CONTRACT NAS9-9953 MSC 02471
DRL NO: MSC T-575, LINE ITEM 68

CR 115406

SD 71-217-2

MODULAR space station

PHASE B EXTENSION

PRELIMINARY SYSTEM DESIGN

Volume II: Operations and Crew Analyses

PREPARED BY PROGRAM ENGINEERING
JANUARY 1972

(NASA-CR-115406) MODULAR SPACE STATION PHASE B EXTENSION PRELIMINARY SYSTEM DESIGN. VOLUME 2: OPERATIONS AND CREW R.D. Meston, et al (North American Rockwell Corp.) Jan. 1972 192 p CSCL 22B G3/31

N72-18882

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Space Division
North American Rockwell

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TECHNICAL REPORT INDEX/ABSTRACT

ACCESSION NUMBER						DOCUMENT SECURITY CLASSIFICATION	
						UNCLASSIFIED	

TITLE OF DOCUMENT	LIBRARY USE ONLY
MSS PRELIMINARY SYSTEM DESIGN VOLUME II OPERATIONS AND CREW ANALYSES	

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CODE	ORIGINATING AGENCY AND OTHER SOURCES	DOCUMENT NUMBER
QN085282	SPACE DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION, SEAL BEACH, CALIFORNIA	SD71-217-2

PUBLICATION DATE	CONTRACT NUMBER
20DEC71	NAS9-9953

DESCRIPTIVE TERMS

MODULAR SPACE STATION (MSS) PROGRAM, BUILDUP MISSION OPERATIONS, ROUTINE MISSION OPERATIONS, PERIODIC OPERATIONS, CREW OPERATIONS, MISSION SEQUENCE PLAN

ABSTRACT

THIS VOLUME OF THE PRELIMINARY SYSTEM DESIGN DOCUMENT DESCRIBES THE MSS FLIGHT AND CREW OPERATIONS. IT CONTAINS ALL ANALYSES AND TRADES CONDUCTED TO ESTABLISH THE MSS OPERATIONS AND CREW ACTIVITIES AND PRESENTS THE MISSIONS AND SUBSYSTEM INTEGRATED ANALYSES THAT WERE COMPLETED TO ASSURE COMPATIBILITY OF PROGRAM ELEMENTS AND CONSISTENCY WITH PROGRAM OBJECTIVES.

FORM M 131-V REV. 1-68

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 II 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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INTRODUCTION

This volume of the Preliminary System Design document describes the modular space station (MSS) flight and crew operations. It summarizes the analyses and trades conducted to establish the MSS operations and crew activities and presents the missions and subsystem integrated analyses that were completed to assure compatibility of program elements and consistency with program objectives.

The buildup, routine mission, and periodic operations are discussed in Section 1. The analyses began with launch of the initial module required for station buildup, continued through buildup, and ended after addressing the activities associated with routine and periodic operations.

Analyses of crew requirements for operation of the station and experiments are presented in Section 2. Crew makeup and organization concepts are discussed; and analyses of crew duty cycles, including personal activities and work cycles, are presented. Crew activities involved in vehicle operations, such as checkout and maintenance and medical care; the experiment operation crew skills; and the integration of these operations are also presented in Section 2.

A representative mission sequence plan is described in Section 3. Included is the scheduling of activities to carry out a reference experiment program. (The derivation of the reference experiment program is described in Volume III, Experiment Analyses (SD 71-217-3), of the MSS Preliminary System Design Report.)

1. MISSION OPERATIONS

1.1 BUILDUP MISSION OPERATIONS

The underlying concept of the modular space station (MSS) is the sequential on-orbit assembly of manned modules that will provide the accommodations and facilities necessary to support an extended experiment program. Buildup includes all operations necessary to bring the station up to a full performance capability for the routine mission phase. The buildup phase of the MSS begins with the launch and delivery to orbit of the first module and is completed when the station is first fully activated and manned by the initial six-man-crew. The following paragraphs discuss the impact of pertinent guidelines and constraints on buildup and present the trade studies conducted to derive the selected station buildup sequence. Throughout the buildup analysis, a fundamental consideration was to minimize the operational and design complexity to reduce impact on primary station design drivers arising from long-term operational requirements.

1.1.1 GUIDELINES AND CONSTRAINTS

A number of guidelines and constraints (G&C's) defined in Reference 1, are uniquely applicable to the space station buildup operations. The principal G&C's affecting the buildup operations are paraphrased in Figure 1-1. As shown, certain of the G&C's are applicable only when the shuttle is on-orbit with the module cluster and assembly operations are being performed. Throughout the buildup operations studies, it was interpreted that the requirements generated by these G&C's need not necessarily be satisfied exclusively by the orbiting module cluster, but may be partially satisfied by the shuttle. Other G&C's are uniquely applicable to the periods of unmanned, unattended operations and must be satisfied by the module cluster during each phase of the buildup. The NR interpretation of the applicable G&C's and the impact on the space station design considerations and buildup operations will be discussed before the buildup analyses and the selected buildup approach are described.

One of the principal constraints affecting buildup operations is G&C 1.204, which states that the shuttle launch frequency will be no greater than one every 30 days and defines the period of unmanned operations of the module cluster between steps in the buildup process. The shuttle launch

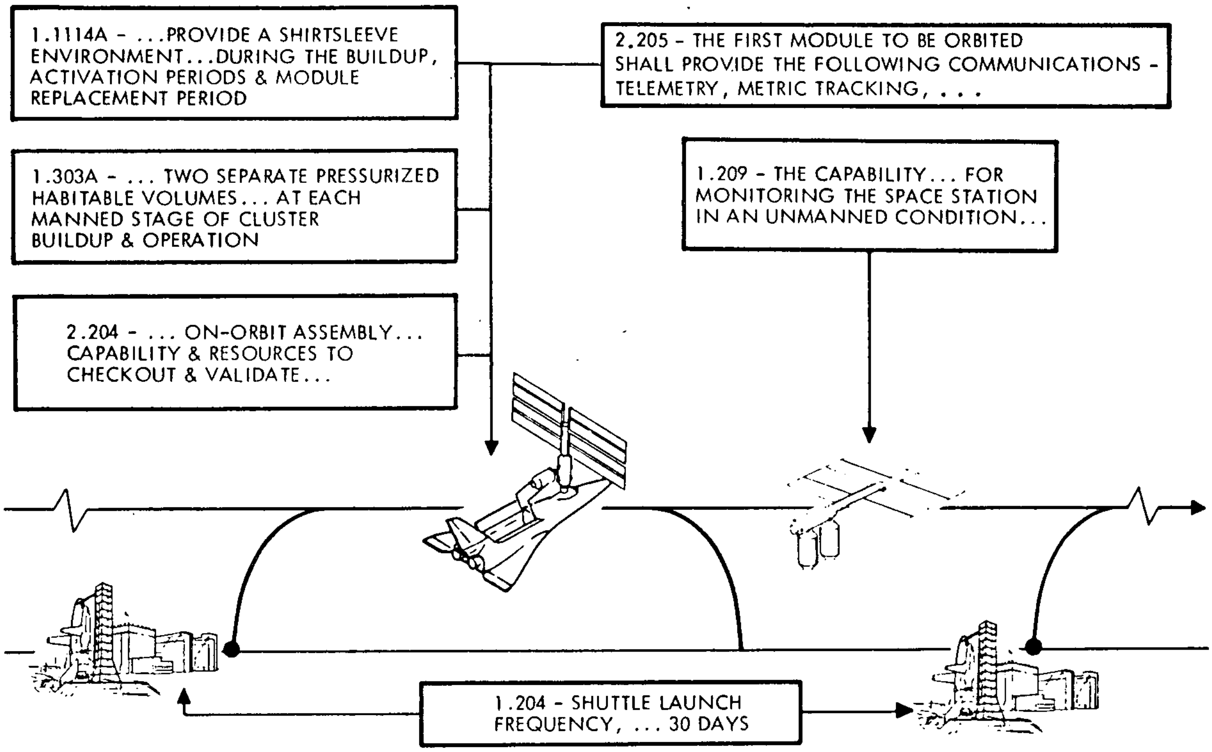


Figure 1-1. Guidelines and Constraints Applicable to Buildup

frequency provides a driver on the subsystem operational requirements during the relatively long periods of unmanned operations with incomplete integration of subsystems. In particular, consumable storage requirements for buildup operations are driven by this constraint. In order to accommodate a missed (or aborted) shuttle launch, the consumable storage capacity must be sized for 60 days, under the assumption that a second 30 days will be required to launch the next shuttle.

Another principal guideline affecting buildup operations is G&C 2.205, which imposes the communication requirement on the initial module placed in orbit. This requirement immediately imposes a buildup scar weight penalty on the initial module launched unless the routine mission requirements of the module dictate the incorporation of transponders, antennas, receivers, and attendant RF hardware to perform the necessary communication. Of equal significance is the fact that this guideline precludes a completely dormant station during the quiescent phases of station buildup. This, in turn, affects the selection of a secondary power source and strongly influences the early delivery of the module containing the primary power source.

Requirements similar to those of G&C 2.205 are imposed by G&C 1.209, which requires that a capability be provided to monitor the space station in an unmanned condition. This guideline not only precludes a completely dormant station during unmanned phases, but also requires a subsystem status monitoring capability. This means that from the initial module on, in addition to an active power source, a limited information subsystem (ISS) capability for subsystem selection and interrogation must be provided. Unless the initial module contains the station ISS, this requirement tends to drive early delivery of the module containing the station control functions to reduce unnecessary ISS redundancy.

The requirement to provide and verify a habitable, pressurized atmosphere in the cluster during each intermittent manned operations is established by G&C 1.1114A. Principal issues that develop in relation to this guideline are whether (1) to impose a shuttle tariff by having the shuttle deliver the necessary gases during the delivery of each module to repressurize the cluster or (2) to initiate early activation of the station environmental control and life support subsystem (ECLSS). Choice 1 poses the potential problem of having to activate subsystem assemblies not otherwise required until normal operations begin. Choice 2 poses the possibility that there will be an inadequate shuttle delivery weight margin after the weight of the module being delivered and the weight of the necessary cluster atmospheric makeup gases are taken into account.

1.1.2 BUILDUP SEQUENCE

The basic issue is the sequential delivery and on-orbit assembly of the space station modules. The goal of the buildup approach (Figure 1-2) is to achieve an initial space station operational capability while minimizing design and operational complexity. The assurance of crew safety during intermittent periods of manned operations and mission continuation during both manned and unmanned operations are also of fundamental importance. As a goal, the selected buildup approach should minimize the impact of the buildup operations on the space station design. The achievement of this goal would result in a space station design which is driven primarily by routine space station operations. The buildup operations would then be performed in a manner which uses the inherent capability of the selected design concept to the maximum extent possible.

Principal Functional Requirements

The selection of a preferred buildup sequence requires the establishment of the functions that must be provided at each step of the buildup. The functions must then be examined; the inherent capability of the space station to provide the functions must be established; and the buildup sequence must be selected.

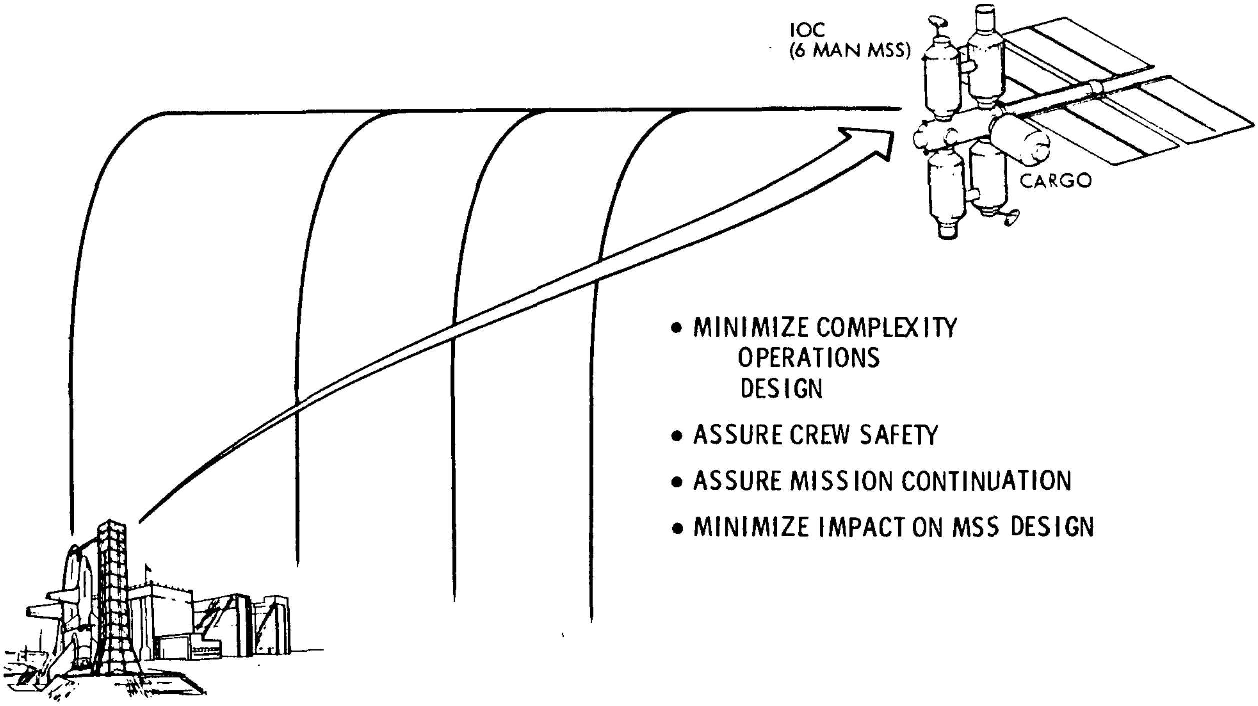


Figure 1-2. Basic Space Station Buildup Goals

The functions required during each mission phase of the buildup will affect the ultimate allocations or requirements for functions in the space station modules. Conversely, the preferred functional allocations based on routine space station operations will have an impact on the selection of the preferred buildup sequence. To obtain an operationally independent rather than design-dependent perspective of the order and number of functions needed during buildup, an analysis was conducted to identify the major functions required in relation to mission phase. The approach taken was to develop a candidate list of major functions required for MSS operations and then to apply a buildup criterion to eliminate those functions not deemed essential until a subsequent phase. The surviving or essential functions for each phase, then, were those that must be provided autonomously by the module cluster or intermittently by the shuttle.

The functional requirements during buildup are dictated primarily by the requirements identified in Figure 1-3. The basic functional requirements are those associated with the on-orbit assembly operations and the unmanned periods of operations between buildup steps. During the periods of unmanned operations, the minimum functions which must be provided are thermal control, attitude control, and subsystem status monitoring. During the on-orbit assembly operations, the basic capability to assemble the modules

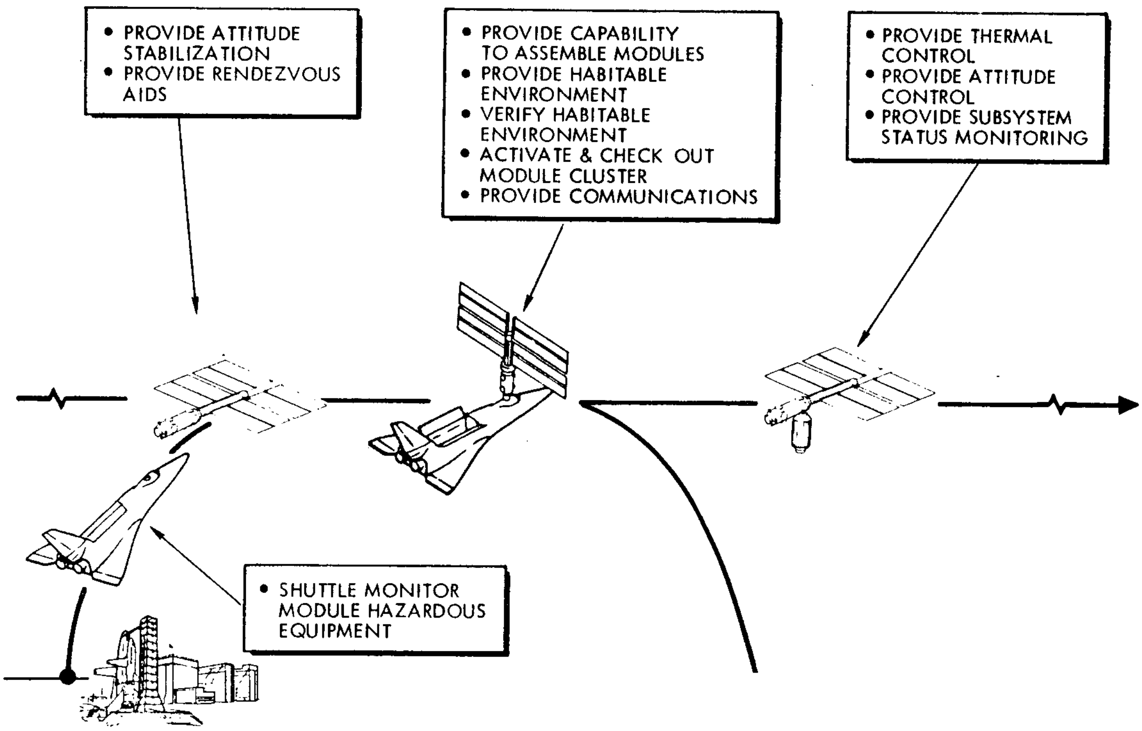


Figure 1-3. Buildup Functional Requirements Drivers

must be provided. Also, the capability to provide and verify a habitable environment must be provided during all periods of intermittent manning. An additional functional requirement is the capability to activate and check out the module cluster at each step of the buildup. The level of activation and checkout of each module is dependent upon the buildup sequence and the requirements imposed by the remaining buildup operations.

In order to execute the buildup operations, the capability to rendezvous and berth with the orbiting cluster must be provided. This requirement imposes a requirement to provide attitude stabilization of the on-orbit cluster and to provide rendezvous aids. During the delivery of modules, the minimum capability which must be provided is that of monitoring hazardous equipment within the modules.

The basic process used in establishing the buildup functional requirements is illustrated in Figure 1-4. The format of the matrix used to identify the functional requirements by mission phase and the criticality of the functions is also shown. Two basic sets of criteria were used to identify the requirements for a given function at each phase of the buildup. The first set (first-order criteria) identify those functions which are essential for mission

MAJOR FUNCTION	CRITERIA		BUILDUP PHASE - STATION REQUIREMENT			
	1ST ORDER	2ND ORDER	INITIAL LAUNCH	PREMANNING	INITIAL CONT MANN	ROUTINE
PRIMARY PWR GEN	■	◕	✓	✓	✓	✓
2ND PWR GEN	■	⊕	✓	✓	✓	✓
PWR DISTRIBUTION	■	◕	✓	✓	✓	✓
LIGHTING	⊞	◑			✓	✓
ATTITUDE POINT./CONTR	■	◕	✓	✓	✓	✓

1ST ORDER CRITERIA

- ⊞ STATION CAN BE LOST WITHOUT FUNCTION
- ⊞ ESSENTIAL TO SUBSEQUENT BUILDUP OPERATIONS
- ⊞ REQUIRED DURING QUIESCENT OPERATIONS
- ⊞ REQUIRED FOR INTERMITTENT MANNED OPERATIONS

2ND ORDER CRITERIA

- ⊕ THE STATION MUST PROVIDE FUNCTION DURING INTERMITTENT MANNED OPERATIONS
- ⊕ THE FUNCTION INVOLVES LOW MAINTENANCE EQUIPMENT
- ⊕ THE FUNCTION CAN BE PERFORMED WITHOUT CREATING A RESUPPLY PROBLEM DURING BUILDUP, I. E., INSENSITIVE TO SHUTTLE LAUNCHES

Figure 1-4. Buildup Functions by Mission Phase

continuation, while the second set (second-order criteria) relate to functional allocation or operational considerations. It is noted that the fourth criterion of the first-order set and the first criterion of the second-order set seem to be identical. The difference is that the first-order criterion can be provided by either the shuttle or the space station during intermittent manned operations; the first second-order criterion specifically requires that the space station provide the functions. The second and third criteria listed under the second-order set were introduced to preclude the unnecessary early activation of high-maintenance equipment and special shuttle resupply flights during buildup.

In reference to the buildup phases shown in the matrix, the initial launch applies to the first module delivered to orbit by the shuttle. The premanning phase deals with the addition of subsequent modules and the quiescent operations during buildup. Initial continuous manning refers to the phase where that station begins initial manned operations, and routine operations refers to the phase of operations when experiments are being conducted and includes the introduction of research and application modules (RAM's) into the space station program.

Figure 1-5 presents the essence of the functional requirements analysis. From the completed matrix, it can be seen that those functions which met all or most of the first-order criteria also met most of the second-order criteria, findings indicating the functions would have to be performed autonomously by the modular assembly. Further, all the functions which met all or most of the first- and second-order criteria, with the exception of two safety functions—subsystem fail degrade and 96-hour emergency provision—were all deemed necessary on the initial launch. Thus, from the data presented, functions such as primary power generation, power conditioning, attitude pointing and control, attitude control propulsion, and the like were considered essential candidates from the initial launch. Other functions, such as atmospheric storage, CO_2 management, and atmospheric control, while essential for intermittent manned operations, were considered as likely candidates to be provided by or shared with the shuttle. Still other functions, such as water management, waste management, food management, and the like were not considered essential until the initiation of continuous manned operations.

As previously stated, the functional requirements analysis was conducted independent of design/configuration constraints. but these constraints had to be considered in determining the final results. The functional requirements defined were used as a basis for the allocation of functions to the different station modules, and they provided a baseline for the development of the buildup sequence.

Buildup Alternatives

Two basic buildup issues requiring analyses of alternatives identified during the study were: "Which is the first module delivered to orbit?", and "What is the level of activation of each module during the buildup process?" As identified in the previous section, a number of functions must be provided by the first module. The ability to provide these functions will potentially have an impact on the design considerations of the first module. Conversely, the preferred design concept based on routine operations will impact the preferred first module delivery selection. In order to minimize the impact of the buildup operations on the nominal space station design, several trades were conducted throughout the modular space station study to ensure that the buildup process will minimize the impact of the buildup operations on the space station design. As noted previously, the goal during the analyses of the buildup operations was to ensure that the space station buildup would minimize the impact on the space station design. Also, it was necessary to ensure that the buildup operations assure mission continuation and crew safety during intermittent periods of manned operations.

MAJOR FUNCTIONS	CRITERIA		FUNCTIONS REQUIRED BY BUILDUP PHASE			
	1ST ORDER	2ND ORDER	INITIAL LAUNCH	PREMANNING	INITIAL CONTINUOUS MANNING	ROUTINE OPERATIONS
PRIMARY POWER GENERATION	■	◕	X	X	X	X
SECONDARY POWER GENERATION	■	◓	X	X	X	X
ENERGY STORAGE	■	◓	X	X	X	X
POWER CONDITIONING	■	◕	X	X	X	X
POWER DISTRIBUTION	■	◕	X	X	X	X
LIGHTING	⊞	◑	X	X	X	X
ATTITUDE POINTING & CONTROL	■	◕	X	X	X	X
ATTITUDE STABILIZATION	■	◕	X	X	X	X
POSITION DETERMINATION	⊞	◑			X	X
VELOCITY DETERMINATION	⊞	◑			X	X
ATTITUDE REFERENCE	■	◕	X	X	X	X
ANGULAR RATE DETERMINATION	■	◕	X	X	X	X
ORBIT MAKEUP COMPUTATIONS	⊞	◑				X
ATMOSPHERE STORAGE	▞	◔	X	X	X	X
CO_2 MANAGEMENT	▞	◔	X	X	X	X
ATMOSPHERE CONTROL	▞	◔	X	X	X	X
THERMAL CONTROL	■	◕	X	X	X	X
WATER MANAGEMENT	▖	◔			X	X
WASTE MANAGEMENT	▖	◔			X	X
HYGIENE	▖	◔			X	X
FOOD MANAGEMENT	▖	◔			X	X
SPECIAL LIFE SUPPORT	▖	◑			X	X
CREW PROVISIONS	▖	◑	X	X	X	X

Figure 1-5. Buildup Functional Requirements (Sheet 1 of 3)

MAJOR FUNCTIONS	CRITERIA		FUNCTIONS REQUIRED BY BUILDUP PHASE			
	1ST ORDER	2ND ORDER	INITIAL LAUNCH	PREMANNING	INITIAL CONTINUOUS MANNING	ROUTINE OPERATIONS
FLUID STORAGE	■	◓	X	X	X	X
PROPELLANT CONDITIONING	■	◕	X	X	X	X
PROPELLANT ACCUMULATOR	■	◕	X	X	X	X
PROPELLANT FEED CONTROL	■	◕	X	X	X	X
ATTITUDE CONTROL PROPULSION	■	◕	X	X	X	X
ORBIT MAKEUP PROPULSION	◫	⊕			X	X
PRIMARY STRUCTURE	■	◕	X	X	X	X
SECONDARY STRUCTURE	■	◕	X	X	X	X
ENVIRONMENTAL SHIELD	⊞	⊕	X	X	X	X
DOCKING/BERTHING	◪	⊕	X	X	X	X
CREW FURNISHINGS	⊞	◑	X	X	X	X
COMMAND FLIGHT CONTROL						
RENDEZVOUS	◪	◕	X	X	X	X
BERTHING PORTS	◪	◑	X	X	X	X
ORBIT DETERMINATION	⊞	◑			X	X
MISSION PLANNING & OPS. SCHED.	⊞	◑				X
DECISIONS & CONTROLS	◫	◑			X	X
OPERATIONS DATA MANAGEMENT						
SUBSYSTEMS STATUS	◪	◕	X	X	X	X
EQUIP. CONFIG. MONITOR & CONTROL	◪	◑	X	X	X	X
COMMAND EXECUTION & VERIFICATION	◪	◕	X	X	X	X
COMPUTER OPS. OF ALL SUBSYSTEMS	⊞	◑			X	X

Figure 1-5. Buildup Functional Requirements (Sheet 2 of 3)

MAJOR FUNCTIONS	CRITERIA		FUNCTIONS REQUIRED BY BUILDUP PHASE			
	1ST ORDER	2ND ORDER	INITIAL LAUNCH	PREMANNING	INITIAL CONTINUOUS MANNING	ROUTINE OPERATIONS
EXPERIMENT DATA MANAGEMENT						
EXPERIMENT CONTROL	⊞	◑				X
EXPER. C/O STATUS	⊞	◑				X
DATA COLLECTION	⊞	◑				X
DATA ROUTING	⊞	◑				X
ON-BOARD C/O MONITOR & ALARM						
SUBSYSTEM CAPABILITY CHECKOUT	◪	●	X	X	X	X
SUBSYSTEMS STATUS DETERMINATION	◪	●	X	X	X	X
CONTINGENCY ALARMS CONT.	◪	◑	X	X	X	X
FAULT ISOLATION	◪	◑			X	X
INVENTORY LOGISTICS MANAGEMENT	⊞	◑				
COMMUNICATION MANAGEMENT						
INTERNAL CCTV, PHONES	⊞	◑			X	X
INTERCOM	◪	◑			X	X
EXTERNAL (TELEMETRY 2-WAY TO GROUND)	◪	●	X	X	X	X
EXTERNAL (TELEMETRY 2-WAY TO SHUTTLE)	◪	●	X	X	X	X
EXTERNAL (VOICE, TV 2-WAY TO GROUND & SHUTTLE)	◪	◑			X	X
CARGO HANDLING	⊞	◑			X	X
STATION MAINTENANCE						
FLUID-MECH.	⊞	⊕			X	X
OPTICS	⊞	⊕			X	X
ELECTRONICS	⊞	⊕			X	X
SAFETY (MANNED OPS)						
DUAL ENTRY/EGRESS	◪	●	X	X	X	X
DUAL IVA/EVA CAPABILITY	◪	◑			X	X
DUAL CONTROL CAPABILITY	◪	◑	X	X	X	X
DUAL PRESSURE VOLUMES	◪	◑			X	X
FAIL DEGRADE	■	◑			X	X
96 HOUR EMERGENCY	■	◑			X	X
ENVIRONMENTAL PROTECTION	■	◑	X	X	X	X

Figure 1-5. Buildup Functional Requirements (Sheet 3 of 3)

During MSS buildup, the primary system elements to be delivered to orbit are the core module, the solar array power module, four station modules, and a cargo module. The delivery sequence of the modules is directly impacted by the on-board capability of the individual module relative to the cumulative required on-orbit capability of the modular cluster during buildup.

For the MSS, modules are categorized as common modules and special modules. Common modules use a common external structure of fixed diameter and include station modules (SM's) that contain most of the living and working facilities and functions. Special modules are functionally unique in construction and are limited in size at launch to an envelope of 15 feet in diameter and 60 feet in length. For the MSS, the only special modules identified are the solar array power module and the core module.

Initial Launch Alternatives

Preferably, the initial module delivered to orbit must have the minimum amount of scar equipment beyond that required for normal operations. Because of this need and the equipment allocation to the various modules, the only viable candidates for first launch were the solar array power module and the core module. Figure 1-6 presents a sketch of the two modules and summarizes the on-orbit functions required by each if it were the one selected for initial launch.

In the case where the power module is delivered first and its solar array is deployed, continuous attitude control of the module must be provided to orient the solar array toward the sun. This need generates a requirement for active thermal control, the capability for subsystem monitoring, and continuous control capability. The resultant impact on the power module requirements, in terms of the subsystems, is defined in Figure 1-7. To maintain the necessary solar array attitude control and module thermal control, several basic requirements are imposed beyond those needed by the module for normal operations. They include the requirements for energy storage, guidance and control (G&C) equipment, reaction control subsystem (RCS) thrusters, propellant storage, active thermal control, and the ISS data processing assembly (DPA). Of these requirements, only the energy storage, RCS quads, and propellant storage are reasonably allocated to the power module when routine operations are considered. For the complete space station assembly, locating the G&C equipment in the core module is preferred so that it will be adjacent to the external viewing RAM's. Also, for the selected space station configuration, adequate heat rejection capability is provided by the station modules during the routine operations period, and active thermal control heat rejection capability is not required on the power module. The preferred location of the data processing assembly is also in

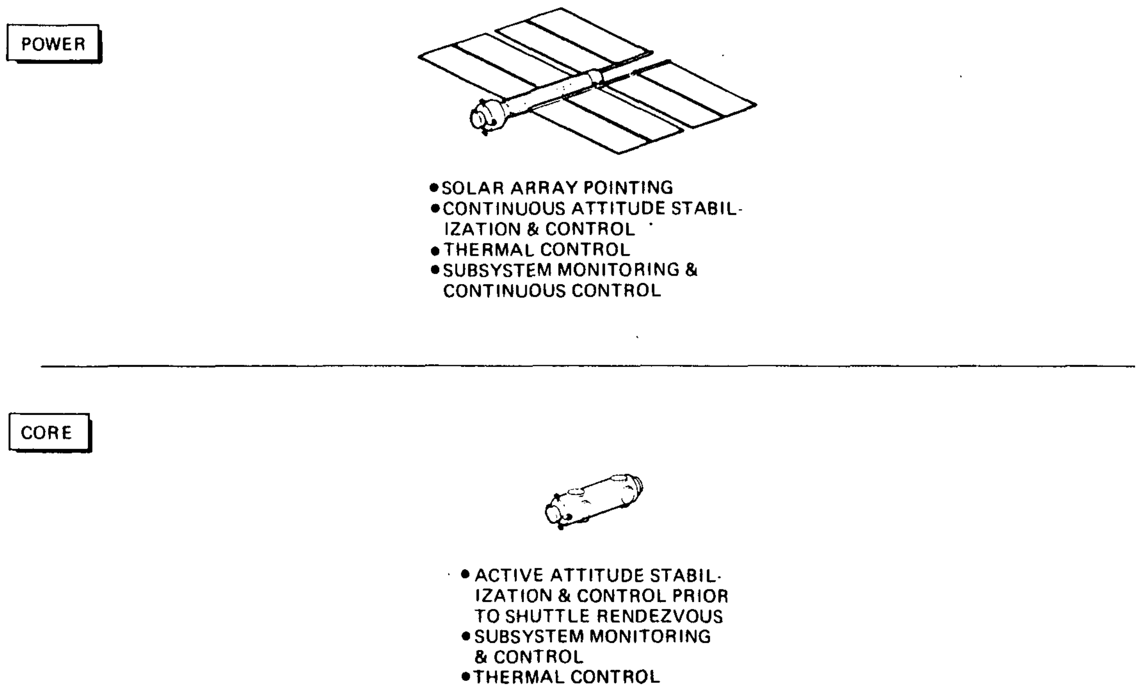


Figure 1-6. Buildup Alternatives—Initial Launch

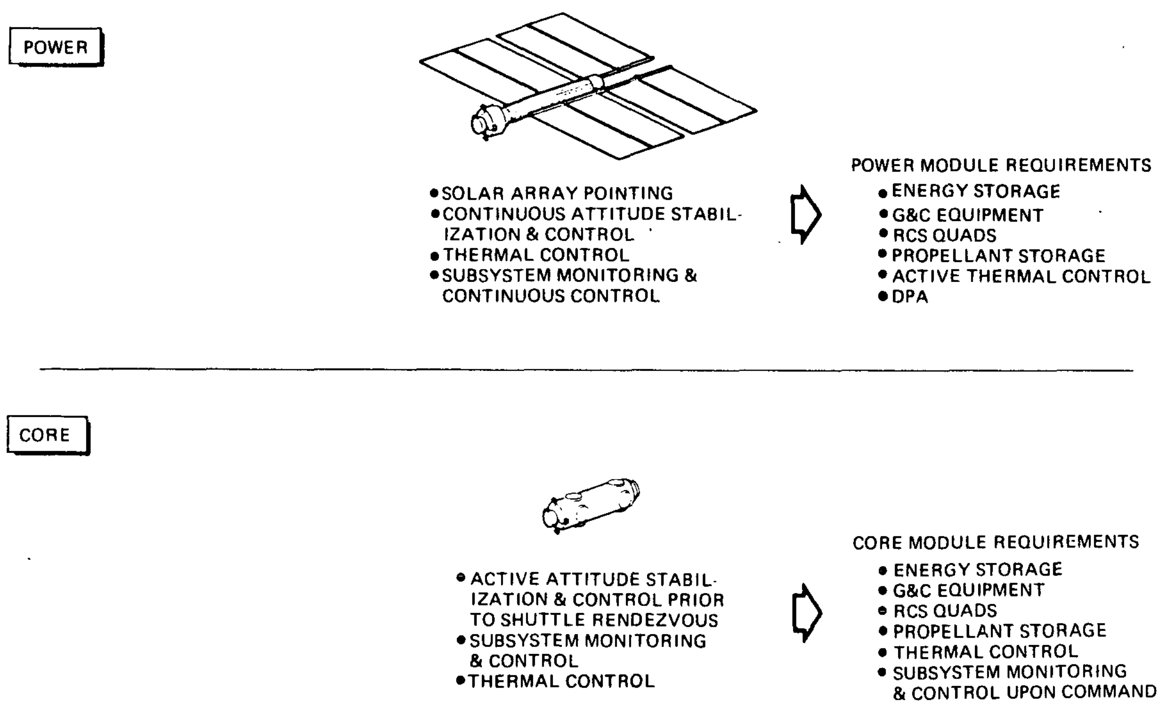


Figure 1-7. Impact of Initial Launch Selection on Subsystem Requirements

the station modules during the routine period of operations. Delivery of the power module first imposes requirements upon this module which are not nominally required during the routine period of operations.

The operational considerations and the associated subsystem requirements for the core module delivery first are also identified in Figures 1-6 and 1-7. If the core module is delivered on the initial launch, attitude stabilization is only required during shuttle berthing and deberthing operations. Subsystems monitoring and control are still required as well as thermal control, but the requirements imposed by delivery of the core module first are less severe than those imposed by the power module delivery first. The resultant subsystem requirements are similar to those imposed by delivery of the power module first, but the requirements are less severe. In the case of the core module delivered first, the goal is to have passive thermal control as opposed to active thermal control as required by the power-module-first alternative. In relation to the ISS requirements, subsystem monitoring and control are still required; however, they are only required upon command. It has been determined that attitude stabilization can be provided by flying a gravity gradient flight mode; thus the RCS and G&C equipment and RCS consumable requirements during buildup are reduced. In general, the subsystems requirements imposed by delivery of the core module first are more consistent with the functional requirements associated with routine operations.

The resultant operational comparisons for the two first-module alternatives are shown in Figure 1-8. During the delivery of the power module, the solar array must be deployed, and its operational capability must be verified. These requirements necessitate activation of the primary electrical power subsystem (EPS), the G&C and RCS equipment for attitude stabilization and control, the ISS equipment for monitor and control of the orbiting module, and the active thermal control loops. With the possible exception of redundancy, the resulting orbiting system has all the characteristics of an unmanned spacecraft rather than the characteristics of an assembly of a manned system. In comparison, delivery of the core module first requires activation of the secondary EPS and a partial activation of the ISS. Activation of the G&C and RCS equipment is only required to verify the operability of these systems. Before shuttle departure, the G&C and RCS subsystems can be deactivated until just prior to delivery of the second module.

The resultant comparison for the two first-module alternatives is identified in Figure 1-9. The figure presents the initial launch alternatives and the major considerations that influenced the selection of the preferred alternative. The core-module-first concept is to employ passive attitude control during unmanned operations by using a gravity gradient flight mode.

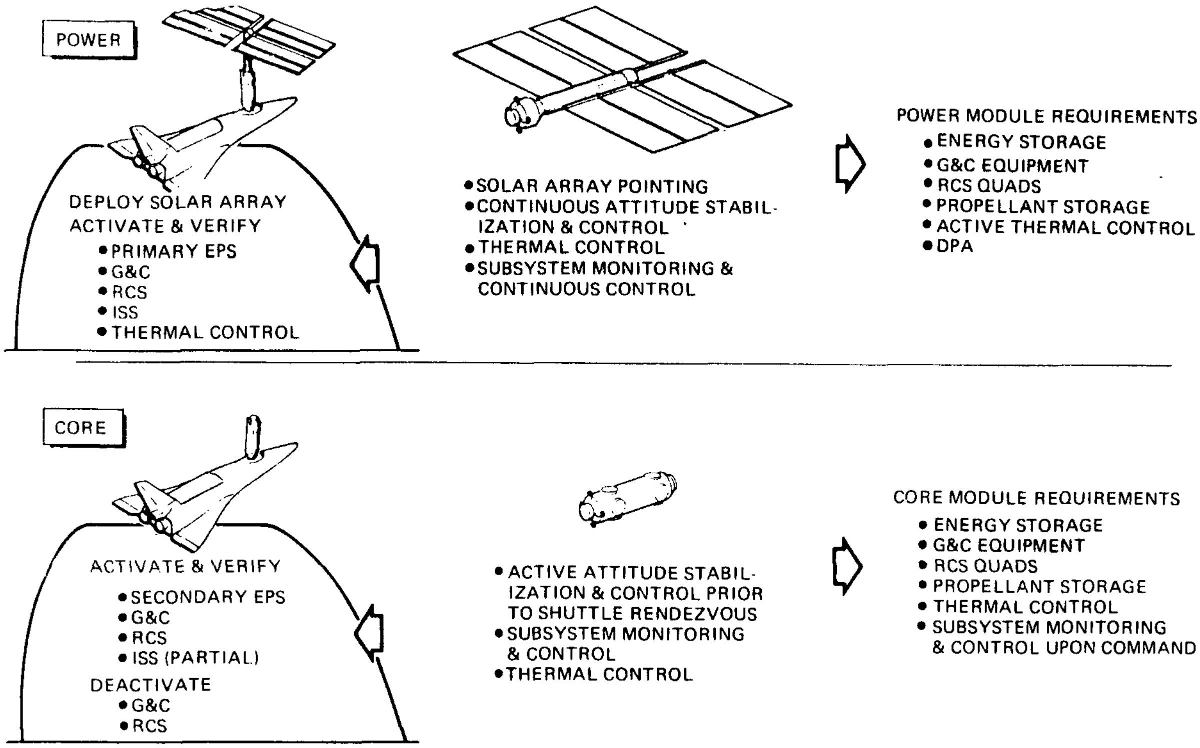


Figure 1-8. Initial Launch Selection Operational Comparison

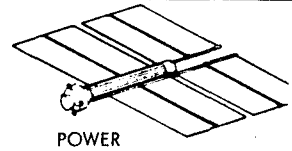
CONSIDERATION	 CORE	 POWER
OPERATIONAL MODE	PASSIVE ATTITUDE CONTROL (GRAVITY GRADIENT)	ACTIVE ATTITUDE CONTROL (SOLAR ARRAY POINTING)
LEVEL OF INITIAL ACTIVATION	MINIMUM ACTIVATION PARTIAL DEACTIVATION PRIOR TO SHUTTLE RETURN	REQUIRES ACTIVATION OF MAJOR ASSEMBLIES
SUBSYSTEM SCARS	EPS, G&C, RCS } NO MAJOR SCARS ECLSS - POTENTIALLY ACTIVE THERMAL CONTROL ISS - "WAKE-UP" RECEIVER & BUILDUP COMM	EPS - PRIMARY BUSES - EMERGENCY STORAGE G&C - TWO CONCEPTS OR REDUNDANT EQUIPMENT RCS - TWO ADDED QUADS ECLSS - ACTIVE THERMAL LOOPS RADIATORS ATMOSPHERIC CONTROL ISS - DPA
WEIGHT SENSITIVITY	NO SINGLE MAJOR ASSEMBLY DRIVER	SINGLE MAJOR ASSEMBLY DRIVER (SOLAR ARRAY)

Figure 1-9. Initial Launch Comparison

Employing passive attitude control permits minimum subsystem activation. The G&C and reaction control subsystems may be deactivated after the module has achieved a gravity gradient mode and before shuttle return to earth. Thermal control is still required. However, in view of the gravity gradient mode, a design goal to provide a passive rather than an active thermal control subsystem for this unique operation would allow further subsystem deactivation. Penalties arising from scars to the basic core module subsystems are minimal. In the G&C subsystem, RCS, and secondarey EPS, there are no major scars to the subsystem assemblies. In the ECLSS, there is the possibility that active thermal control may be required. This requirement would impose the addition of equipment such as heat exchangers and radiators to that normally required in the module. The ISS requires a transmitter, wake-up receiver and antenna, a simplified DPA to monitor subsystem status, and a direct RF link to the G&C subsystem and RCS. These additions to the ISS would provide the initial buildup communication capability and enable the shuttle to remotely control the attitude and stability of the module for berthing operations. With reference to Figure 1-9, a final consideration was in the area of weight sensitivity at the subsystem level. Examination of the core module subsystems disclosed no major subsystem that by itself could drive the module over its target weight.

Also in reference to Figure 1-9, the viability of launching the solar array power module first is examined. In this concept, the solar arrays are only partially deployed to provide the power consistent with buildup demands. Partial rather than full array deployment is preferred to enhance the ballistic coefficient of the module for orbit preservation and to minimize excessive power generation and consequently thermal control requirements. To realize the power-generating capability of the partially deployed arrays, the module must have active attitude control to provide solar array pointing. Orientation maneuvers will be shared by the array and the module. To conserve RCS propellant, employing active attitude control requires the continuous performance of all subsystems and an active thermal control subsystem.

The penalties incurred in terms of subsystem scars by launching the power module first are quite significant. The EPS will require primary buses and energy storage assemblies. The G&C subsystem needed will nearly duplicate that found on the core module. A complete RCS, including propellant tanks, distribution lines, and four reaction quads, will have to be installed as well as an active thermal control unit, including coolant loops and radiators. To control and operate these subsystems, a sophisticated ISS is required that imposes the installation of a data processing assembly. As with the core module, the ISS on the power module must also provide buildup communication capability. Included must be equipment for monitoring the subsystem performance of the module and statusing this information to earth during unmanned operations, which will provide RF links to enable the shuttle to orient and stabilize the module and inhibit the arrays for berthing operations. Adding this equipment to the power module will make it a complex module with undue subsystem redundancy in orbit after buildup.

Finally, if the power module is launched first, it has a major subsystem assembly that potentially could drive the module beyond its target launch weight. This assembly is the solar array itself. If projected performance declines, the weight of the additional required array surfaces could cause the weight of the module to exceed launch limits.

Although the power module provides early delivery of abundant power, many additional functions that are not required during normal operations must be added to the module to support that power source. The core module alternative permits use of the normally installed secondary power source and requires minimal additional support functions. The preferred alternative then was to launch the core module first. The power module was rejected for initial launch because of the significant scar penalties and the potential weight sensitivity.

Subsequent Module Selection

After the core module for the initial launch was selected, several alternative concepts were left for accomplishing subsequent station buildup. Candidate buildup options considered are shown in Figure 1-10. As shown, there are four options for second launch: the power boom with its array deployed or left retracted upon delivery, the station module containing the primary control center, or a station module with one of the life support subsystems aboard. However, either the control center module or a life support module delivered on the second launch requires a significant increase in electrical power for operation. The fuel cells, which are the secondary power source located in the core module, require large quantities of reactants to provide the necessary power over an extended period of time without resupply. Delivery of the power module on the second launch with solar arrays retracted was the selected approach. Leaving the solar arrays retracted requires no additional support in terms of control equipment at this point in the buildup. It also provides a modular cluster with a higher ballistic coefficient and consequently less orbit decay than if the arrays were deployed. After the power module has been attached to the core module, the cluster operates by using the initial subsystems in the core module.

