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SD 71-217-1

MODULAR space station
PHASE B EXTENSION

PRELIMINARY SYSTEM DESIGN

Volume I: Summary

PREPARED BY PROGRAM ENGINEERING
JANUARY 1972

Space Division
North American Rockwell

12214 Lakewood Boulevard, Downey, California 90241

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MODULAR SPACE STATION, PHASE B DEFINITION OF MODULAR SPACE STATION, MODULAR SPACE STATION CONFIGURATION, MODULAR SPACE STATION MODULE DESIGN, MODULAR SPACE STATION SUBSYSTEMS, MODULAR SPACE STATION GENERAL PURPOSE LAB, MODULAR SPACE STATION OPERATIONS

ABSTRACT

THIS VOLUME OF THE MODULAR SPACE STATION PRELIMINARY SYSTEM DESIGN REPORT SUMMARIZES THE DESIGN AND OPERATION OF THE INITIAL MODULAR SPACE STATION. THE PRELIMINARY DESIGN FOR A CREW OF SIX (6) IS PRESENTED AND CONCEPTS FOR GROWTH TO TWELVE (12) ARE DISCUSSED, WHICH INCLUDES A DESCRIPTION OF THE CONFIGURATION, SUBSYSTEMS, EXPERIMENT LABORATORIES AND FLIGHT OPERATIONS. STATION MODULE DESIGNS ARE DESCRIBED AND DESIGN FEATURES OF THE ARRANGEMENTS, CONFIGURATION AND SUBSYSTEMS ARE DISCUSSED. A REFERENCE EXPERIMENT PROGRAM IS PRESENTED WHICH INCLUDES A REPRESENTATIVE PHASING OF EXPERIMENT ACTIVITY FOR BOTH AN INITIAL AND GROWTH STATIONS. THE FLIGHT OPERATIONS REQUIRED FOR STATION ASSEMBLY AND FOR CARRYING OUT THE REFERENCE EXPERIMENT PROGRAM ARE DISCUSSED.

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APPROVED BY

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FOREWORD

This document is one of a series required by Contract NAS9-9953, Exhibit C, Statement of Work for Phase B Extension-Modular Space Station Program Definition. It has been prepared by the Space Division, North American Rockwell Corporation, and is submitted to the National Aeronautics and Space Administration's Manned Spacecraft Center, Houston, Texas, in accordance with the requirements of Data Requirements List (DRL) MSC-T-575, Line Item 68.

Total documentation products of the extension period are listed in the following chart in categories that indicate their purpose and relationship to the program.

ADMINISTRATIVE REPORTS	TECHNICAL REPORTS		STUDY PROGRAMMATIC REPORTS	DOCUMENTATION FOR PHASES C AND D	
				SPECIFICATIONS	PLANNING DATA
EXTENSION PERIOD STUDY PLAN DRL-62 DRD MA-207T SD 71-201	MSS PRELIMINARY SYSTEM DESIGN DRL-68 DRD SE-371T SD 71-217	MSS DRAWINGS DRL-67 DRD SE-370T SD 71-216	EXTENSION PERIOD EXECUTIVE SUMMARY DRL-65 DRD MA-012 SD 71-214	MSS PRELIMINARY PERFORMANCE SPECIFICATIONS DRL-66 DRD SE-369T SD 71-215	MSS PROGRAM MASTER PLAN DRL-76 DRD MA-209T SD 71-225
QUARTERLY PROGRESS REPORTS DRL-64 DRD MA-208T SD 71-213, -235, -576	MSS MASS PROPERTIES DRL-69 DRD SE-372T SD 71-218, -219	MSS MOCKUP REVIEW AND EVALUATION DRL-70 DRD SE-373T SD 71-220			MSS PROGRAM COST AND SCHEDULE ESTIMATES DRL-77 DRD MA-013(REV. A) SD 71-226
FINANCIAL MANAGEMENT REPORTS DRL-63 DRD MF-004	MSS INTEGRATED GROUND OPERATIONS DRL-73 DRD SE-376T SD 71-222	MSS KSC LAUNCH SITE SUPPORT DEFINITION DRL-61 DRD AL-005T SD 71-211			MSS PROGRAM OPERATIONS PLAN DRL-74 DRD SE-377T SD 71-223
	MSS SHUTTLE INTERFACE REQUIREMENTS DRL-71 DRD SE-374T SD 71-221	INFORMATION MANAGEMENT ADVANCED DEVELOPMENT DRL-72 DRD SE-375T SD 72-11			
	MSS SAFETY ANALYSIS DRL-75 DRD SA-032T SD 71-224				

This document is Volume I of the Modular Space Station Preliminary System Design Report, which has been prepared in the following seven volumes:

I	Summary	SD 71-217-1
II	Operations and Crew Analysis	SD 71-217-2
III	Experiment Analyses	SD 71-217-3
IV	Subsystem Analyses	SD 71-217-4
V	Configuration Analyses	SD 71-217-5
VI	Trades and Analyses	SD 71-217-6
VII	Ancillary Studies	SD 71-217-7

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1. INTRODUCTION

This volume of the Modular Space Station Preliminary System Design report summarizes the design and operation of the initial modular space station (MSS). During the MSS Phase B Extension study a space station system concept was defined that consisted of an assembly of modules delivered to orbit by the space shuttle. The system provides capability to operate initially with a crew of six and, after the addition of modules, with a crew of 12.

The system is capable, in conjunction with the space shuttle, of supporting an effective long-duration earth-orbital experiment program. A representative experiment program was established for the time-phased operation of the initial and growth stations. The sensitivity of the MSS design to alternative programs was established and system requirements defined.

Design and operational concepts for both the initial and growth stations were analyzed and a concept selected that was optimized for the initial crew of six but contained capability for growth to the 12-man crew. A preliminary design analysis was conducted of the initial six-man station and preliminary performance specifications prepared.

The MSS Phase B Extension study contained two major elements of activity, a 10-month conceptual and preliminary design analysis of the modular space station and an 18-month effort associated with information management advanced development. In defining the modular space station, the schedule (Figure 1-1) was arranged to provide a conceptual analysis period followed by selection of system and subsystem concepts and culminating with preliminary design and documentation. Full-scale mockups of a crew/control module and a general-purpose laboratory module were fabricated.

In May 1971, the MSC-NR study team initiated investigation of the sortie-mission mode of operation that could occur after space shuttle IOC and before IOC of the modular space station. Module and subsystem commonality and evolution issues were investigated and are reported in Volume VII, Ancillary Studies (SD 71-217-7) of the preliminary design report. In mid-July 1971, a study was initiated to investigate the impact of reduced payload size on the modular station. The results of this study are also summarized in Volume VII. In September 1971, analyses of several program options were initiated and completed in November. The results of these analyses are summarized in the Extension Period Executive Summary (SD 71-213).

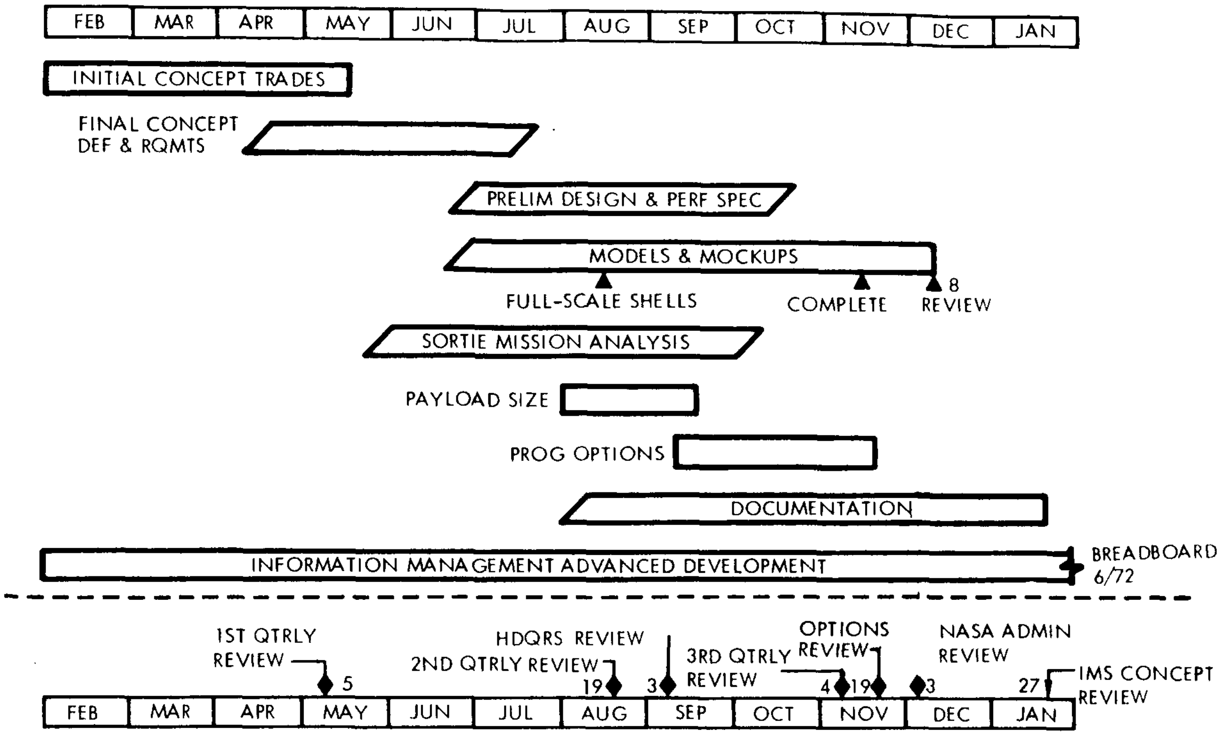


Figure 1-1. MSS Phase B Summary Schedule

The study guidelines established the overall program approach and system requirements. The program contained two time-phased capability plateaus which utilized operation of an initial six-man station for five years followed by growth to a 12-man station. The growth station, with capability equal to the 33-foot diameter single launch station defined in August 1970, operated an additional five years. The growth station would have capability to accommodate all the functional program elements (FPE's) defined in the NASA preliminary edition of Reference Earth Orbital Research and Applications Investigations (NHB 7150.1, "Blue Book", January 1971). The initial station capability would support selected or modified FPE's and be fully configured, including a general-purpose laboratory, with capability to support at least two research and application modules (RAM's).

The modules of the station were to be contained within a launch envelope of 15-foot diameter and 60-foot length and a design-to weight of 20,000 pounds to assure compatibility with the space shuttle. Shuttle launches at a frequency no greater than one every 30 days were available for assembly and operation of the MSS. At each manned stage of buildup, the station was to provide a minimum of two separate pressurized habitable volumes with independent life support capability and other essential services. The assembled station was to be capable of operation in an orbit of 55-degree inclination at an altitude between 240 and 270 nautical miles. Capacity for independent operation for 120 days was to be built into the system.

The Phase B Extension Study was initiated utilizing results of the prior Phase A analyses in addition to the study guidelines. The Phase A study, which analyzed many alternatives of four major classes of configurations, recommended the open class for further definition. The open class configurations are characterized by a central core with crew and facility modules end-docked. Closed, clustered, or hybrid configurations exhibited characteristics presenting unnecessary design and operational complexity.

The definition of the modular space station system required resolution of many issues to establish requirements. During concept definition, there were five major issues: (1) What experiment capability was required in the initial station? (2) Does the station require a manipulator? (3) How should maintenance be accomplished? (4) What subsystems should be selected for the initial station? (5) How should the station accommodations be arranged within modules and into a system configuration?

The basic approach used in analysis of key issues (Figure 1-2) was to conduct a study of alternatives in a series of controlled iterations. Since the interactions among experiments, configuration, operations, and subsystem are complex, it was necessary to control or limit the options in three of these areas while studying alternatives in the fourth area. Alternatives in all four areas were analyzed concurrently by setting controlled baselines. Thus, at the beginning of each iterative step the alternatives of a key study issue were established and a baseline was set for the other elements or parts of the system and then held constant for that iterative step. After review of the results of the initial iteration step, undesirable alternatives were rejected and the impact or sensitivity of the fixed baseline was identified. Additional iterative steps were initiated to evaluate the remaining alternatives and revised baselines were established where required. A major consideration in each of the iterative steps was to select alternatives leading to less complex designs and operations and to lower program costs.

The analyses and results of the study to establish the experiment capability requirements are documented in Volume III, Experiment Analyses (SD 71-217-3), of the MSS preliminary systems design report. Experiment accommodation concepts were established which defined a general-purpose laboratory capability with functional support, utilities, and operating volume for all experiments not assigned to RAM's. Experiments to be performed in the GPL or in RAM's are accomplished in laboratories whose capabilities evolve during the MSS program. In general, more costly experiment provisions were deferred to later operational periods in the program. Laboratory concepts and requirements were defined which provide a system insensitive to program emphasis.

Manipulator studies (Volume VI, Trades and Analyses, SD 71-217-6) selected a shuttle-located manipulator for berthing station and cargo modules

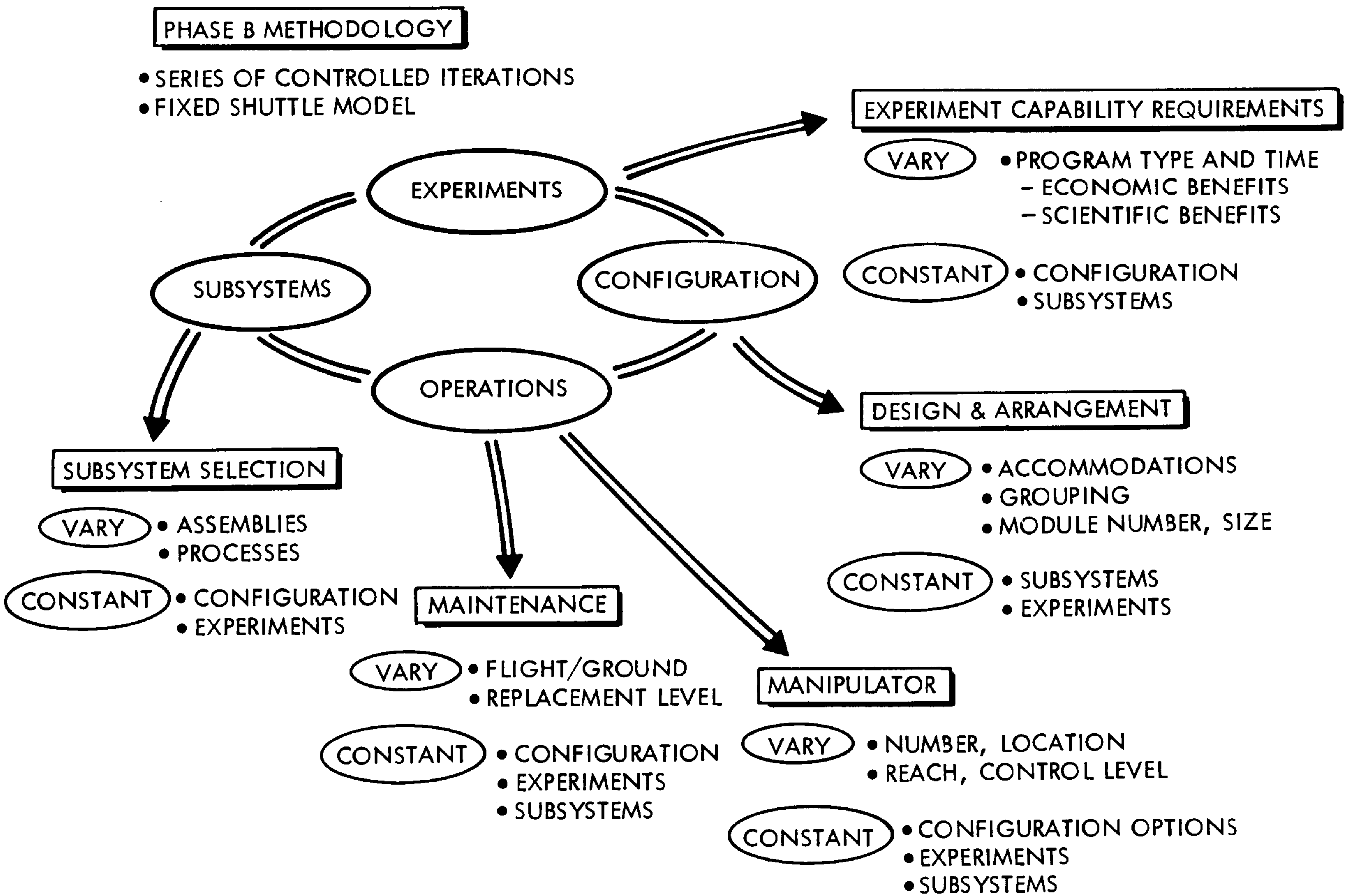


Figure 1-2. Phase B Methodology and Key Issues

or RAM's. Adaptability to a docking mode was retained in the configuration and module design by maintaining a 5-foot spacing between modules and structural provisions for active and passive docking rings. The approach for maintenance (also in Volume VI) incorporated into the station was to design subsystems for on-orbit maintenance and provide capability for module return. Volume VI also contains a summary of the major trades leading to the subsystem selections which are described in detail in Volume IV.

The analysis of functional and equipment allocations, the internal arrangement of modules, and the overall configuration analyses are discussed in Volume V, Configuration Analyses (SD 71-217-5). The analyses resulted in an initial station consisting of four station modules with a high degree of commonality, a core module, and a power module with a replaceable solar array. The initial station contains large general-purpose laboratory areas, including two large airlocks, and has the ability to support two attached or detached RAM's. Growth to the full 12-man station requires the addition of two station modules each with crew and laboratory facilities and subsystem equipment, a small core module to accommodate additional RAM's, and a larger solar array (10, 000 square feet).

The following sections of this volume present a summary description of the initial station preliminary design and the flight operations. A detailed discussion of the operational analyses and crew operations can be found in Volume II (SD 71-217-2) of the preliminary design report. The analyses of ground operations required to support the initial modular space station are described in MSS Integrated Ground Operations (SD 71-222).

2. PRELIMINARY DESIGN - INITIAL STATION

2.1 MSS CONFIGURATION

The modular space station configuration is arranged for an initial operational capability, at a crew size of six, with provisions for addition of modules to operate with a crew size of 12. The initial station configuration (Figure 2-1) consists of four common station modules, power and core modules, and a cargo module. The station modules are assembled on the core module in a single plane (Z axis) which is normally vertical to the earth's surface. Spacing between modules can accommodate either manipulator berthing or direct docking assembly modes. The two laboratory modules have experiment airlocks attached at the outer ports; one provides zenith or celestial pointing for experiments, the other nadir or earth pointing along the local vertical. The two crew/control modules have removable packages attached that contain K- , S- , and VHF-band antennas.

The power module is designed for solar array replacement by removing the turret and arrays from the module. The 7000-square foot array is replaced by a 10,000-square foot array in the growth station configuration.

The cargo modules are docked in the Y plane, alternately on one side of the core and then the other on successive cargo deliveries. Cargo modules normally use the core module ports nearest the power module. Each cargo module contains storage of oxygen and hydrogen for emergency power and nitrogen for leakage makeup as well as storage for consumable supplies.

In addition to the modules berthed to the core, a shuttle adapter is mounted on the end port. This unit provides the mating interface between shuttle and station when the shuttle is berthed. The other core module ports are available for operation or service of RAM's.

The operational configuration of the initial station varies as RAM's are added or returned to earth. The initial station has provisions for accommodating at least two RAM's, either or both operating in an attached or detached mode. The figure shows an operational configuration in which two RAM's are attached. The initial station also has provisions for accommodating many multidisciplinary experiments in the general-purpose labs in the station. The basic design approach was to provide general-purpose laboratory facilities with functional capability to support a wide variety of experiments. The common lab functions defined are implemented in the

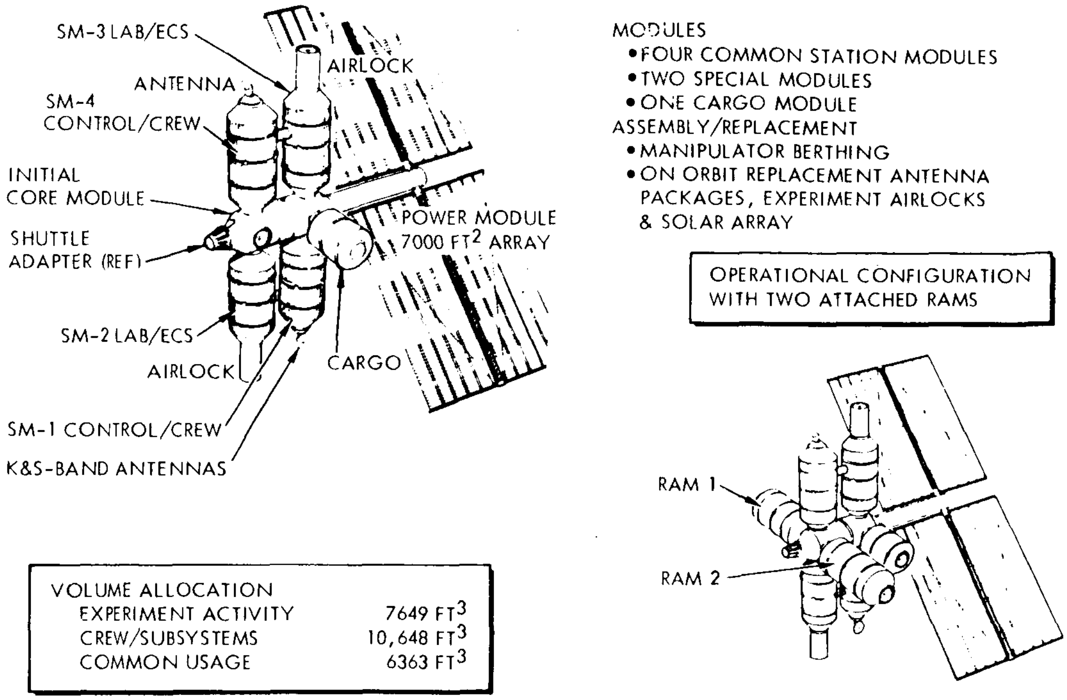


Figure 2-1. MSS Configuration (Initial Station)

experiments. The common lab functions defined are implemented in the station modules. Utilities, equipment, and operating volume are provided for all experiments not assigned to a RAM.

Application of safety criteria during the trades and preliminary design resulted in a station configuration with dual habitable volumes and inhabited station modules connected by means of flexports to adjacent modules to provide alternative shirtsleeve passageways. Subsystem redundancy and installation in the two pressure volumes provide habitability, life support, and station control with any module or volume lost due to depressurization, fire, or presence of hazardous atmosphere. This design approach provides capability of mission continuation in either volume.

In the configuration arrangement, modules SM-2 and SM-4 with one-half of the core module make up one of the redundant volumes. Modules SM-1 and SM-3 make up the other volume. An EVA/IVA airlock is provided in the core module between the two volumes. The EVA/IVA airlock and flexports between adjacent station modules provide dual shirtsleeve or IVA egress or ingress between the dual habitable volumes.

The overall dimensional characteristics of the initial station (Figure 2-2) are: length 100 feet, width 160 feet at the solar array and approximately 117 feet across the berthed station modules. The centerline spacing between station modules is 20 feet, thus providing a 5-foot clearance between modules.

The dual habitable volumes (V_1 and V_2) influenced the station functional allocation. Primary functions (life support and controls) located in one volume require backup functions in the adjacent volume. The backup functions need not require identical equipment nor operate at the same operational level. However, redundant equipment required to meet failure criteria can be installed in alternate volumes and provide identical equipment and operate at nominal level. Where backup functions are required and equipment is provided, it is located in similar areas in the module of the opposite volume.

The basic station module design approach considered commonality of functions, equipment design arrangement, and structure to achieve low cost and accommodate module replacement. Through module commonality, manufacturing, checkout, and maintenance (both on orbit and ground) tasks are simplified. The commonality of functions and arrangement achieved is shown in Figure 2-3. There are two basic types of modules: Type A, which primarily contain crew quarters and station control, and Type B, which primarily contains general-purpose labs and environmental control equipment. The station configuration has one Type A and one Type B in each isolatable volume.

The two Type A modules have identical arrangements of crew quarters, personal hygiene facilities, and control centers. Below deck the subsystem equipment installations are identical. The remaining above-deck area arrangements contain specific facilities for Volume 1 or Volume 2. Likewise, the two Type B modules have identical installations of air revitalization and thermal equipment below deck and specific facilities above deck for each station volume.

The allocation and arrangement considered (1) area and volume requirements, (2) shape factors and traffic patterns, (3) facility interrelationships, (4) equipment interrelationships, and (5) weight distribution. The final facility sizes and module locations (Table 2-1) were integrated with the subsystem equipment required for support to establish the functional allocation (Figure 2-4) for the initial station.

