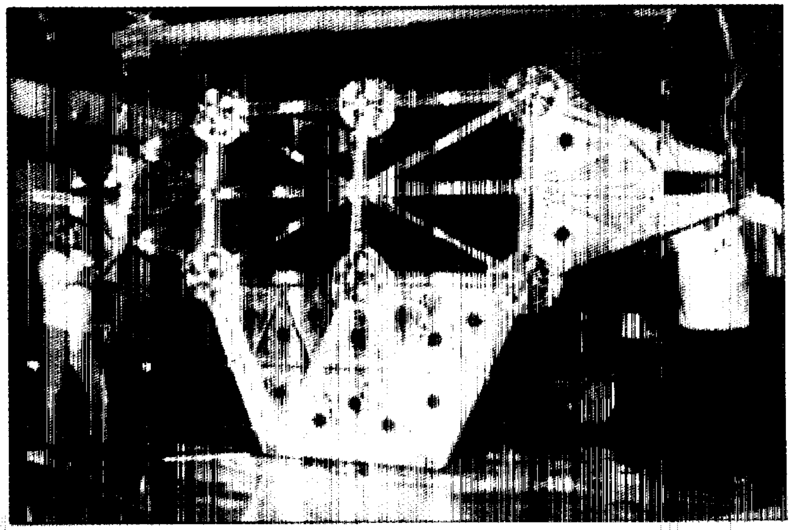
The Mission Operations Integration Room (MOIR), located on the first floor, will serve as a central point of information exchange and resource management, during missions, between the SSCC and such external elements as the Space Station Training Facility, Engineering Support Centers located in the U.S., Canada, Europe and Japan, as well as the POIC.

Also on the first floor is the Operations Data Room (ODR) in which technical experts representing the Space Station Program and international partners can monitor and analyze realtime and recorded telemetry.

The SSCC is composed of five basic but critical ground systems that directly support SSF operations:

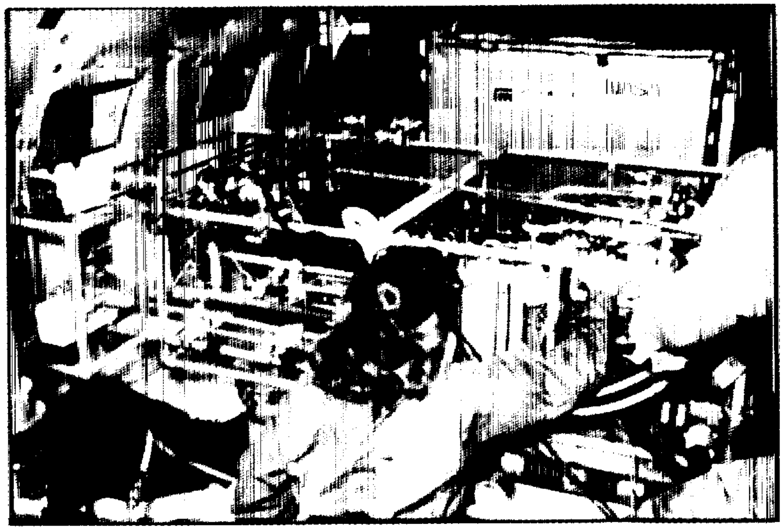
- Flight Support System,
- Data Storage and Retrieval System,
- Communications and Data Distributions System,
- Ground Support System, and
- Trajectory, Command, Analysis and Timeline Systems.

Propulsion Thruster Test

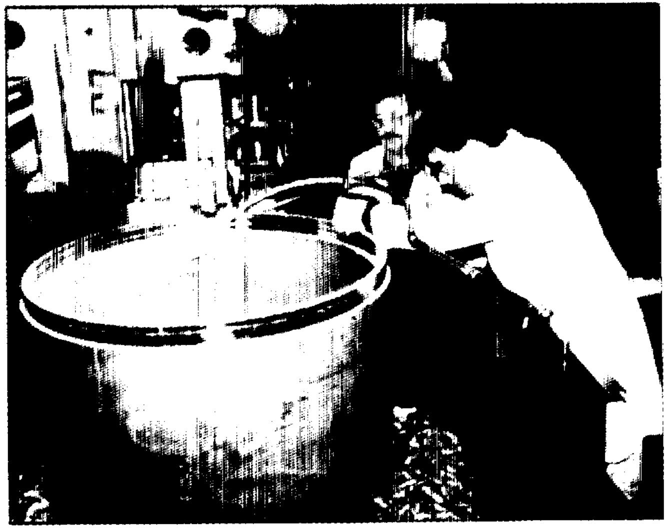


Propulsion Module Structural Test Article

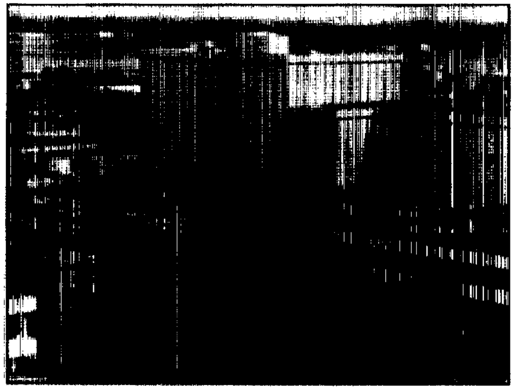
Testing the ATCs



Propellant Tank Fabrication



Test and
Prototype
Hardware

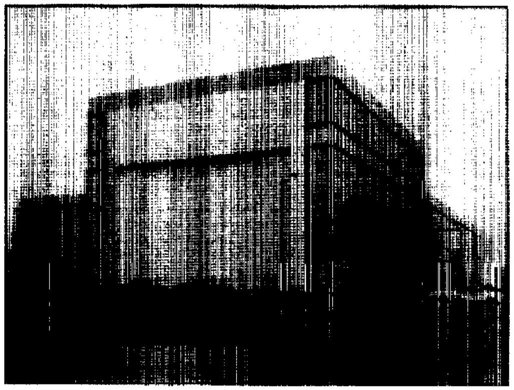


Facilities

Space Station Control Center (SSCC)

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

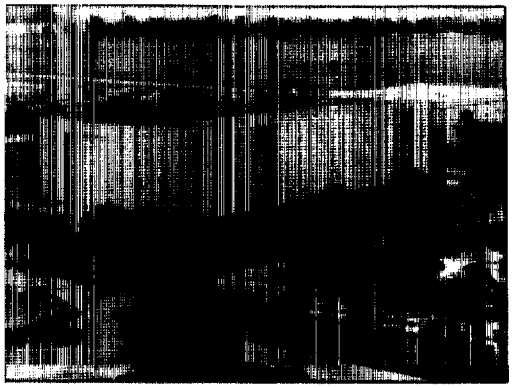
A five-story addition has been constructed at the southwest corner of the existing Mission Control Center (MCC). The addition consists of approximately 102,000 square feet of usable space for space station operations support and data processing and storage. The facility will be fully operational approximately one year prior to launch of the first element, in order to conduct simulations. It will house four computer mainframes, 90 workstations and 300 personnel.



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 and 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 48,000 square-foot addition has been 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 27,000 square-foot, three story, laboratory support area.



Space Station Training Facility (SSTF)

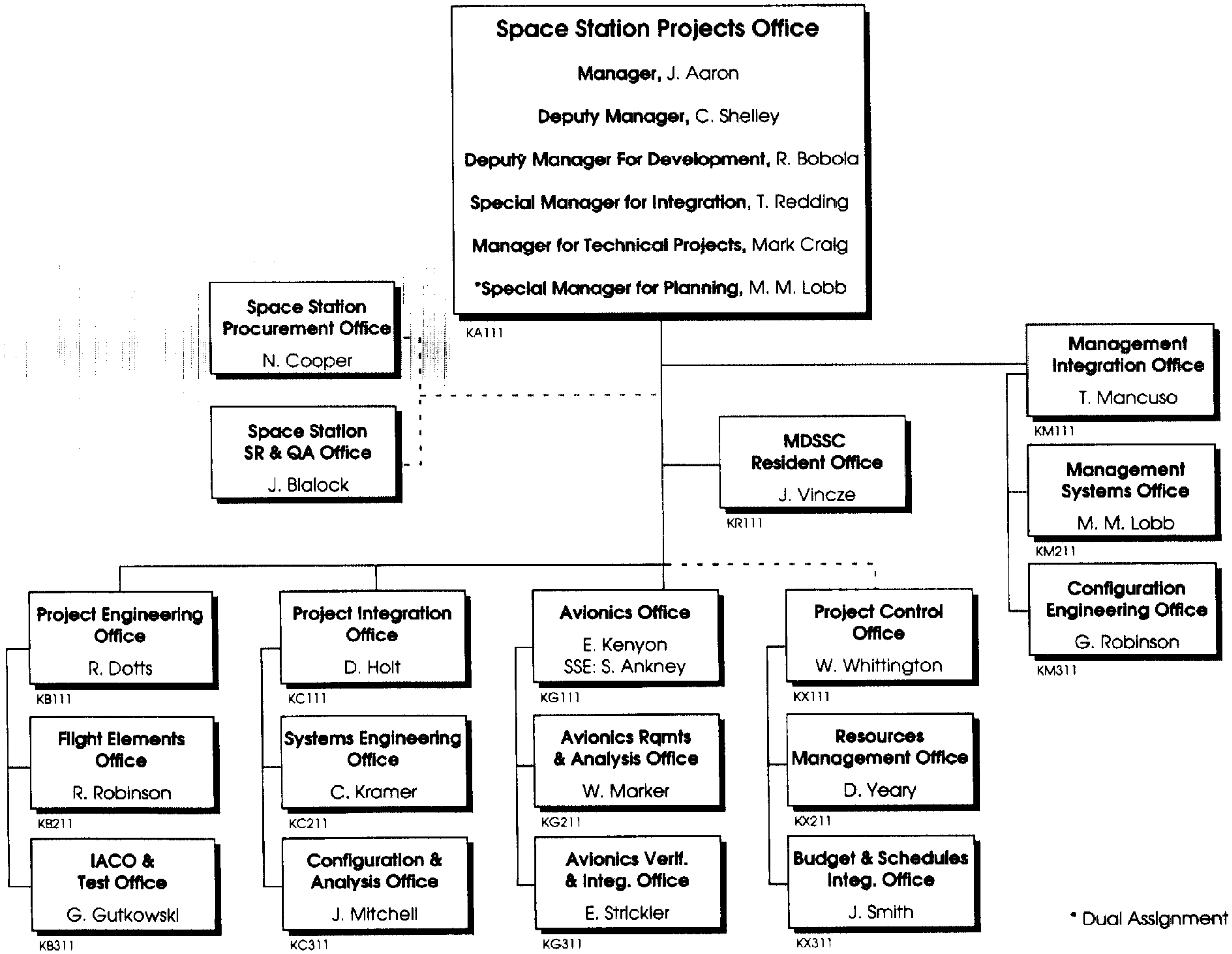
This facility will support Ground Training Applications Software Development; Manned Base Training for Crew and Ground Support Personnel; Integrated Operations Training for Systems and Payloads; Flight and Ground Procedures Verification; Flight Software Verification; and Space Station Information System Network simulation. A three-story addition has been constructed on the south side of the existing south-wing high bay of Building 5 and is being outfitted. The addition includes approximately 23,200 square feet of floor space. A variety of trainers needed for the unique space station systems will be housed in the facility.

Space Station Freedom Projects Office

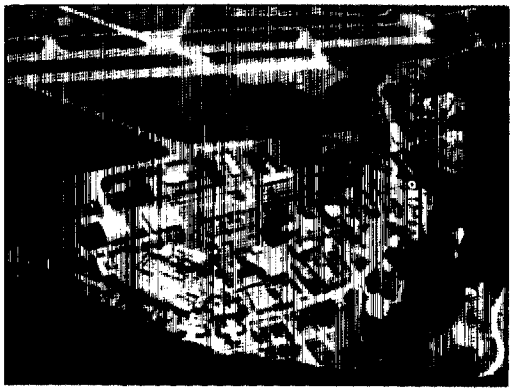
JSC is responsible for the design, development, verification, assembly and delivery of the Work Package 2 flight elements and systems. This includes the pre-integrated truss assembly, propulsion assembly, mobile transporter, resource node design and outfitting, external thermal control, data management,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

JSC has established the Level III Space Station 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 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 SSCC and ultimately the POIC when the station becomes permanently manned.



* Dual Assignment



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 in 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 government personnel number about 2,800 people plus 1,400 on-site contractors and the Center has 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.

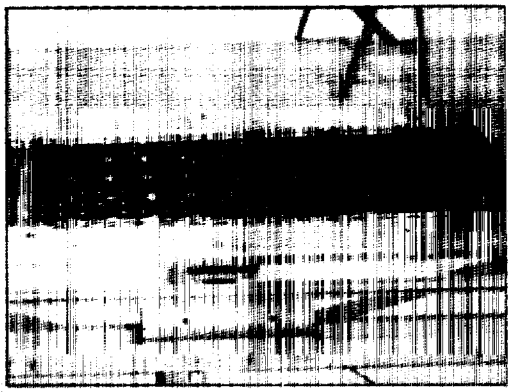
Whereas Lewis personnel have continued their traditional work in aircraft propulsion, they have expanded their expertise into space propulsion, space power and satellite communications. Lewis has managed the development of many NASA launch vehicles in the past 25 years, including the Atlas, Titan and Centaur rocket vehicles. In space communications, Lewis is currently managing the Advanced Communications Technology Satellite (ACTS) program. Lewis is also noted worldwide for its expertise in space power. Additionally, they have applied this fundamental knowledge to terrestrial applications such as solar and wind energy, automotive propulsion, advanced technology batteries, fuel cells and biomedical engineering.

A number of large facilities at Lewis 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. Some of the unique facilities supporting programs and basic research include the following:

- Power Systems Facility,
- Propulsion Systems Laboratories,
- 8- by 6-foot Transonic/Supersonic Wind Tunnel,
- 9- by 15-foot Low Speed Anechoic 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, and
- Plum Brook Space Power Facility (which includes a 100 ft. diameter by 120 ft. high vacuum chamber, the largest in the free world).

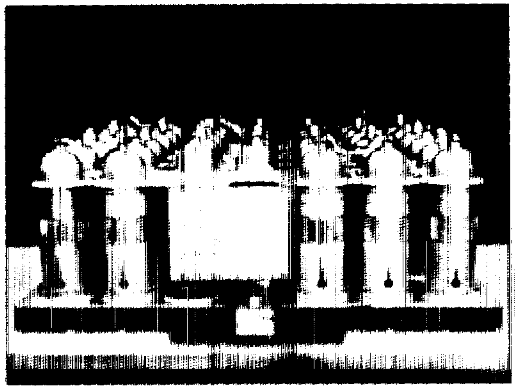
The new Power Systems Facility will test the Space Station Freedom Power System. Lewis is well-prepared to manage the end-to-end electric power system architecture for the station including solar arrays, batteries and common power distribution.

Space Station Freedom Unique Activities (Summary)



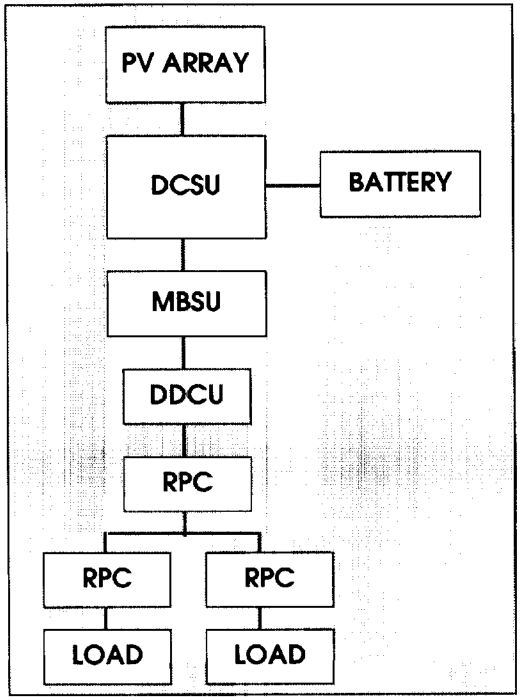
Solar Arrays

A series of six solar array wings will be utilized to provide electric power aboard the Space Station Freedom during its early years. Each 39- by 112-foot wing consists of two blanket assemblies, each covered with 16,400 solar cells. Each wing blanket assembly consists of solar cells attached to a flexible substitute, permitting the wing to be completely stowed for deployment.



Batteries

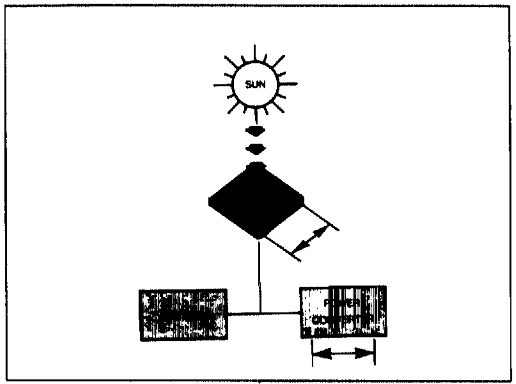
The energy obtained from the sunlight will be stored in Nickel-Hydrogen (Ni-H_2) batteries for later use when the station is in the Earth's shadow. A battery orbital replacement unit (ORU) is made up of 38 Ni-H_2 cells, the wiring harness and mechanical/thermal support components. Two ORUs in series will comprise a single battery, with a total of six batteries in each PV module.



PV = photovoltaic
DCSU = direct current switching unit
MBSU = main bus switching unit
DDCU = DC to DC conversion unit
RPC = remote power controller

Power Management and Distribution (PMAD)

The 160 VDC Power Management and Distribution (PMAD) system is designed specifically to meet aerospace system requirements. The system is based upon rapid semiconductor switching in DC to DC Conversion Units (DDCUs) and electro-mechanical devices to tailor voltage and energy levels of the system. The PMAD system will deliver controlled power to many scattered and different user loads.



Elements and Systems

Electrical Power System (EPS)

NASA Lewis Research Center is responsible for the end-to-end electric power system architecture for the space station. The EPS provides all user and housekeeping electrical power and is capable of expansion as the station is assembled and grows. Initially, the EPS will supply 18.75 kW of electrical power, which will increase to 56.25 kW at PMC (Permanently Manned Capability). The EPS consists of power generation and energy storage subsystems grouped into a Photovoltaic (PV) Module which feeds power into the Power Management and Distribution (PMAD) subsystem.

Power Generation Subsystem

A photovoltaic (PV) power generation subsystem was selected for the Space Station Freedom. 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.

Power for the space station will be provided by 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-41B. Each 39 ft. x 112 ft. (11.9 m. x 34.2 m.) 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 an extendible mast. A tension mechanism will supply tension to the blanket as it reaches complete extension. The entire wing will be tied structurally to the Photovoltaic Module 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 Photovoltaic Modules, providing increments of 18.75 kW of power per module.

Energy Storage Subsystem

The primary purpose of the Energy Storage Subsystem (ESS) is to provide electrical power during the eclipse portion of each orbit. The ESS stores energy for this purpose during the isolation portion of the orbit and is capable of providing both peaking and contingency power. The ESS consists of six nickel-hydrogen ($Ni\text{-}H_2$) batteries, each with a dedicated battery charge/discharge unit (BCDU), per PV module. This configuration is known as the full battery complement configuration. Each of the PV modules, however, is scheduled to be placed into orbit in the "offloaded" configuration consisting of four batteries and BCDUs, with the final two batteries being added later. Each battery assembly consists of two 38-cell battery ORUs. The Ni/H_2 battery design has been chosen for SSF because of its high energy density (light weight) and proven heritage in space applications since the early 1970s.