After selection of the core module for the first launch and the power module for the second, the principal considerations in selecting the subsequent module delivery sequence were to provide control as soon as possible

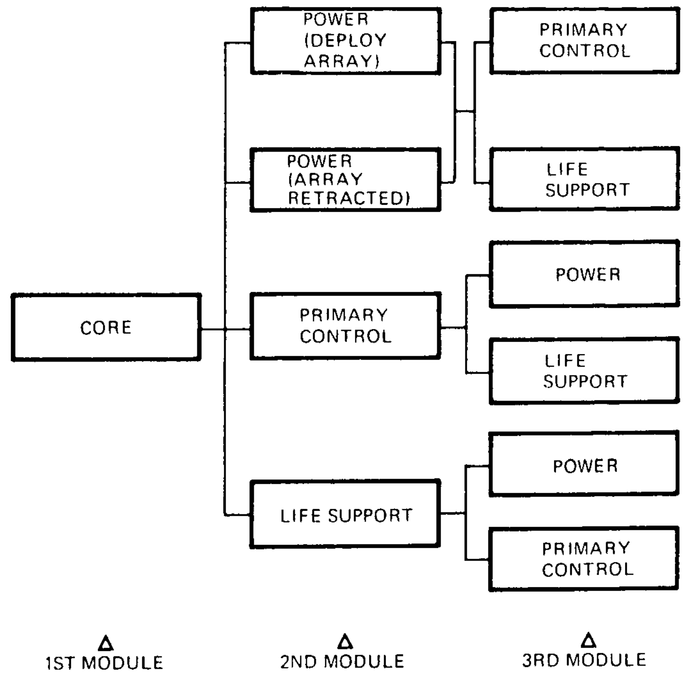


Figure 1-10. Buildup Alternatives—Subsequent Modules

in order to exploit the primary EPS, minimize scar equipment requirements, and delay the delivery of potentially high-maintenance modules. The module containing the primary control was required for the third launch since it delivers a full ISS capability, which permits solar array deployment, attitude control, and heat rejection capability with no scars. Conversely, the delivery of a life support module was rejected since it contains no inherent control capability but does have the potentially high-maintenace life support subsystem. Figure 1-11 summarizes the selection and sequence of delivery for the first three modules.

At this time, the solar arrays are partially deployed to provide the power consistent with subsequent buildup requirements. The G&C subsystem and RCS are activated for continuous operation to provide the necessary flight mode attitude control and stability.

Following delivery of the primary control module, the fourth launch provides a life support module. With the delivery of the life support module, all critical functions relative to station operations are available, and a continuous manning capability exists should it be desired.

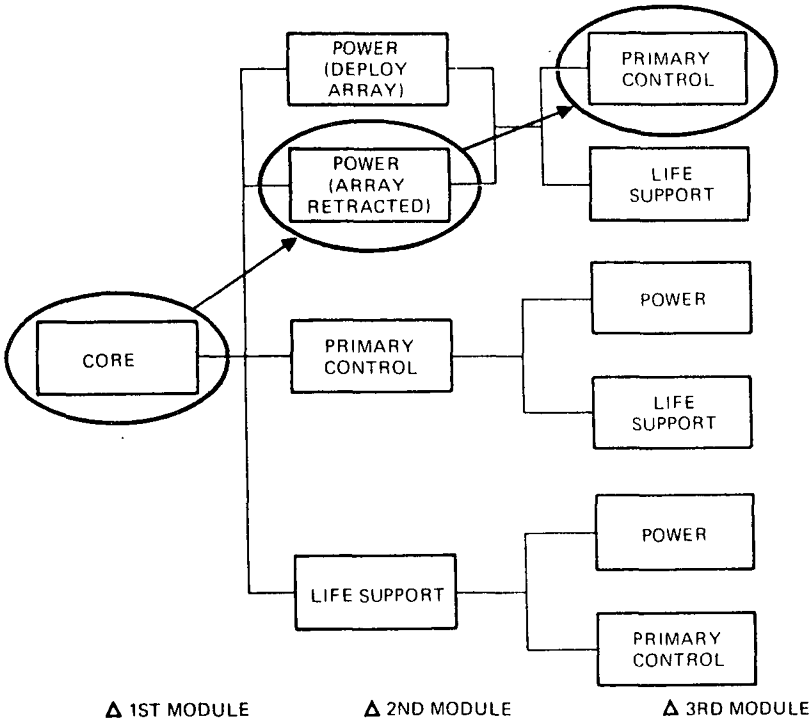
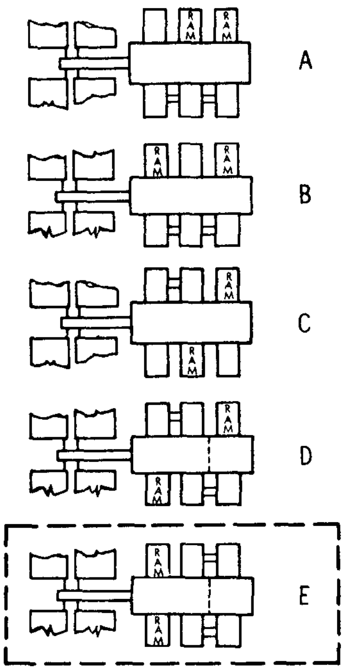


Figure 1-11. Selected Buildup Sequence

The basic concept, however, is not to man the station until it is completely built up. Further, to reduce the risk of component failure during buildup, the potentially high-maintenance systems on the life support modules are not activated until initial continuous manning.

The fifth launch delivers the second life support module, which is followed by the second control module on the sixth launch. At this time, all the functions and facilities for continuous manned operation have been assembled in orbit. The seventh shuttle launch will deliver a cargo module and the initial six-man station crew, at which time all the station's subsystems will be fully activated and routine operations will be initiated.

An additional consideration associated with the buildup following delivery of the power module is the location of the modules on the core. Figure 1-12 is a partial definition of the major barbell configuration arrangement alternatives which are available using a core module with six berthing ports. Among the considerations that must be investigated are (1) placement of modules on the core module so that dual egress is possible and reasonable arrangements for a habitable environment and critical services in each of two pressurized volumes (V_1 and V_2) are available, (2) intermodule convenience, and (3) flight mode characteristics.



- 10 ADDITIONAL ALTERNATES
  1. CORE LONGITUDINAL LOCATION
  2. TOP-OR-BOTTOM LOCATION
- CONSIDERATIONS
  1. FLEX PORTS, DURING BUILDUP & AT INITIAL CONTINUOUS MANNING (SAFETY ISSUES)
  2. INTER MODULE CONVENIENCE
  3. FLIGHT MODE CHARACTERISTICS
- BEST
  CONFIGURATION E
  BUT . . . FURTHER CONSIDERATION OF RAM PLACEMENT REQUIRED

Figure 1-12. Module Arrangement Alternatives

The preferred alternative is Configuration E. This arrangement permits flexports across two separate pressurizable volumes since the station modules are adjacent to each other. Configurations A through C would require flexports between station modules and RAM's in order to satisfy the dual egress criteria. These flexports would necessitate the delivery of RAM's whether or not they are required by the experiment program. Configuration D has adjacent station modules but an unequal distribution of modules between V_1 and V_2. As a result, the volume containing the single station module would have to contain all functions necessary for operations of the space station following loss of pressurization in the other volume. The selected barbell configuration is arranged like Configuration E, the station modules berthed to adjacent ports separated by an EVA/IVA airlock.

An additional consideration is the sequence in which the modules are delivered. The basic alternatives for the delivery of the station modules are illustrated in Figure 1-13. Either alternative permits the berthing of modules to the core without interference by other modules between the berthing port and the space shuttle. In selection of the preferred sequences, the functional allocation in the modules and the functions required to continue the buildup

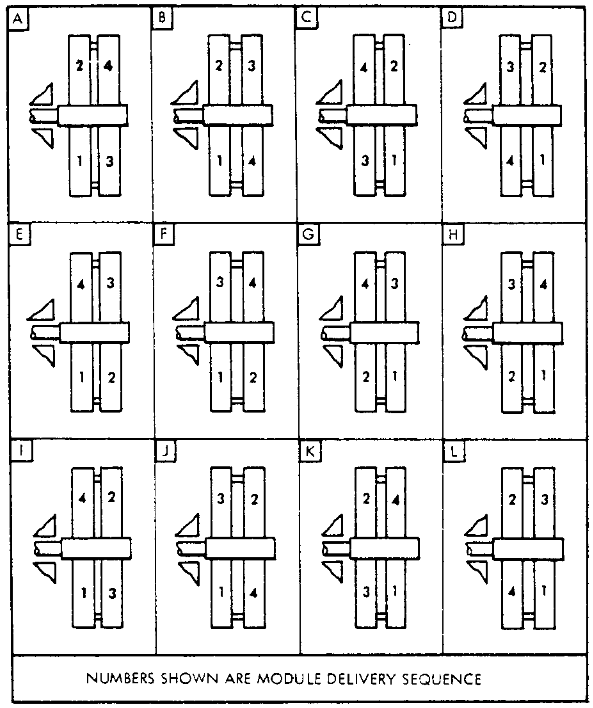


Figure 1-13. Station Module Delivery Sequence Alternatives

operations must be considered. Both alternatives provide the required functions. Concept A was selected as the baseline approach, but Concept B is a viable programmatic alternative.

Analysis of the barbell configuration, as described in Volume V, Configuration Analysis (SD 71-217-5), of the MSS Preliminary System Design Report, showed the single core to be severely overweight. Further analysis of a two-core configuration showed that several configuration-dependent drivers, such as high propellant usage, large CMG's, structural stiffness, increased in complexity. The buildup of a two-core configuration extended the buildup time and required adding subsystem control capability to the core in order to continue operations until delivery of the station modules.

These configuration-dependent issues are inherent in the barbell arrangement. As discussed in Volume V, these issues are significantly relieved by berthing the cargo modules and RAM's in a plane normal to the station modules. In the resulting configuration, the station control and ECLSS modules are attached to a single-core module as shown in Figure 1-13, and docking or berthing ports are provided in V_1 and V_2 of the core module for attachment of the cargo module and RAM's.

The resultant buildup sequence for the initial space station is shown in Figure 1-14. The core and power modules are the first modules delivered; however, the solar array is not deployed until delivery of the control and crew module (SM-1) on the third launch. An initial continuous manning capability exists following the fourth launch when the ECS and laboratory module (SM-2) is delivered. The module cluster, at this point in the buildup, has one complete set of subsystems, and dual egress capability. These modules also include part of the general-purpose laboratory (GPL) capability. In order to man at this step in the buildup, the fifth launch must be a cargo module that contains the necessary consumables for continuous station operations plus a 96-hour emergency life support capability. This cargo module launch would also deliver the initial space station crew. A reasonable crew size at this step in the buildup, if continuous manned operations are assumed, would be four.

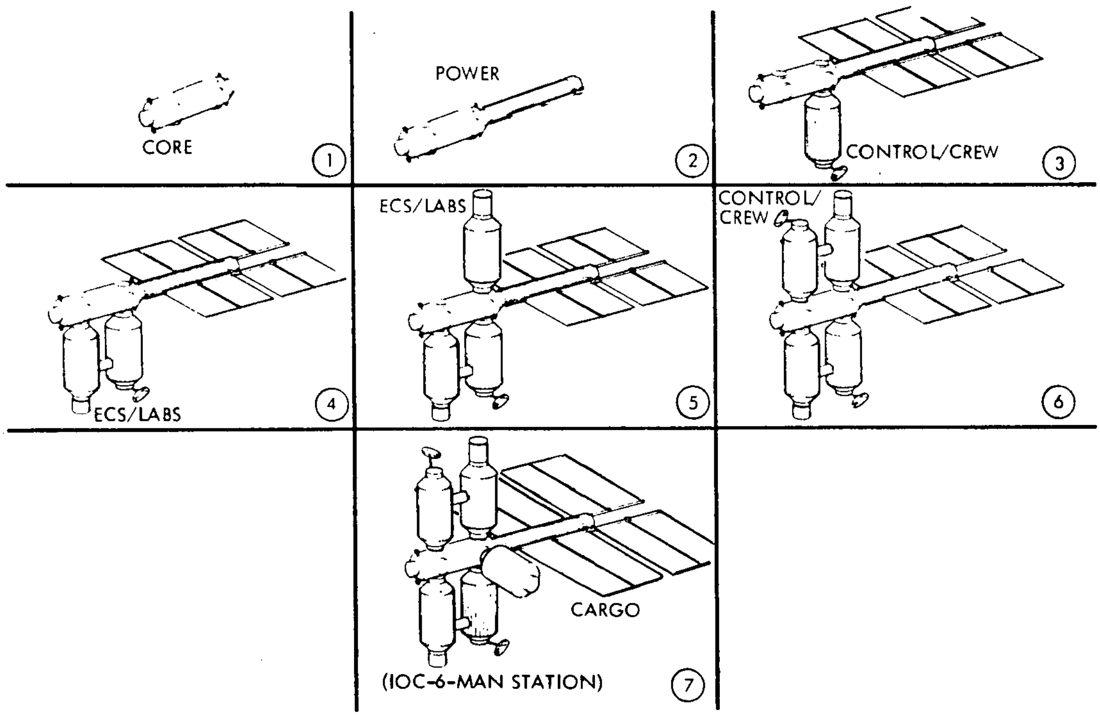


Figure 1-14. Initial Space Station Buildup Sequence

Continued buildup (without early continuous manning) results in the initial space station operational capability in seven launches, the final step being the delivery of a cargo module and the initial space station crew. At this point, the space station is capable of commencing routine operations, including the capability to support either two attached RAM's, two detached RAM's, or combinations thereof. Redundant subsystems and complete general-purpose laboratories are available at this point to begin experiment operations with a six-man crew.

Subsystem Activation

The level of subsystem activation during each step of the buildup is limited to that required for mission continuation. The subsystem activation requirements for the buildup sequence (discussed previously) are shown in Figure 1-15, which identifies major space station assemblies, by subsystem, that must be activated throughout the buildup process.

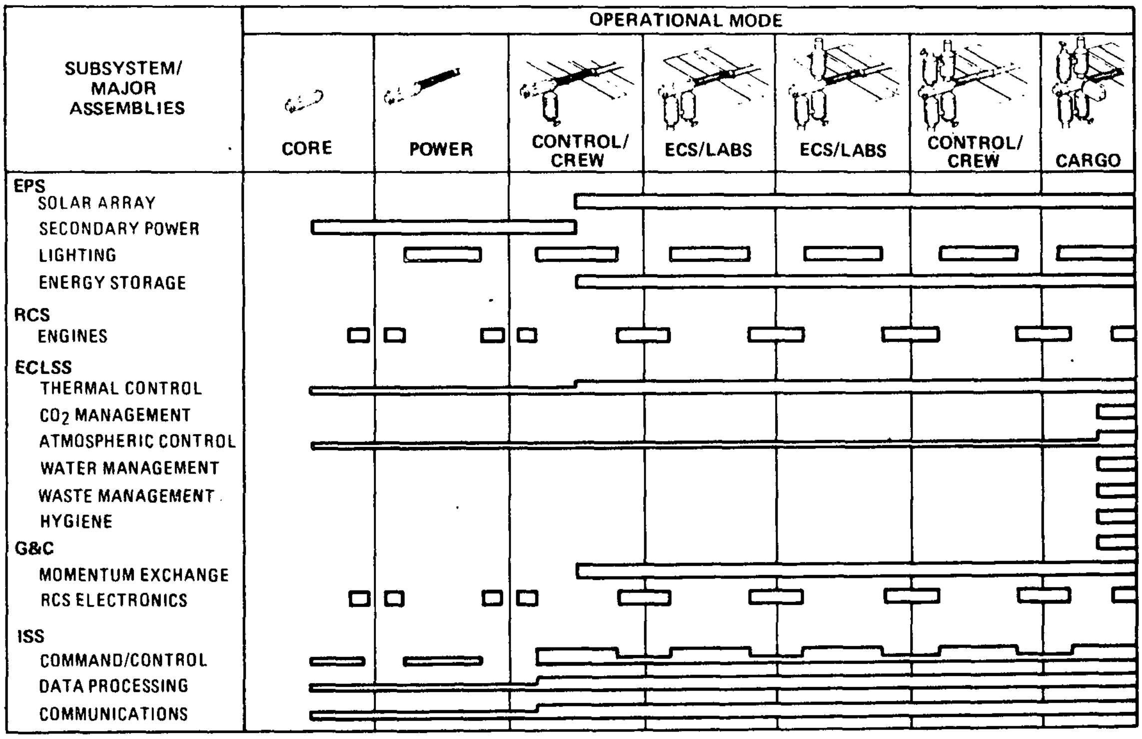


Figure 1-15. Subsystem Activation Requirements

Functions such as CO_2 management, waste management, and the like are not activated until buildup is complete and continuous manned operations are initiated. These assemblies generally have high power, control additional thermal, and maintenance requirements, and initiating operations of these assemblies is not desirable until a continuous manned capability exists. Also, there is no identified functional requirement for the operations of these assemblies before initial continuous manned operations. The solar array is not deployed until after delivery of the control and crew module, and electrical power is provided by secondary power (fuel cells) before deployment of the solar array. Since the core module and core module plus power module cluster utilize a gravity gradient flight mode, the G&C and RCS activation requirements are limited to those necessary to provide attitude stabilization and control of the module cluster before rendezvous and berthing of the shuttle and to attitude-stabilize the cluster following separation of the shuttle.

Following delivery of the control and crew module, the RCS engines and the associated RCS electronics must be activated during those periods when the shuttle is not berthed to the module cluster. Attitude stabilization and control are provided by the shuttle when the shuttle is berthed to the cluster; therefore, the RCS engines and associated RCS electronics are deactivated when the shuttle is berthed to the module cluster.

A limited ISS capability is required before delivery of the control and crew module when the basic characteristics of a fully integrated system exist. At this point, the data processing assembly must be activated to maintain integrated command and control of the three-module orbiting cluster.

Subsystems activated when the control and crew module is delivered remain active throughout the remainder of the buildup operations, except for G&C and RCS assemblies deactivated when the shuttle is berthed to the module cluster. Full activation is then accomplished when the cargo module is delivered on the seventh step, and the space station is brought up to full operational status.

Flight Mode

The selections of the flight modes during the buildup process were based on considerations of providing adequate thermal control capability, minimizing subsystem requirements, and minimizing consumable requirements. The selected flight modes at each step of the buildup are summarized in Table 1-1. The core module and the core module and power module cluster will both utilize a gravity gradient flight mode during the periods of unmanned, quiescent operations. While in this mode, the RCS engines and RCS electronics can be deactivated during periods of unmanned operations. During

Table 1-1. Flight Mode Selection

Configuration	Flight Mode: Quiescent Operations	Flight Mode: Rendezvous Berthed Unberthed	Flight Mode: Shuttle Berthed
Core	Gravity gradient	XPOP inertial	Shuttle preferred
Core/power	Gravity gradient	XPOP inertial	Shuttle preferred
Core/power/SM-1 and subsequent	XPOP/ZLV/ principal axes	XPOP inertial	Principal axes

the actual buildup process, the preferred attitude orientation must be flown, and attitude stabilization must be provided in order to effect berthing and buildup of the module cluster. The preferred flight mode during these phases is with the X axis (longitudinal axis) of the module cluster perpendicular to the orbit plane and the Y and Z axes held inertially fixed (XPOP/inertial). During the periods when the space shuttle is berthed to either the core module or the core module and power module cluster, no attitude preference is imposed by either of these modules and an attitude which accommodates the shuttle can be flown.

Following delivery of the first crew and control module (SM-1), the module clusters are flown in XPOP local vertical flight mode with the space station +Z axis in the direction of the earth (XPOP/ZLV). In order to minimize RCS propellant requirements during buildup, the principal axes are used as the reference axis system rather than the space station geometric axes. An XPOP/inertial/attitude mode is again used during periods of shuttle rendezvous, berthing, and unberthing throughout the remaining buildup phases. Following the delivery of SM-1, either an XPOP/local-vertical/ principal-axis flight mode or a shuttle preferred flight mode is utilized. Again, there is not a preferred flight mode driven by station requirements during these operations. The attitude mode must, however, be compatible with the electrical power requirements and the associated solar array orientation requirements considering interference between the space shuttle and the solar array.

Buildup Launch Frequency

The shuttle launch frequency has been established by a guideline and constraint which states that the shuttle launch frequency will be no greater than one every 30 days. This requirement results in a period of quiescent unmanned operations of the module cluster between steps in the buildup process. Some buildup equipment is required that would not be needed for normal station operations. For example, this launch frequency has created the conversion of 300-pounds-per-square-inch accumulators, used in normal operations, to 2500-pounds-per-square-inch accumulators. Quiescent operations also adds a special atmosphere monitor in the core module, special batteries, inverters, and a unique information and RF command system.

The launch frequency, when coupled with the guideline requiring "checkout of the operational and technical adequacy of the cluster at each stage or buildup," adds further potential complications. For example, the CO_2 management function delivered on the fourth shuttle delivery flight (SM-2), if activated, must be passivated following crew departure. Without added complexity to the equipment, this task cannot be achieved within the five-day shuttle stay time. In addition, the cluster is required to fly gravity gradient mode until the third module is delivered. Then it must fly the principal axis-oriented mode to accommodate the solar arrays. Although a minor complication, it nonetheless is a penalty paid for launch frequency and quiescence.

Special buildup equipment can be eliminated if the shuttle launch frequency can be increased to that required to eliminate equipment activation and return to a quiescent state each time a module is added in buildup. Figure 1-16 shows the launch frequency, the number of shuttles, and the launch pads required to achieve this capability.

The flight and ground operational requirements to provide this capability are as follows. A shuttle launch is required every six days, except that the second shuttle launch could occur four days after the initial launch of the core module, which would permit a shuttle to be on-orbit for the entire buildup phase. Each shuttle mission would not exceed seven days. Three shuttle vehicles must be dedicated to buildup. Ground refurbishment time from landing to launch must not exceed 11 days. Two launch pads are required to support the six-day launch frequency. Pad turnaround time must not exceed 10 to 12 days. All these operational requirements are within projected estimates of launch rates and refurbishment time documented in the MSS Program Phase B Definition Shuttle Model, SD 71-206 (1 June 1971).

The increased shuttle launch frequency, shown in Figure 1-16, will result in deletion of all special equipment required for quiescent operations during buildup and completion of initial station buildup in 35 days. Since these advantages are significant and could result in lower program costs, it is recommended that a change to the shuttle launch frequency guideline

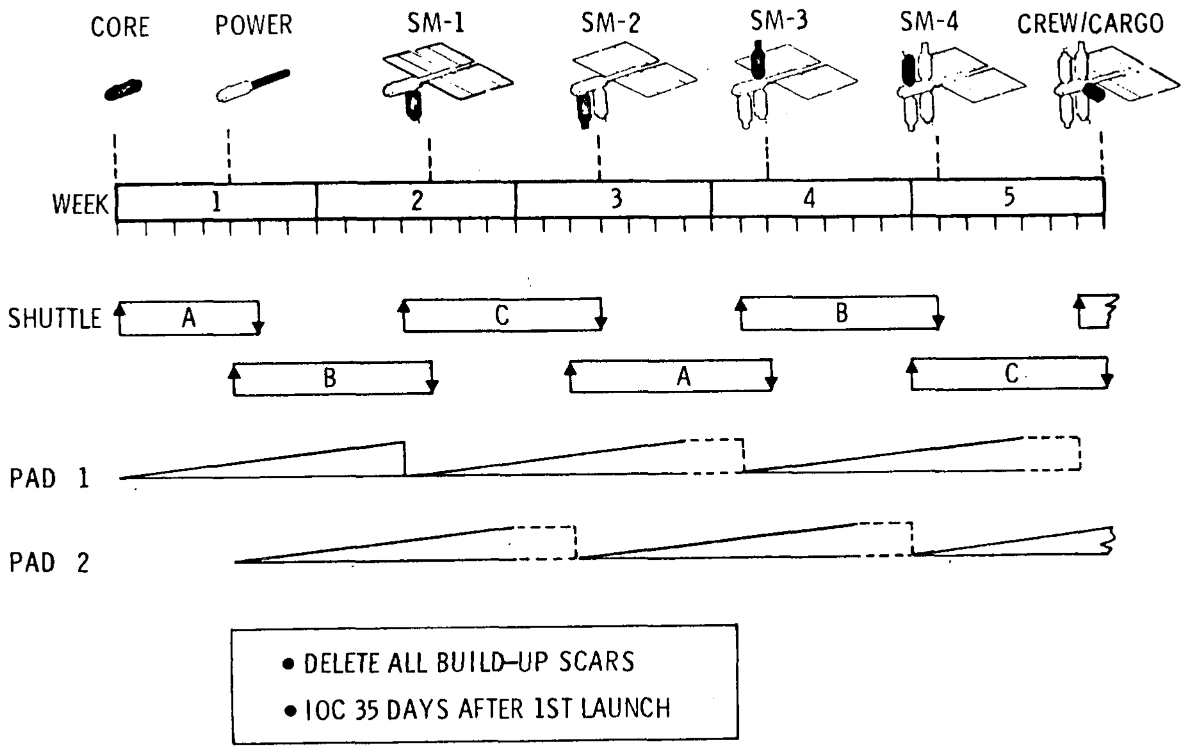


Figure 1-16. Increased Shuttle Launch Frequency—Buildup Potential

and constraint be considered in later MSS studies. The existing guideline is more than adequate for normal station operations but it could be expended to permit a maximum feasible launch rate during buildup to initial operational capability (IOC).

Orbit Makeup Requirements

Modular assembly orbital decay rates during station buildup were based on the $+2\sigma$ mean Jacchia atmosphere for July 1981. Calculations showed that, for ballistic coefficients attendant with the modular configurations during the first two months of buildup, decay rates on the order of one nautical mile per month would be realized. Therefore, to preclude orbit makeup during the first two months of station buildup, it was determined that, on the initial launch, the shuttle would place the core module in a 272-nautical-mile circular orbit. During the following quiescent period and while the core module is in a gravity gradient flight mode, the orbit would be allowed to decay.

Thirty days after the initial launch, the shuttle would deliver the power module and rendezvous with the core module at 271-nautical mile altitude. After assembly, the power module solar array would be left in the retracted position. The core module/power module (CM/PM) cluster would then be left in a gravity gradient flight mode, and the orbit would be allowed to decay during the second quiescent phase.

Sixty days after core module insertion into orbit, the shuttle would deliver SM-1 and rendezvous with the CM/PM assembly at 270-nautical-mile altitude. After attachment of SM-1 to the modular assembly, the ISS would be activated and the solar array panels would be deployed 25 percent. The cluster would then fly a minimum propellant flight mode—principal-axis orientation—during the subsequent quiescent phases during buildup.

Orbit makeup is to be performed during quiescent phases together with control moment gyro (CMG) desaturation. Table 1-2 lists the estimated impulse budget required during the buildup sequence and includes the impulse required to orient and stabilize the cluster for shuttle rendezvous, damping of separation transients, and phases after delivery of SM-1 (with orbit makeup-CMG desaturation).

Table 1-2. Impulse Budget for Buildup Sequence

Period	Description	Requirement (lb-sec)
First 30 days	Core module	2,400
Second 30 days	Core module and power module No array deployment	10,200
Third 30 days	CM + PM + SM-1 25 percent array deployment	16,900
Fourth 30 days	CM + PM + SM-1 + SM-2 25 percent array deployment	22,000
Fifth 30 days	CM + PM + SM-1 + SM-2 + SM-3 25 percent array deployment	27,000
Sixth 30 days	CM + PM + SM-1 + SM-2 + SM-3 + SM-4 25 percent array deployment	31,550

Consumable Requirements

The consumable requirements for the buildup operations are dictated by the number and level of space station subsystem activations. Basic considerations include the consumption of oxygen and hydrogen for fuel cell and RCS operations. The rates at which these consumables are required are established by the power requirements and the attitude stabilization and orbit makeup requirements.

During the first two months of station buildup, the module assembly electrical power is supplied by fuel cells in the core module. During this phase, the fuel cells and RCS operating open loop with high-pressure gaseous oxygen and hydrogen. The fuel cells provide an average usable power of 425 watts and generate approximately 572 pounds of water during the 60 days. This water is stored in tanks in the core module to be used, after the delivery of SM-1 and solar array deployment, as a source for electrolysis to produce gaseous oxygen and hydrogen for the RCS and for fuel cell secondary power operation. The RCS for the first two months requires approximately 4.3 pounds of hydrogen and 35.2 pounds of oxygen. In summary, the EPS and RCS combined require 611 pounds of high-pressure gaseous oxygen and hydrogen for the first two months of operation.

As shown in Table 1-3, high-pressure gas (oxygen and hydrogen) is delivered as follows: 375 pounds in tanks in the core module on the initial launch; and another 307 pounds in tanks in the power module on the second launch. The high-pressure gas delivered in the first two modules meets consumable requirements for the first two months and provides an additional 70 pounds of reactants. The additional 70 pounds of high-pressure gases arise from meeting the three-out-of-four tank redundancy criteria during buildup.

With delivery and assembly of SM-1 into the modular assembly, the solar arrays are partially deployed and become the primary source of electrical power. At this time, the electrolysis unit is activated, the fuel cells begin operating closed loop, and the RCS is provided gaseous oxygen and hydrogen from the electrolysis unit. Figure 1-17 shows the water generation and usage by the EPS and RCS during buildup. The fuel cells generate 572 pounds of water during the first 60 days. Following delivery of SM-1, the electrolysis unit converts water from the storage tank into gaseous oxygen and hydrogen for the RCS. During this period, the RCS requires 304 pounds of water, which leaves a residual supply of approximately 276 pounds with the arrival of the first crew and cargo module. However, only 196 pounds of this residual supply can be assigned to future RCS consumption since the 24-hour cycle of the fuel cell energy storage system requires 80 pounds of water, the redline value shown in the figure.

Table 1-3. Operational Weight Summary

	CORE	POWER	SM-1	SM-2	SM-3	SM-4	TOTAL
SERVICE FLUIDS & GASES							
REPRESS O_2		194					194
REPRESS N_2		381					381
LAUNCH ATMOSPHERE	285	74	322	322	322	322	1647
ELECTROLYSIS ACCUM. H_2O				50	50		100
INTERNAL THERMAL LOOP H_2O	148		199	98	98	199	742
EXTERNAL THERMAL LOOP FREON	191		604	223	223	604	1845
WATER MANAGEMENT LOOP H_2O	5		6	6	6	6	29
EPS & RCS BUILDUP O_2	333	273					606
EPS & RCS BUILDUP H_2	42	34					76
TOTAL	1004	956	1131	699	699	1131	5620
EXPERIMENT EQUIPMENT							
P-2 PLASMA PHY & ENVIR PORT					1003		1003
P-4 PHYSICS & CHEMICAL FACILITY					866		866
T-1 CONTAMINATION MEASUREMENT				807			807
TOTAL	0	0	0	807	1869		2676
LOGISTICS ITEMS							
POTABLE H_2O						400	400
96-HR EMERGENCY LiOH				112	112		224
MED. & PHARM SUPPLIES						110	110
P-2, P-4, T-1 EXP CONSUM				302			302
TOTAL	0	0	0	414	112	510	1036
SHUTTLE TARIFF							
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 O_2/N_2	0	165	180	210	210	210	
SHUTTLE EPS REACTANTS	50	365	495	383	383	405	
Δ TANK WEIGHT	97	425	425	425	425	425	
MSS/SHUTTLE ADAPTER		600					
TOTAL	1264	2764	2344	2232	2232	2260	

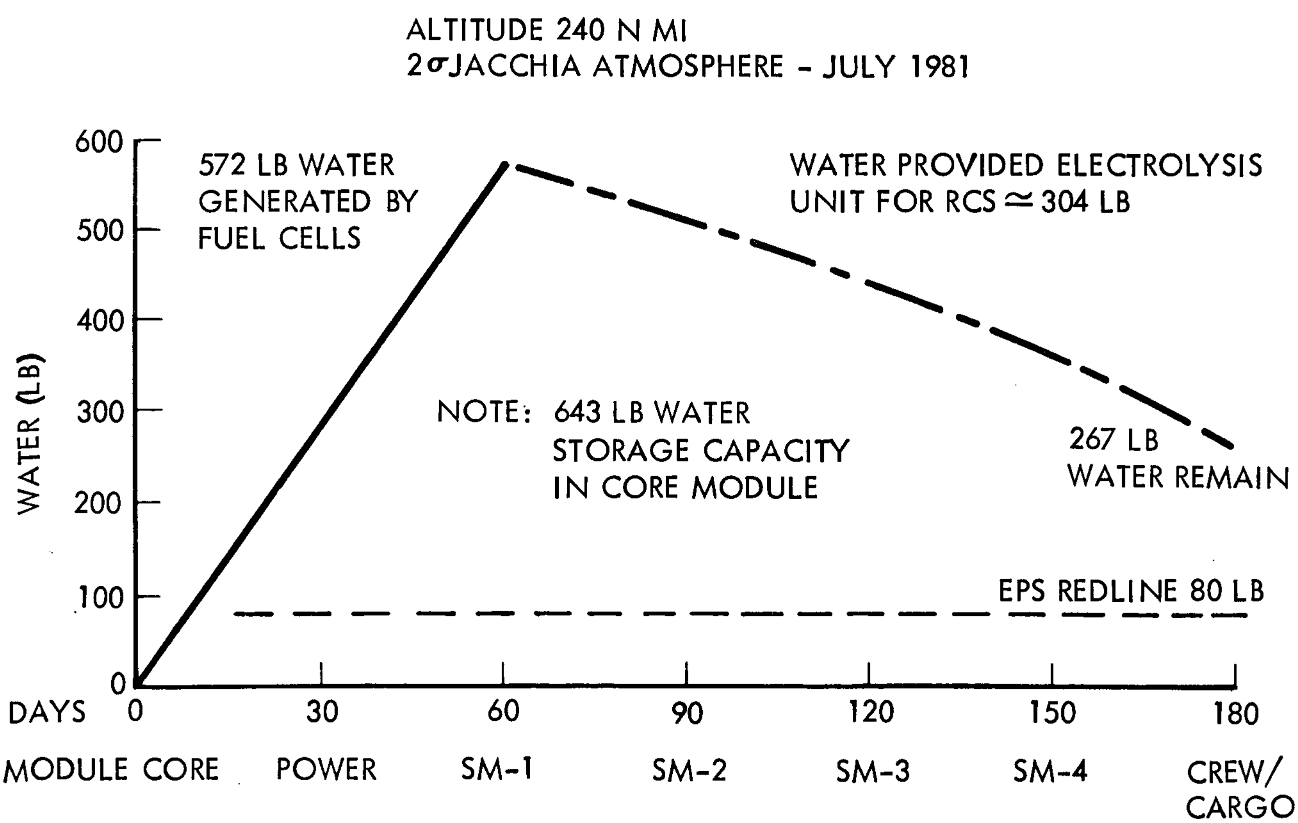


Figure 1-17. Water Generation and Usage During Buildup

Another requirement for consumables during station buildup is attributed to environmental control and life support. The operational concept calls for the repressurization of each module or combination of modules at each step of buildup to a pressure of 14.7 psia. In addition, leakage makeup and station assembly crew consumption gaseous requirements for a maximum five-day shuttle stay must be provided. The quantities of gases estimated to meet these requirements are shown in Table 1-4.

Table 1-4. ECLSS Consumable Requirements for Buildup

Configuration for Leakage Consideration	Initial Leak Rate (lb/day O_2/N_2)	Pressure at 30 Days (psia)	Repressurization to 14.7-Psia Qty (lb)	Five-Day Leakage (lb O_2/N_2)	Two-Man Crew Five Days (lb O_2)	Gas Total (lb O_2/N_2)
Core	5.5	8.0	134	27	18.4	179.4
Core, power	5.5	8.0	134	27	18.4	179.4
Core, SM-1	6.0	11.2	145	30	18.4	200.4
Core, SM-1, SM-2	6.5	12.5	197	32	18.4	247.4
Core, SM-1, SM-2, SM-3	7.0	13.0	193	35	18.4	246.4

From Table 1-4, it can be seen that approximately 1053 pounds of oxygen and nitrogen are required during buildup. In Table 1-3, the delivery of these consumables is accounted for under "Shuttle Tariff." The two-man crew five-day oxygen requirements make up part of the "Crew Provisions" weights for the assembly crew. Because the shuttle tank size limits the delivery of makeup gases to 210 pounds per launch, the higher requirements on the last two launches are delivered with SM-1 and SM-2. The modular assembly is repressurized slightly above 14.7 psia on these launches, which reduces the repressurization requirements on the SM-3 and SM-4 launches.

1.1.3 SEQUENCE OF OPERATIONS

Throughout the analyses of the buildup alternatives, operational analyses were conducted to ensure the operational viability of the buildup alternatives. These analyses were conducted to an increasing level of definition until the final buildup alternative was selected and the resultant operational sequences were defined. This section presents the sequence of operations required for buildup of the selected modular space station configuration.

The initial space station buildup phase begins with the shuttle launch and delivery to orbit of the first module and is completed when the space station is first fully activated and manned by the initial six-man crew. The sequence of operations for buildup of the initial space station consists of the seven steps summarized in Figure 1-18 and presented in the buildup operational timelines in Table 1-5. Since the assembly period is constrained by the shuttle launch frequency of one every 30 days, the overall buildup time associated with the selected sequence requires at least 180 days. Should a shuttle miss a scheduled launch at any time during the buildup sequence, the assembly period could increase to 210 days.

On Day 0, the initial module (core module) is delivered to orbit by the shuttle. It takes approximately four hours from launch for shuttle ascent to the operational altitude. Upon reaching the desired altitude, the core module is manually activated in the shuttle cargo bay. Access is obtained via a transition tunnel from the shuttle to the core module +X berthing port. This activation includes energizing power buses, activating fuel cells, and verifying ISS operation, ECS coolant loop operation, communications, IMU operations, and control functions. After the operational integrity of the core module subsystems has been verified, the electrical and communications hardline interfaces between the module and the shuttle are disconnected. The core module is then deployed out of the cargo bay by the shuttle manipulator and positioned for final operational verification before release.

After the core module has been deployed, the special two-man crew aboard the shuttle conducts by RF link a rendezvous aid check of the module, activates the core module RCS, and then releases the module. After separation, the core module RCS will damp the separation transients and, upon commands from the module IMU, stabilize the module in a gravity gradient attitude. Upon completion of these maneuvers, the shuttle crew prepares the core module for its quiescent operational mode. This preparation includes shutting down the G&C subsystem and RCS by remote RF commands. This mode is maintained until the module is awakened, and its subsystems are activated before the next module delivery. After the final operational status of the core module is verified, the shuttle remains on-orbit and stationkeeps in the vicinity of the core module for at least one day before returning to earth. This period enables the crew to visually observe and verify the attitude stability of the core module.

The module is left in a nominally quiescent state for the next 27 days. During this period, status data are transmitted upon ground command.

On Day 30, the power module is launched. Before launch, ground stations remotely verify, on a day-to-day schedule, the operational integrity of the operating core module subsystems. The time required from launch until the shuttle accomplishes on-orbit rendezvous with the core module can

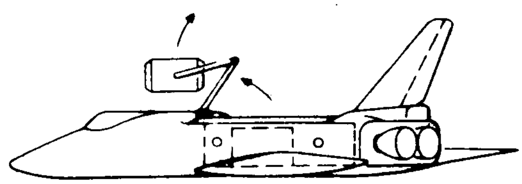
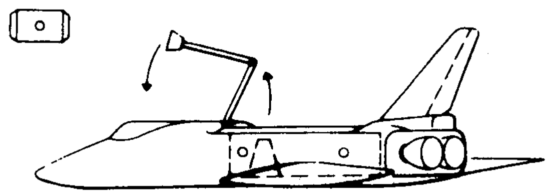
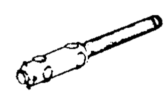
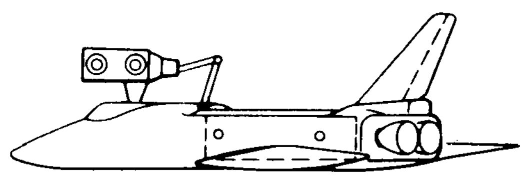
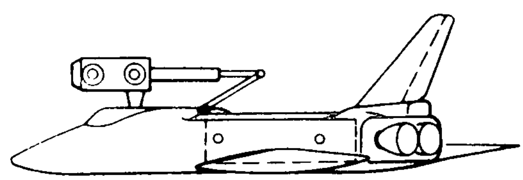
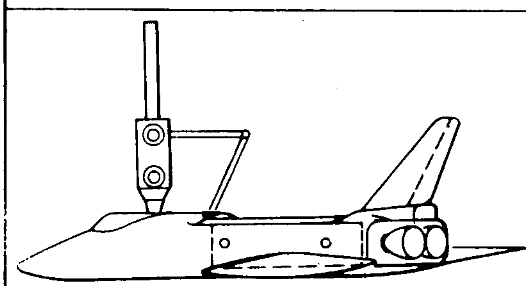
MODULE DELIVERED	PRINCIPAL OPERATIONS		ORBITAL CONFIGURATION
CORE		• ACTIVATE • CHECKOUT • DEPLOY	 CORE
POWER		• REMOVE ADAPTER FROM SHUTTLE CARGO BAY AND BERTH ADAPTER TO SHUTTLE INGRESS/ EGRESS PORT	 POWER
		• ATTACH MANIPULATOR TO CORE MODULE AND BERTH TO ADAPTER	
		• REMOVE POWER MODULE AND BERTH TO CORE MODULE	
		• REBERTH CORE AND POWER MODULE CLUSTER TO ADAPTER AT -X AXIS BERTHING PORT. • DEPLOY MODULE CLUSTER	

Figure 1-18. Initial Space Station Buildup Sequence
(Sheet 1 of 2)

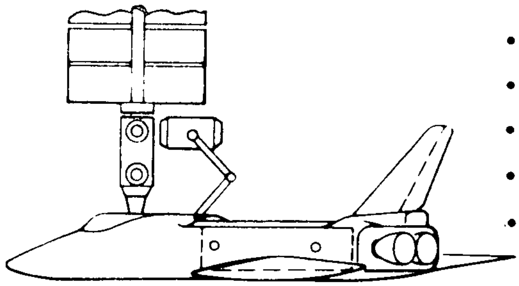
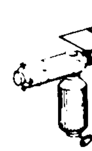
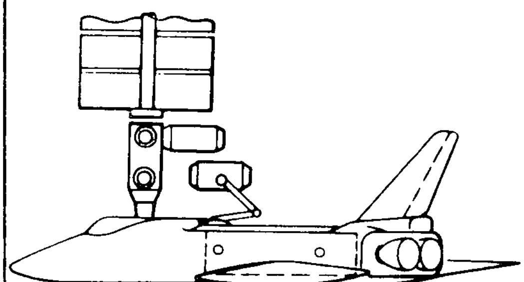
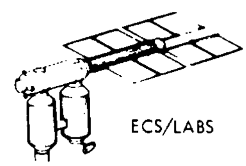
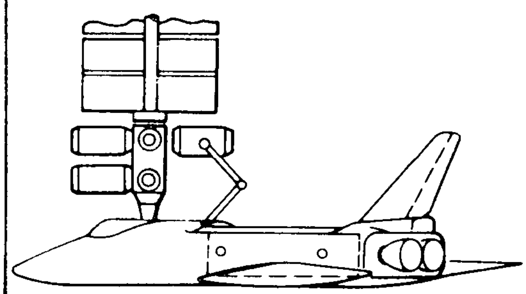
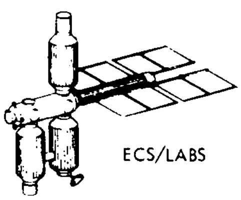
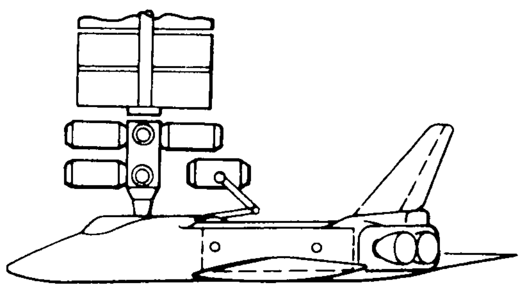
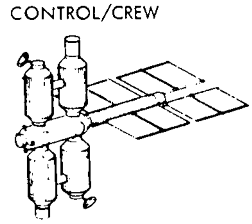
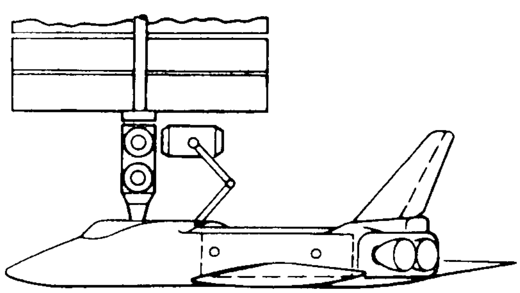
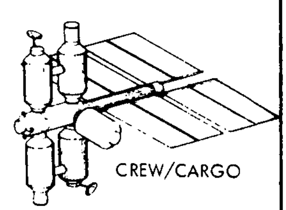
MODULE DELIVERED	PRINCIPAL OPERATIONS		RESULTANT CONFIGURATION
SM-1 (CONTROL/ CREW)		• BERTH CORE AND POWER MODULE CLUSTER TO SHUTTLE • REMOVE SM-1 AND BERTH TO CORE MODULE • PARTIALLY ACTIVATE SM-1 • PARTIALLY DEPLOY SOLAR ARRAY (25%) • DEPLOY MODULE CLUSTER	 CONTROL/CREW
SM-2 (ECS/LABS)		• BERTH MODULE CLUSTER • REMOVE SM-2 AND BERTH TO CORE MODULE • PARTIALLY ACTIVATE SM-2 • DEPLOY MODULE CLUSTER	 ECS/LABS
SM-3 (ECS/LABS)		• BERTH MODULE CLUSTER • REMOVE SM-3 AND BERTH TO CORE MODULE • PARTIALLY ACTIVATE SM-3 • DEPLOY MODULE CLUSTER	 ECS/LABS
SM-4 (CREW/ CONTROL)		• BERTH MODULE CLUSTER • REMOVE SM-4 AND BERTH TO CORE MODULE • PARTIALLY ACTIVATE SM-4 • DEPLOY MODULE CLUSTER	CONTROL/CREW 
CARGO MODULE		• BERTH MODULE CLUSTER • FULLY DEPLOY SOLAR ARRAYS • REMOVE CARGO MODULE AND BERTH TO CORE MODULE • FULLY ACTIVATE INITIAL SPACE STATION • DEPLOY INITIAL SPACE STATION • COMMENCE ROUTINE SPACE STATION OPERATIONS	 CREW/CARGO

Figure 1-18. Initial Space Station Buildup Sequence (Sheet 2 of 2)

Table 1-5. Modular Space Station Buildup Operations Timeline
(Core Module Delivery)

Operation	Phase Time, Hours	Cumulative Time to Complete, Days + Hours
ASCENT TO ORBIT Altitude = 272 NM Inclination = 55 degrees . Open cargo bay doors at h = 50 NM . Crew monitors payload status through hardline interfaces	4	0+4
ON ORBIT CHECKOUT OF CORE MODULE IN CARGO BAY . Crew ingress core module in shirtsleeves through shuttle/core access tunnel . Activate core module electrical power . Verify ISS operations . Verify coolant loop operations . Verify communication operations . Verify IMU operations . Verify attitude control functions . Crew egress core module, secure hatch	8	0+12
CREW REST PERIOD . Sleep, 2 meals, personal hygiene	12	1+0
DEPLOY CORE MODULE WITH SHUTTLE MANIPULATOR . Manually disconnect shuttle/core interface lines . Deploy both manipulators (operated from shuttle control station) . Engage core module with manipulator . Lift and deploy core module from cargo bay	4	1+4
CREW REST PERIOD . 1 meal, personal hygiene	2	1+6
VERIFY CORE MODULE OPERATIONS BY SHUTTLE RF LINK . Enable G&C and RCS quads . Verify RCS operations . Verify rendezvous aids (lights and transponder)	1	1+7