Growth Flexibility

There are several avenues of growth beyond the six-man level. The initial station can be operated at increased levels of activity for temporary

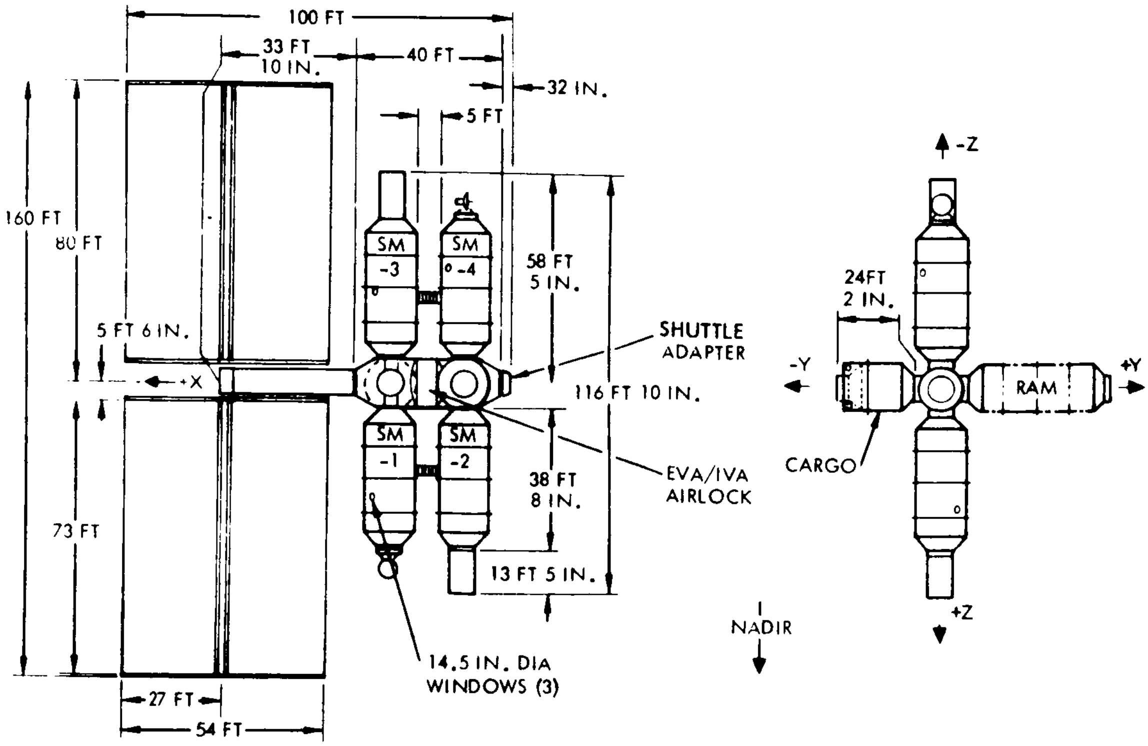


Figure 2-2. Initial Station Dimensional Characteristics

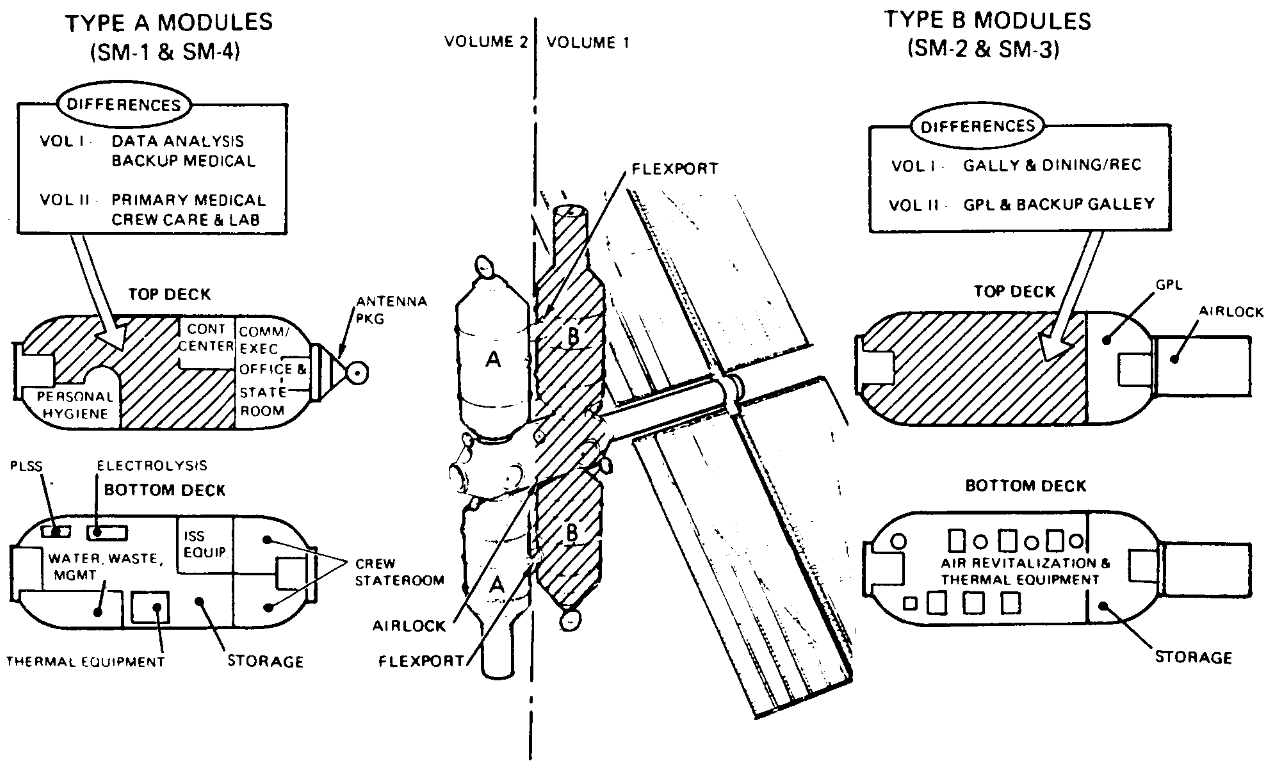


Figure 2-3. Station Module Commonality

Table 2-1. Final Facility Sizing (Initial Station)

Item	V1		V2		Area (sq. ft.)
	SM-2	SM-4	SM-1	SM-3	
General stateroom		2	2		200
Commander's stateroom/office backup control			1		115
Executive staterooms		1			115
Personal hygiene					
With shower			1		56
Without shower		1			45
Primary control center No. 2		1			60
Primary control center No. 1			1		60
Primary galley				1	99
Backup galley	1				8
Dining/recreation				1	183
Prime crew care/exercise		1			224
Backup medical care/exercise			1		55
EVA/IVA airlock		Core			60
GPL (physics)				(1)	62
GPL (biomedical/biological)				1	62
GPL (mechanical, electrical optical maintenance)	1				263
GPL (photo lab)			1		33
GPL (data analysis)			1		100
Experiment operations (zenith airlock)				1	50
Experiment operations (nadir airlock)	1				174

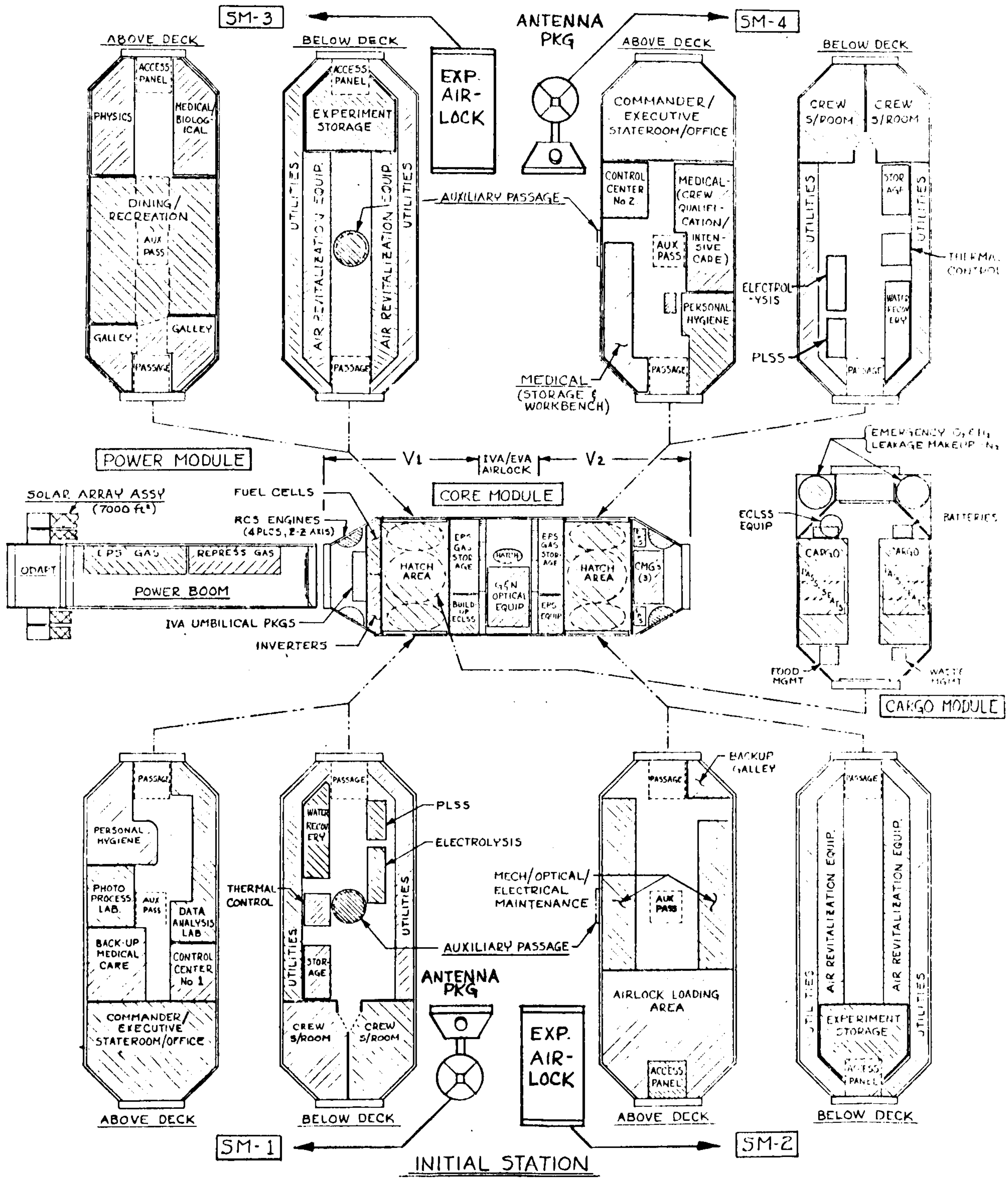


Figure 2-4. Functional Allocation

periods if future studies show this to be practical. Since the solar array is sized to provide adequate power after degrading for 5 years, additional power is available in the early years from the array. The fuel cells can also be used to provide additional power by increasing the delivery of consumables. Capability also exists for rejecting an additional 5 kilowatts of thermal energy in the local vertical flight mode. The design provisions for double occupancy in the crew quarters and the subsystem redundancy built into the dual volumes will accommodate additional crewmen. Temporary occupancy by a crew of eight or nine can provide a significant increase in available experiment man-hours.

The initial station secondary performance capability also can be used for added experiments. Additional volume is available because the module size was defined by internal facility dimensions and the density by the target weight. The volume can be used for integral experiments. Additional power to operate these experiments also is available.

Other avenues of growth beyond the six-man initial space station are shown in Figure 2-5. One approach is to add the two common crew/lab modules of the growth station. These modules each contain three crew staterooms, a six-man life support system, a GPL area, and additional control consoles. After addition of the 10,000-square-foot solar array,

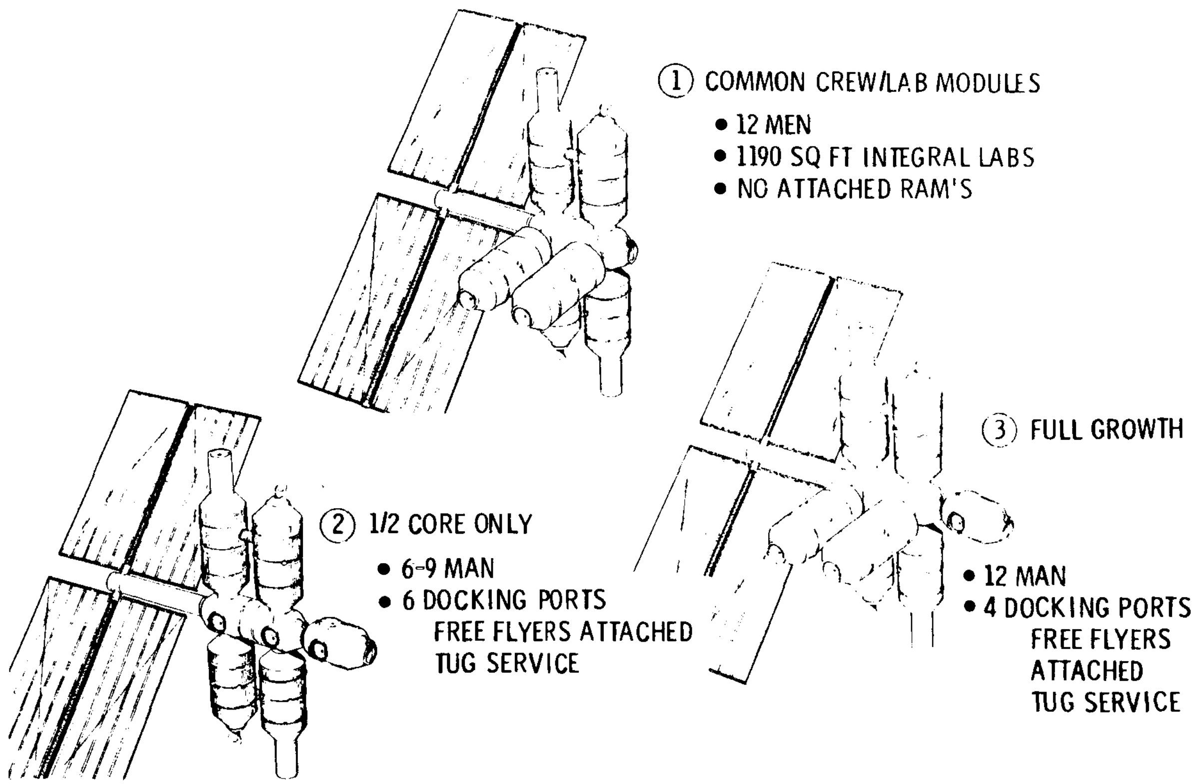


Figure 2-5. Growth Flexibility

this would provide a continuous 12-man capability. In this configuration a large increase is achieved in capability to conduct experiments integral to the station. Since the additional modules occupy two ports, no RAM support provisions are available.

Another alternative is to add the growth station "half-core" module to the initial station to increase the number of docking ports for RAM or tug support. The station could remain at the six-man level or, using the secondary performance capability, operate at an eight- or nine-man level. This system configuration alternative offers maximum program flexibility with respect to non-station program elements such as tugs and RAM's.

The full growth station as currently defined adds both the crew/lab modules and the half-core module, thus bringing the initial station capability level up to 12-man occupancy with additional GPL and four ports for RAM or tug support.

Module Designs

The preliminary design of the initial station included four station modules and two special modules. The power and core modules are unique special-purpose modules while the station modules have a high degree of commonality.

Power Module

The power module (Figure 2-6) contains two assemblies, a power boom and a solar array. The power module overall length is 33 feet 10 inches. The solar array assembly consists of the arrays, an orientation drive, and a power transfer mechanism. The solar array assembly is replaceable and utilizes the standard berthing port. For the initial station the solar array panel area is 7000 square feet.

The power boom is 88 inches outside diameter by 27 feet 6 inches long. The 88-inch diameter boom allows the solar array panels to stow (folded) within the 15-foot diameter shuttle payload envelope. The boom is of monocoque construction utilizing 0.145-inch thick aluminum (5052) which increases its stiffness and consequently increases the natural frequency of the total space station assembly. A berthing port assembly is located at each end of power boom. It also contains four manipulator sockets near the +X-axis end.

Ten high-pressure gas storage tanks are located within the power boom. Four of these tanks provide the repressurization gas (oxygen and nitrogen). The other six tanks are used for the 30-day station interval for fuel cell reactant gas (oxygen and hydrogen).

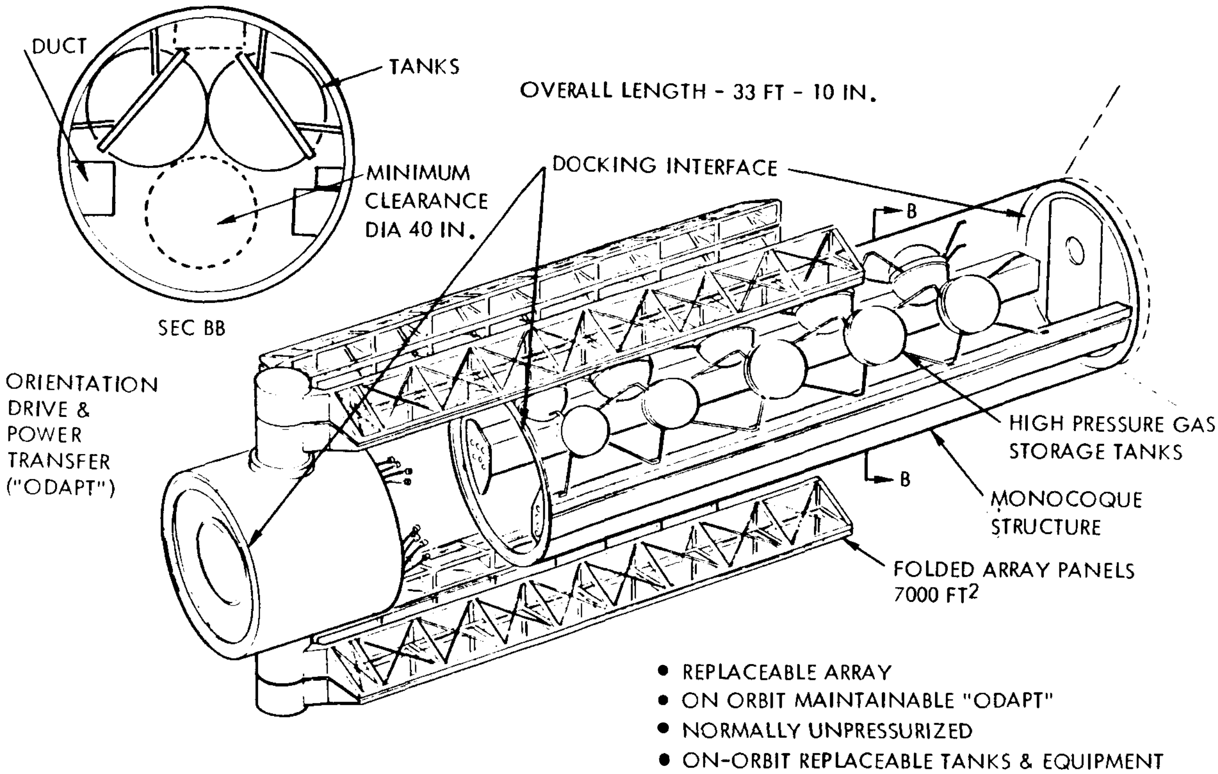


Figure 2-6. Power Module

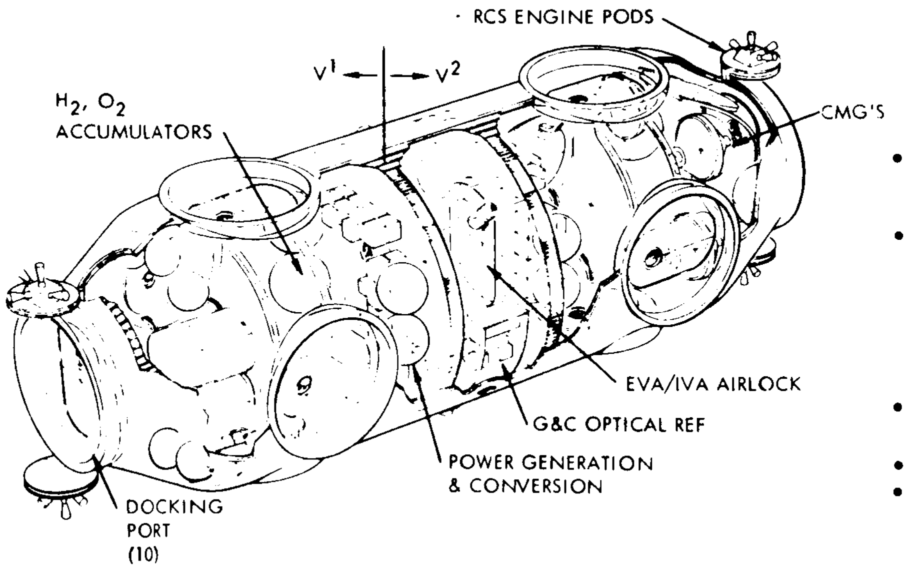
Capability for shirtsleeve environment for maintenance and replacement of equipment is provided even though the module is normally operated unpressurized.

Core Module

The core module (Figure 2-7) is 40 feet long between berthing interfaces and is 12 feet 8 inches outside diameter. The module is of semi-monocoque construction with sidewalls of 0.040-inch thick integral skin-stringer machined 2219-T-87 aluminum.

There are passive berthing ports on each end of the module and two banks of four radial passive berthing ports in the cylindrical portion. The eight side-berthing ports are spaced 20 feet apart, which allows a 5-foot clearance between the station modules. Maintainable RCS quads are mounted on the Z axis at each end of the module.

The core module provides the main passageway between individual modules and contains the power generation, G&C, and RCS equipment. These subsystems are distributed between V_1 and V_2 volumes separated by the EVA/IVA airlock. The airlock is sized to accommodate two suited crewmen. All of the hatches open outward from the airlock. The EVA hatch



- MAX DIMENSIONS
  - LENGTH - 40 FT
  - DIA - 15 FT
- MAIN UTILITY DISTRIBUTION
  - WIRING
  - DUCTS
  - PLUMBING
  - REDUNDANT & SEPARATED
- DUAL VOLUME SEPARATED FUNCTIONS
- LOW CREW OCCUPANCY
- CENTRALIZE G&C
  - RAM INTERFACE
  - ALIGNMENT
  - STABILITY

- ALL SUBSYSTEMS ON-ORBIT REPLACEABLE
- MODULE SPACING FOR DIRECT DOCKING OR BERTHING
- FIRST MODULE LAUNCHED - MINIMIZES COMPLEXITY OF POWER MODULE
  - REDUCES BUILDUP SCARS

Figure 2-7. Core Module

(40-inch-diameter clear opening) is located at a 45-degree angle to provide the maximum clearance between the attached modules. The G&C optical reference and control-moment gyros (CMG's) are located on each side of the RAM berthing ports to provide the maximum pointing accuracy for the RAM's.

The aft side of the airlock bulkheads are used to mount accumulators, the water pump package, and its storage tanks. In addition, it contains equipment required for station buildup such as data processing, communications, and Freon-water pump packages and intercooler.

The end bulkheads are used to mount fuel cells, inverters, and RCS driver electronics. Control-moment gyros are located on the bulkhead near the RAM docking ports at the -X-axis end. IVA umbilical packages are located on the bulkhead at the other end of the core module (+X axis).

All subsystem components are installed for on-orbit maintenance and the utilities routing from port-to-port and end-to-end are redundant and separated for damage containment and safety. All of the G&C and reaction control subsystem assemblies are located in the core module for normal mission operations. Communication wake-up receivers and antennas, as well as the thermal radiators, are installed for buildup and are not used in normal operations. The secondary power and gas storage tanks are installed and are used for both buildup and normal operations.

Station Module Design

The design for commonality includes a standard berthing port interface among all modules and a universal structural design for the station modules. The structure for all of the station modules (Figure 2-8) is 38 feet 8 inches long between berthing interfaces and provides a 13-foot 8-inch clear inside diameter. The external frames and attach points extend to 15 feet. An active berthing port is provided at the core module interface and a passive port at the other end. The interface provisions across the berthing ports are identical. Each module has four manipulator sockets for shuttle deployment and four shuttle bay attach fittings. Radiators cover the exterior of the cylindrical portion of the modules. The radiators and thermal and meteoroid protection installation is identical for each of the station modules.

The longitudinal floor provides a single structural component for mounting of equipment both above and below decks, greatly simplifying the manufacturing installation and design details. The longitudinal orientation also simplifies other ground operations of module assembly, checkout, and shuttle installation.

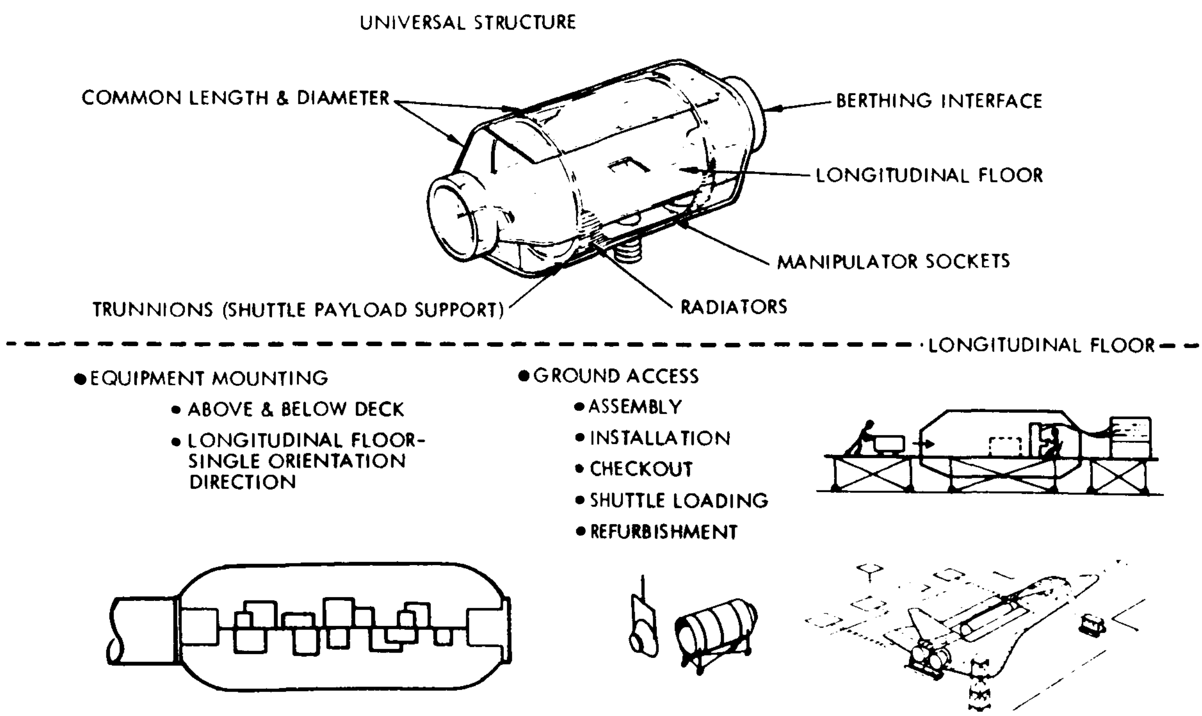


Figure 2-8. Structure Commonality

Habitability, a major consideration, is designed into each of the station modules to provide comfort, a familiar environment, and special conveniences. An up-direction from all floors of each module is the same throughout the station to eliminate reorientation from location to location. Privacy is provided, yet areas are left as open as possible to create a sense of spaciousness. Rectilinear facility shapes are used and all interior equipment is installed in an upright (earth-like) orientation.

Modules SM-1 and SM-4. Modules SM-1 and SM-4 have common functions and equipment location. The crew staterooms, which are common, occupy the entire outboard end of both modules and use a split-level arrangement (Figure 2-9). The commander's area above deck contains an office with a removable conference table which will accommodate three people. Office storage area is provided along the side. A commander's/executive console next to the desk area provides capability for control and monitoring station functions.

The two crew staterooms in the lower level are separated by a room divider. Each room contains a desk, chair, bunk, backup bunk, and closet area. A remote terminal unit also is installed in each stateroom to provide audio and visual communication. Telephones also are provided for private communication and conference calls throughout the station and to the ground. Closed-circuit TV is provided for operations or experiment support and for entertainment.

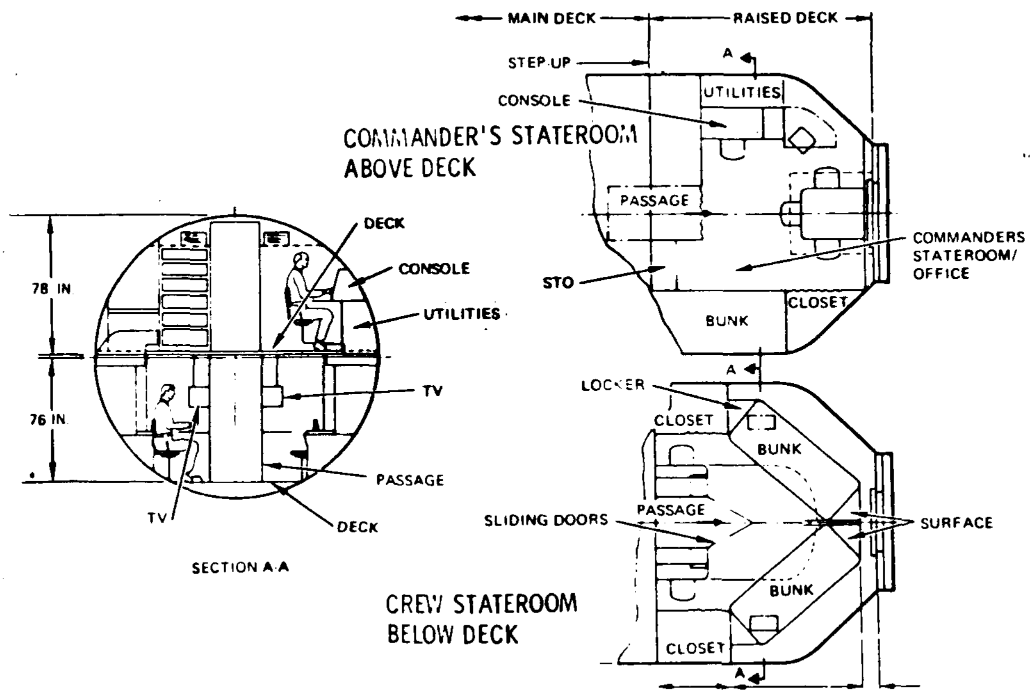


Figure 2-9. Split-Level SM-1 and SM-4 Staterooms

The personal hygiene facilities in both SM-1 and SM-4 (Figures 2-10 and 2-11) are located above deck at the inboard end. They contain a "dry john" toilet with wall-mounted, water-flush urinals. A shower is provided for the initial station and is located in SM-1.

Control consoles are located above deck adjacent to the staterooms in both modules. They contain a central processor and a command/control/monitoring assembly. This equipment is capable of performing the total station operations function. A window (14-inch diameter) is located next to the operator's position at the control console for viewing. Normally, the control center in SM-1 is prime for station operations and the one in SM-4 is used for experiments. Either facility can perform both functions.

The data analysis area in SM-1 has capability for review and analysis of both film and taped data. This includes film analysis by projection onto viewing screens and illuminated table viewing and film editing. Capability is provided for taping and playback of both audio and video tapes and for X-Y plotting data. A control console is provided for control and support of data analysis processes.

A photo processing lab is located across from the data analysis lab. Capability is provided for data and film developing, printing, and editing. It contains a work bench, light table, and storage space.

A small area is provided next to the commander's stateroom for the backup medical care. It contains a folding examination table and medical supplies sufficient for emergency use only.

The functions below deck of SM-1 and SM-4 are similar (Figure 2-12). They each have a water recovery system. The water purity is maintained thermally (160 F) and by silver ion generation. The processed water is stored in the potable water tanks and resupply water storage is in the cargo module. Thermal control equipment (Freon pump package, water pump package, and intercoolers) are located in this area for both modules. Air return ducts and utilities distribution routing are adjacent to each side wall beneath the floor.

The upper deck of SM-4 contains the crew care and exercise area. An isolatable medical area for specialized care for ill or injured crewmen is located across from the control center. It is complete with diagnostic equipment and has separate air vent and temperature control. A medical work area located opposite the hygiene area provides capability for crew stay time qualification and general-purpose laboratory support for life sciences experiments.