Solar Power Module (SPM)

The SPM consists of the power generation subsystem, the energy storage subsystem, a PV Module thermal control subsystem and Power Management and Distribution (PMAD) components, all mounted on a structure called the Integrated Equipment Assembly (IEA). The SPM generates 18.75 kW of power for the loads and is mounted on the Space Station Freedom outboard of the alpha gimbal assemblies. By definition, the collection of PV Modules on each end of the Space Station Freedom are called Solar Power Modules (i.e., a grouping of one or more Photovoltaic Modules).

The solar array wings will be mounted on the PV Module structure by means of the beta gimbal assemblies which allow for the changes of angle needed by the wings to track the sun as the seasons change throughout the year. The basic structure within the PV Module consists of the Integrated Equipment Assembly (IEA). There is one IEA in each of the PV Modules.

The energy storage subsystem will include four batteries per Module, at the time of the initial Man-tended Configuration. These provide power during time periods when the sun is not visible. In later stages of the Station assembly the four batteries will be replaced by six per Module in order to allow for both greater eclipse power capability and longer battery life.

The thermal control system maintains component temperatures within safe limits by means of a coolant circulated through chilled plates on which the components are mounted. The coolant rejects heat into space through a radiator assembly which is also mounted on the IEA.

The PMAD components regulate the DC voltage supplied by the arrays to usable levels and control the charging and discharging of the SPM batteries.

Primary Power Distribution

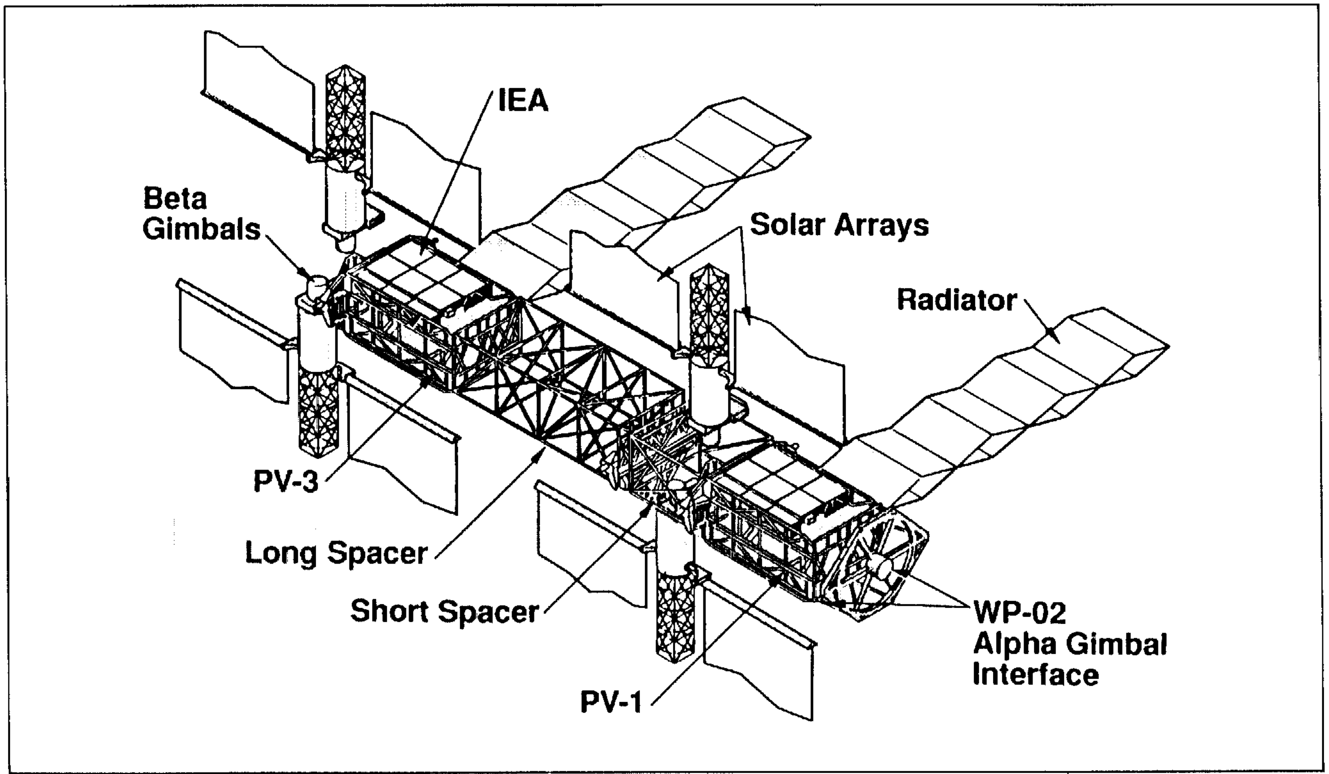
The 160 VDC Power Management and Distribution (PMAD) system is designed specifically to meet aerospace system requirements. The system is based upon rapid semiconductor switching DC to DC Converter Units (DDCUs) and electromechanical devices to tailor voltage and energy levels of the system.

The overall distribution equipment will include cables, load converters, regulators switches and other 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.

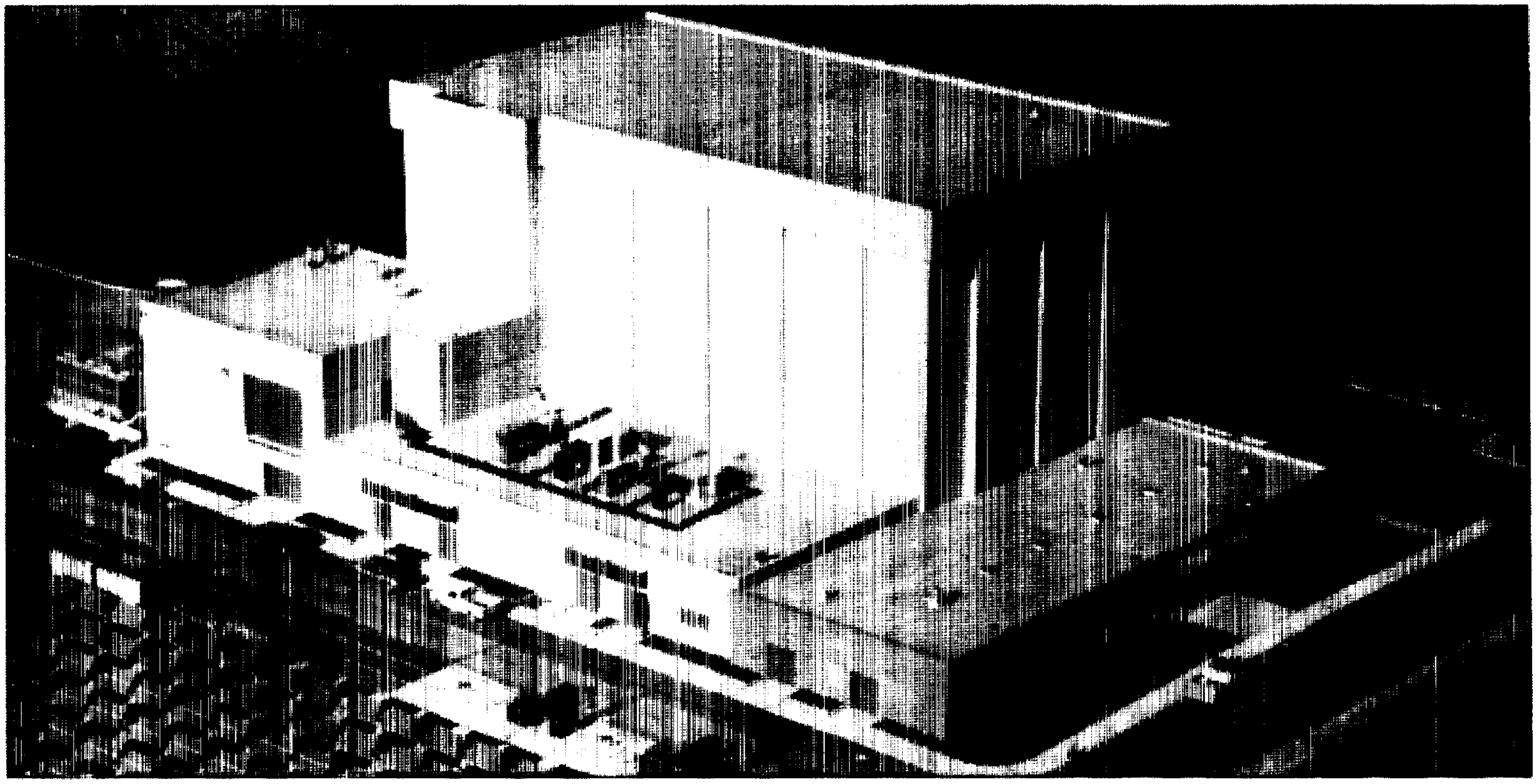
Electrical loads will receive power from the primary power system via secondary power switches connected to DDCUs. The DDCUs serve a dual function in the SSF power system. First they will serve as power transformers from primary to secondary power. Secondly, they will act to isolate the primary power system from the secondary one. This is beneficial in several ways. Above all, the primary power system will not be subjected to any harmful effect due to secondary power problems, and secondary power will not be subject to any degraded power quality from transient primary power transmission problems.

A significant design decision for the primary power system has been the use of the structural truss system as the principal ground system. This has resulted in a significant reduction in cable weight for the SSF Power System. This decision was made possible by a change in the design of the structural truss from a composite design to a conductive aluminum material.

Terrestrial AC power systems were used as a basis for the design of the primary power protection system. The protection system employs time coordinated overcurrent trip devices similar to those found in AC electrical power distribution cabinets encountered in everyday life. These devices are designed to detect, locate and interrupt electrical faults in the primary system, without endangering either personnel or equipment, while not interrupting power to the entire SSF.



Space Station Solar Power Module (Photovoltaic)



Facilities

Power Systems Facility (PSF)

The PSF provides the capability for development, testing, and evaluation of prototype power systems hardware for the space station program. The facility is 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 has a total area of approximately 31,000 square feet and includes a high bay test area with Class 100,000 Clean Room capability, a loading-unloading-workshop area, laboratory rooms and support areas. Batteries, other system components, and the Power Management and Distribution System will be tested in PSF. 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 simulators for the power generation system, others will require use of the outside solar array, powered by the sun.

Space Station Freedom Systems Directorate

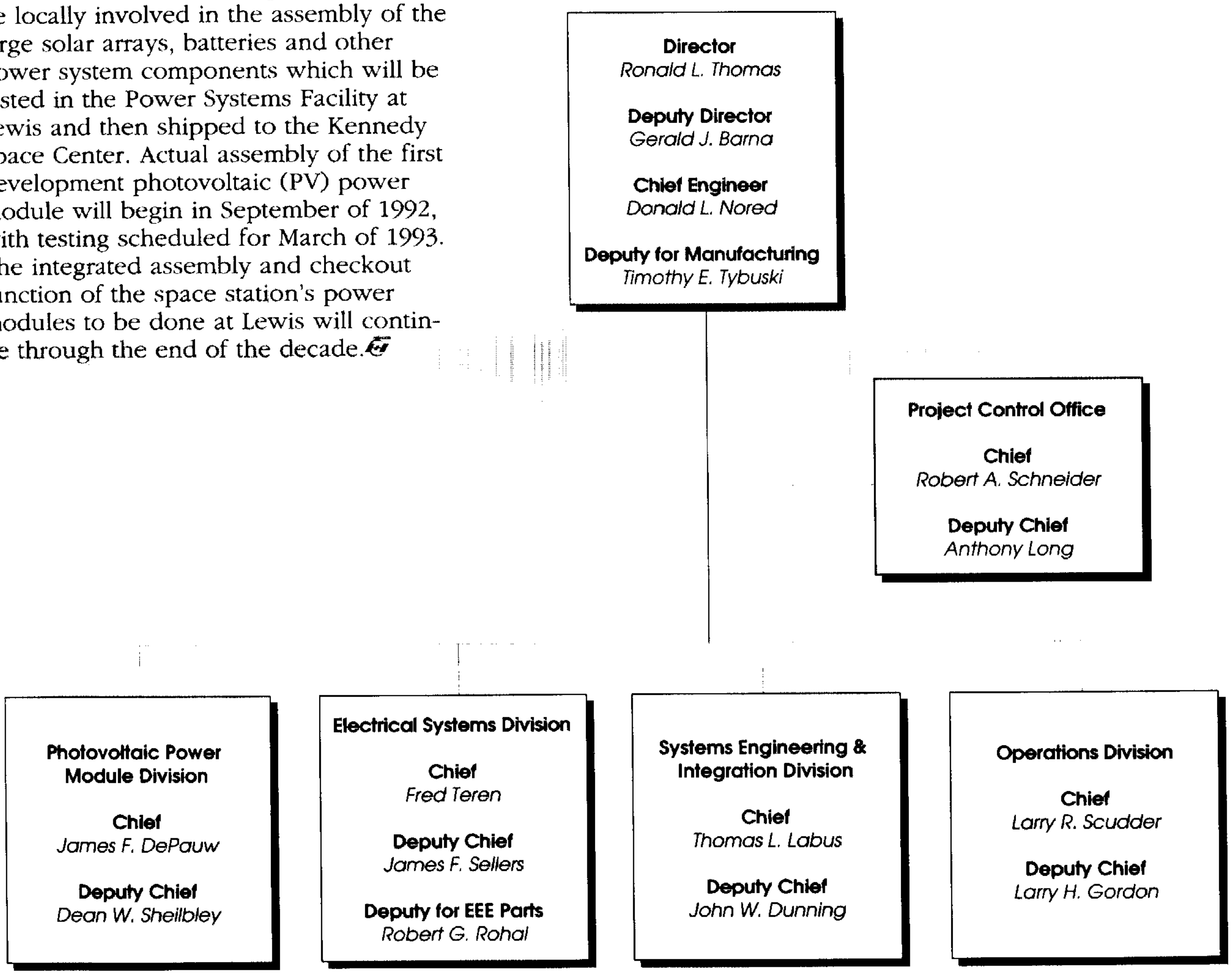
NASA's Lewis Research Center in Cleveland, Ohio, is responsible for the Work Package 4 portion of the Space Station Freedom Program. The Space Station Systems Directorate is responsible for the design and development of the Electric Power System. In effect, this Directorate is the Space Station Freedom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

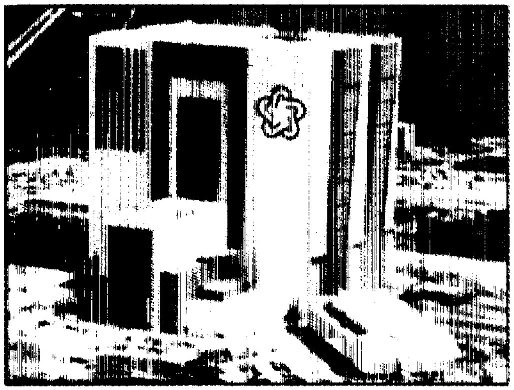
This organization currently includes approximately 250 civil servants. There are an additional 150 people in other Lewis organizations working on areas such as reliability and quality assurance, loads, structural dynamics and thermal IV and V test and evaluation, construction and outfitting of the Power Systems Facility and power related research.

Lewis Research Center/Rocketdyne Team Support

An additional 80 contract personnel will be locally involved in the assembly of the large solar arrays, batteries and other power system components which will be tested in the Power Systems Facility at Lewis and then shipped to the Kennedy Space Center. Actual assembly of the first development photovoltaic (PV) power module will begin in September of 1992, with testing scheduled for March of 1993. The integrated assembly and checkout function of the space station's power modules to be done at Lewis will continue through the end of the decade.



KENNEDY SPACE CENTER



Traditional Center Roles and Missions

Carved out of virgin savanna 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, prelaunch checkout and launch of the Space Shuttle and its payloads, including those of Space Station Freedom.

This responsibility extends to Space Shuttle operations, including the construction and maintenance of Shuttle payload and flight element processing facilities, and the development of ground operations management, processing schedules and logistics, and their use in support of Shuttle missions and payloads. The construction of a Space Station Processing Facility began in April of 1991.

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 were 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, crawlerways to Complex 39 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 Space Shuttle elements. The Launch Control Center (LCC) is described as the "brain" of Complex 39. Launch, mission support, and loading are controlled here.

Twelve manned and unmanned 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 former 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 Shuttle four times.

The current phase, commencing in 1982, is called the Shuttle 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 Space Shuttles. 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 resumed its primary role in preparing and launching America's Space Shuttles. KSC also continues its role of launching unmanned rockets as America prepares to enter the space station era.

Space Station Processing Facility (SSPF)

By September of 1994, Kennedy Space Center plans operational readiness for an approximately $72 million Space Station Processing Facility (SSPF). Construction began in 1991.

The SSPF will be a 466,500 square foot building designed especially for the processing of Space Station Freedom elements. These payloads will be launched by multiple Space Shuttle missions using the cargo bay for transportation and staging.

A high bay will support on-line module and element processing and large attached payload processing operations. An intermediate bay will provide rack and payload processing areas. Logistics and support areas will also be provided.

Nineteen laboratories will be provided in an area adjacent to the intermediate bay. There will be two chemical labs, two dark rooms, and fifteen labs for general experiments.

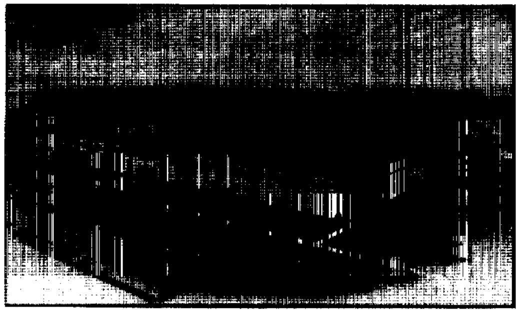
Flight elements will arrive at KSC by various means, including a C-5A, which has been modified by the U.S. Air Force to carry Shuttle payloads. A mobile transporter will move the hardware to the SSPF where it will be removed from shipping containers, inspected, and serviced in preparation for power-up testing, if necessary. Other elements, such as pressurized modules, will require full functional testing at the SSPF. Specific processing steps will be selected from capabilities appropriate for each flight element.

Generally, each flight element will follow a multiphase handling. The processing will move from post-arrival inspection through various technical tests and evaluations that cover all phases of electrical, electronic, and mechanical systems. These checks will constitute a well-balanced approach to the systematic testing of elements prior to flight. During the processing flow, the elements will be protected via fire suppression, climate control, and other ground support elements.

Since Space Station Freedom is an international program in scope, elements from Canadian, Japanese, and European partners will also be processed at Kennedy Space Center. Working with KSC engineers and technicians, representatives from international flight organizations will ensure that international and American elements test out together, and that they are compatible in both software and hardware applications. The processing will also include important testing between Payloads Operations Control Centers at various sites in the U.S. and abroad.

Throughout the process, astronauts will participate in key testing milestones. This will allow them to become familiarized with the elements they will be transporting to and using on Space Station Freedom.