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(Core Module Delivery)

Operation	Phase Time, Hours	Cumulative Time to Complete, Days + Hours
SHUTTLE/CORE MODULE SEPARATION . Manipulator release of core module in gravity gradient orientation (during sunlight) . Stow manipulators in cargo bay . Move shuttle to stationkeeping position for observation of core module by shuttle crew	1	1+8
PREPARE CORE MODULE FOR QUIESCENT OPERATIONS USING SHUTTLE RF LINK . Shutdown core module RCS . Shutdown G&C . Shutdown rendezvous aids when not observing core module . Verify stability of core module in gravity gradient mode (during sunlight periods)	4	1+12
CREW REST PERIOD . Sleep, 2 meals, personal hygiene	12	2+0
VERIFY CORE STABILITY & STATUS . Obtain core module subsystem status check by RF link . Intermittent observation of core module stability (during sunlight periods)	8	2+8
SHUTTLE DEORBIT & LANDING	4 to 26 (max)	3+10 (max)

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(Power Boom Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete, Days + Hours
ASCENT TO ORBIT Altitude = 271 NM Inclination = 55 degrees . Orbit Insertion, open cargo bay doors at h = 50 NM . Crew monitors payload status through hardline interfaces to shuttle . Phasing orbit insertion maneuver . Height adjustment maneuver . Coelliptic maneuver, h = 260 NM	4 to 26 (max)	31+2 (max)
ACTIVATE CORE MODULE . Activate G&C, RCS, and rendezvous aids by RF link . Command core module to assume X-POP inertial attitude for berthing . Shuttle terminal phase initiation . Shuttle terminal phase final . Shuttle stationkeep with core module	1	31+3
CORE MODULE BERTHING . Deploy both manipulators (operated from shuttle control station) . Engage shuttle/station adapter in cargo module with manipulator (during sunlight) . Deploy and berth adapter to shuttle crew ingress/egress port with manipulator (during sunlight) . Shuttle close distance to 30 feet from core module . Engage core module with manipulator (during sunlight) . Inhibit core module RCS by RF command . Berth core module to shuttle/station adapter (see Figure 1-19) (during sunlight)	3	31+6
CREW REST PERIOD . 1 meal, personal hygiene	2	31+8

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(Power Boom Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete, Days + Hours
CORE/POWER MODULE ASSEMBLY . Manually assembly core module/adapter/ shuttle interface lines (electrical power, communications, atmospheric ventilation) . Verify core module habitability . Crew ingress core module (shirtsleeves) . Crew retract forward RCS quads on core (to permit adequate clearance for berthing) . Check TV alignment and other berthing aids at core module +X axis port . Crew egress core into shuttle . Crew manually uncouples shuttle/power module interfaces at cargo bay . Engage power module with manipulator . Lift and deploy power module from cargo bay with manipulator . Berth power module to core module +X axis berthing port (during sunlight) . Verify hard berth through hardline communication interface	6	31+14
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	32+2
CORE/POWER MODULE INTERFACE ASSEMBLY . Crew ingress core module (shirtsleeves) . Crew pressurize power/core interface volume (using pressure equalization valve in core module hatch) and open core module +X hatch . Crew manually connects and verifies power/core module interface lines 2 H_2 lines and barriers 2 O_2 lines and barriers 1 N_2 line and barrier 1 Air line and barrier 12 Power terminals 2 Data bus terminals 2 Air ducts . Crew activates all interface lines	5	32+7

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(Power Boom Delivery and Assembly) (Cont)

Operations	Phase Time, Hours	Cumulative Time to Complete, Days + Hours
CREW REST PERIOD . 1 meal, personal hygiene	2	32+9
PREPARE CORE/POWER MODULE FOR QUIESCENT OPERATIONS . Crew extends forward RCS quads on core to normal operating positions . Verify flow of $H_2/O_2/N_2$ from power module tanks to EPS and RCS subsystems in core . Crew closes core module +X berthing port hatch . Crew installs TV camera at SM-1 berthing port hatch . Crew configures core subsystems for quiescent operations and egresses core module to shuttle/station adapter . Crew retracts aft RCS quads on core (to permit adequate clearance when berthing core to adapter) . Disengage manipulator from power module and engage core module manipulator socket (during sunlight) . Crew closes core module hatch and disconnects core/adapter interface lines . Crew ingresses shuttle and closes shuttle hatch	5	32+14
CREW REST PERIOD . 2 meals, sleep, personal hygiene, etc.	12	33+2
RECONFIGURE CORE/POWER/ADAPTER CONFIGURATION . Manipulator unberths core/power module configuration from adapter . Manipulator reberths core/power module configuration at -X axis berthing port to adapter (during sunlight) . Crew verifies hard berth by hardline signal to shuttle . Crew pressurizes adapter from shuttle . Crew enters adapter and connects all adapter/core module interface lines . Crew ingresses station and extends aft RCS quads on core to normal operating position . Crew egresses station and closes station hatch	5	33+7

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(Power Boom Delivery and Assembly)

Operations	Phase Time, Hours	Cumulative Time to Complete, Days + Hours
CREW REST PERIOD . 1 meal, personal hygiene	2	33+9
POWER/CORE/ADAPTER DEPLOYMENT . Crew disconnects adapter/shuttle interface lines . Enable and verify G&C, RCS quads, and rendezvous aids by RF link . Manipulator deploys station configur-tion to gravity gradient orientation and releases configuration (during sunlight) . Stow manipulators in cargo bay . Move shuttle to stationkeeping position to observe stability of configuration by shuttle crew . Command power/core module quiescent operations (shutdown G&C, RCS)	5	33+14
CREW REST PERIOD . Sleep, 2 meals, personal hygiene	12	34+2
VERIFY CORE STABILITY AND STATUS . Obtain power/core module subsystem status check by RF link . Intermittent observation of power/ core module stability (during orbit sunlight time) . Shutdown rendezvous aids when not observing core module	5	34+7
SHUTTLE DEORBIT AND LANDING	4 to 26 (max)	35+9 (max)

Table 1-5. Modular Space Station Buildup Operations Timelines (Cont)
(SM-1 Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
ASCENT TO ORBIT Altitude = 270 NM Inclination = 55 degrees . Orbit insertion, open cargo bay doors at h = 50 NM . Crew monitors SM-1 status through hardline interfaces to shuttle . Phasing orbit insertion maneuver . Height adjustment maneuver . Coelliptic maneuver, h = 260 NM	4 to 26 (max)	61+2 (max)
ACTIVATE POWER/CORE MODULE . Activate G&C, RCS and rendezvous aids by RF link . Command power/core module to assume X-POP inertial attitude for berthing . Shuttle terminal phase initiation . Shuttle terminal phase final . Shuttle stationkeep with power/core configuration	1	61+3
POWER/CORE MODULE BERTHING TO SHUTTLE . Deploy both manipulators (operated from shuttle control station) . Shuttle close distance to 30 feet from core module -X axis port with adapter (during sunlight period) . Engage adapter with manipulator . Inhibit core module RCS by RF command . Berth power/core/adapter configuration to shuttle ingress/egress port (see Figure 1-20) during sunlight period . Verify hard berth at shuttle port . Manually assemble adapter/shuttle interface lines	4	61+7
CREW REST PERIOD . 1 meal, personal hygiene	2	61+9
SM-1/CORE ASSEMBLY . Verify core module habitability . Crew ingress core module (shirtsleeves) . Check TV alignment and other berthing aids at core module forward +Z axis port	5	61+14

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-1 Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
SM-1/CORE ASSEMBLY (Cont)		
. Crew egress to shuttle		
. Manually uncouple shuttle/SM-1 interfaces at cargo bay		
. Engage SM-1 with manipulator		
. Lift and deploy SM-1 from cargo bay with manipulator		
. Berth SM-1 to core module forward +Z axis berthing port during sunlight period		
. Verify hard berth through hardline communications interface		
CREW REST PERIOD		
. 2 meals, sleep, personal hygiene	12	62+2
SM-1/CORE MODULE INTERFACE ASSEMBLY	5	62+7
. Crew ingress core module (shirtsleeves)		
. Crew pressurize SM-1/core interface volume (using pressure equalization valve in core module hatch) and open core module hatch		
. Crew equalize pressure between core and SM-1		
. Crew opens SM-1 hatch (for better access to interface connections)		
. Crew manually connects fluid lines, gas lines, and ducts and conducts pressure checks and venting of interface connectors		
4 Freon lines		
7 H_2O lines		
2 O_2 lines		
1 N_2 line		
2 H_2 lines		
1 Air line		
2 Air ducts		
. Crew egresses core module		
CREW REST PERIOD	2	62+9
. 1 meal, personal hygiene		

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-1 Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
SM-1/CORE MODULE INTERFACE (Cont) . Crew ingresses core module . Disconnect vent lines (at interface), install line barriers, and actuate deadface valves on both sides of interface . Hookup electrical connectors on both sides of interface . Perform continuity and resistance checks using portable test unit 4 power connectors 20 coax and/or twisted shielded pairs . Crew egress core module	5	62+14
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	63+2
SM-1/CORE MODULE INTERFACE ASSEMBLY (Concluded) . Crew ingress core module . Crew completes electrical hookups and continuity and resistance checks using portable test unit . Crew opens deadface switches on both sides of interface . Activate ISS and transfer control from core module to SM-1 . Crew egress SM-1 and core module	5	63+7
CREW REST PERIOD . 1 meal, personal hygiene	2	63+9
SUBSYSTEM ACTIVATION & CHECKOUT . Crew ingress core and SM-1 . Initiate active thermal control with ISS . Disconnect manipulator from SM-1 and deploy second manipulator for solar array viewing . Deploy solar arrays (25%) with ISS during sunlight period . Use both manipulators for external viewing by TV hardline display in station and shuttle	5	63+14

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-1 Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
SUBSYSTEM ACTIVATION & CHECKOUT (Cont) . Exercise solar array positioning with ISS and initiate automatic positioning during sunlight period . Transfer power from fuel cells to solar array . Activate H_2/O_2 regeneration assemblies . Activate control moment gyros . Crew egress station, monitor caution and warnings for activated subsystems in shuttle		
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	64+2
SUBSYSTEM ACTIVATION & CHECKOUT (CONCLUDED) . Crew ingress core and SM-1 . Continue subsystem checkout and subsystem monitoring functions. Adjust subsystem operation as required. . Crew egress SM-1 and core	5	64+7
CREW REST PERIOD . 1 meal, personal hygiene	2	64+9
PREPARE CONFIGURATION FOR UNMANNED OPERATIONS . Crew ingress core and SM-1 . Crew installs TV camera at rear +Z axis berthing port . Crew configures ISS for unmanned operations and transmittal of subsystem status data to ground, extinguish all unnecessary lights and other unnecessary equipment . Crew egresses core module and closes core module -X axis hatch . Attach manipulator to SM-1 socket during sunlight period . Crew disconnects shuttle/adapter interfaces and closes shuttle hatch . Crew deploys power/core/SM-1 configuration to approximate principal axis flight mode orientation	5	64+14

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-1 Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
PREPARE CONFIGURATION FOR UNMANNED OPERATIONS (Cont) . Manipulator releases configuration and both manipulators are stowed in shuttle cargo bay during sunlight period . Activate configuration RCS by RF link to damp separation transients . Shuttle moves to stationkeeping position and maintains subsystem status watch by RF link		
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	65+2
CONFIGURATION STATUS CHECKS . Crew monitors configuration performance and subsystem status	4	65+6
SHUTTLE DEORBIT AND LANDING	4 to 26 (max)	66+8 (max)

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-1 Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
ASCENT TO ORBIT Altitude = 270 NM Inclination = 55 degrees . Orbit insertion, open shuttle cargo bay doors at h = 50 NM . Shuttle crew monitors payload status through hardline interface to shuttle . Phasing orbit insertion maneuver . Coelliptic maneuver, h = 260 NM	4 to 26 (max)	91+2
ACTIVATE STATION MODULE CLUSTER . Activate G&C, RCS, and rendezvous aids by RF link . Command station module cluster to assume X-POP inertial attitude for berthing . Inhibit solar array motion by RF link . Shuttle terminal phase initiation . Shuttle terminal phase final . Shuttle stationkeep with module cluster	1	91+3
STATION MODULE CLUSTER BERTHING . Deploy both manipulators (operated from shuttle control station) . Shuttle close distance to 30 ft. from station during sunlight period . Engage adapter with manipulator during sunlight period . Inhibit RCS commands by RF link . Retrieve station and berth to shuttle ingress/egress port (station -X port) during sunlight period	3	91+6
CREW REST PERIOD . 1 meal, personal hygiene	2	91+8
SM-2/CORE MODULE ASSEMBLY . Manually assemble core module/adapter/ shuttle interface lines (communications) verify . Verify core and station module cluster habitability . Crew ingress core module (shirtsleeve) . Check TV alignment and other berthing aids at aft +Z axis port	6	91+14

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-2 ECLS/Labs Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
SM-2/CORE MODULE ASSEMBLY (Cont) . Crew egress core module to shuttle . Crew manually disconnects SM-2/ shuttle interfaces at cargo bay . Engage SM-2 with manipulator . Lift and deploy SM-2 from cargo bay with manipulator . Berth SM-2 to aft +Z berthing port during sunlight period . Verify hard berth through hardline communication interface		
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	92+2
SM-2/CORE MODULE INTERFACE ASSEMBLY . Crew ingress core module (shirtsleeve) . Crew pressurize SM-2/core module interface volume (using pressure equalization valve in core module hatch) and open core module +Z hatch . Crew verify habitability of SM-2 and equalize pressure using pressure equalization valve in SM-2 hatch . Crew open hatch in SM-2 . Crew manually connects and verifies crew module/SM-2 module interface lines: 4 Freon lines 7 H_2O lines 1 O_2 line 1 N_2 line 1 Air line 2 Air ducts 2 Electrical power connectors 16 Electrical signal feed-throughs (ECLSS, ISS, communication-audio/visual, data-digital/analog)	6	92+8
CREW REST PERIOD . 1 meal, personal hygiene	2	92+10

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-2 ECLS/Labs Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
VERIFY ELECTRICAL INTERFACE CORE/SM-2 . Verify deadface switch positions . Hook up test unit to deadface switch test points . Perform continuity and resistance checks . Disconnect test unit . Open deadface switches	6	92+16
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	93+4
SM-1/SM-2 FLEXPORT INSTALLATION . Crewman stationed at SM-1 flexport receiving port window . Crewman unlatches flexport in SM-2 -- (flexport extends and self-centers in SM-1 flexport ring) . Flexport latched and sealed to SM-1 (hard latched) . Pressurize flexport using equalization valve in SM-1 flexport hatch . Verify pressure seals and ability to hold pressure in flexport (pressure decay time) . Open flexport hatches SM-1 and SM-2 . Crew visually checks flexport full installation . Flexport hatches placed in normal operational position (closed)	4	93+8
CREW REST PERIOD . 1 meal, personal hygiene	2	93+10
PREPARE STATION MODULE CLUSTER FOR QUIESCENT OPERATIONS . Crew installs TV camera in -Z forward berthing port . Crew configures subsystems for quiescent operations and egresses core module to shuttle/station adapter . Crew closes core module hatch and disconnects adapter/shuttle interface lines . Enable and verify G&C, RCS quads, and rendezvous aids by RF link	6	93+16

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-2 ECLS/Labs Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
PREPARE STATION MODULE CLUSTER FOR QUIESCENT OPERATIONS (Cont) . Manipulator deploys station (by SM-2) to principal axis orientation mode and releases cluster during sunlight period . Stow manipulators in cargo bay . Move shuttle to stationkeeping position to observe stability of cluster by shuttle crew . Enable solar array motion by RF link . Command station module cluster quiescent operations (shutdown G&C, RCS)		
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	94+4
VERIFY STATION MODULE CLUSTER STABILITY AND STATUS . Obtain cluster status check by RF link . Intermittent observation of cluster stability during sunlight periods . Shutdown rendezvous aids when not observing cluster	4	94+8
SHUTTLE DEORBIT AND LANDING	4 to 26 (max)	95+10 (max)

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-3 Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
ASCENT TO ORBIT	4 to 26 (max)	121+2 (max)
Same assembly sequence of operations as SM-2 except flexport assembly is deleted.	74	124+4
SHUTTLE DEORBIT AND LANDING	4 to 26 (max)	125+6 (max)

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(SM-4 Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
ASCENT TO ORBIT	4 to 26 (max)	151+2 (max)
Same assembly sequence of operations as SM-2 with flexport assembly included. Interface hookups are similar to that for SM-1 as well as second control center activation and checkout.	100	155+6
SHUTTLE DEORBIT AND LANDING	4 to 26 (max)	156+8 (max)

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(Cargo Module Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
ASCENT TO ORBIT Altitude = 270 NM Inclination = 55 degrees . Orbit insertion, open shuttle cargo bay doors at h = 50 nm . Crew monitors payload status through hardline interfaces to shuttle . Phasing orbit insertion maneuver . Coelliptic maneuver, h = 260 NM	4 to 26 (max)	181+2 (max)
ACTIVATE STATION (PARTIAL) . Activate G&C, RCS, and rendezvous aids by RF link . Command station to X-POP inertial attitude for berthing . Inhibit solar array motion by RF link . Shuttle terminal phase initiation . Shuttle terminal phase final . Shuttle stationkeep with station	1	181+3
STATION BERTHING . Deploy both manipulators (operated from shuttle control station) . Shuttle close distance to 30 ft. from station . Engage core module with manipulator during sunlight period . Inhibit RCS command by RF link . Retrieve station and berth to shuttle ingress/egress port during sunlight period . Status cargo module	3	181+6
CREW REST PERIOD . 1 meal, personal hygiene	2	181+8
STATION ACTIVATION (FINAL) . Manually assembly core module/adapter/shuttle interfaces (ISS bus, communications) -- verify . Verify habitability of station . Crew ingress station (core module) shirtsleeve . Activate remaining ECLSS: - CO_2 management; full atmospheric control; water management; waste management; hygiene	6	181+14

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(Cargo Module Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
STATION ACTIVATION (FINAL) (Cont) . Deploy manipulators for solar array deployment viewing by TV . Deploy solar arrays completely during sunlight period . Status cargo module		
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	182+2
STATION VERIFICATION . Verify control of all subsystems from both control stations	5	182+7
CREW REST PERIOD . 1 meal, personal hygiene	2	182+9
DEPLOY AND BERTH CARGO MODULE . Verify cargo module status . Remove berthing port environmental cover (+Y forward port) . Install TV camera at +Y forward port . Check TV alignment and other berthing aids . Disconnect cargo module/shuttle interfaces . Engage cargo module (in shuttle bay) with manipulator . Lift and deploy cargo module from cargo bay with manipulator . Berth cargo module to +Y forward port during sunlight period . Verify hard berth through hardline communications	5	182+14
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	183+2
CARGO MODULE INTERFACE ASSEMBLY . Equalize pressure - cargo module to station (using pressure equalization valve in core module hatch) . Open core module +Y forward hatch . Crew manually connects and verifies cargo/core module interface lines:	6	183+8

Table 1-5. Modular Space Station Buildup Operations Timeline (Cont)
(Cargo Module Delivery and Assembly)

Operation	Phase Time, Hours	Cumulative Time to Complete Days + Hours
CARGO MODULE INTERFACE ASSEMBLY (Cont) 7 H_2O lines 1 O_2 line 1 N_2 line 1 H_2 line 1 Air line 2 Air ducts 2 Electrical power connectors 12 Electrical signal feed-throughs (ECLSS, ISS, communications-audio/visual) . Shuttle crew disengage manipulator from cargo module and stow		
CREW REST PERIOD . 1 meal, personal hygiene	2	183+10
VERIFY ELECTRICAL INTERFACE C/CM . Verify deadface switch positions . Hook up test unit to deadface switch test points . Perform continuity and resistance checks . Disconnect test unit . Open deadface switches	5	183+15
CREW REST PERIOD . 2 meals, sleep, personal hygiene	12	184+3
INITIATE NORMAL STATION OPERATIONS		
SHUTTLE DEORBIT AND LAND	4 to 26 (max)	185+5

vary from 4 to 26 hours since phasing is required between the shuttle and core module. Activation of the core module RCS, G&C subsystem, and rendezvous aids by shuttle RF link occur approximately 90 minutes before the final phase of rendezvous. After the shuttle rendezvous with the core module, the shuttle/MSS adapter is disconnected from the cargo bay mounts and, by using the shuttle manipulator, deployed and berthed to the passenger docking port on the shuttle. The shuttle crew then commands by RF link the core module to maintain a stable initial attitude preparatory to retrieval and berthing. The shuttle then closes with the core module; the shuttle manipulator attaches to the core module; the module and G&C subsystem RCS are deactivated by RF commands; and the module is berthed to the adapter.

The core module docking port used is on the +Z axis nearest the power module/core module interface. Further, the core module is berthed so that its longitudinal axis is rotated 45 degrees relative to the shuttle longitudinal axis as shown in Figure 1-19. This unique berthing orientation is used to minimize manipulator reach requirements during berthing of the power module to the core module. After the core module has been berthed to the adapter, the shuttle/adapter/core module interfaces are manually connected, and the core module environment is verified for shirtsleeve entry. The power module is disconnected from the shuttle cargo bay, deployed, and berthed to the +X axis port on the core module by the shuttle manipulator.

The special crew (two men) enters the core module, manually connects and verifies the power module/core module interfaces and configures the assembly for detached operations (power module subsystems are not activated at this time). The special crew returns to the shuttle, and the interfaces between the adapter and core module are disconnected. The shuttle manipulators are then used to detach the core module from the adapter. The core module and power module cluster is then rotated and reberthed to the adapter at the core module -X axis port. The adapter on the -X axis port of the core module remains on-orbit with the cluster. It is the designated shuttle/modular cluster berthing interface (S/MCBI) for the remainder of the buildup operations as well as for subsequent routine operations.

After the adapter-to-core module interface is connected and verified, the adapter/core module/power module cluster is manually disconnected from the shuttle and positioned for final operational verification before release. Through RF links, the special crew conducts final checkout and activates the core module subsystems, and the modular cluster is released in the gravity gradient attitude. Autonomously the separation transients are dampened, and the gravity gradient attitude mode is stabilized by the core module subsystems. The cluster is then configured for quiescent operations, and its subsystem operational status is verified using RF by the shuttle crew before departure and earth return. This mode is maintained until the

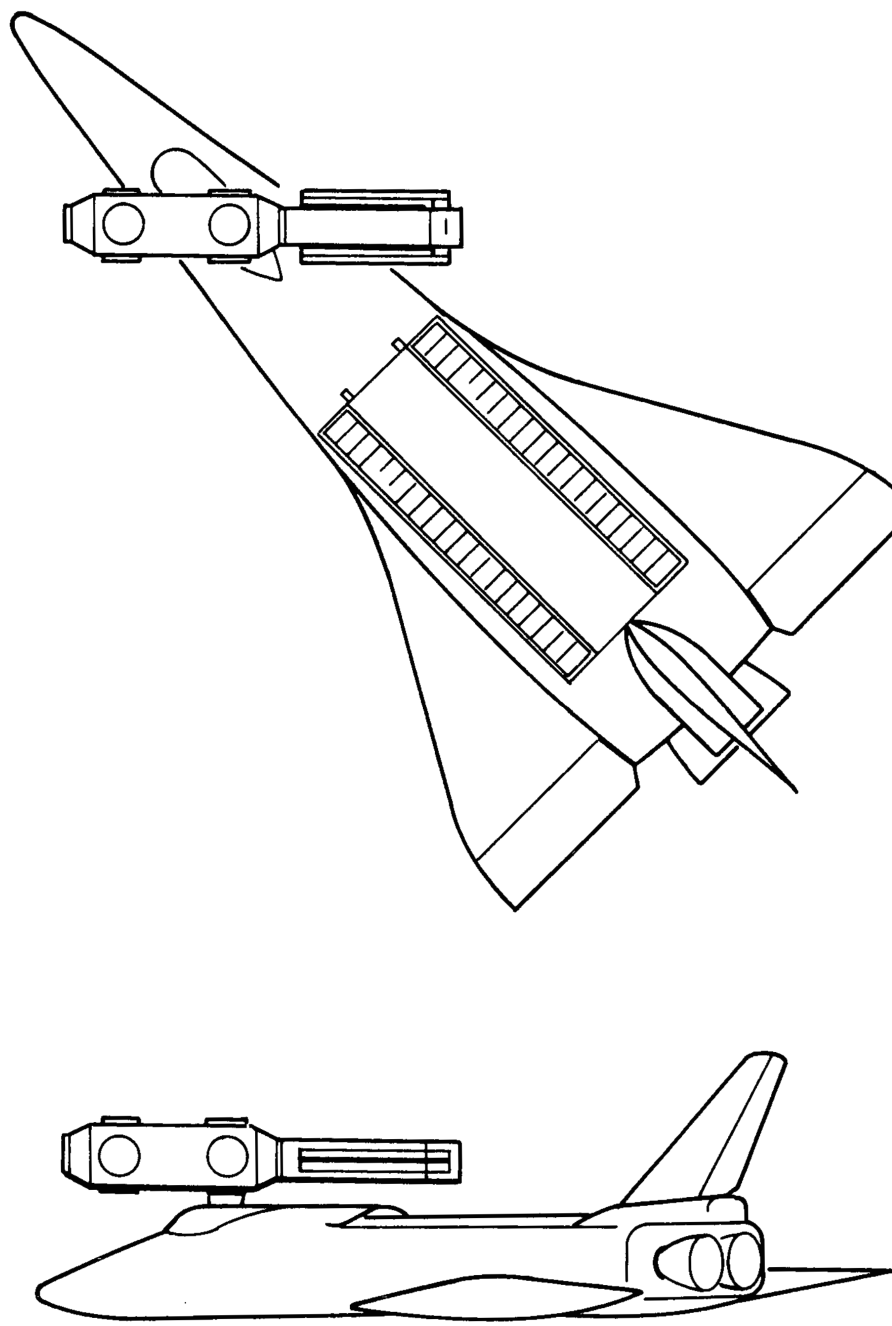


Figure 1-19. Power Module Berthing

modular cluster is awakened, and its subsystems are activated before the next module delivery, approximately 26 days later.

Sixty days after the core module is launched, the third module, SM-1, is launched. Since phasing is required, the elapsed ascent time from launch to rendezvous can vary from 4 to 26 hours. The sequence of operations for delivery of SM-1 is summarized in Figure 1-20. (This sequence is representative of the operations required during the delivery of all subsequent station modules.) After the shuttle accomplishes rendezvous, the CM/PM cluster is commanded to stabilize and maintain attitude and is configured for berthing by RF commands from the shuttle by the special crew. The shuttle then closes with the modular cluster and the CM/PM cluster is retrieved by the shuttle manipulator. The core module RCS is deactivated, and the cluster is berthed to the shuttle passenger berthing port.

For all station module, cargo module, and RAM deliveries to the initial station, the berthed orientation of the core module Y and Z axes is skewed 45 degrees with respect to the longitudinal axis of the shuttle as shown in Figure 1-21. This berthing orientation is used to minimize manipulator reach requirements during berthing or unberthing of modules as well as to provide manipulator arm (and elbow) clearance in removal and replacement of modules in the cargo bay.

The modular cluster/shuttle interfaces are manually connected and verified, and the CM/PM habitable environment is established. The special crew then enters the berthed cluster (in shirtsleeves) and configures it for SM-1 attachment to the forward +Z axis port on the CM by uncovering the berthing port and checking the television camera and alignment. After crew egress from the CM, SM-1 interfaces are disconnected from the shuttle. The module is lifted out of the cargo bay and berthed to the designated port on the CM by the shuttle manipulator. The special crew enters the CM; the CM/SM-1 electrical and fluid interface connections are manually assembled; and a habitable environment is established and verified in SM-1. The crew enters SM-1, and the control center is activated for modular cluster subsystem integration and checkout with the ISS. The primary power buses are engaged; the solar array panels are deployed 25 percent and their operation and electrical power output (4.87 kw) are verified. Primary power is then transferred from fuel cells to solar array. The electrolysis units for the RCS and fuel cells are activated, and the cluster subsystems operation is checked out. The modular cluster is then configured for free flight; the shuttle/cluster interfaces are disconnected; and the cluster is deployed and positioned for release by the shuttle manipulator. A final operability check on the modular cluster subsystems is performed by RF link; the RCS is enabled; the solar array panels are uninhibited; and the cluster is released. Separation transients are dampened, and a principal-axis attitude flight mode is accomplished autonomously by the modular cluster. The principal-axis attitude is maintained for 25 days until the next shuttle visit when the module is commanded by RF link to fly an XPOP inertial attitude before

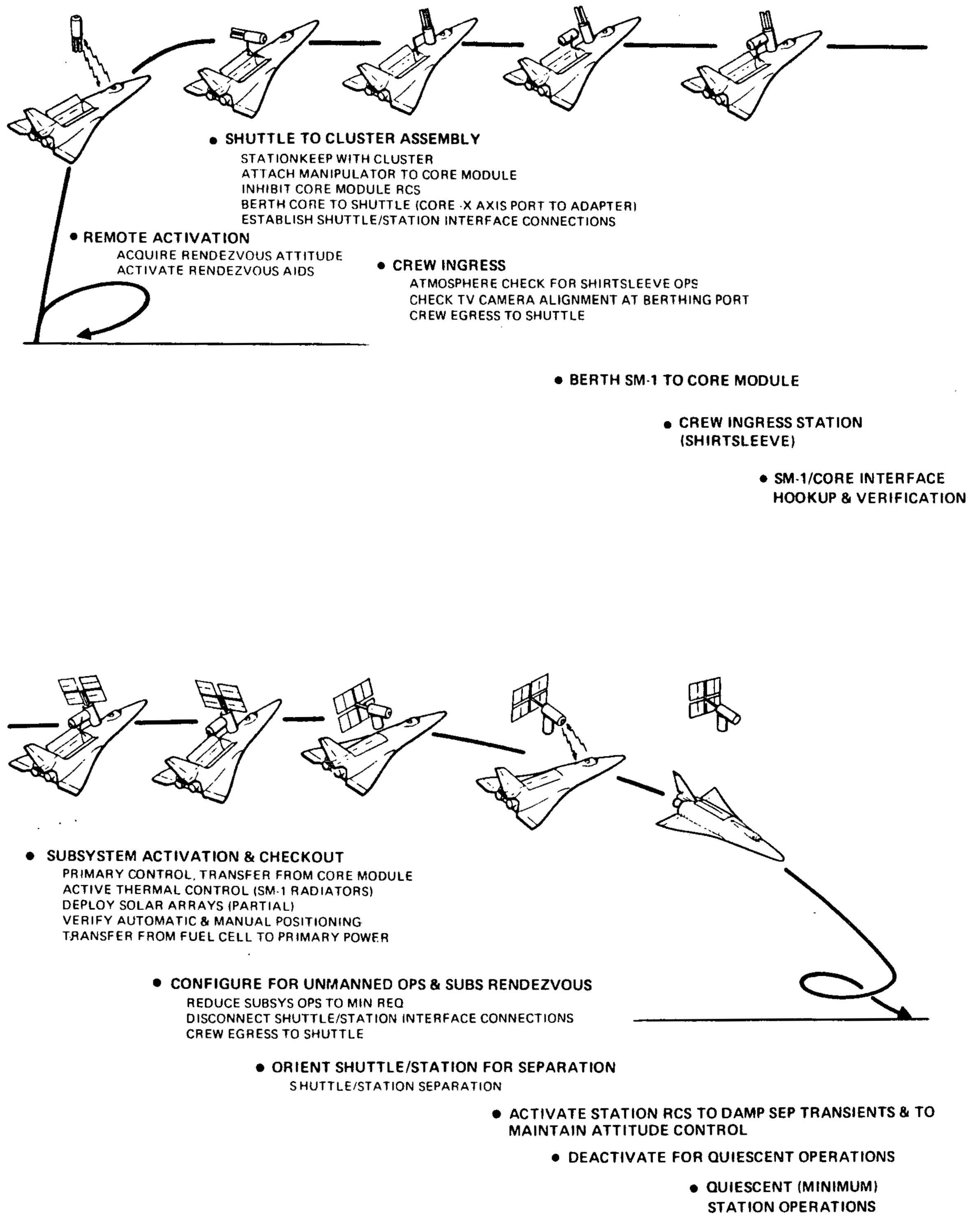


Figure 1-20. Typical Delivery Operations Sequence

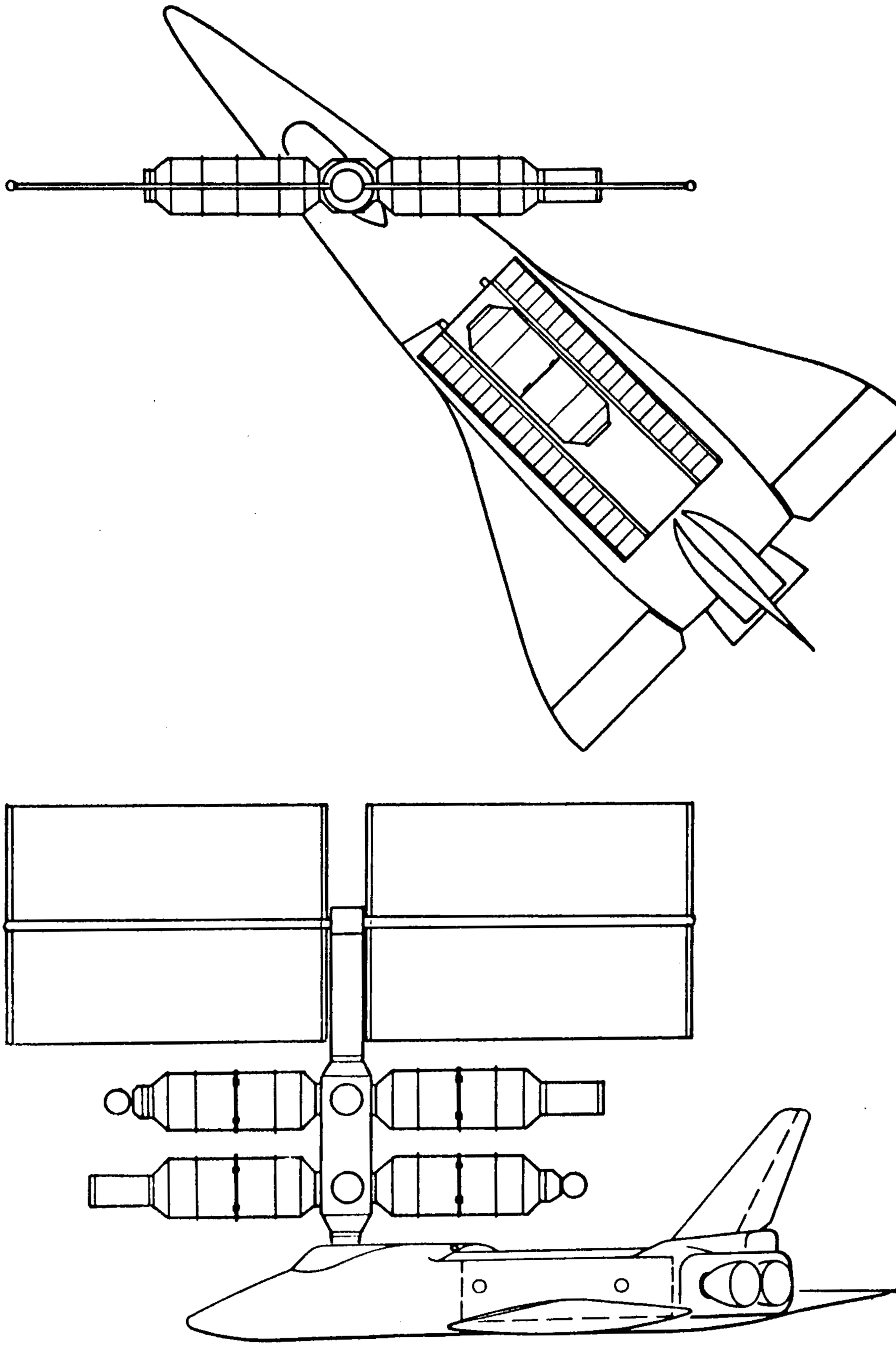


Figure 1-21. Shuttle Normal Berthing Orientation

berthing. The cluster is configured for partial quiescent operations by RF commands, and its status is verified by the shuttle crew before departure and earth return.

The estimated duration of operational activities associated with the assembly of the control and crew module are listed in Figure 1-22. For the activities listed, it is assumed that two special crewmen working together, in shirtsleeves, will perform the activities while the shuttle pilot crewmen monitor caution and warning devices, maintain the preferred shuttle attitude, and provide some limited operational support from the shuttle vehicle. One work day refers to a period of 10 hours.

SM-1-to-station hookup and verification are based on 19 fluid and gas lines, or ducts, at the interface of which eight have line barriers which prevent the escape of dangerous gases or fluids into the station. Twenty-four electrical connectors are included in the hookup and verification sequence.

As noted, one day of on-orbit contingency time is available to complete the listed operations. This represents the minimum time available since additional time (up to 1+ days) may be available from the maximum times assumed for ascent and deorbit.

OPERATIONS ACTIVITY	ESTIMATED DURATION, HR	
ASCENT TO ORBIT & RENDEZVOUS	26	~ 1+ DAY
BERTHING - SHUTTLE TO STATION	3	~ 1 WORK DAY
ESTABLISH SHUTTLE/STATION INTERFACE CONNECTIONS	2	
CREW INGRESS, ATMOSPHERE CHECK & PRE-BERTHING PREPARATIONS (SM-1)	2	
BERTH SM-1 TO STATION	3	
SM-1/STATION INTERFACE HOOKUP & VERIFICATION	15	~ 1.5 WORK DAYS
SUBSYSTEM ACTIVATION & CHECKOUT	10	~ 1.0 WORK DAY
ACTIVATE PRIMARY CONTROL, TRANSFER CONTROL FROM CM		
INITIATE ACTIVE THERMAL CONTROL		
DEPLOY SOLAR ARRAYS (PARTIAL)		
VERIFY AUTOMATIC SOLAR ARRAY POSITIONING		
TRANSFER FROM FUEL CELL TO PRIMARY POWER		
PREPARE CONFIG FOR QUIESCENT (UNMANNED) OPERATIONS	3	~ .5 WORK DAY
DISCONNECT SHUTTLE/STATION INTERFACES & CREW EGRESS	2	
SHUTTLE DETACHMENT & SEPARATION	2	~ 1+ DAY
DEORBIT & LANDING	24	
		6 DAYS*
* 1 DAY REMAINS FOR ON-ORBIT CONTINGENCY		

Figure 1-22. Typical Module Assembly Operations and Checkout

Ninety days after the core module is launched, the fourth module, SM-2, is launched. Ascent time from launch to rendezvous may vary from 4 to 26 hours since phasing with the orbiting modular cluster is required. After the shuttle accomplishes rendezvous, the modular cluster is commanded to assume and maintain an XPOP inertial flight attitude and is prepared for berthing, which includes inhibiting the solar array panels. The shuttle then closes with the cluster, and the cluster is retrieved by the shuttle manipulator. The core module RCS is deactivated, and the cluster is berthed to the shuttle passenger berthing port. The modular cluster/ shuttle interfaces are manually connected and verified, and the CM/PM/ SM-1 habitable environment is established. The special crew then enters the berthed cluster (in shirtsleeves) and configures it for SM-2 attachment to the aft +Z axis port on the CM by the shuttle manipulator. This includes removal of the berthing port cover and checking of the television camera alignment and operation. The special crew again enters the CM after SM-2 berthing; the CM/SM-2 interfaces are manually connected and verified and a habitable environment is established and verified in SM-2. The crew enters SM-2, and the flexport is manually extended and connected to the flexport hatch on SM-1. The modular cluster (CM/PM/SM-1/SM-2) is configured for free flight; the shuttle/modular cluster interface is disconnected; and the cluster is deployed and positioned for release by the shuttle manipulator in its approximate flight mode attitude. A final operability check on the modular cluster subsystems is performed by using RF; the RCS is enabled; the solar array panels are uninhibited; and the cluster is released. Separation transients are then dampened, and a principal-axis attitude flight mode is stabilized by the modular cluster. The principal axis attitude is maintained for 26 days until the next shuttle visit. The cluster is configured for partial quiescent operations and its status is verified (using RF) by the shuttle crew departure and earth return.

SM-3, is the fifth module delivered to orbit, is launched 120 days after the launch of the core module. The ascent, awakening, retrieval, berthing, attachment, interfacing, and the like operations are similar to those previously described for SM-2, except that the flexport is not extended and connected until SM-4 is delivered. SM-3 is berthed to the forward -Z axis port on the core module. The CM/PM/SM-1/SM-2/SM-3 cluster will fly a principal axis attitude mode during its partial quiescent operations phase that last for 26 days.

SM-4 is the sixth and last of the station modules that make up the basic initial MSS to be delivered. This module is launched 150 days after initial launch of the core module and is attached to the aft -Z axis port on the core module. The ascent, retrieval, berthing and the like operations are similar to those previously described for SM-2, including the flexport extension and attachment operation between SM-4 and SM-3. In addition, the second control center, similar to that on SM-1, is activated, connected to the data bus, and checked out. The unmanned MSS flies a principal-axis attitude mode during its partial quiescent operations phase that lasts for 26 days.

One hundred eighty days after launch of the CM, the first cargo module and initial six-man station crew are launched. As before, the ascent time takes from 4 to 26 hours; the unmanned MSS subsystems are statused each day before shuttle launch; and after rendezvous, the station is commanded to an XPOP inertial mode, and its solar array panels are inhibited for retrieval and berthing. After the unmanned station is retrieved and berthed to the passenger berthing port of the shuttle, the shuttle/station interfaces are connected and verified and a habitable environment is verified in the station. The initial manning crew then enters the station; the solar array panels are fully deployed, both control centers are fully activated; and all subsystems are brought onto line and checked out.

After operational integrity of the station has been established, the cargo module/shuttle cargo bay interfaces are disconnected, and the cargo module is deployed and berthed to the station by the shuttle manipulator. The cargo module may be berthed to either of the forward Y axis (+ or -) ports. The station/cargo module interfaces are manually secured, and the shuttle prepares for earth return. The cargo module stays with the station and acts as a supply center as well as provides a 96-hour emergency life support capability. The shuttle/station interfaces are disconnected; the shuttle performs a separation maneuver from the station and configures for earth return. At this time, approximately 185 days after launch of the CM, the station is fully assembled, activated, manned, and capable of initiating routine operations.

The resultant orbital configuration of the initial space station, shown in Figure 1-23, consists of the core module, power module, four station modules, and the initial cargo module. During the period of routine station operations, RAM's are delivered and berthed to the aft Y axis (+ or -) berthing ports as required to support experiment operations.

After five to six years of initial space station operations, additional modules are delivered to achieve a growth (12-man) space station capability. Growth capability is achieved by replacement of the solar array, addition of a second (short) core, and addition of two station modules with crew quarters and life support capability. Shuttle operations for the growth buildup phase are similar to those for buildup to the initial space station. The shuttle performs a rendezvous with the station; shuttle/station berthing is accomplished with the manipulator; and the station module is removed from the cargo bay and berthed to the appropriate -Y axis core module port. The space station configuration at each stage of the buildup (Figure 1-24) shows building from an initial station that has two RAM's attached.

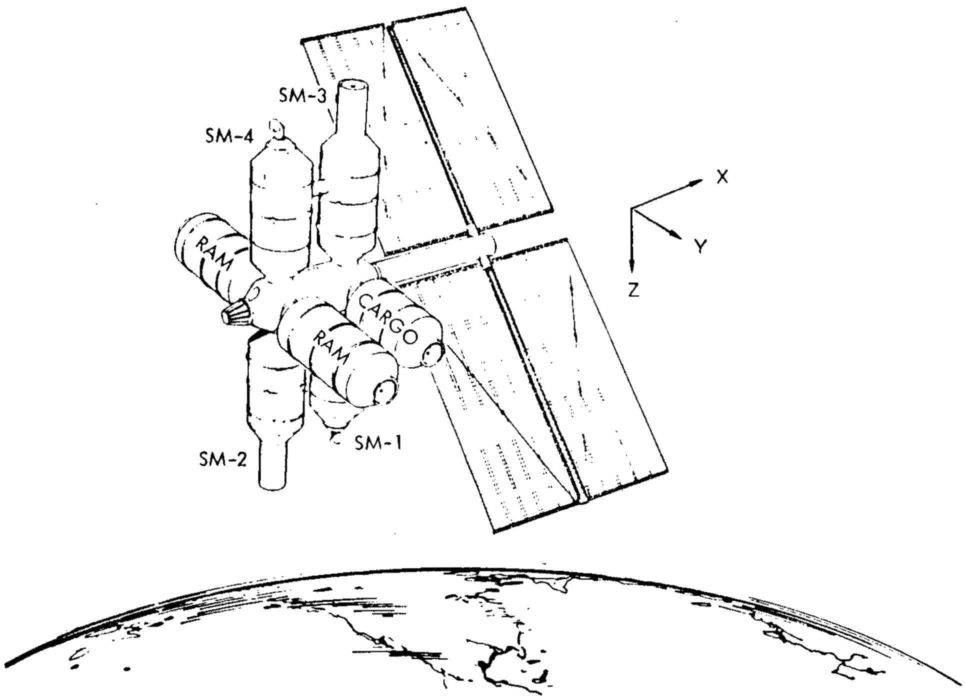


Figure 1-23. Initial Space Station Orbital Configuration

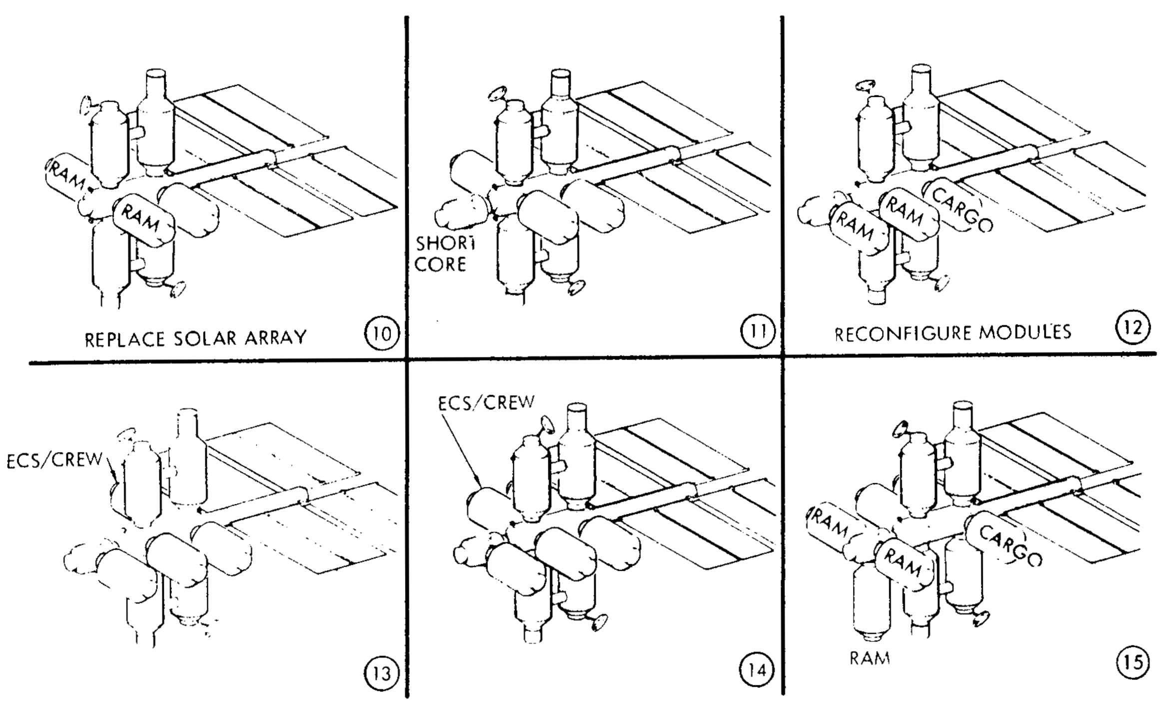


Figure 1-24. Growth Space Station Buildup

1.1.4 SHUTTLE SUPPORT OPERATIONS

During buildup of the space station, the space shuttle is used to deliver and assemble the modules in orbit. The capability of the space shuttle impacts the design constraints which must be imposed on the modules in terms of the gross module weight at shuttle liftoff. In this section, the shuttle payload delivery capability for the first and subsequent modules is discussed. Also, the implications of the shuttle delivery capability and the limiting module weights are presented.