Modules SM-2 and SM-3. Modules SM-2 and SM-3 (Figure 2-13) have common functions which are primarily located below deck. These consist of air revitalization, utilities distribution, and storage.

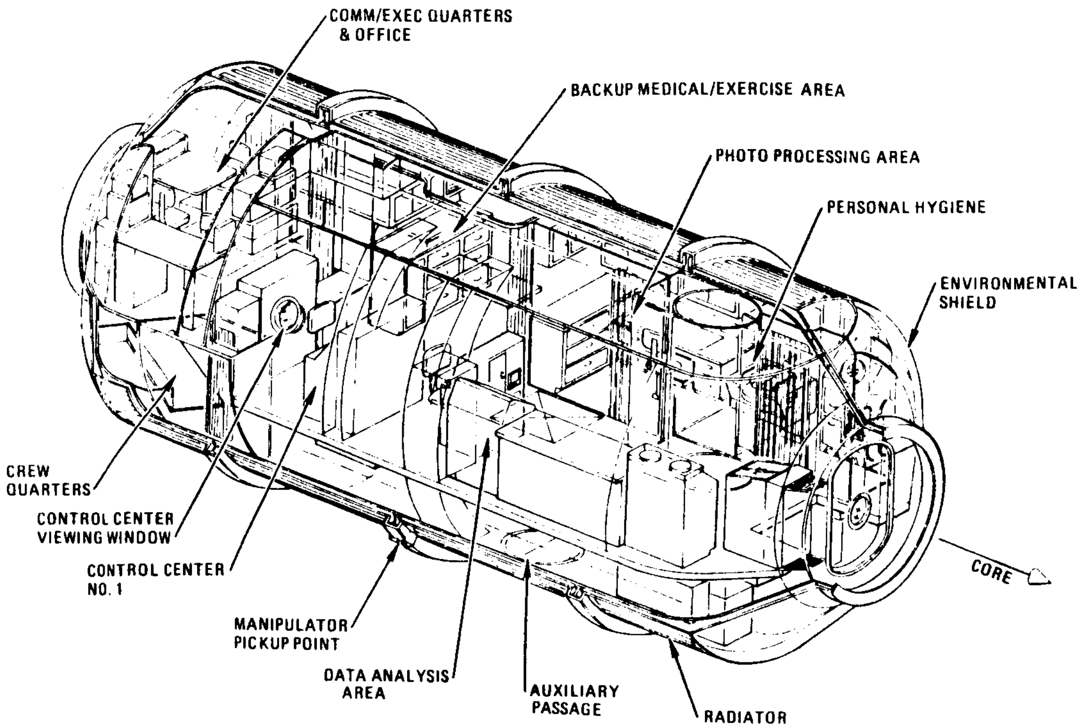


Figure 2-10. Station Module 1

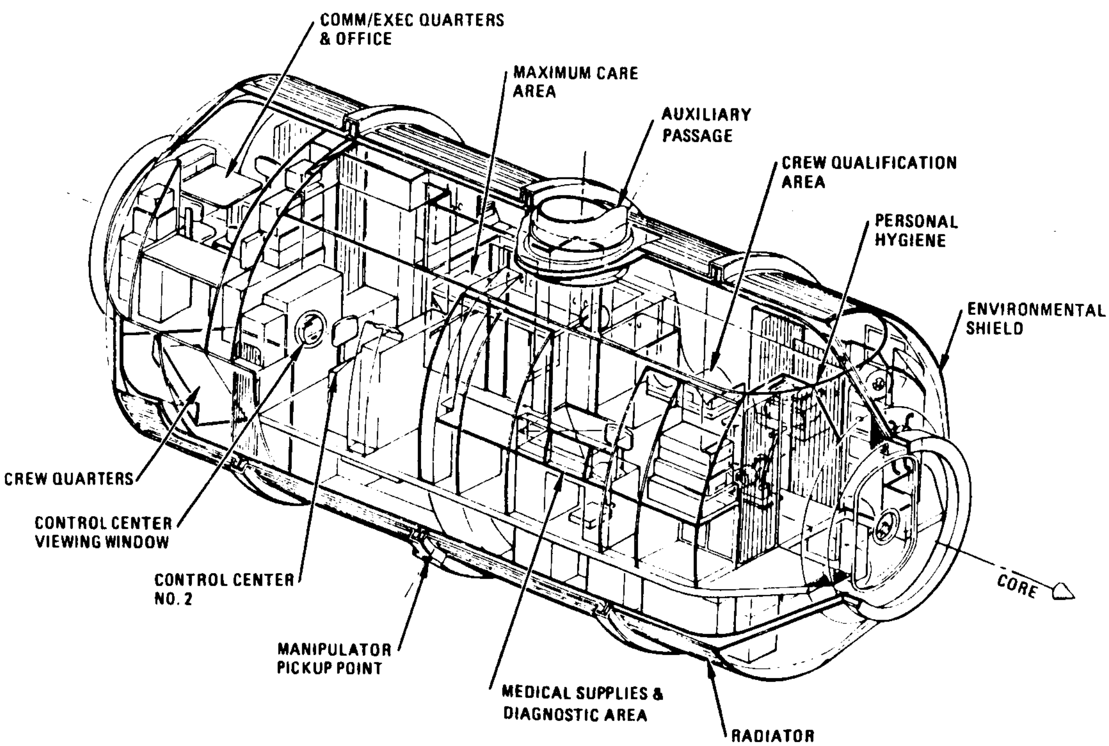


Figure 2-11. Station Module 4

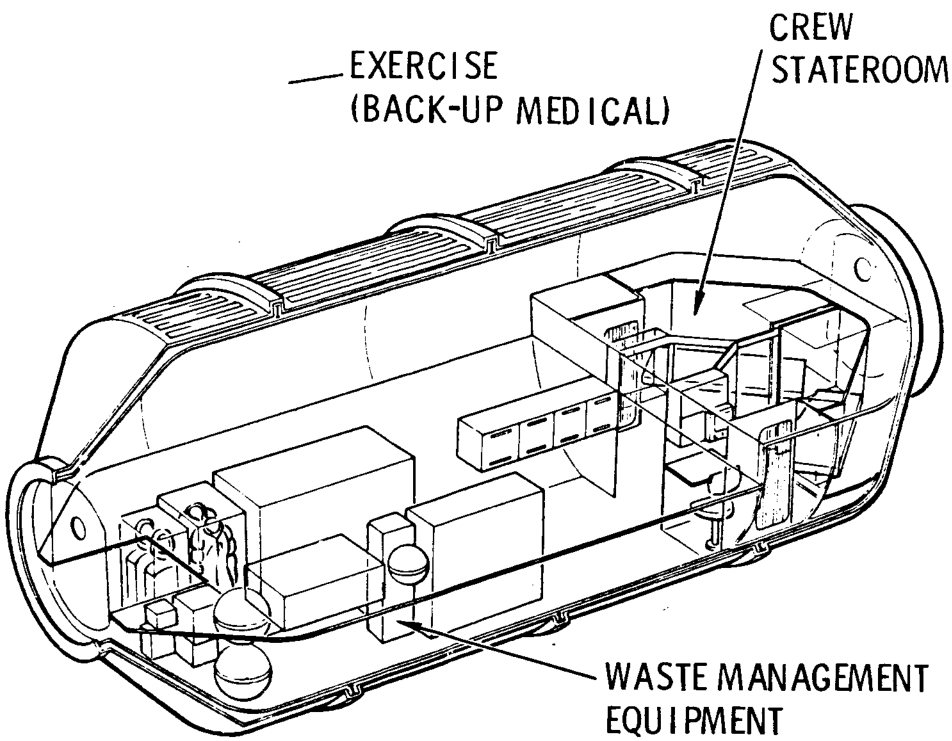


Figure 2-12. Below-Deck Installations, SM-1 and SM-4

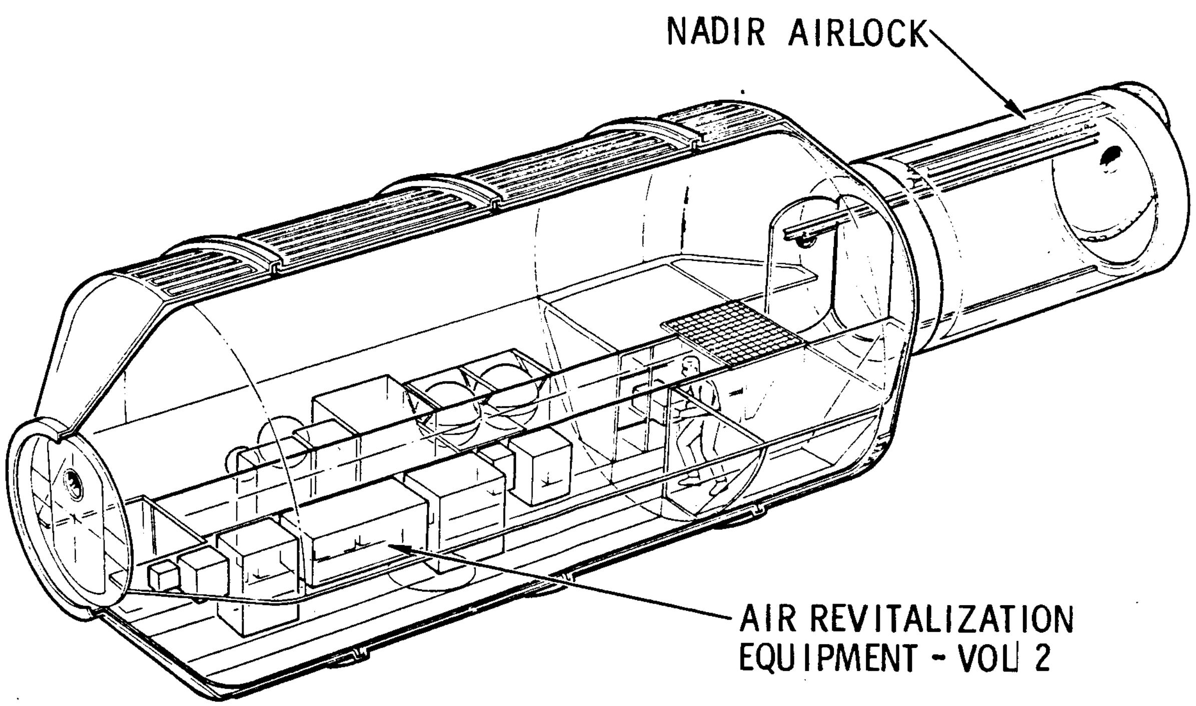


Figure 2-13. Below-Deck Installations, SM-2 and SM-3

Air revitalization equipment (contamination control, humidity control, CO_2 removal, and water electrolysis units) are located along both sides of a center passageway 42 inches wide. This provides easy access for maintenance and service. This equipment conditions the return air and it is then recirculated throughout the station. The utilities distribution routing and return air ducts are adjacent to each side wall, just beneath the floor for the entire length of the module.

Airlocks for deployment of experimental equipment and sensors are attached to the outboard ends of these modules. A large area at these ends is available for storage of experiment equipment and supplies.

The only difference between the lower deck area of the two modules is that SM-3 contains an auxiliary passage (flexport). The auxiliary passage for SM-2 is located in the above-deck area.

The upper deck of SM-2 (Figure 2-14) is primarily dedicated to laboratory functions, except a small area for a backup galley. A major portion of this area is allocated for calibration and services of mechanical, electrical, electronic, and optical experimental equipment. The optical lab has provisions for optical component cleaning and minor adjustment and calibration of optical assemblies and instruments. The mechanical and electrical labs contain equipment and work areas for calibration, checkout, and service of experimental equipment throughout the station or for attached RAM's.

General and emergency equipment (e.g., portable lights, emergency oxygen masks, mobility aids, first aid kits) are stored near the inboard end of SM-2.

The above-deck area in SM-3 (Figure 2-15) contains the primary galley, dining/recreation, and GPL areas (physics and medical/biological). The galley occupies both sides of the passageway at the inboard end of the module. It contains equipment such as a freezer, refrigerator, resistance and microwave ovens, sink, reconstitution unit, cabinets, inventory control unit, and a compactor for trash processing. A backup galley in SM-2 contains a food reconstitution unit, serving and cleanup equipment, Skylab food warmer trays, and food supplies.

The dining/recreation area is near the center of the module. Two dining tables are provided which can be used with table games and craft material for recreation. The area is also available for viewing motion pictures and television. A window (14 inches in diameter) is located near the center of the module angle for observation.

The GPL areas for SM-3 are located at the outboard end of the module. They provide capability for physics, biomedical, or small bioscience

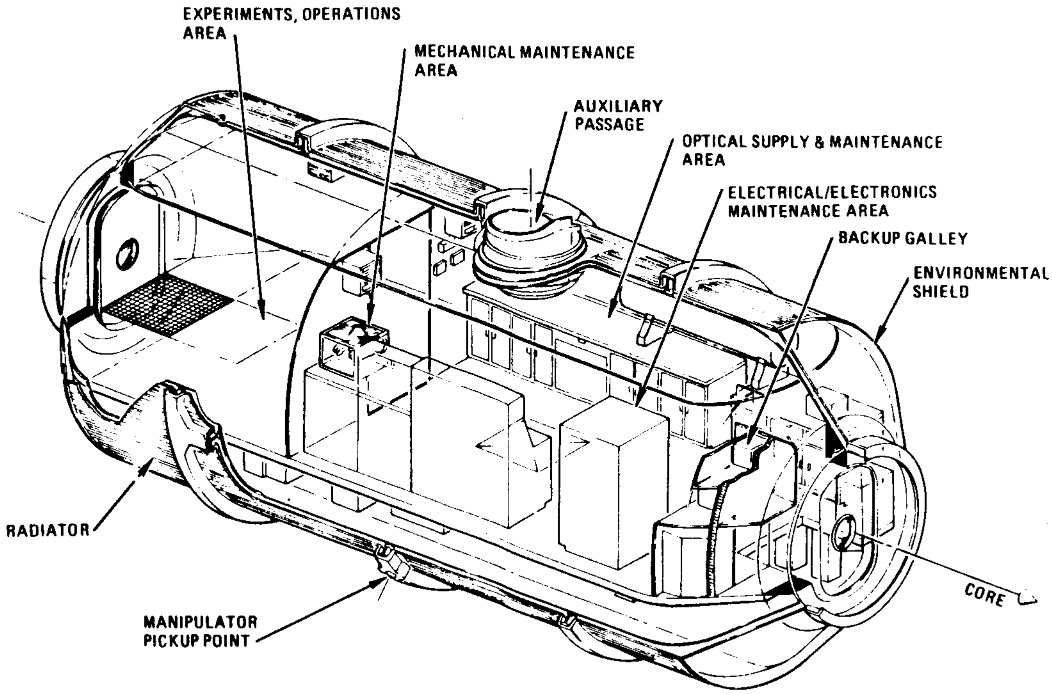


Figure 2-14. Station Module 2

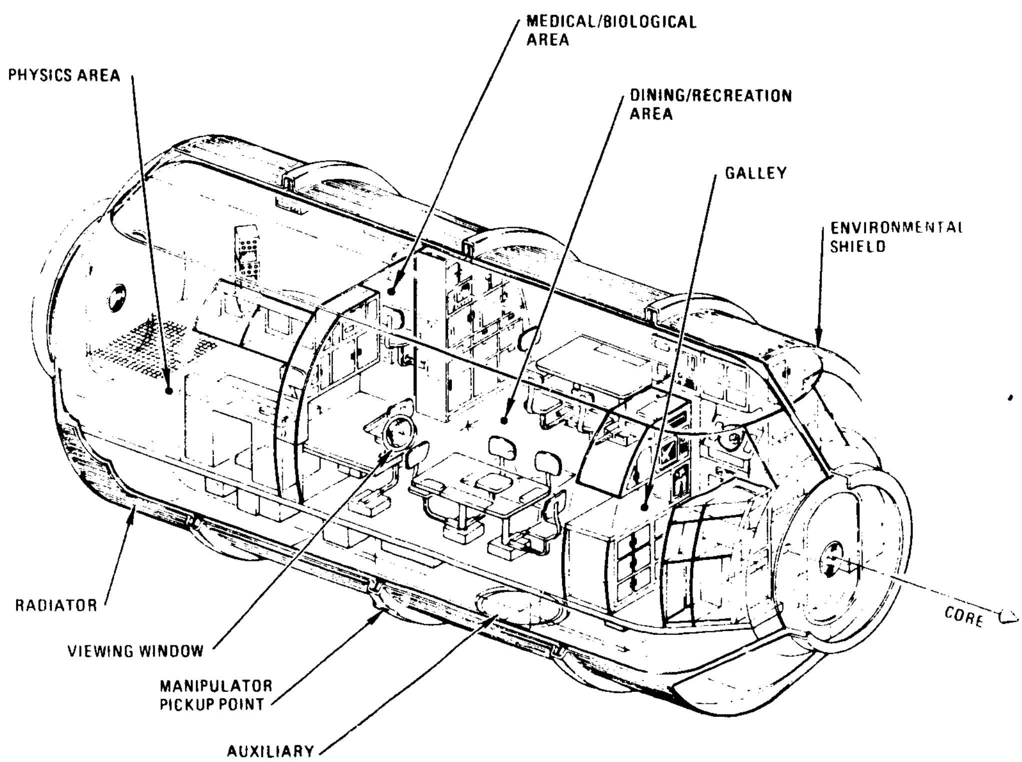


Figure 2-15. Station Module 3

experiments. Much of the biomedical general-purpose equipment is common to the medical and crew care and qualification facilities of SM-4. The physics area contains a work bench and associated equipment (mass spectrometer, portable reflectrometer, sample and retrieval box).

Berthing Port

The design approach to commonality includes a standard berthing interface among all modules. The major functional requirements of the berthing system are to provide (1) controlled mating of various modules, (2) a structural attachment and a sealed volume between modules, (3) utilities interface connections, and (4) accommodations for cargo transport equipment.

There are two types of berthing port assemblies used on the modular space station. These consist of an active and passive configuration which are shown in Figures 2-16 and 2-17. The difference between these two designs is that the passive port does not have berthing latches, alignment wedges, and interface seals. The alignment wedges act as fingers which are tapered so that the approaching ring's alignment guide will mesh with it. The intermeshing tapered wedges and guides provide radial and angular indexing capability. The wedges and guides also provide final alignment and shear capability. The passive port is used in locations subjected the longest to the space environment. This is to increase reliability by reducing failures because of seals and moving parts. Therefore, the core module contain all passive ports and station modules contain an active and a passive port assembly. The capability also exists to mate an active port to another active port.

The berthing design accommodates a ±2-inch centerline miss distance, a ±1-degree miss angle, an angular velocity of 0.10-degree per second,and lateral and longitudinal velocities of 0.05 foot per second.

Each assembly is of cylindrical shape 88 inches in diameter and 10 inches in depth. An opening 42 by 66 inches is provided for cargo and crew passage. This access is sealed, when required, by a pressure hatch. The hatch contains a window 14 inches in diameter located in the center.

The berthing ports and their backup structure are designed to support all loads due to berthing, pressure differentials, and loads from station or shuttle maneuvers. Sealing of the berthing interface is accomplished with dual seals in the face of the active berthing ring. The passive ring represents a smooth seal face and provides the berthing seal surface. Upon berthing, the latches pull the seal faces together.

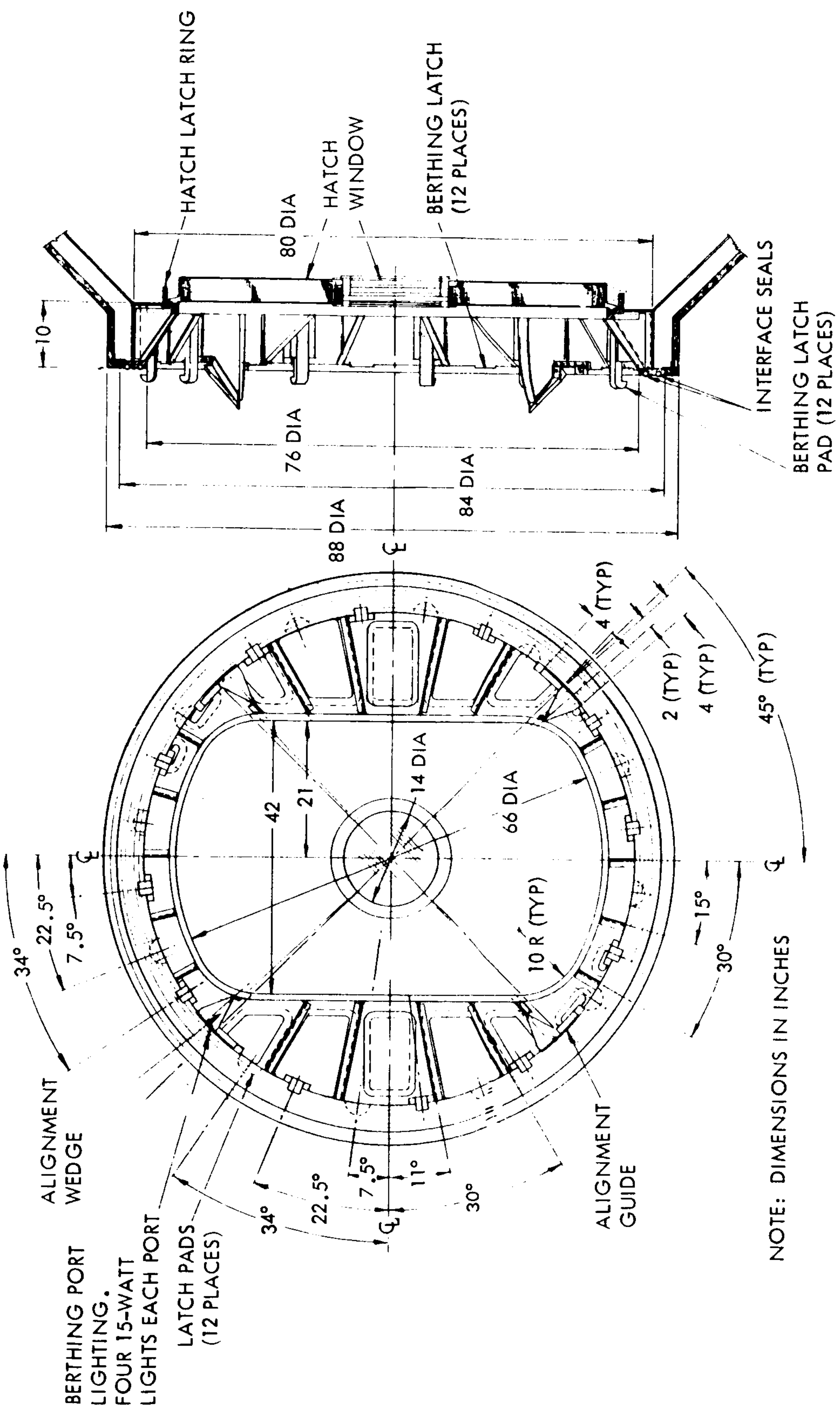


Figure 2-16. Active Berthing Port

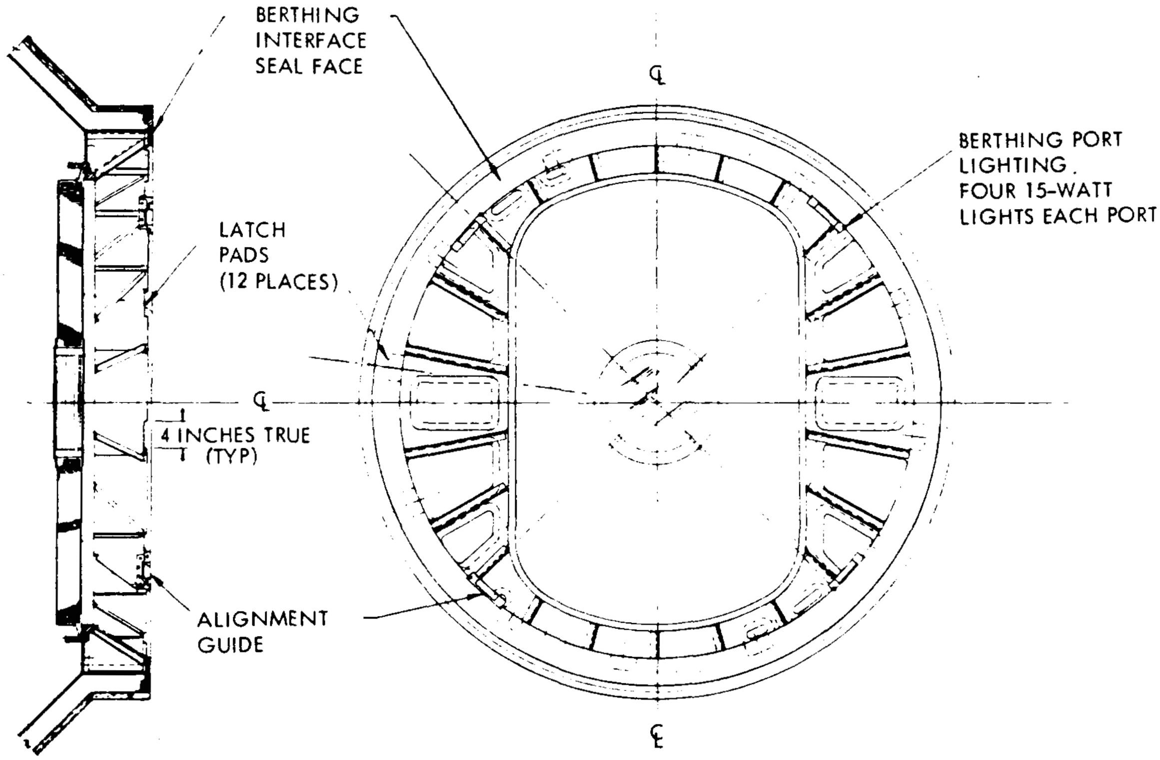


Figure 2-17. Passive Berthing Port

The utilities that are located at the berthing ports (Figure 2-18) include electrical signal and power, plumbing, and air processing duct functions. Space has been provided between the berthing ring and the hatch opening to accommodate 52 total umbilical connections. There are 18 plumbing lines (water, nitrogen, hydrogen, oxygen, Freon), two air processing ducts, 20 electrical signal connections, and 12 electrical power connections that can be made across the interface.

The utility interfacing connections are distributed around the periphery of the bulkhead and are separated to provide redundancy, minimize electrical interference, and to separate potentially hazardous gas and fluid lines. Individual plates to which the utility connections are mounted are sized to fit between the structural ribs of the pressure bulkhead. This arrangement provides the flexibility to accommodate any combination of utilities required for any particular berthing port. Not all of these connections are made at every interface. However, dedicated locations for the specific utility interface is common for all berthing ports. These connections are manually installed across the berthing interface by the crewman after berthing, sealing, and pressurization have taken place. Manual connection of the umbilicals has been utilized to take advantage of the crewman's ability and to minimize system complexity.