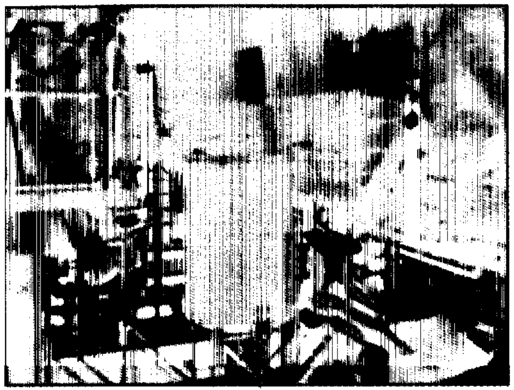
Upon return of the Shuttle from orbit, user payloads will be removed at the SSPF and routed to international, governmental, and private users. Logistics modules will be refurbished and refilled for the next flight to the station. Thousands of orbital replacement line items will be handled at KSC for logistical purposes aboard the space station. Nonhazardous station elements will be processed at the SSPF. Such items as fuel and oxidizers 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 will lead to the Kennedy Space Center in Florida. The various shipments will be off-loaded at KSC for receiving and inspection in the Space Station Processing Facility (SSPF). There the space station elements, systems and user payloads to be launched by the Space Shuttle will be inspected and monitored for damage or leaks. All structural and mechanical parts will be reviewed for safety, verification, and interface with elements or systems from other Centers and partners. Both hardware and software will be verified for post-shipment health, fit, and functionality. Pressure, temperature, and humidity will be evaluated, and some assembly may take place there before the payload is placed into a canister for transport.

Ground processing of logistics elements will be critical to Space Station Freedom operations. Three types of logistics carriers



will be 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 will handle the resupply of consumables for the on-orbit Environmental Control and Life Support System, laboratories and satellite servicing. An unpressurized cargo pallet will carry tools, equipment, and supplies. Each of these will be loaded into the payload canisters 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. Payload canisters are environmentally controlled. Supporting subsystems, such as instrumentation, monitoring devices, fluids, gases and electrical power are used as needed. Users will be 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 will be required before canisters leave the Space Station Processing Facility.

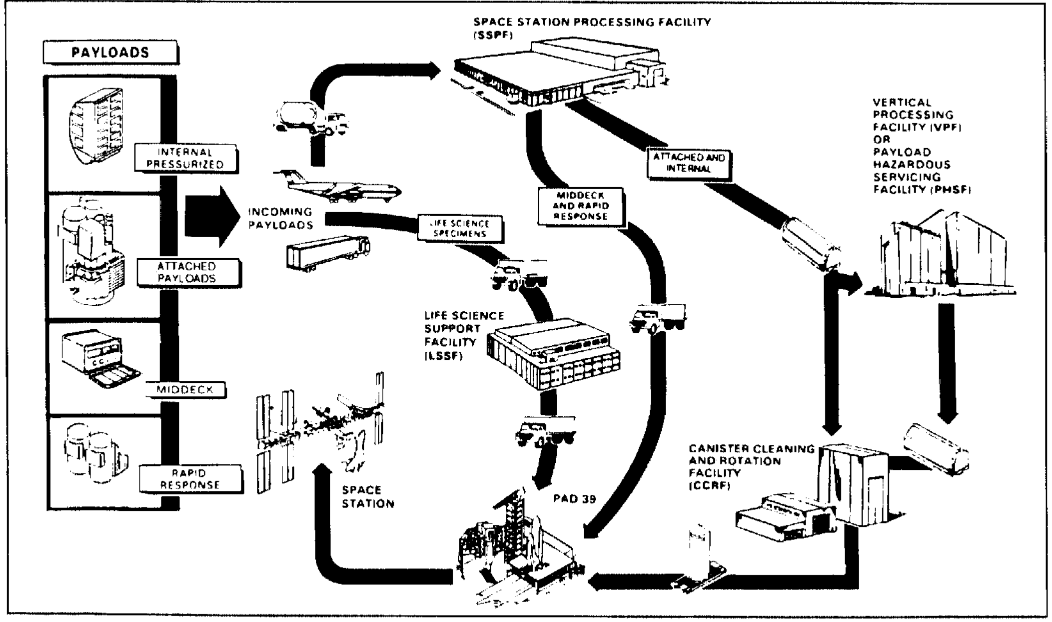
Various types of payload processing facilities will be used to support SSPF work, depending upon the mission-unique requirements. Meanwhile, the orbiter will be prepared for flight, and mated with the solid rocket boosters and external tank in the Vehicle Assembly building (VAB) in Complex 39. The VAB covers eight full acres and stands 525 feet high, one of the largest buildings in the world.

The orbiter and its stack will be moved to the launch pad in a vertical position. They will be carried by a crawler with four double-track drives, each 10 feet high and 41 feet long. They will travel along a roadway as broad as an eight-lane turnpike at about two miles per hour. Environmentally controlled canisters transport payloads to the Space Shuttle for installation into the payload bay. Most Space Station Freedom elements will be installed vertically at the launch pad after the orbiter is rolled out to the launch pad. Payloads loaded horizontally are installed in the Orbiter Processing Facility prior to VAB operations.

Nominal post-landing processing follows roughly the same procedure in reverse. The returned payload from Space Station Freedom will be transported to the Space Station Processing Facility after the Orbiter has been returned and the flight systems hardware removed. At the SSPF, Kennedy Space Center workers will examine the payload and return the experiments or products to the users. The reusable flight systems hardware will be refurbished and tested for the next flight to Space Station Freedom.

Currently, Shuttle 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 time, payloads for several flights can be processed.

Space Station Payload Processing Flow



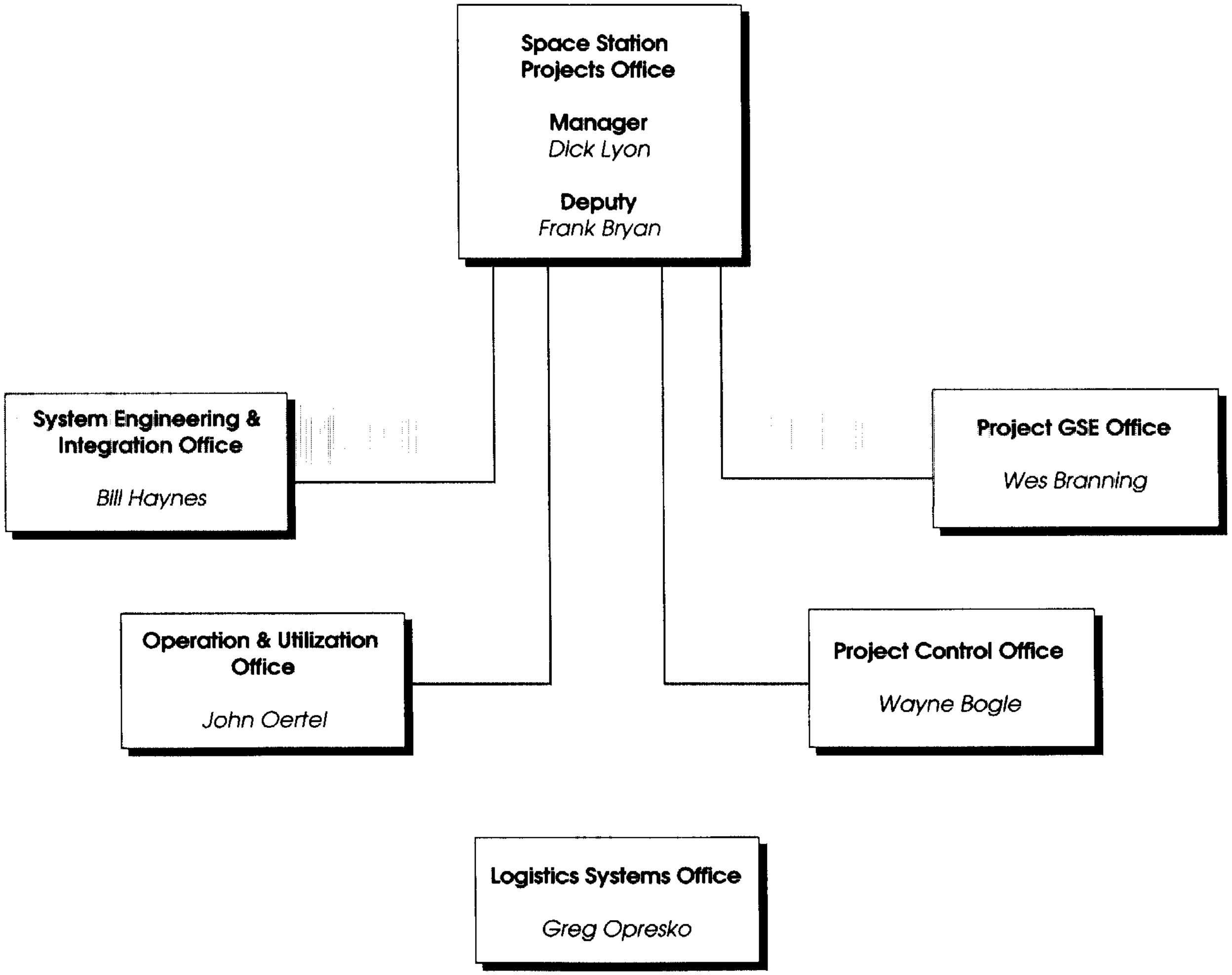
Space Station Freedom Project Office

The KSC Space Station Project Office plans for and oversees systems engineering and integration, ground support equipment management, operations and customer support, project control, and logistics systems.

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 prelaunch 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.

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 (LaRC) is in Hampton, Virginia, on the tidewater peninsula within the mouth of Chesapeake Bay (Hampton Roads). Langley's history is a history of NASA itself, having officially been established by the National Advisory Committee for Aeronautics (NACA), NASA's predecessor, in 1917. Popularly known as "Langley Field," the Center was dedicated as the Langley Memorial Aeronautical Laboratory on June 11, 1920, to honor Samuel Pierpont Langley—a contemporary of the Wright brothers who very nearly was successful in his own quest to achieve the first engine-powered, piloted flight. The laboratory was NACA's first research center—and remained its only such facility until 1939. Langley's first wind tunnel began operation in 1921, and the Center has since garnered five Collier Trophies.

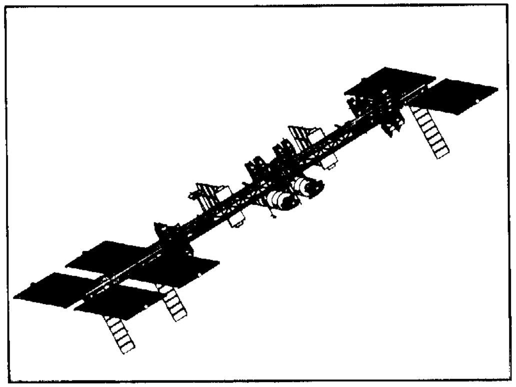
Langley has grown to cover more than 800 acres. The Center now manages nearly 2,000 contracts and a work force of approximately 5,500 civil service or contract personnel, and is one of the world's premier aerospace research operations. More than 50 major research and simulation facilities are utilized for work in aeronautics or space technology, supporting research and development in the fields of aerodynamics, advanced materials and structures, flight systems, information systems, acoustics, aeroelasticity, and atmospheric science. Approximately 26 major wind tunnels are now being used to explore the entire flight range at a variety of scales.

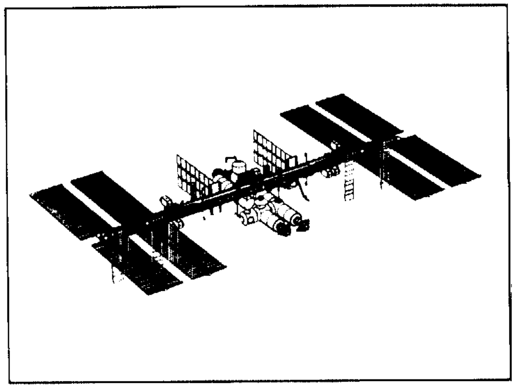
Aeronautical research accounts for 60 percent of Langley's work. Its programs reflect studies over the entire range of aeronautical design, from general aviation and transport aircraft through hypersonic vehicles. Researchers are working on basic technologies to improve aircraft through the development of advanced avionics and new composite fabrication materials, the investigation of vortex flow and laminar flow, and research to find ways to cope with dangerous weather conditions such as wind shear, heavy rain, and lightning. In addition, extensive work was performed in helping NASA develop the Space Shuttle, and the Center is now applying its expertise to the design of the proposed National Aerospace Plane.

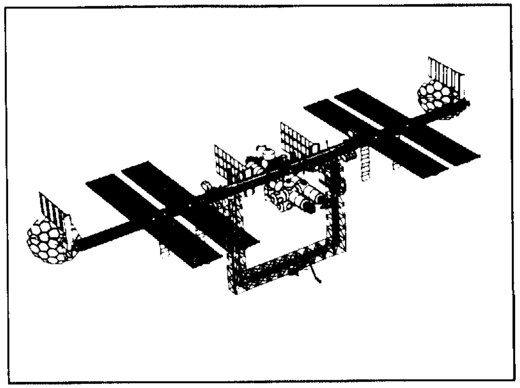
Langley became part of the National Aeronautics and Space Administration when NASA was formed in 1958. The historic Mercury program was managed at the Center by its pioneering Space Task Group. However, important unmanned space programs have also been managed at Langley. Langley's Lunar Orbiter Program successfully photographed candidate landing sites on the moon as a precursor to the Apollo program, and the Center also managed the Viking Project which, in 1976, placed two unmanned spacecraft into orbit about Mars and two unprecedented robotic landers on the surface of the Red Planet. Viking Lander 1, the first spacecraft to land successfully on Mars, continued to take pictures and monitor Martian weather at its landing site until November of 1982.

Important NASA Space Shuttle payloads have been developed at Langley, including the Long Duration Exposure Facility (LDEF) and ACCESS (Assembly Concept for Construction of Erectable Space Structures). ACCESS, an experiment designed to demonstrate that large structures can be assembled, tested, repaired and manipulated in Earth orbit, was flown on STS Mission 61-B in 1985; its experience will be applied to the development of improved structural assembly technologies that will one day be utilized in the space station.

LDEF contained 57 experiments contributed by the United States and eight other countries. It was brought back to Earth during the STS-32 mission in January 1990, after spending nearly six years in space. LDEF data derived from the effects—on various materials—of long term exposure to space environments, as well as data on the manmade and natural debris environment in low Earth orbit, will be extremely beneficial to the design of the space station.







Space Station Freedom Unique Activities

Space Station Evolution

Langley is responsible for the definition of space station evolution to meet future needs, such as: increased research and development activities, support of a return to the moon and support of a manned expedition to Mars. This responsibility includes conducting missions, systems and operations analyses; systems level planning of options and/or 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.

Systems Engineering and Analysis

Langley's Space Station Freedom Office is responsible for providing Level I engineering support for various systems engineering and analysis activities. This responsibility includes carrying out continuing planned studies to provide accurate and current requirements, as well as engineering analyses for upcoming program milestones. The engineering analyses involve systems requirements analysis and definition and systems engineering studies of space station systems, interfaces and performance. Support is also provided for the technical assessment of Level I changes and the independent assessment of flight and ground systems.

Utilization Representation

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 user accommodation analyses; representing NASA's Office of Aeronautics and Space Technology (OAST) on various space station users panels and working groups; participating in OAST's In-Space Technology Experiments Program; identification and analysis of the evolutionary space station's technology needs for OAST; and managing the space station modal identification experiment.

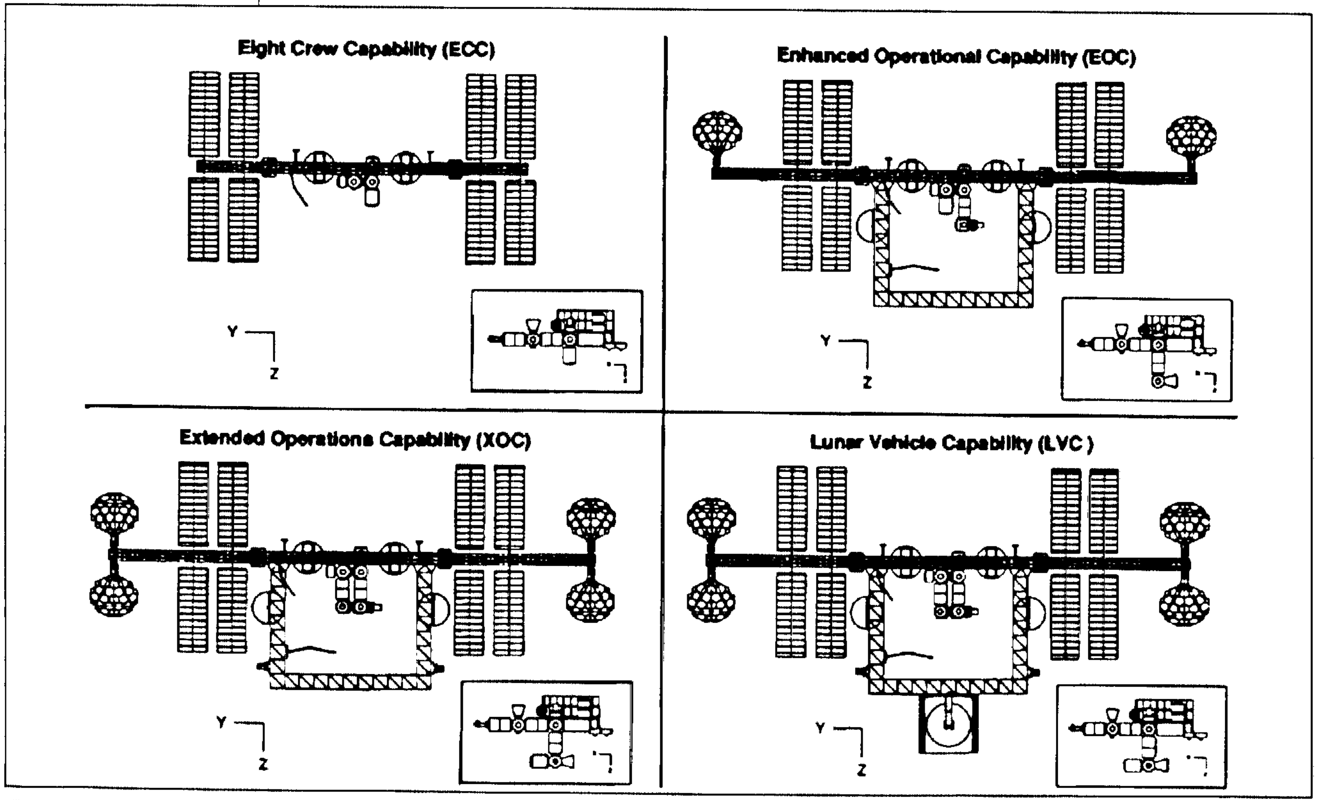
Langley is also responsible for providing system engineering and utilization support to the Microgravity Science and Application Division in the Office of Space Science and Applications.

Space Station Evolution

Space Station Freedom is designed to evolve as a highly flexible and expandable research platform which will accommodate future software and hardware growth elements. Langley Advanced Programs Office (APO) is responsible for studying its evolution in the context of future needs. This goal reflects research being focused on systems growth beyond that reflected in the initial completed

Space Station Freedom Evolution Configurations

- *Permanently Manned Capability (PMC)*
  - *Development Program Baseline*
- *Eight Crew Capability (ECC)*
  - *Crew and Power Augmentation*
- *Enhanced Operation Capability (EOC)*
  - *Enhanced Attached Payload and Micro-G Accommodations*
- *Extended Operations Capability (XOC)*
  - *Crew and Power Augementation for Increased R&D Utilization*
- *Lunar Vehicle Capability (LVC)*
  - *LTV Assemby, Test, Launch, Recovery and Turnaraound Operations*
  - *Focused R&D*
  - *Aggressive Life Sciences Research (CM Development)*



configuration, including the study of systems needed to support initiatives to return to the moon and undertake the human exploration of Mars.