The shuttle design reference mission (DRM) provides the capability to deliver a 25,000-pound payload to a 270-nautical-mile, 55-degree inclination orbit. The capability also exists to return an equivalent payload, e.g., delivery and return of cargo modules. This capability is associated with routine space station operations and is, therefore, based on a shuttle mission profile which includes rendezvous and docking operations. These operations are not required for delivery of the first space station module; therefore the on-orbit ΔV requirements are decreased. The reduced ΔV requirements decrease the propellant requirements (ACPS and OMS) by approximately 4725 pounds, a decrease which permit a corresponding increase in the first module weight. The corresponding payload increase, illustrated in Figure 1-25, permits the delivery of a 29,725-pound payload on the first module launch (including shuttle tariffs and weight growth margin allowance).

The source of the propellant reduction is shown in Table 1-6, which shows the shuttle DRM on-orbit propellant requirements and the reduced requirements associated with the first module delivery. The total shuttle DRM propellant requirement is 27,730 pounds, including 4538 pounds for rendezvous and 467 pounds for docking. The propellant requirement for the first module launch is reduced to 23,005 pounds by eliminating the rendezvous and docking propellant requirements while increasing the orbit injection propellant requirement. The increased orbit injection propellant is required to permit delivery of the first station module to an altitude above 270 nautical miles since orbit makeup is not performed during the early phases of space station buildup. The first module is delivered to 272 nautical miles and allowed to decay during the first two to three months of the buildup operations.

Additional propellant reductions, and thus payload increases, could be achieved by further reducing the on-orbit maneuver requirements. The capability for five days of stationkeeping was retained—694 pounds of attitude control propulsion subsystem (ACPS) propellant—although the baseline space station mission profile is estimated to require only one day. Also, the capability to retrieve and return the first module was retained to permit return of the module if it cannot be fully activated and its operability verified by RF link on-orbit. Elimination of this capability would also eliminate the redocking (reberthing) propellant requirement (622 pounds of ACPS propellant) and reduce the deorbit, preentry, and entry propellant requirements.

Associated with the delivery of the space station modules are support items which must be charged against the shuttle payload. During buildup of the MSS, these tariffs vary from 1264 pounds for the core module up to a maximum of 2764 pounds for the power module. The tariffs for all modules and the tariff items are defined in Table 1-7. These tariffs effectively reduce to shuttle payload since the identified items are not inherently provided by the shuttle. As an example, delivery of the core module imposes a 1264-pound tariff. The core module is the first station module for the selected buildup sequence. Therefore, the maximum launch weight of the core module (including weight growth margin allowance) is 28,461 pounds. The corresponding maximum allowable module launch weights for all space station modules are also shown in Table 1-7. The weights shown, with the exception of the core module, are based on a 25,000-pound payload launch weight capability and, therefore, include any weight growth margin allowance.

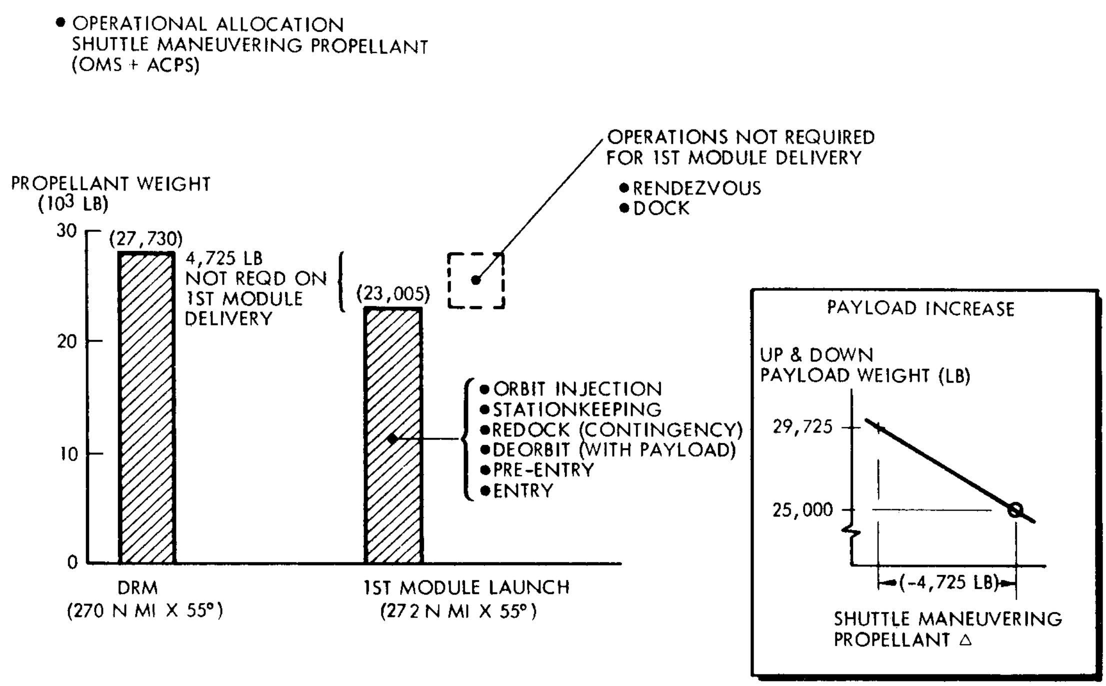


Figure 1-25. Shuttle Fist Module Launch Capability

Table 1-6. On-Orbit Propellant Requirements
(First Module Delivery)

Mission Phase	Requirements			
	Shuttle DRM			First Space Station Module Delivery
	ACPS (lb)	OMS (lb)	Total (lb)	Total (lb)
Orbit injection	751	10,311	11,062	11,342
Rendezvous	1,242	3,296	4,538	-
Docking (berthing)	467	-	467	-
Stationkeeping (five days)	694	-	694	694
Redocking (reberthing)	622	-	622	622
Deorbit	254	8,744	8,998	8,998
Preentry	149	-	149	149
Entry	1,200	-	1,200	1,200
Total	5,379	22,351	27,730	23,005

Table 1-7. Shuttle Tariffs

Tariff Item	Tariff Weight (lb)					
	Core (WBS 01)	Power (WBS 02)	SM-1 (WBS 03)	SM-2 (WBS 04)	SM-3 (WBS 05)	SM-4 (WBS 06)
Two crew	400	400	400	400	400	400
Two crew provisions	300	300	300	300	300	300
Two PLSS and two PGA	354	354	354	354	354	354
Passenger provisions	63	155	190	160	160	166
Leakage makeup oxygen and nitrogen	0	165	180	210	210	210
Shuttle EPS reactants	50	365	495	383	383	405
Delta tank weight	97	425	425	425	425	425
MSS/shuttle adapter	NA	600	NA	NA	NA	NA
Total	1,264	2,764	2,344	2,232	2,232	2,260
Maximum allowable module weight (including growth margin allowance)	28,461	22,236	22,656	22,768	22,768	22,740

1.2 ROUTINE MISSION OPERATIONS

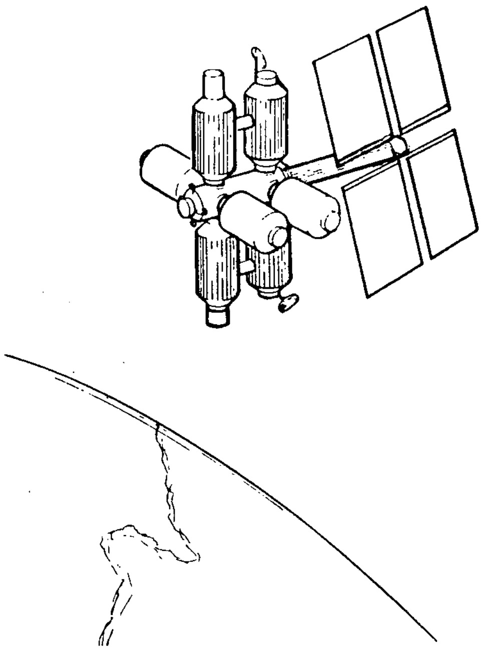
1.2.1 STATION OPERATIONS

Routine space station operations are those daily activities necessary to maintain the operational integrity of the space station. During the routine operations mission phase, several operations either impact the space station design requirements or are driven by the design concept selection. The principal considerations are the flight mode selection and the associated orbit makeup requirements. Other factors dictated by these considerations are the required solar array orientation time history and the total station consumable requirements.

Flight Mode

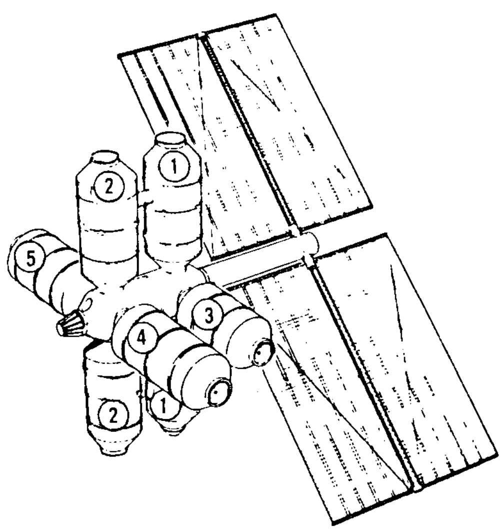
In the selection of the space station flight mode, the influences of both subsystem and experiment operations must be considered. The major factors which either impact or are impacted by the flight mode selection are summarized in Figure 1-26. Evaluation of the severity of these interferences or effects on the identified subsystems and the experiments has resulted in the selection of a preferred flight mode.

One of the principal factors influencing the flight mode selection is module heat rejection capability. The module heat rejection capability is shown in Figure 1-27 for selected module locations. Although the module heat rejection capability is configuration dependent and must, in the final analysis, be integrated over an orbit, the minimum heat rejection capability shown provide an indication of the heat reject capabilities. As can be seen, the vertical modules which are the farthest from the solar array have the highest heat rejection capability. The vertical modules adjacent to the solar array have a reduced capability, but it is still better than either of the horizontal modules. The preference on the basis of ECLSS considerations would be to provide radiators on the vertical modules. From design simplicity and operational considerations, it is preferred to have the radiators on station modules rather than RAM's or cargo modules. This selection results in the heat rejection from modules whose interfaces are established and nominally remain unbroken throughout the operational lifetime of the space station.



- EPS
  - SOLAR ARRAY ORIENTATION
  - SHADOWING OF SOLAR ARRAY
- G&C
  - CMG SIZING
  - IMPULSE REQUIREMENTS
- RCS
  - ENGINE QUAD LOCATIONS
- ECLSS
  - HEAT REJECTION
  - SHADOWING BY SOLAR ARRAY
- EXPERIMENTS
  - SOLAR ARRAY INTERFERENCE
  - AIRLOCK ORIENTATION & VIEW
  - VEHICLE AXES
- ISS
  - ANTENNAE LOCATION & VIEW ANGLES

Figure 1-26. Flight Mode Considerations



MODULE	MINIMUM HEAT REJECTION CAPABILITY (KW_t)
1	7.6
2	9.8
3	2.1
4	3.5
5	4.7

PREFERENCE:
RADIATORS ON VERTICAL MODULES
RADIATORS ON STATION MODULES
∴ STATION MODULES VERTICAL

Figure 1-27. Typical Heat Rejection Capability

The resultant preferred local-vertical flight mode is with the station modules vertical. During the short periods of inertial attitude hold, the modules will not remain vertical, a degraded heat rejection capability being the result. The inertial mode was not considered a major driver since these periods will nominally be for one day or less.

Considerations of the heat rejection capability provided one constraint in the selection of the preferred flight mode. The remaining viable alternatives are shown in Figure 1-28. In all the remaining alternative modes, the space station +Z axis (geometric) is in the direction of earth as shown in the figure. Whether or not the +Z axis is opposite the space station position vector depends upon which attitude reference axes are used: geometric axes or principal axes. The preferred alternative is to orient the station with respect to the geometric axes since they are constant and provide a constant reference base for external viewing experiments. Use of principal axes would reduce the G&C subsystem and RCS sizing requirements, but the orientation of the principal axes is dependent upon the space station configuration. Therefore, the orientation of the principal axes is time varying (e.g., with the addition of each RAM).

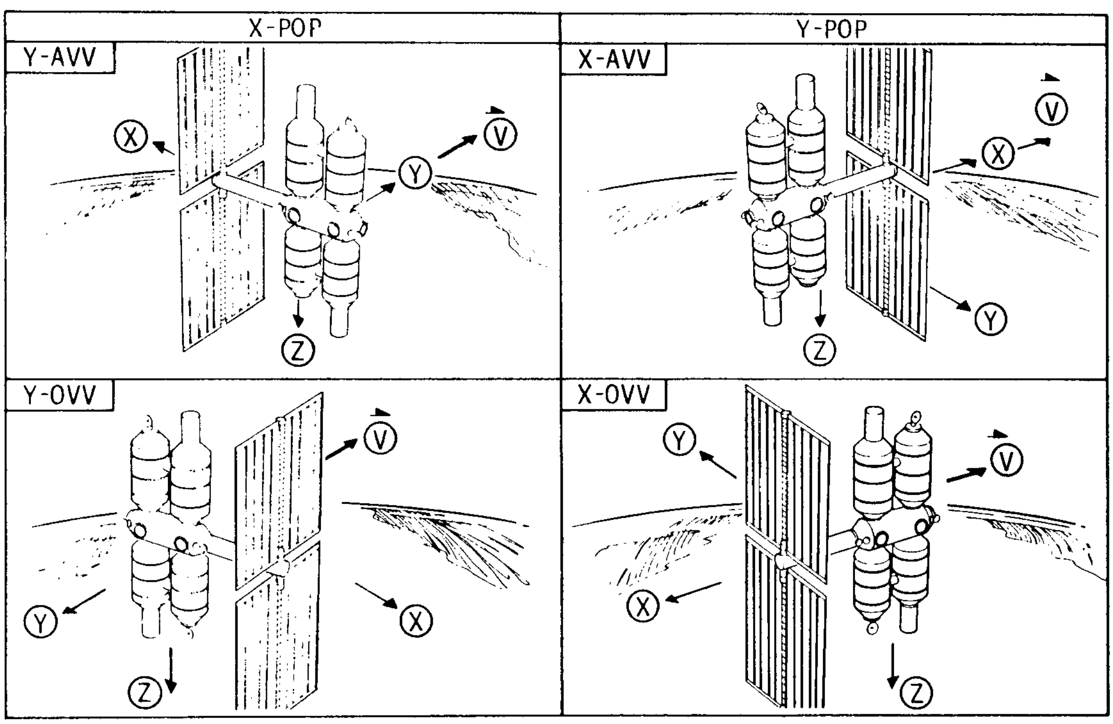


Figure 1-28. Flight Mode Alternatives

The remaining alternatives shown in Figure 1-28 differ only in the direction of the +X and +Y axes. In two of the alternatives, the +X axis is perpendicular to the orbit plane (XPOP). The variations of this mode are: +Y axis along the space station velocity vector (XPOP/YAVV) and +Y axis opposite the velocity vector (XPOP/YOVV). For the remaining alternatives, the +Y axis is perpendicular to the orbit plane (YPOP), and the +X axis is either along the space station velocity vector (YPOP/XAVV) or opposite the velocity vector (YPOP/XOVV). The selection of the preferred mode from this reduced set is dependent upon additional subsystem and experiment operations considerations.

The impact of the flight mode selection on the sizing requirements for the G&C subsystem and RCS is summarized in Figure 1-29. As can be seen from the figure, the flight mode selection has a significant impact on the CMG and total impulse requirements. Although the values shown are for a specific space station configuration, the conclusions obtained from this case are representative of the conclusions obtained from the investigations of alternative configurations. In general, the XPOP flight modes (either XPOP/YAVV or XPOP/YOVV) required smaller CMG's than the YPOP flight modes. Also, longer intervals between desaturation maneuvers could be tolerated with reasonable sizing requirements. In contrast, the impulse requirements for CMG desaturation and orbit makeup for the XPOP flight modes are higher than the YPOP requirements. As a result, the logistics resupply requirements are increased. For the differences shown, the XPOP flight mode would require the equivalent of two additional shuttle flights over a ten-year operational period. Since the G&C subsystem and RCS sizing requirements are configuration dependent, the final configuration must be selected and additional factors must be considered in the flight mode selection.

An additional consideration affecting the final flight mode selection is the location of the RCS thrusters. Since the preferred thruster location was on the core module (Reference 2), the flight mode selection will influence where on the core module the thrusters are located. The considerations which impact the thruster location selection are summarized in Figure 1-30 for the XPOP and YPOP flight modes. The basic considerations are (1) the number of thrusters available for orbit makeup, (2) the ability to combine orbit makeup and CMG desaturation maneuvers, and (3) thruster plume impingement.

In all cases except one, only two thrusters are available for orbit makeup. The exception is the XPOP flight mode with thrusters in the X-Z plane (Z axis thrusters). For this case, four thrusters are available for

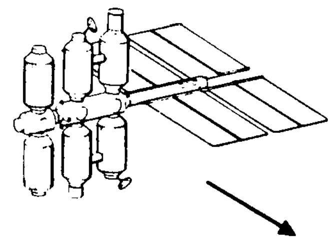
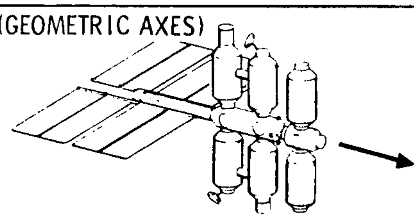
FLIGHT MODE	CMG'S (INITIAL)	IMPULSE (MILLIONS OF LB-SEC PER 120 DAYS)	
		INITIAL	GROWTH
X-POP (GEOMETRIC AXES) 	4 CMG'S (4250 FT-LB-SEC EACH) OR 3 CMG'S (5660 FT-LB-SEC EACH) (DUMP EVERY 6 ORBITS)	1.42	1.65
Y-POP (GEOMETRIC AXES) 	4 CMG'S (6200 FT-LB-SEC EACH) (DUMP EVERY 3 ORBITS)	0.89	1.39

Figure 1-29. G&C Sizing Requirements

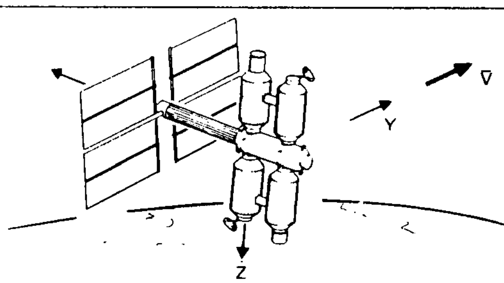
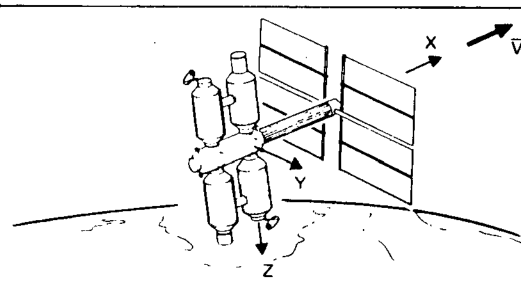
X-POP		Y-POP	
			
QUAD LOCATION	CONSIDERATIONS	QUAD LOCATION	CONSIDERATIONS
Y-AXIS	• TWO THRUSTERS FOR ORBIT MAKEUP • ORBIT MAKEUP & CMG DESATURATION CAN NOT BE COMBINED • PLUME IMPINGEMENT ON MODULES	Y-AXIS	• TWO THRUSTERS FOR ORBIT MAKEUP • ORBIT MAKEUP & CMG DESATURATION CAN NOT BE COMBINED • PLUME IMPINGEMENT ON MODULES • PLUME IMPINGEMENT ON SOLAR ARRAY DURING ORBIT MAKEUP (X-OVV ONLY)
Z-AXIS	• FOUR THRUSTERS FOR ORBIT MAKEUP • COMBINED CMG DESATURATION & ORBIT MAKEUP POSSIBLE • PLUME IMPINGEMENT ON MODULES	Z-AXIS	• TWO THRUSTERS FOR ORBIT MAKEUP • COMBINED CMG DESATURATION & ORBIT MAKEUP POSSIBLE • PLUME IMPINGEMENT ON MODULES • PLUME IMPINGEMENT ON SOLAR ARRAY DURING ORBIT MAKEUP (X-OVV ONLY)

Figure 1-30. RCS Engine Quad Location

orbit makeup maneuvers. This alternative, as well as the YPOP/Z axis thrusters alternative, also permits combined orbit makeup and CMG desaturation maneuvers. The significance of having this combined maneuver capability is reflected in the resultant propellant requirements. The impulse requirements for CMG desaturation are either greater than or only slightly less than the requirements for orbit makeup. Thus, proper scheduling of CMG desaturation maneuvers will also satisfy, or nearly satisfy, the orbit makeup requirements. (The degree to which combined maneuvers will satisfy the orbit makeup requirements depends upon configuration and operational altitudes.) On the basis of these considerations, the preferred combination of attitude mode and thruster location would be one which permits combining CMG desaturation and orbit makeup. Of the two alternatives available, the XPOP flight mode with Z axis thrusters has the most (four) thrusters available for orbit makeup and is the preferred flight mode and thruster arrangement.

Examination of the plume impingement considerations shows that all alternatives have some impingement; only the conditions differ under which it occurs. The worst case of plume impingement occurs with the YPOP/XOVV flight mode. Impingement on the solar array will occur during orbit makeup since the solar array is trailing (Figure 1-28) in this mode.

The final consideration before attitude mode selection relates to the solar array orientation time history and the associated solar array interference considerations. The required solar array orientation time histories are shown in Figure 1-31 for the XPOP and YPOP flight modes. The figures show the required solar array roll and pitch angles as a function of the space station orbital position and the angle between the orbit plane and the earth-sun vector (solar out-of-plane angle, β). Also shown are the conditions under which the sun will be occulted by the earth. For the XPOP flight mode, the solar array pitch angle is constant for a given solar out-of-plane angle. Therefore, the rate at which the array must rotate about the pitch axis is relatively slow and is defined by the orbit regression rate and the motion of the earth about the sun. The array must have the equivalent of the capability to rotate through 360 degrees once each orbit, however. This capability could be achieved by cycling the array; and for those solar out-of-plane angles where the sun is occulted by the earth, this cycling could be performed during the dark side pass. For high solar out-of-plane angles, the space station will be continuously illuminated, and array cycling will have to be based on other considerations, primarily orientation mechanism design.

The short-term magnitude of the solar array roll angle requirements is less severe for the YPOP flight mode, but the rates are higher. Also, the overall orientation time history is more complex. In the XPOP mode,

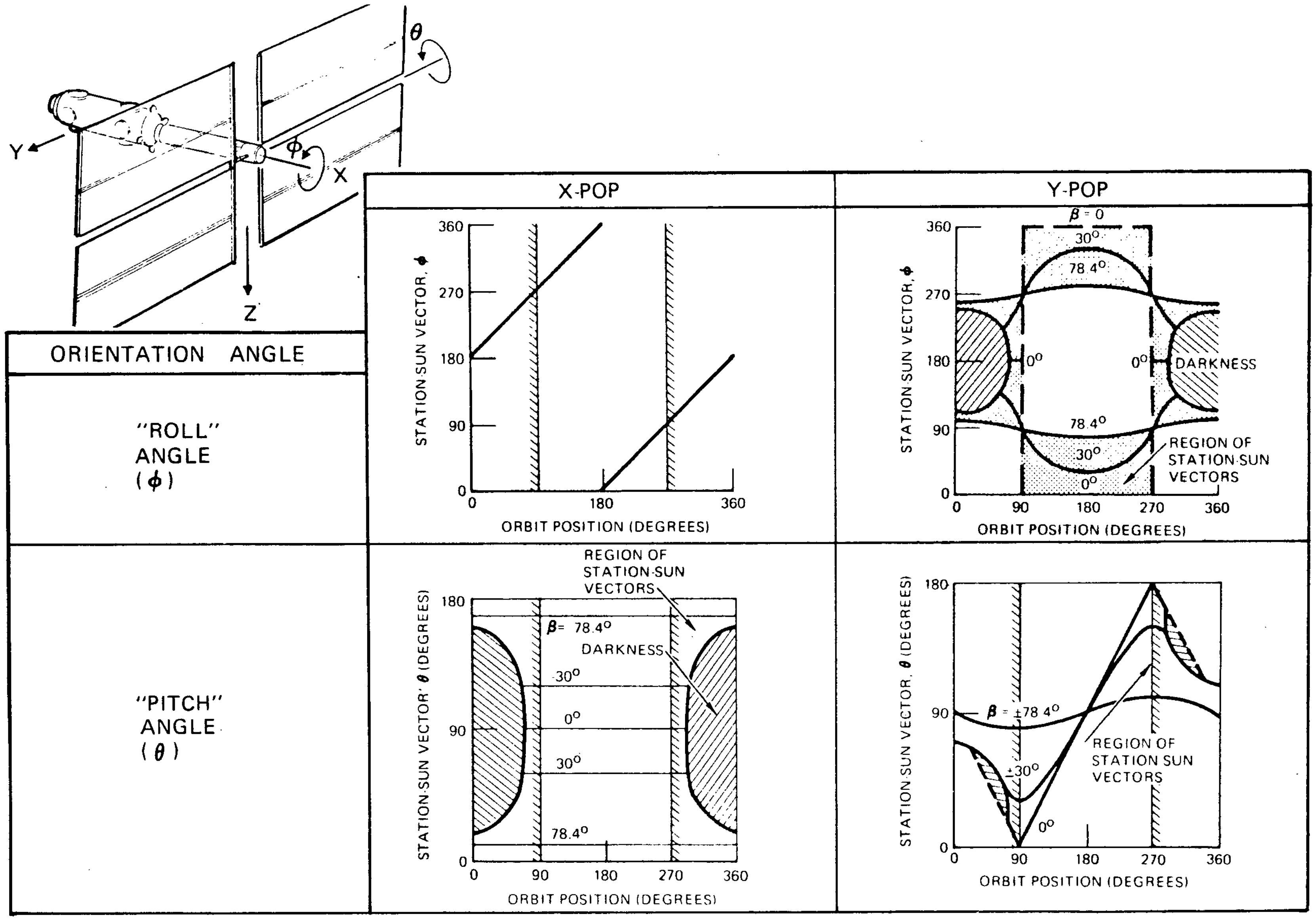


Figure 1-31. Solar Array Orientation History

the pitch angle is essentially fixed, and the array rolls at orbital rate. The YPOP mode requires combined pitch and roll motions to maintain the array normal to the station-sun vector. The complexity of the orientation history for the YPOP mode must also be assessed when the feasibility of manually orienting the array following a failure, or failures, of an automated solar array drive mechanism is considered. In the XPOP mode, the array pitch angle could be periodically set, and the array could be rolled at a uniform (orbital) rate. The YPOP mode would require continuous, generally non-uniform rate, orientation of the array. This is considered to be a complex, not very accurate, manual operation.

The solar array interference considerations, illustrated in Figure 1-32, include line-of-sight interference with antennas and external viewing sensors, shadowing of modules with heat rejection radiators, and shadowing of the array by the station modules. The solar array interference effects are summarized in Figure 1-33 for the XPOP flight mode and Figure 1-34 for the YPOP mode. For each case, the effects are summarized for the two limiting conditions: in-plane solar orientation (β = 0 degrees) and maximum out-of-plane solar orientation (β = 78.4 degrees).

Shadowing of the solar array by the space station modules will occur with both flight modes, but the conditions under which they occur differ. For the XPOP mode, the array will be shadowed when the solar out-of-plane angle is a maximum (β = 78.4 degrees) and the sun-station vector is in the direction of the station +X axis. No shadowing occurs when the sun is in the station orbit plane or when the solar out-of-plane angle is a maximum and the sun-station vector is opposite the direction of the station +X axis. Solar array shadowing occurs when the station is in the vicinity of the terminator, and the sun is in-plane for the YPOP flight mode. The interference occurs at sunrise for the YPOP/XOVV mode, as shown in Figure 1-34 and at sunset for the YPOP/XAVV mode. No array shadowing occurs when the solar out-of-plane angle is a maximum for the YPOP mode. The array shadowing occurs when the period of solar illumination is a maximum for the XPOP flight mode and when it is a minimum for the YPOP mode. Therefore, the effects of solar array shadowing are minimized with the XPOP flight mode.

The interference of the solar array with earth-viewing sensors is similar for both flight modes. There is no interference at the closest approach to the subsolar point ($R_{station} \times R_{sun}$ = minimum). Either the edge or the rear of the solar array will be in the field of view in the vicinity of the terminator for both flight modes. The basic difference for the two modes is the direction in which the solar array interference with earth-viewing sensors occurs. The interference is normal to the orbit plane for XPOP mode and in-plane for the YPOP mode. The YPOP in-plane interference is opposite the direction of motion for the YPOP/XOVV mode (Figure 1-34) and in the direction of motion for the YPOP/XAVV mode.

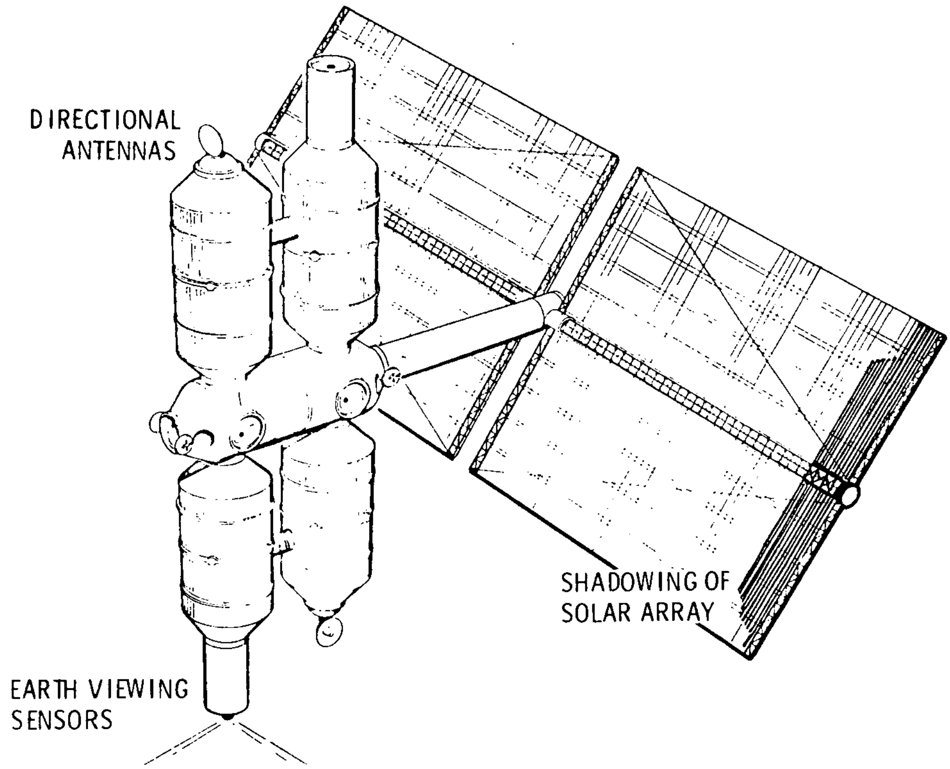


Figure 1-32. Solar Array Interference Considerations

On the basis of these earth-viewing sensor interference considerations, the YPOP/XOVV flight mode is preferred since the interference effects are considered the most acceptable; i.e., when interference occurs, it is opposite the direction of motion of the space station. The YPOP/XAVV mode is considered the least desirable because interference occurs in the direction of motion and the capability for unobstructed viewing in this direction is considered to be highly desirable. Although not as desirable as the YPOP/XOVV mode, the XPOP (either YOVV or YAVV) mode is considered acceptable.

The final interference consideration is the solar array blockage of the communication link line-of-sight to the detached RAM's and to a tracking and data relay satellite (TDRS). In all flight modes, periodic interference with the TDRS line of sight of a single antenna will occur, but the interference will be of short duration and will be predictable. Therefore, this effect can be minimized by operational procedures and is not considered a major driver on the flight mode selection. Since the orbit of the detached RAM's will be coplanar, the YPOP flight mode places the array in the line of sight whether +Y or -Y is along the velocity vector. Hence, XPOP modes are preferred for detached RAM communications.

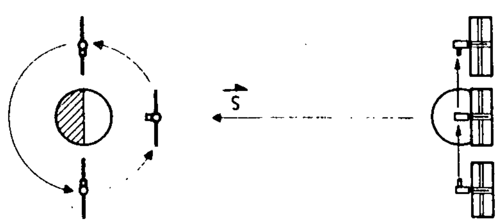
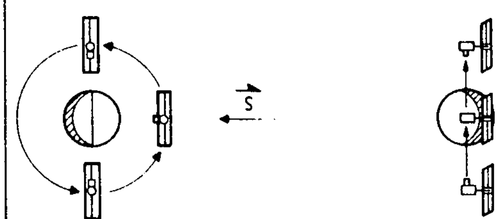
ATTITUDE MODE	SOLAR ARRAY ORIENTATION	INTERFERENCE
X-POP	β = 0 	EPS - NO SHADOWING OF ARRAY EXPERIMENTS • "EDGE" OF ARRAY IN FIELD-OF-VIEW • INTERFERENCE NORMAL TO ORBIT PLANE • NO INTERFERENCE AT SUBSOLAR POINT DIRECTIONAL ANTENNA - PERIODIC INTERFERENCE WITH TRDS
	β = 78.4° 	EPS - ARRAY SHADOWED BY MODULES EXPERIMENTS • REAR OF ARRAY IN FIELD-OF-VIEW • INTERFERENCE NORMAL TO ORBIT PLANE • NO INTERFERENCE AT SUBSOLAR POINT DIRECTIONAL ANTENNA - PERIODIC INTERFERENCE WITH TDRS

Figure 1-33. Solar Array Interference Summary (XPOP)

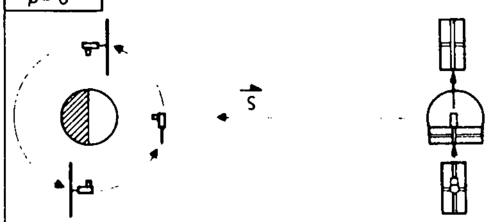
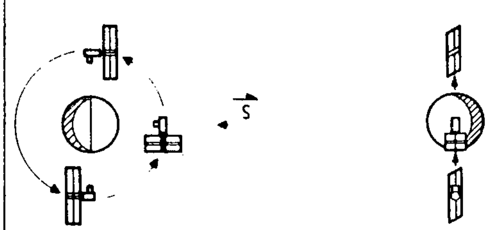
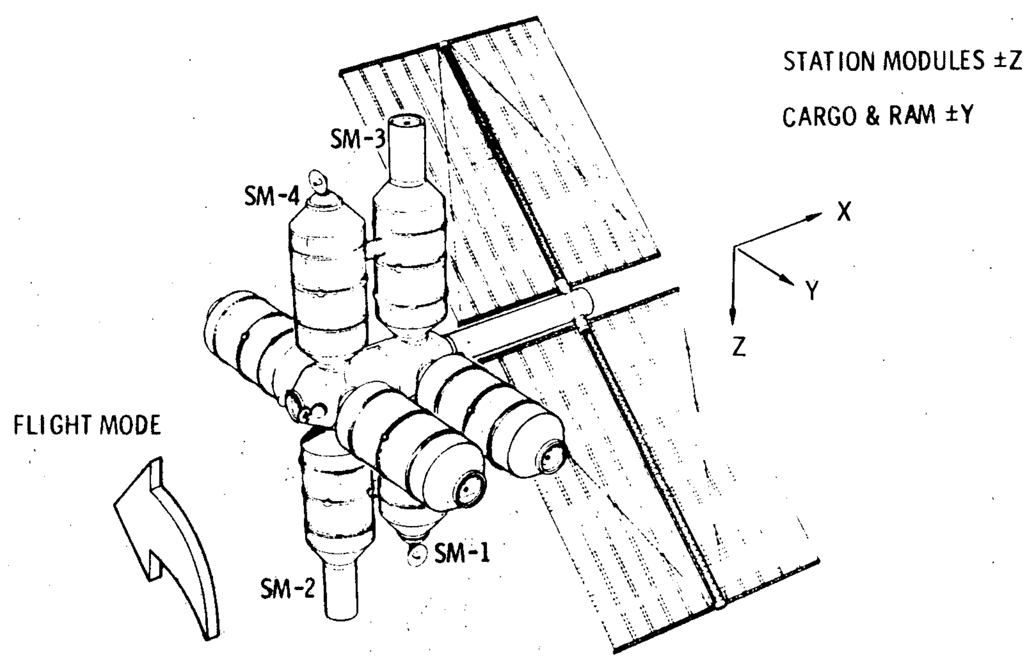
ATTITUDE MODE	SOLAR ARRAY ORIENTATION	INTERFERENCE
Y-POP	β = 0 	EPS - ARRAY SHADOWED BY MODULES AT TERMINATOR EXPERIMENTS • REAR OF ARRAY IN FIELD-OF-VIEW • INTERFERENCE IN ORBIT PLANE • NO INTERFERENCE AT SUBSOLAR POINT DIRECTIONAL ANTENNA - PERIODIC INTERFERENCE WITH TRDS
	β = 78.4° 	EPS - NO SHADOWING OF ARRAY EXPERIMENTS • "EDGE" OF ARRAY IN FIELD-OF-VIEW • INTERFERENCE IN ORBIT PLANE • NO INTERFERENCE AT SUBSOLAR POINT DIRECTIONAL ANTENNA - PERIODIC INTERFERENCE WITH TDRS

Figure 1-34. Solar Array Interference Summary (YPOP)

In the final selection of the preferred flight mode, the combined effects of the influencing factors which have been discussed must be considered. The principal considerations are summarized in Table 1-8, and the fundamental conclusions that were developed are noted, i.e., station modules vertical (ZLV) for heat rejection, RCS engine quads in the X-Z plane (Z axis thrusters), and attitude reference to geometric axes on the basis of experiment considerations. The remaining considerations have conflicting requirements and depend partly on configuration.

The impact of the conflicting CMG sizing and impulse requirements was minimized by selecting a configuration that is more symmetrical than the configuration present in Figure 1-29. The selected configuration and the associated CMG sizing and impulse requirements are shown in Figure 1-35.

The remaining considerations are the impact of the engine quad location, the solar array orientation history, solar array shadowing, and interference of the solar array with external viewing experiments. On the basis of these considerations, the YPOP/XOVV mode is unacceptable because of RCS plume impingement on the solar array even though this mode is the preferred mode for experimental external viewing. The YPOP/XAVV mode is the least desirable for experiment viewing; and as with the YPOP/XOVV mode, complex



FLIGHT MODE	CMG SIZING (INITIAL STATION)	TOTAL IMPULSE (MILLIONS OF LB-SEC) PER 120 DAYS	
		INITIAL	GROWTH
XPOP/Z-LV	3 CMG'S @ 1100 FT-LB-SEC EACH	0.290	0.374

Figure 1-35. CMG Sizing and RCS Impulse Requirements (Selected Configuration)

Table 1-8. Summary of Flight Mode Considerations

Flight Mode Selection Consideration		Flight Mode Selection Impact	
Area	**Consideration**	**XPOP**	**YPOP**
ECLSS	Module heat rejection	Radiators on vertical modules Radiators on station modules Station modules vertical (ZLV)	
G&C	CMG sizing impulse requirements	Minimizes sizing requirements (CMG and impulse requirements-configuration dependent)	Minimizes sizing requirements
RCS	Engine quad location	Z axis thrusters Four thrusters for orbit makeup Combined CMG desaturation and orbit makeup	Two thrusters for orbit makeup Combined CMG desaturation and orbit makeup YPOP/XOVV plume impingement on solar array during orbit makeup
EPS	Solar array orientation Shadowing of solar array	360-degree rotation per orbit Simple array motion Minimizes impact of array shadowing	Complex array motion
ISS	Line-of-sight interference	Periodic line-of-sight interference	
Experiments	Solar array interference Reference axes	Interference acceptable for attached experiments Eliminates interference with detached RAM communications Geometric	YPOP/XOVV minimizes interference impact YPOP/XAVV least desirable mode

solar array motion is required. Both YPOP modes present communication interference problems with detached RAM's. Because of these considerations, the YPOP mode was eliminated. The desirable features of the remaining mode (XPOP) are:

1. Four RCS thrusters are available for orbit makeup.
2. Combined CMG desaturation and orbit makeup maneuvers can be performed with Z axis thrusters.
3. No RCS plume impingement on the solar array will occur during nominal operations.
4. The solar array orientation motion is simple.
5. Effects of solar array shadowing by the station modules are minimized.
6. The solar array interference with earth-viewing sensors is acceptable.

Of these desirable features, the second is also applicable to the YPOP flight mode.

The resultant preferred local-vertical flight mode and the desirable characteristics thereof are shown in Figure 1-36. There were no strong drivers which would permit the selection of either an XPOP/YAVV or XPOP/YOVV mode. For consistency in the study, however, it was necessary to select a single mode, and the XPOP/YOVV was selected as the reference flight mode.

1.2.2 ATMOSPHERIC EFFECTS

Although the atmospheric density at the space station operational altitudes is extremely low, the density is of sufficient magnitude to produce aerodynamic torques and drag forces on the orbiting space station. These forces are of sufficient magnitude that they will have an impact on the space station CMG sizing and RCS impulse requirements. These subsystems must be sized to accommodate the aerodynamic forces produced over the operational envelope (240 to 270 nautical miles at an orbit inclination of 55 degrees). The atmospheric model, effects of aerodynamic forces, and the resultant space station sizing requirements are discussed in this section.

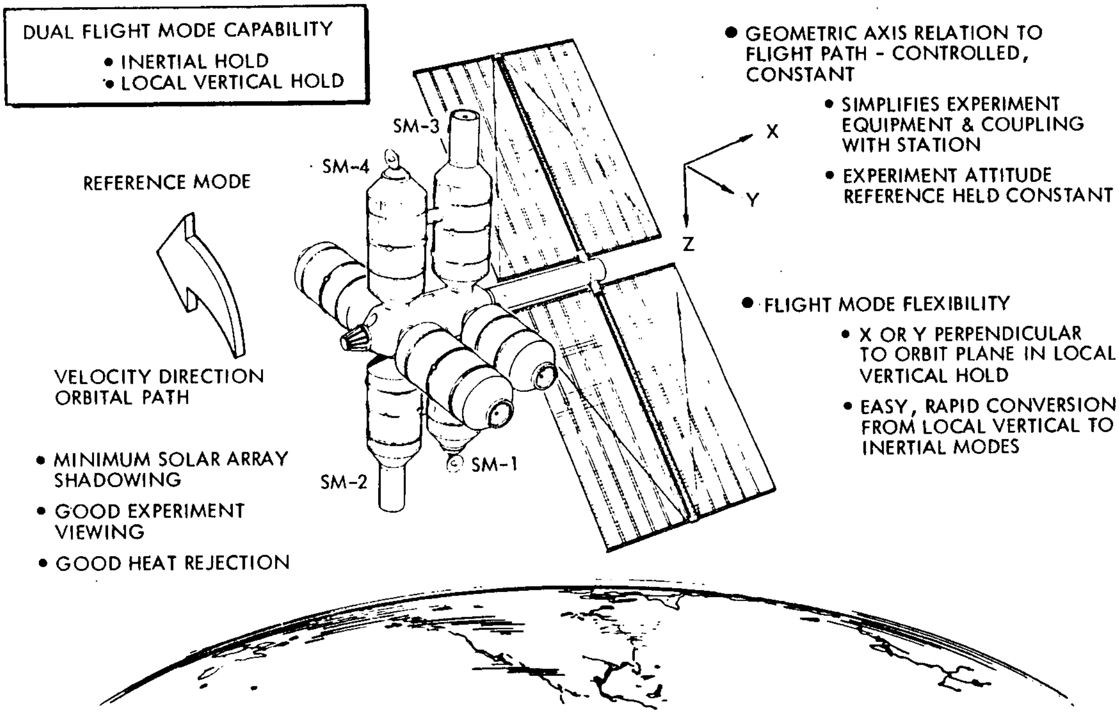


Figure 1-36. Flight Mode Characteristics Summary

Several atmosphere models reflecting the dynamic atmosphere aspects of the upper atmosphere have been prepared, and the one most widely accepted and the one used in this study is the Jacchia model which gives the orbital density as a function of position and time, and incorporates the effect of the solar activity, diurnal bulge, geomagnetic flux, and the like. With this model, the orbital drag becomes a function not only of altitude but also of the year, orientation (launch time), inclination position in orbit, and time of year.