DUCTING AND PLUMBING UTILITIES											
INTERFACE		CORE/CORE	POWER	SM-1	SM-2/5	SM-3/6	SM-4	RAM	CARGO	ANT. PKG	A/L EXP.
FREON SUPPLY (PRI & SEC)	1	2		2	2	2	2				1
FREON RETURN (PRI & SEC)	2	2		2	2	2	2				1
H_2O COOLANT SUPPLY (PRI & SEC)	3	2		2	2	2	2	2	2	1	
H_2O COOLANT RETURN (PRI & SEC)	4	2		2	2	2	2	2	2	1	
H_2O POTABLE SUPPLY	5	1		1	1	1	1	1	1		
H_2O WASTE RETURN	6	1		1	1	1	1	1	1		
H_2O ELECTROLYSIS	7	1		1	1	1	1	1	1		
O_2 SUPPLY (& EPS)	8	2	2	2	1	1	2	1	1		1
N_2 SUPPLY	9	1	1	1	1	1	1	1	1		1
H_2 RCS OR EPS	10	2	2	2			2		1		
AIR PRESS/DEPRESS.	11	1	1	1	1	1	1	1	1	1	1
AIR PROCESSING DUCTS	12	2	2	2	2	2	2	2	2		
ELECTRICAL UTILITIES											
INTERFACE		CORE/CORE	POWER	SM-1	SM-2/5	SM-3/6	SM-4	RAM	CARGO	ANT. PKG	AL. EXP.
POWER-PRIMARY (20 KW)	13	8	8								
-SECONDARY (7 KW)	14	4	4	2	2	2	2	2	2	4	2
G/N - RCS	15	✓	✓	✓			✓				
ECLSS	15	✓	✓	✓	✓	✓	✓	✓	✓		
ISS	15	✓	✓	✓	✓	✓	✓	✓	✓	✓	
COMM. - AUDIO/VISUAL	15	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
DATA-DIGITAL/ANALOG	15	✓	✓	✓	✓	✓	✓	✓		✓	✓

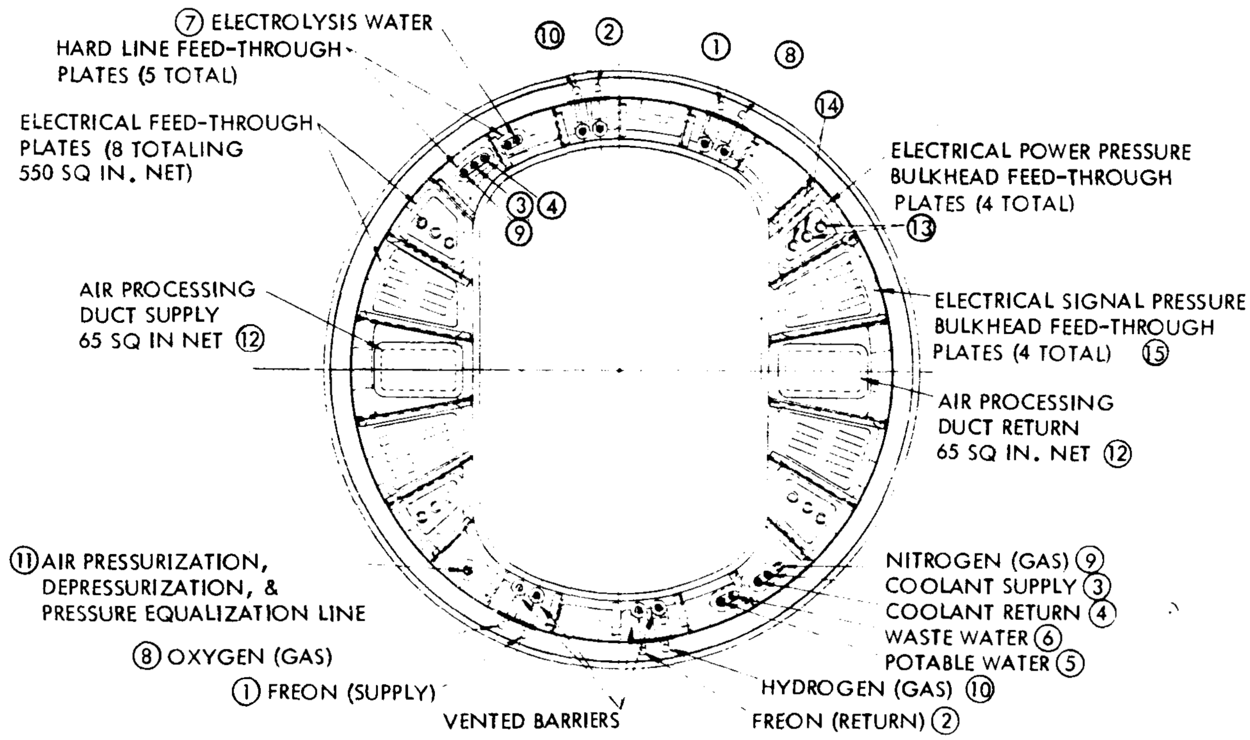


Figure 2-18. Berthing Interface

2.2 SUBSYSTEMS

The equipment required to perform the modular space station system functions were grouped into seven subsystems. These subsystems and their major assemblies (Figure 2-19) are described concisely in the following paragraphs. A detailed description is presented in Volume IV, Subsystems Analyses (SD 71-217-4), of the MSS Preliminary Systems Design report.

The preliminary design of selected subsystems emphasized safety, reliability, durability, and flexibility of station use. The subsystems selected have almost complete maintenance capability without requiring EVA. Cost effectiveness was a major consideration in selection of subsystems. Integrated trades and analyses were conducted to minimize hardware and hold the development costs down. Volume VI, Trades and Analyses (SD 71-217-6), of the MSS Preliminary System Design report summarizes the key trades and analyses subsystem options leading to the selection of concepts for preliminary design.

Functions performed by assemblies of the reaction control, life support, and electrical power subsystems are integrated in the MSS preliminary design (Figure 2-20). The design integrates the hydrogen and oxygen gas generation, gas, and water storage functions which maximizes the use of common hardware.

The EPS utilizes four regenerative fuel cell assemblies, each consisting of one fuel cell, electrolysis unit, hydrogen accumulator, oxygen accumulator, and a water storage tank. The assembly can receive or supply in an emergency hydrogen, oxygen, or water to the ECLSS and RCS. The life support subsystems uses a closed oxygen and water cycle concept consisting of hydrogen depolarizer for CO_2 removal, Sabatier for CO_2 reduction, electrolysis for oxygen recovery and for RCS hydrogen-oxygen generation, and vapor compression for water reclamation. The ECLS subsystem assemblies store the water and the RCS stores hydrogen-oxygen gasses generated at 300 psia by the ECLSS. Water, resupplied on cargo flights, is the only consumable required for these integrated assemblies.

The same electrolysis units are used in the electrical power and life support subsystems, and are compatible with units in the space station technology program developments. The design of the secondary (emergency) power and energy storage assemblies of the EPS utilize space shuttle-developed fuel cells.

All subsystems use electrochemical processes based on the hydrogen and oxygen chemical reactions, with similar working fluids, hardware, maintenance, checkout, and overall technologies. These features result in the lowest-cost integrated EPS, RCS, and ECLSS. The low cost

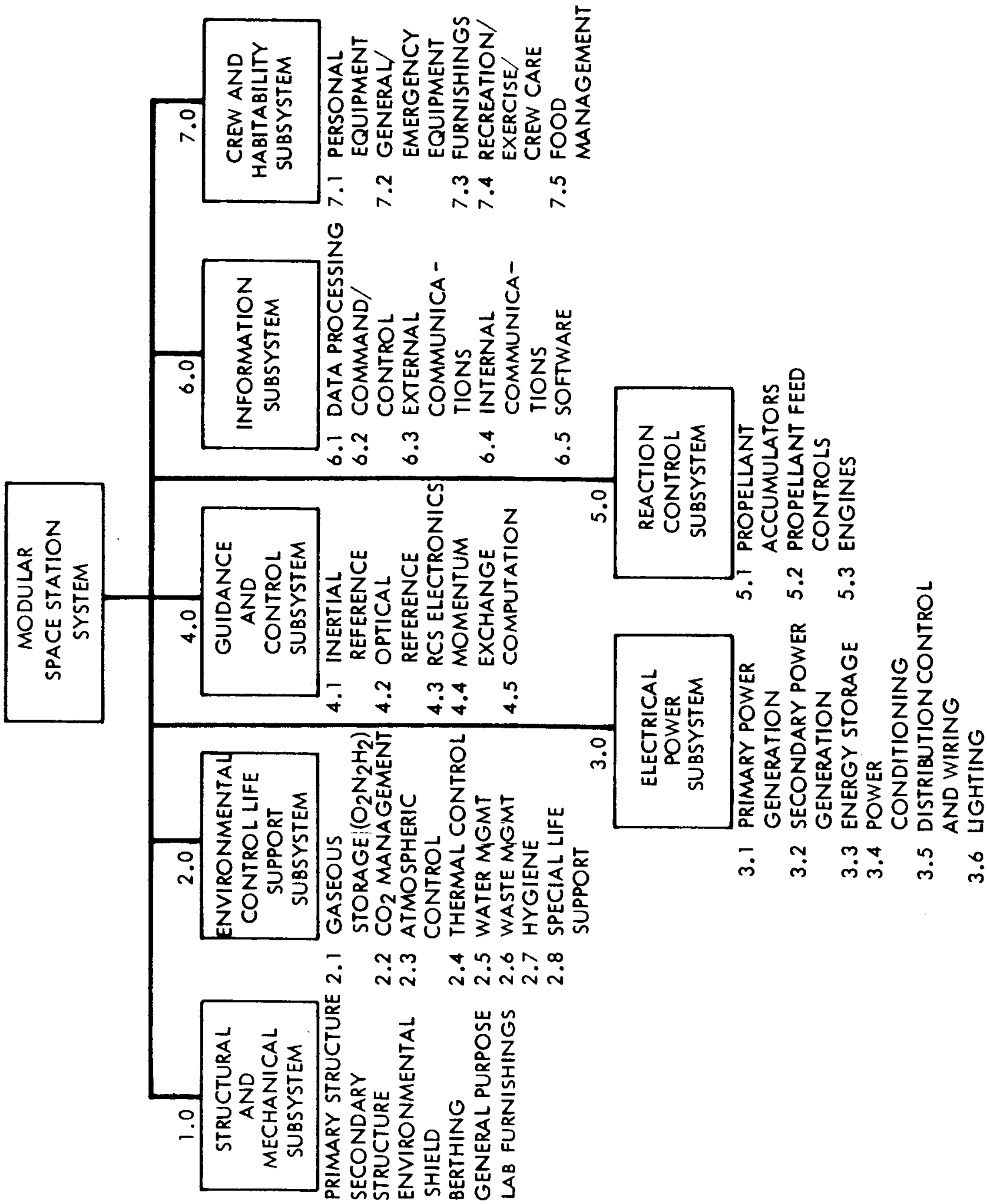


Figure 2-19. Subsystem Functional Tree

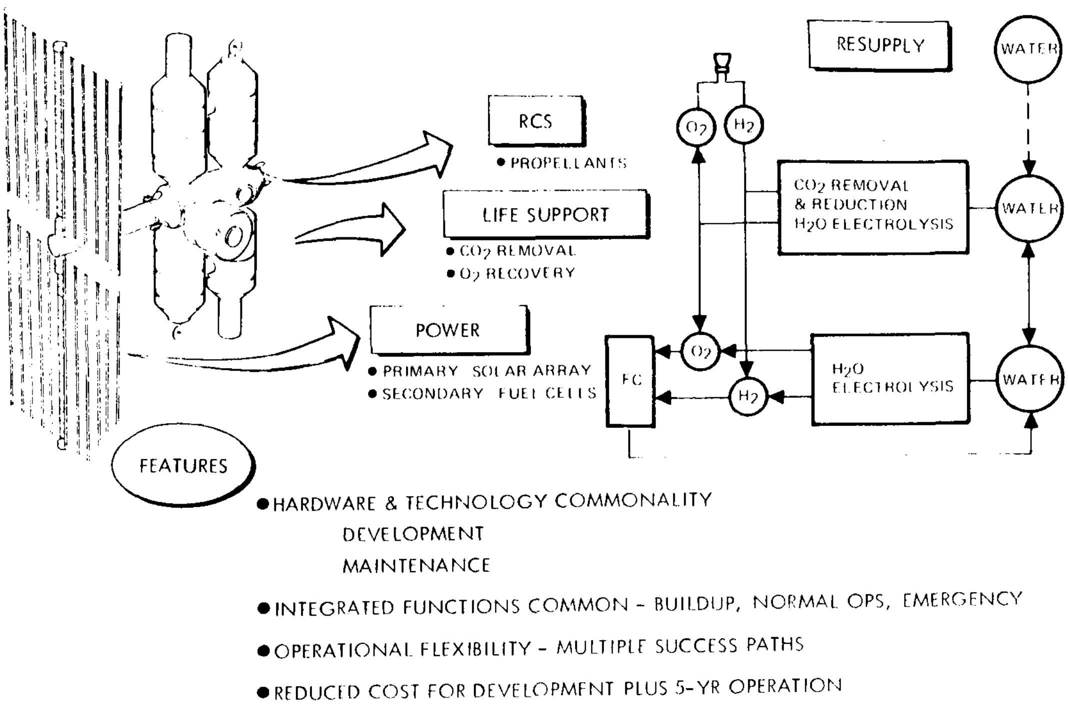


Figure 2-20. Integrated Subsystems

derives from (1) shared development, (2) reduced hardware through shared redundancy, and (3) reduced logistics through shared contingency consumables. In addition, mission operational flexibility is improved by providing multiple success paths for critical functions (hydrogen, oxygen generation) and increased secondary performance through shared capabilities.

Structural and Mechanical

The structural and mechanical subsystem provides the space station pressure enclosure as well as the living and working quarters contained within the structure. It provides for the mounting of associated subsystem components, general-purpose laboratories, and storage facilities. The environmental shield provides thermal, meteoroid, and radiation protection. The structure provides berthing ports and mechanisms for crew and equipment transfer. This structure must provide adequate stiffness to maintain satisfactory vehicle stability and control characteristics in both launch and orbital configurations.

Habitable areas are pressurized to a nominal level of 14.7 psia for orbital operations. Compartments that are normally pressurized during orbital operations are sealed before launch and the corresponding compartment absolute pressure is considered in structural design for shuttle transport conditions.

Structural Arrangement

The structural and mechanical preliminary design of the common station modules is shown in Figure 2-21. The station modules utilize a monocoque structure,the core module utilizes a semimonocoque skin and stringer arrangement, and the power boom utilizes a monocoque construction similar to the station modules. Generally, structural components that are subjected to long-term loadings such as the pressure shell or require welded joints are constructed from either 2219-T87 or 5052-H34 aluminum alloys. Components that do not require welding and are not subjected to long-term loadings are constructed from 7075-T6 aluminum alloy.

The monocoque construction has several other definite advantages over other methods of construction:

1. The monocoque skin thickness allowed a lower strength aluminum to be used. 5052-H34 was chosen because of its ease of manufacture, low cost, and high elongation properties. Manufacturing costs of the monocoque shell are approximately 60 percent of the cost of the foam-stiffened or integral skin stringer constructions. Also, greater radiation protection is provided.

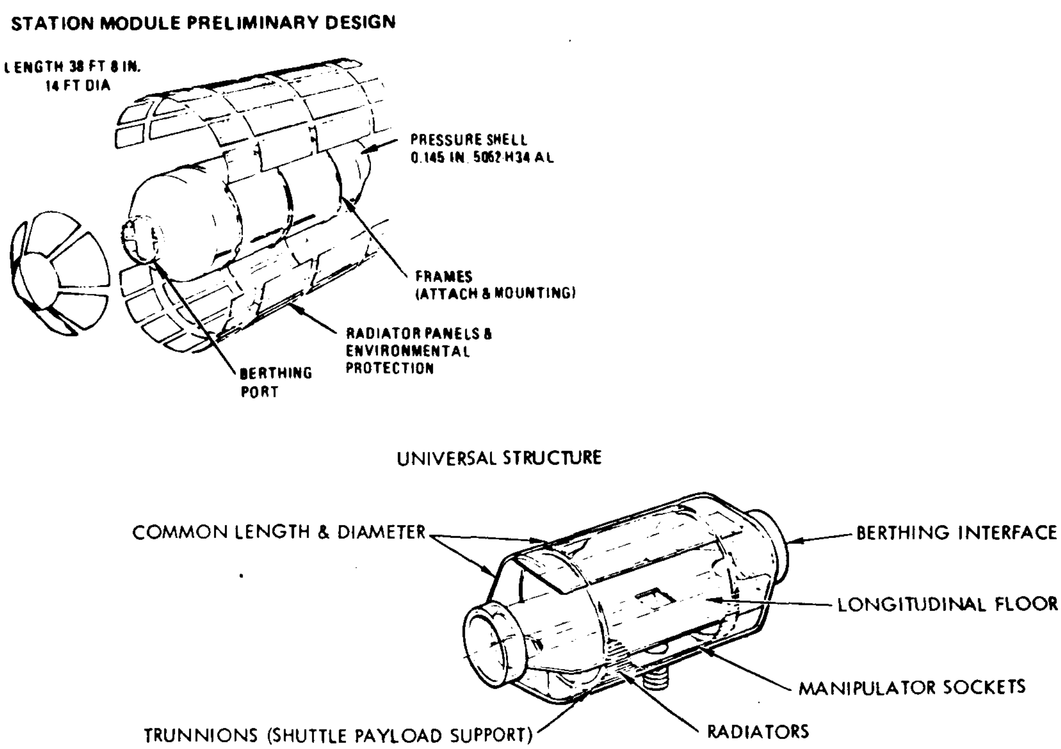


Figure 2-21. Structure and Mechanical Subsystem

2. Increased station stiffness resulting from the thicker monocoque shell raises the lowest mode natural frequencies of the station configuration.

3. Ground handling restrictions are less severe for the monocoque shell compared to the other constructions because of the inherent damage resistance of the thicker aluminum skin.

4. Maintainability and repair is much easier for the monocoque than the skin-stringer type of construction.

The common modules are designed to facilitate the use of floors either parallel or normal to the module longitudinal axis. The floors are a honeycomb sandwich construction with 7075-T6 aluminum facing sheets and 5056-H38 aluminum core.

Environmental Protection

Environmental protection includes thermal protection, meteoroid protection, and radiation protection.

The thermal protection assemblies consist of environmental shield panels which cover the end domes and cylindrical surfaces of the modules. The outer surface provides the carrier panel to mount the insulation and strength and stiffness to withstand acoustic pressures inside the shuttle cargo bay. The outer surface is 0.030-inch-thick fiberglass laminate for the power and core modules and 0.030-inch thick aluminum for the station modules. This outer surface is the primary meteoroid bumper. The insulation blanket is the inside layer of the shield assembly and consists of approximately 60 layers of aluminized Mylar. It is supported from the outer surface panel with venting provisions designed for boost and orbital conditions. The insulation assembly is enclosed in a 10-mil-thick Kapton film which protects the insulation from handling damage and permeation of cabin atmosphere leakage. This film also serves as a secondary meteoroid bumper.

Protective covers which incorporate the same general features are installed on four core module (Y-axis) berthing ports. These covers are rotated out of the way to allow operation of the protected item. Protective covers also are provided for the three standard windows in Station Modules 1, 3, and 4, and the window in the EVA airlock.

Hatches

A common hatch (Figure 2-22) is located on the ends of every module with the exception of the power module. The power module utilizes the

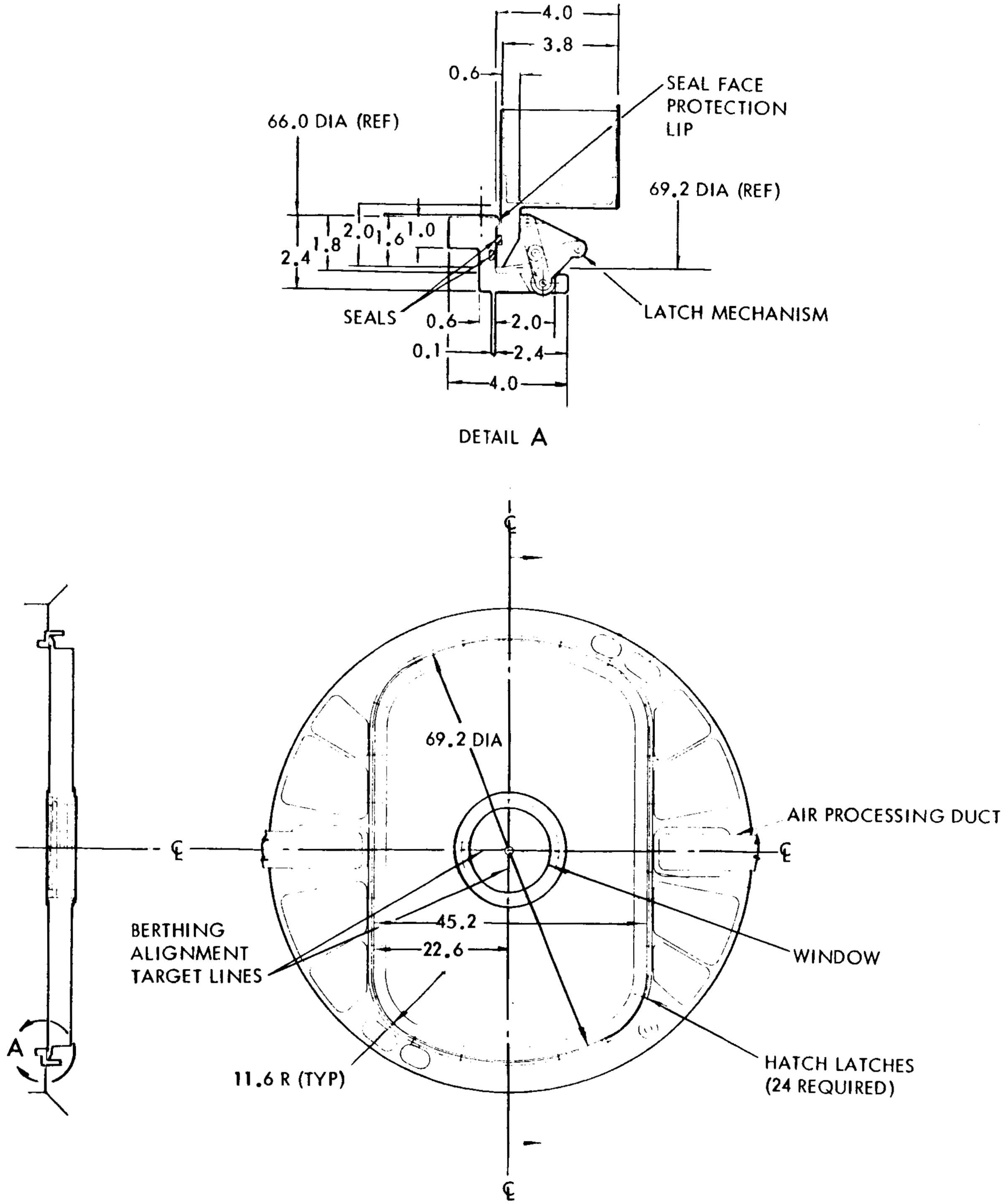


Figure 2-22. Common Hatch

common hatch at the interface to the core module but provides only a 44-inch diameter hatch on the end of the solar array turret. This hatch is utilized for personnel exit only. Each of the berthing ports contains the common hatch. The common hatches all open inward, which permits the module pressure to assist the sealing.

The station module hatches at the core module interface are returned to earth after berthing to increase usable of space and access. The core module hatches, therefore, will provide the means of closing off the individual modules if required to isolate the volume or if required when removing a module.

Another group of hatches, 40 inches in diameter, is provided to close off the port auxiliary passages which provide the second means of access from each of the station modules. Each auxiliary passage hatch contains a four-inch diameter clear window. This window is utilized for observation when the auxiliary passage is being used.

Each common hatch contains a standard 14-inch clear diameter window. These windows are utilized by the berthing alignment TV to view a berthing target on the window of the approaching module. These windows are also utilized for observation of the solar arrays and observation of an EVA crewman when there are no modules covering the port.

Windows

There are three habitability windows in the station module pressure shell. All habitability window centerlines are located 51 inches from the longitudinal floor. Station Modules 1 and 4 have a standard window in the control console area and Station Module 3 has a standard window in the dining and recreation area. The windows are protected by a cover when not in use. The window cover is opened and closed by a manually operated handle and displacement mechanism. The cover is locked and sealed (dual seals) when in the closed position, providing shirtsleeve environment for maintenance on the window assembly.

Auxiliary Passage

A second means of egress from the modules is provided by the auxiliary passage (flexport). Hatches are provided on both sides of the passage, which permits isolation of any one module. This passage may be normally pressurized or not. Access to the auxiliary passages is accomplished from the upper deck in SM-2 and -4, and from the lower deck in SM-1 and -3. A removable panel is provided in the floor of the modules in line with the auxiliary passageways. These panels provide access to the auxiliary passageways from the lower deck of SM-2 and -4 and from the upper deck of SM-1 and -3.

Environmental Control and Life Support

The ECLSS provides for the functions of gaseous storage, CO_2 management, atmospheric control, thermal control, water management, waste management, hygiene, and special life support. In addition, the electrolysis units of the CO_2 management assembly are used to supply the RCS propellants. The selected concepts to satisfy these functions are listed in Table 2-2.

Table 2-2. ECLSS Concepts

Function	Concept
Gaseous Storage	High-pressure (3000 psi) storage for repressurization leakage makeup, and emergency ECLSS, EPS, RCS Cargo module and power module storage
CO_2 Management	CO_2—hydrogen depolarizer (LiOH 96-hour emergency CO_2 reduction—Sabatier CH_4 dump Oxygen recovery—solid-polymer water electrolysis
Atmospheric Control	Humidity control—central humidity condenser Contaminant control—nonregenerable charcoal and catalytic oxidizer Monitoring—Gas chromatograph, mass spectrometer
Thermal Control	Active central dual coolant (water and Freon 21) 180-degree segmented radiators on station modules
Water Management	Water reclamation—vapor compression Purity control—160 F and silver ions
Waste Management	Dry john, low-temperature vacuum drying Trash compactors Urinals, wall-mounted, water-flushed
Hygiene	Full body shower, sinks, vacuum cleaning
Special Life Support	Fire control—condensate nuclei detector, CO_2 fire extinguisher IVA air and water plumbing EVA PLSS servicing—high-pressure oxygen, water, LiOH

The major requirements which influenced selection of or sized ECLSS equipment are listed in Table 2-3.

Table 2-3. Major ECLSS Requirements

Item	Requirement
Crew	6 man growth to 12-man
Storage capacity	120-day expendables
Atmosphere	14.7-psia oxygen-nitrogen shirtsleeve
Emergency provision	96 hours
Pressure volume	Dual, repressurization of 1 volume
Water vapor	8-12 mm Hg
CO_2 concentration	3 mm Hg
Thermal control	
System	Independent of orientation as design goal; no condensation
Module loss; gain	2,000 Btu/hr; 1,000 Btu/hr
Crew metabolic	11,900 Btu/man-day
Oxygen consumption	184 lb/man-day
Carbon dioxide production	225 lb/man-day
Water usage	24 lb/man-day
Station leakage	10 lb/day initial, 15 lb/day growth
Experiment support	
Oxygen consumption	1.2 lb/day
RAM leakage	1.0 lb/day
Water usage	35 lb/day
Thermal control	7,000 watts max.
Waste disposal	2.2 lb/day

The dual pressure volume requirements, in conjunction with the failure criteria for the MSS, established the ECLSS redundancy and equipment sizing requirements for dual 6-man equipment. The 3.0 mm Hg pp CO_2 requirement, in conjunction with the 12-hour experimental no-venting requirement and minimization of electrical power, forced selection of a hydrogen depolarizer concentrator concept for CO_2 removal. The on-orbit repressurization requirement of one pressure volume of the MSS drives the high-pressure gas storage assembly to large volumes located in nonhabitable areas. The ECLSS also has several requirements to provide experiment support. These include thermal control, water and waste management, and atmospheric makeup. The ECLSS preliminary design is shown in Figure 2-23.

The gaseous storage assembly utilizes high-pressure (3000-psia) gas storage tanks for the nitrogen, oxygen, and hydrogen requirements of the ECLSS, EPS, and RCS. All high-pressure storage is in normally nonhabitable volumes of the MSS. The nitrogen and oxygen repressurization gases and the EPS fuel cell oxygen and hydrogen reactants for the second 30-day buildup phase are stored in the power boom. The nitrogen leakage makeup, the EPS-RCS emergency oxygen and hydrogen, and the ECLSS emergency, EVA, and prebreathing oxygen consumables are stored in the cargo module.

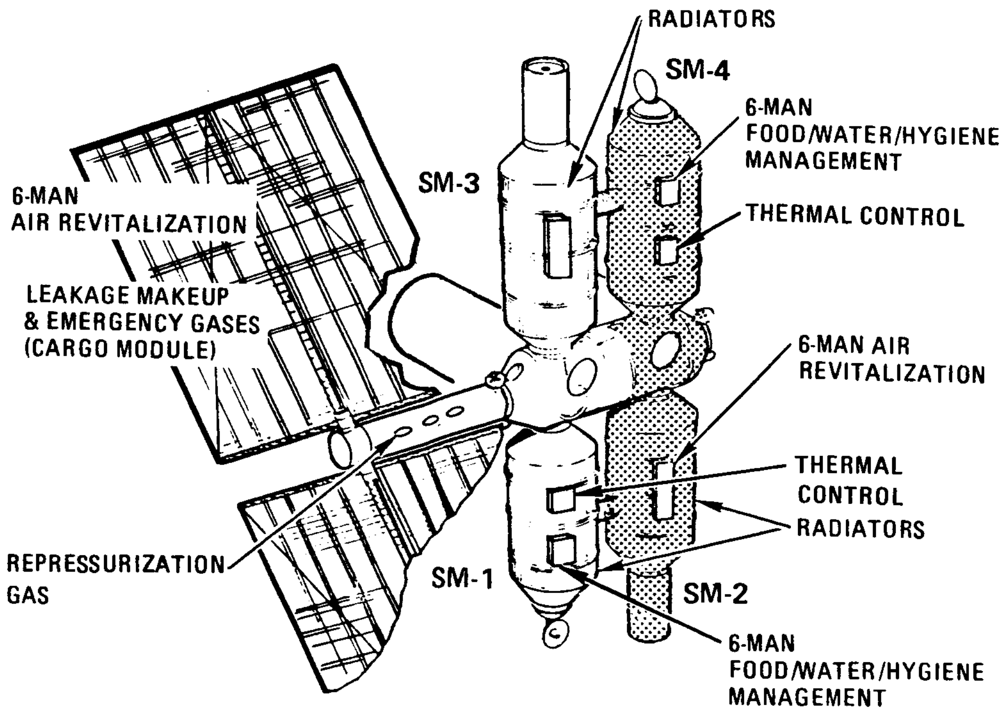


Figure 2-23. ECLSS Preliminary Design

The CO_2 management assembly uses a hydrogen depolarizer CO_2 concentrator for CO_2 removal, a Sabatier unit for CO_2 reduction, and solid polymer water electrolysis for oxygen recovery. The electrolysis units are also used to provide the RCS hydrogen and oxygen propellant gases and can be used as backup for the EPS regenerative fuel cell energy storage assembly. Each pressure volume contains a 96-hour emergency supply of LiOH for CO_2 removal while emergency oxygen is retained in the gas storage assembly.