This responsibility includes conducting evolution studies for Level I, advanced program definition, change request evaluation for impacts to evolution capabilities and evolution technology analyses for OAST. The goals of this work are to define evolution configurations that are consistent with both user requirements and program constraints, and the baseline accommodations necessary to satisfy evolution requirements. A systems analysis capability and an operations simulation capability to study the operational feasibility of growth configurations have been or are being developed for this effort.

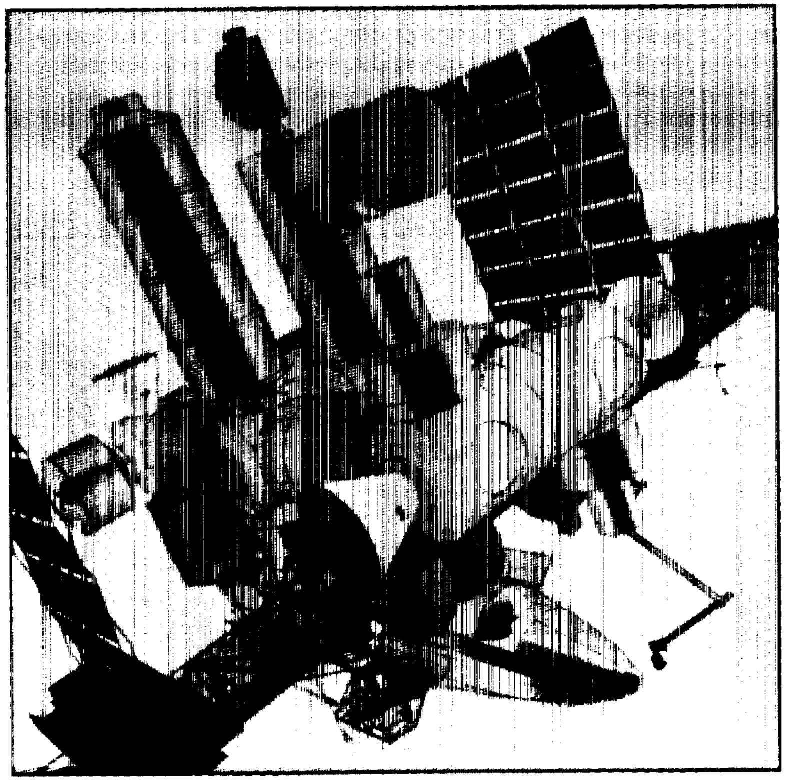
Systems Engineering & Analysis

Langley's space station office provides Level I engineering support for various systems engineering and analysis activities. The Center's previous SE&I involvement in the Space Station Freedom Program included key studies associated with configuration definition and launch vehicle utilization, including single/dual keel microgravity assessment, critical evaluation task force, rephased program options, the Administrator's mixed fleet study/report, the ASRM enhanced assembly sequence and Shuttle-C utilization options. A number of special studies were also performed for agency management, including the joint LaRC/GSFC stationkeeping platform, SSF assembly alternatives, and the commercially developed space facility (CDSF) definition. Langley

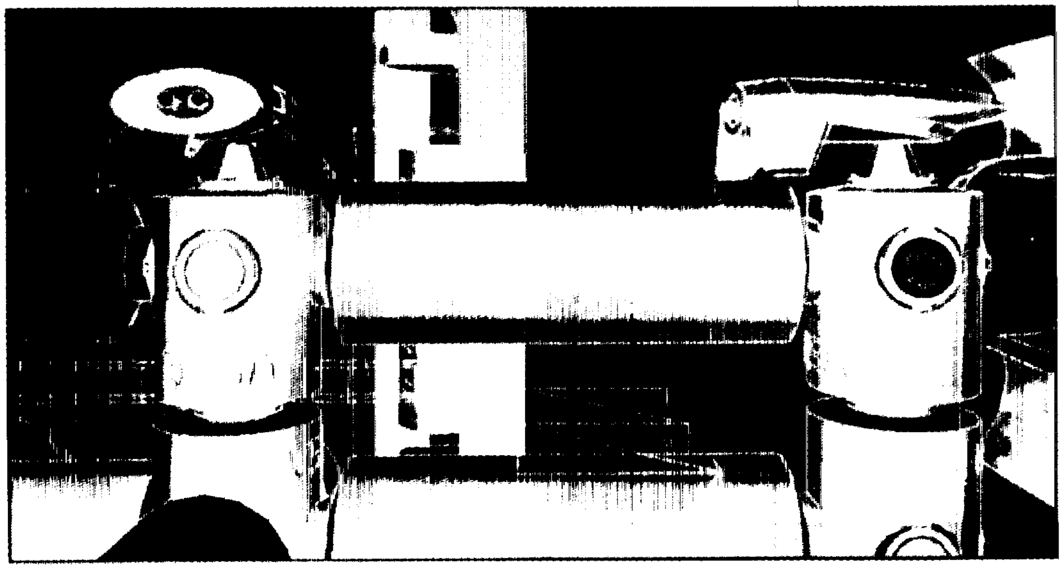
- *Space structures*
- *Space environmental effects*
- *Power systems and thermal management*
- *Fluid management and propulsion systems*
- *Automation and robotics*
- *Sensor and information systems*
- *In-space systems*
- *Humans-in-space*

also participated in the 90-day study of the Human Exploration Initiative (HEI) now called Space Exploration Initiative (SEI).

Langley has developed an extensive multidisciplinary systems engineering analysis capability supported by advanced CAD/CAE analytical tools. The Level I engineering support role will utilize this capability to conduct various user studies of SSF systems, interfaces and performance. These studies are expected to include such issues as: EVA utilization, space suit development, and assembly stage systems performance issues associated with in-flight assembly and buildup alternatives; assembly and logistics relating to the use of a mixed launch vehicle fleet; power and thermal systems capacity; phase-up ACRV accommodation/interface assessments; information management and software system architecture performance assessment.



Assembly Complete; Steady State Microgravity with Orbiter Docked



Study of ACRV Docking Locations

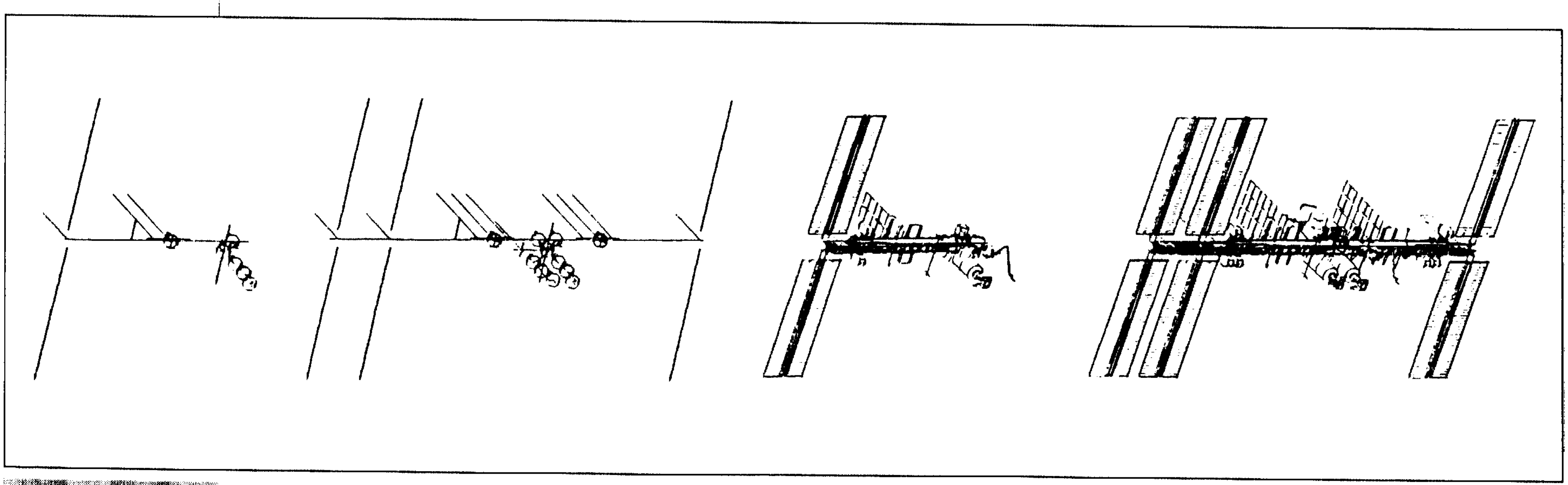
Utilization Representation

To ensure that the space station will accommodate a variety of 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 databases; technology development involving test and evaluation of prototype components and subsystems; and demonstrations involving proof of maturity and performance verification in integrated system context.

Langley is also responsible for conducting various use accommodation analyses such as determining support equipment outfitting needs, assessing the station's ability to accommodate all known technology disciplines, and developing and maintaining a technology experiment database of all planned technology experiments. Langley represents OAST on various space station user panels and working groups, including the user integration panel; user design accommodation working group; design reference mission working group; ground operations panel; multilateral payload integration emulation study; small and rapid response steering committee; and the support equipment development steering committee which defines and develops industry, academic and NASA in-space experiments.

The program includes experiments in 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, and humans-in-space systems. These experiments will initially utilize the Space Shuttle or ELVs (expendable launch vehicles) but they will transition to the space station as it becomes available. One of these experiments, the Space Station Modal Identification 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.

The space station modal identification experiment begins with the first assembly flight.

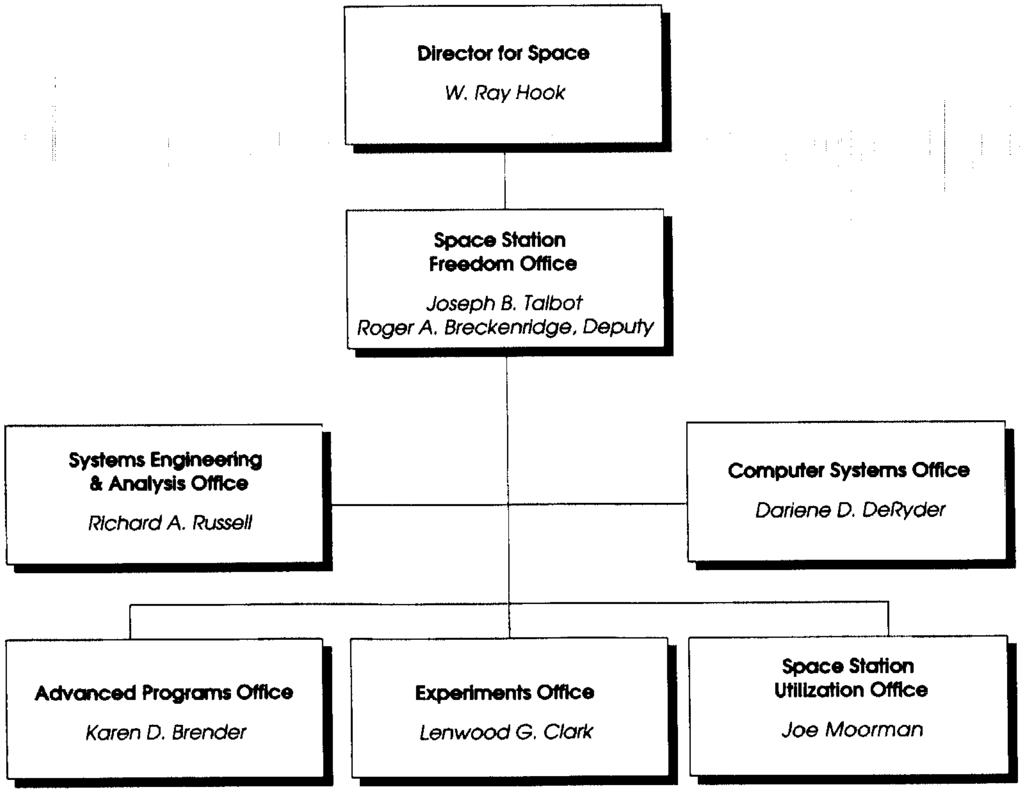


Space Station Freedom Organization

The Langley Space Station Freedom Office is the focal point for the 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 the program. This organization currently includes more than 40 civil servants, and there are an additional 50 people working in other Langley organizations supporting research, studies and analysis.

The Langley Space Station Freedom Office is NASA's lead office for the identification, definition and evaluation of evolutionary space station capabilities, and for the identification of technology and advanced development required for long-term evolutionary development. The office also has a lead role in providing Level I engineering support for systems engineering and analysis.

Finally, this organization represents the engineering community that will be involved with the space station as technology users. It advocates flight experiments for future NASA Space Shuttle flights that will contribute to space station technology use, as well as those from technology programs that can contribute to both the initial space station operational capability and the evolutionary space station.



Traditional Center Roles and Responsibilities

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 Facility 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 430 acres of land adjacent to the U.S. Naval Air Station, Moffett Field, California.

Ames-Dryden, which is located in the high desert about 80 miles northeast of Los Angeles, occupies about 520 acres adjacent to Edwards AFB. This facility was established in 1947 as a NACA flight research station at the U.S. Army Air Corps Test Facility, Muroc, CA (now Edwards AFB). In 1959, the station became the NASA Flight Research Center, and in 1976 it was renamed the Dryden Flight Research Facility in honor of D. Hugh Dryden, Chairman of 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:

- Computational fluid dynamics,
- Advanced life support,
- Artificial intelligence,
- Flight simulation,
- Flight research,
- Life sciences,
- Computer science and applications,
- Rotorcraft and powered lift technology,
- Aeronautical and space human factors,
- Space sciences,
- Interplanetary missions,
- Airborne science and applications,
- Search for extraterrestrial intelligence,
- Earth systems science, and
- Infrared astronomy.

About 2,200 civil service employees and almost 2,100 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 while still transmitting data, as it does today.

Ames has some of the most unique facilities in the country including:

- National Full-Scale Aerodynamics Complex, which includes the largest wind tunnels in the world,
- Numerical Aerodynamic Simulation Complex, which houses the world's most powerful supercomputer system ,
- Ames' fleet of airborne laboratories,
- Vestibular Research Facility,
- Human Research Facility,
- Suite of rotating devices for animal and human research,
- Man-Vehicle Systems Research Facility,
- Human Performance Research Lab,
- Automated Sciences Research Facility, and
- Piloted flight simulation facilities.

New programs for the 1990s and beyond include Space Exploration Initiative (SEI), Stratospheric Observatory for Infrared Astronomy (SOFIA), Comet Rendezvous Asteroid Flyby (CRAF) and Shuttle life sciences experiments.

Space Station Freedom Unique Activities

Ames Research Center serves in a dual role for Space Station Freedom. Ames has provided a source of research, advanced development and technology for the space station since the inception of the program. Ames is also poised to become a major scientific user of the space station, taking advantage of the unique microgravity research capabilities that Space Station Freedom will provide. In addition, Ames has developed a number of unique facilities that will support operations and research for Space Station Freedom.

Most of the Ames work concerns human-centered technologies. The common objective is to find better ways to support and enhance space crew performance in the living and working environment on Space Station Freedom and on future long-duration exploration missions. Some of the Ames space station user payloads will support basic science research, notably the Closed Ecological Life Support System (CELSS) Test Facility and the Gas-Grain Simulation Facility. (See Appendix E). Space Station Freedom is essential to carry out the many scientific and technical investigations being conducted at Ames Research Center.

Life Science

Increasing our understanding of the human response to spaceflight has long been considered crucial to our long-term objectives for human space exploration, particularly long duration missions to other worlds. However, the space environment also provides a unique laboratory for biomedical research that may allow us to significantly increase our knowledge of the nature and treatment of terrestrial diseases and medical conditions. Recent flights have produced tremendous evidence that space-based biomedical research has the potential to improve our understanding of the cardiovascular system, gerontological conditions such as osteoporosis and arthritis, the immune and hormonal systems, the vestibular (balance and orientation) system and fluid and electrolyte balance mechanisms.

Centrifuge Facility

The Centrifuge Facility Program will provide key laboratory hardware elements required to support a life sciences research program in Earth orbit. It will afford the life sciences community an opportunity to gain an understanding of the role of gravity in living systems. These objectives can only be accomplished through long-term controlled experimentation with a significant number and variety of experimental subjects. The Centrifuge Facility will provide life support for various types of plant and animal subjects, and controlled levels of gravity for experiments utilizing these subjects. The controlled artificial gravity, provided by the Centrifuge, is necessary to isolate the effects of weightlessness from other environmental factors (such as radiation) and examine the influence of gravity on biological systems as a function of gravity level. Space Station Freedom will be an excellent platform for the long duration in situ research needed to determine the biological effects of space flight, with the objective of better protecting the health, well being and performance of humans in space.

Scientific investigations using the Centrifuge Facility will contribute to a core science knowledge base as well as provide a proper foundation for enabling extended-duration exploration missions. Research in the Centrifuge Facility will enable experiments to address the time course of adaptation to microgravity and readaptation to earth's gravity, effectiveness of artificial gravity as a therapeutic countermeasure to long-duration exposure to microgravity, adaptation to gravity levels simulating the moon and Mars, and the characterization of minimum levels (thresholds of intensity and duration) of gravity required to maintain normal physiological structure and function. Scientific issues encompass all of the space life sciences disciplines, including musculoskeletal, cardiopulmonary, neuroscience, regulatory physiology, environmental health and radiation, behavior and performance, cell and developmental biology and plant biology.

The major flight system elements of the Centrifuge Facility include:

- Modular Habitats – file drawer size containers which house plant and animal biospecimens and, when installed in the Centrifuge and Habitat Holding Units, provide environmental control and life support for the biospecimens;
- Centrifuge – 2.5 m. in diameter, supports a number of Modular

Habitats while providing selectable gravity levels between 0.01 and two-g; and

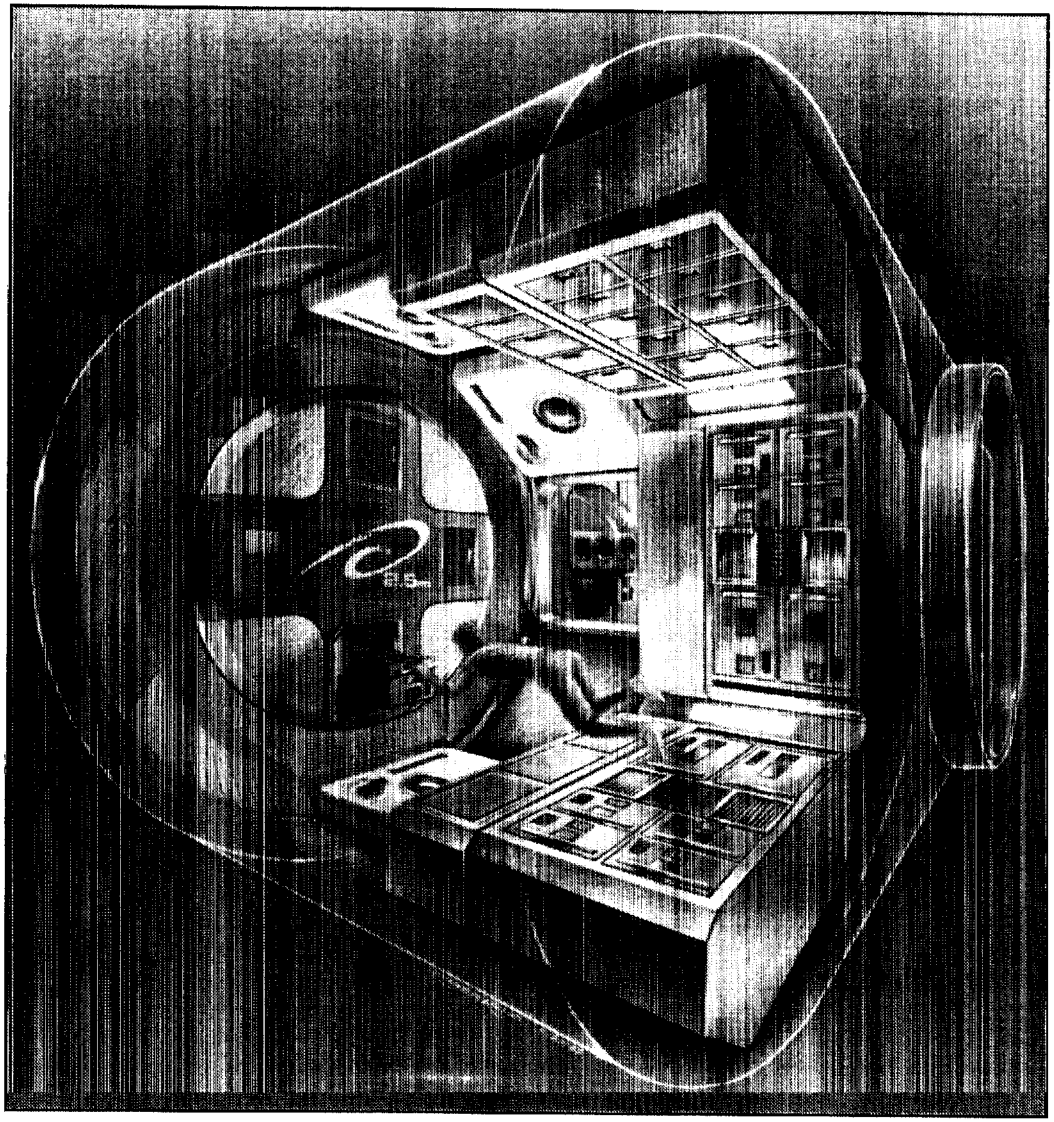
- Habitat Holding Units – standard racks (approximately two file cabinets in size), which serve as support systems for Modular Habitats in the ambient microgravity environment.