The variation of density with time, over the period of interest, as computed with the Jacchia model is shown in Figure 1-37 for an altitude of 240 nautical miles and an inclination of 55 degrees. Presented are the nominal annual variation and the annual average and $+2\sigma$ densities, the $+2\sigma$ values representing the peak density experienced in orbit during a $+2\sigma$ level of solar activity. Also shown is the annual average $+2\sigma$ mean density, which is the mean density over one orbit revolution.

The nominal annual average and the $+2\sigma$ mean annual average densities were chosen as the operate-to and design-to densities to be used, respectively, as shown in Table 1-9. The usage is based on estimated initial station operational dates. To establish estimates of logistics resupply requirements the 270-nautical-mile nominal Jacchia atmosphere at 55-degree inclination on February for each year from 1982 to 1987 was used. The RCS impulse

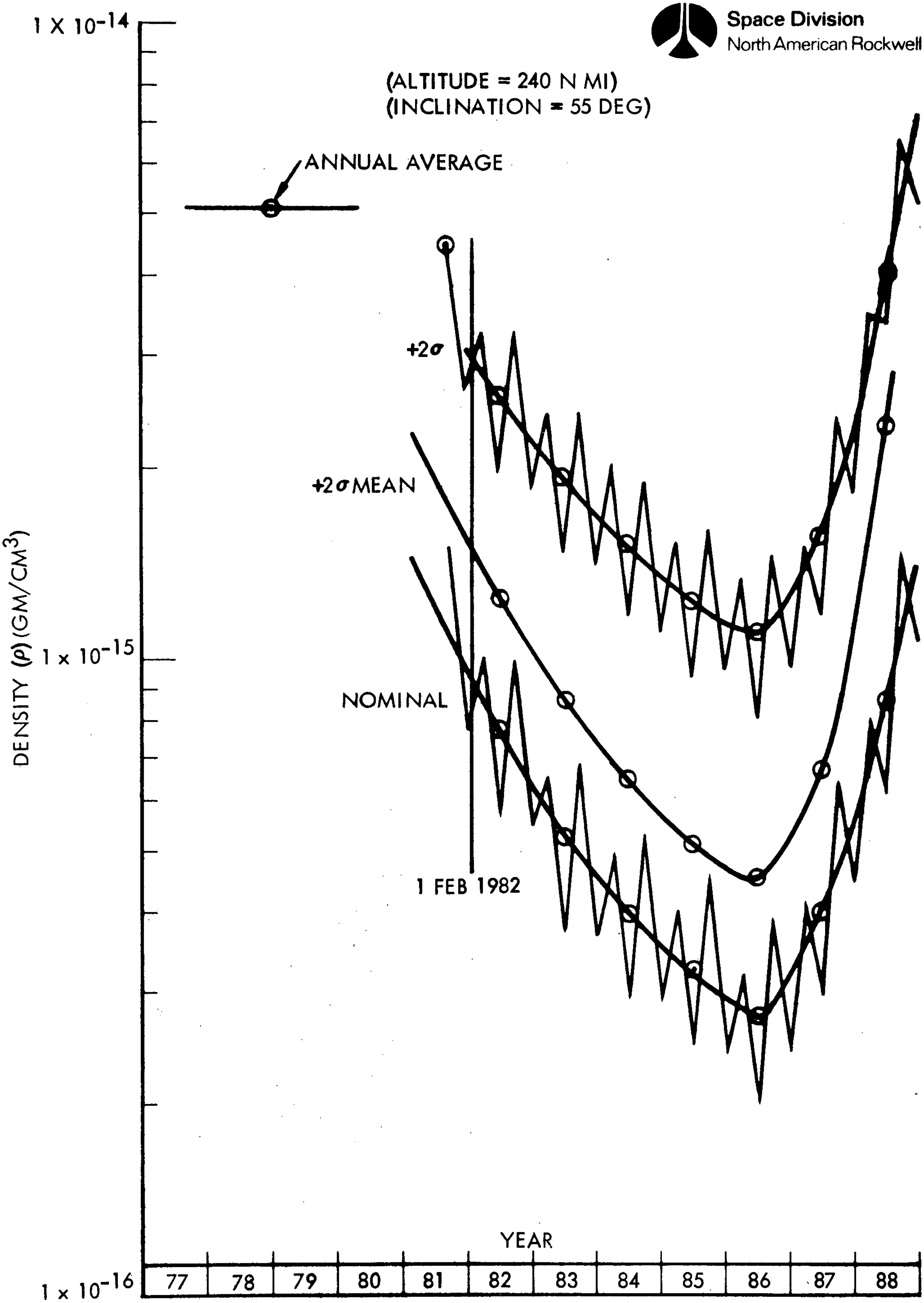


Figure 1-37. Atmospheric Density

Table 1-9. Equipment Sizing Criteria

Equipment	Atmosphere and Altitude
CMG's ECLSS/RCS electrolysis capability	240 nautical miles 2σ mean Jacchia atmosphere at February 1982
Solar array, end of life power	240 nautical miles 2σ nominal Jacchia atmosphere at February 1987
Logistic resupply	270 nautical miles Nominal Jacchia atmosphere at February 1982 to 1987

requirements for equipment sizing to perform the necessary orbit maneuvers were generated by using the 240-nautical-mile Jacchia atmosphere for February 1982 and the 270-nautical-mile Jacchia atmosphere for nominal resupply requirements.

The design-to atmospheric model for solar array sizing was set at the end of five years of initial station operation. The array must be sized to provide adequate power for electrolysis of water to supply RCS reactants that are a function of the atmosphere density. Other constraints used in deriving the impulse requirements were that orbit makeup would normally be conducted concurrent with CMG desaturation, and two RCS jets in the station X-Z plane would be used. Furthermore, the nominal time between CMG desaturation would not be less than 12 hours and venting of other gases and liquids would be scheduled during desaturation. This venting requirement provides a ten-hour clear period for earth survey and astronomy observations assuming two (2) hours will be adequate for the dissipation of vented gases and liquids. The effects of orbit makeup and CMG desaturation impulse as a result of atmospheric variation are presented in Table 1-10.

Table 1-10 shows that the RCS tanks have been sized to accommodate the highest 90 day impulse requirement. However, as previously stated, logistic resupply requirements are based on the 270-nautical-mile atmosphere. The initial RCS consumable value used in estimating the overall station resupply requirements was taken as 292 pounds of water per 90 days. Figure 1-38 shows how much RCS logistic water resupply requirements decrease in the years from 1982 to 1987.

Table 1-10. Atmospheric Model Impact Comparison
(IOC, February 1982)

Atmospheric Model	Initial Station	
	Impulse/90 Days (lb-sec)	Water Requirement/ 90 days (lb)
Jacchia 2σ mean 240 nautical miles (sizes solar array)	196,600	614
Nominal 240 nautical miles (sizes solar array)	149,000	465
Nominal 270 nautical miles (sizes logistic requirements)	93,400	292

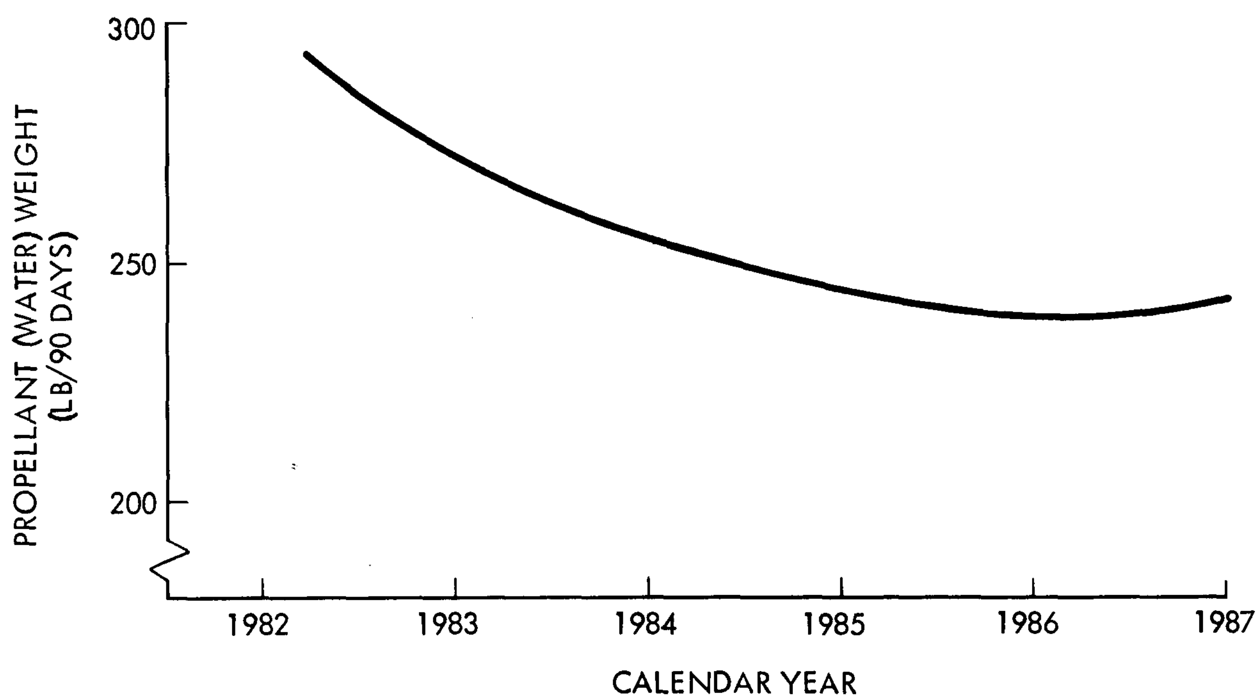


Figure 1-38. RCS Logistics Resupply Requirements

1.3 PERIODIC OPERATIONS

Periodic space station operations are those major activities that occur on a cyclic, recurring, intermittent, or infrequent basis concurrently with routine space station operations. The major periodic operations are logistics resupply of consumables and crew rotation by the space shuttle, the delivery and return of RAM's, and the replacement of the space station solar array. The frequency at which these operations occur is, in part, dictated by the scheduling of the experiments, as discussed in Section 3, Mission Sequence Plan.

1.3.1 LOGISTICS SUPPORT

Logistics resupply operations are the flight operations required to transport and return crewmen and to deliver cargo to the station. The frequency of logistic flights is dictated by the support requirements (consumables, spares, replacements, waste, down experiment data, and crew rotation), but is always less than 180 days, the maximum crew rotation interval. Station operations in support of logistics resupply operations consist of command control, berthing, crew and cargo transfer, and attitude and stability control operations.

In the logistic concept selected for the MSS, the cargo module is employed as a supply center, or pantry, for station and experiment consumables as well as providing the life support consumables for the 96-hour emergency requirement. In this concept, a cargo module is required continuously, and one is always berthed to either of the two forward Y axis ports on the CM.

A typical cargo module delivery/replacement begins with the shuttle delivery of the new cargo module to the vicinity of the station. The station then transfers to and stabilizes in an XPOP inertial attitude mode, and the shuttle is cleared to initiate berthing operations. The shuttle manipulator attaches to the station adapter on the -X axis CM port and berths the station to the shuttle passenger port. After the shuttle/station interfaces are connected and verified, the new station crew, if one has been brought up, exits the cargo module and enters the station through the shuttle. The new cargo module shuttle cargo bay interfaces are disconnected, and the module is lifted out of the bay and berthed to the "free" forward Y axis port on the CM by the manipulator. The used cargo module/station interfaces are then disconnected, and the module is detached and stowed in the shuttle cargo bay by the manipulator. After the used cargo module/shuttle interfaces are connected and verified, the shuttle/station interfaces are disconnected, and the shuttle is prepared for earth return. If a station crew is being returned to earth, the returning crew exits the station through the adapter and enters the used cargo module through the shuttle, after the cargo module/shuttle interfaces and cargo module habitable environment are established.

The scheduling of the logistics support operations depends on the scheduling of the space station operations defined by the Mission Sequence Plan. The Mission Sequence Plan, summarized in Figure 1-39, provides the time phasing of all program elements, including the shuttle support requirements. The Mission Sequence Plan (detailed in Section 3) defines the schedule for delivering the station modules, delivering and returning cargo modules, and delivering and returning space station crewmen. It also defines the scheduling of all FPE's identified in the 1971 Blue Book. The logistics support requirements, which are discussed in more detail further on, are summarized as well as the scheduling of all shuttle launches. The resultant operational program has a duration of approximately 16 years from the first space station module launch to the return of all crewmen after the completion of experiment operations.

Six months will be required for initial station buildup, with IOC occurring in January 1982. The station will operate at a six-man level for five years while experiments are conducted in six of the seven experiment disciplines. Initial operations will be primarily conducted in the GPL. However, the first attached RAM will be introduced midway of the first year of experiment operations, and the first detached RAM will be launched in the fourth year. As presented, the Mission Sequence Plan was developed on the assumption that each FPE will be operated for the minimum duration consistent with the achievement of significant objectives. Thus, each FPE will be accommodated at the earliest possible date.

The total logistics requirements necessary to support the space station operations and the experiment program defined by the Mission Sequence Plan are shown in Table 1-11. Approximately 1900 pounds per month will be required for basic operations of the initial space station, whereas 3600 pounds per month will be required for the growth space station. Based on the experiment scheduling previously identified, approximately 1000 pounds per month will be required for operations of the initial space station experiments, and 1800 pounds per month for the growth space station. The experiment logistics requirements shown are an average value of the requirements for consumables and experiment equipment that must be delivered during the operation of the space station. An additional logistics requirement is imposed by the need for oxygen and nitrogen for emergency operations. The resultant cumulative requirements are shown in Figure 1-40, where the lower line represents the cumulative requirements for basic station operations and the upper line represents the total, including experiment operations.

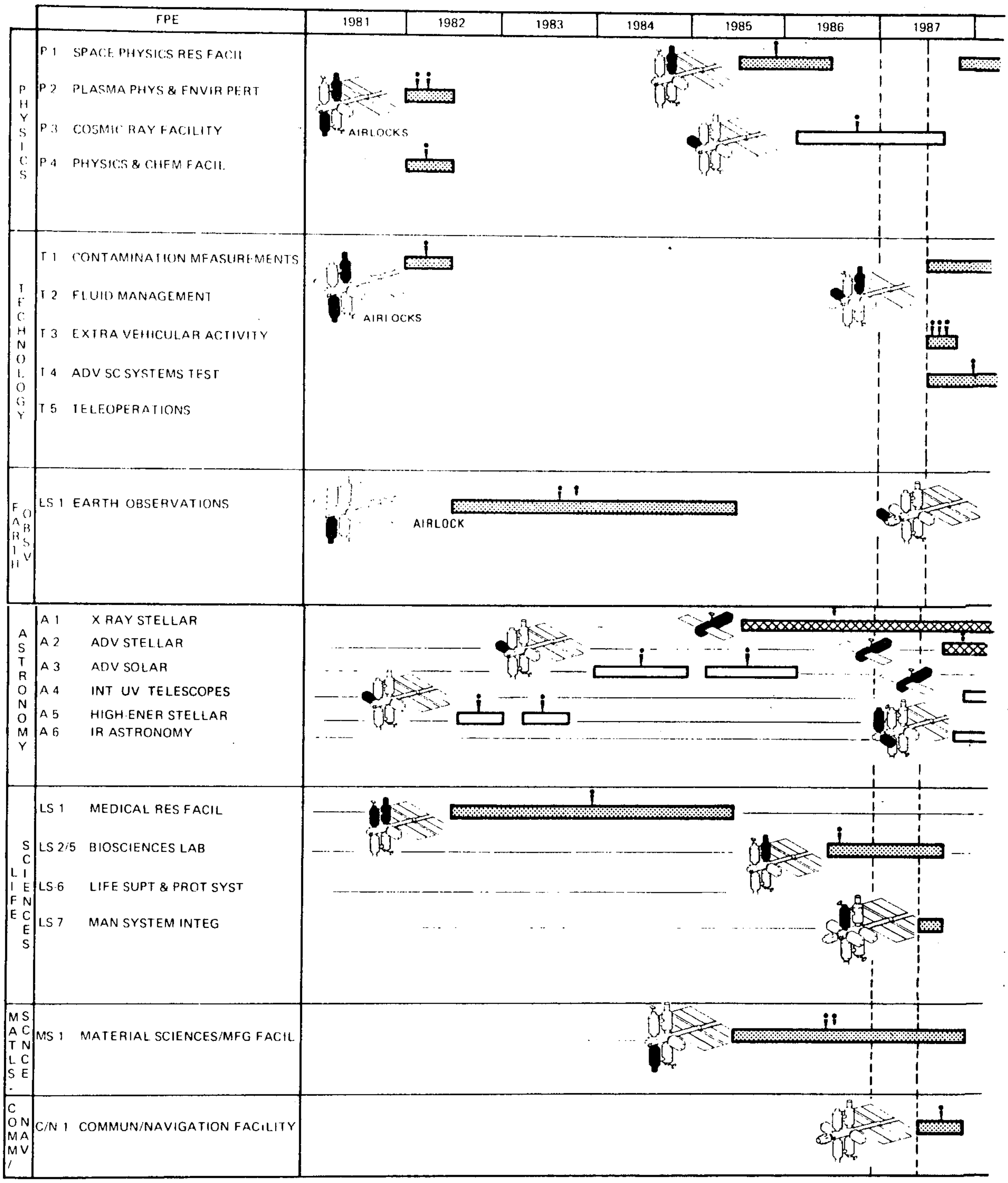


Figure 1-39. Mission Sequence Plan Summary
(Sheet 1 of 2)

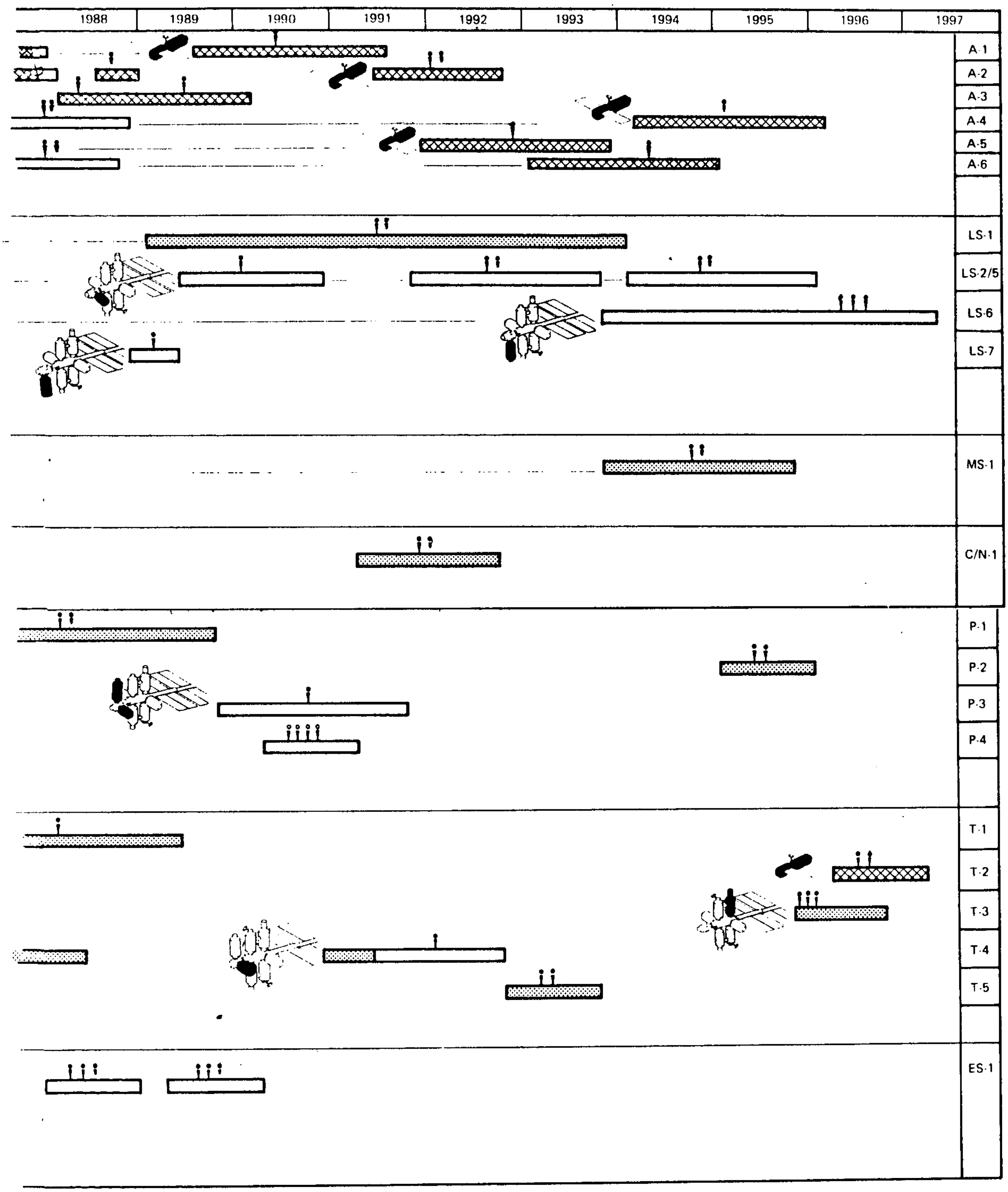


Figure 1-39. Mission Sequence Plan Summary
(Sheet 2 of 2)

Table 1-11. Average Station Resupply 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 – O_2	3	3
– N_2	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 HR) O_2	404	633
H_2	23	36
TOTAL EMERGENCY	427	669

*Includes RCS Impulse Requirements

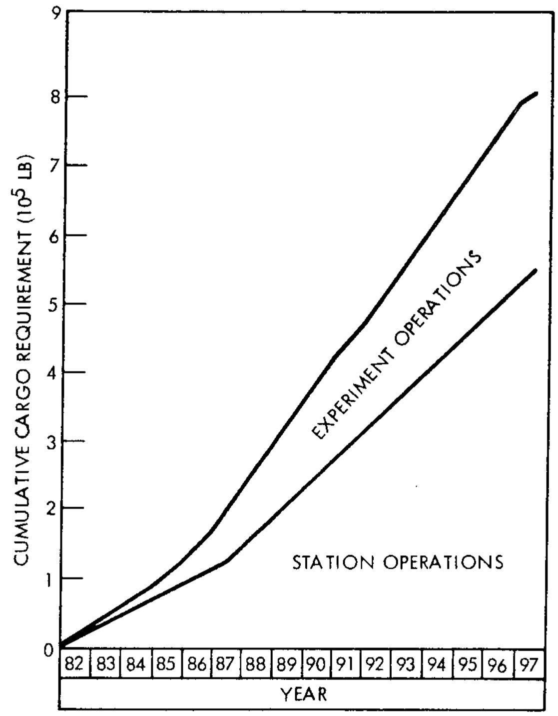


Figure 1-40. Cumulative Station Resupply Requirements

The resultant shuttle requirements for support of the space station are summarized in Figure 1-41 and Table 1-12 in terms of the missions required for the delivery of station modules, crew and/or cargo, RAM's, and RAM support sections. Six shuttle missions will be required for delivery of the initial space station modules, and an additional four shuttle missions will be required for buildup to the growth space station, including one launch for replacement of the solar array. Seventy-four shuttle missions will be required for the delivery of crew and cargo, and 51 flights will be required for RAM's and support sections. The shuttle launch frequency for delivery of crew and cargo is dictated primarily by considerations of crew rotation, because these missions occur at a frequency that permits the concurrent delivery of the cargo necessary for the support of the station and experiment operations. The logistics capability for crew and cargo delivery is based on a cargo module capacity of approximately 11,800 pounds per flight for shuttle missions, which concurrently deliver up to six crewmen. As previously noted, the cargo requirements will be approximately 2900 pounds per month for the initial space station, and 5400 pounds per month for the growth space station.

In addition to the shuttle missions required for the delivery of the station modules and for crew and cargo delivery, additional shuttle missions

Table 1-12. MSP Statistical Summary

		81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Station Modules	Up	6						4										
	Down							1										
Cargo Modules	Up		5	5	3	3	4	4	6	5	5	5	5	5	5	5	5	3
	Down		4	5	3	3	4	4	6	5	5	5	5	5	5	5	5	4
RAM's	Up		1	1	1	2	1	3	4	4	1	3	1	2	1		1	
	Down			2		1	1	1	4	3	3	3	1	1	1	1	2	2
Support Sections	SS1																	
	SS2																	
Crewmen	Up	*	30	30	18	18	24	26	24	24	24	24	24	24	24	24	24	12
	Down		24	30	18	18	24	20	24	24	24	24	24	24	24	24	24	24
No. of Shuttle Flights		6	6	8	4	7	5	12	12	11	9	11	7	8	7	7	8	7

Initial Buildup (81); Initial Operations — 6 Men (82–86); Growth Buildup (87); Growth Operations — 12 Men (88–97)

*Excludes crew for buildup

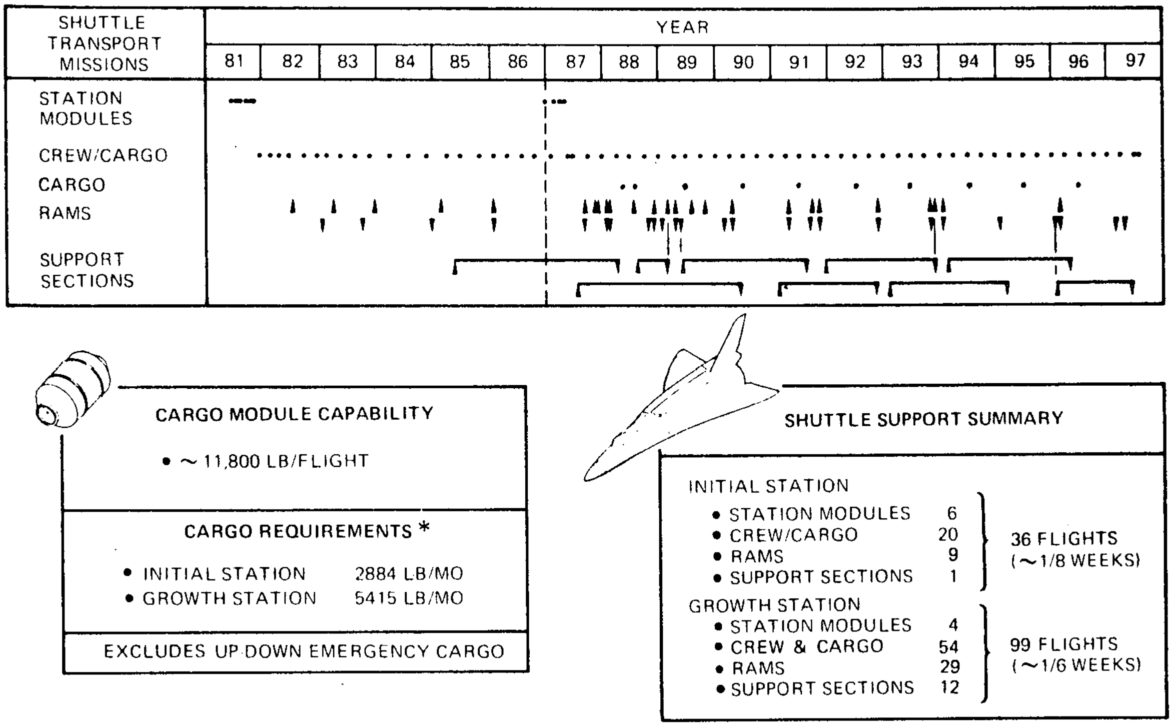


Figure 1-41. Shuttle Support Requirements Summary

will be required for the delivery of RAM's and the support sections necessary for the operation of detached RAM's. For the reference experiment program, only two support sections will be required to support the operations of detached RAM's. These support sections and RAM's will be periodically returned to earth for refurbishment and redelivered to orbit for further utilization.

The resultant total shuttle support requirement is 36 flights for the initial space station and 99 flights for the growth space station, including the four shuttle launches for delivery of the station modules necessary for buildup to the growth space station. The resultant launch frequency is approximately one every eight weeks for the initial space station and one every six weeks for the growth space station.

1.3.2 RESEARCH AND APPLICATION MODULE (RAM) DELIVERY

RAM delivery operations include the shuttle operations needed to deliver attached and detached RAM's to the station. The timing of these flights will depend on the experiment program schedule. Station operations in support of these operations include command control, berthing control, and attitude and stability control. A typical RAM delivery begins when the shuttle delivers the RAM to the station. The station transfers to and stabilizes in an XPOP inertial attitude mode and the shuttle is cleared to initiate berthing operations. The shuttle manipulator attaches to the station adapter on the -X axis CM port and berths the station to the shuttle passenger ingress/egress port. After the shuttle/station interfaces are connected, the RAM is lifted out of the cargo bay and berthed to the designated aft Y axis port on the CM by the manipulator. If no RAM's are to be returned to earth or replaced in orbit, the shuttle is detached and separated from the station and both elements (station and shuttle) are configured for their respective mission phase. If a RAM is to be returned to earth or placed in orbit, the manipulator of the attached shuttle will latch onto the designated RAM, the station/RAM interfaces disconnected, and the RAM detached and stowed in the shuttle cargo bay. The shuttle/station interfaces are then disconnected, the shuttle separated, and both elements configured for their next mission phase.

1.3.3 SOLAR ARRAY REPLACEMENT

Planned or unplanned solar array replacements may be required during the operational life of the MSS. The primary solar array replacement operations consist of a shuttle launch to deliver the replacement array and return the used array; a power transfer to the fuel cell power system; electrolysis units shutdown; folding back (retracting) the old array panels; detachment and stowage of the used array; attachment of the new array to the boom; deployment of the new array panels; transfer of the power source from the fuel cell to the solar array; and electrolysis units activation.

During solar array replacement, reactants for fuel cell operation at an average 10 kw usable for five days must be provided as well as a five-day supply of gases for station atmospheric makeup and RCS requirements. These consumables and associated storing and transfer equipment will be delivered on the same launch that brings up the new solar array.

The operational requirements attendant with solar array removal and replacement are illustrated in the sequence of sketches in Figure 1-42. The sequence begins after the shuttle has removed the berthing adapter from -X axis station location and has berthed to the power boom (the solar arrays have been retracted and folded and station power is obtained from the fuel cells). The old array is separated from the power boom using the manipulator. The shuttle moves to a stationkeeping position to perform the array exchange shown in sketches 4 through 7 (Figure 1-42). The old array is berthed to the fixture at the end of the cargo bay and the new array is positioned on the berthing adapter (sketch 5). Before reberthing the new array to the station, the launch support structure (which supports the array in the cargo bay) is moved from the new array to the old array as shown in sketch 6. The old array is then stowed in the cargo bay. With the manipulator, the power boom of the station is captured and berthed to the new array. After

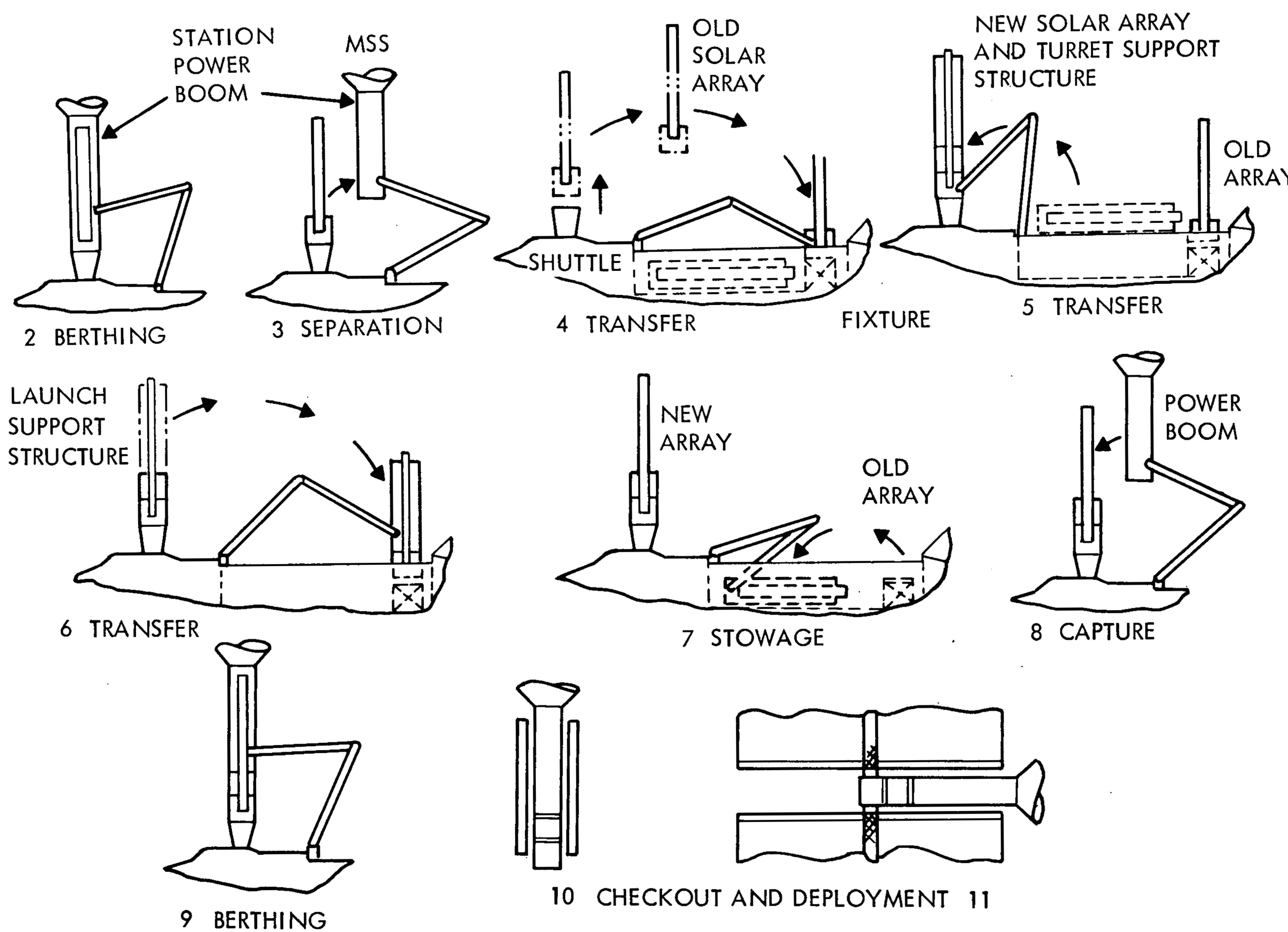


Figure 1-42. Solar Array/Turret Replacement Sequence

shuttle/adapter separation, the new solar arrays are unfolded, extended, and activated, and the berthing adapter is replaced on the core module -X axis port.

1.3.4 SPACE STATION DISPOSITION

Upon completion of routine space station operations, the modules will be returned to earth by the shuttle. Research and application modules will be returned first followed by a planned disassembly of the station in the reverse sequence used for buildup. The primary exception to the reverse sequence is that a cargo module will remain attached to the core module to provide storage for fuel reactants (needed for electrical power) until all the station modules and the power module are returned. The final return sequence will be: station modules; power module; cargo module; and core module.

2. CREW OPERATIONS

2.1 CREW OPERATIONAL AND ORGANIZATIONAL CONCEPTS

The crew is a critical part of the MSS system and, like other valuable resources of this system, must be used effectively. The MSS system crew consists of a large number of trained individuals whose activity and partipation vary widely over the many years of the program operation. The nominal crew size for the initial space station is six members at any specific time. This crew size represents a range of technical and scientific disciplines operating as independently as any naval vessel or remote expedition with periodic logistics support. This independence from ground support requires skills and capabilities to conduct all normal operations and maintenance and emergency repair as well as a comprehensive program of research, investigation, and development operations. Technical support and direction will be available from the ground through the MSS communications system.

The application of some formal organizational guidelines appears necessary if the desired degree of operational effectiveness is to be achieved and maintained. At the minimum, the requirements of safety dictate the use of an authoritative commander. In addition, the duality of the station mission, i.e., perform experiment operations and operate the vehicle, indicates the need for delegation of responsibility.

2.1.1 ANALOGOUS INSTITUTIONS

A review was conducted of the organizational and personnel mix complements of certain civilian and quasimilitary organizations. Included was the North American Rockwell Science Center. The principal similarity is that the primary objectives of the science center are to conduct research and experimentation. The center is dissimilar in that, though it is self-sufficient from morning to night, it does not have 24-hour personal living facilities, nor is it a complex, mobile vehicle in a hazardous environment. Also, the personnel size is significantly larger. The organization is based primarily on a group of scientific specialty cells, consisting of scientists and support technicians. General technical support functions are shared by all units. The total organization, including small administrative units, is under the direction of a company executive. A comparison of the Science Center organization structure with that of the MSS is shown in Table 2-1.

Table 2-1. Selection of Space Station Crew
Using NR Science Center Analog

Job Specialty	Manpower Distribution (percent)	Analog to Space Station (percent x 6)
Executives	1	0.2
Upper management	2	
Secretaries	11	Allocated
Ph.D group leaders	6	2.2
Ph.D experimenters and theorists	26	
Direct associates and technicians	25	1.7
Shop supervision	1	0.7
Designers, mechanics, technicians	9	
Services supervision	4	1.2
Services personnel	15	
Total	100	6.0

A Coast Guard vessel, U.S.C.G. Burton Island, was surveyed on the basis that it supports the conduct of scientific investigations in the Antarctic. Other similarities are that the vessel operates self-sufficiently and nearly autonomously for extended periods (about nine months) with a multi-system vehicle in a hazardous environment. Dissimilarities include the fact that the vessel does not provide experiment facilities per se, that scientists are quartered aboard for relatively short segments of the mission, and that they are outnumbered by the large crew size about 30 to 1. The crew is organized according to Coast Guard or Naval convention, with an authoritative commander, and various subordinate ranks. The ship's captain has no control over the scientists, who have no control of any ship's functions other than to request support for scientific activities. A comparison of the organizational structure of the Burton Island with that of the space station is shown in Table 2-2.

Other types of U.S. Navy vessels which operate under the control of Military Ships Transport Service (MSTS) are manned by civil service crews and perform scientific investigations under the direction of an onboard crew of investigators. The ship's captain is totally responsible in matters affecting the safety of the ship, and has the final say in operations recommended by scientists. The scientists generally direct the desired course and objective. The scientists are coordinated by one of their number for purposes of efficiency and commonality. Table 2-3 compares crew-distribution analogs with the selected crew for routine activities.

Table 2-2. Comparative Organizational Breakdown - U.S.C.G. Burton Island Versus Space Station

	Manpower Distribution (percent)	Analog to Space Station (percent x 6)
Officers	7.5	0.6
Administrative	10.0	0.8
Utility systems	6.0	0.5
Electronic systems	9.5	0.8
Seamen	25.0	Allocated
Enginemen	12.0	0.9
Damage and firemen	12.0	0.9
Commissary (cooks)	8.0	0.7
Scientists	6.5	0.5
Medical	2.0	0.2
Pilots	1.5	0.1
Total	100.0	6.0

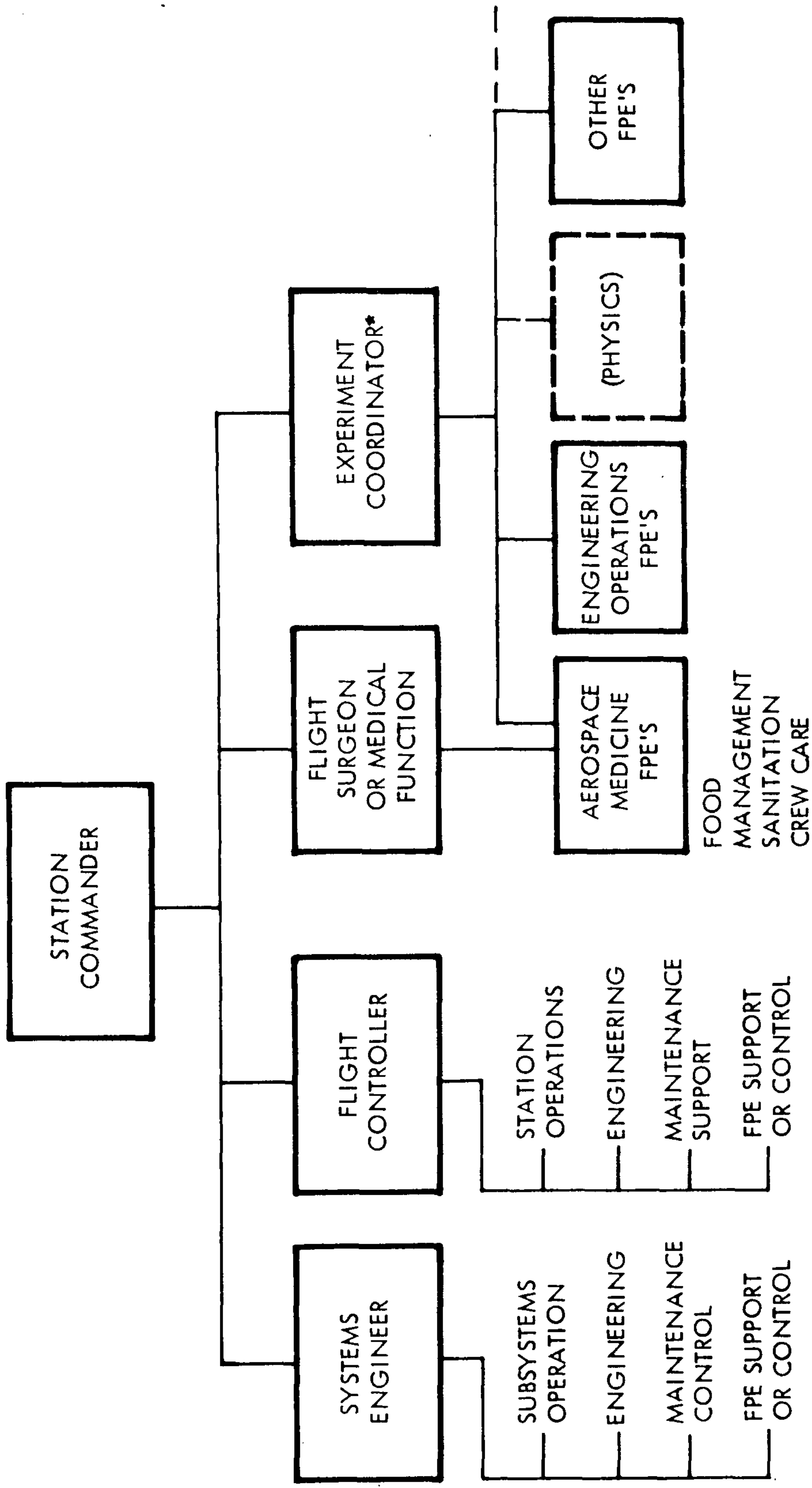
Table 2-3. Selected Crew Versus Crew-Distribution Analogs

Function	NR Science Center	USCG Burton Island	Selected Station Crew
Executive / Administrative	0.2	0.6	0.4
Scientists (experimenters)	2.2	0.5	3.5
Support technicians	1.6	3.1	0.8
Station operations	0.7	1.0	0.6
Station services	1.3	0.8	0.7
Total	6.0	6.0	6.0

2.1.2 RECOMMENDED ORGANIZATION

The space station shall be under the control of one man who is responsible for the safety and operation of the vehicle. This station commander should delegate command responsibilities to other individuals to assure operation and safety of all onboard systems and the accomplishment of maintenance and housekeeping tasks, and to perform all basic flight operations and mission tasks. This delegation provides backup to the command function and makes maximum use of onboard specialties. Two other areas of responsibility not associated with station command are to coordinate the requirements and scheduling of all experiment activities, and to monitor health and life-support conditions. These delegations are not necessarily assigned to four different crew members, but are dependent on crew makeup at a given mission time. No purpose would be served in identifying these individuals by a title other than that reflected by their job, since a rank would be meaningless. These functions direct and support any necessary technician support personnel and would act for the commander as necessary under appropriate procedure or precedence.

Each FPE and discipline should be under the control of one man, operating independently except for the necessary liaison with other experimentors via the experiment coordinator and with the approval of the station commander. The crewman assigned to act as an experiment coordinator would work to achieve efficiency, commonality, and to establish priorities for the various experiment disciplines, as well as directing or operating his own specialty areas. The primary purpose of this job is to present unified and coordinated requirements to the station commander. Figure 2-1 shows the recommended space station organization, subject to variations in skills and manpower needs.



*THE EXPERIMENT COORDINATOR CAN BE SELECTED FROM ANY DISCIPLINE

Figure 2-1. Recommended Organization

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2.2 CREW OPERATIONS CONSTRAINTS

Various missions, mission support, station, and experiments elements are constraints for crew operations. These are sometimes subject to trade-offs but, in all cases, require integration and scheduling to establish crew operations and skill requirements.

2.2.1 CONTINUOUS EXPERIMENT FUNCTIONS

Experiment activities such as earth and celestial observation are available for scheduling throughout a 24-hour period. Regardless of true workload, three men could profitably be assigned to participate in the experiment operation. Functions of this nature thus tend to constraint crew duty cycles. The tradeoff involved is the value of continuous observation in one discipline versus the application of the extra man-hours to a different discipline.

2.2.2 ON-ORBIT MAINTENANCE

The station-life time which dictates the on-orbit maintenance concept requires that the crew makeup always contain at least a minimum of skills and manpower available for maintenance. The minimum is based on safety and criticality considerations, as well as on the tradeoff between cost of on-orbit manpower versus cost of short-term logistics support (ground crews). The maintenance workload is established to correlate with the number of skilled personnel who would be required on orbit to respond to safety needs.

2.2.3 ROUTINE ORBIT OPERATIONS

The nature of the nominal earth orbit is that flight operations are generally routine, with infrequent special flight operations. This requires design of equipment and possibly special job aids to maintain proficiency in complex operator tasks over extended periods.

2.2.4 CREW STAY TIME

The necessity of qualifying crews for extended zero-g operations constrains the stay times of the early crews.