The atmospheric control assembly uses a central humidity condenser to satisfy the 8-12 mm Hg water vapor requirement. Contamination control utilizes nonregenerable charcoal and catalytic oxidizers. Monitoring is through use of both gas chromatograph and mass spectrometer.

The thermal control assembly consists of an active central dual coolant loops (water internal, Freon 21 external) concept with heat rejection from 180-degree segmented radiators mounted on the station modules. A small radiator is included on the core module for the buildup heat rejection requirements.

The water management assembly uses vapor compression units for the water reclamation function. Water purity is maintained thermally (160 F) and by silver ion generation. Resupply water storage is maintained on the cargo module with processed water stored in the potable water tanks located in the station modules. Water storage also is available in the EPS regenerative fuel cell energy storage tanks (643 pounds).

The waste management assembly uses a dry john toilet and wall-mounted, water-flush urinals. Trash compactors are located in the station modules. Waste processing utilizes vacuum drying scheduled during the crew night so as to minimize venting during experimental operational periods.

Hygiene facilities, including a full body shower and sinks, are conveniently located in the crew/control station modules.

The special life support assembly provides for fire detection and control via condensate nuclei detectors and CO_2 fire extinguishers. Module depressurization can also be used for fire control. EVA PLSS servicing is from the gas storage assembly supplies located in the cargo module. IVA air and water provisions are incorporated into the MSS.

Electrical Power

The EPS provides for primary power generation for normal operations, secondary power generation for station buildup and emergency and solar array replacement operations, energy storage for orbital dark periods, power transfer, conditioning and distribution, and spacecraft lighting.

The selected concepts to satisfy these functions are presented in Table 2-4.

Table 2-4. EPS Description

Function	Concept
Primary Power Generation	7000 sq. ft. solar array
Energy Storage	Fuel cell (shuttle) Rated power = 7.0 kw per full cell (4 required) Special reactant consumption = 0.82 lb. /kwh Electrolysis (ECLSS) Reactant rate = 3 lb/hr (4 required) Special power consumption = 2.32 kwh/ lb H_2O Accumulators H_2 = 33 in. diam. (4 required) O_2 = 27 in. diam. (4 required) Water storage tanks
Secondary Power Generation	Energy storage assembly fuel cells High-pressure hydrogen and oxygen storage
Power Conditioning and Distribution	Primary busses 240/416 volts ac 400 Hz 240/416 volts ac 400 Hz Secondary busses 120/208 volts ac 400 Hz 56 volts dc

The major requirements which influenced the EPS selection trades and sized the equipment are:

1. Solar array primary power generation (2 degrees of orientation)
2. Separate and independent emergency (secondary) power assembly
3. Five-year operational life, initial and growth station

4. 55-degree inclination by 240 to 270-nautical mile altitude

5. Failure criteria:

   Nominal operations - One failure
   Degraded operations - Two failures
   Emergency operations - Three failures (96 hours)

6. Inflight maintenance without primary power shutdown

7. Power requirements (not including distribution or conditioning losses)

   Buildup - 290 watts (60-day intervals)
   Normal operation - 18.7 kw (4.5 kw experiments) (continuous)
   Fail degrade - 13.4 kw (continuous)
   Emergency - 1.75 kw (96 hours)

The solar array primary power generation selection was established by a NASA guideline while the sizing was based on the normal operations power level of 18.7 kilowatts (excluding distribution and conditioning losses). This power level includes 4.5 kilowatts as the experimental operational requirements. Other major power requirements are (1) 290 watts average for the MSS buildup power prior to solar array deployment (60-day duration) and (2) 1.75 kilowatts emergency power (loss of solar array primary power generation) for 96 hours. The fail degrade requirement of 13.4 kilowatts is primarily an influence on power conditioning, distribution, and control equipment sizing and redundancy rather than selection. The independent and separate emergency power assembly is a requirement based on failure analyses of MSS subsystems while the 1.75-kilowatts power level and the 96-hour duration (168 kilowatt-hours) specified the selection. Figure 2-24 illustrates the EPS preliminary design.

The primary power generation assembly is the 7000-square-foot solar array using the Lockheed technology concept. Power switching on the solar array has been incorporated to improve regulation and management and to provide power deadfacing at the interface for maintenance purposes. Energy storage is accomplished by four regenerative fuel cell assemblies (one per primary bus). The fuel cells also serve the function of secondary (emergency) power generation when supplied by high-pressure stored gasses.

The four primary buses have been selected as 240/416 volts ac, 400-Hertz, 3-phase power and the secondary busses provide both the high (240/416 volt ac) and the low (120/208 volt ac) 400 Hertz, 3-phase power. The selection again was made on the basis of cost and availability. The hardware for switching large blocks of power is presently available only for

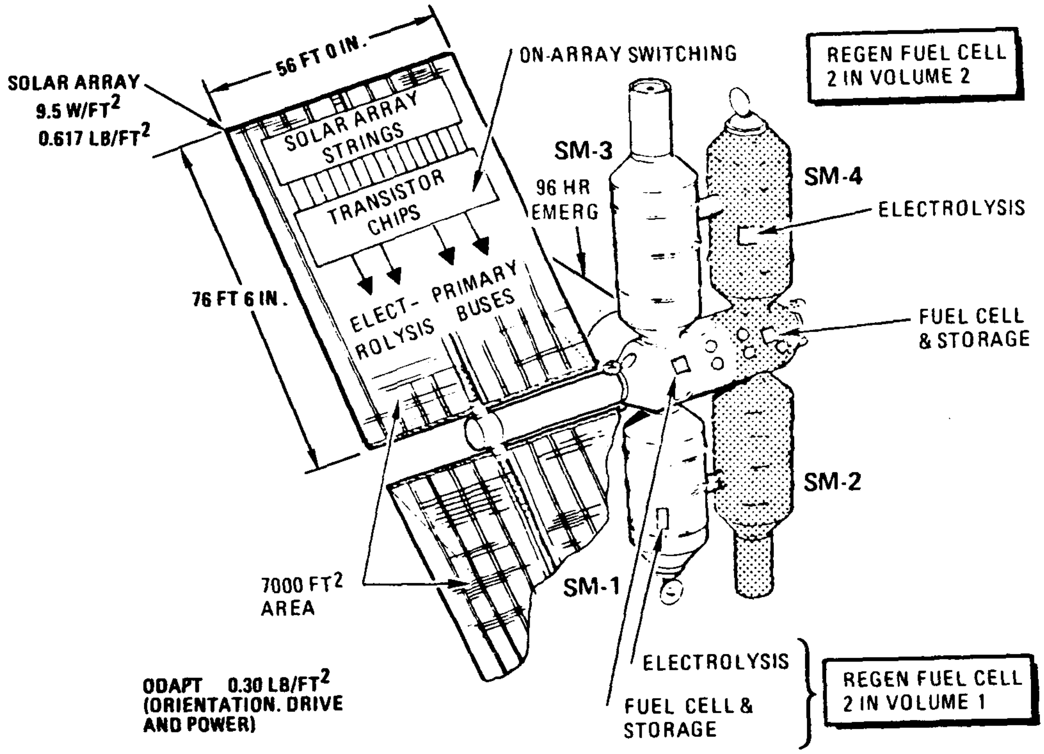


Figure 2-24. EPS Preliminary Design

ac power. The fact that commercial and military aircraft are tending toward all-ac systems utilizing computer-controlled solid-state circuit breakers was a main consideration in the selection. This minimized the cost and development risks to the program for inverters, regulators, transformers and filters, solid-state circuit breakers or switching devices, and software.

Two primary and secondary busses, two regenerative fuel cell assemblies, and two inverters are located in each pressurized volume. Each station module contains two secondary busses, one from each primary bus of the associated volume. Critical loads are supplied from either secondary bus while noncritical loads are supplied from only one bus.

Special EPS circuits, including an RF wake-up circuit, are provided for buildup operations. These special circuits are used to meet the unmanned operational requirements before installation of the ISS and to minimize the power losses that would occur if the larger power normal hardware were used.

Guidance and Control

The G&C subsystem provides for the functions of guidance and navigation and stabilization and control of the MSS in conjunction with the RCS. The selected concept to satisfy these functions is presented in Table 2-5.

Table 2-5. G&C Hardware Description

Assembly	Concept
Inertial Reference	Six gyro skew-symmetric (dodecahedron) strapdown
	Preprocessor
Optical Reference	Two double-gimbal star trackers
	One four-head horizon edge tracker
	One manual sextant telescope
	Two three-axis autocollimator alignment links
	Preprocessor
Momentum Exchange	Three double-gimbal control moment gyros (planar array)
	Reprocessor
RCS Electronics	Two preprocessors

The G&C major requirements are:

1. Guidance and Navigation—autonomous station navigation, orbit maintenance guidance.

2. Stabilization and Control—local level mode (geometric axes), orbit referenced inertial mode, minimum fuel mode with shuttle attached, contamination (operation without jets for minimum of eight orbits), automatic normal operations and manual backup for docking (control stick and window).

Figure 2-25 shows the G&C preliminary design and location of equipment.

The inertial reference assembly includes a strapdown inertial measurement unit and a preprocessor. The strapdown IMU includes six gyros and six accelerometers in a skew-symmetric configuration. This concept provides satisfactory performance with any three gyros working and in fact is more reliable than an orthogonal arrangement of nine gyros.

The optical reference assembly consists of two double-gimballed star trackers, a four-head horizon edge tracker, a sextant and telescope, three optical alignment units, and a preprocessor. This equipment is used to

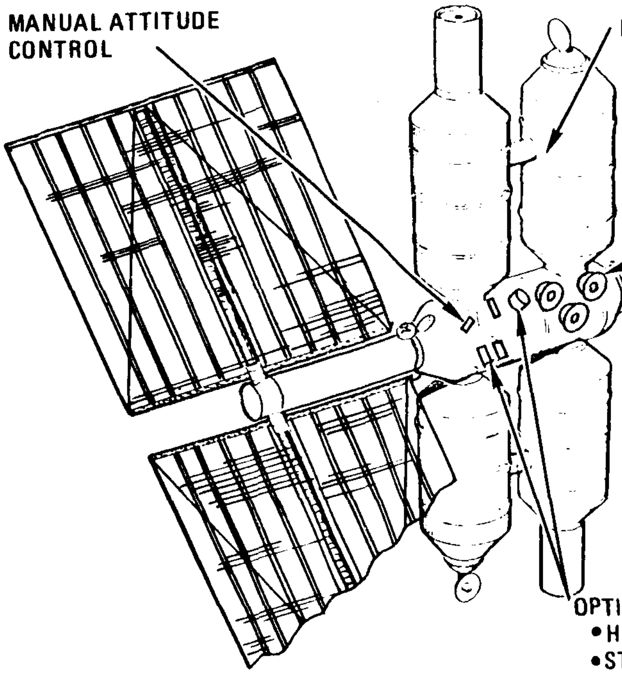


Figure 2-25. G&C Preliminary Design

provide an attitude reference (both local level and inertial), alignment between the G&C equipment and experiment equipment, autonomous navigation measurements, and unknown target tracking for experiment support.

The RCS electronics assembly includes four RCS jet driver electronics units and two preprocessors. The driver units amplify the logic level outputs of the preprocessors to provide operating power for the solenoids and ignitors of the RCS jets. Each preprocessor is hardwired to all four quad driver units and each is capable of controlling the vehicle without relying upon the other. The preprocessors provide limited failure monitoring for the RCS.

The momentum exchange assembly includes a planar array of three double-gimballed control moment gyros and a preprocessor. The angular momentum of each gyro is 1100 ft.-lb.-sec. The array will provide momentum exchange with one gyro down for repair. The CMG's are designed for on-orbit repair at the module level. The CMG's are desaturated using the RCS or when operations permit using gravity-gradient torques.

The computation assembly represents the software for the G&C computations performed within the ISS. These computations are in general highly interrelated with other computations performed by the ISS to support such functions as flight control and experiment operations.

Local level mode attitude control is accomplished using the star trackers and horizon trackers as the attitude reference. Yaw attitude is computed from star tracker data. Angular rates are derived from the attitude signals. Control torques are obtained from the CMG's. This mode is completely automatic. Crew attention is required in case of an indicated failure.

Inertial mode attitude control is performed as described with the exception of the attitude reference function. The inertial mode attitude reference can be obtained using either the strapdown IMU or using both star trackers simultaneously.

Emergency power attitude control is the mode used during an electrical power emergency when power is obtained from the fuel cells and the solar array is inoperable. The attitude reference is provided by the strapdown IMU. Control torques are provided by the strapdown IMU. Control torques are provided by the RCS and the CMG's are deactivated to conserve power. The optical reference is a potential lower power alternative to the strapdown IMU. This mode is automatic.

Orbit maintenance translation control is normally conducted simultaneoulsy with local level mode attitude control. The strapdown IMU is used for velocity measurements and the translation thrusts are applied using the attitude control jets.

Manual control with visual cues is an emergency mode that can be used to perform the only critical G&C function (stabilization for docking). The mode is completely manual using a hand controller and "out-the-window" cues. This control function can be performed from either volume in the core module. The hand controller switches are hardwired to the RCS electronics driver units which activate the RCS jets. The only objective in this mode is to provide sufficient rate stabilization so a rescue shuttle can dock.

Local level navigation is the primary navigation mode performed autonomously and automatically using star-horizon measurements taken by a star tracker and the horizon edge tracker. The bulk of the navigation computations are performed within the ISS central processor.

Inertial or manual navigation is performed by the manual landmark tracking technique using the sextant and telescope. The strapdown IMU is used to maintain the necessary inertial reference. This navigation mode can be used in conjunction with the inertial attitude control mode. It can also be used during local level operations as a check on the performance of the nominal navigation mode.

Reaction Control

The RCS provides thrust for stabilization and docking, orbit maintenance, CMG desaturation, and maneuvers. In addition, under the integrated subsystem concept, the RCS includes the hydrogen and oxygen accumulators which will store all the gasses provided by the ECLSS electrolysis. The stored quantities include the orbital dark period hydrogen for the Sabatier and the hydrogen and oxygen for the depolarizer. The water storage has been integrated into the ECLSS, cargo module, and the EPS. The selected concept to perform these functions is presented in Table 2-6.

Table 2-6. RCS Concepts

Item	Concept
Propellants	Gaseous hydrogen and oxygen supplied by water electrolysis (ECLSS); EPS electrolysis is backup supply. EPS high-pressure storage tanks supply reactants for buildup operations 4 hydrogen and oxygen accumulators sized for 12-hour firing interval (orbit makeup plus CMG desaturation. They provide ECLSS Sabatier and hydrogen depolarizer orbital night supplies. Accumulators are designed for 300 psi normal operations
Engine Quads	10-pound thrust engines 8:1 oxidizer-fuel ratio 320 ISP Inflight maintainable

The major requirements and hardware sizing influences are:

1. Failure criteria:

   Buildup - after two failures capability to stabilize and dock
   Normal - after one failure
   Degraded - after two failures
   Emergency - after three failures capability to stabilize and dock

2. 55-degree orbit altitude between 240 and 270 nautical miles.

3. 120 day on-orbit propellant supply.

4. Jacchia (2 σ mean) 240-nautical miles atmosphere for equipment sizing and impulse requirements

5. Logistics requirements based on 270-nautical miles nominal atmosphere (IOC February, 1982)

6. CMG desaturation and orbit makeup at 12-hour intervals (experiment requirement)

7. Impulse requirements for initial station (growth station in parentheses):

   Orbit makeup and CMG desaturation - 166,000 (236,000) lb sec
   Maneuvers - 48,000 (48,000) lb sec
   Shuttle docked - 28,000 (28,000) lb sec
   Contingency - 48,000 (62,000) lb sec

   120-day total - (290,000)(374,000) lb sec

Two failure criteria are major design considerations for the RCS. During buildup the requirement is the capability to stabilize and dock after two failures. In addition, the design requires activation and operation of the RCS via RF communication links (VHF and S band) from the ground or the shuttle. During manned operations the capability to stabilize and dock after three failures is required.

The atmospheric model is a driver on the RCS. The impulse numbers identified are based on a 240-nautical mile, 55-degree orbit and a Jacchia (2 σ mean) atmosphere. This model in conjunction with an initial station IOC forms the basis for RCS equipment sizing of electrolysis units, accumulators, and water storage tanks. A nominal mission of 270-nautical mile, 55-degree orbit was used to define the RCS logistics resupply and the RCS average power requirements. The 12-hour no-venting requirement imposed by the experiments also influenced RCS accumulator sizing.

The MSS RCS uses a medium-thrust, hydrogen and oxygen gaseous propellant, in-flight maintainable engine quad concept. The hydrogen and oxygen propellants are supplied by water electrolysis from the ECLSS. The EPS electrolysis is also integrated into the RCS and can be utilized as a backup supply. The quads utilize 10-pound thrust engines and an oxidizer fuel ratio of 8:1. This is the combination ratio of hydrogen and oxygen and was selected to minimize venting from the station. Some penalty in ISP was accepted (320 at 8:1 versus 419 at 3:1). The engine quads are located on the Z axis at each end of the core module. The RCS preliminary design is shown in Figure 2-26.

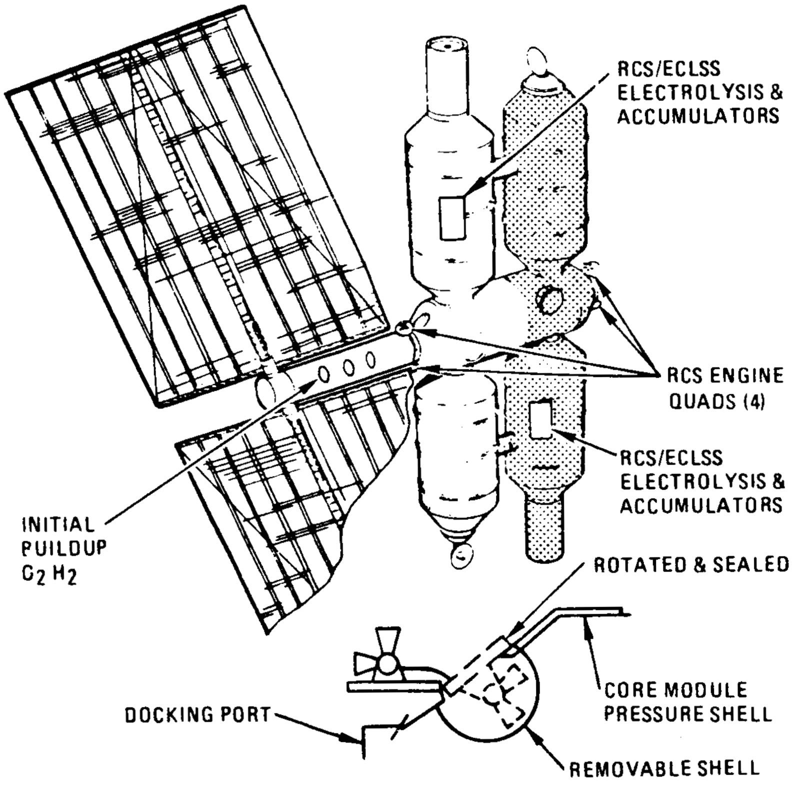


Figure 2-26. RCS Preliminary Design

Four each hydrogen and oxygen accumulators are provided by the RCS and are located, two each, in station modules SM-2 and SM-3. The accumulators are sized for engine firing at 12-hour intervals during the crew night periods.

The MSS buildup requirements are satisfied by the RCS four-engine quad installation for normal manned operations. For the first 60 days of buildup (core and power module launches) the RCS propellant requirements are supplied from hydrogen and oxygen gaseous supplies stored at 3000 psi in the EPS accumulators. After the launch of station module SM-1 and activation of the solar arrays the RCS propellants are supplied by the EPS electrolysis units.

Information Subsystem

The information subsystem performs services for the MSS which are necessary to tie the subsystem together as a working unit and provide for the command and control of the station and its experiments. These services are defined as station operations and experiment management and have been further categorized as: operations data management, command and control/ flight control, mission planning and operations scheduling, onboard checkout/ monitor and alarm, communications management, crew data management, and experiment data management.

The selected concept to perform these services is presented in Table 2-7.

Table 2-7. ISS Hardware Concepts

Item	Concept
Data Processing Assembly	Central processing (multiprocessors) Universal distributing and acquisition
Command/Control Monitoring Assembly	Universal multiformat-callable operational console Commander's multiformat-callable console Portable control and checkout Local monitor alarm Emergency G&C control
External Communications	K band- narrow beam, steerable S band - semi-directional VHF - semi-directional
Internal Communications	Private phone Intercomm and paging TV cameras and monitors (color and black and white) Recorders (audio, video, digital, alarm)
Software	Computer programs Microfilm Paper (printer and facsimile)

The external communication assembly (Figure 2-27) is located in both SM-1 and -4. Each module contains a parabolic directional antenna-electronic package at K band for communications with the NASA tracking data relay satellite (TDRS). The electronics, which are redundant, are mounted on the antenna. Each module also contains two semi-directional antenna-electronic packages at S band for wide-angle coverage with the ground, shuttle orbiter, and detached RAM's, and two VHF band antenna-electronic packages for communications with any EVA activity, the TDRS, orbiter, or any object with VHF capability. Two S band and two VHF antennas are located in the core module for communications during buildup.

The data processing assembly as shown in Figure 2-28 is located in the control centers in both SM-1 and SM-4. Each central processor in the

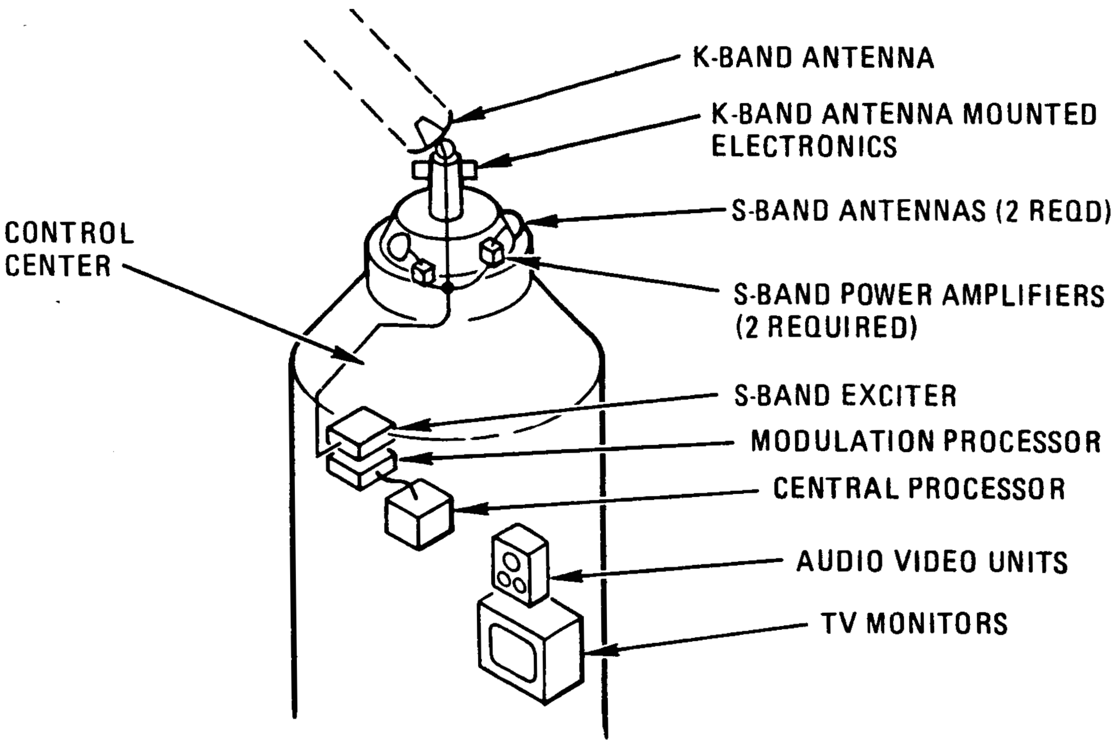


Figure 2-27. External Communications - Internal Busses

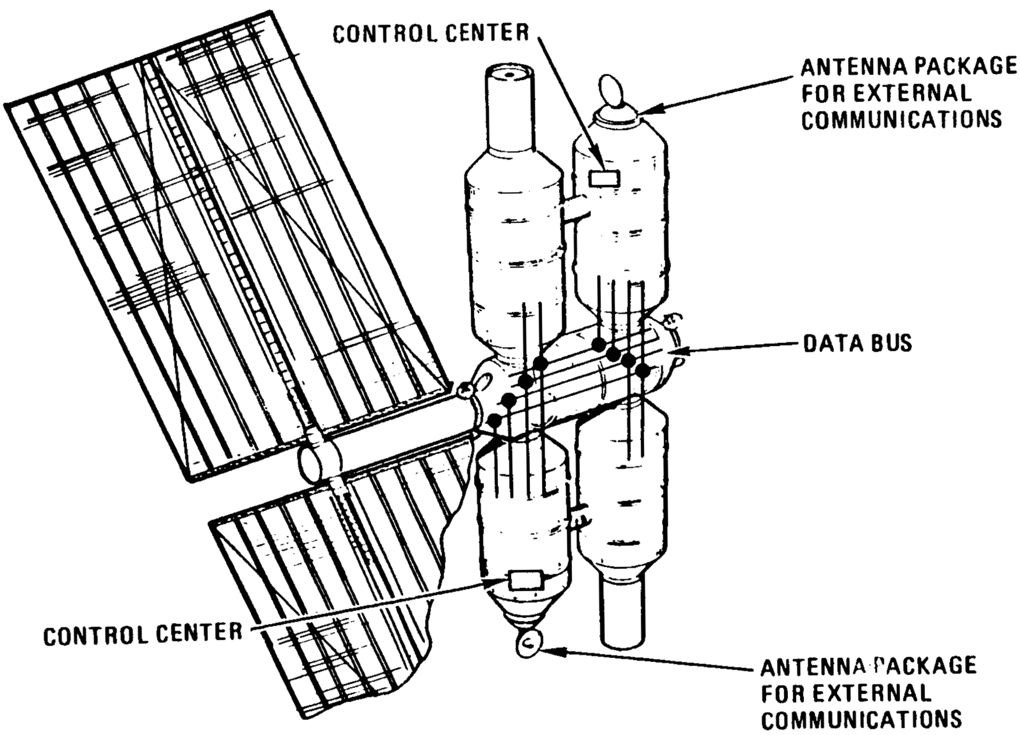


Figure 2-28. ISS Preliminary Design

data processing assembly is capable of performing the total station operations function. During normal operations, one central processor is performing station operations and the second experiment operations and storing enough station operations data to allow it to take over in case of a complete failure of the first processor. Data processing capability is provided in the core and power module for use during buildup.

The command/control/monitoring assembly is located in the control centers in both SM-1 and SM-4. Like the data processing assembly, each center can perform station operations with the first normally performing station operations and the second, experiment operations. The commander's console and portable units are used for remote access to the central processor.

The internal communications assembly is located near the control centers in SM-1 and SM-4. Audio video units are located throughout the station with TV monitors in each stateroom and laboratory area.

The software consists of the computer tapes, microfilm, and printer paper for station and experiment operation. Storage areas are located near the control centers in SM-1 and SM-4. The preparation of the computer programs is included in the assembly to allow visibility and therefore better control of this significant effort.

Crew and Habitability

The crew habitability subsystem specifies metabolic, atmospheric, and habitability criteria and provides food supplies, clothing, and furnishings necessary for crew comfort, well being, and survival. The subsystem provides general equipment including tools, mobility aids, emergency oxygen masks, and radiation monitoring devices for the crew. In addition, equipment is provided for crew recreation, exercise, and medical care. The subsystem also provides pressure suits, portable life support systems, and related equipment for EVA/IVA operations.