Ames will develop the required ground operations units, software, Ground Support Equipment, Flight Support Equipment, and Orbital Support Equipment as part of the Centrifuge Facility.

Other major hardware systems required to support the research to be conducted using the Centrifuge Facility are listed below.

- A Life Sciences Glovebox to provide an isolated work volume for conduct of laboratory procedures and operations in which biospecimens, consumables and equipment are manipulated and transferred in and out of Modular Habitats, equipment transport modules and Rodent Transporters;
- A Service Unit to provide storage of laboratory equipment, consumables, and laboratory waste including new and used specimen chambers, waste trays, filters, spares, etc., in close proximity to the Life Sciences Glovebox; and,
- Rodent Transporters to provide environmental control and life support for rodents in the Space Shuttle middeck during transportation to and from orbit.

Centrifuge Facility in Space Station Node with Centrifuge in Endcone



The Life Sciences Glovebox is presently part of the Space Station Freedom Program, and the Service Unit and Rodent Transporters are included in the overall Office of Space Science and Applications (OSSA) program to support life sciences research.

Gravitational Biology Facility

The Gravitational Biology Facility is an ensemble of laboratory equipment designed to augment and enhance the capabilities of the Space Station Biosciences Laboratory. It will provide advanced physiological sensors and radio-frequency biotelemetry to monitor animal subjects. Sophisticated instruments such as gas chromatograph/mass spectrometers and high performance liquid chromatographs will be used to evaluate plant growth and metabolism. The Gravitational Biology Facility will augment and enhance the capabilities of the Space Station Biosciences Laboratory. It will integrate with other elements of the Laboratory, such as the Centrifuge Facility and the Closed Ecological Life Support System (CELSS) Test Facility. The variety of modular habitats for plants and animals and cell and tissue culture will enable the Gravitational Biology Facility to support novel and serendipitous scientific study in the unique environment of space.

Exo-Biology

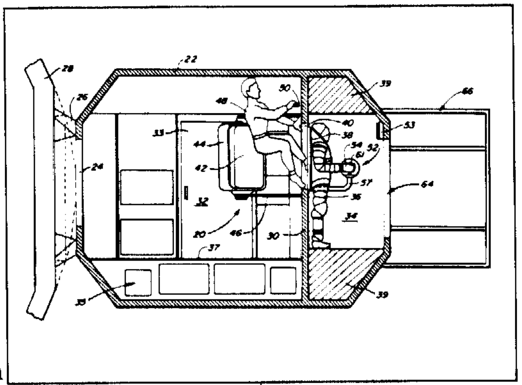
Gas-Grain Simulation Facility

The Gas-Grain Simulation Facility (GGSF) will provide a new and essential tool for studying small particle phenomena. These basic phenomena are important to the fields of exobiology, planetary science, astrophysics and atmospheric science, biology, chemistry and physics. The GGSF is planned as a multidisciplinary facility that will enable researchers to simulate and study fundamental chemical and physical processes such as formation, growth, nucleation, condensation, evaporation, accretion, coagulation, collision and the mutual interaction of small (sub-micron to millimeter size) particles (e.g., crystals, powders, liquid droplets and dust grains).

In the study of small particle processes, the demands on experiment design are severe. Two common requirements are low relative velocities between particles and long time periods during which the particles must be suspended. Sufficiently long duration suspension times to do this fundamental research cannot be attained in one-g, but can be investigated with this general-purpose particle research facility in Earth orbit.

Scientists at Ames Research Center, other NASA Centers, and academic institutions have suggested a wide range of fundamental scientific questions involving interactions between small particles. The GGSF will accommodate a wide variety of sub-micron sized particle experiments that require the long-term, low-gravity (micro-gravity) environment that will be available on Space Station Freedom. When installed in Space Station Freedom, the GGSF will provide a truly unique opportunity to perform small particle experiments in micro-gravity.

Life Support



Space Station Freedom has its own life support system, which benefits from decades of research at Ames Research Center in life support principles and technologies. Now Space Station Freedom will help advance research in life support by providing operational experience with regenerative life support technology and providing research facilities for developing and validating new technologies.

CELSS Test Facility

The CELSS Test Facility will serve as a laboratory facility on Space Station Freedom. It will be used to compare the productivity of plants in micro-gravity to productivity on the ground. In this case, productivity is defined as the ability of a crop to produce biomass and food, to exchange carbon dioxide and oxygen, and to transpire water per unit of volume and power used. The data gathered by the CELSS Test Facility is essential in evaluating the capabilities of plants to function in space as components of a human life support system. The data are vital for planning the life support systems that will be necessary for long duration human missions in space, such as an expedition to Mars and the establishment of permanent outposts on the moon or Mars. Thus, the CELSS Test Facility will evaluate the growth characteristics and productivity of a variety of potential crop plants, and will measure growth rates, times to maturation, and other parameters relevant to life support issues. The CELSS Test Facility consists of equipment contained within two standard international space station racks, and will function in bioisolation from the space station crew environment.

The Salad Machine

The "Salad Machine" is a unique application of technology derived from the CELSS program at NASA-Ames in collaboration with industry, universities and other NASA centers.

The primary purpose of the Salad Machine is to provide fresh salad vegetables for consumption by crew members on Space Station Freedom and other long-duration missions, including an initial lunar base, or a Mars Transfer Vehicle. The Salad Machine represents the first step away from the total reliance of astronauts on resupply for food. Work completed to date within the NASA CELSS program suggests that the technologies needed for growing plants in the space environment are sufficiently well understood to allow an early application that can provide dietary benefits and enhance the sense of well-being of crew members on extended duration missions.

Human Factors, Architecture and Habitability

Ames has supported the space station by providing human factors and habitability research on space station-specific questions throughout the Advanced Development Program and continues to advise the work package centers. Ames participated in the early configuration definition studies and contributed research to the design of the space station configuration and module architecture, including the nodes, airlock, windows, cupola, interim design and habitability enhancement. Ames has worked closely with the Man/Systems organizations at both Johnson Space Center (JSC) and at Marshall Space Flight Center (MSFC). For both of these collaborations Ames drew upon research to provide guidelines, criteria and recommendations, for designing and building prototype flight hardware for human factors demonstration purposes.

Habitability and Wardroom

Under the Ames/Johnson Space Center collaboration, Ames investigated the requirements for a wide range of crew performance and human productivity needs and capabilities, including safety, private sleep quarters, the "wardroom and associated activities," crew workload, interior layouts and design, window and window/workstation design. The deliverables were typically design criteria and guidelines, or prototype hardware. One task that involved prototype development was crew group activities centered around the wardroom where the crew would prepare food, dine, hold meetings and conferences, and perhaps assemble or repair equipment. Ames developed a prototype Space Station Wardroom Table and module mockup to demonstrate these findings.

Operational Simulation

Ames developed "OpSim," a low-cost, operational simulation Macintosh computer-based modeling tool to aid in understanding the planned resource utilization and the projected scenarios involving space station crews, equipment and mission objectives. Ames validated OpSim against the actual flight logs of the Spacelab 3 mission. Ames uses OpSim to study crew safety, crew activity and operations questions, including Space Station Life Science Mission Plan.

Element Control Work Station

Under the Ames/Marshall Space Flight Center collaboration, Ames designed a prototype Element Control Work Station to monitor and control the critical functions of the internal payloads of the U.S. Laboratory Module and selected external payloads. This work station includes a Deployable Video Conference Table to support video conferences between the Lab Module crew and principal investigators on the ground. This multi-purpose, group work station would provide the lab crew with a place to meet and hold "office hours" for principal investigators, while simultaneously monitoring and multiplexing the data and video links to share them with their colleagues on the ground.

Orbital Operations

Ames researched and developed a number of tools and simulation capabilities for space station orbital operations capabilities. These activities included the Space Station Proximity Operations Simulator, an integrated window/work station simulator. The "Prox-Ops" simulator employed active computer graphics in three viewing ports and interactive displays and controls including a voice recognition-based checklist, Shuttle side-arm controller for orbital maneuvering and a 3D perspective display derived from an air traffic collision avoidance system. The Prox-Ops work led to a number of products for planning orbital maneuvering, including "Navie," which runs on an Iris work station, and "Eivan," which runs on a Macintosh personal computer. Ames is continuing state of the art research and development work in these space operations tools.

Human Factors of EVA

Ames has also researched a number of human factors aspects of extravehicular activity (EVA). For the Advanced Development Program, Ames designed a new airlock concept, the "Suitport" that supports the AX-5 hard suit or other rear-entry suit for much more efficient and reliable don/doffing, egress and ingress and suit servicing. Other "human factors of EVA" studies include maneuvering operations and the rescue of a free-floating astronaut.

AX-5 Space Suit

Ames Research Center has developed the Ames Experimental 5 (AX-5) hard space suit under the Space Station Advanced Development Program to support routine safe and productive extravehicular activity on Space Station Freedom. (The official baseline suit is the current version of the Shuttle suit made by Hamilton Standard.) This prototype space suit is made from parts milled numerically from solid aluminum and assembled with a unique set of rotating seals and bearings. All the joints on the AX-5 are mechanical; there are no fabrics or soft parts that would be vulnerable to damage by abrasion, tearing, or chemical attack by rocket fuel or free atomic oxygen in the upper atmosphere. The AX-5 is designed for high reliability and low maintenance, while enhancing the mobility and comfort of the crew member who wears it. Because of its double aluminum shell structure, the AX-5 shields the wearer against radiation and the impact of small meteoroids and space debris more effectively than earlier fabric suits. This hard suit maintains a constant internal volume, so that the internal pressure remains constant, reducing resistance to the astronaut's movements. The AX-5 has a modular design that employs Ortman couplings to allow the easy change-out, of parts to fit the full anthropmetric range of astronaut sizes.

The AX-5 suit is being evaluated in a series of water immersion tests at Ames Research Center and at Johnson Space Center. Immersion in water under neutral buoyancy protocols simulates the effects of weightlessness. The AX-5 offers improvements both in its performance for EVA and for doffing and donning. The crew member can put on the suit or take it off in just a few seconds compared to a number of minutes for the current Space Shuttle suit. This improvement is made possible through the rear-entry hatch, through which the astronaut enters, putting in the legs first, followed by the upper part of the body. The new hard suit no longer requires an astronaut to devote several hours to prebreathing pure oxygen before EVA to prevent the bends (as is necessary with the 4.3 psi Shuttle suit) because the AX-5 can support a higher internal operating pressure of 8.3 psi, which is sufficient to minimize the bends.

Information Science

Thermal Control System Testbed and TEXSYS

The System Autonomy Demonstration Project for the advanced demonstration of the Space Station Freedom Thermal Control System (TCS) Testbed was a joint effort between Ames and Johnson Space Center. The project consisted of the development and validation of a knowledge-based system to perform real-time control, fault detection and isolation (FDIR) of the Thermal Control System Testbed.

This testbed project included a Thermal Expert System (TEXSYS) as the knowledge-based controller and FDIR. Two associated software modules, Thermal Data Acquisition System (TDAS) and Human Interface to TEXSYS (HITEX) were operated in conjunction with TEXSYS during a five day test demonstration at Johnson Space Center in August of 1989. During this test, the system automation successfully controlled, monitored and operated the functioning of the TCS breadboard, without need of human intervention.

TEXSYS demonstrated significant enhancements over current conventional means available to the thermal engineer for the real-time analysis of faults, and recovery from complex fault situations. TEXSYS can analyze a fault situation, display pertinent schematics and data histories, recommend recovery actions, and explain the analysis of the problem to the human operators. The Thermal Control System Testbed is a significant step forward for automating thermal control systems in human spacecraft. It also represents a new paradigm for automating both the "system executive" and the human-machine interface for a wide range of other critical systems on spacecraft in the future.

Advanced Space Station Freedom Data Management System Architectures

This ongoing task is to define and evaluate the spaceborne hardware and system software technologies, and the ground-based automation programs that will lead to a practical, evolvable and reliable data management system (DMS) for Space Station Freedom. This goal is being accomplished through the use of increasingly higher fidelity software simulations and hardware testbeds. This analysis places the options for the DMS design in the perspective of existing and past manned spacecraft computer systems and the capabilities that they were required to provide.

The most recent work concentrates on the analysis of the Standard Data Processors, the fiber-optic wide area network, Software Standard Services and Engineering, System Reliability (FDIR), and the DMS support of Space Station Freedom operations. Researchers at Ames are performing a detailed analysis of the DMS design to assess its adequacy to satisfy programmatic issues and performance requirements. These requirements include payload use, ground systems versus onboard system functional allocation, system safety, availability and reliability. This analysis addresses high level program requirements for failure tolerance, real-time response, and central processing unit (CPU) performance, specifically concerning the Intel 80386 versus 80486 CPUs.

Supporting Facilities

Ames has developed and operates a number of unique life science research facilities that will support both research and operations on Space Station Freedom, and

Human Performance Research Laboratory (HPRL) and the Automation Sciences Research Facility (ASRF) provide research and technology development for future space station evolution.

Automation Sciences Research Facility

In 1992, Ames opened the Automation Sciences Research Facility (ASRF) with over 57,000 square feet to provide eleven technology research and development laboratories. These individual laboratories will support research in a variety of domains. The Advanced Mission Technology Lab performs testing and integration of electromechanical systems. The development of software tools to test and validate artificial intelligence concepts in robotics will occur in the Robotics Lab. The Multiprocessing Testbed Lab specializes in real-time parallel processing of knowledge-based systems, visualization techniques, and adaptive operating systems, as well as testing and evaluating multiprocessor prototypes for space applications.

The Advanced Architectural Lab emphasizes advanced automation, computer architectures, and tools for the simulation and monitoring of computer systems. The Optical Processing Lab focuses on optical correlators for image recognition and matrix processor applications. Other labs include the Systems Evaluation, Information Systems, Rapid Prototyping, and Intelligent Agent Testbed Labs.

Human Performance Research Laboratory (HPRL)

In 1990, Ames opened the HPRL. This 65,000 square foot facility is used to study the performance and interaction of humans with machines, with other crew members, and with mission or flight controllers in advanced aircraft and space missions. It also supports the study and development of teleoperation and virtual reality techniques that allow Earth-based researchers to "bring space down to Earth" to improve their ability to conduct remote operations in space. NASA's future challenges such as Space Station Freedom, the National Aero-Space Plane (NASP), and lunar and Mars exploration impose complex mission objectives that require computer-operated systems that complement highly-trained human crew members. The HPRL supports research on both sides of this equation: the human/machine interaction including cognitive and perceptual aspects of complex operations on the one side, and crew training team work, organization, habitability, scheduling, and environmental interactions on the other. A long-term interest is development of simulation tools and planning for space orbital and planetary surface operations.

Human Research Facility (HRF)

Ames has operated the HRF since the 1960s to investigate the effects of varied gravity regimes upon human physiology and behavior and to identify possible countermeasures to the debilitating effects of prolonged exposure to microgravity. These effects include bone demineralization, fluid shifts in the body, loss of muscle tone and muscle mass, cardiovascular deconditioning and changes in weight. The primary components of the HRF are the Bedrest Facility and the 20-g Centrifuge. The Bedrest Facility provides 12 beds for human subjects to experience simulated reduced gravity conditions for periods of typically up to 30 days. The 20-g Centrifuge provides the capability to expose these subjects to simulated gravity stresses of reentry to Earth after a prolonged period of deconditioning.

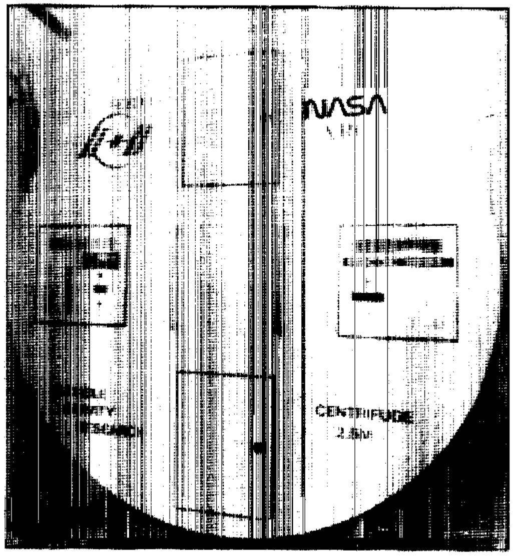
Space Life Sciences Payload Facility

Ames currently has the responsibility for designing, integrating and preparing for flight all the non-human experiments for the Spacelab life sciences flights. Ames will extend this capability to support the life science payloads for the Centrifuge Facility Project and draw on this experience to support other space station payloads including the CELSS Test Facility and the Gas-Grain Simulation Facility.

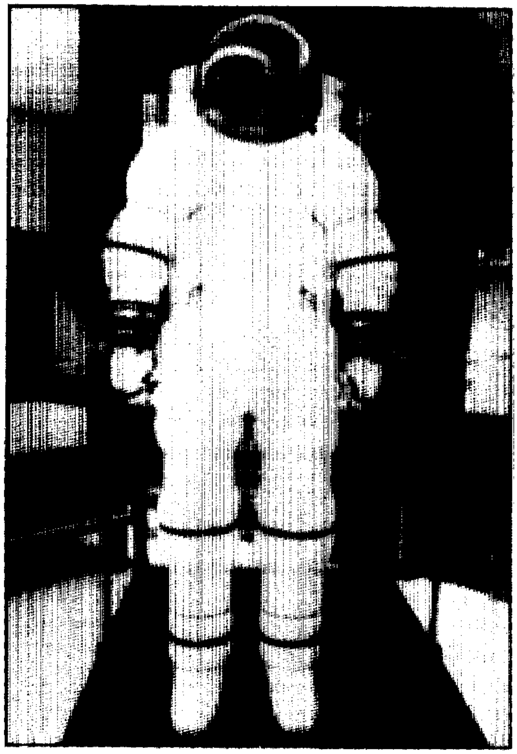
Vestibular Research Facility (VRF)

The VRF enables scientists and medical researchers to investigate the important role of the vestibular organs in governing the performance of humans, particularly the abilities involving balance, coordination, sense of orientation and space adaptation mechanisms, both in an altered environment and on Earth. This understanding is essential for the effects of varied gravity regimes on human physiology and behavior.