2.3 CREW DEFINITION

For this study, the on-orbit station crew is divided into three functional categories: flight operations crewmen, support technicians, and scientists/experimenters. These terms are oversimplifications used to designate basic skill and background requirements, and should not be interpreted as specific areas in which a crewman will be exclusively utilized. Since the primary purpose of the MSS is to perform experiments, it is expected that the entire crew will be involved to some degree in the experiment activities, with station operations as a part-time activity by certain eligible crew members.

2.3.1 FLIGHT OPERATIONS PERSONNEL

This term applies to crewmen considered "next-generation" astronauts (in the system sense, not biological). In general terms, this is a trend away from the military and engineering test pilot and toward the systems engineer or operator of complex automated systems, perhaps analogous to the flight controller in some respects. Flight operations personnel are responsible for station operation, management, and maintenance (commander, flight controller, and systems engineer).

2.3.2 SUPPORT PERSONNEL

The term "technician" generally implies an individual well grounded in the technical skills, including manual and cerebral capabilities. It is not intended to rule out undergraduate academic training. On the contrary, it is anticipated that degrees for an engineer, in some cases, or for most laboratory technicians, in other cases, are virtual requirements. In the areas of electrical, mechanical, and electronics, these persons support both the station and experiment operations.

2.3.3 EXPERIMENTS PERSONNEL

The term "scientist" is generally used to identify individuals who are specialized in more classical disciplines and who generally have achieved advanced degrees and, perhaps, recognition in their field. These individuals are responsible for the conduct of experiments (astronomer/astrophysicist, material scientist, medical doctor, etc.).

2.4 NOMINAL CREW (INITIAL STATION)

Selection of crews for the initial station is based on qualifications determined by the skills and disciplines needed to control, operate, and support the MSS first and then the FPE's as time, skill, and disciplines allow. Initial crew makeup consists of three operations personnel, two support personnel, and one scientist (refer to Table 2-4). As a general rule, each crew member is assumed to have a basic skill background (eight to ten years training and experience) and a capability of achieving a level of proficiency in two similar fields.

It is estimated that average workload allocations for the initial station will require approximately 40 percent of the available man-hours for vehicle operations and 60 percent for FPE activities. For the growth station, the man-hour distribution ratio is expected to be 25 percent for vehicle operations and 75 percent for experiments.

Table 2-4. Nominal Six-Man Crew Makeup and Work Allocations (Initial Station)

Position	Basic Skill and Background	Compatible Experiment Skill Area	Average Man-Hours/Day	
			Station	Experiments
1. Commander (28)	Engineering, test and operations, command/control	Advanced technology, material processing	4.3	5.7
2. Flight controller (29)	Engineering (electronic), navigation and orbital operations	Commander/navigation, advanced technology (FF RAM monitoring and control)	5.9	4.1
3. Systems engineer (30)	Engineering (aeronautical/ mechanical)	Life support, man-machine interfaces, etc.	5.9	4.1
4. Electromechanical technician (12)	Engineering (mechanical), test and maintenance	Various equipment operator skills	3.8	6.2
5. Electronic engineer (13)	Engineering (electronic), test and maintenance	Various equipment operator skills	3.8	6.2
6. Experiment coordinator or scientist	Medicine or astronomy or physics, etc. - program phased	Generally by discipline	1.1	8.9
		Total	24.8	35.2

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2.5 CREW PERSONAL REQUIREMENTS

As crew sizes and mission durations increase, the need for detailed definition of crew personal requirements takes on added importance. In U.S. spaceflights to date, the tasks demanded of mission timelines, although fulfilled remarkably well by the various crews, have often been in excess of levels desirable for long-term space flight. For extended-duration missions, the problem is one of pacing. Preliminary studies suggest that the safest course for extended periods, is to aim for conventional, earth-based-type schedules, unless the particular type of mission or experiment strongly demands alternative scheduling. This means that crews should normally maintain a regular, diurnal schedule, more than seven hours of sleep per day, and work should not exceed 10 hours per day. Paying attention to these principles should enhance the probability of mission success, while totally disregarding them would almost surely result in serious mission degradation or failure because of degraded crew efficiencies.

2.5.1 PERSONAL TIME

A nominal value of 14 hours per man-day is established for crew personal time. This includes the following:

Activity	Time Allocation (hours)
Sleep	8.0
Eating	2.5
Recreation, exercise, and medical	2.5
Personal hygiene	1.0

Although the total personal time value appears higher than that deemed essential for routine operations, it does allow for greater flexibility of scheduling, and permits contingency time encroachment without causing undue crew stress. There is no intention to specify individual time allowances. Individuals might spend two hours on personal hygiene. Many people require more than 8 hours or as little as six hours of sleep, etc. The purpose here is to establish planning norms of 14 hours personal and 10 hours work, with optional workloads available for those who desire additional work. A discussion of the personal time breakdown follows.

Sleep

Sleep periods are scheduled for about eight hours, with simultaneous sleeping of all or the majority of the crew preferred. The criterion of concurrent sleep is to assure maximum quiet and thus achieve seven-plus hours of undisturbed sleep for each crewman. Slight differences in start and stop times may be required to alleviate overloading of personal hygiene and dining facilities. Station design should not be constrained to this concept, however, and should allow split-shift or continuous-shift operation.

Contingency schedules should allow at least four consecutive hours for sleep.

Meal Periods

Eating periods of 45, 45, and 60 minutes per day are allocated for daily food consumption. Meal periods are shared by the crew to the maximum extent, limited largely by the availability of dining accommodations. The dining area is sized to accommodate a minimum of six crewmen at a time.

Recreation and Exercise

Provisions for recreation and exercise help maintain the morale and efficiency of long-term mission crews, for physiological as well as psychological reasons. Approximately 2.5 hours per man per day are established for this purpose.

A definite exercise regimen is required to counter the effects of weightlessness on physiological functioning, as well as for the usual physiological benefits of exercise. The exercise area should be large enough to accommodate two men and exercise equipment at one time. The biomedical time allocated indicates a requirement for some continuing crew monitoring and conditioning throughout the life of a mission. This time would be preempted by any specific biomedical research program.

Recreational facilities are provided to combat confinement, enhance sensory variation, and reduce social friction, and to supply sufficient variety to permit shifts in interest after extended time periods. These facilities include book, film, and educational provisions, and incorporate individual preferences. In general, crew recreational periods should be concurrent to permit as much social interaction as desired. The proportion of the crew using the facilities at one time may vary from 50 to 100 percent. Each crewman will have freedom of choice in recreational materials in addition to the provisions built into the station.

Potential activities whose recreational validity may be questionable but are nevertheless worthy of consideration concern the possible use of tobacco products and alcoholic beverages by those crewmen so inclined.

Although no hard data are available, the general consensus is that additional filtering requirements (with possible significant system impact) may be imposed on the ECLSS if smoking is permitted. This, coupled with health hazard warnings presently being issued by the medical profession and by the U. S. Department of Health, leads to the recommendation that no use of tobacco products be allowed. On the other hand, occasional moderate was of alcoholic beverages might be useful in reducing tensions and stimulating social interaction. This, of course, must be weighed against possible adverse effects and political ramifications. Nevertheless, it is recommended that provision be included for consumption of alcoholic beverages, with the control of their use being available to the spacecraft commander and doctor.

Personal Hygiene

A nominal value of one hour per man per day has been allotted for personal hygiene activities. Although the frequency of bathing in western civilization is much greater than is justifiable for health reasons, regular bathing is recommended on long-duration missions to assure social acceptability and for the individual satisfaction it provides. The capability for two showers per man per week is considered the minimum requirement to satisfy this need.

Staggered scheduling will be observed to reduce facilities use, with peak morning and evening periods staggered to accommodate approximately one-third of the crew. Crew-time estimates are approximately 15 to 20 minutes for morning and evening use and 5 to 10 minutes at other times.

Sufficient quantities of expendable hygiene items (soaps, body wipes, bactericides, dentifrice, and temporary dental restoratives) must be provided as well as hygiene procedures and equipment which are effective in zero g. The hygiene equipment (i. e. , hair and nail clippers, shavers, and whole-body showers) must be capable of functioning properly over an extended period with minimal maintenance and repair.

2.5.2 WORK SHIFTS

Crew availability to accomplish nominal station workload requirements has been established at 60 man-hours per day for the initial station and 120 man-hours per day for the growth station. Selection of the crew shift schedule that best satisfies this requirement will, of course, depend more on such factors as the need for time sharing of work space and facilities than on individual preferences.

Concurrent, consecutive, or irregular shift operations all offer certain advantages. However, each must be investigated in depth to discover which schedule yields the best performance. Of primary importance is the need to retain maximum scheduling flexibility. System constraints that would preclude a single-shift operation or preclude continuous operation are not imposed on the station design. As a general rule, baseline scheduling criteria will observe a single-shift operation, with second or third shift assignments as exceptions to this rule, and only for demonstrable requirements.

2.5.3 DUTY CYCLES

Most studies concerning work-rest cycles generally conclude that a 24-hour period, distributed in a manner to which man is already adapted, is the best scheduling criteria. When a typical cycle is imposed, man's physiological rhythms may be expected to show some adaptation to the non-24 hour periodicity—but adaptation is not likely to be uniform for all individuals. This underscores the desirability of pre-adaptation to a given schedule if that schedule is to differ significantly from the normal regime of 16 hours of wakefulness and 8 hours of sleep. Additionally, the scheduling of crew activities must not merely avoid gross overload; it must be structured to combat gradual degradations in interest and capacity. Continuous work periods without a break should not exceed four hours in length. Sleep periods should be arranged so they will come at essentially the same time each day so that adjustments to the circadian rhythms will be facilitated.

Table 2-5 summarizes the crew duty cycle requirements.

Table 2-5. Nominal Crew Duty Cycle

Activity	Man-Hours
REQUIREMENTS	
Work	10.0
Eating	2.5
Sleep	8.0
Personal and hygiene	1.0
Recreation, medical, and exercise	2.5
SCHEDULE CRITERIA	
Medical and Exercise. Consecutive so as to reduce equipment duplication and ensure availability of medical skills.	
Work and Sleep. Concurrent, with slight differences in start and stop times to reduce loading of eating and personal hygiene facilities. Second- or third-shift assignments are exceptions to this rule, and are only for demonstrable requirements.	
Eating. Crew size: 5 or less, concurrent; 6 to 12, 50 percent to 100 percent	
Personal Hygiene. Random periods, 45, 45, and 60 minutes, with peak a.m. and p.m. periods and a staggered schedule of about 33 percent of the crew to reduce facilities use. Periods - 15 to 20 minutes a.m. and p.m., 5 to 10 minutes in between.	
Recreation. Concurrent, generally, to permit as much social interaction as crew desires. Percent using facilities varies with crew size, as follows: 7 to 12 - 70 percent to 100 percent, concurrent.	

2.6 VEHICLE OPERATIONS

The following paragraphs define the crew activities associated with the operation of the initial MSS and its subsystems. They cover all on-orbit functions and the crew time requirements associated with their performance, except those dictated by conduct of experiments. Vehicle operations are categorized as flight operations, administration and management, maintenance, and housekeeping and sanitation.

The operation functions of each of these six categories have time-related characteristics such as routine operations (normally occurring every day), periodic operations (occurring at regular intervals other than in one day), and random operations (not occurring at any regular interval). Crew time estimates are made in each category to aid in establishing the number of personnel assigned to each function.

The equivalent manpower requirements for station operations (initial station) are estimated at 24.8 man-hours per day. These requirements are summarized in Figure 2-2.

2.6.1 FLIGHT OPERATIONS

The crew will include personnel skilled in control and operation of spacecraft and their subsystems. However, with certain exceptions, the flight maneuvers performed in current spacecraft and more directly associated with pilot skills will not be required. Rather, the functions will be mainly those of a systems engineering operation and will be largely routine but considerably abbreviated by elimination of repetitive tasks.

The performance requirements for the guidance and control subsystem are currently dictated by the earth observation and astronomy experiments and by autonomous mission planning functions. In order to satisfy these requirements, it is estimated that the navigation equipment will operate continuously. The primary method of navigation employs a star tracker and horizon scanners to perform star local-level measurements. The sensor outputs are filtered to provide continuous local-level attitude-control information and are periodically sampled for navigation update. This method has the advantage of being automatic and autonomous. Manual navigation is a backup method to provide navigational data if known landmarks are tracked or to estimate the location of targets of opportunity in support of earth-viewing experiments. The estimated crew time requirement for manual navigation sightings is two man-hours per day.

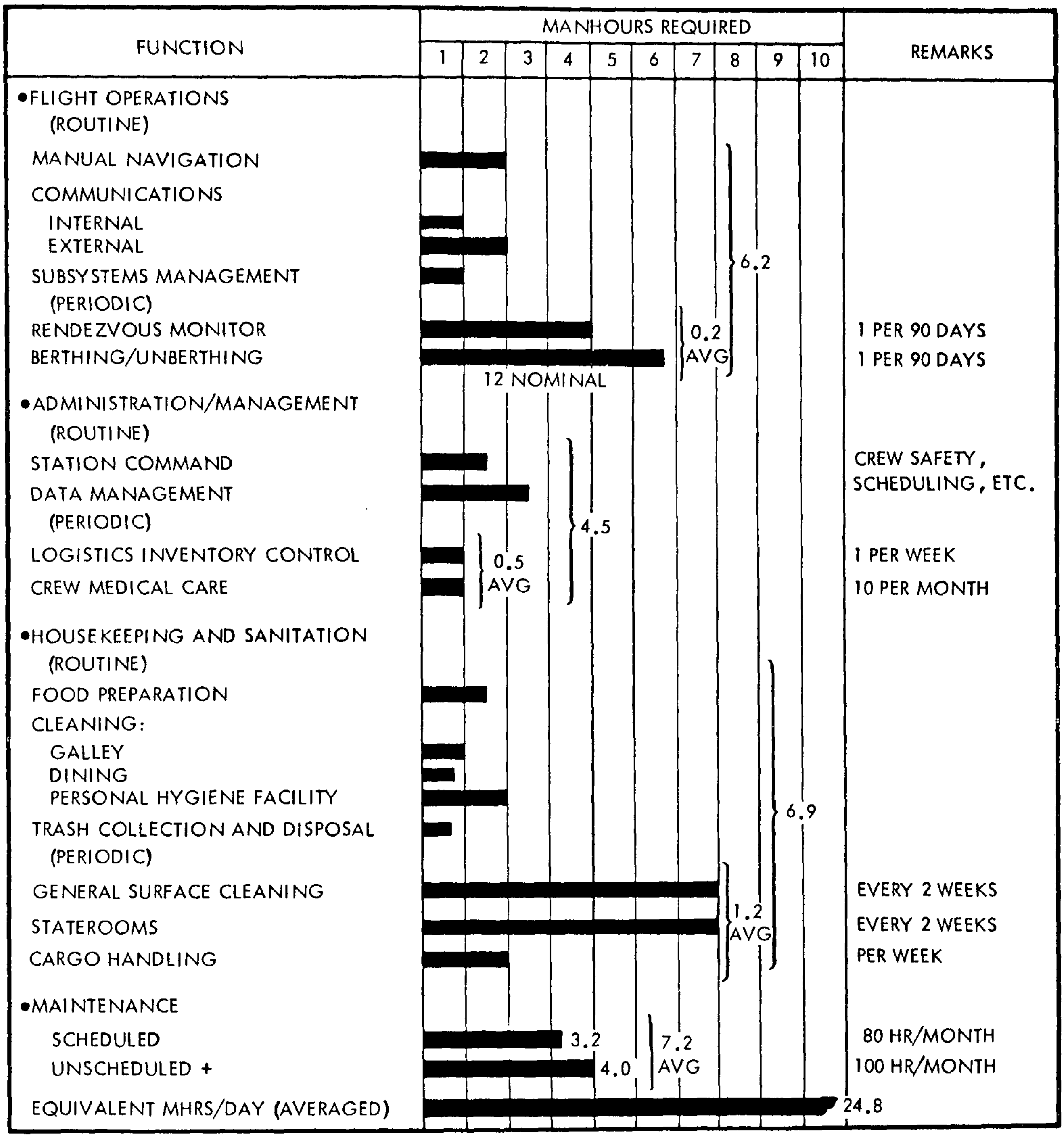

Figure 2-2. Station Operations—Crew Support Summary (Initial Station)

Station crew requirements are also affected by shuttle orbiter operations. Basic flight operations requiring periodic crew support are those connected with rendezvous and berthing.

Space station crew duties start with advice from the ground on the planned shuttle launches and times. From shuttle launch to rendezvous, the station receives updated time and position data and is prepared to provide mission control and tracking support to the ground or shuttle. While the shuttle is in coelliptic orbit, before terminal phase, the crew initiates continuous open communication and tracking with the shuttle that will continue until after berthing. However, tracking is not required after the final terminal phase of rendezvous. Crew time requirements in command and control for shuttle minimum phase angle launch or FPE retrieval rendezvous and berthing are two hours continuous plus two hours in 20-minute segments for one man. For a maximum phase angle shuttle insertion, they are two hours continuous plus three hours in 20-minute segments for one man.

Space station crew requirements during berthing operations are to retain voice and data communications with the shuttle via radio frequency (RF) until hardline attachments are made. Closed circuit television (CCTV) also will be monitored up to hard berth, both station and shuttle verification of berthing completion being communicated by both station and shuttle to the shuttle crews. At least one crewman will stand by the berthing hatch with capability for visual monitoring and voice communication. His primary function will be to verify physical readiness of the berthing port, along with alignment of both berthing interfaces, to accomplish hatch operations and assemble interfaces after docking. The control center operations require two men up to 15 minutes after berthing. The berthing port observation and operation will occupy one man for 30 minutes before and after berthing (this does not include complete interface assembly).

Requirements for crew participation in routine communication functions can generally be divided into two functional areas: intercommunications between modules, compartments, and subsystems of the space station, and those involving communication links between the station, shuttle, and ground. Also included is crew time for experiment communications processed through or handled by the station control center.

Crew time requirements for conducting routine internal communications are estimated at one man-hour per day. Included are the intercommunication of intelligence between compartments, subsystems, integral experiments, attached modules, and control centers, and to the external communication links. This intelligence consists of voice, audio alarm, video, and public address information; operations, maintenance, and experiment data; control and display signals; and audio-video information.

The equivalent of two man-hours per day has been allotted for conducting routine external communication functions. Included are the crew performance requirements associated with transmissions from the space station to ground, ground to station, and space station to shuttle and detached modules. Information to be handled includes image, voice, telemetry, text, hard copy, and command transmissions. The communication link between the station and the ground is by direct transmission or through the tracking data relay satellite system.

Subsystem management encompasses the crew tasks associated with preparing the utility subsystems for operation during various mission phases, operating these systems, and maintaining subsystem status. The utility system management functions will normally be performed with minimum crew participation. Maximum use is made of automatic techniques for data collection and evaluation. Crew time and skill will be required only for evaluation of displayed parameters and to assess subsystem compatibility with mission plans. Crew performance to support the subsystem management functions is estimated at one man-hour per day.

2.6.2 ADMINISTRATION AND MANAGEMENT

This functional area encompasses all tasks associated with station command, operation of the data management subsystems, logistics inventory and control, and crew care activities. Equivalent man-hours required to accomplish the average daily administration and management functions are estimated at 4.5 man-hours per day. Administration and management include any function associated with the control of operations of the station and the conduct of its mission that affects the safety or day-to-day living needs of its crew. Mission management support, i.e., long-range planning, scheduling, and logistics inventory control functions, will be provided through the ground-based mission management system. On-board execution of these functions (mission control), however, will be under the administrative direction of the spacecraft commander. While normally subservient to the needs of the experiment program, station operations may at the discretion of the spacecraft commander take precedence over experiments. Such changes in priority will normally be to maintain a viable safety management program and to preclude or counteract any outright emergency. Priority changes may also be justified on the basis of significant operational efficiency.

Command

Station command encompasses the command decision tasks—based on the mission planning and operations scheduling functions—to assure that all in-flight activities are accomplished successfully and in an integrated and coordinated fashion. These tasks include altering or updating schedules based on real-time decisions so that overall mission requirements can be satisfied. They also include scheduling and crew services administration and safety management. Approximately 1.5 man-hours per day are estimated for the station command functions.

Data Management

Data management functions can, in general, be divided into two categories: (1) Operations data management, concerned with processing and routing of data received from the operating subsystems; and (2) experiment data management, involving the reception, storing, processing, and routing of scientific data received from experiment operations. Crew-time requirements for operations data management functions are estimated at 2.5 man-hours per day. The extent and duration of crew involvement with experiment data management activities is determined by the FPE phasing schedule and the level of experiment activities being performed.

Logistics Inventory

Logistics inventory and control functions are composed of crew visual tasks, real-time monitoring and updating, and generation of consumables profiles based on usage rates for all replaceable supplies. Included in this category are foods, atmospheric (ECLSS) components, supplies (paper, pens, pencils, and the like), spare parts, tools, specialized crew skills, and data storage needs. If a high degree of automation in maintaining these data is assumed, requirements for manual inputs to the systems are estimated at no more than one man-hour per week.

Crew Care

Crew medical data yielded from space flights to date indicate that in-flight stresses may produce physiological or performance decrements in man. In addition to these, spontaneous pathological states (disease or injury) may develop during a mission. On-board medical skills and resources must be adequate to cope with these conditions. On-board equipment and treatment capability includes facilities and supplies adequate for the diagnosis and treatment of infectious disease, simple fractures, minor dental and surgical emergencies, and the initial care of seriously injured or ill crewmen to prepare them for evacuation to ground-based medical facilities. Flight-qualified equipment should include physical examination instruments and a laboratory facility which will allow basic X-ray, urinalysis, hematology, blood and urine chemistry, and bacteriology procedures. Selection of the in-flight treatment methods will depend upon the pathological manifestations predicted for a specific mission, upon selection of the most appropriate form of therapy consistent with up-to-date medical practice, and upon the applicability of this therapy to the space-flight situation. Crew-care requirements for the crew of six (excluding biomedical monitoring and testing) should, generally, be accomplished within a nominal value of four to six man-hours per week. The facilities should support alternative concepts of an on-board medical doctor, on-board full- or part-time medical technician skills, or shuttle-delivered medical doctor.

In general, the mode for crew treatment is:

1. First aid for injury and followup care for several days; crewman return to earth by shuttle for more serious and more extended treatment.

2. More extensive treatment only for conditions that would not permit the elapsed time to return to earth or forces encountered during entry.

3. Illness normally treated and crewman returned to own quarters.

4. Probability of illness reduced by preflight quarantine of about three weeks.

5. Routine physical examinations conducted for crewmen not participating in biomedical research at about 30-day intervals.

Information to date on space flights shows that principal problems are respiratory infections and minor bodily or gastrointestinal discomforts. However, the potential exists for more serious problems. Overall probability data from various sources, primarily USAF survey data, are sum-summarized for a 12-man crew per year as follows:

1. One major injury per four years that probably would call for immediate return of crewman.

2. About 0.0005 major illness per year which might require immediate return of crewman.

3. About 0.002 major contagion per year which may require return of all crewmen.

4. One minor injury per 1.5 years.

5. About 25 minor illnesses per year.

The predictions of illnesses and disease are only estimates and usually only serve to indicate that sufficient probability exists to justify a flexible treatment capability. It should be realized that occurrences may become manifest at any time in the life of the station. It is not possible to predict the communication of disease, once it appears, without detailed design information, procedures, and timelines; but in most cases it can be assumed that a highly viable pathogen, once introduced, will be propagated to some extent because communicability frequently precedes definitive symptoms.

These predictions are the basis for the requirement for adequate medical facilities aboard the station during its ten-year life. This requirement may prevent the necessity for a shuttle flight due to illness or injury.

It is assumed that the crew complement is made up of healthy males and females under the age of 40. The prevalence of diseases will probably be associated with crew changes and the intermittent contact with shuttle crewmen on cargo or RAM logistic flights. However, disease or illness spread in a crew will also be due to the many potentially pathogenic organisms in the upper airways and intestinal tract of man. Many diseases are infectious before the acute stages and can easily be spread among the confined and intimate relationships inherent to space station life. Epidemics can occur far more easily than on earth because of the intimacy of daily associations, and their prevention will be a function of waste management, personal hygiene, and ECLSS design and efficiencies. However, no effort has been made to estimate the occurrence of additional cases of a specific illness following its initial appearance.

Diagnostic and surgical training beyond that of the general physician is not considered a requirement so long as clinical laboratory and X-ray capabilities are sufficiently extensive to provide detailed information to the ground for consultation. A large crew complement, with its inherent, personal drug idiosyncrasies, and the individual resistances of many diseases to specific drugs (i.e., antibiotics), will necessitate an adequate pharmaceutical inventory. Rehydratable intravenous fluids will be desirable and should be developed.

Tables 2-6 and 2-7 show examples of potential crew injuries and illnesses, including consequences, and examples of special treatment and provisions required. However, considerable research is still required concerning the overall problem of categorizing potential illnesses and injuries and establishing specific prophylactics and treatment requirements and provisions.

Table 2-6. Possible Crew Injuries and Required Treatment and Provisions

Severity	Consequences	Examples of Possible Injury	Special Treatment and Provisions Required
Minor injury	No lost time	Abrasion, blister, minor laceration	Common first-aid-kit provisions
	Limited duty	Simple fracture of wrist or arm, joint sprain, minor muscle strain, minor burn	X-ray, pressure bandages, cold packs, splints and casts, analgesics, antibiotics
Major injury	Bed rest	Fracture of back, leg, or cranium; chest wound; poisoning	X-ray; traction devices, braces, casts; clinical laboratory tests; gastric lavage; anticonvulsants; surgical closure provisions
	Return to earth	Fracture of neck with paralysis, head injury, coma, foreign body in trachea, third-degree burns	X-ray; traction devices, braces; bladder catheter; anesthesia; blood transfusion; clinical laboratory tests; fluoroscope; intravenous feeding and fluid replacement

Table 2-7. Possible Crew Illnesses and Required Treatment and Provisions

Severity	Consequences	Examples of Possible Illness	Special Treatment and Provisions Required
Minor illness	No lost time	Atheletes foot, dermatitis, conjunctivitis, rhinitis, urethritis, pharyngitis, abscess of mouth and gum	Fungicides, steroids, antibiotics, antihistamines, nose drops, decongestants, analgesics, anesthetic lozenges, improved hygiene practices
	Limited duty or minimum lost time (< one week)	Bronchitis, cystitis, diarrhea, dysentery, fever, common cold or influenza, gastritis	Antibiotics, decongestants, antitussives, analgesics, cathartics, antispasmodics, antipyretics, isolation, antiemitics, special diet
Major illness	Bed rest and lost time (> one week*)	Appendicitis, bronchial pneumonia; infectious hepatitis, meningitis-epidemic, prostatitis, thrombophlebitis	Antibiotics, intravenous fluids, surgery, X-ray, expectorants, clinical laboratory tests, steroid therapy, analgesics, catheterization, intensive care, isolation; anticoagulant
	Return to earth	Encephalitis, myocardial infarction, ileitis	Intravenous fluids, tracheotomy, sedatives, oxygen, anticoagulant, clinical laboratory tests, antispasmodics, special diet

*Seriousness and extent of these illnesses may require return of crewmen to earth.

2.6.3 MAINTENANCE

This functional category encompasses all crew activity associated with the operation of station subsystems with the objective of preventing, discovering, isolating, and correcting equipment malfunction or failure. Station maintenance falls into two broad categories: scheduled (preventive) maintenance and unscheduled (corrective) maintenance. In-flight maintenance is the use of available maintenance accessories and technical information, in accordance with procedures established in the in-flight maintenance plan, to maximize the safety of the crew, augment the probability of mission success, and contribute to a complete MSS mission life.

Preventive maintenance, scheduled to occur during the mission, will be based upon the results of detailed and comprehensive maintenance analyses taking into account system hardware design, human factors, safety, and reliability considerations. Corrective maintenance inside and outside the spacecraft will be performed as a result of equipment malfunction, failure, or accidental damage to the spacecraft.

Crew Considerations

Principal considerations of maintenance for the crew are total man-hours per period of time, required on-board skills, percent of total crew involved in maintenance, and average and peak man-hours per task.

Four of the station crewmen are normally expected to be qualified to perform all the on-orbit maintenance, station and experiment, in addition to their other activities. This number requires some overlap (thus redundancy) in skill areas without requiring excessive cross training. Table 2-8 provides a matrix of the personnel and their complementary/overlap skill areas. The concept assumes degrees of overlap expertise.

Maintenance Concept

The basic maintenance concept on the MSS is removal and replacement of inflight replaceable units (IFRU's). A unit will normally be removed, replaced by another unit, and returned to earth. On-board repair is considered only where replacement of the failed unit is not feasible. This method of maintenance minimizes the skills and time required by the crew. Servicing, adjustment, and calibration will also be utilized where it further enhances system operation and is consistent with projected technology. These maintenance actions will normally be accomplished on a regularly scheduled basis.

Table 2-8. Matrix of Maintenance Skills and Personnel

Personnel	Maintenance Category						
	Test and Checkout Engineering Skills	Engineering and Technician Skills	Fluid Mechanical Skills	Electrical and Electronics Skills	Systems Oriented	Component and Instrument Oriented	IVA-EVA Qualified
Spacecraft	x			x	x		x
Spacecraft systems engineer	x		x		x		x
Electromechanical technician		x	x			x	x
Electronic engineer		x		x		x	x

Important characteristics of an IFRU are:

1. The design should permit direct visual and physical access by the crew with interface and attachment provisions which facilitate ease of removal and replacement. Access should be available in all credible attitudes and require a minimum of subsystem disturbance. Access doors and panels should be sized so that affected components can easily be inspected, adjusted, or replaced. Hinged access doors should be provided with quick-release type of fasteners.

2. Subsystems and their line-replaceable units should be designed so that removal and replacement of a faulty IFRU will not require removal of other IFRU's nor breaking of any functional flight connection other than those required for removal of the faulty unit.

3. IFRU's that are part of time-critical functions should allow for two consecutive unsuccessful repairs before a critical condition results.

4. Provisions should be made to positively secure electrical, pressure, and fluid supply to IFRU interfaces to facilitate maintenance action. IFRU functional interfaces should be minimized to simplify maintenance, reduce human error potential,

and permit straight-forward off-line diagnostic routines with high confidence in success of the maintenance action. Retest requirements should necessitate only retest of the replaced IFRU for compatible performance with interfacing subsystems.

5. Capability should also be provided to isolate segments of station and experiment hardware so that, during maintenance, critical functions remain active and hazard to personnel and contamination of the environment or subsystem are prevented.

6. Maintainability design characteristics should be incorporated which facilitate maintenance action without tools where practical, standard tools where necessary, and special tools where essential.

7. Requirements for precision maintenance motions should be minimized and facilitated with suitable aids (alignment guides, locks, and the like). Spacing between plug-in units and other components should be sufficient to allow technicians to grasp by hand to remove and replace.

8. Replaceable units should be designed so that removal of the unit does not disturb the integral structure of the module.

9. Consideration should be given to current technology for material selection and related design characteristics so that, where practical, normal wear and age deterioration will not degrade performance beyond acceptable tolerances within subsystem or IFRU life cycle requirements.

Onboard Checkout

Certain features must be incorporated into any system for it to be maintainable in space. In general, failure or malfunction occurrence must be detected, and the problem must be isolated to a specific component relatively quickly and easily. The on-board checkout (OBCO) function of the ISS provides this capability. The space station crew will rely on OBCO to monitor and interpret system operating condition, event verification or caution condition, and system trouble. The OBCO must have the capability to receive data from subsystem sensor points, determine when a subassembly or a specific mode is not working, and isolate the fault to the IFRU level. To provide this fault detection and isolation service, it is necessary to know the failure pattern of the subassemblies and IFRU's and to have sufficient monitoring points to make the necessary determination. The capability must also be provided to evaluate data after a repair and at other periodic intervals.

Replaceable Units

The replaceable units of the MSS were divided into two basic classes: IFRU's and ground replaceable units (GRU's). Within the basic classifications, there were subclassifications: Type I required ISS fault isolation and detection; Type II required no ISS support. Figure 2-3 is an example of the data sheets that define the replaceable units within assemblies as either IFRU's or GRU's. As shown in the example, estimates were made that included quantities of units for the initial station, estimated life (in years) of these replaceable units, their classification, and the crew time (hours) required to complete the removal and replacement (R&R) portion of maintenance. Figure 2-4 is a summation of the individual data sheets for each subsystem.

Failure Data

Two considerations were applied to the useful life of replaceable units, i.e., component wearout and random failure. These categories cause essentially all the in-flight unscheduled maintenance actions and impose significant unplanned demands upon crew time.

The wearout category includes all IFRU's having a useful life expectancy of greater than 0.5 year and less than ten years. Wearout, a life limiting factor, is characteristic of rotating and cycling elements. It also applies to items and materials whose performance is degraded or otherwise substandard because of deterioration. Short-life items (< 0.5 year) are not included in the wearout category and are considered replaceable on a regularly scheduled basis. In computing crew time requirements, a nominal value of approximately 0.5 hour was added to the estimated replacement times for preparation and closeout of each maintenance action.

While the probability of random failure cannot be predicted with precise accuracy, predictive techniques can be quite useful in defining subsystem areas where provisions for redundancy or spares should be incorporated. Failure rates were established at the IFRU level, based in part on failure rate data of similar equipment. An extension of these data led to the projected IFRU random failures and the crew time (hours) required to complete the removal and replacement portion of maintenance. Additional crew time (about 0.5 hour) was added for preparation and closeout of each maintenance action.

Examples of data computations used to determine crew time estimates for scheduled and unscheduled maintenance are illustrated in Figure 2-5.

STUDY CONTINUATION SHEET								SHEET 1 OF 8
TITLE ETC/LSS MAINTENANCE CATEGORIES (REFERENCE SUBSYSTEM)								UCN S810015 INITIATOR GIANFORMAGGIO DATE: MARCH 9, 1971
ASSEMBLY SUBASSEMBLY COMPONENT	QUANT FOR INITIAL STATION	ESTIM LIFE YR	IFRU I	IFRU II	GRU I	GRU II	CREW TIME HR	RATIONALE/REMARKS
• ATMOSPHERE STORAGE								0.42 HR/MONTH
N2 SUPPLY								
CONDITIONING HX	2	23			X		1.0	EST LONG LIFE/PASSIVE
SURGE TANK	2	23			X		2.0	EST LONG LIFE/PASSIVE
PUMPDOWN								
RECEIVERS	1	10			X		10.0	EST LONG LIFE/PASSIVE
L COMPRESSOR	1	1.6	X				1.0	SHORT LIFE - ROTATING
S COMPRESSOR	8	1.6	X				3.0	SHORT LIFE - ROTATING
PRESSURE REGULATORS	8	1.2	X				0.5	
• ATMOSPHERIC CONTROL								
PRESSURE CONTROL								
N2 FILTER	2	0.5		X				
N2 REGULATORS	2	1.2	X					
O2 FILTER	2	0.5		X				
O2 REGULATOR	2	1.2	X					
TIMER	2	2.3	X					
O2 CONTROLLER	2	2.3	X					
PP O2 SENSOR	10	0.3	X					
CABIN PRESS. RER	2	0.3						
CABIN DUMP VALVES	10							

IFRU - INFLIGHT REPLACEABLE UNIT
GRU - GROUND REPLACEABLE UNIT
TYPE I - ISS REQUIRED TO DETECT & ISOLATE FAILED UNIT
TYPE II - NO ISS SUPPORT REQUIRED

Figure 2-3. Subsystems Replaceable Unit Definitions

SUBSYSTEM	RU QUANTITY	IFRU I	IFRU II	GRU I	GRU II
STRUCTURES	458	160	246	0	52
ETC/LSS	1,525	585	279	628	33
EPS	1,625	1,470	148	1	6
G&C	40	40	0	0	0
RCS	142	106	0	36	0
ISS	265	148	117	0	0
SUBTOTALS		2,509	790	665	91
TOTALS	4,055	3,299		756	

CONSIDERATIONS

- SOME UNIQUE REPLACEABLE UNITS COULD DISTORT THE TOTAL MAINTENANCE PICTURE
  - CIRCUIT BREAKERS (1200)
  - BATTERY CELLS (220)
  - COLD PLATES (160)
- IFRU CLASSIFICATION
  - LEVEL 6 DEFINITION (PHASE B) IS USUALLY HIGHER THAN IFRU LEVEL
  - DESIRABLE IFRU CHARACTERISTICS CAN BE DEFINED IN PHASE B

Figure 2-4. Preliminary Estimates of Replaceable Units

SCHEDULED MAINTENANCE - REGULAR PERIODIC REPLACEMENT

SUBSYSTEM IFRU	QTY REQ'D	REPLACE FREQ	CREW TIME	TOTAL MHRS	MO. AVG. MHRS
ECLSS - (ATMOS. CONTROL)					
N_2 FILTER	2	0.5 YR	0.7	1.4	0.2
O_2 FILTER	2	0.5 YR	0.7	1.4	

UNSCHEDULED MAINTENANCE - DUE TO WEAROUT

SUBSYSTEM IFRU	IFRU QTY	EST. LIFE (YRS)	REPLACE 10 YRS	CREW TIME	TOTAL MHRS	MO AVG MHRS
ECLSS - (CO_2 MGMT)						
REGULATORS	18	1.2	144	0.8 HR	115.0	0.9
ELECTROLYSIS STACK	4	1.0	36	4.5 HR	162.0	1.3
VALVES (ISOLATION)						

UNSCHEDULED MAINTENANCE - DUE TO RANDOM FAILURE

SUBSYSTEM IFRU	IFRU QTY (N)	FAIL RATE 10^6 HR (λ)	TOT. EST. FAIL RATE (N, λ)	TIME (HOURS) (T)	EST NO. FAILURES (N, λ, T)	CREW TIME T	EST MHRS MO. AVG. (N, λ, T, T)
STRUCTURES (S.A. TURRET)							
BEARINGS	12	11.6	139.2	720	0.100	8.0	0.8
SEALS	4	59.2	236.8	720	0/170	4.0	0.6

Figure 2-5. Typical Estimating Data for On-Orbit Maintenance

Figure 2-6 is a summation of the crew man-hours per month for unscheduled maintenance. Crew time associated with the GRU classification represent nominal crew involvement for module replacement.

Maintenance estimates for the MSS are summarized on Figure 2-7. The total hours (approximately 178) are consistent with recommended scheduling allocations for the initial six-man station. If the present estimates of maintenance man-hour requirements are incorrect, that is, too low or too high, the resultant impact occurs with experiment operations. Because maintenance is a part of scheduled station operations, additional maintenance hours will decrease time available for experiment operation hours. When maintenance is required for a critical subsystem, completing the maintenance action will have high priority and could also involve the use of unscheduled crew man-hours (free time).

SUBSYSTEM	IFRU					GRU			TOTALS
	TROUBLE ANAL	FAILURE		WEAROUT (P/C & R/R)	BENCH REPAIR CALIB	TROUBLE ANAL	FIX PROB	REPL MODULE	
		P&C	R&R						
STRUCTURE		←30.3→		3.7			1.1	2.2	37.3
ELECTRICAL POWER SYSTEM		0.25	2.4	0.05			0.7	1.3	4.7
REACTION CONTROL SYSTEM		0.01	0.04	2.7		0.1		NEGL	1.8
ENV CONT AND LIFE SUPT SYS		1.25	4.1	34.3	1.0	1.0	1.0	3.2	45.8
GUIDANCE AND CONTROL		0.25	0.62	0.43					1.3
INFORMATION SUBSYSTEM		4.2	1.4	3.2					8.8
SUB-TOTAL		5.9	38.8	43.4	1.0	1.1	2.8	6.7	99.7

Figure 2-6. Crew Man-Hours per Month — Unscheduled Maintenance

SUBSYSTEM	SCHEDULED MAINTENANCE							UNSCHED MAINT TOTAL	TOTALS
	INSP	SERVICE	TEST & C/O	IFRU		BENCH REPAIR CALIB	SUB-TOTAL		
				R&R	P&C				
STRUCTURE	3.7		1.8				5.5	37.3	42.8
ELECTRICAL POWER SYSTEM	1.0			4.7	1.5	2.0	9.2	4.7	13.9
REACTION CONTROL SYSTEM								1.8	1.8
ENV CONT AND LIFE SUPT SYS	4.0	16.0		20.8	18.4	1.0	60.2	45.8	106.0
GUIDANCE AND CONTROL	←0.2→		0.5				0.7	1.3	2.0
INFORMATION SUBSYSTEM			3.5				3.5	8.8	12.3
SUB-TOTAL	8.9	16.0	5.8	25.5	19.9	3.0	79.1	99.7	178.8

Figure 2-7. Crew Man-Hours per Month — Maintenance Summary

2.6.4 HOUSEKEEPING AND SANITATION

It is estimated that approximately seven man-hours per day will be required for basic housekeeping functions, i.e., cleaning, servicing, food preparation, cargo handling, and the like. A nominal workload breakdown of housekeeping activities will generally be distributed as follows:

Item	Time (Man-Hours/Day)
Food preparation	
0.5 hr per meal	1.5
Cleaning and servicing	
Galley - 0.3 hr per meal	1.0
Dining - 0.2 hr per meal	0.6
Personal Hygiene - 1.0 hr per facility	2.0
General Surface - 6.0 hr every 2 weeks	0.5 (average)
Staterooms - 6.0 hr every 2 weeks	0.5 (average)
Trash collection and disposal	0.5
Cargo handling	
2.0 hr per week	0.3 (average)
Equivalent man-hours per day (averaged)	6.9

While certain of these tasks may be deferrable on the basis of crew time availability, it is generally concluded that a daily average of six to eight man-hours will be required in fulfilling the total housekeeping requirement.

The rotating roster concept is generally recommended for satisfying general cleaning, replenishment of soap and tissue dispensers, trash collection and disposal, and the like, cleanup of crew staterooms being the responsibility of their occupants. As a crew option, meal preparation functions may be satisfied by using the rotating roster concept, or through selection of a "dedicated chef." Regardless of the concept selected, training and experience in this skill category are required.

2.7 EXPERIMENT OPERATIONS

The preliminary edition of the Reference Earth Orbital Research and Applications Investigations (January 1971 Blue Book) provides the requirements for crew skills, manpower, and schedules.

2.7.1 EXPERIMENT DISCIPLINES

The seven Blue Book disciplines and the FPE's within these disciplines are as follows:

1. Astronomy

   X-ray astronomy (A-1)
   Advanced stellar astronomy (A-2)
   Advanced solar astronomy (A-3)
   Intermediate size UV telescopes (A-4)
   High-energy stellar astronomy (A-5)
   IR astronomy (A-6)

2. Physics

   Space physics research laboratory (P-1)
   Plasma physics and environmental perturbations Laboratory (P-2)
   Cosmic ray physics laboratory (P-3)
   Physics and chemistry laboratory (P-4)

3. Earth Observations

   Earth observations facility (ES-1)

4. Communications/Navigation

   Communications/navigation research facility (C/N-1)

5. Materials Science and Manufacturing

   Materials science and manufacturing in space (MS-1)

6. Technology

Contamination measurements (T-1)
Fluid management (T-2)
Extravehicular activity (EVA) (T-3)
Advanced spacecraft systems test (T-4)
Teleoperations (T-5)

7. Life Sciences

Medical research facility (LS-1)
Vertebrate research facility (LS-2)
Plant research facility (LS-3)
Cells and tissues research facility (LS-4)
Invertebrate research facility (LS-5)
Life support and protective systems (LS-6)
Manned system integration (LS-7)

2.7.2 EXPERIMENT OPERATIONS CREW SKILLS

The crew skill specialties required to support all the candidate FPE's are given in the following list.

1. Biological Technician
2. Microbiological Technician
3. Biochemist
4. Physiologist
5. Astronomer/Astrophysicist
6. Physicist
7. Nuclear Physicist
8. Photo Technician/Cartographer
9. Thermodynamicist
10. Electronic Engineer
11. Mechanical Engineer
12. Electromechanical Technician
13. Medical Doctor
14. Optical Technician
15. Optical Scientist
16. Meteorologist
17. Microwave Specialist
18. Oceanographer
19. Physical Geologist
20. Photo Geologist
21. Behavioral Scientist
22. Chemical Technician
23. Metallurgist
24. Material Scientist
25. Physical Chemist
26. Agronomist
27. Geographer

These skills are by no means required concurrently; and in all probability, the on-board skills will not be identical for any two crews. Conceptually, it is estimated that the average crew of six (for the initial space station) will normally require proficiency in no more than 7 to 9 specialty areas, although some additional skills might be needed for backup. For the growth space station, with a crew of twelve, approximately 11 to 19 experiment sp specialty skills will be required depending on experiment schedules. Crew members will specialize in areas which show commensurate task times and secondarily will be assigned tasks in the most closely related areas. In general, all critical skill specialties will be backed up by one or more overlap crewmen. Figure 2-8 shows candidate crew skills by discipline. A gross indication of the crew skill distribution requirements for the period 1982 to 1986 is illustrated in Figure 2-9. Representative crew mixes and typical workload allocations for selected segments of the MSS mission sequence plan are shown in the subsequent paragraphs.