All of the crew and habitability subsystem equipment, facilities, dimensional criteria, and arrangement data provide for the physiological and phychological needs of the crew. The space station interior is designed with good architectural and decorator practices in order to provide comfortable, efficient, and attractive living and work spaces. The long-duration missions envisioned for the space station crew requires an environment similar to that in a normal earth situation.

The food management assembly provides for food storage, preparation, serving, cleanup, and inventory control. The galley equipment must accommodate a large range of food types, cooking operations, and crew use modes.

Medical and dental equipment and supplies are provided for routine crew monitoring as well as for diagnosis and treatment of injury and illness. The medical and dental equipment is as follows: X ray, drugs, dressing, bandages, wraps, splints, cold packs, and heat pads, body and specimen mass measurement devices, lower body negative pressure unit, biomonitoring and display equipment, behavioral evaluation equipment, laboratory analysis equipment, refrigerator and freezer, oven and sterilizer.

Passive-type recreation equipment and supplies are provided for the crewmen. The complement includes the following: audio and video units, motion picture projector and screen, film library, reading material, tape deck and library, craft material, table games, and puzzles. An ergometer and isotonic equipment are provided for exercise and crew conditioning.

2.3 SYSTEM WEIGHTS

The system weights are described in three categories or levels (Figure 2-29): (1) design-to-weight, (2) closeout weight, and (3) shuttle payload weight. Each is discussed briefly in the subsequent paragraphs.

The design-to weight category consists of both dry weight and the required fluids and gasses. The dry weight is apportioned to seven functional subsystem groupings for each module as shown in Table 2-8, with their respective weights. These weights include mounting and installation provisions as well as standard utilities such as wiring, ducts, and tubing. The two-digit codes are the Level 6 major assemblies.

The general-purpose laboratory (GPL) furnishings as reflected in code 1.5 of the table are primarily dedicated to modules SM-2 and SM-3. These two modules contain the labs with their associated equipment plus the two external airlocks. In addition, two antenna packages allocated to SM-1 and SM-4 are in the dry weight estimation and identified as external communications.

Modules are delivered on-orbit serviced with the required fluids and gasses. The ground servicing procedure allows purging of lines and functional checks on hardware and plumbing and minimizes on-orbit operational complexity. The weight summary for these fluids and gasses is presented in Table 2-9.

A design-to weight summary is presented in Table 2-10.

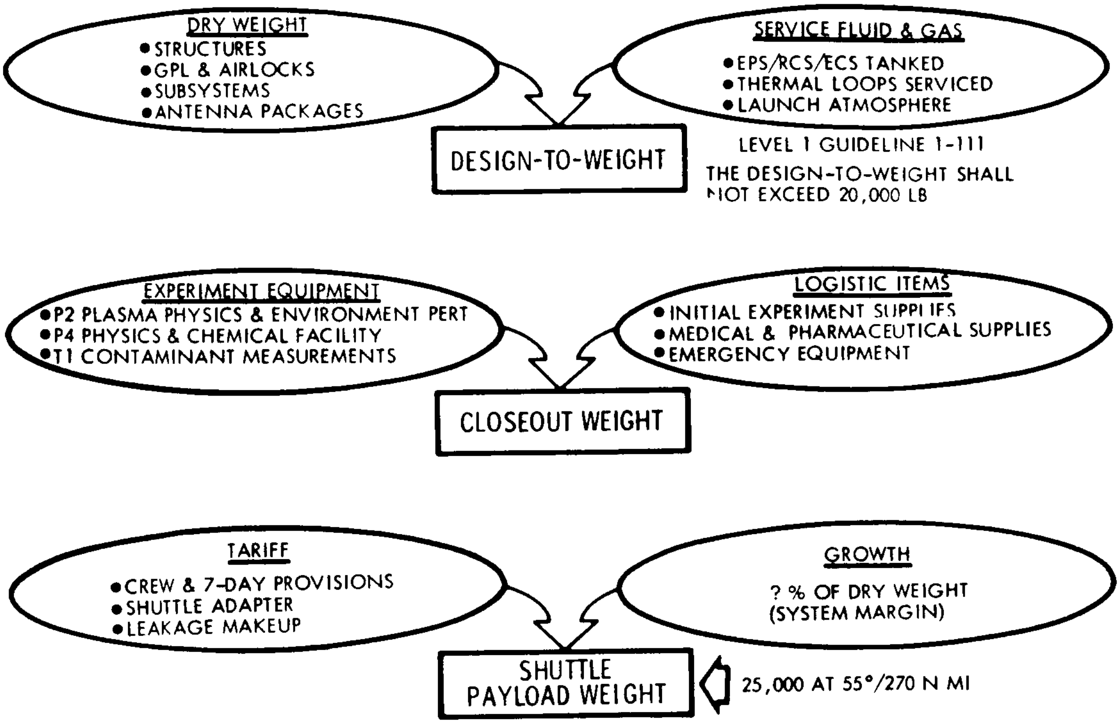


Figure 2-29. System Weight

Table 2-8. Module Dry Weight Summary

	SUBSYSTEM/MAJOR ASSEM	CORE	POWER	SM 1	SM 2	SM 3	SM 4	TOTAL
1	STRUCTURAL & MECHANICAL	12690	3670	10160	12330	10700	9490	59040
11	PRIMARY STRUCTURE	5742	1878	4700	4700	4700	4700	26420
12	SECONDARY STRUCTURE	3399	410	3218	3350	3446	3378	17201
13	ENVIRONMENTAL SHIELD	1119	582	746	735	746	746	4674
14	BERTHING	2430	800	490	490	490	490	5190
15	GENERAL PURPOSE LAB FURNISH	0	0	1006	3055	1318	176	5555
2	ENVIRONMENTAL CONTROL/LIFE SUPPORT	1619	849	3690	3310	3415	3420	16303
21	GASEOUS STORAGE	42	765	0	11	11	0	829
22	CO_2 MANAGEMENT	4	0	4	741	741	4	1494
23	ATMOSPHERIC CONTROL	750	84	567	876	876	554	3727
24	THERMAL CONTROL	681	0	1969	1570	1570	1969	7759
25	WATER MANAGEMENT	20	0	638	23	23	638	1342
26	WASTE MANAGEMENT	0	0	86	0	79	163	328
27	HYGIENE	0	0	370	27	53	56	506
28	SPECIAL LIFE SUPPORT	122	0	36	62	62	36	318
3	ELECTRICAL POWER	3790	7800	1762	545	545	1762	16204
31	PRIMARY POWER GEN	0	6676	0	0	0	0	6676
32	SECONDAY POWER GEN	0	0	0	0	0	0	0
33	ENERGY STORAGE	2449	985	766	0	0	766	4966
34	POWER CONDITIONING	379	0	16	16	16	16	443
35	DISTRIB CONTROL & WIRING	776	115	834	383	383	834	3325
36	LIGHTING	186	24	146	146	146	146	794
4	GUIDANCE & CONTROL	1470	0	0	0	0	0	1470
41	INERTIAL REFERENCE	65						65
42	OPTICAL REFERENCE	346						346
43	RCS ELECTRONICS	75						75
44	MOMENTUM EXCHANGE	984						984
46	COMPUTATION	0						0
5	REACTION CONTROL	180	0	0	153	153	0	486
51	PROPELLANT ACCUMULATOR				88	88		176
52	PROP FEED CONTROLS	60			65	65		190
53	ENGINES	120						120
6	INFORMATION	462	116	2740	134	161	2640	6253
61	DATA PROCESSING	171	91	692	64	64	692	1774
62	COMMAND/CONTROL & MONITOR	59	4	478	40	40	478	1099
63	EXTERNAL COMMUNICATIONS	193	0	849	0	0	749	1791
64	INTERNAL COMMUNICATIONS	39	21	641	30	57	641	1429
65	SOFTWARE	0	0	80	0	0	80	160
7	CREW HABITABILITY	733	125	503	233	1271	990	3855
71	PERSONAL EQUIPMENT	0	0	0	0	0	0	0
72	GENERAL/EMERG EQUIP	733	125	145	145	145	145	1438
73	FURNISHINGS	0	0	220	0	160	206	586
74	RECREATION/EXER/CREW CARE	0	0	138	0	210	639	987
75	FOOD MANAGEMENT	0	0	0	88	756	0	844
SUBTOTAL (DRY WEIGHT)		20944	12560	18855	16705	16245	18302	103611

Table 2-9. Fluids and Gasses Weight

Item	Core	Power	SM-1	SM-2	SM-3	SM-4	Total
Repressurization O_2 oxygen		194					194
Repressurization nitrogen		381					381
Launch Atmosphere	285	74	322	322	322	322	1, 647
Electrolysis Accumulator (water)				50	50		100
Internal Thermal Loop (water)	148		199	98	98	199	742
External Thermal Loop (Freon)	191		604	223	223	604	1, 845
Watermanagement Loop	5		6	6	6	6	29
EPS & RCS Buildup oxygen	333	273					606
EPS & RCS Buildup hydrogen	42	34					76
Total	1, 004	956	1, 131	699	699	1, 131	5, 620

Table 2-10. Design-to-Weight Summary

Category	Core	Power	SM-1	SM-2	SM-3	SM-4	Total
Structural & Mechanical	12, 690	3, 670	10, 160	12, 330	10, 700	9, 490	59, 040
Environmental Control & Life Support	1, 619	849	3, 690	3, 310	3, 415	3, 420	16, 303
Electrical Power	3, 790	7, 800	1, 762	545	545	1, 762	16, 204
Guidance & Control	1, 470	0	0	0	0	0	1, 470
Reaction Control	180	0	0	153	153	0	486
Information	462	116	2, 740	134	161	2, 640	6, 253
Crew & Habitability	733	125	503	233	1, 271	990	3, 855
Subsystem Dry Weight	20, 944	12, 560	18, 855	16, 705	16, 245	18, 302	103, 611
Service Fluids and Gasses	1, 004	956	1, 131	699	699	1, 131	5, 620
Design to Weight	21, 948	13, 516	19, 986	17, 404	16, 944	19, 433	109, 231

As part of the closeout weight, experiment equipment, supplies, and crew logistics items can be added to selected modules. Those added, as shown in Table 2-11, are used in the beginning of initial station operations and thus provide a fully operational facility when manned.

Table 2-11. Logistics and Experiment Equipment Weight

Item	Core	Power	SM-1	SM-2	SM-3	SM-4	Total
Experiment Equipment							
P2 Plasma Physics and Environmental Port					1,003		1,003
P4 Physics and Chemical Facility					866		866
T1 Contamination Measurement				807			807
Total	0	0	0	807	1,869		2,676
Logistics Items							
Potable water						400	400
96-Hr Emergency LiOH				112	112		224
Medical and Pharmacy Supplies						110	110
P2, P4, T1 Experiment Consumables				302			302
Total	0	0	0	414	112	510	1,036

An operational alternative exists in that these items could be transferred to cargo module launches if necessary. These weights added to the design-to-weights makeup the closeout weights as shown in Table 2-12.

Table 2-12. Closeout Weights

Item	Core	Power	SM-1	SM-2	SM-3	SM-4	Total
Design-to Weight	21,948	13,516	19,986	17,404	16,944	19,433	109,231
Experiment Equipment	0	0	0	807	1,869	0	2,676
Logistic Items	0	0	0	414	112	510	1,036
Closeout Weight	21,948	13,516	19,986	18,625	18,925	19,943	112,943

The payload launch weights also include items required during buildup which are not provided by the baseline shuttle orbiter (Table 2-13). The shuttle mission profile for buildup operations is nominally seven days, with five days allocated to on-orbit operations. During these five days, the orbiter is in a "powered-down," stationkeeping mode. When a "powered-up" orbiter is required, additional reactants and tankage must be provided.

The station buildup operations crew and their provisions are not included in the baseline orbiter. Hence, weight for two crewmen and support

Table 2-13. Shuttle Tariff Weight

Item	Core	Power	SM-1	SM-2	SM-3	SM-4
2 Crew	400	400	400	400	400	400
2 Crew Provisions	300	300	300	300	300	300
2 PLSS & 2 PGA	354	354	354	354	354	354
Passenger Provisions	63	155	190	160	160	166
Leakage Makeup Oxygen/Nitrogen	0	165	180	210	210	210
Shuttle EPS Reactants	50	365	495	383	383	405
2 Tank Weight	97	425	425	425	425	425
MSS Shuttle Adapter		600				
Total	1,264	2,764	2,344	2,232	2,232	2,260

provision must be included in the payload launch weight. The weights shown in the table include support provisions such as seats, portable life support units, pressure garments, and life support consumables.

During buildup and assembly of the station modules, gasses are carried on each launch for pressurizing the modular cluster if leakage has occurred. A shuttle adapter also is required during buildup. The adapter is carried only once, on the power module launch, and remains with the station for use during subsequent operations. The weights of these items are also included in the payload launch weight.

The shuttle tariff weights, added to the closeout weights and the total subtracted from the shuttle launch weight capability, gives the weight growth margin allowance (Table 2-14).

Table 2-14. Weight Growth Margin

Item	Core	Power	SM-1	SM-2	SM-3	SM-4
Payload Launch Weight	29,725	25,000	25,000	25,000	25,000	25,000
Shuttle Tariff	1,264	2,724	2,344	2,232	2,232	2,260
Closeout Weight	21,948	13,516	19,986	18,625	18,925	19,943
Total	23,212	16,240	23,330	20,857	21,157	22,203
Weight Growth Margin	6,513	8,720	2,670	4,143	3,843	2,797

Items such as spares and consumables, crew, crew personal items, and GPL experiments are delivered via cargo module.

The payload launch weight capability is greater for the first module launched than for the subsequent launches. The first module delivery does not require the rendezvous and docking maneuvers that are required on subsequent launches.

The shuttle design reference mission (DRM) and baseline configuration has the ability to deliver and return 25,000 pounds to the 270-nautical mile altitude orbit at a 55-degree inclination. The total shuttle orbiter DRM propellant requirement is 27,730 pounds (Figure 2-30), including 4,538 pounds for rendezvous and 467 pounds for docking. An increase in injection propellant of 280 pounds is required to place the first module at a 272-nautical mile altitude. Thus the 4,725 pounds of propellant not required on the first launch provides a capability for delivery of 29,725 pounds.

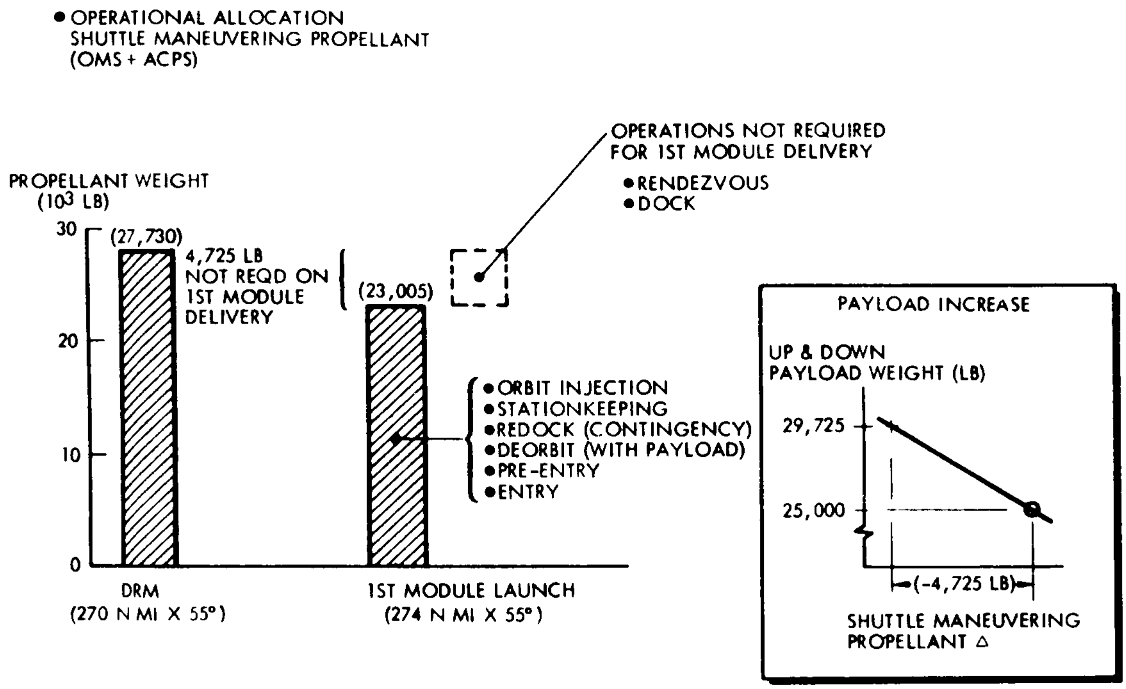


Figure 2-30. MSS Buildup - First Launch Capability

3. SYSTEM OPERATION

3.1 EXPERIMENT OPERATIONS

The initial modular space station provides the capability to operate at least two research and applications modules in either an attached or detached operating mode, as well as internal general-purpose laboratories with capability to conduct multidiscipline carry-on experiments.

The study guidelines established the overall program approach. Two time-phased capability plateaus were identified which utilized operation of an initial 6-man station for five years followed by growth to a 12-man station. Analyses of experiment capability requirements established an approach for an experiment program (see Volume III, Experiment Analyses, SD 71-217-3) for both the initial and growth phases. NR defined a series of buildup steps for each FPE laboratory facility identified in the NASA 1971 Blue Book, in which each would be partially implemented in the initial station and expanded to full implementation in the growth station. Fully implemented FPE's can be accommodated by the initial station.

The evolutionary buildup of laboratory facilities makes use of the general-purpose laboratory (GPL) to accomplish partial FPE's during the early phases of the program. GPL functions were selected for the initial station to provide a multidisciplinary capability which did not preclude experiment program emphasis. The initial station emphasizes integral lab and attached RAM accommodation modes where feasible. Thus, although a reference program was established and used in operations analyses, flexibility is designed into the system to accommodate alternative programs.

<u>General-Purpose Laboratory (GPL)</u>

The general-purpose laboratory areas provide facilities and equipment to support a variety of experiments. These provisions include standard equipment items which have general-purpose application, utilities interface for investigator-furnished equipment and experiments, area to operate the experiments, and storage volume for spares and supplies. The provisions support activities such as maintenance and calibration of equipment as well as processing and analysis of data. The station GPL is designed to support all experiments not assigned to a RAM and provides support for operating and utilities provisions at the berthing interface for service of attached and detached RAM's.

The experiment support functions are grouped by equipment and function commonality. To facilitate crew operations and efficient utilization of equipment, the GPL functional areas are placed in suitable locations throughout the station modules. Many support functions are provided by equipment installed for station operation, such as control consoles; other support functions are provided by special GPL equipment. The GPL functions and equipment are grouped into the following areas and laboratories that are either shared with station operations or dedicated to experiment operations:

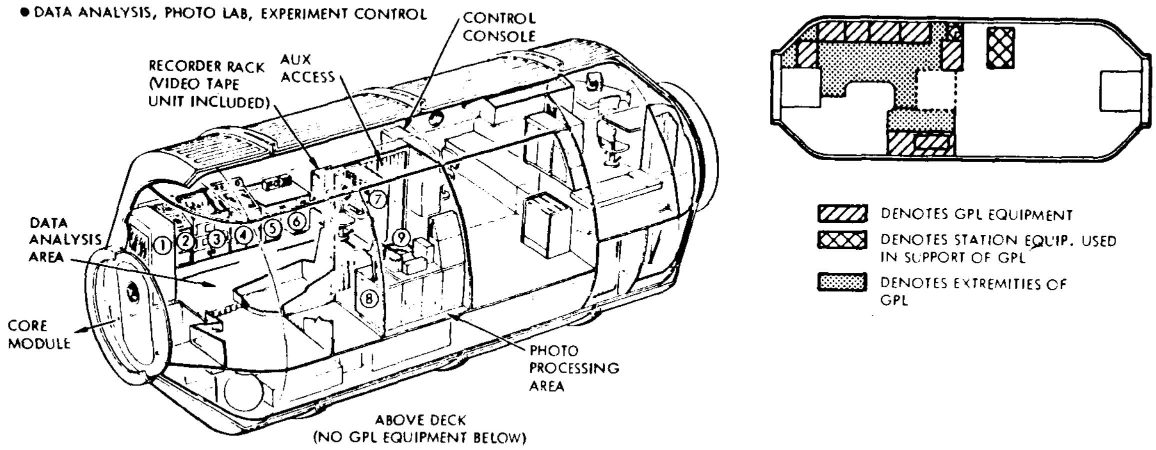
- Experiment control
- Data analysis
- Photo processing
- Airlocks
- Mechanical maintenance lab
- Electrical and electronic maintenance lab
- Optical supply and maintenance lab
- Physics lab
- Biomedical lab
- Storage

The general-purpose laboratory areas contained in Station Module 1 are shown in Figure 3-1. The figure also identifies the GPL equipment that is provided to support the experiment operations.

The data analysis area has capability for review and analysis of both film and taped data. This includes film analysis by projection onto viewing screens and illuminated table viewing, and film editing. Capability is provided taping and playback of both audio and video tapes and for X-Y plotting of data. A control console is provided in the data analysis area for display of data being analyzed and for control of and support to the data analysis processes.

A separate operations console, one of two in the station, is located in SM-1. This console provides capability for control and monitoring of experiments that are being conducted in any of the GPL areas or in attached or detached RAM's. Under nominal station operations, the operations control console is available for full-time use for experiment control. The operations console is located adjacent to the data analysis area.

A photo processing lab is located in an isolatable area across from the data analysis laboratory. Capability is provided for developing and printing of small and medium-size film formats. Environmentally controlled storage is available for undeveloped film. The area also provides film editing, splicing, and viewing capability.



• DATA ANALYSIS AREA EQUIPMENT
1 G027 TAPE DECK STRIP CHART
2 G024 FILM VIEWER/EDITOR
3 G025 X-Y PLOTTER
4 G023 LIGHT TABLE
5 G022 WORK BENCH/DESK
6 G028 CABINET, STORAGE (DATA REVIEW)
7 G021 CONTROL CONSOLE
STATION PROVIDED:
G026 VIDEO TAPE UNIT

• PHOTO PROCESSING AREA EQUIP:
8 G049 EDITOR/FILM PROCESSOR BENCH
9 G050 LIGHT TABLE

• EXPERIMENT CONTROL:
STATION PROVIDED:
G051 OPERATIONS CONSOLE

Figure 3-1. Station Module 1 GPL Area

The GPL areas contained in Station Module 2 are shown in Figure 3-2. The entire upper deck is dedicated to laboratory functions, except for a small area for a backup galley, and storage area is provided below deck for experiment equipment and supplies. The SM-2 GPL contains an airlock for deployment of experimental equipment and sensors. The airlock centerline points toward the earth along the local vertical in the nominal space station flight mode. The outer door of the airlock provides a full diameter opening. A large area for assembly and service of equipment to be installed in the airlock is located inside the module.

A major portion of the GPL in SM-2 provides capability for calibration and service of mechanical, electrical, electronic, and optical experimental equipment. The optical lab has provisions for optical component cleaning and minor adjustment and calibration of optical assemblies and instruments. Photographic cameras and supplemental lighting equipment are provided for recording experiment operations throughout the station. The mechanical and electrical lab areas provide equipment and work areas for calibration, checkout, and service of experimental equipment throughout the station or in attached or detached RAM's.

The use of the outboard end of SM-2 GPL is shown in Figure 3-3 for a typical set of investigator-supplied experiment equipment. The example shown is of the earth observations FPE. Selected groups of sensors are

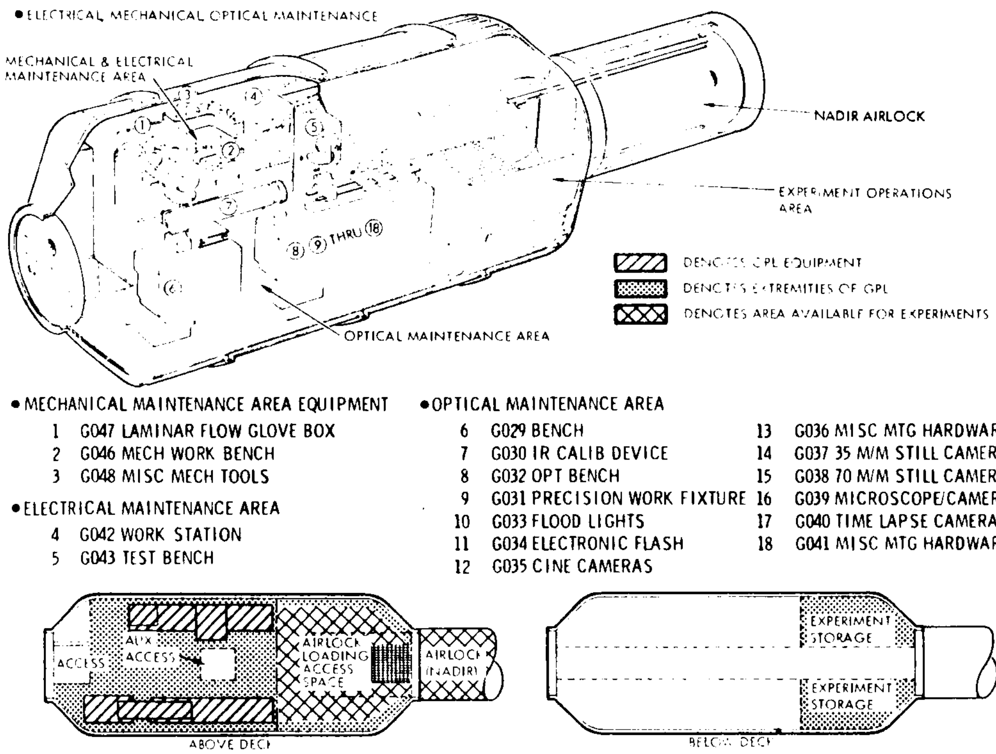


Figure 3-2. Station Module 2 GPL Area

inserted into the airlock and deployed. Sensors can be deployed in groups sequentially, deferring the need for a dedicated RAM in the initial phases of the program. Equipment groups are assembled in the area inside the module and transferred on guiderails into the airlock. A portable control console, one of two available for experiment support from the station operating equipment inventory, is available for the operator's control and monitoring of the equipment. The investigator has the option of controlling the experiments and viewing the data coming from the sensors at this location or from the experiment control console in SM-1.

The GPL areas in SM-3 provide capability for physics, biomedical, or small bioscience experiments. The SM-3 GPL (Figure 3-4) has a large storage area below deck for experiment equipment and supplies, a large airlock for deployment of sensors and work area with general-purpose support equipment. With investigator-supplied equipment, the area can be configured to support the different disciplines on a time-shared or area-shared basis. Much of the biomedical general-purpose equipment is common to the medical and crew care and qualification facilities of SM-4. The SM-4 area also provides capability for time-phasing biomedical experiments. The equipment listed in the figure includes general-purpose furnishings available to each investigator. Portable control consoles are available for checkout, monitoring, and operation of the experiments. The investigator may also monitor the activity and view and control the data being recorded from the experiment control console in SM-1.