Life Sciences Glovebox and Habitats
Ames developed the Life Sciences Glovebox and Modular Habitats for the Centrifuge Facility on Space Station Freedom. The Glovebox provides an isolated work volume for conduct of laboratory procedures and operations in which biospecimens, consumables and equipment are manipulated and transferred in and out of Modular Habitats, equipment transport modules and rodent transporters.



Life Sciences Centrifuge
Ames will develop a centrifuge, a 2.5 meter circular device, that rotates with specimen habitats around its circumference. Test subjects such as cells, tissues, small plants and animals will be subjected to variable gravity between zero-g and two-g allowing investigators to examine the effects of variable gravity. Observations of any changes in the test subjects will be performed by the crew.

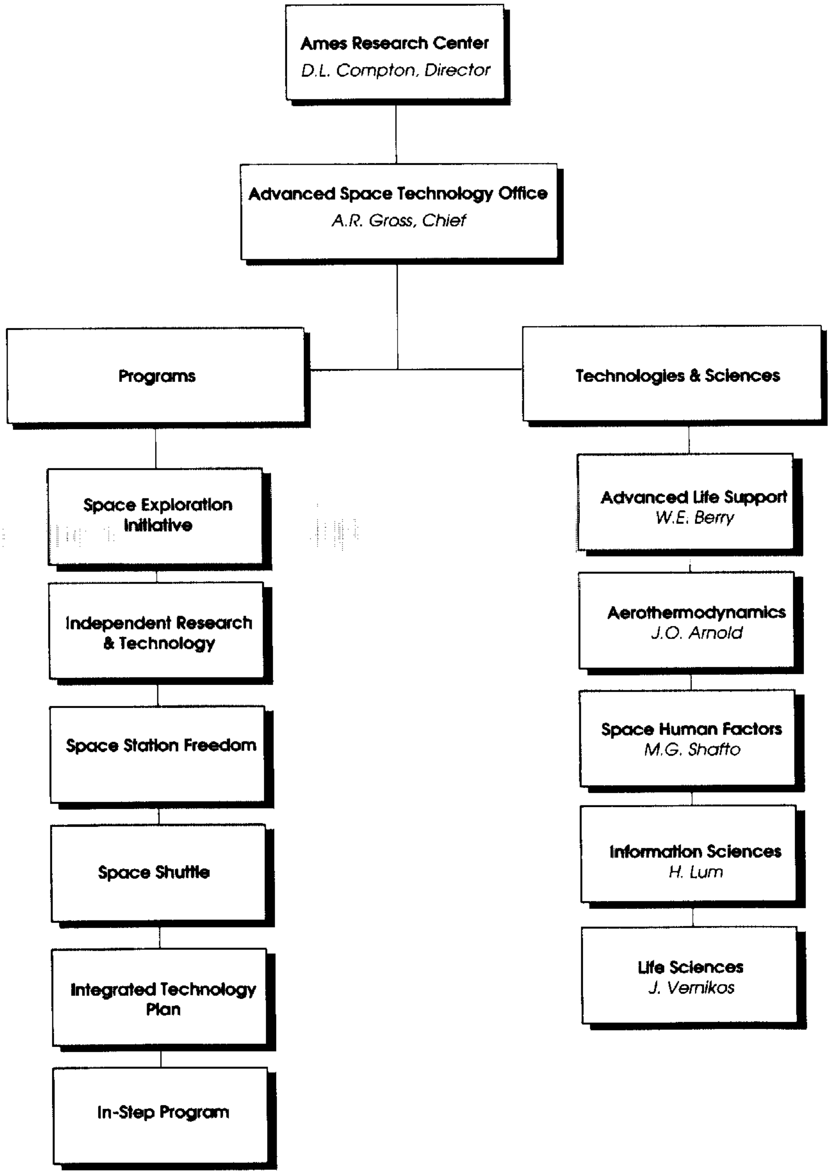


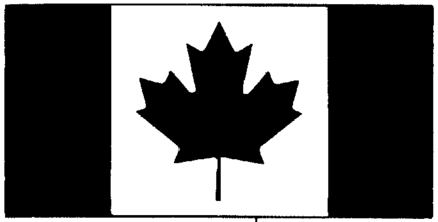
Advanced Space Suits
Ames developed the AX-5 prototype hard suit. The suit is highly reliable, requires little maintenance, and is more comfortable to wear. The suit can be put on or taken off in just a few seconds compared with several minutes for the current spacesuit. The new suit has an internal pressure of at least 8.3 psi which minimizes the possibility of the crew getting the bends. It is made from parts milled from solid aluminum and assembled with a unique set of rotating seals and bearings.

Advanced Space Technology Office

The Advanced Space Technology Office is responsible for coordinating the Center's activities in NASA space programs and projects, such as the Space Exploration Initiative (SEI), Space Station Freedom, and the Space Shuttle Program. The Office is the focal point for the Center's participation in all aspects of these programs. The Office also serves as the focus for new opportunities to participate in space technology programs, as well as enhancing the transfer of its research and technology developments to other organizations, including industry, other government laboratories, and other NASA centers. This includes such space-related disciplines as Advanced Life Support Technology, Space Human Factors, Life Sciences, Artificial Gravity, Information Sciences, and Aerothermodynamics and Aerobraking Technologies.

The Office is also responsible for coordinating and directing new interdisciplinary multi-organizational space research and technology programs and projects, with the objective of utilizing the unique technical strengths at the Center to further NASA space programs.





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 has committed $1.2 billion on the program through the year 2000.

Canada will provide the Mobile Servicing System (MSS) for Space Station Freedom. The MSS will play the main role in Space Station Freedom's assembly and maintenance, moving equipment and supplies around the station, 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 the Shuttle's cargo bay.

NASA considers the MSS as part of the station's critical path; an indispensable component in the assembly, performance and operation of Space Station Freedom. Canadian involvement in the space station program includes total design, development and long-term operations support of the MSS through space station hardware and extensive ground facilities.

The basic flight element of the MSS is the Mobile Remote Servicer (MRS), which consists of the MRS Base System (MBS) and the Space Station Remote Manipulator System (SSRMS). The MRS and its U.S. provided, rail-mounted, Mobile Transporter (MT), which will move along the truss, comprise the Mobile Servicing Center (MSC). The MBS will also carry servicing tools and support payloads.

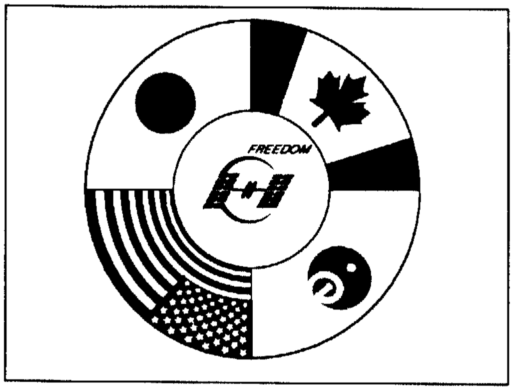
The SSRMS will be the next generation of Canadarm, currently being used on the Shuttle Orbiter. The arm will be 58 ft. (17.6 m.) long with a payload capacity of 128 tons (116,000 kg.).

The MSS has a second smaller robot, called the Special Purpose Dexterous Manipulator (SPDM), which has two arms, each 6.65 ft. (2 m.) 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 mounted on the SSRMS. It will contain tactile sensors for "feeling" surfaces and carry a set of tools to enable it to perform many functions.

Crewmembers can operate the MSS from internal control stations and can carry out MSS maintenance and servicing tasks using spare parts and tools housed in the MSS Maintenance Depot (MMD).

In addition to the MRS, SPDM and MMD, Canada will supply MSS work and control stations, a power management and distribution system, a data management system and components of the video system, all of which form part of the main space station support systems.

On the ground, Canada is developing a Manipulator Development and Simulation Facility (MDSF) and will build mission operations facilities and equipment, including a Canadian Engineering Support Center (CESC). The MDSF is being used for the design and development phase of MSS and will later be used in conjunction with the CESC to provide support of MSS operations as well as continued development of MSS technology for growth applications on space station.

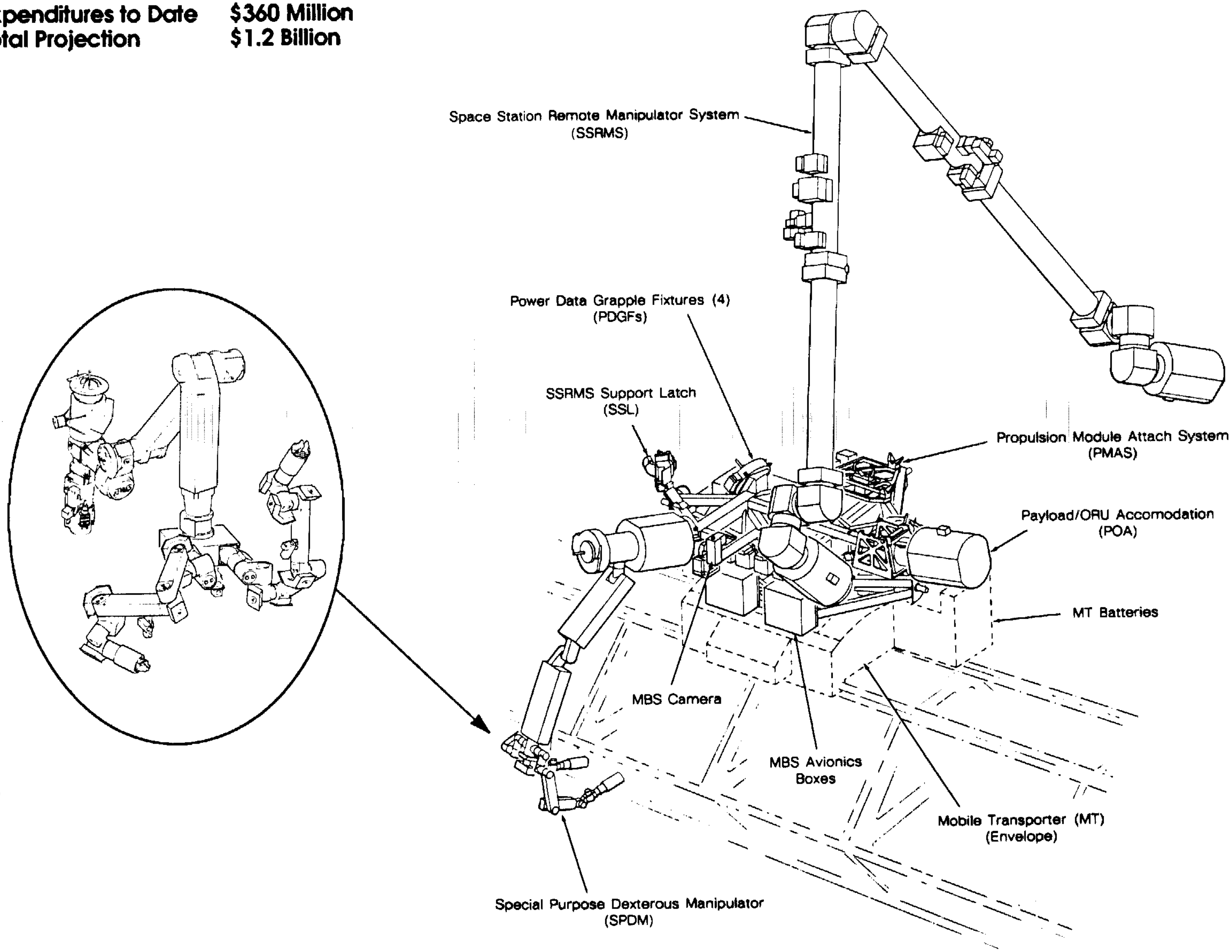


Besides the creation and operation of hardware systems for the MSS, involving advanced technology, Canada has put in place a User Development Program (UDP) to ensure that the Canadian scientific community and industry can take full advantage of Canada's share in space station utilization. The User Development Program will enable Canada to expand its program of microgravity research and to capture its share of the large anticipated market for products developed on Space Station Freedom.

The Strategic Development Programs aim to develop in Canadian industry the capability to support MSS evolution throughout the 30 year life of Space Station Freedom and to maximize use of MSS technology for other applications.

Project management is handled by the Space Station Program Office, Canadian Space Agency.

Expenditures to Date	**$360 Million**
Total Projection	**$1.2 Billion**



Mobile Servicing Center and Special Purpose Dexterous Manipulator

European Space Agency (ESA)

Columbus is the name of a large, multi-element program with complex interfaces to other major ESA activities which together make up the international space station and a European-based in-orbit infrastructure.

The Columbus philosophy aims at providing an in-orbit and ground infrastructure compatible with European and international user needs from the late-1990s onward. 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, often called the Attached Pressurized Module (APM), will be permanently attached to the station's manned base. It is about 38.7 ft. (11.8 m.) long and 14.7 ft. (4.5 m.) in diameter and weighs about 37,400 lbs. (17,000 kg.) at launch, 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. In addition to the internal user accommodation volume of 20 standard payload racks (of which 46 percent are reserved for U.S. users and 3 percent for Canadian users), an external viewing platform for small experiments requiring exposure to space vacuum is provided.

The APM will be launched from the Kennedy Space Center on a dedicated Shuttle flight, removed from the 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, and will be launched together with its initial payload, by an Ariane 5 from the Centre Spatial Guyanais (CSG) in Kourou, French Guiana.

It consists of a two-segment pressurized module for the accommodation of payloads, and an integrated resource module which provides the main utilities and services required by the Free-Flyer and its payloads. It is about 39.4 ft. (12 m.) long and 14.7 ft. (4.5 m.) in diameter and weighs about 40,200 lbs. (18,200 kg.). It will be routinely serviced in-orbit by Hermes at approximately six-month intervals. Backup servicing will be performed by the Shuttle.

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.

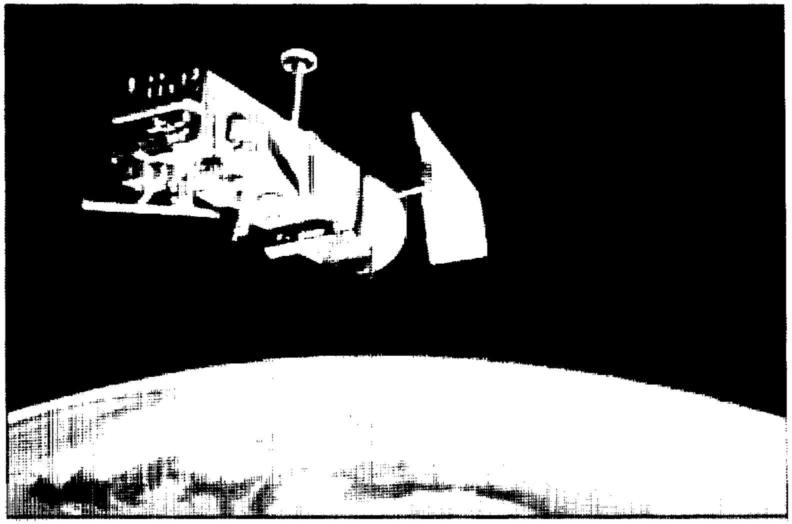
The platform is not serviceable and is designed to operate over a minimum of a four-year lifetime. The platform will accommodate between 3750 lbs. (1700 kg.) and 5290 lbs. (2400 kg.) of ESA and internationally provided payloads.

Precursor Flights

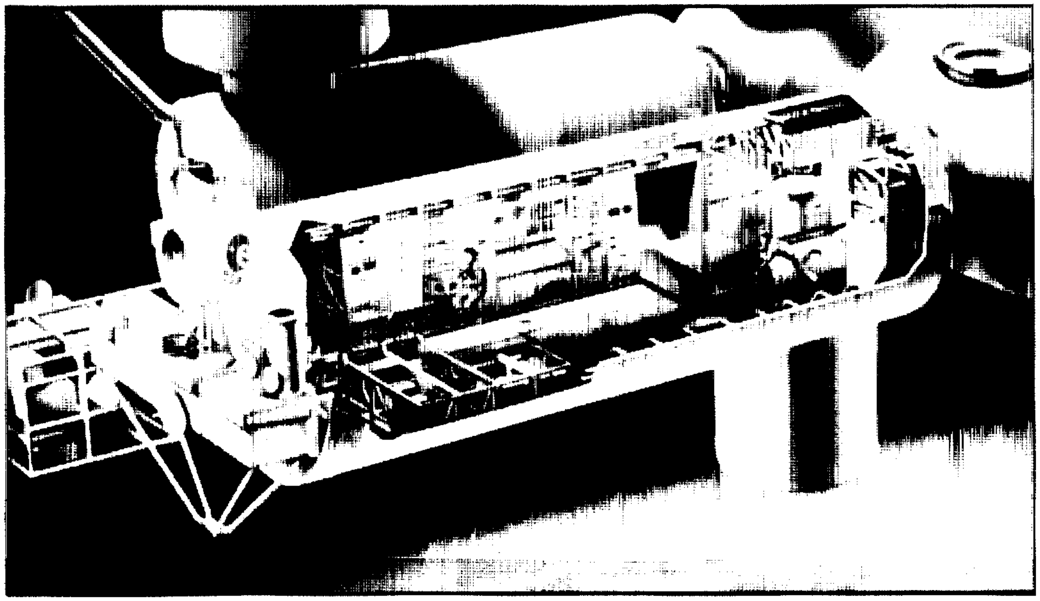
Researchers have the opportunity to utilize two Eureca free-flyers and two Spacelab flights in the 1994 and 1996/97 time frames to prepare for Space Station Freedom research.

Expenditures to Date	**$1 Billion**
Total Projection	**$5 Billion**
(Ref. 1988)	

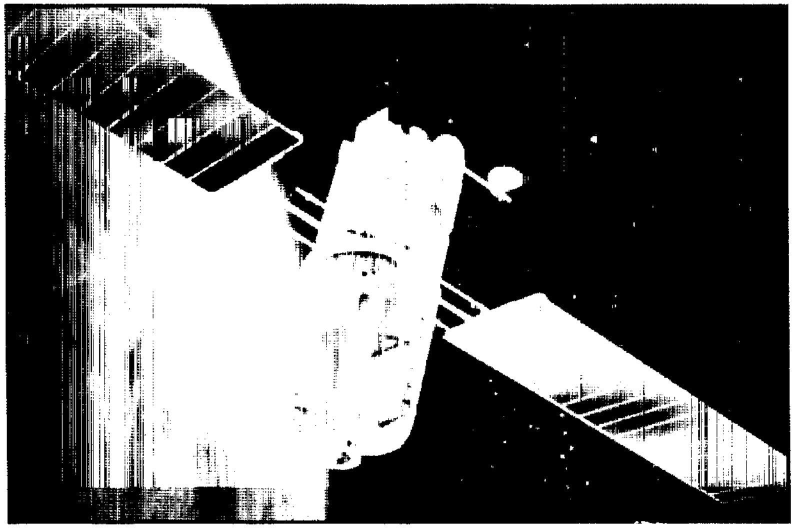
Columbus Polar Platform
Length 34.4 ft. (10.5 m.)–Deployed 85 ft. (26 m.)
Diameter 15 ft. (4.6 m.)
Weight 23,000 lbs. (50,600 kg.)