DISCIPLINE	BIOLOGICAL TECHNICIAN	MICROBIOLOGICAL TECH.	BIOCHEMIST	PHYSIOLOGIST	ASTRONOMER/ASTROPHYSICIST	PHYSICIST	NUCLEAR PHYSICIST	PHOTO TECH/CARTOGRAPHER	THERMODYNAMICIST	ELECTRONIC ENGINEER	MECHANICAL ENGINEER	ELECTROMECHANICAL TECH.	MEDICAL DOCTOR	OPTICAL TECHNICIAN	OPTICAL SCIENTIST	METEOROLOGIST	MICROWAVE SPECIALIST	OCEANOGRAPHER	PHYSICAL GEOLOGIST	PHOTO GEOLOGIST	BEHAVIORAL SCIENTIST	CHEMICAL TECHNICIAN	METALLURGIST	MATERIAL SCIENTIST	PHYSICAL CHEMIST	AGRONOMIST	GEOGRAPHER
LIFE SCIENCES	X	X	X	O								X	X	X							O	X					
ASTRONOMY					X	X				X		X		X	X												
COMMUNICATION/ NAVIGATION										O		O		O			O										
EARTH OBSERVATIONS								O				X		X		O		O	O	O						O	O
TECHNOLOGY						X			X	X	X	X															
SPACE PHYSICS					X	X	X		X			X													X		
MATERIALS SCIENCES	X											X										X	O	X			

O INITIATED SUBSEQUENT TO GROWTH BUILDUP

Figure 2-8. Candidate Crew Skills Versus Discipline—Experiment Operations

FIRST DATE REQUIRED	1/82	7/82	12/83	7/85	2/86	5/86	8/86
SKILL / CREW NOS.	1-3	4-9	10-14	15-16	17	18	19
BIOLOGICAL TECHNICIAN		X	X	X	X	X	X
MICROBIOLOGICAL TECH		X	X			X	X
BIOCHEMIST		X	X			X	X
ASTRONOMER/ ASTROPHYSICIST		X		X	X	X	X
PHYSICIST	X	X	X	X	X	X	
NUCLEAR PHYSICIST					X		
THERMODYNAMICIST	X						X
ELECTRONIC ENGINEER		X					
ELECTROMECHANICAL TECH	X	X	X	X	X	X	X
MEDICAL DOCTOR		X	X				
OPTICAL TECHNICIAN		X	X	X	X	X	X
OPTICAL SCIENTIST			X				
CHEMICAL TECHNICIAN				X	X	X	X
MATERIAL SCIENTIST				X	X	X	X
PHYSICAL CHEMIST	X						

Figure 2-9. Crew Skill Distribution—Initial Station

2.8 CREW INTEGRATED OPERATIONS

This subsection integrates the station operations with the experiment (FPE) operations and identifies the resultant system requirements, skill requirements, daily tasks, and any unique duty-tour operations. As described previously the crew definitions are broken down into three categories: station operations, crewmen support technicians, and scientists and experimenters. The crew requirements for station operations and experiment support operations are on the order of 25 man-hours per day. These operations include the routine daily operations of the space station—routine and periodic maintenance, housekeeping, monitor and control of detached RAM's and the like—and the experiment support operations associated with the daily conduct of the space station experiments. Based on 25 man-hours per day for station operations and experiment support operations and a 10-hour work day, approximately 35 man-hours per day remain available for experiment operations for the initial station. The corresponding crew time distribution for the growth space station is 30 man-hours per day required for station and experiment support operations; the 90 man-hours per day remaining are available for experiment operations.

2.8.1 CREW SKILLS

Twenty-seven crew skills have been identified that are necessary for conduct of the experiment operations. Three additional skills (Figure 2-10) have been identified for spacecraft operations and have been added to the basic 27 skills previously identified. The titles of the three additional skills are represented by actual spacecraft operational descriptions. Proficiency in one or more of the other 27 skills will be required for specific missions and probably would vary as mission experiment operational requirements change.

The time phasing of the skill requirements, based on the mission sequence plan, Section 3 of this document, results in a variation in the number of skills required throughout the program. During early phases of the initial space station operations, only four skills are required for experiment operations (plus three skills for station operations), or approximately 1.2 skills per crewman. During remaining operations of the initial station, the average number of skills for station and experiment operations is 11.4 or approximately 1.9 per crewman. During operations of the growth station, between 14 and 22 skills are required, or approximately 1.5 skills per crewman.

DISCIPLINE	1 BIOLOGICAL TECHNICIAN	2 MICROBIOLOGICAL TECHNICIAN	3 BIOCHEMIST	4 PHYSIOLOGIST	5 ASTRONOMER/ASTROPHYSICIST	6 PHYSICIST	7 NUCLEAR PHYSICIST	8 PHOTO TECH/CARTOGRAPHER	9 THERMODYNAMICIST	10 ELECTRONIC ENGINEER	11 MECHANICAL ENGINEER	12 ELECTROMECHANICAL TECHNICIAN	13 MEDICAL DOCTOR	14 OPTICAL TECHNICIAN	15 OPTICAL SCIENTIST	16 METEOROLOGIST	17 MICROWAVE SPECIALIST	18 OCEANOGRAPHER	19 PHYSICAL GEOLOGIST	20 PHOTO GEOLOGIST	21 BEHAVIORAL SCIENTIST	22 CHEMICAL TECHNICIAN	23 METALLURGIST	24 MATERIAL SCIENTIST	25 PHYSICAL CHEMIST	26 AGRONOMIST	27 GEOGRAPHER	28 COMMANDER *	29 FLIGHT CONTROLLER *	30 SYSTEMS ENGINEER *
LIFE SCIENCES	X	X	X	O								X	X	X							O	X								
ASTRONOMY					X	X				X		X		X	X															
COMMUNICATION/ NAVIGATION										O		O		O			O													
EARTH OBSERVATIONS								O				X		X		O		O	O	O						O	O			
TECHNOLOGY						X			X	X	X	X																		
SPACE PHYSICS					X	X	X		X			X													X					
MATERIALS SCIENCES	X											X										X	O	X						
VEHICLE OPERATIONS																												X	X	X

O INITIATED SUBSEQUENT TO GROWTH BUILDUP

*NOTE: THESE ADDITIONAL SKILLS (28, 29, 30) ARE PRESENTED ON THIS FIGURE BY ACTUAL SPACECRAFT OPERATIONS; HOWEVER, PROFICIENCY IN ONE OR MORE OF THE OTHER 27 SKILLS IS REQUIRED.

Figure 2-10. Candidate Crew Skills Versus Distribution

2.8.2 CREW SKILL DISTRIBUTION

Based on the phasing of the skill requirements, represented on the mission sequence plan, Crew 15, time period July 1985, for the initial station and crew 23/24, time period October 1987, for the growth station were selected for establishing a representative crew, complete with man-hours per day per each skill requirement for that time period covering the scheduled experiment operations. Figure 2-11 shows these crew skills-per-man-hours-per-day distribution.

By utilizing the same representative crews for the initial station and growth station previously established, the man-hours per day per each skill requirement are shown in Figure 2-12.

By combining data in Figures 2-11 and 2-12, the station operation skills per man-hour per day and the experiment operations skills per man-hour per day are integrated into a single presentation of total crew operational skills per day per man (Figure 2-13). The total hours represented are in accordance with the previously established 10-hour work day, based on a six-day-week work schedule.

INITIAL STATION CREW NO. 15 JULY 1985	SKILL																												TOTAL EXP HR/DAY
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	A	
1 COMMANDER					5.7																								5.7
2 FLIGHT CONTROLLER					3.1									1															4.1
3 SYSTEMS ENGINEER												3.3												0.8					4.1
4 ELECTRO-MECHANICAL TECHNICIAN												3												3.2					6.2
5 ELECTRONIC ENGINEER					1.2							3.7											1.3						6.2
6 EXPERIMENT COORDINATOR AND SCIENTIST	2					5																	1.7						8.7
HOURS/SKILL/DAY	2				10	5						10		1									3	4					35

GROWTH STATION CREW NO. 23/24 OCTOBER 1987	SKILL																												TOTAL EXP HR/DAY
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	A	
1 COMMANDER					4.5																								4.5
2 FLIGHT CONTROLLER					2.6									0.5															3.1
3 SYSTEMS ENGINEER											( )													3.1					3.1
4 ELECTRO-MECHANICAL TECHNICIAN						2						3.2																	5.2
5 ELECTRONIC ENGINEER										5.2																			5.2
6 EXPERIMENT COORDINATOR AND SCIENTIST	2					2.9											4												8.9
7 ASTRONOMER/ASTRO-PHYSICIST					8										2														10.0
8 ASTRONOMER/ASTRO-PHYSICIST					10																				( )				10.0
9 PHYSICIST					7.9	2.1			( )																				10.0
10 ELECTRONIC ENGINEER										3.8		6.2																	10.0
11 METALLURGIST												7											3						10.0
12 ELECTRO-MECHANICAL TECHNICIAN												9.1												0.9					10.0
HOURS/SKILL/DAY	2				33	7			( )	9	( )	25.5		0.5	2		4						3	4	( )				90

( ) REQUIRED DURING DETACHED RAM DOCKING, APPROXIMATELY ONCE PER 60 DAYS

Figure 2-11. Typical Crew Skill Distribution—Experiment Operations

INITIAL STATION CREW NO. 15 JULY, 1985	SKILL																														TOTAL STATION HR/DAY
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	25	24	26	27	28	29	30	
1 COMMANDER																												4.3			4.3
2 FLIGHT CONTROLLER																													5.9		5.9
3 SYSTEMS ENGINEER																														5.9	5.9
4 ELECTRO-MECHANICAL TECHNICIAN												3.8																			3.8
5 ELECTRONIC ENGINEER										3.8																					3.8
6 EXPERIMENT COORDINATOR AND SCIENTIST					1.3																										1.3
HOURS/SKILL/DAY					1.3					3.8		3.8																4.3	5.9	5.9	25.0

GROWTH STATION CREW NO. 23/24 OCTOBER 1987	SKILL																														TOTAL STATION HR/DAY
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1 COMMANDER																												5.5			5.5
2 FLIGHT CONTROLLER																													6.9		6.9
3 SYSTEM ENGINEER																														6.9	6.9
4 ELECTO-MECHANICAL TECHNICIAN												4.8																			4.8
5 ELECTRONIC ENGINEER										4.8																					4.8
6 EXPERIMENT COORDINATOR AND SCIENTIST					1.1																										1.1
7 ASTRONOMER/ASTRO-PHYSICIST																															
8 ASTRONOMER/ASTRO-PHYSICIST																															
9 PHYSICIST																															
10 ELECTRONIC ENGINEER																															
11 METALLURGIST																															
12 ELECTRO-MECHANICAL TECHNICIAN																															
HOURS/SKILL/DAY					1.1					4.8		4.8																5.5	6.9	6.9	30.0

Figure 2-12. Typical Crew Skill Distribution—Station Operations

INITIAL STATION CREW NO. 15 JULY, 1985	SKILL																														TOTAL INTEGR HR/DAY
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1 COMMANDER					5.7																							4.3			10.0
2 FLIGHT CONTROLLER					3.1									1															5.9		10.0
3 SYSTEMS ENGINEER											3.3													0.8						5.9	10.0
4 ELECTRO-MECHANICAL TECHNICIAN											6.8													3.2							10.0
5 ELECTRONIC ENGINEER					1.2					3.8	3.7												1.3								10.0
6 EXPERIMENT COORDINATOR AND SCIENTIST	2				1.3	5																	1.7								10.0
HOURS/SKILL/DAY	2				11.3	5				3.8	13.8			1									3.0	4.0				4.3	5.9	5.9	60.0

GROWTH STATION CREW NO. 23/24 OCTOBER 1987	SKILL																														TOTAL INTEGR HR/DAY
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
1 COMMANDER					4.5																							5.5			10.0
2 FLIGHT CONTROLLER					2.6									0.5															6.9		10.0
3 SYSTEMS ENGINEER																								3.1						6.9	10.0
4 ELECTRO-MECHANICAL TECHNICIAN						2						8																			10.0
5 ELECTRONIC ENGINEER										10																					10.0
6 EXPERIMENT COORDINATOR AND SCIENTIST	2				1.1	2.9											4														10.0
7 ASTRONOMER/ASTRO-PHYSICIST					8										2																10.0
8 ASTRONOMER/ASTRO-PHYSICIST					10																										10.0
9 PHYSICIST					7.9	2.1																									10.0
10 ELECTRONIC ENGINEER										3.8		6.2																			10.0
11 METALLURGIST												7											3								10.0
12 ELECTRO-MECHANICAL TECHNICIAN												9.1												0.9							10.0
HOURS/SKILL/DAY	2				34.1	7.0				13.8		30.3		0.5	2		4						3	4				5.5	6.9	6.9	120.0

Figure 2-13. Typical Crew Skill Distribution, Crew Integration Operations

3. MISSION SEQUENCE PLAN

The modular space station is to support the conduct of experiment operations. It is therefore necessary to develop a representative experiment program in order to support space station conceptual design and, for a given space station design concept, to validate the capability of the concept to support experiment operations. Experiment program analyses were conducted to assess the sensitivity of the space station design concept, Volume III, Experiment Analyses (SD 71-217-3), and to establish a representative experiment program that accommodates a NASA 1971 Blue Book. The space station program presented is not intended to represent the experiment program that must be scheduled, because the space station has the inherent capability and flexibility to accommodate alternative programs, e. g., one that emphasizes socio-economic benefits or one that emphasizes advancements in scientific knowledge. The program presented here is representative of a family of programs that could be accommodated by the selected space station design concept.

Total definition of a space station program consists of time phasing of all program elements along with the associated master program phasing and program costs. The characteristics necessary to define the space station program are summarized in Figure 3-1. The basic program elements consist of the generic experiments defined by the NASA Blue Book, the MSS, the RAM's and the earth orbit shuttle. The operational time phasing of these elements is defined by the mission sequence plan. Further definition, based on the mission sequence plan, is provided by the master program phasing and the program cost, which are defined in References 3 and 4, respectively. The time phasing of the program elements and significant conclusions from it are discussed in this section.

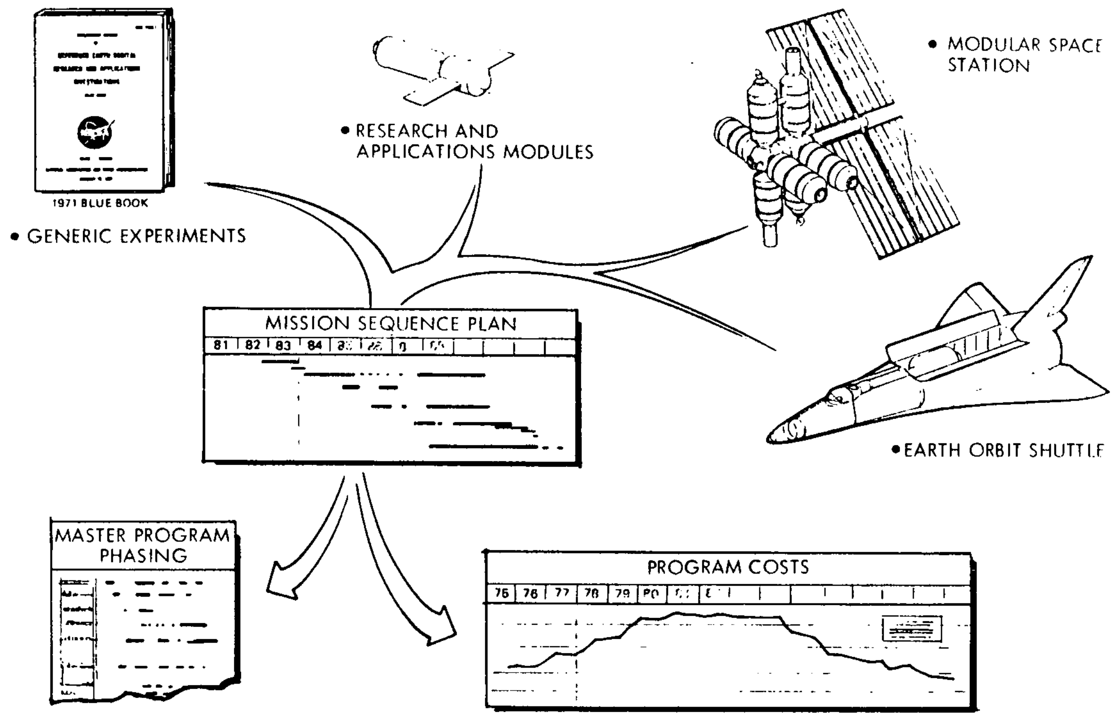

Figure 3-1. Space Station Program Definition Summary

3.1 MISSION SEQUENCE PLAN DEVELOPMENT APPROACH

The overall approach used in developing the reference program is shown in Figure 3-2. The basis of the mission sequence plan is the NASA 1971 Blue Book, which defines a generic set of experiment laboratories and the associated experiment equipment, resource requirements, and operational characteristics that the space station must accommodate. The Blue Book was used as a basis for generating an experiment data book that provides an interpretation of the Blue Book and provides the basis for conduct of an experiment driver analysis. From data contained in the experiment data book, an evolutionary program philosophy was developed wherein two basic experiment laboratory activity levels were identified. The philosophy permits the deferment of experiment costs and the scheduling of major experiments in each discipline to provide a balanced program throughout the total operations of the MSS. For each laboratory, the operational concept (duration, accommodation mode, and special requirements) and the support requirements (crew, electrical power, data, and logistics) were defined. Also, laboratory priorities were defined; they were based on benefit categories and worth ratings presented in the experiment data book. From these data, a reference experiment program was developed by considering FPE interrelationships and constraints. With this program, the final mission sequence plan was developed by considering operational factors such as space station buildup, crew rotation, RAM delivery, and logistics resupply. The resultant mission sequence plan summarizes the operational characteristics and experiment scheduling that are compatible with the selected MSS design concept. Both the reference experiment program and the mission sequence plan satisfy the NASA-provided guidelines and constraints.

The principal guidelines and constraints applicable to the definition of the experiment program are paraphrased in Table 3-1. The first guideline and constraint (G&C 1.102A) defines the basic scheduling limitations within which the space station program must operate. Based on a Phase C go-ahead in fiscal year 1975 and the program development schedule discussed in Reference 3, launch of the first space station module occurs on 1 July 1982. The space station will then conduct experiment operations at a 6-man level (G&C's 1.102A and 1.105A) followed by buildup to a growth space station (12-man capability). The initial space station is capable of supporting selected, partial, modified, or combined functional program elements (FPE's) from the Blue Book (G&C 1.116), the experiments being conducted in the space station general-purpose laboratories (GPL) and RAM's (G&C 1.105A).

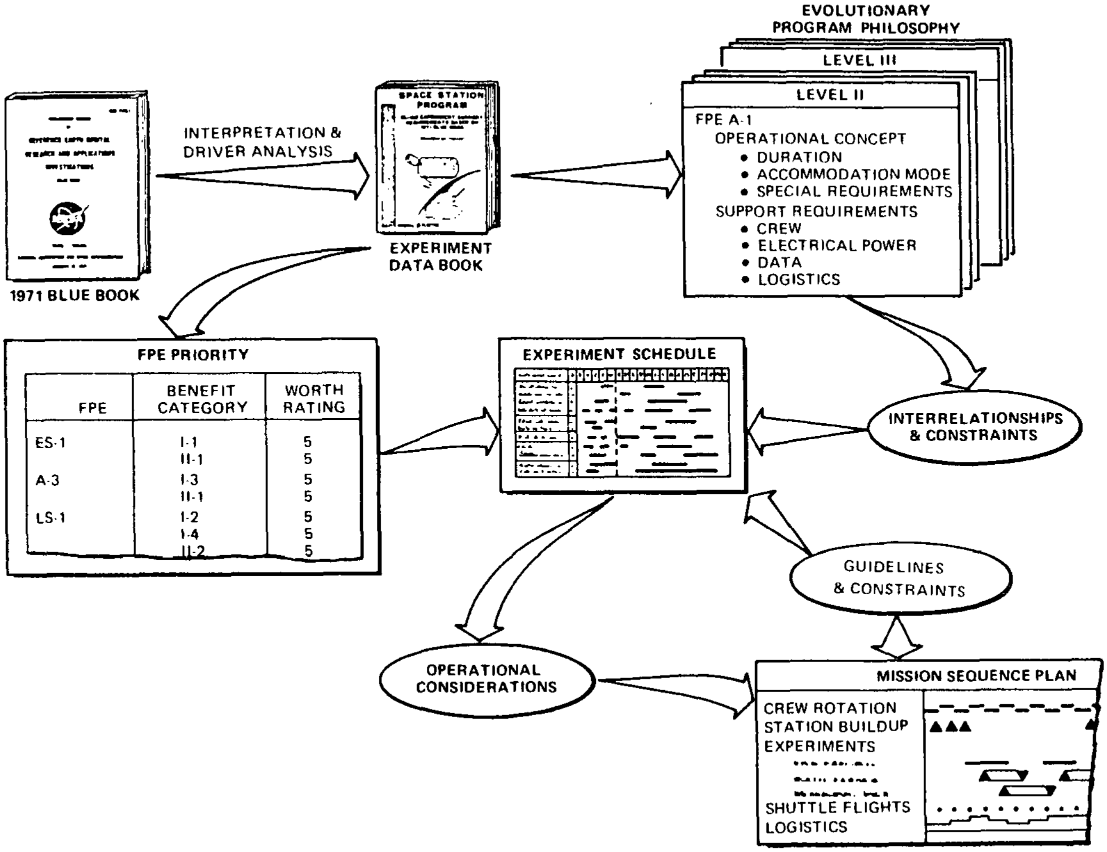

Figure 3-2. Mission Sequence Plan Development Approach

The growth space station is capable of accommodating all FPE's defined by the Blue Book, but these FPE's are not accommodated simultaneously (G&C 1.117A).

The remaining guidelines and constraints imposed programmatic operational restrictions. The principal impact of the guidelines and constraints on the shuttle launch frequency (G&C 1.204) is the space station buildup duration and the associated impact on subsystem requirements for buildup operations. These considerations were discussed previously. G&C's 1.205, 1.111, and 1.202 primarily constrain the design characteristics in terms of module weight and space station consumable storage requirements.

In development of the mission sequence plan, it was necessary to establish the basic ground rules and assumptions summarized in Table 3-2. The programmatic ground rules relate to the first module launch date, the date on which initial operating capability (IOC) of the space station is achieved and the period of operation of the initial space station. The remaining ground rules and assumptions relate primarily to the shuttle operations in support of the MSS.

Table 3-1. Applicable Guidelines and Constraints

Designation	Guidelines and Constraints
1.102A	Space station Phase C go-ahead in fiscal year 1975. Total program length not specified. Identifiable plateau in initial space station configuration. Full growth space station capability five to six years after launch of the first initial space station module. Growth space station operations for five years.
1.105A	Initial space station operational when fully manned (at least six crewmen) and fully configured, including a general-purpose laboratory capability in addition to at least two RAM's.
1.111	Design-to weight of shuttle-transported modules not to exceed 20,000 lb.
1.116	Initial space station capable of supporting selected, partial, modified, or combined FPE's from the Blue Book; Blue Book experiments and RAM's to be scheduled in accordance with station capability.
1.117A	Growth space station capable of accommodating all Blue Book FPE's, but not simultaneously.
1.204	Shuttle launch frequency, to support space station program, no greater than one every 30 days.
1.205	Initial space station with capacity for independent operation with the full crew for a period of 120 days; capacity can be included in cargo module.
1.202	At least 30 days of consumables, including subsystems and experiments, available beyond scheduled resupply mission.

Table 3-2. Basic Ground Rules and Assumptions

Type	Description
Programmatic	1. Five years of initial station operations. 2. First station module launch on 1 July 1981, based on Phase C go-ahead in 1975. 3. IOC on 1 January 1982, based on initial buildup schedule.
Logistics launch	1. Payload weight allocated as follows: Payload — Crew and Cargo (lb) — Cargo Only (lb) Six passengers plus personal effects — 1,200 — Cargo — 11,800 — 13,000 Cargo module structure and equipment* — 12,000 — 12,000 Total — 25,000 — 25,000 2. Airlocks to be delivered with modules. 3. Only one RAM to be delivered at a time. 4. Support section may be launched with RAM if length permits.
Crew transport	1. Shuttle may transport two passengers without cargo module. 2. Shuttle may transport six passengers with cargo module. 3. Shuttle can rescue and return 12 passengers with cargo module.
Crew rotation	1. Initial crew tour limited to 60 days (qualified to 56 days by Skylab). 2. Crew tour stay increased by qualification to 90, 120, and 180 days progressively. 3. Medical technician required during crew qualification period. 4. Two crewmen, in addition to medical technician, assumed sufficient for establishing extended stay capability.

*Excludes growth

3.2 REFERENCE EXPERIMENT PROGRAM

In order to develop the mission sequence plan, it was first necessary to develop a reference experiment program that defines the time phasing of all experiments. The overall approach used is shown in Figure 3-3. The basic data sources were the laboratory definition, priorities, and scheduling interrelationships and constraints detailed in SD 71-217-3. For purposes of completeness, the data sources used to develop the reference experiment program are summarized in this subsection. On the basis of the laboratory priorities and the scheduling interrelationships and constraints, a preferred experiment sequence was defined. This sequence plus the applicable guidelines and constraints and scheduling ground rules provided the basis for developing the reference experiment program.

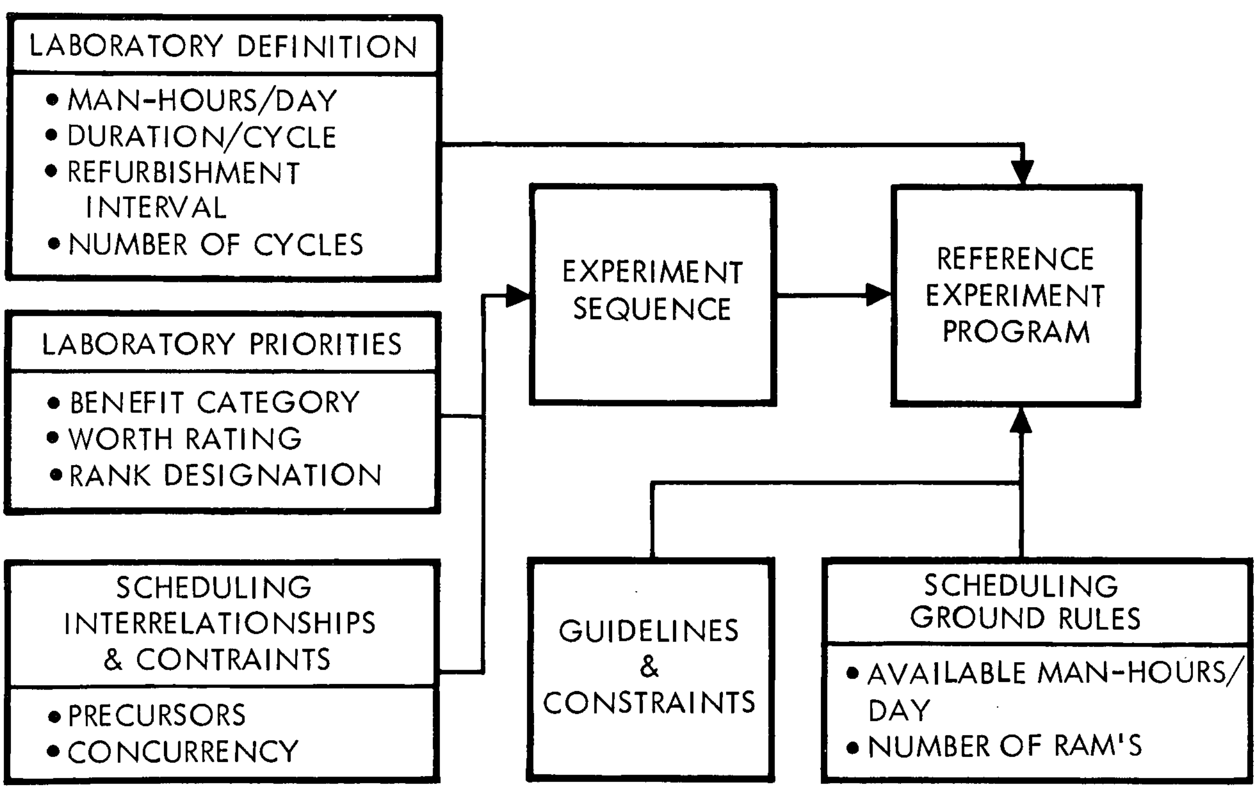

Figure 3-3. Reference Experiment Program Development

For development of the reference experiment program, the experiment laboratories are adequately defined by the number of operational cycles, number of years per cycle, man-hours per day, and refurbishment interval. In order to schedule the laboratories, priorities must be defined. The technique used during this study was to assign each FPE (or experiments within the FPE's) a benefit category and worth rating. These data provided a means by which a rank designation could be assigned to each FPE or sometimes to individual experiments within FPE's. In addition, scheduling interrelationships and constraints that impose a preferred relative order of FPE's or experiments were developed.

The definition of the experiment operating cycles as interpreted from the 1971 Blue Book is summarized in Table 3-3 for Level II and Level III definitions of the laboratories. Also shown, where appropriate, are the preferred separation intervals between multiple cycles of a given laboratory. As will be discussed in detail, application of these operating durations resulted in an excessively long experiment program.

The manpower requirements to support the experiment operations and the associated crew skills requirements are summarized in Tables 3-4 and 3-5. Table 3-4 shows that the man-hour-per-day requirements vary from a minimum of 4 for some astronomy experiments to a maximum of 24 for FPE's in the earth observations, technology, and life sciences disciplines. During the analyses, the manpower requirements were interpreted as being equivalent man-hours per day, based on a 10-hour day, 6-day work week. Of the 30 crew skills identified for operations of the space station and the experiments, 21 skills were required for experiment operations. Of these, four are required only during the operations of detached RAM's.

The logistic requirements, in terms of pounds per month for support of the experiment operations, are summarized in Table 3-6. Both the minimum and maximum requirements are imposed by laboratories in the technology discipline. Average values are approximately 133 pounds per month for all Level II laboratories and 289 pounds per month for the Level III laboratories. The corresponding power requirements, in terms of the maximum sustained power, are shown in Table 3-7. The average power requirement for Level II laboratories is approximately 1.02 kw, and 1.26 kw is the average requirement for the Level III laboratories.

The foregoing definitions of the laboratories establish the resource requirements that must be provided for conduct of the experiment program. Further definition is provided by the experiment priorities given in Table 3-8, where the experiment number, benefit category, worth rating, and rank designation are defined. Experiments that have both high socio-economic benefit and high scientific value are scheduled first to produce a balanced program.

Table 3-3. Experiment Cycling Definition

FPE	Level II			Level III			Remarks
	Preferred No. of Cycles and Duration	Alternative No. of Cycles and Duration	Separation Interval	Preferred No. of Cycles and Duration	Alternative No. of Cycles and Duration	Separation Interval	
A-1	2 at 2Y		3 to 6M	3 at 2Y		3 to 6M	
A-2	2 at 6M		3 to 6M	6 at 1.5Y		3 to 6M	
A-3	3 at 1Y		2M	2 at 2Y		3M	
A-4	3 at 1Y		1 to 2M	4 at 2Y		2M	
A-5	4 at 6M		1M	4 at 2Y		3M	
A-6	4 at 1Y		1 to 3M	3 at 2Y		3M	
P-1	1 at 1Y	2 at 6M	3M	1 at 2Y	2 at 1Y	3M	
P-2	1 at 6M	2 at 3M	3M	1 at 1Y	2 at 6M	3M	
P-3	1 at 1Y			1 at 2Y			
P-4	1 at 6M	2 at 3M	3M	1 at 1Y	2 at 6M	3M	
ES-1	1 at 3Y	6 at 6M	3M	N at 1Y		2M	
C/N-1	1 at 6M			1 at 1.5Y			
MS-1	1 at 2Y	4 at 6M	3 to 6M	4 at 2Y		3 to 6M	
T-1	1 at 6M			1 at 2Y			
T-2	-			1 at 1Y	2 at 6M	6M	
T-3	1 at 4M			1 at 1Y	2 at 6M	6M	
T-4	1 at 1Y			1 at 2Y			
T-5	-			1 at 1Y	3 at 4M	6M	
LS-1	1 at 3Y			1 at 5Y			
LS-(2-5)	1 at 9M			3 at 2Y		3M	1 at 27M for Level IIA
LS-6	-			2 at 37M		3M	
LS-7	3 at 3M		2M	8 at 3M		1M	

M - months
N - continuous
Y - years

Table 3-4. Manpower Requirements Matrix
(Sustained Equivalent Manhours per Day)

Discipline		FPE						
Title	Code	1	2	3	4	5	6	7
Astronomy	A	4 8	4 15	8 10	14 5	9 10	14* 12**	
Physics	P	11 13	19 19	8 10	9 37			
Earth Observation	E	14 24						
Communications and Navigation	C/N	10 18						
Material Sciences	MS	13 14						
Technology	T	9 9	- 20	24 24	10 11	- 19		
Life Sciences	LS	9 18		8 11*** 13			1 11	

*Level II
**Level III
***Level IIA

Table 3-5. Crew Skill Requirements (Man-Hours per Day)

	FPE											
	A-1		A-2		A-3		A-4		A-5		A-6	
	Level											
Crew Skill	II	III	II	III	II	III	II	III	II	III	II	III
1. Biological Technician												
2. Microbiological Technician												
3. Biochemist												
4. Physiologist												
5. Astronomer/Astrophysicist	4	8	4	15	5	10	10	5	4	14	10	12
6. Physicist									4	10		
7. Nuclear Physicist												
8. Photo Technician/Cartographer												
9. Thermodynamicist												
10. Electronic Engineer							1	D	1	D		
11. Mechanical Engineer												
12. Electromechanical Technician	D	D	D	D	1	D	1	D			1	D
13. Medical Doctor												
14. Optical Technician	(D)	(D)										
15. Optical Scientist	(D)	(D)	D	D	1	D	2	D				
16. Meteorologist												
17. Microwave Specialist												
18. Oceanographer												
19. Physical Geologist												
20. Photo Geologist												
21. Behavioral Scientist												
22. Chemical Technician												
23. Metallurgist												
24. Material Scientist												
25. Physical Chemist												
26. Agronomist												
27. Geographer												

D = when detached RAM is docked
(D) = optional with other D

Table 3-5. Crew Skill Requirements (Man-Hours per Day) (Cont)

Crew Skill	FPE											
	P-1		P-2		P-3		P-4		ES-1		C/N-1	
	Level											
	II	III	II	III	II	III	II	III	II	III	II	III
1. Biological Technician												
2. Microbiological Technician												
3. Biochemist												
4. Physiologist												
5. Astronomer/Astrophysicist	1	2										
6. Physicist	5	7	10	12	2	9						
7. Nuclear Physicist					5	6						
8. Photo Technician/Cartographer										4		
9. Thermodynamicist							2	9				
10. Electronic Engineer												
11. Mechanical Engineer												
12. Electromechanical Technician	5	4	9	7	3	4	3	10	3	1	1	1
13. Medical Doctor												
14. Optical Technician									1	1	1	3
15. Optical Scientist												
16. Meteorologist										4		
17. Microwave Specialist											4	5
18. Oceanographer										4		
19. Physical Geologist										2		
20. Photo Geologist										4		
21. Behavioral Scientist												
22. Chemical Technician												
23. Metallurgist												
24. Material Scientist												
25. Physical Chemist							2	9				
26. Agronomist										2		
27. Geographer										2		
Any									10			

Table 3-5. Crew Skill Requirements (Man-Hours per Day) (Cont)

	FPE											
	MS-1		T-1		T-2		T-3		T-4		T-5	
	Level											
Crew Skill	II	III	II	III	II	III	II	III	II	III	II	III
1. Biological Technician	2	2										
2. Microbiological Technician												
3. Biochemist												
4. Physiologist												
5. Astronomer/Astrophysicist												
6. Physicist			3	3								
7. Nuclear Physicist												
8. Photo Technician/Cartographer												
9. Thermodynamicist						4			(4)	(5)		
10. Electronic Engineer									( )	( )		6
11. Mechanical Engineer									( )	( )		6
12. Electromechanical Technician	4	4	6	6		16	24	24	6	6		7
13. Medical Doctor												
14. Optical Technician												
15. Optical Scientist												
16. Meteorologist												
17. Microwave Specialist												
18. Oceanographer												
19. Physical Geologist												
20. Photo Geologist												
21. Behavioral Scientist												
22. Chemical Technician												
23. Metallurgist	3	4							( )	( )		
24. Material Scientist	4	4							( )	( )		
25. Physical Chemist												
26. Agronomist												
27. Geographer												

(n) = n rotated through others marked ( )

Table 3-5. Crew Skill Requirements (Man-Hours per Day) (Cont)

Crew Skill	FPE											
	LS-1		LS-(2-5)			LS-6		LS-7		Core Equip		
	Level											
	II	III	II	IIA	III	II	III	II	III	II	IIA	III
1. Biological Technician	5	8	3	5	7		2			1		3
2. Microbiological Technician	1	5	4	2	2							
3. Biochemist	1	1	1	1	1							
4. Physiologist				2	4							
5. Astronomer/Astrophysicist												
6. Physicist												
7. Nuclear Physicist												
8. Photo Technician/Cartographer												
9. Thermodynamicist												
10. Electronic Engineer												
11. Mechanical Engineer					7				9/9			
12. Electromechanical Technician					6				11/10	1	2	3
13. Medical Doctor	1	2							5/3			
14. Optical Technician										1	1	3
15. Optical Scientist												
16. Meteorologist												
17. Microwave Specialist												
18. Oceanographer												
19. Physical Geologist												
20. Photo Geologist												
21. Behavioral Scientist									2/5			
22. Chemical Technician		1								1	2	3
23. Metallurgist												
24. Material Scientist												
25. Physical Chemist												
26. Agronomist												
27. Geographer												
Any	3	4					8	5	8			

n/d = n hr/day every d days

Table 3-6. Logistic Requirements Matrix
(Lb/Month Experiment Support)

Discipline	Laboratory							
Title	Code	1	2	3	4	5	6	7
Astronomy	A	60 60	85 170	122 153	12 25	88 111	183* 183**	
Physics	P	180 280	18 24	300 345	100 200			
Earth Observation	E	265 920						
Communications and Navigation	C/N	42 63						
Material Sciences	MS	603 603						
Technology	T	33 33	- 370	220 1000	72 160	- 400		
Life Sciences	LS	25 94		75 250*** 795			- 73	45 300

*Level II
**Level III
***Level IIA

Table 3-7. Electrical Power Requirements Matrix
(Maximum Sustained KW)

Discipline	Laboratory								
Title	Code	1	2	3	4	5	6	7	Core
Astronomy	A	0.22 0.45	0.22 0.57	0.72 0.78	0.30 0.60	0.12 0.25	0.75* 0.75**		
Physics	P	1.60 1.63	0.25 0.35	0.70 0.71	0.34 3.85				
Earth Observation	E	4.10 4.10							
Communications and Navigation	C/N	0.96 1.07							
Material Sciences	MS	5.0 5.0							
Technology	T	0.40 0.40	- 0.25	0.33 0.33	3.0 3.0	- 0.30			
Life Sciences	LS	0.05 1.26		0.05 0.15*** 0.16			- 1.0	0.05 0.40	1.25 1.30 1.90

*Level II
**Level III
***Level IIA

Table 3-8. Balanced Program, Priority Ratings

Benefit Category	Worth Rating	Experiment No.	Rank Designation
I. 1 and II. 1	5	ES-1. 1, -1. 6	First
I. 1	5	ES-1. 2, -1. 3, -1. 4, -1. 5	Second
I. 3, II. 1	5	A-3	Third
I. 2, II. 3, I. 4	5	L/S-1	Fourth
II. 1	5	A-1 A-5 P-3	Fifth
I. 3, II. 1	4	P-1. 1	Sixth
I. 3	4	C/N-1. 9 M/S-1	Seventh
I. 2	4	E/S-1. 7 C/N-1. 3, -1. 4	Eighth
I. 4	4	T-4, -5 C/N-1. 1, -1. 2	Ninth
II. 1	4	A-2. 2 P-4	Tenth
II. 3	4	L/S-3, -4	Eleventh
I. 2	3	T-1 L/S-6, -7 C/N-1. 8	Twelfth
I. 4	3	C/N-1. 5, -1. 6, -1. 7, -1. 10 C/N-1. 11, -1. 12, -1. 13 T-3	Thirteenth
II. 1	3	A-4 P-1. 2, -2	Fourteenth
II. 3	3	L/S-2, -5	Fifteenth
II. 2	3	A-2. 1	Sixteenth
II. 4	3	T-2	Seventeenth
II. 2	2	P-1. 4	Eighteenth

The scheduling interrelationships and constraints that must be satisfied are summarized here.

1. Start T-1 at least six months before E-1 initiation.

2. Start T-1 at least two years before A-3 initiation.

3. Conduct T-1 and P-4 in same time frame, if possible.

4. Conduct T-1 and P-2 in same time frame, if possible.

5. Start P-1 at least one year before A-2 initiation.

6. Start E-1 at growth IOC.

7. Start T-1 (growth phase) at growth IOC.

FPE numbers used in the preceding summary are defined as follows:

T-1 Contamination measurements
E-1 Earth observations facility
A-2 Advanced stellar
A-3 Advanced solar
P-1 Space physics research facility
P-2 Plasma physics and environmental PERTS
P-4 Physics and chemistry facility

The basic constraint imposed is relative to those laboratories that permit measurement of the environment about the operating space station. The principal FPE for conducting these operations is the contamination measurement FPE (T-1). This FPE establishes the space station exterior environment through which external viewing sensors (earth surveys and astronomy) must operate. It is desirable, although not required, that the external viewing physics experiments (P-2 and P-4) be scheduled in the same time frame as the contamination measurement experiments. The scheduling desirability is based primarily on considerations of similar equipment requirements for the operations of these FPE's. An additional constraining consideration is the operation of the space physics research laboratory. This laboratory includes a small astronomy telescope experiment (P-1.4) and it is desirable to conduct experiments with these sensors at least one year before operations of the advanced stellar astronomy experiments (FPE A-2) are started. By operating FPE P-1 before FPE A-2, early knowledge will be gained relative to the earth orbital operations of a stellar telescope.

The preferred scheduling sequence that results from the applications of the rank designation and the application of the scheduling interrelationships and constraints is shown in Table 3-9. Exception for the first FPE's at the Level II laboratories, the scheduling sequence follows the rank designation. As discussed previously, the first three laboratories are scheduled concurrently for measuring the space station environment and for the sake of convenience. At Level III, the physics experiments are ordered by their rank designation when only the contamination FPE (T-1) has a high scheduling order. Again, the high sequence for FPE T-1 is justified to measure the space station environment at the growth level.

Before the scheduling considerations that have been discussed thus far were applied, a set of experiment scheduling ground rules was developed. These ground rules, summarized in Table 3-10, relate to considerations such as the crew man-hours per day available for experiment operations, the initial and growth space station IOC dates, the capability to accommodate attached or detached RAM's, and the scheduling philosophy. These ground rules are consistent with the guidelines and constraints and the operational capability of the selected space station design concept.

Alternative approaches for developing the reference experiment program were investigated. Figure 3-4 is a schematic representation of the alternatives considered. In the first approach, all Level II and Level III activities were scheduled sequentially, and multiple Level III cycles were also scheduled. The resultant experiment program emphasized the high priority FPE's and required 30 to 40 years to complete. This definition was not considered to be representative of the operations of the MSS.

A second approach was investigated in which all Level II activities were completed before initiation of Level III activities. Again, multiple Level III cycles were utilized in this program. The experiment program resulting from the second approach is summarized in Figure 3-5. As shown, the high-priority FPE's are emphasized once the Level III laboratories have been initiated. This program requires approximately 35 years to complete and was, as with the first approach, not considered to be representative of the space station experiment operational program.

The third alternative approach was to complete the Level II activities and complete only a single cycle of the Level III activities. Table 3-11 defines the laboratories in terms of the accommodation mode and the operating duration for this philosophy. The maximum operational duration for any given laboratory is 5 years (medical research). In general, the Level III laboratories operate for one or two years. The result of truncating the operational duration of the laboratories is illustrated in Figure 3-6, which schematically shows which cycles were dropped for the laboratories.

Table 3-9. Scheduling Sequence

FPE No.	Laboratory Title	Rank	Preferred Sequence Level II	Level IIA	Level III
P-4	Physics and Chemistry	Tenth	1		8
T-1	Contamination Measurements	Eleventh	1		1
P-2	Plasma Physics and Environmental Perturbations	Fourteenth	1		12
ES-1	Earth Observations	First and second	2		1
A-3	Advanced Solar Astronomy	Third	3		2
LS-1	Medical Research	Fourth	4		3
A-1	X-Ray Stellar Astronomy	Fifth	5		4
A-5	High-Energy Stellar Astronomy	Fifth	5		4
P-3	Cosmic Ray Physics	Fifth	5		4
P-1	Space Physics Research	Sixth	6		5
MS-1	Materials Science and Manufacturing in Space	Seventh	7		6
C/N-1	Communications/Navigation	Seventh	7		6
T-4	Advance Spacecraft Systems Test	Ninth	8		7
T-5	Teleoperations	Ninth			7
A-2	Advanced Stellar Astronomy	Tenth	9		8
A-6	Infrared Astronomy	Tenth	9		8
LS-3	Plant Research	Eleventh	10	1	9
LS-4	Cells and Tissues Research	Eleventh	10	1	9
LS-6	Life Support and Protective Systems	Twelfth			10
LS-7	Man-System Integration	Twelfth	11		10
T-3	Extravehicular Activity (EVA)	Thirteenth	12		11
A-4	Intermediate-Size UV Telescopes	Fourteenth	13		12
L-2	Vertebrate Research	Fifteenth	14	1	13
L-5	Invertebrate Research	Fifteenth	14	1	13
T-2	Fluid Management	Seventeenth			14
-	Core Equipment	None	Concurrent with L(N)		

Table 3-10. Experiment Scheduling Ground Rules

Ground Rule	Remarks
Crew man-hours per day available for experiment operations, initial station = 35 man-hours/day	
Crew man-hours per day available for experiment operations, growth = 90 man-hours/day	
Initial space station IOC = Jan 1982 Growth space station IOC = July 1987	
Initial space station is capable of accommodating two RAM's (attached or detached).	RAM scheduling is dependent upon experiment requirements.
Growth space station is capable of accommodating three attached RAM's and three detached RAM's.	RAM scheduling is dependent upon experiment requirements.
Operations of high-priority initial-phase laboratories are initiated at initial space station IOC.	
Operations of high-priority growth-phase laboratories are initiated at growth space station IOC. Scheduling of lower-priority initial-phase laboratories continues.	Gap between completion of initial-phase laboratory operations and initiation of growth-phase laboratories is minimized.
Operations of initial-phase laboratories are completed before operations of growth-phase laboratories are started.	Initial-phase laboratory operations are considered precursor to growth-phase laboratory operations.
In growth phase, all cyclic laboratory operations are limited to one cycle.	ES-1 is considered continuous, although it is refurbished annually.
Priority of experiments is based on "balanced program-priority rating," (Table 3-8).	