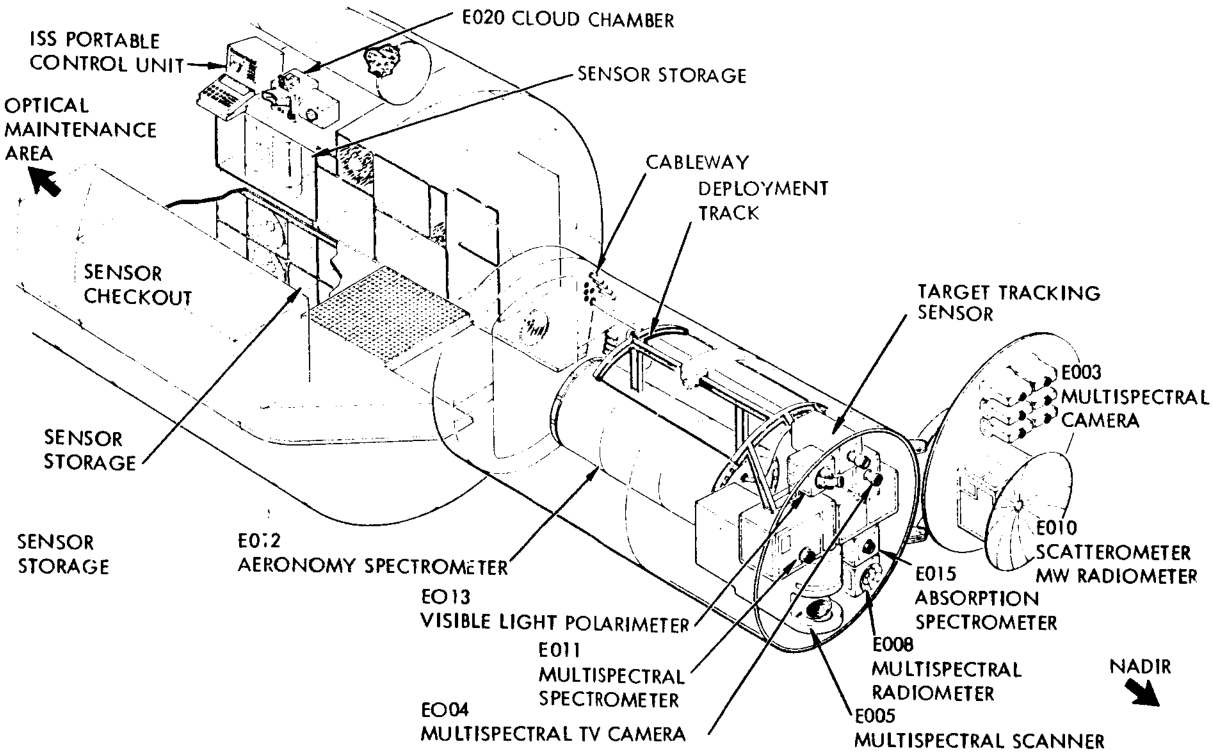
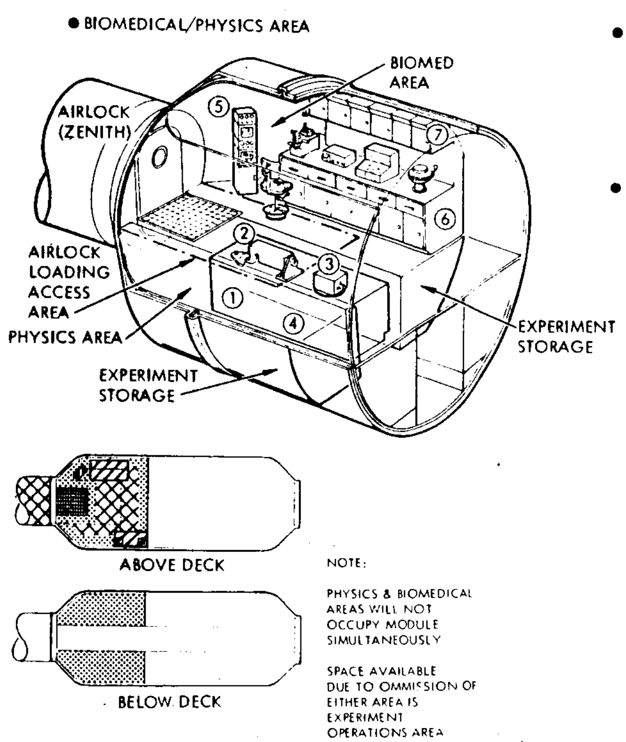


Figure 3-3. Typical GPL Operations



- PHYSICS AREA EQUIPMENT:
  1 G-020 WORKBENCH
  2 G-017 REFLECTOMETER PORTABLE
  3 G-019 MASS SPECTROMETER
  4 G-018 SAMPLES & RETRIEVAL BOX
- BIOMEDICAL AREA EQUIPMENT:
  5 G-009 INCUBATORS (2)
  6 EQUIPMENT GROUP COMPRISING
  G-001 HYDROCARBON ANALYZER
  G-002 NITROGEN ANALYZER
  *G-003 AUTOCYTOMETER
  G-004 COLORIMETER
  *G-007 MICROSCOPE & KIT
  G-008 LYOPHILIZER
  G-013 AUTOCLAVE
  *G-014 CENTRIFUGE
  7 *G-005 STAINING APPARATUS
  G-006 CULTURE CHAMBER

*STATION PROVIDED EQUIP. IN SM-4

DENOTES GPL EQUIPMENT
DENOTES EXTREMITIES OF GPL
DENOTES AREA AVAILABLE FOR EXPERIMENTS

Figure 3-4. Station Module 3 GPL Area

The airlock in SM-3 GPL is identical to that in SM-2 GPL. As a result of the location of SM-3 in the station configuration, the SM-3 airlock centerline is celestial pointing.

Subsystem Support

The MSS, as a manned orbital facility, provides crew and utilities support for the conduct of space applications experiments and scientific investigations. Of the six crewman nominally accommodated by the station, more than one-half are dedicated to experiment operations which, on a six-day work week, provides at least 210 man-hours of activity. The space shuttle logistics support provides capability for periodic exchange of experiment investigator skills, as well as delivery of equipment and supplies, on nominal launch intervals of 30, 60, 90, or 120 days.

The station flight characteristics are shown in Figure 3-5. The MSS provides a very stable platform in either of two flight modes. In the nominal flight mode the station holds a constant attitude with respect to the local earth vertical. For example, the airlock pointed toward earth will point to the local vertical throughout the orbit. In this mode the station core module centerline or geometric axis is held normal to the orbit plane thus providing, for experiments, a constant geometric reference. Capability is also provided for an inertial attitude hold flight mode to accommodate experiments with celestial or solar pointing requirements.

In either flight mode the reaction jet firing for orbit makeup and CMG desaturation, as well as the subsystem effluent dump, occurs only once each 12 hours. This allows clearing of the effluents providing many hours of effective experiment sensor operation. During orbital flight the position and velocity references for experiments can be provided by autonomous navigation.

The MSS subsystems provide utility support for experiment operations in the general-purpose laboratory areas and at berthing port interfaces shown in Figure 3-6. In addition, communication capability is provided for control and data transfer to and from detached RAM's. Multiple channels of S-band and K-band data links are available on MSS to receive detached RAM data, including TV, as well as to transmit data directly to the ground or via a data relay satellite.

The station subsystems provide an environment within labs as shown in the figure and oxygen, water, waste, and thermal load support for the GPL or attached RAM's. Consoles, both fixed and portable, are provided for experiment control, data monitoring, and processing. Each console has access to the computer which has speed, operating memory, and mass

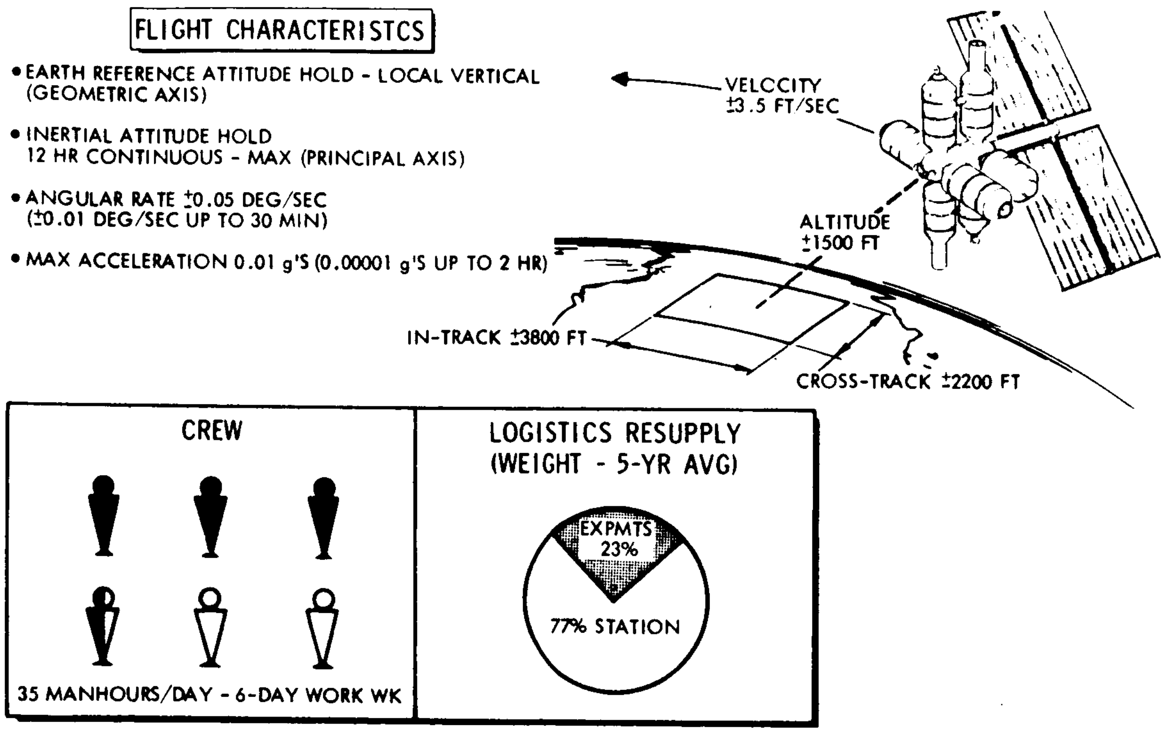


Figure 3-5. MSS System Flight Characteristics

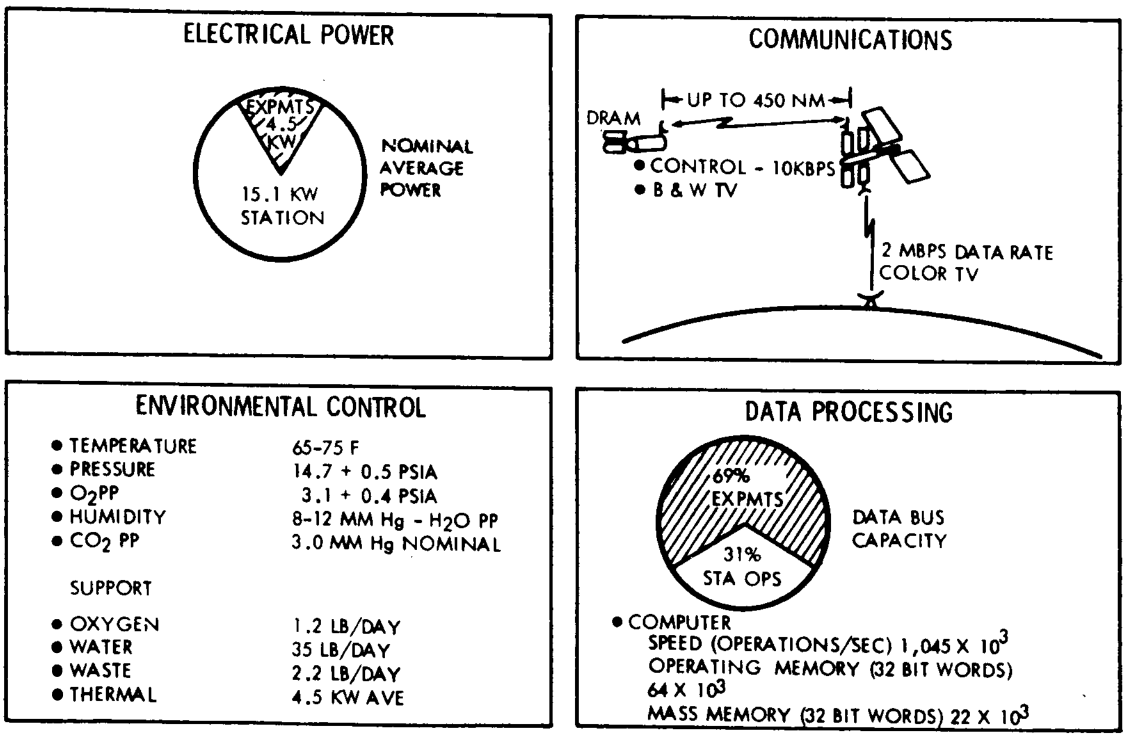


Figure 3-6. Subsystem Support for Experiments

memory characteristics available for experiments. The computer archive memory is supplied by tape cartridges as required for the specific experiments.

Electrical power is provided in the GPL and at RAM docking ports at 120/208 volt ac 3-phase, 4-wire at 400 Hertz. A limited amount of direct current power is available in the GPL at 56 volts dc. A nominal power level of 4.5 kilowatts is provided for experiments. However, the station is capable of providing an additional 3.4-kilowatt average for experiments if required.

Reference Experiment Program

One major feature of the NASA 1971 Blue Book was the introduction of the facility concept for FPE's. NR defined a series of buildup steps for each FPE facility and identified the experiments associated with a balanced, low-cost program. These buildup steps were applied to the initial and growth stations with operational phasing as defined by the study guidelines. The FPE laboratory facilities are partially implemented in the initial station and expanded to full implementation in the growth station. The initial station emphasizes accommodation of the experiments in the station general-purpose laboratory or in attached RAM's where feasible. In general, more costly experiment provisions were deferred to later operating periods in the program to reduce early costs.

The evolution of laboratory facility capability was defined in three implementation levels (see Volume III, Experiment Analyses, SD 71-217-3). Level I is that portion of the total facility which supports experiments of short duration, seven to 30 days. Emphasis is placed on applications and precursor-type experiments. Level II adds those experiments associated with long duration and those permanent-type emphasing a balanced but low-cost program. Level III consists of the fully implemented facility as defined by the NASA 1971 Blue Book. In general, Level I laboratories were defined so as to be compatible with the space shuttle sortie mode of implementation. Level II laboratories contain implementation of Level I; thus, no Level I laboratories are required in the reference MSS program.

The reference experiment program (Figure 3-7) shows the time-phased sequence of the laboratories by discipline. The implementation priorities and scheduling relationships, established in the referenced experiment analyses, and the initial and growth station resources, in terms of crew hours and subsystems support, were considered in the referenced program scheduling. Each laboratory, when operating on-orbit, consumes resources at a rate which depends on its implementation level. Limitations on crew man-hours resulted in all Level III (and some Level II) labs being deferred until the growth station.

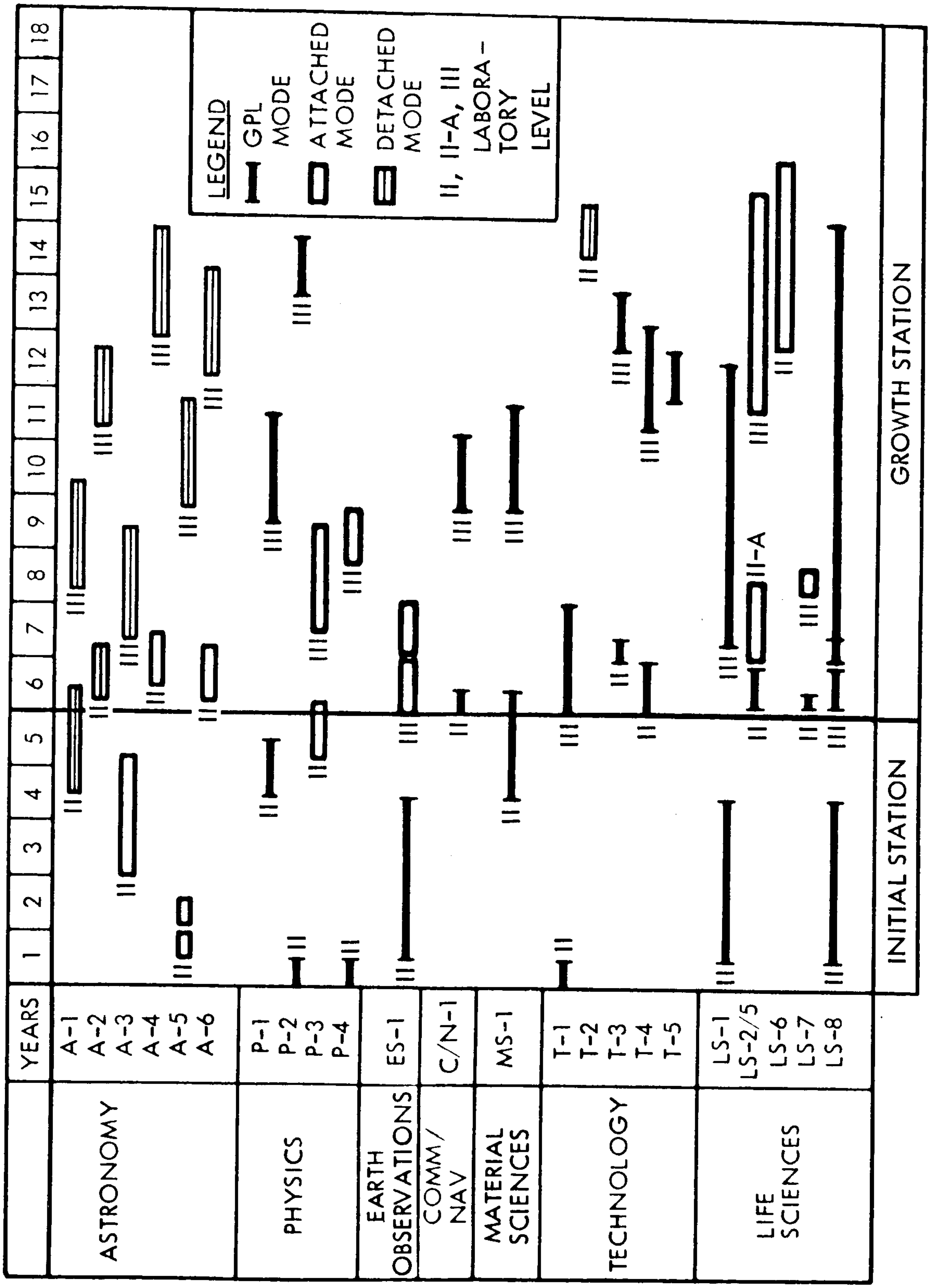


Figure 3-7. Reference Experiment Program

The reference program contains two attached and one detached RAM for astronomy FPE's operating with the initial station. High-energy stellar astronomy experiments (A-5) are accommodated in an attached RAM to provide gamma ray background and source mapping, extend X-ray source surveys, and improved X-ray spectra of selected sources. Advanced solar astronomy experiments are also accommodated in an attached RAM on the initial station to provide high-resolution monitoring of the solar disc activity and processes. Correlated extreme ultraviolet (UV) and X-ray solar imagery are also obtained. The Level II X-ray stellar astronomy (A-1) experiments are operated in a detached RAM to provide highly accurate and sensitive surveys.

Since many scientific operations are sensitive to the "atmospheric" environment surrounding the station the space physics lab will investigate and monitor these phenomena. Level II experiment equipment for plasma physics and environmental perturbation (P-2) will be deployed from the station GPL airlocks. The physics and chemistry experiments (P-4) at Level II implementation will be operated in the station GPL airlocks to provide data on atmospheric interactions and fluid thermodynamics in the zero-gravity environment.

The Level II space physics research (P-1) experiments are also accommodated in the station GPL. They will extend the investigation of environmental phenomena surrounding the station and include atmospheric and magnetospheric studies utilizing a small optical astronomy telescope including UV observations. Cosmic ray physics (P-3) experiments are accommodated in an attached RAM which provides facilities for measuring cosmic ray particle fluxes, energy, and identity.

Earth observations (ES-1) laboratory facilities are initiated early in the reference program. The early Level II experiments are housed in the station GPL where groups of sensors are deployed through the airlock. Capability is provided for control and monitoring of large groups of sensors such as multispectral cameras, radiometers, and spectrometers, either concurrently or sequentially. The full implementation (Level III) of the earth observations lab is provided by an attached RAM to allow simultaneous deployment of a larger number of sensors.

The materials science and manufacturing in space laboratory (MS-1) is accommodated in the initial station GPL to investigate approaches to determining feasibility of potential applications. The Level II investigations include research on the physical properties of fluids in zero gravity, crystal growth, medically oriented biological processing, and manufacturing process development.

The early implementation of the technology discipline contamination measurements lab (T-1) provides capability to survey the induced environment around the station. The Level II experiments will investigate external contaminant composition, quantity, sources, transport mechanisms, buildup and dissipation rates. The equipment is accommodated in the station GPL and utilizes the airlocks for sensor deployment.

Life science discipline experiments are time-phased throughout the reference program. The initial station implements the medical research laboratory (LS-1) in the GPL. In conducting these experiments the crew is involved as both operators and subjects. The investigations will extend throughout periods of manned occupancy at varying levels of activity. Other life science FPE laboratories are time-phased in the referenced program to operate with the growth station.

3.2 FLIGHT OPERATIONS

The reference program flight operations begin with the launch of the first module and buildup of the initial station. After delivery of the first cargo module with the six-man crew, initial station operations begin and continue for five years. Buildup to the 12-man growth configuration is then begun and completed in successive launches. Operations at the full capability are continued to carry out the reference experiment program. The following discussion summarizes the initial station buildup operations, describes the overall mission operations for both initial and growth stations, and discusses the initial station communications operations.

Initial Station Buildup

The basic approach for buildup of the station is (1) to deliver and assemble modules with complete subsystems installed that contain the functions required for continuation, (2) to activate only the equipment necessary for continuation of buildup, and (3) to activate station subsystems fully on arrival of the first crew complement. The station buildup approach minimizes the complexity of operations and design, assures crew safety and mission continuation, and also minimizes the impact of buildup on the basic station designed for nominal operations.

The initial station buildup (Figure 3-8) begins with the core module launch. The core module contains stabilization equipment for buildup operations normally quiescent, which can be activated by remote command. Power is supplied by fuel cells using stored gas. The second launch adds the power module to the core and the assembly continues in a normally quiescent mode. The third launch adds the crew/control module and partial activation is begun. Thermal control is partially activated to prevent fluid freezing during the remaining buildup steps.

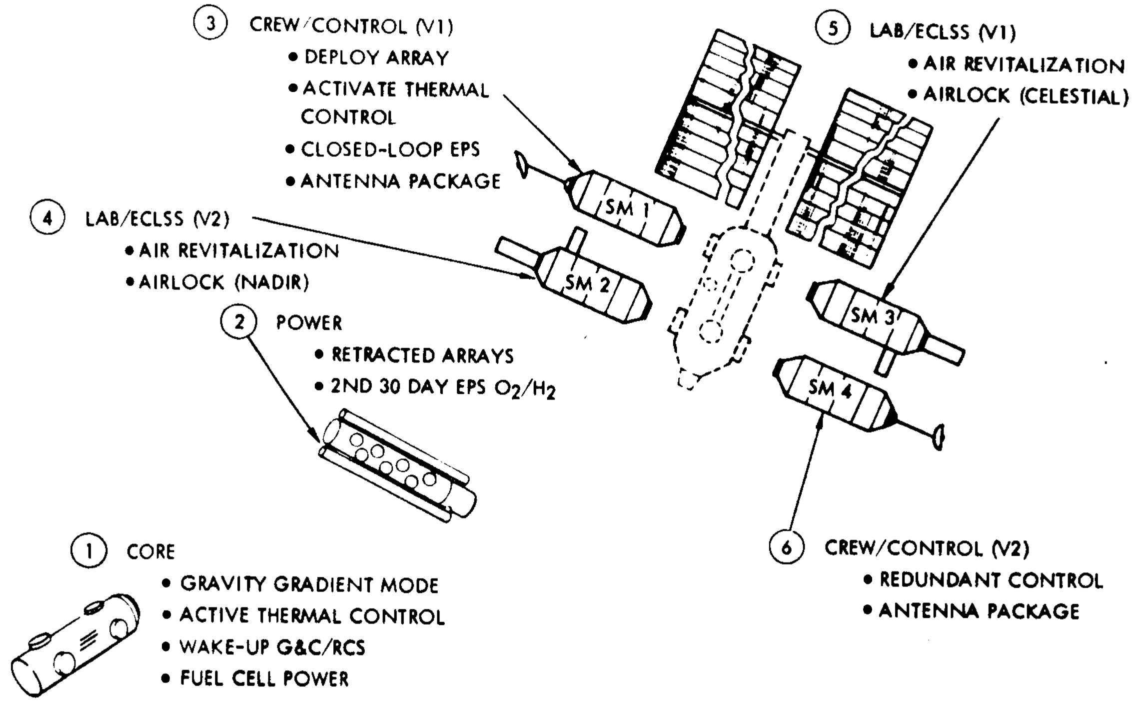


Figure 3-8. Initial Station Buildup Approach

The solar arrays are partially deployed and begin automated operation to provide added power and eliminate the need for fuel cell consumables. The buildup continues with the assembly of Station Modules 2, 3, and 4. With the addition of a cargo module and the six-man crew, the configuration is ready to begin its initial operations.

The core module is launched to a 272-nautical-mile altitude to allow for orbit decay. Orbit makeup is not required until after partial deployment of the solar array. Upon arrival at orbital altitude, checkout and activation of the core module is begun while the module is in the cargo bay of the shuttle orbiter. The fuel cells are activated and the busses energized. Control, communication, and coolant loops are verified. The module is then deployed, with the shuttle manipulator, from the cargo bay to an extended position where the final verification of RF links and rendezvous aids is completed. The RCS quads are then enabled and the module oriented with the longitudinal axis along the local vertical. After separation from the module, the shuttle transmits command for attitude stabilization to damp out separation transients.

Commands are then given for pitch at orbital rate to achieve the gravity-gradient stabilized mode; then the core module RCS and G&C are shut down. The module is left in a nominally quiescent state for the next 27 days. During this period, status data are transmitted on ground command.

The core module is activated on command from the space shuttle or ground and the module is inertially stabilized and docking aids turn on as the shuttle arrives with the power module. A shuttle-to-module docking adapter and leakage makeup gasses are carried on this flight in addition to the power module. The shuttle manipulator is attached to the core module and the module RCS and rendezvous aids are inhibited. After the core module is berthed to the shuttle the interface lines are connected and verified so that crewmen can enter the module. If leakage has occurred, the module will be repressurized to match the shuttle cabin pressure. The power module is removed from the cargo bay and berthed by the manipulator to the end of the core module and the power-core module interface connections made and verified. The power-core assembly is then deployed and left in a quiescent state in a gravity-gradient flight mode similar to that of the core module. Timelines show about 4 days of operations from shuttle launch to landing for the power module delivery and assembly. Because of the variations for time and position phasing of the ascent and descent, the launch to landing time could be as long as 6 days.

The crew/control module, SM-1, is the next module launched and added to the power-core assembly. Since time phasing is required to achieve rendezvous position, the elapsed ascent time from launch to rendezvous can vary from 4 to 26 hours, depending on station position at shuttle launch. After stabilizing the assembly by RF commands, the shuttle attaches the manipulator, deactivates (by RF link) the core module control subsystem, and berths to the end port as shown in the upper portion of Figure 3-9. For all station modules, cargo module, and RAM deliveries, the shuttle axis when berthed to the station is skewed 45 degrees from the Z-axis plane of the station modules. After connecting and verifying the shuttle-station interface and the station internal environment, two crewmen enter the assembly and prepare for berthing the SM-1. Repressurization gasses are carried in the shuttle payload bay to make up for leakage if required.

The module is removed from the cargo bay, berthed to the forward Z-axis port, and the crew connects and verifies the SM-1-core interface. The crew then enters SM-1 and activates the control center. Utilizing software programs prepared for buildup checkout and activation the crew engages the primary power busses and deploys the solar array to 25 percent of full area and verifies their operation and electrical output of 4.870 kilowatts. Primary power is transferred from the fuel cells to the solar array. The SM-1 subsystems required for operation during buildup, such as the thermal control fluid circulating loops, are activated and checked out.