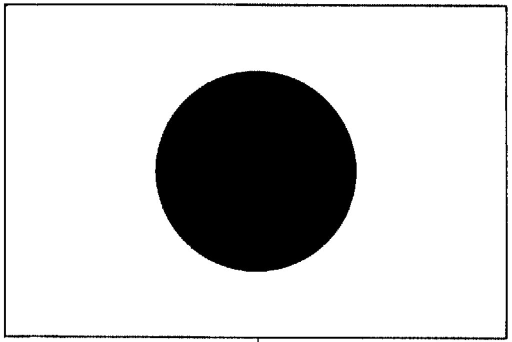


Columbus Attached Laboratory or Attached Pressurized Module (APM)
Length 38.7 ft. (11.8 m.)
Diameter 14.7 ft. (4.5 m.)
Weight 37,400 lbs. (17,000 kg.)



Columbus Free-flying Laboratory
Length 40 ft. (12 m.)
Diameter 14 ft. (4.4 m.)
Weight 38,720 lbs. (17,600 kg.)





Japan

Japan initiated its space station program in 1985 in response to the United States' 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 program with its own experimental module. On the basis of the committee's conclusion, the Science and Technology Agency (STA) concluded a 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, is currently conducting the detailed definition and 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 33 ft. (10 m.) long tubular cylinder with a diameter of 13.8 ft. (4.2 m.). It has a pressurized volume of approximately 140 cubic meters. The PM can accommodate 10 international standard payload 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 Exposed Facility.

Exposed Facility (EF)

The EF is a box type experiment platform connected to the PM by a berthing mechanism. 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 crew access. However, by employing a local manipulator and an equipment airlock, both operated within the PM, this access can be partially accomplished while minimizing extravehicular activity. Scientific observation, communication experiments, scientific/engineering and materials experiments will be conducted on the EF.

Experiment Logistics Module (ELM)

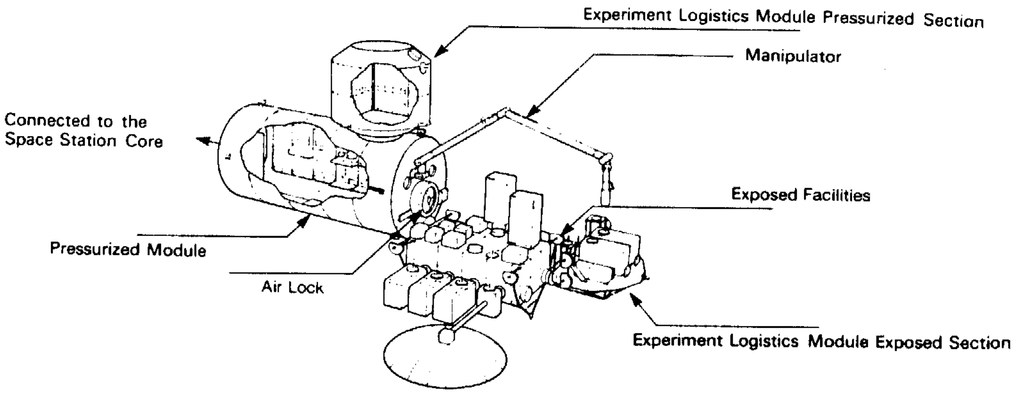
The ELM provides on-orbit storage volume and can transport JEM logistics supplies such as experiment specimens, gases and fluids, equipment for configuration change and spare parts for maintenance. The ELM will consist of two sections: a pressurized section and an exposed section. The pressurized section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

The JEM will be launched on two Shuttle flights. The first flight will transport the PM. The second flight will bring up the EF 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 1992 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 Astronautical Science (ISAS), STA/NASDA and Ministry of International Trade and Industry (MITI)/New Energy Development Organization (NEDO) aiming at the launch in 1994. Many governmental agencies, universities and private companies are also promoting basic research and research support for space utilization in Japan.

	Pressurized Module	Experiment Logistics Module		Exposed Facility
		Pressurized Section	Exposed Section	
Structural Type	Cylindrical	Cylindrical	Frame	Box
Diameter (m) (internal)	4.2	4.2	Width 4.4 Height 3.3	Width 5.6 Height 3.4
Length (m)	10	4.1	2.2	5.0
Dry Weight (ton)	14	2.4	0.7	3.2
Payload	10 racks	8 racks	3 (max.)	10
Electrical Power	25 kW (max.), 120 VDC			
Data Transfer	Payload network 10 Mbps High rate data system 100 Mbps (max.)			

JEM System Primary Characteristics



Japanese Experiment Module

APPENDIX A

Work Package Contractors

Work Package 1

Company	Location	Type of Work
Boeing Defense & Space Group	Huntsville, AL	Prime Contractor
Teledyne Brown Engineering	Huntsville, AL	Lab Outfitting Equipment, Payload Integration, Ground-Support Equipment and Laboratory Support Equipment
TRW, Inc.	Huntsville, AL	Systems Simulation and Training Software
Allied-Signal AiResearch	Torrance, CA	Thermal Control, Environmental Control and Life Support, Valves, Fire Detection
Lockheed Missiles and Space Co.	Sunnyvale, CA	Life Sciences and Animal Research Facilities Outfitting
Hamilton Standard	Windsor Locks, CT	Water Recovery (hygiene and potable), Temperature and Humidity Control; Avionics Cooling, Commode/Urinal Subassembly
Arde	Norwood, NJ	ECLSS Tank Sets
Loral Fairchild	Syossett, NY	Video Systems
Astro International Corp.	League City, TX	ECLSS Processing Control Water Quality Monitoring
Grumman Aerospace Corp.	Houston, TX	Design and Outfit Habitation Module
ILC Space Systems	Houston, TX	Galley, Laundry, Refrigerator, Trash, Storage
Life Systems	Cleveland, OH	CO_2 Reduction, O_2 Generator, Urine Processor
Camus, Inc.	Houston, TX	Mockups, Trainers, Simulators, Flight Hardware
Harris Corp	Melbourne, FL	Internal Audio/Video System
Perkin-Elmer	Pomona, CA	Atmosphere Composition Monitor
Ball Aerospace Co.	Boulder, CO	Fluid Subcarrier Tank Sets
ILC Technology	Sunnyvale, CA	General Lighting

Work Package 2

Company	Location	Type of Work
McDonnell Douglas	Huntington Beach, CA	Prime Contractor
McDonnell Douglas	Houston, TX	Software Development, Operations Planning, Flight Crew Integration, Airlock Testing
Lockheed Missiles & Space Co.	Sunnyvale, CA	Thermal Control System, Support to EVA Rotary Mechanisms
Lockheed Eng. & Sciences	Houston, TX	EVA Technical Support

Work Package 2, continued

Company	Location	Type of Work
Hamilton Standard	Windsor Locks, CT and Houston, TX	Shuttle Extravehicular Mobility Unit (EMU) Program Interfacing
LTV	Grand Prarie, TX	Heat Rejection System
General Electric	Camden, NJ	Communication & Tracking System
Motorola	Scottsdale, AZ	Various Communications Equipment
Spar Aerospace	Canada	Station Antennae
Honeywell, Inc.	Clearwater, FL	Control System
Honeywell, Inc.	Glendale, AZ	Multiplexer/Demultiplexer (MDM)
Allied Signal	Teteboro, NJ	Control Moment Gyros
IBM	Houston, TX	Data Management System
IBM	Oswego, NY	Data Management System, Flight Hardware
Astro	Carpinteria, CA	Mobile Transporter
Eagle	Houston, TX	Technical Services

Work Package 4

Company	Location	Type of Work
Rockwell International	Canoga Park, CA	Prime Contractor: System Integrator, PMAD
Rocketdyne Division		Software, Beta Gimbal, IEA
Allied-Signal Aerospace	Tempe, AZ	Closed Brayton Cycle Engine
Allied-Signal Aerospace	Torrance, CA	Solar Receiver
Ford Aerospace	Palo Alto, CA	Batteries, DC Source PMAD, EEE Parts
Lockheed Missiles & Space	Sunnyvale, CA	Solar Arrays
Hamilton Standard	Windsor Locks, CT	Thermal Control System, Pump Flow Control System
Harris Corporation	Melbourne, FL	Solar Concentrator
LTV	Dallas, TX	SD Radiator
Spectrolab, Inc.	Sylmar, CA	Solar Cells
Applied Solar Energy, Corp.	City of Industry, CA	Solar Cells, Bypass Diode
Honeywell Space & Aviation	Durham, NC	Motor Drive Assembly
AEC-Able Engineering	Goleta, CA	Mast Canisters
Sheldahl, Inc.	Northfield, MN	Kapton Coating, FCC Cable
Whittaker-Yarndey	Pawcatuck, CT	Battery Cells
Gates Corporation	Gainsville, FL	Battery Cells

APPENDIX A

Management Support and Information Systems Contractors

Technical and Management Information Systems

Boeing Computer Services	Reston, VA	Prime Contractor for computer integration of TMIS

Space Station Engineering and Integration Contractor

Grumman Space Station Program Support Division	Reston, VA	Level II SE&I Contractor for the Space Station Freedom Program Office. Providing support for program control, management, information systems, operations, utilization systems, engineering, SRM&QA and international integration

Software Support Environment

Lockheed Missiles and Space Co.	Sunnyvale, CA	Provide a program-wide software support environment including architecture, design, acquisition, development, implementation and maintenance.

Level I Support Contractors

BDM, International	McLean, VA	Provides technical services to the Director, Space Station Engineering for evolutionary growth.
Booz, Allen & Hamilton, Inc.	Bethesda, MD	Conducts technical and policy analyses and performs engineering assessments and trade studies to assist in developing technical approaches, program planning alternatives and operations and economic analyses.
The Egan Group	Washington, D.C.	Provides policy support for commercial utilization of Space Station Freedom.
Technical and Administrative Services Corporation (TADCORPS)	Washington, D.C.	Provides Level I with management and administrative support services including: Official Level I documentation, formal presentations, general management status reviews, conferences, workshops, Public Affairs documents, technical writing and editing, and support to all Divisions.

Locations of Space Station Freedom Contractors

(State Contract Values Greater Than $1 Million Through FY '91)

Geographic Locations of NASA and Space Station Freedom Contractors

APPENDIX B

Acronyms & Abbreviations

A&R	Automation & Robotics
AC	Assembly Complete
ACRV	Assured Crew Return Vehicle
ACS	Attitude Control System
AI	Artificial Intelligence
APA	Attached Payload Accommodation
APM	Attached Pressurized Module
ARC	Ames Research Center
ASI	Italian Space Agency
ASRF	Automation Science Research Facility
AXAF	Advanced X-Ray Astrophysics Facility
BCD	Baseline Configuration Document
BCDU	Battery Charge/Discharge Unit
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
C&T	Communications & Tracking
CDR	Critical Design Review
CELSS	Closed Ecological Life Support System
CESC	Canadian Engineering Support Center
CETA	Crew and Equipment Translation Assembly
CHeCs	Crew Health Care System
CMGs	Control Momentum Gyro(s)
COP	Co-Orbiting Platform
CRAF	Comet Rendezvous Asteroid Flyby
CSA	Canadian Space Agency
CSG	Center Spatial Guyanois (Kouroer, French Guiana)
DC	Direct Current
DCR	Design Certification Review
DCSU	Direct Current Switching Unit
DDCU	DC to DC Conversion Unit
DDT&E	Design, Development, Testing & Evaluation
DMS	Data Management System
DOC	Discipline Operations Center
ECLSS	Environmental Control and Life Support System
EF	Exposed Facility
EIC	Engineering and Integration Contract
ELM	Experiment Logistics Module
ELV	Expendable Launch Vehicle
EOC	Enhanced Operations Capability
EOS	Earth Observing System
EPS	Electrical Power System
ESA	European Space Agency
ESC	Engineering Support Center(s)
ESS	Energy Storage System
EVA	Extravehicular Activity
FDIR	Fault Detection, Isolation, and Recovery
FEL	First Element Launch
FF	Free-Flyer
FMS	Fluid Management System
FTS	Flight Telerobotic Servicer
GEO	Geosynchronous Earth Orbit
GGSF	Gas Grain Simulation Facility
GN_2	Gaseous Nitrogen
GN&C	Guidance, Navigation and Control
GPS	Global Positioning System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HMF	Health Maintenance Facility
HPRL	Human Performance Research Laboratory
HRF	Human Research Facility
HQ	Headquarters (NASA)
ICD	Interface Control Document
IEA	Integrated Equipment Assembly
IGA	Intergovernmental Agreement
IML	International Microgravity Laboratory
IOC	Initial Operational Capability
ISAS	Institute of Space and Astronautical Science (Japan)
ITA	Integrated Truss Assembly
IVA	Intravehicular Activity
IWGS	Integrated Waste Gas System
IWS	Integrated Water System
JEM	Japanese Experiment Module
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LCC	Life Cycle Costs
LCC	Launch Control Center
LDEF	Long Duration Exposure Facility
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LVC	Lunar Vehicle Capability
MB	Mission Build
MBSU	Main Bus Switching Unit
MBPS	Megabits per Second
MCC	Mission Control Center
MITI	Ministry of International Trade and Industry (Japan)
ML	Mini Laboratory
MMD	Mobile Servicing Center Maintenance Depot
MOD	Mission Operations Directorate (SSC)
MOU	Memorandum of Understanding

MPAC	Multipurpose Application Console
MPLM	Mini Pressurized Logistics Module
MRS	Mobile Remote Servicer
MS	Manned System
MSC	Mobile Servicing Center
MSFC	Marshall Space Flight Center
MSS	Mobile Servicing System
MTC	Man-Tended Capability
MTE	Mobile Transporter Equipment
MTFF	Man-Tended Free-Flyer
MVC	Mars Vehicle Capability
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NBL	Neutral Buoyancy Laboratory
NEDO	New Energy Development Organization
Ni-H_2	Nickel-Hydrogen
NSTS	National Space Transportation System
OAST	Office of Aeronautics and Space Technology
OCP	Office of Commercial Programs
ODS	Operational Data System
OF	Outfitting Flight
ORD	Operational Readiness Date
ORU	Orbital Replaceable Unit
OSF	NASA Office of Space Flight
OSSA	NASA Office of Space Science and Applications
OSSD	NASA Office of Space Systems Development
PCG	Protein Crystal Growth
PGS	Power Generating System
PLC	Pressurized Logistics Carrier
PLM	Payload Logistics Module
PM	Pressurized Module
PMAD	Power Management and Distribution
PMC	Permanently Manned Capability
PMMS	Process Material Management System
PMS	Platform Management System
POIC	Payload Operations Integration Center
POP	Polar Orbiting Platform
PRR	Program Requirements Review
PSC	Platform Support Complex
PSF	Power Systems Facility
PTC	Payload Training Complex
PTF	Payload Training Facility
PV	Photovoltaic
QA	Quality Assurance
RCS	Reaction Control System
RFP	Request for Proposal
RMS	Remote Manipulator System
ROC	Regional Operations Center
RPU	Remote Power Unit
SEI	Space Exploration Initiative
SE&I	Systems Engineering & Integration
SFU	Space Flyer Unit (Japan)
SLC	Shuttle Launch Complex (VAFB)
SOFIA	Stratospheric Observatory for Infrared Astronomy
SPDM	Special Purpose Dexterous Manipulator
SRR	Systems Requirements Review
SSAIAF	Space Systems Automated Integration and Assembly Facility
SSC	John C. Stennis Space Center
SSCC	Space Station Control Center
SSE	Software Support Environment
SSF	Space Station Freedom
SSFP	Space Station Freedom Program
SSFPO	Space Station Freedom Program Office
SSP	Space Station Program
SSPF	Space Station Processing Facility
SSRMS	Space Station Remote Manipulator System
SSTCB	Space Station Training Control Board
SSTF	Space Station Training Facility
STA	Science and Technology Agency (Japan)
STS	Space Transportation System
TCS	Thermal Control System
TDRSS	Tracking and Data Relay Satellite System
TMIS	Technical and Management Information System
ULC	Unpressurized Logistics Carrier
USL	United States Laboratory
VAB	Vehicle Assembly Building
VAC	Volts Alternating Current
VAFB	Vandenberg Air Force Base
VDC	Volts Direct Current
VRF	Vestibular Research Facility
VLSIC	Very Large Scale Integrated Circuits
WBS	Work Breakdown Structure
WP	Work Package
WTR	Western Test Range
XOC	Extended Operations Capability
ZOE	Zone of Exclusion

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 preprogrammed 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 56 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

Co-Orbiting Platform (COP)

An unmanned platform, co-orbiting with the space station manned base, serviced by the Space Shuttle. Provided for in the reference evolutionary design of the space station program. Nominally, co-orbiting objects occupy different positions (right ascensions) in the same orbit.

Columbus Attached Laboratory

The ESA-provided attached pressurized module (APM) 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
- Hyperbaric Airlock
- Logistics Module

U.S.-provided elements (unpressurized)
- Truss Element
- Mobile Transporter (MSS Base)
- Servicing Facility (Evolutionary Phase)
- Solar Power Modules
- 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)

Evolutionary Growth Phase

The third phase of the space station program, during which the following components might be added to the PMC configuration:

- Eight Crew Capability
- Enhanced to extended operational capability
- Lunar Vehicle Capability

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 structures and those subsystems necessary to sustain the initial package until additional hardware is placed in orbit.

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: Canadian Space Agency, National Space Development Agency (NASDA) of Japan, the European Space Agency (ESA) and the Italian Space Agency (ASI).

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 O
Office of the NASA Administrator at Headquarters.

Level I
Management organization at the level of the NASA Deputy Associate Administrator for the Office of Space Systems Development 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 centers 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)
An orbiting spacecraft that may require servicing. Free-flyers may have their own movement capability or require another vehicle for orbit maneuvers. The Columbus Free-Flying Laboratory is a MTFF.

Mobile Servicing Center (MSC)
Includes the Canadian MSS (below) and the U.S.-provided Mobile Transporter Element (MTE).

Mobile Servicing System (MSS)
The Canadian contribution to the MSC consisting of the Mobile Remote Servicer which includes the Space Station Remote Manipulator and its Base System as well as the Special Purpose Dexterous Manipulator.

Operational Data System (ODS)
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.

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. Achieved after the 17th assembly flight.

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, 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 Remote Manipulator System (SSRMS)
The station equivalent of the Shuttle Remote Manipulator System (Canadarm) but which is mounted on a mobile transport mechanism. (See MSS.) 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.

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)
- 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 Information 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 interaction 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.

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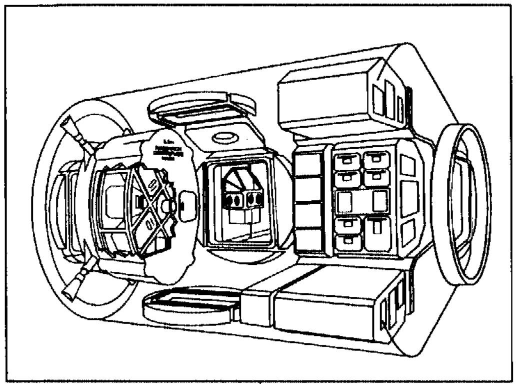


The Centrifuge Facility

Space Station Freedom Payloads

This appendix summarizes the payloads which are under consideration for launch on Space Station Freedom by NASA's Office of Space Science and Applications (OSSA), Office of Aeronautics and Space Technology (OAST) and Office of Commercial Programs (OCP).