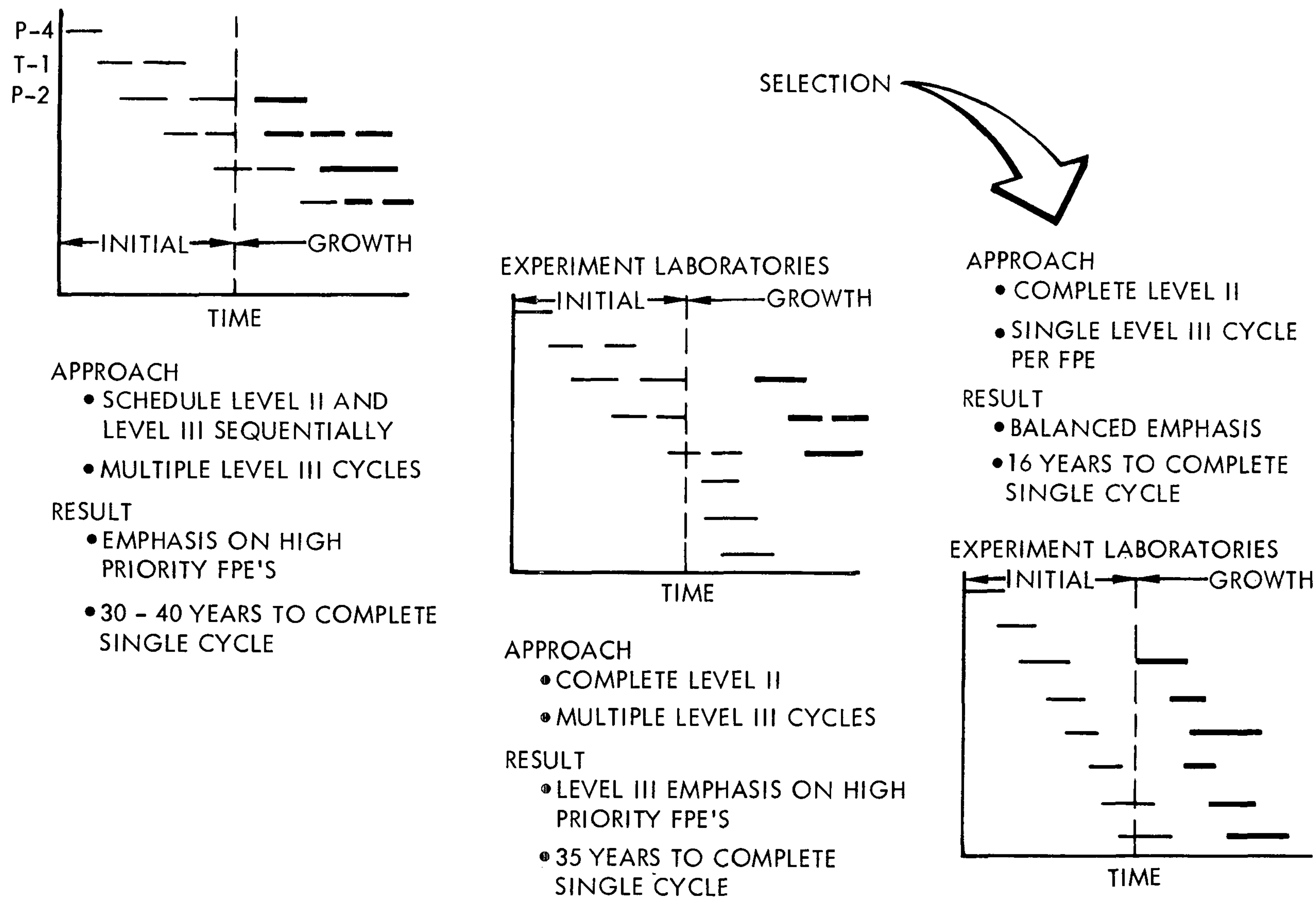

Figure 3-4. Alternative Scheduling Approaches

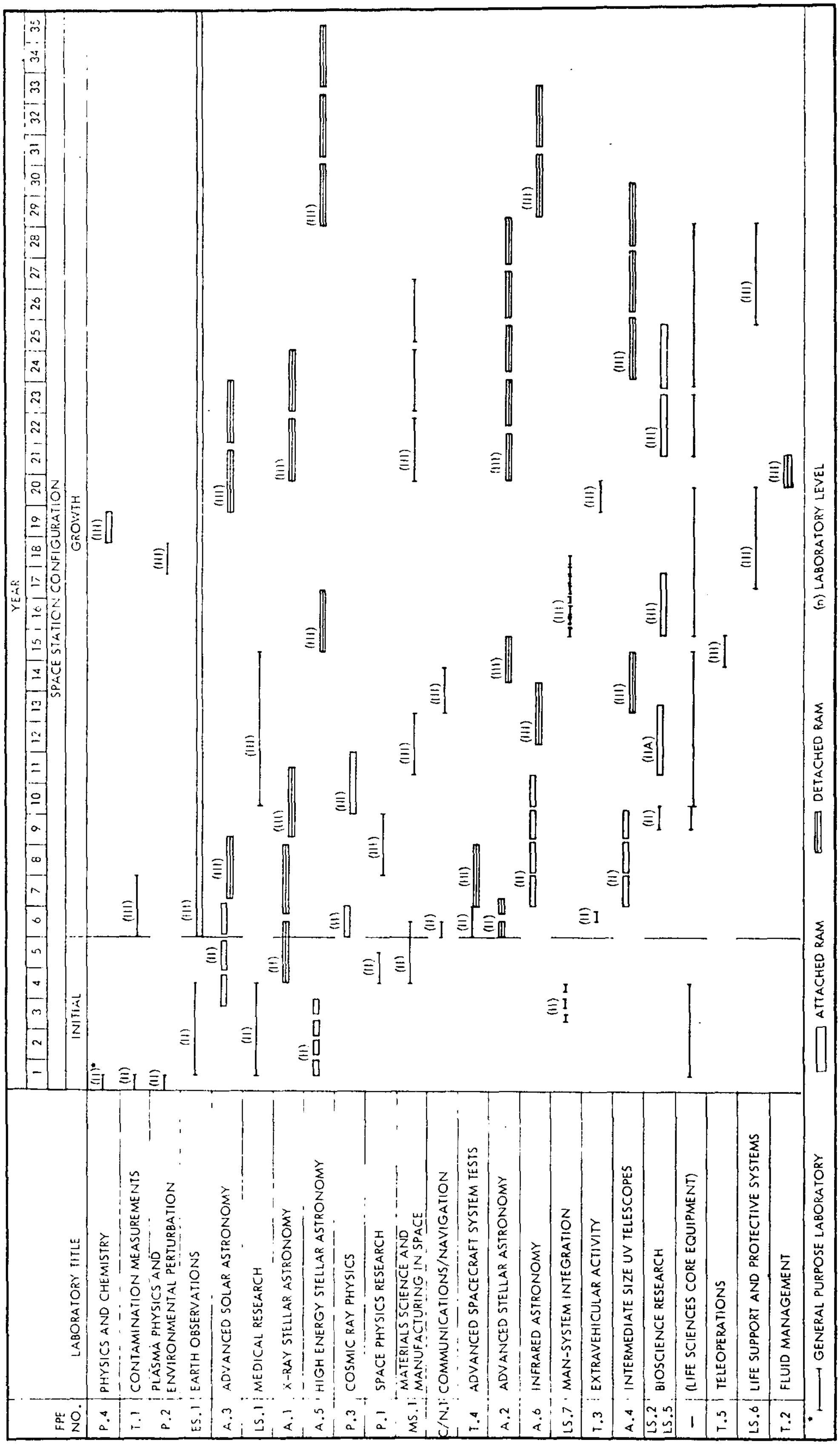

Figure 3-5. Experiment Laboratory Schedule (Approach 2)

Table 3-11. Functional Program Elements

Discipline	FPE No.	FPE Title	Level II Mode	Level II Duration	Level IIA Mode	Level IIA Duration	Level III Mode	Level III Duration
Astronomy	A-1	X-Ray Stellar	D	2Y	-	-	D	2Y
	A-2	Advanced Stellar	D	1Y	-	-	D	18M
	A-3	Advanced Solar	A	2Y	-	-	D	2Y
	A-4	Intermediate Size UV Telescope	A	1Y	-	-	D	2Y
	A-5	High Energy Stellar	A	1Y	-	-	D	2Y
	A-6	IR Astronomy	A	1Y	-	-	D	2Y
Physics	P-1	Space Physics Research Facility	GPL	1Y	-	-	G+S	2Y
	P-2	Plasma Physical and Environment Ports	GPL	6M	-	-	G+S	1Y
	P-3	Cosmic Ray Facility	A	1Y	-	-	A	2Y
	P-4	Physical and Chemistry Facility	GPL	6M	-	-	A	1Y
Earth Observations	ES-1	Earth Observation Facility	GPL	3Y	-	-	A	2Y
Communications and Navigation	C/N-1	Communications and Navigation Facility	GPL	6M	-	-	GPL	18M
Material Sciences	M-1	Material Science and Manufacturing Facility	GPL	2Y	-	-	GPL	2Y
Technology	T-1	Contamination Measurements	GPL	6M	-	-	GPL	2Y
	T-2	Fluid Management	-	-	-	-	D	1Y
	T-3	Extravehicular Activity	GPL	4M	-	-	GPL	1Y
	T-4	Advanced Spacecraft System Test	GPL	1Y	-	-	GPL	2Y
	T-5	Teleoperations	-	-	-	-	GPL	1Y
Life Sciences	L-1	Medical Reserach Facility	GPL	3Y	-	-	GPL	5Y
	L-2	Vertebrate Research Facility						
	L-3	Plant Research Facility						
	L-4	Cells and Tissue Research Facility	GPL	9M	A	18M	A	4Y
	L-5	Invertebrate Research Facility						
	L-6	Life Support and Protection System	-	-	-	-	G+A	37M
	L-7	Man-System Integration	GPL	3M	-	-	G+A	6M
		Core Equipment	GPL	*	GPL	*	GPL	*

*As required to support concurrent FPE's.

M = Months
Y = Years

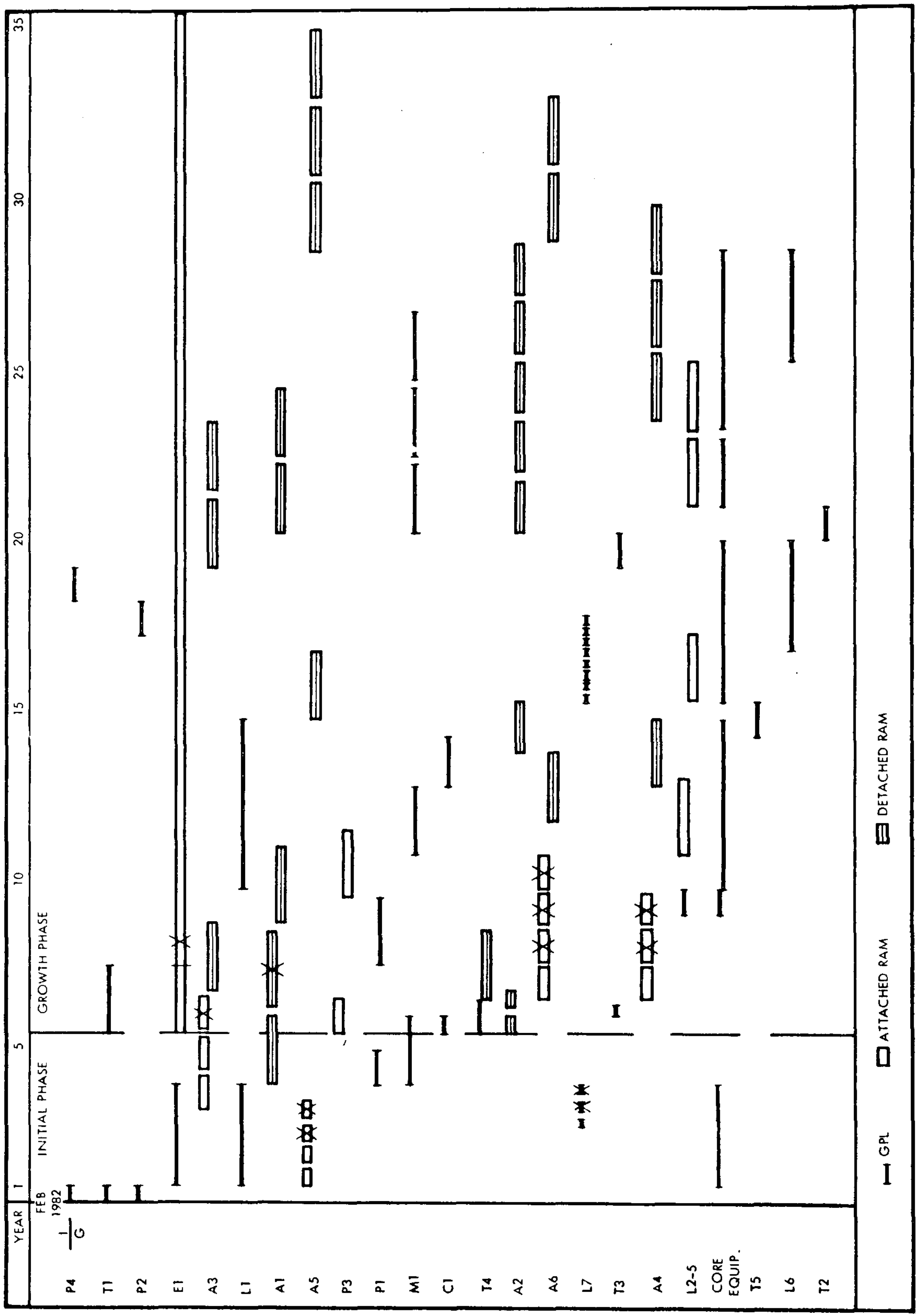

Figure 3-6. Experiment Laboratory Schedule (Approach 3 Impact on Approach 2)

The experiment program shown in Figure 3-7 requires approximately 15 years to complete. The program provided the basis for development of the mission sequence plan discussed in the next subsection. The basic constraint used in development of the reference experiment program was crew man-hours per day. During this and past analyses, it was determined that crew man-hours per day are the most vital space station resource and all other resource limitation can be met by judicious short-term scheduling. All Level II activities are completed during the first eight years of space station operations. Level III activities are initiated at growth space station IOC and are completed after 10 years of growth space station operations.

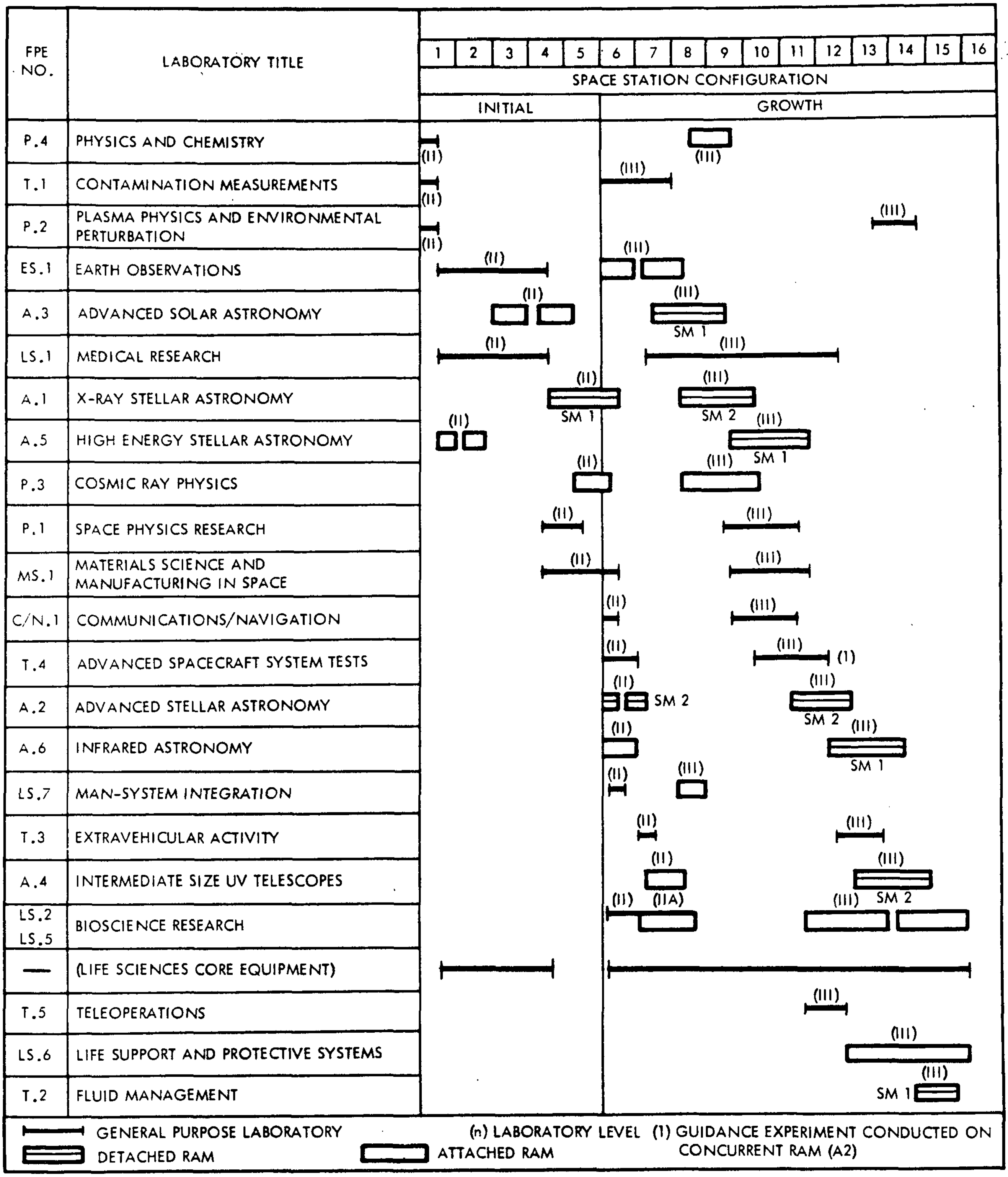

Figure 3-7. MSS Reference Experiment Program

3.3 REFERENCE PROGRAM

The building blocks that were integrated to establish a reference program are presented in Figure 3-8. The basic building block was the reference experiment program defined in the previous section. In order to establish the total mission sequence plan (MSP), the space station buildup operations, and crew rotation operations must be integrated. The resultant total operational program is presented in Figure 3-9.

The MSP integrated the scheduling of all FPE's, the shuttle flights to support the space station and experiment operations, the logistics requirements for station and experiment operations, and the crew rotation cycles. The fundamental characteristics of the MSP and the pertinent conclusions obtained therefrom are summarized in Figures 3-10 through 3-13.

The degree of continuity in the operations of experiments within each of the seven disciplines is illustrated in Figure 3-10, which shows both the levels and the crew man-hours per day by discipline. The operations of

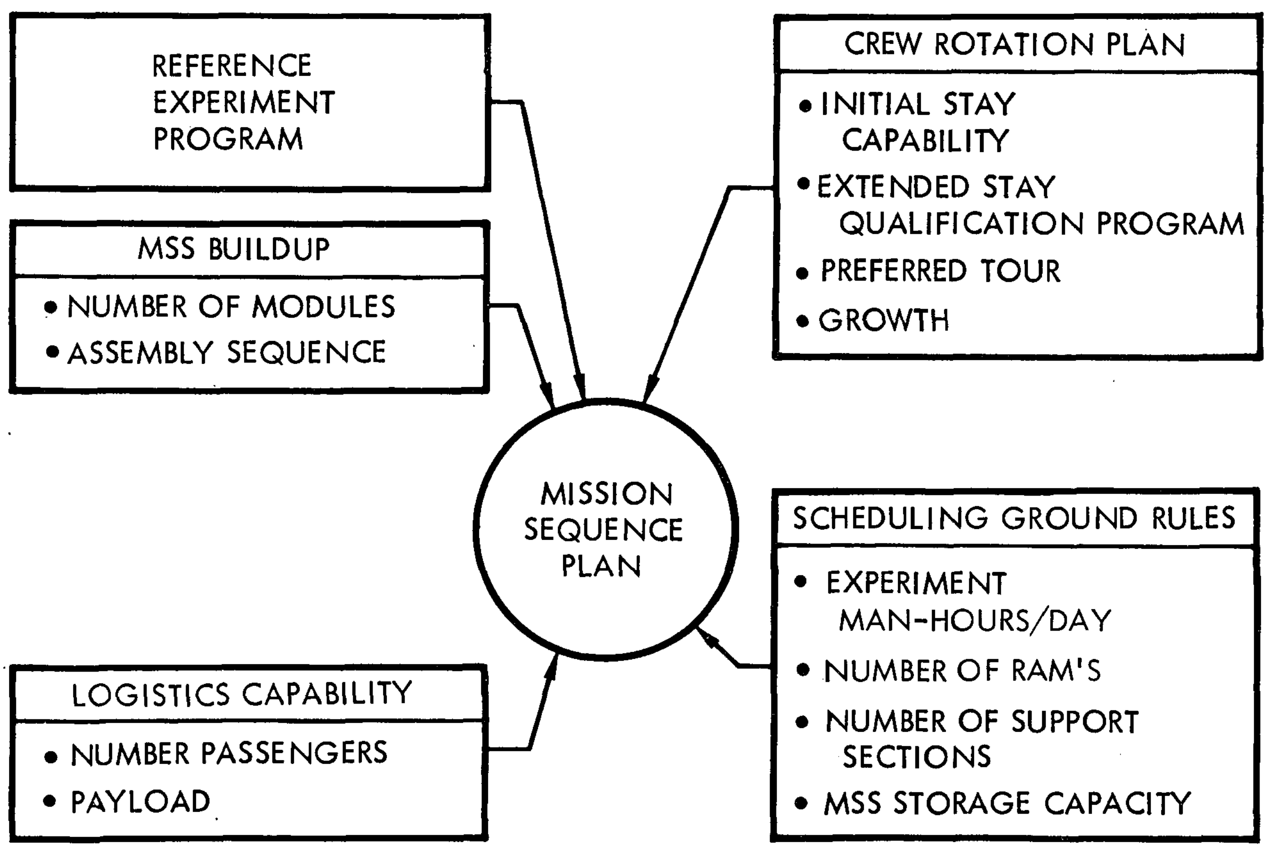

Figure 3-8. Mission Sequence Plan Development

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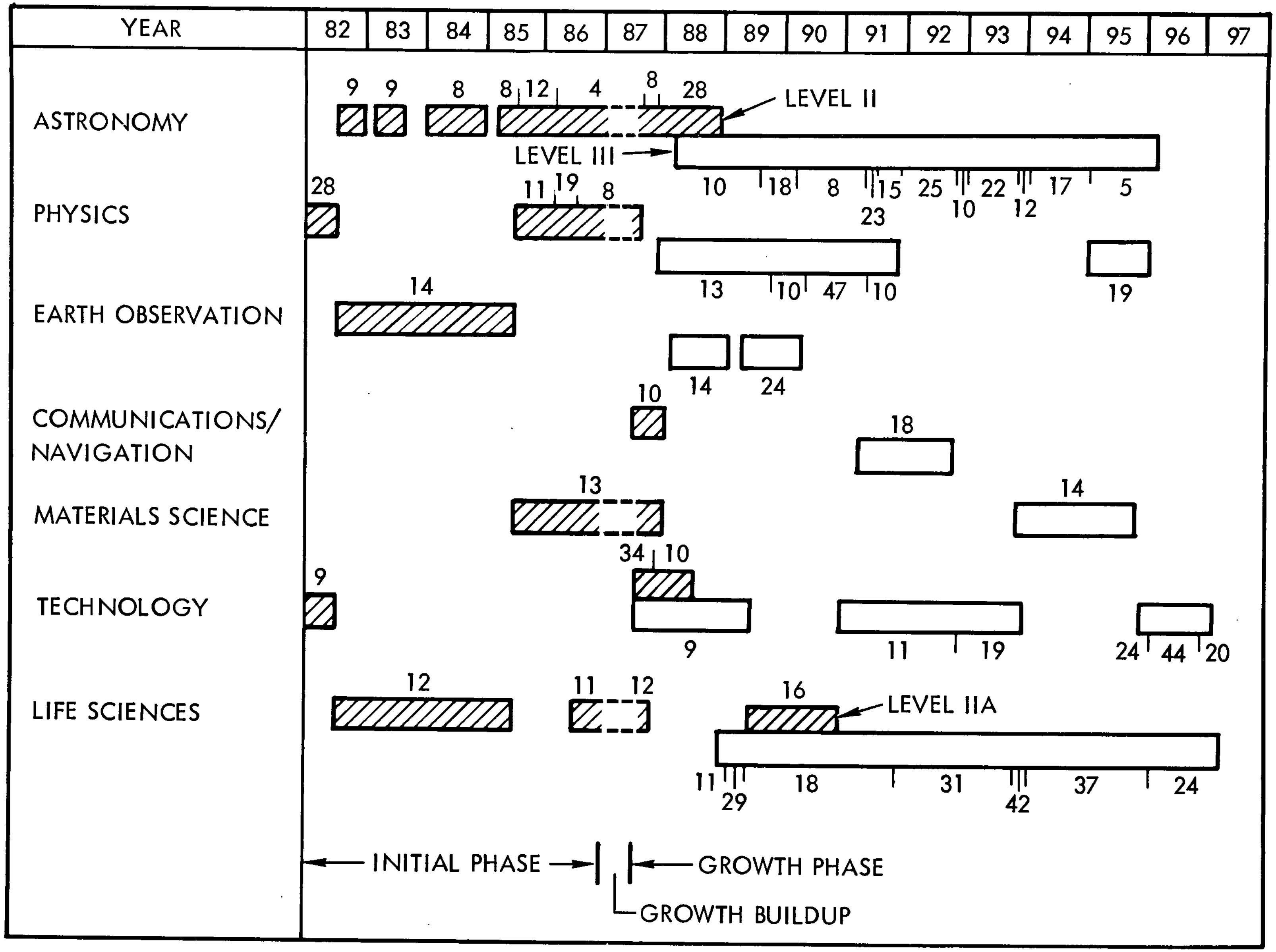

Figure 3-10. Experiment Program Schedule by Man-Hours Per Day Per Discipline

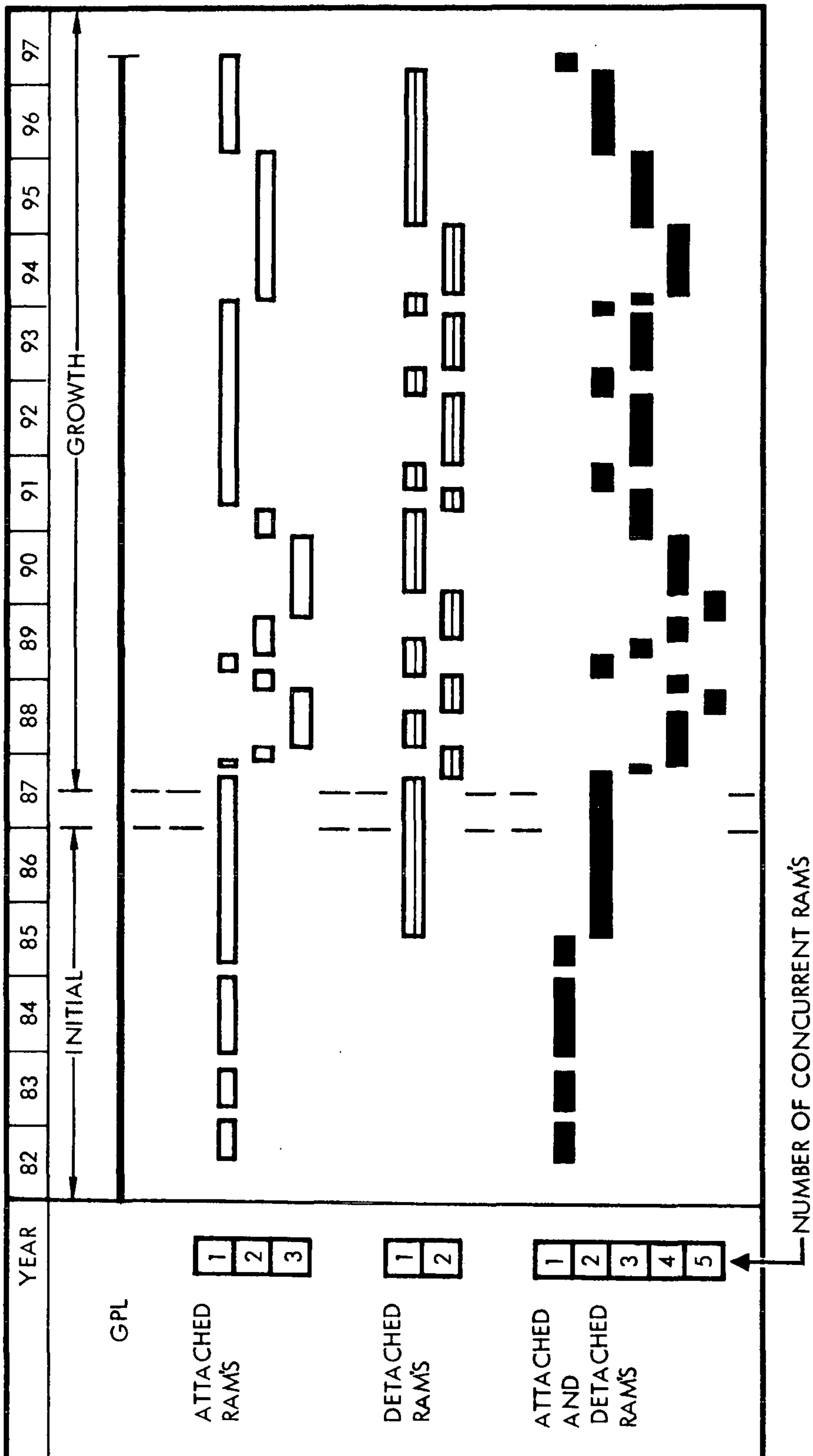

Figure 3-11. Schedule of Operational Modes

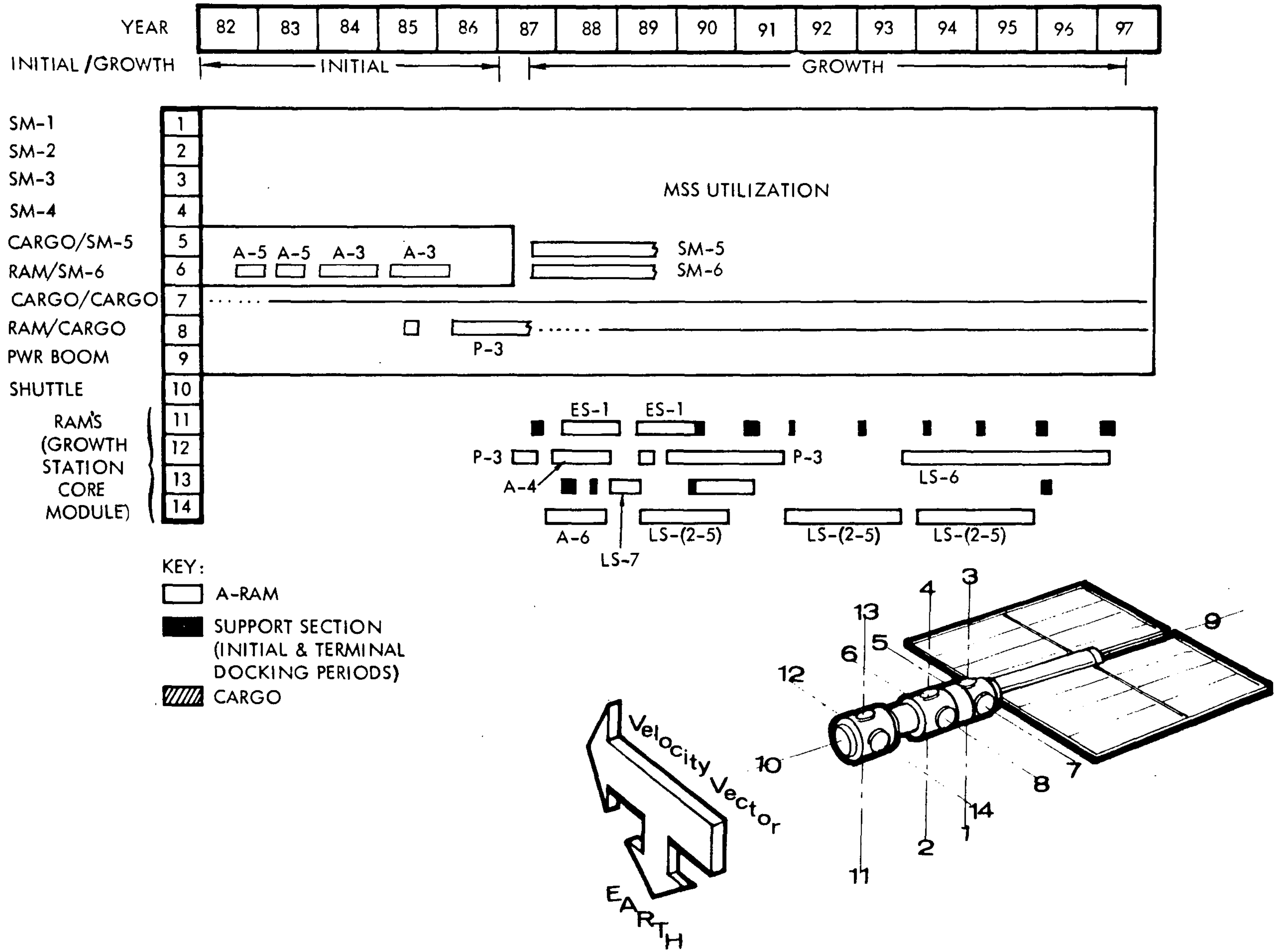

Figure 3-12. Docking Port Utilization

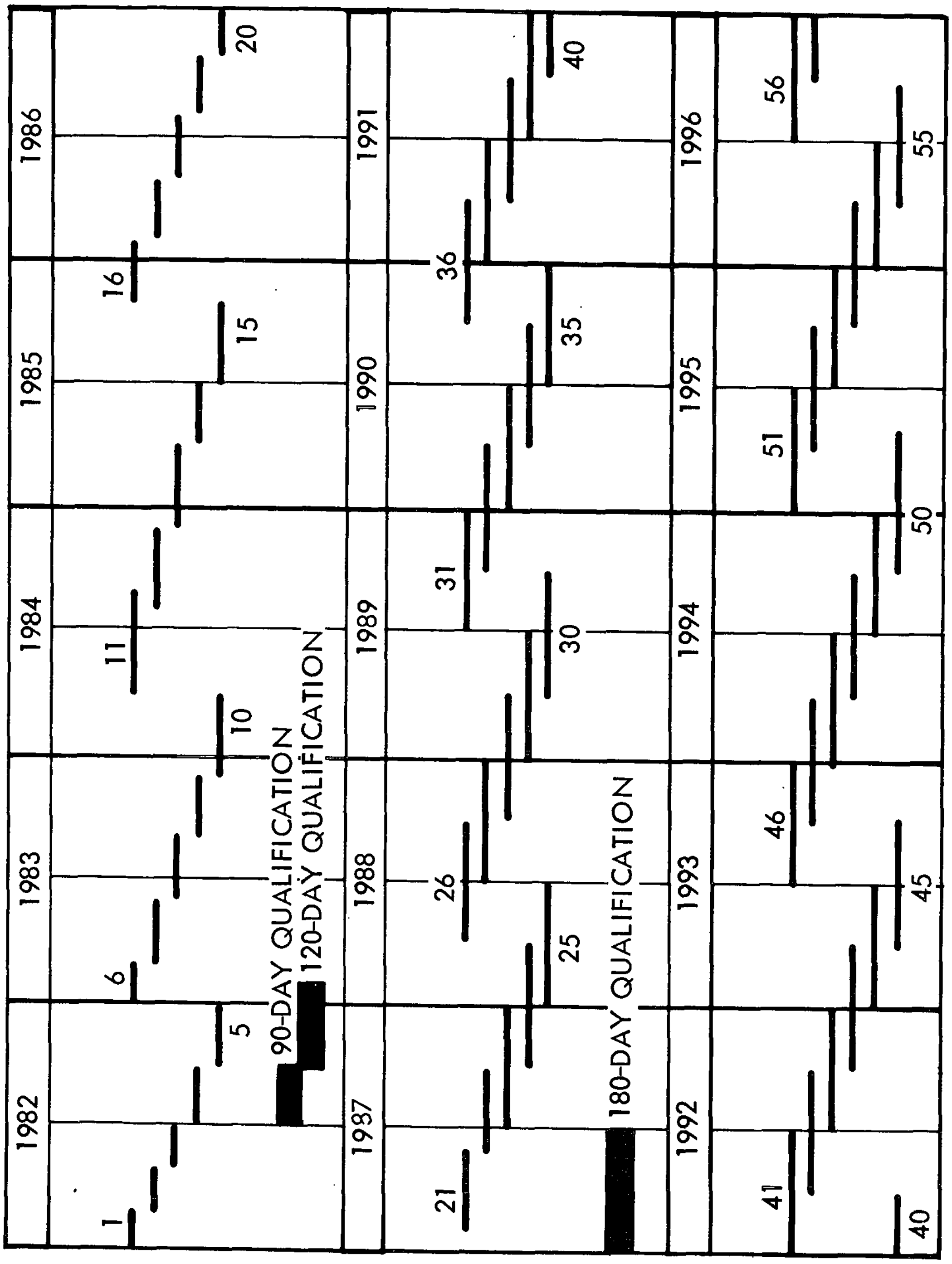

Figure 3-13. Crew Rotation Plan

experiments within the astronomy, physics, and life sciences disciplines are relatively continuous. Also, relatively continuous operations of experiments in the technology discipline are achieved once the Level III laboratory capability is achieved. Operations of the earth observations (FPE ES-1) is relatively limited due primarily to the high manpower requirements, the desirability of accommodating the entire Blue Book within a reasonable time period, and the desirability of retaining a relatively balanced program throughout the space station operational lifetime. The short operational durations for the communications/navigation and materials science disciplines are due primarily to the ability to "complete" the Blue Book-defined experiments in relatively short time periods.

The overall operational capability of the space station is presented in Table 3-12. The table shows, in terms of equivalent crewmen, a gross approximation of the level of activity that can be accommodated by the initial and growth space stations. The initial space station is capable of supporting the equivalent of a one-man level of activity in astronomy, a 1.5-man level of activity in physics and earth observations, and a one-man level in the remaining disciplines. For the growth space station, the values vary from the equivalent of a one-man level up to a maximum of a two-man level in the life sciences disciplines. The foregoing values are based on the reference experiment program, and the selected space station design concept has the inherent flexibility to accommodate variations in the distributions. The data in Table 3-12 do indicate, however, the relatively balanced operational capability that can be achieved.

Another significant conclusion that can be drawn from the MSP is the distribution of the utilization of the facilities (GPL, attached RAM's and detached RAMs), as shown in Figure 3-11. As would be expected, the GPL facilities will be used continuously throughout the programs. No more than three attached RAM's will be required at any point in the program. Only one attached RAM will be required at any point in time during operations of the initial space station. During growth space station operations, only one attached RAM will be required approximately 50 percent of the time, two for approximately 30 percent of the time, and three for the remaining 20 percent of the operations.

The reference MSP also minimizes the number of detached RAM's required throughout the program, and at no point in the program will more than two detached RAM's be required. Therefore, only two RAM support sections will be required to support the experiment operation. As a result, only three support sections will be required to support the total program, including one spare.

Table 3-12. Approximate Experiment Operations Manpower Distribution

Discipline	Manpower Distribution	
	Initial Station	Growth Station
Astronomy	1.0	1.0
Physics	1.5	1.0
Earth Observations		1.5
Communication/Navigation	-	-
Materials Science		1.5
Technology	1.0	1.0
Life Sciences		2.0
Total Available	3.5	9.0

The total number of RAM's required (attached and detached) will usually be four or less, although two relatively short periods occur when five RAM's (three attached and two detached) will be required. By limiting RAM requirements, program costs can be reduced by limiting the required number of experiment equipment modules and support sections.

One impact the number of RAM's operating concurrently will have is on the utilization of the space station docking/berthing ports. A representative docking/ berthing port utilization history is presented in Figure 3-12. During the period of initial space station operations, Ports 5 and 7 will be used alternately for cargo module berthing. One berthing port for a growth space station module (Port 6 or Port 8) will be used for attached astronomy and physics RAM's. During the initial period of space station operations, all the nominally available berthing ports will be required to support the operations of attached and detached RAM's. Since the cargo module uses two ports alternately, one port will be available between resupply operations that is not used in the MSP. During the remainder of the program, berthing ports will be required for attached RAM's and for periodic support of the detached RAM's.

The crew rotation plan that resulted from development of the MSP is summarized in Figure 3-13. Crew qualification for stay times up to 120 days will be accomplished during operations of the initial space station and extended to 180 days during growth station operations. The associated distribution of the crew skills requirements, based on the crew skills requirements defined in Figure 2-8, is presented in Table 3-13. The distributions of the crew skills are presented in terms of the crew number, defined in Figure 3-13, and the date on which the skill is first required. During initial space station operations, a maximum of 12 crew skills will be required. An average of 18.5 skills will be required during growth space station operations, with maximum of 22 skills required during a single time interval. The resultant average number of skills per experiment and station operations crewman are approximately 1.9 and 1.7 for the initial and growth space stations, respectively.

Table 3-13. Crew Team Skills

Crew Skill	Crew Number 1-3	4-9	10-14	15-16	17	18	19
Date Required	1/82	7/82	12/83	7/85	2/86	5/86	8/86
1. Biological Technicial		X	X		X	X	X
2. Microbiological Technician		X	X	X		X	X
3. Biochemist		X	X			X	X
4. Physiologist							
5. Astronomer/Astrophysicist		X	X	X	X	X	X
6. Physicist	X	X		X	X	X	
7. Nuclear Physicist					X		X
8. Photo Technician/Cartographer							
9. Thermodynamicist	X						
10. Electronic Engineer		X					
11. Mechanical Engineer							
12. Electromechanical Technician	X	X	X	X	X	X	X
13. Medical Doctor		X	X				
14. Optical Technician		X	X	X	X	X	X
15. Optical Scientist			X				
16. Meteorologist							
17. Microwave Specialist							
18. Oceanographer							
19. Physical Geologist							
20. Photo Geologist							
21. Behavioral Scientist							
22. Chemical Technician							
23. Metallurgist							
24. Material Scientist				X	X	X	X
25. Physical Chemist				X	X	X	X
26. Agronomist	X						
27. Geographer							
28. Commander	X	X	X	X	X	X	X
29. Flight Controller	X	X	X	X	X	X	X
30. Systems Engineer	X	X	X	X	X	X	X
Total Number of Skills	7	12	11	10	11	12	12
Average Number of Skills	7	11.4					
Average Skills per Crewman	1.1	1.9					

Table 3-13. Crew Team Skills (Cont)

Crew Skill	Crew Number 22 23	23 24	24 25	25 26	26 27	27 28	28 29
Date Required	6/87	10/87	1/88	4/88	7/88	10/88	1/89
1. Biological Technician	X	X					X
2. Microbiological Technician	X						X
3. Biochemist	X						X
4. Physiologist							
5. Astronomer/Astrophysicist	X	X	X	X	X	X	X
6. Physicist	X	X	X	X	X	X	X
7. Nuclear Physicist	X						
8. Photo Technician/Cartographer			X	X	X	X	X
9. Thermodynamicist	X	X	X				
10. Electronic Engineer	X	X	X		X	X	
11. Mechanical Engineer	X	X	X			X	X
12. Electromechanical Technician	X	X	X	X	X	X	X
13. Medical Doctor						X	X
14. Optical Technician	X	X	X	X	X	X	X
15. Optical Scientist	X	X	X	X	X	X	X
16. Meteorologist			X	X	X	X	X
17. Microwave Specialist	X	X					
18. Oceanographer			X	X	X	X	X
19. Physical Geologist			X	X	X	X	X
20. Photo Geologist			X	X	X	X	X
21. Behavioral Scientist	X					X	
22. Chemical Technician							X
23. Metallurgist	X	X	X				
24. Material Scientist	X	X					
25. Physical Scientist	X	X	X				
26. Agronomist			X	X	X	X	X
27. Geographer			X	X	X	X	X
28. Commander	X	X	X	X	X	X	X
29. Flight Controller	X	X	X	X	X	X	X
30. Systems Engineer	X	X	X	X	X	X	X
Total Number of Skills	20	16	20	15	16	19	21
Average Number of Skills	18.5						
Average Skills per Crewman	1.5						

Table 3-13. Crew Team Skills (Cont)

Crew Skill	Crew Number							
	29 30	30 31	31 32	32 33	33 34	34 35	36 37	37 38
	Date Required							
	4/89	7/89	10/89	1/90	4/90	7/90	1/91	4/91
1. Biological	X	X	X	X	X	X	X	X
2. Microbiological Technician	X	X	X	X	X	X	X	X
3. Biochemist	X	X	X	X	X	X	X	X
4. Physiologist	X	X	X	X	X	X	X	
5. Astronomer/Astrophysicist	X	X	X	X	X			X
6. Physicist	X	X			X	X	X	X
7. Nuclear Physicist			X	X	X	X	X	X
8. Photo Technician/Cartographer	X	X	X	X		X	X	
9. Thermodynamicist					X	X	X	X
10. Electronic Engineer						X	X	X
11. Mechanical Engineer	X					X	X	X
12. Electromechanical Technician	X	X	X	X	X	X	X	X
13. Medical Doctor	X	X	X	X	X	X	X	X
14. Optical Technician	X	X	X	X		X	X	X
15. Optical Scientist						X	X	X
16. Meteorologist	X	X	X	X				
17. Microwave Specialist								
18. Oceanographer	X	X	X	X				
19. Physical Geologist	X	X	X	X				
20. Photo Geologist	X	X	X	X				
21. Behavioral Scientist	X							
22. Chemical Technician	X	X	X	X	X	X		X
23. Metallurgist						X		X
24. Material Scientist								
25. Physical Chemist						X		X
26. Agronomist	X	X	X	X				
27. Geographer								
28. Commander	X	X	X	X	X	X	X	X
29. Flight Controller	X	X	X	X	X	X	X	X
30. Systems Engineer	X	X	X	X	X	X	X	X
Total Number of Skills	22	20	20	20	14	20	17	19

4. REFERENCES

1. Phase B Program Definition Study Modular Space Station Guidelines and Constraints Document, Final Edition. NASA MSC-03696 (12 November 1971).

2. Modular Space Station Phase B Extension Second Quarterly Report. DRL No. MSC T-575, Line Item 64, Contract NAS9-9953 NR/SD, SD 71-235 (2 September 1971).

3. Modular Space Station Program Master Plan. DRL No. MSC-T-575, Line Item 76, Contract NAS9-9953, NR/SD, SD 71-225 (December 1971).

4. Modular Space Station Program Cost and Schedule Estimates. DRL No. MSC-T-575, Line Item 77, Contract NAS9-9953, NR/SD, SD 71-226, (January 1972).