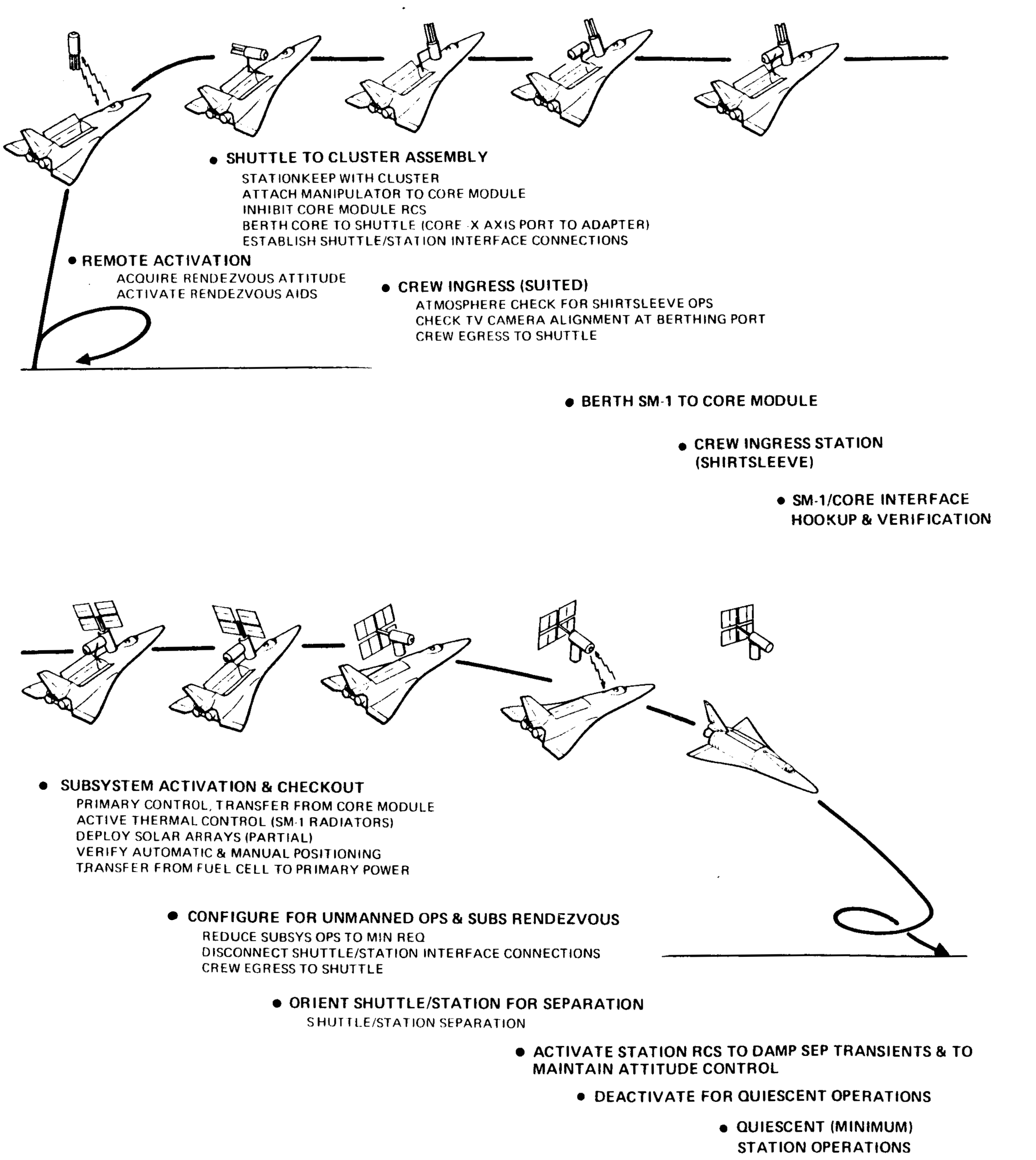


Figure 3-9. Typical Delivery Operations Sequence

The crew returns to the shuttle, disconnects the shuttle-station interface, and separates from the modular assembly. By remote command the RCS quads and control system are enabled and the solar array orientation mechanism uninhibited. The control system damps separation transients and establishes the flight attitude (for minimum fuel consumption) of the assembly. The modular assembly remains in this configuration until the launch of the next module, about 25 days later. Status of subsystems is transmitted to the ground on command (approximately once per day). The delivery and assembly timelines show about 5 days nominal to 7 days maximum from shuttle launch to landing for SM-1.

The delivery and assembly operations for SM-2, -3, and -4 are similar to SM-1. However, since the checkout and activation is less complex the launch to landing times are each about 4 days nominal and 6 days maximum. The modular assembly remains in the same quiescent flight mode after each module is added. During the 26 days of quiescent operations, status of subsystems is transmitted to the ground stations on command.

One hundred and eighty days after the core module launch, the first cargo module and the initial station crew of six are launched. Shuttle berthing and interface, assembly, and verification operations are similar to those for the other modules. When the interface verification is completed the station crew enters the station through the shuttle berthing port. The crew, through the station operations control console, fully deploys the solar array panels and activates all of the subsystems.

After the operational integrity of the station has been established, the cargo module is deployed from the shuttle and berthed to the station. The cargo module remains with the station and provides a supply center and 96-hour emergency supplies. The shuttle-station interfaces are disconnected and the shuttle separates from the station and returns to earth. The space station crew establishes the station nominal flight attitude by placing the core module X-axis perpendicular to the orbit plane with the minus Y axis in the direction of flight and the station module's Z axis in the local earth vertical plane. The initial station, at this point, is fully assembled, activated, manned, and capable of initiating routine operations.

Mission Operations

The sequence of operations for a representative mission plan (Figure 3-10) is based on carrying out the reference experiment program. The plan shows the specific phasing of FPE experiment activity for each discipline laboratory, the accommodation mode, and the level of crew support. Shaded bars indicate station GPL operations; open bars, attached RAM; and cross-hatched bars, detached RAM's. The length of the bar indicates the on-orbit operation time of each lab and the crewman symbols above the bar indicate the average number of men operating the lab or RAM. For example, in the first months of 1982, four crewmen are operating the labs P-2, P-4, and T-1 in the station GPL and airlocks. In the later months of 1982, earth observations lab ES-1 and the medical research lab LS-1 are operated in the station GPL and the high-energy stellar lab A-5 is brought up by the shuttle and operated attached to the station. Later in the program the ES-1 lab is operated as an attached module lab and A-5 is operated in a detached RAM.

The support required to carry out the reference experiment program, in terms of crew hours and subsystem support, was defined. This was integrated with the station operating requirements and the available resources were scheduled to provide timely support to both activities to establish a representative mission sequence plan. It is not intended to represent a program which must be scheduled since the station has the inherent capability and flexibility to accommodate alternative programs.

The crew requirements (Figure 3-11) for the initial station system operation average about 25 man-hours per day and about 30 man-hours for the growth station. These system operations include routine daily operations of the space station, routine and periodic maintenance, housekeeping, logistics operations, and monitoring and flight control of detached RAM's.

Crew personal time (14 hours per man each day) was allocated to provide crew well-being to assure mission success. A regular diurnal schedule was maintained which provides for 8 hours of sleep, 2.5 hours for food preparation and eating, 1 hour for personal hygiene, and 2.5 hours for recreation, exercise, and medical care. This averages 84 man-hours per day for the initial station.

With a 10-hour per man-day work schedule, 60 man-hours are provided for initial system operations and applications and experiment operations. Approximately 35 man-hours per day are directed to applications and experiment operations on the initial station and 25 man-hours to system operations. The growth station directs approximately 90 man-hours to applications and experiment operations.

Twenty-seven skills are required for the conduct of the applications and experiment operations and three additional skills for station system operation. The phasing of the skills requirements, based on the reference plan, results in a variation in the number of skills required by the given crew complement. The average number of skills per crewman is 1.9 for the initial station and only 1.5 with the larger crew of the growth station.

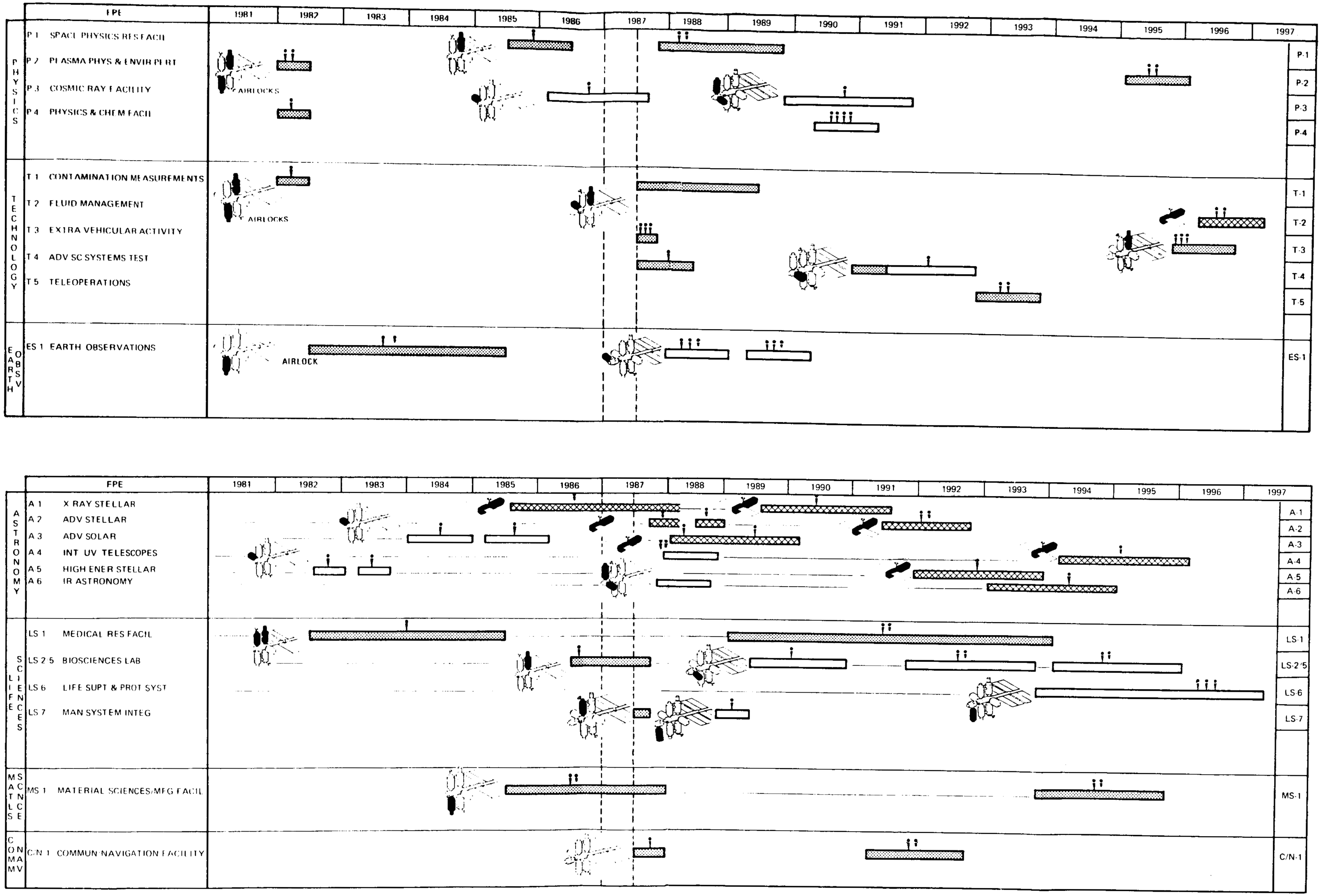
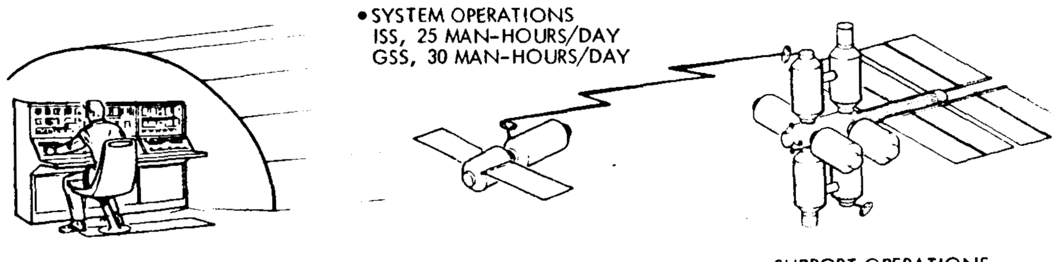
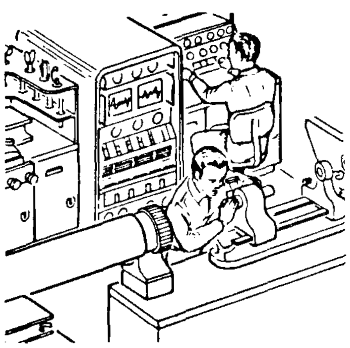


Figure 3-10. Mission Sequence Plan



• APPLICATIONS & EXPERIMENT OPERATIONS



ISS - 35 MAN-HOURS/DAY | GSS - 90 MAN-HR/DAY

CREW NO	1 3	4 9	10 14	15 16	17	18	19 21	22 23	23 24	24 25	25 26	26 27	27 28	28 29	29 30	30 31	31 32	33 34	34 35	36 37	37 38
DATE REQD	1/82	7/82	12/83	7/85	2/86	5/86	8/86	6/87	10/87	1/88	4/88	7/88	10/88	1/89	4/89	7/89	10/89	4/90	7/90	1/91	4/91
SKILL																					
1 BIOLOGICAL TECH		X	X	X	X	X	X	X	X					X	X	X	X	X	X	X	X
2 MICROBIOL TECH		X	X			X	X	X						X	X	X	X	X	X	X	X
3 BIOCHEMIST		X	X			X	X	X						X	X	X	X	X	X	X	X
4 ASTRON/ASTROPHYS															X	X	X	X	X	X	
26 AGRONOMIST										X	X	X	X	X	X	X	X				
27 GEOGRAPHER										X	X	X	X	X	X	X	X				
TOTAL NO OF SKILLS	4	9	8	7	8	9	9	17	13	17	12	13	16	18	19	17	17	11	17	14	16
"AVERAGE" NO OF SKILLS PER CREWMAN	1.1	1.9						1.5													

Figure 3-11. Crew Requirements

The average resupply requirements (Table 3-1) for supporting the crew, station subsystems, and experiments are approximately 2900 pounds per month during initial station operations and 5400 pounds per month during growth station operations. The high-pressure gasses for 96-hour emergency operation are installed in the cargo module, hence must also be included in each logistics launch. Approximately 1900 pounds per month are required for basic station operations of the initial station. This is an average of less than 320 pounds per man per month.

Approximately 1000 pounds per month are needed for the initial phase of the reference experiment program. This average does not include RAM's but does include logistics supplies for their operation. It includes all experiment equipment and consumables for internal GPL operation of experiments. Since the reference program requirements vary, the requirements shown in the table are average values.

The shuttle support requirements (Figure 3-12) for the reference program include launches to accommodate for crew rotation, cargo resupply, and RAM and RAM support section delivery and return as well as initial and growth station buildup. The shuttle launch frequency for delivery of crew and cargo is dictated primarily by considerations of crew rotation. The crew rotation occurs at a frequency which permits the concurrent delivery of all the cargo necessary to operate the station and experiments. The logistics capability was based on the cargo module design concept which has a capacity for 11,800 pounds per flight concurrent with delivery of a crew of six.

Table 3-1. Up-Cargo Requirements

Logistics Item	Resupply Requirement (lb/30 Days) Initial	Growth
Clothing	76	152
Linens	62	124
Grooming	10	20
Medical	15	30
Utensils	56	112
Food	650	1300
Gaseous storage		
Oxygen	3	3
Nitrogen	247	377
Water	369	716
Special life support		
LiOH	10	10
Water management	40	81
Atmospheric control	217	434
CO_2 management	57	113
Waste management	27	53
Hygiene	11	21
Spares	34	69
Subtotal	1884	3615
Average experiment resupply	1000	1800
Total 30-Day Average	2884	5415
Up-down emergency (96-hour)		
Oxygen	404	633
Nitrogen	23	36
Total Emergency	427	669

In addition to the shuttle missions required for the delivery of the station modules and for the crew and cargo delivery, shuttle missions are required for the delivery of RAM's and the support sections necessary for the operation of detached RAM's. For the experiment program previously identified, only two support sections are required to support detached RAM

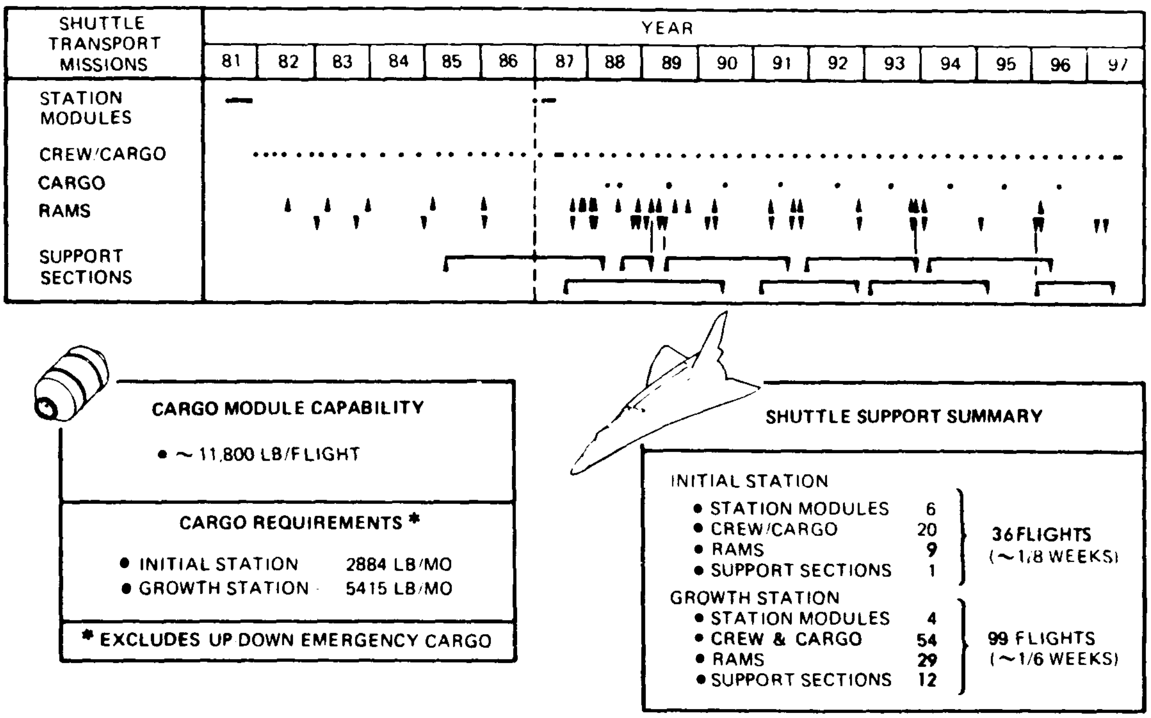


Figure 3-12. Shuttle Support Requirements

operations. These support sections are periodically returned to earth for refurbishment and redelivered to orbit for further utilization.

Control and Communications Operation

Command and control capability is provided for both station and experiment management. Flight control, operations scheduling, subsystem control (including onboard checkout), and communications control are key functions in station management. Experiment management includes the functions of planning, scheduling, operating, performance analysis, data processing, and annotation.

Command, control, and monitoring is accomplished by the crew through the displays and control consoles. In the initial station there are two operational control consoles (one in each pressure-isolatable volume), a commander's control console, and portable control units (Figure 3-13). Local monitor and alarm displays and audio and video capability are also provided throughout the station.

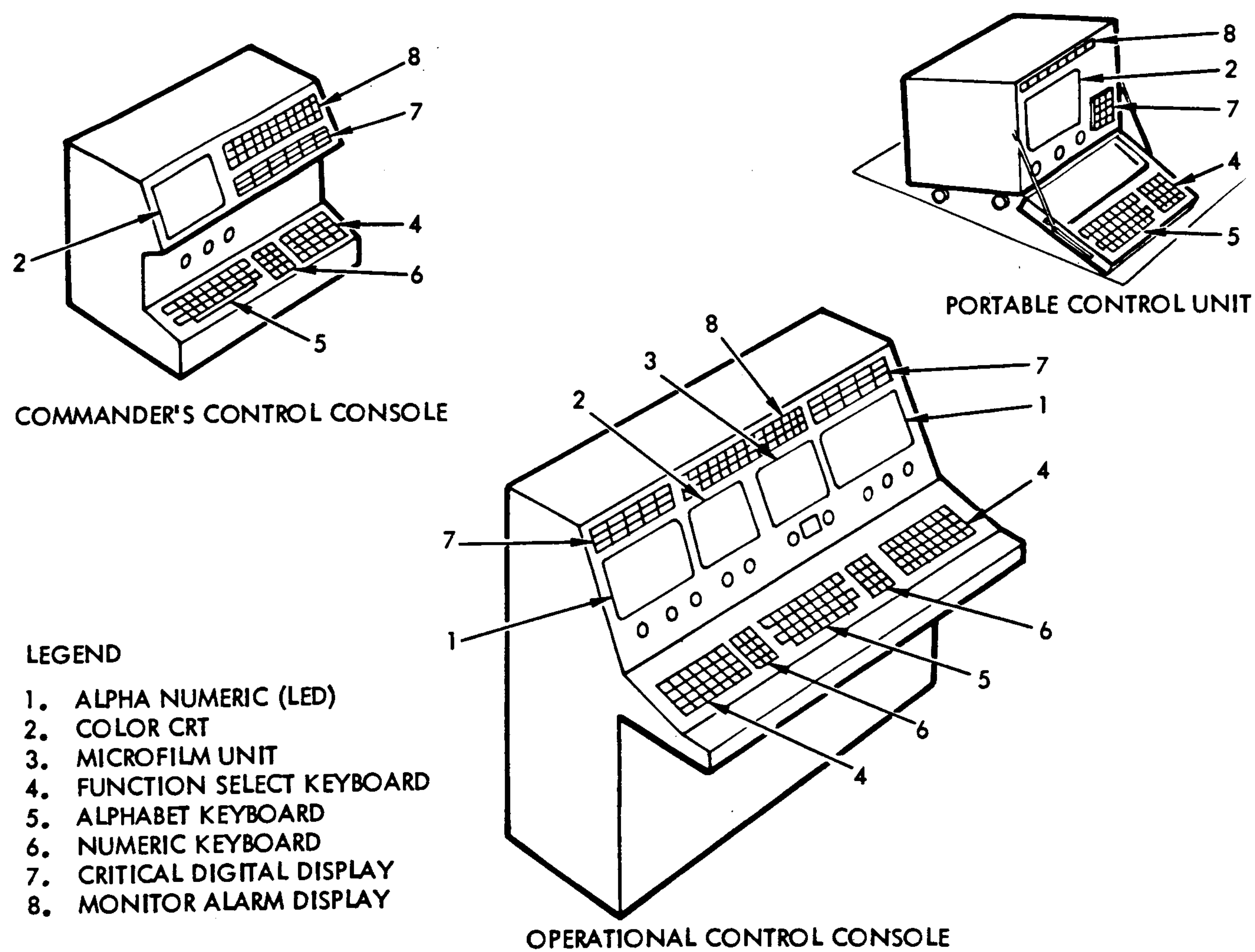


Figure 3-13. Control Consoles

The station normal operational mode for subsystems is automatic without necessity for crew intervention. Data are collected, evaluated, commands issued and displayed, or alarm provided where abnormal conditions exist. Status or commands can be initiated from any one of the control consoles. The central data processing assemblies, located in each of the operational consoles, is accessible (via the data bus) to the commander's or portable units for control of station or experiment operations. The portable units provide capability for local control of experiment operations and for subsystem maintenance or repair operations.

During nominal station operations, one of the operational control consoles is used as an experiment control center, the other for station control. Since both of the operational consoles are identical, the experiment control center can be used as a backup to the primary control. Multiformat color CRT is used to display pictorial, graphic, or alphanumeric information to the crew. Station position and other continually updated information are displayed on alphanumeric message panels. Critical digital data and monitor/alarm displays provide the operator with fixed but selectable vital information.

The crew controls the operations through the keyboards and hand controller. The hand controller provides a manual three-axis control of the station or detached RAM, or for slewing of antennas or remote TV cameras, selected by use of the keyboard. The crew can select the type of function to be controlled through the function select keyboard. Through this keyboard crewman can configure the station subsystems or experiments into the desired operating mode, select a specific subsystem, and select what he wants to do; operate, control, or monitor. A standard alphanumeric typewriter keyboard provides access to the central processor programs or other stored data. Existing programs or data can be modified or new programs entered to carry out the desired operation.

The crew selects and controls the internal and external communications modes through the control consoles. Stored programs are available for configuring the system to routing or normal modes.

The modular space station has external communication links directly with the ground, the tracking and data relay satellite (TDRS), detached RAM's, personnel conducting EVA, and with the space shuttle (Figure 3-14). Transmission of station operations and experiment data to the ground can be accomplished either directly through the MSFN stations using S band or via the TDRS system using K band or VHF. The TDRS system makes available a nearly continuous (approximately 85 percent of the time) two-way link with capability of carrying color TV. Also, one of the four uplink voice channels is a high fidelity channel for crew entertainment and recreation.

The MSS system provides a voice conference capability among the station, the space shuttle, and the ground, and also among EVA operations,

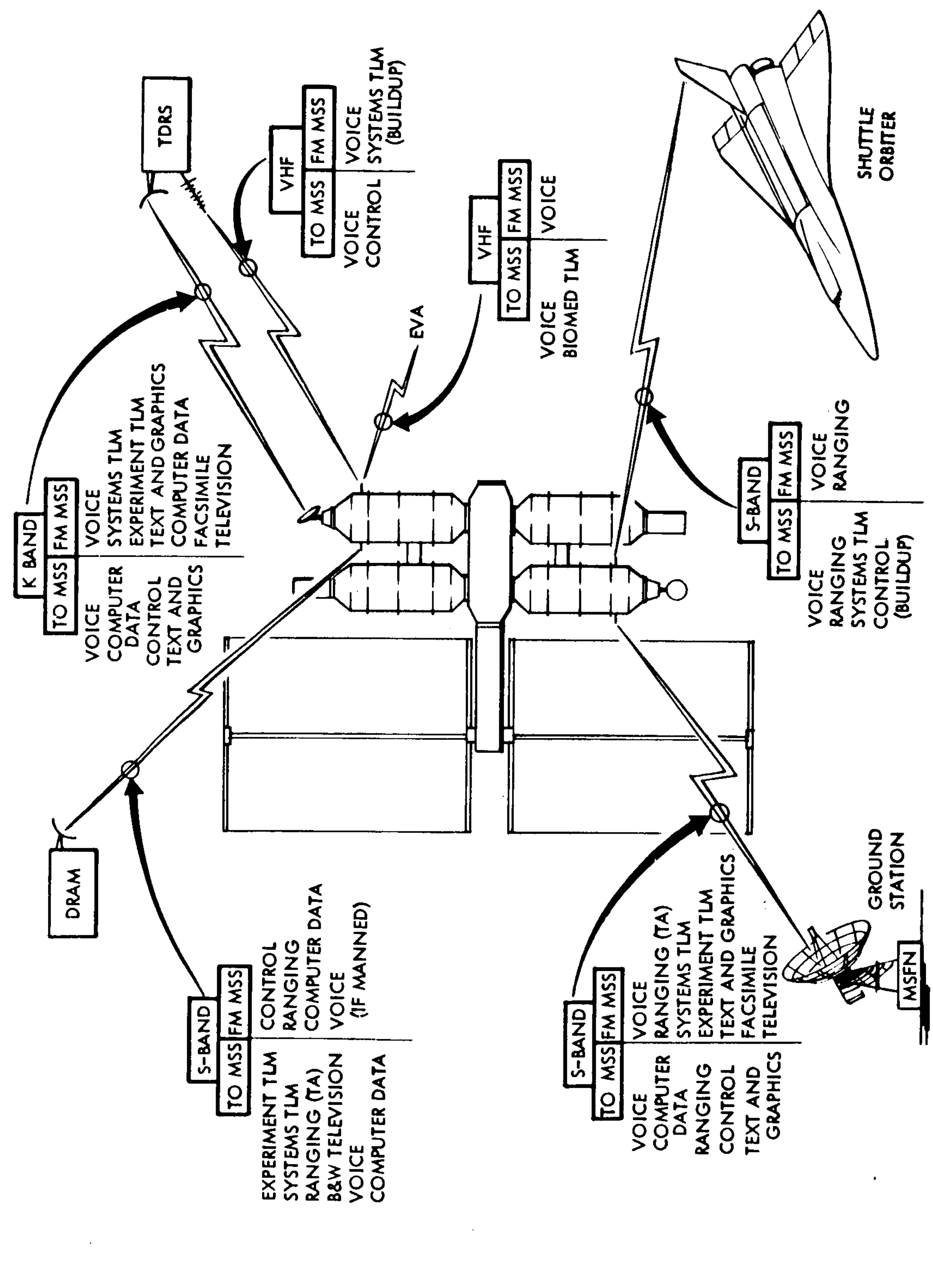


Figure 3-14. MSS External Communications Links

the station, and the ground. The station operates as the common relay switching center. The shuttle-MSS link would be full-duplex or S band. The MSS and the ground stations would be linked via TDRS using either VHF or K band. Translation from K band to S band is accomplished at the station. The voice signals are available to all station personnel through the internal telephone system and to all shuttle and ground crewmen.

A communication link is maintained with detached RAM's to provide operations control, including tracking and ranging, as well as for experiment data collection. In nominal operations, S band is used for transmitting control and ranging data to detached RAM's. The flight path of a detached RAM is coplanar with the station. Its position with respect to the station progressively changes, first leading the station at slightly higher altitude, then—after orbit decay—trailing the station at the same altitude, then—after further decay—again leading the station at lower altitude. After command and execution of an altitude change, the RAM is then leading the station at a higher altitude. The range of these operations is 450 nautical miles from the station. Although S band is used for these operations and can receive black and white TV from the RAM's, K band is available for longer ranging and color TV reception if the RAM's are designed to transmit.