OSSA Payloads

The Office of Space Science and Applications is responsible for planning, directing, executing and evaluating scientific studies of the universe and studies of physical problems on Earth. OSSA also provides a scientific research foundation for expanding human presence beyond Earth into the solar system. In its role as a sponsor of space station users, OSSA has identified several payloads and payload concepts as candidates for flight on Space Station Freedom. They are being considered by OSSA's Life Sciences Division and Microgravity Science and Applications Division.

OSSA Payloads: Life Sciences Division (LSD). The OSSA LSD's focus is to conduct a comprehensive program in operational medicine, biomedical monitoring and countermeasures, space biology, exobiology, and Controlled Ecological Life Support System (CELSS) development.

Currently, the LSD is studying five space station facility concepts to support life sciences research. The five facilities are: Centrifuge Facility, Gravitational Biology Facility, Biomedical Monitoring and Countermeasures Facility, CELSS Test Facility and Gas-Grain Simulation Facility. Each facility is modular in construction to support a large number of different scientific investigations. The modularity also enables the facility to be easily upgraded when new equipment and techniques become available and to accommodate new directions in research that will occur in the future.

Centrifuge Facility. The Centrifuge Facility is expected to be the single most important research tool for space life sciences. The Centrifuge Facility is scheduled to be placed in a node and launched on the first Shuttle flight after PMC.

The Centrifuge Facility will be utilized to conduct basic research to determine the influence of gravity and radiation on biological systems, and to develop countermeasures to enable long-duration human activity in space. The facility will accommodate the diverse requirements of a wide variety of biological investigations using animals, plants, cells and tissue cultures. The effects of the space environment, including gravity and radiation, on reproduction, development and maturation of living systems will be of particular interest. By studying these effects down to the cellular level, scientists will learn how long-duration spaceflight affects living systems over single and multiple generations. The facility will also be used to examine the need for artificial gravity in long-duration manned flight.

In order to investigate the effects of microgravity in space, the Centrifuge Facility provides animal and plant vivaria at the ambient microgravity level (Modular Habitats in Holding Systems) and housing at controlled gravity levels (Modular Habitats in the Centrifuge). The Centrifuge Facility is composed of two major systems: a 2.5 m. Centrifuge Rotor and the Habitat Holding Systems with Modular Habitats.

The Modular Habitats are specimen chambers for housing small animals (mice, rats and monkeys) and plants, along with the structure and engineering subsystems required to supply consumables, maintain the appropriate environment, control experiment sensors and collect data. The habitats are modular and have standardized interfaces allowing them to be changed-out and used in the Centrifuge Rotor, Habitat Holding Systems and Life Sciences Glovebox.

The Centrifuge Rotor is able to generate fractional gravity levels between zero-gravity (impossible to do on Earth) and two-g, allowing investigators to examine the effects of variable gravity. The Rotor provides accommodations for a mixed group of Modular Habitats, thus supporting concurrent research on multiple species.

Gravitational Biology Facility. The Gravitational Biology Facility will be a two-rack facility that is launched in several complements. The facility will include equipment to support experiments that utilize the Centrifuge Facility and includes the Life Sciences Experiment Control Computer System. The Gravitational Biology Facility will also include additional multipurpose life sciences equipment utilized by both human and non-human life sciences experiments.

Typical examples of hardware which may be included in the Gravitational Biology Facility are:

Animal Biotelemetry System – a set of sensors and transducers to monitor various physiological parameters of animal specimens through telemetered data to the Experiment Control Computer System;

Mass Spectrometer – an instrument used to determine components of a solution or gas by analyzing the molecular fragments according to their atomic mass;

Perfusion and Fixation Unit – a set of chemicals and ancillary hardware required to treat and preserve tissue samples for later examination and study;

Plant HPLC Ion Chromatograph – an instrument to separate and identify components of a solution by the differences in type and magnitude of ionic charge, specifically designed for monitoring plant specimens;

Tissue Equivalent Proportional Counter – a microdosimeter designed to determine radiation dosimetry at the organ/cellular level and to assess radiation damage to tissue; and,

Experiment Control Computer System – a life sciences computer system to provide buffer memory and mass storage capability for experiments, and an interface between experiment hardware and the SSF data management system.

Biomedical Monitoring and Countermeasures (BMAC) Facility. The BMAC Facility is designed to provide an understanding of the underlying mechanisms of the physiological changes induced by spaceflight; develop and validate countermeasures to prevent or reverse undesirable effects of prolonged exposure to weightlessness; ensure human performance and well-being in space and enable successful readaptation to Earth's gravity.

The BMAC Facility will contain hardware that will evaluate physiological control mechanisms and behavioral processes of man in the space environment. Systems to be studied include cardiopulmonary and musculoskeletal adaptation, neurovestibular function, behavior, radiation exposure, blood cell dysfunctions and alterations in physiological regulation mechanisms.

Typical examples of hardware which may be included in the BMAC Facility are:

Blood Flow and Plethysmography System – a system for measuring and recording the changes in volume of an organ, part or limb, and the amount of blood present or passing through it;

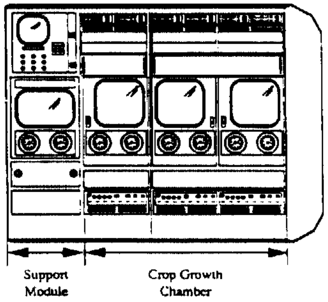
Electrocardiograph (ECG) System – a system that measures, records and displays the electrical activity of the heart;

Fundus Camera – a handheld instrument used in examining the fundus region of the retina of the eye;

Image Digitizing System – a system that converts images from any source into digital form; performs limited pattern recognition and transfers digital data from Space Station Freedom to the ground;

Motion Analysis System – a video system used to monitor, record and analyze the motion of crew members during weightlessness; and,

Pulmonary Analysis System – a system that measures respiratory system functions by determining expired and inspired air amounts and total lung volume.

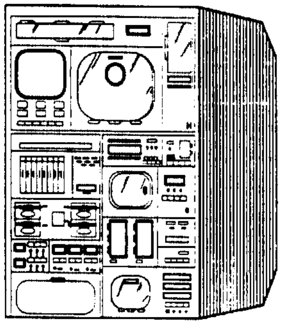


CELSS Test Facility

CELSS Test Facility. The purpose of the CELSS Test Facility (CTF) on Space Station Freedom is to provide NASA with a test bed to develop advanced life-support systems based on biological systems. The long on-orbit time gives scientists the capability to study plant populations throughout complete life cycles and over many generations in a controlled microgravity environment. The monitoring and environmental control of the experiment will be fully automated, including a robotic arm for specimen handling.

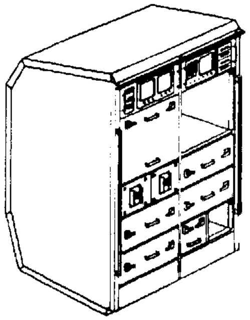
CTF results will be used to identify candidate crops for future CELSS, to determine how well the experiment's subsystems work and to pinpoint plant growth techniques that yield the highest quality and quantity of crops. The CTF's experiments will determine the best combinations of environmental factors such as lighting, humidity, temperature and plant growth area. The amount of plant growth area needed is particularly important given the limited quarters on the Station.

Gas-Grain Simulation Facility. The Gas-Grain Simulation Facility will be used to simulate and study fundamental chemical and physical processes, such as the formation, growth and interaction of clouds, dust grains and other small particles in microgravity. These studies will help scientists address questions related to phenomena such as solar system formation and the origin of life. Studies performed in this facility will also address scientific issues relevant to the disciplines of exobiology, planetary science, astrophysics, atmospheric science, biology, physics and chemistry. In the study of small particle process, the demands on experiment design are severe. Two common requirements are low relative velocities between particles and long time periods during which the particles must be suspended. Sufficiently long duration suspension times to do this fundamental research cannot be attained on Earth, but can be investigated with this general-purpose particle research facility in Earth orbit.

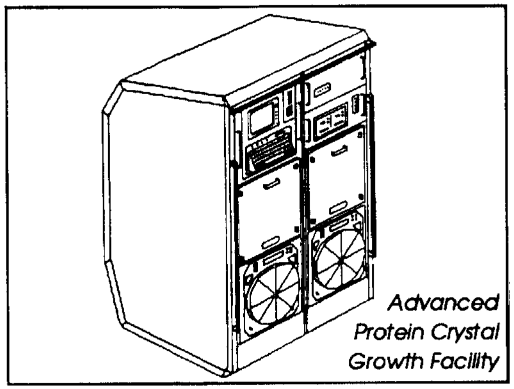


Gas-Grain Simulation Facility

OSSA Payloads: Microgravity Science and Applications Division. Currently, the MSAD is studying six Space Station Facility concepts to support microgravity research. The six facilities are: Advanced Protein Crystal Growth Facility, Biotechnology Facility, Fluid Physics Dynamics Facility, Modular Combustion Facility, Modular Containerless Processing Facility, and the Space Station Furnace Facility. Each facility is modular in construction to provide the flexibility needed to support a large number of different scientific investigations. The modularity also enables the facility to be easily upgraded as new equipment and techniques become available and to accommodate new directions in research that will occur in the future.

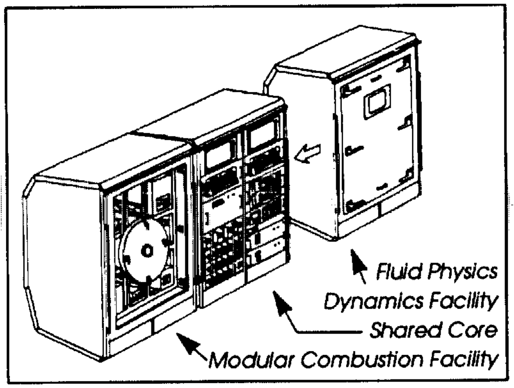


Microgravity Science and Applications Division



Advanced Protein Crystal Growth Facility (APCGF). The Advanced Protein Crystal Growth Facility will support biotechnology research by growing macromolecular protein crystals. Preliminary research indicates that some types of protein crystals grow with a higher degree of internal order in the microgravity environment of low Earth orbit. Highly ordered crystals may be used to improve our understanding of the three dimensional structure of proteins. The APCGF will house long-duration protein crystallization experiments designed to understand the growth process of protein crystals and to grow crystals of better quality than those grown in the Space Shuttle Middeck and on Earth. This knowledge will be used to aid protein crystallization efforts on Earth.

Biotechnology Facility (BTF). The BTF will provide the capability to culture both mammalian cells. These cells or their constituent molecules may be used to culture tissues in an environment more conducive to tissue development and differentiation. This will allow biological processes to be studied and unique biologic materials to be produced. These products could include membranes, monoclonal antibodies or new tissues for transplantation research and treatment. The BTF will be a multi-user facility designed to house a wide variety of biotechnology experiments.

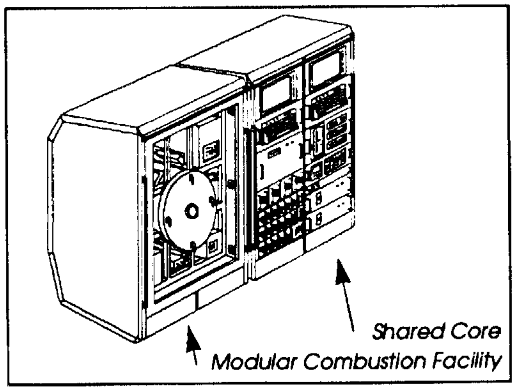


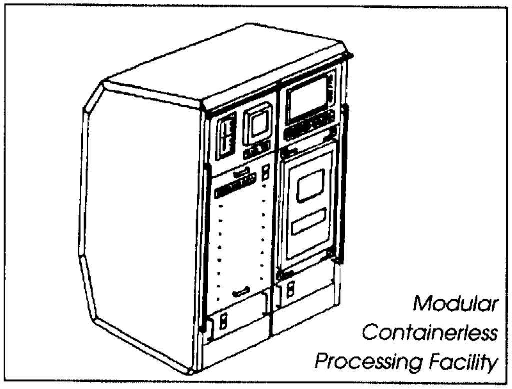
Fluid Physics Dynamics Facility (FPDF). The FPDF will be used by the science and engineering community to perform experiments in a reduced gravity environment to further understand fundamental theories of fluid behavior, to provide improvements in thermophysical property measurement and to provide scientific and engineering data related to a wide variety of fluids-related applications and systems.

The FPDF consist of a fluids experiment rack which will be supported by a control rack associated with the Modular Combustion Facility.

Modular Combustion Facility (MCF). The MCF will be used by the science and engineering community to perform experiments in a reduced gravity environment to develop a further understanding of fundamental theories of combustion processes and phenomena and to provide scientific and engineering data for a wide variety of combustion related applications, such as spacecraft fire safety.

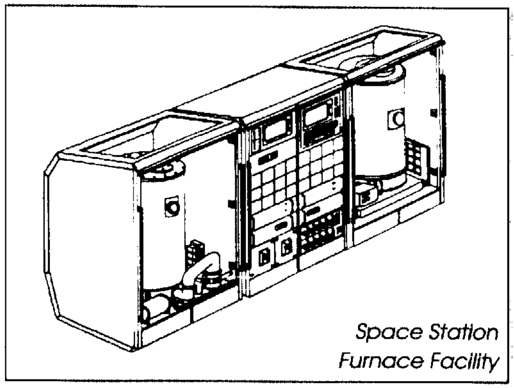
The MCF will initially be housed in two space station racks. One of these will be the control rack, and the other, the experiment rack. The control rack, which contains the support systems, will provide common support for both the combustion and fluids experiment racks.





Modular Containerless Processing Facility (MCPF). MCPF will accommodate a variety of experiments requiring the positioning and manipulation of materials without physical contact with other solids. This facility will allow researchers the opportunity to conduct studies minimizing contamination or other physical effects from container walls.

The experiments being designed for the MCPF will test theories pertaining to phenomena that range from the behavior of liquid drops to the characterization of metal, glass and ceramic samples heated to temperatures up to and even over 2700C. The individual experiment modules will employ acoustic, electrostatic and magnetic forces to position the samples without using physical contact with solid materials. Heating will be provided by combinations of resistive furnaces, induction, microwave and light beams. Rapid cooling, needed by some experiments, will be provided. The facility itself will provide services and equipment common to many experiments such as advanced optical diagnosis, non-contact temperature measurement and data services not otherwise provided by Space Station Freedom. The configuration now being planned will include three kinds of test chambers for MSAD experiments. One test chamber will be used to conduct experiments at near ambient temperature. The second will be used to conduct experiments with ceramic, glass and metal samples at temperatures up to about 1700C in an inert atmosphere. The third experiment chamber will provide the capability to process metal samples at temperatures up to about 2700C in either a vacuum or an inert atmosphere.



Space Station Furnace Facility (SSFF). The SSFF will accommodate solidification research in electro-optic materials, metals and alloys, composite materials, glasses and ceramics. Apparatus optimized to perform melt, vapor and solution crystal growth will be included, as well as instruments to perform thermophysical property measurement of materials and directional solidification of metals and alloys.

The SSFF will allow two furnace modules to be operated simultaneously, allowing a high throughput of investigations when resources are available. Crew interaction will be used primarily for furnace reconfiguration, maintenance and repair. The crew will also install the samples to be processed and harvest them after an experiment. Some crew interactive research will be required for certain types of experiments. The SSFF will accommodate the use of telescience, so that ground investigators will be able to directly influence their experiments in near real-time when the crew is unavailable.

OAST Payloads

The Office of Aeronautics and Space Technology (OAST) is responsible for the on-orbit evaluation of advanced space technologies utilizing Space Station Freedom. Advanced technology experiments are those which gather data relating to space environmental effects, communications, automation and robotics, information systems, advanced space structures and systems and human systems engineering. Some of the experiments which OAST is considering for flight on Space Station Freedom are as follows:

In Situ Trace Contaminants Analysis. This is a real-time system consisting of a mass spectrometer and sampling apparatus which will identify and measure trace atmospheric contaminants within the Station. This experiment will provide data to validate current atmospheric trace contaminants models and will demonstrate the technology required to provide long-term real-time monitoring and analysis of spacecraft atmosphere.

Spacecraft Strain and Acoustic Sensors. Advanced sensors will be integrated in the Station's structural components to measure strain. Both acoustic emission and fiber-optic sensors will be used. This information will be used to assess the level of wear, predict failures and develop improved materials and structural designs for future spacecraft.

Advanced Sensor Development. The shirt-sleeve environment on Space Station Freedom will be used to develop advanced Earth/space viewing sensors. Using the optical window in the U.S. Laboratory Module, advanced sensors can be developed and tested in a short time frame for rapid technology transfer to civil applications.

Transient Upset Phenomena in VLSIC Devices. Very Large Scale Integrated Circuits (VLSIC), which are especially fabricated to permit accurate detection of circuit failures (upsets), will be exposed to environmental radiation within the space station. This experiment will provide technologies to improve reliability and the ability to recover from upsets for future spacecraft and large scale Earth-based computer systems.

OCP Payloads

The Office of Commercial Programs (OCP) has identified several potential commercial payloads for flight on Space Station Freedom. Some of these payloads are:

Bioregenerative Water System (BWS). The Bioregenerative Water System (BWS) will conduct experiments to quantify to what extent plant systems can be used to purify and recycle water in space and to validate the reliability and safety of such a system for closing the air and water loops of an environmental control system. During the man-tended phase of Space Station Freedom's operations, the BWS experiment will utilize a proprietary water condensing subsystem developed by the Wisconsin Center for Space Automation and Robotics to quantify the amount of water that can be obtained from a unit area of growing plants. The experiments will provide information on the extent that waste water can be used by the plant growing unit to provide purified potable water. The availability of a reliable and safe potable water supply system will significantly reduce the costs of maintaining any long-duration space mission, such as Space Station Freedom, a mission to Mars or a base on the moon.

U.S. Commercial Electrophoresis (USCEPS). U.S. Commercial Electrophoresis (USCEPS) will develop better methods to separate biological materials into pure components for commercial biomedical purposes. Continuous flow electrophoresis conducted in space can often be used to separate closely related cell lines, or complex protein mixtures much better than the same process conducted on Earth. Microgravity eliminates dispersion effects caused by density differences in the fluid, sample and product streams which hamper the process on Earth. Biological materials separated in space via electrophoresis can yield larger quantities of purer products than can be produced on Earth using the same process. U.S. companies could use space-based electrophoresis to purify existing or new products such as growth hormone, beta cells and epidermal growth factors.

Float Zone Crystal Growth (FZCG). The purpose of Float Zone Crystal Growth (FZCG) is to grow large, high-quality, single crystals of cadmium telluride and other electro-optical materials utilizing a furnace facility. The elimination of the harmful role of gravity convection and sedimentation, as well as the possibility of growing electronic crystals in space without contact with ampoule walls, allows an improvement of the structure and properties of semiconductor materials grown in space compared to their ground equivalents.

Protein Crystal Growth (PCG). When crystals are grown on Earth, gravitational forces cause sedimentation and density-driven convection which results in poor quality crystals. Protein Crystal Growth (PCG) will utilize the microgravity environment of space to grow highly-ordered, high-quality, large protein crystals which will be analyzed via X-ray diffraction to reveal the proteins' three-dimensional structure. The end product of the space-borne protein crystal growth experiments is knowledge which has practical pharmaceutical applications in many health-related areas such as treatments for cancer and diabetes.

NOTES