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MSFC-DPD-235/DR NO. MP-01

SPACE STATION (MODULAR) MISSION ANALYSIS

Volume I Mission Analysis

NOVEMBER 1971

MDC G2684

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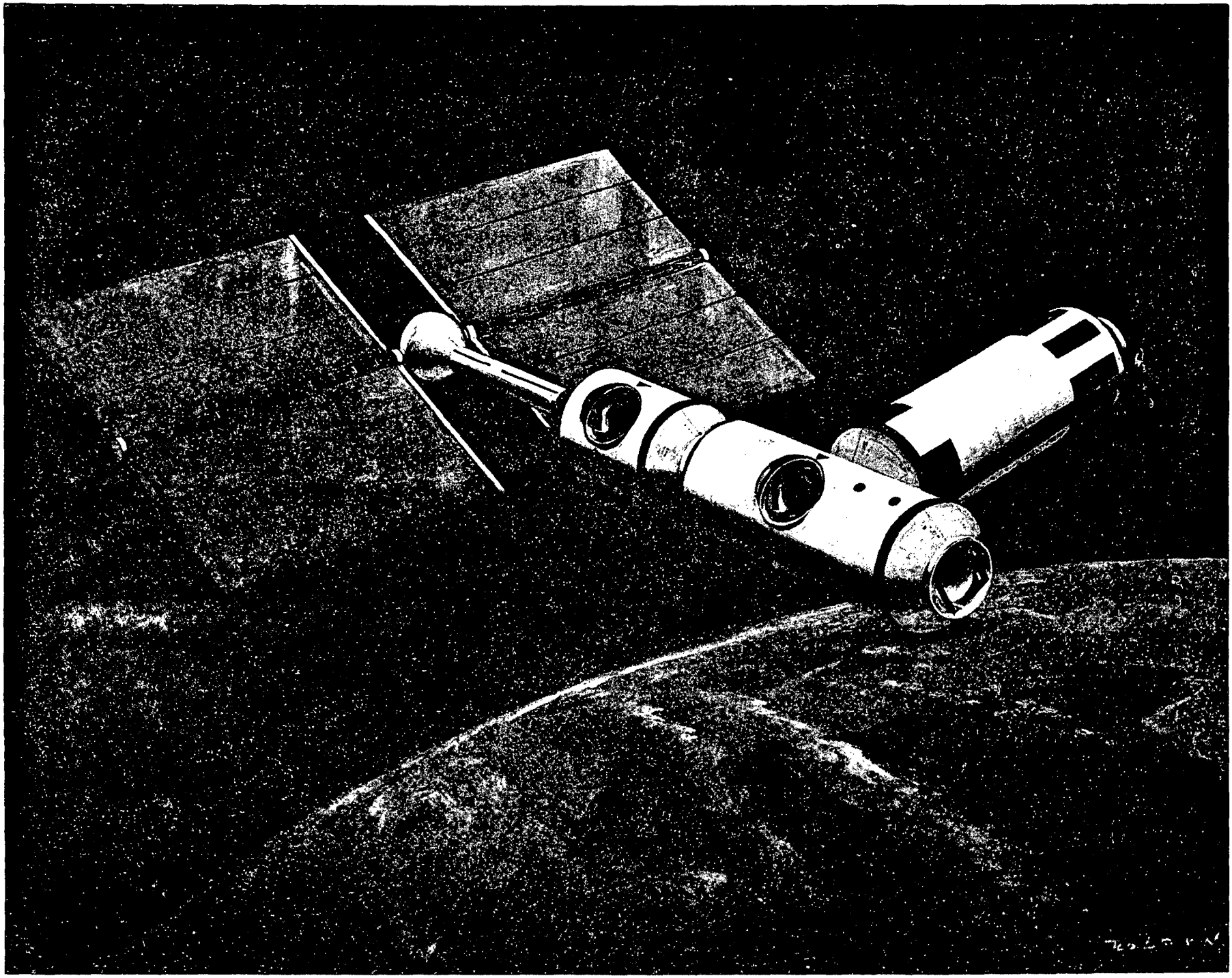
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PREFACE

The work described in this document was performed under the Space Station Phase B Extension Period Study (Contract NAS8-25140). The purpose of the extension period has been to develop the Phase B definition of the Modular Space Station. The modular approach selected during the option period (characterized by low initial cost and incremental manning) was evaluated, requirements were defined, and program definition and design were accomplished to the depth necessary for departure from Phase B.

The initial 2-1/2-month effort of the extension period was used for analyses of the requirements associated with Modular Space Station Program options. During this time, a baseline, incrementally manned program and attendant experiment program options were derived. In addition, the features of the program that significantly affect initial development and early operating costs were identified, and their impacts on the program were assessed. This assessment, together with a recommended program, was submitted for NASA review and approval on 15 April 1971.

The second phase of the study (15 April to 3 December 1971) consists of the program definition and preliminary design of the approved Modular Space Station configuration.

A subject reference matrix is included on page v to indicate the relationship of the study tasks to the documentation.

This report is submitted as Volume I of Data Requirement MP-01.

DATA REQUIREMENTS (DR's)
MSFC-DPD-235/DR Nos.
(contract NAS8-25140)

Category	Designation	DR Number	Title
Configuration Management	CM	CM-01	Space Station Program (Modular) Specification
		CM-02	Space Station Project (Modular) Specification
		CM-03	Modular Space Station Project Park 1 CEI Specification
		CM-04	Interface and Support Requirements Document
Program Management	MA	MA-01	Space Stations Phase B Extension Study Plan
		MA-02	Performance Review Documentation
		MA-03	Letter Progress and Status Report
		MA-04	Executive Summary Report
		MA-05	Phase C/D Program Development Plan
		MA-06	Program Option Summary Report
Manning and Financial	MF	MF-01	Space Station Program (modular) Cost Estimates Document
		MF-02	Financial Management Report
Mission Operations	MP	MP-01	Space Station Program (Modular) Mission Analysis Document
		MP-02	Space Station Program (Modular) Crew Operations Document
		MP-03	Integrated Mission Management Operations Document
System Engineering and Technical Description	SE	SE-01	Modular Space Station Concept
		SE-02	Information Management System Study Results Documentation
		SE-03	Technical Summary
		SE-04	Modular Space Station Detailed Preliminary Design
		SE-06	Crew/Cargo Module Definition Document
		SE-07	Modular Space Station Mass Properties Document
		SE-08	User's Handbook
		SE-10	Supporting Research and Technology Document
		SE-11	Alternate Bay Sizes

SUBJECT REFERENCE MATRIX

LEGEND
- CM Configuration Management
- MA Program Management
- MF Manning and Financial
- MP Mission Operations
- SE System Engineering and Technical Description

	CM				MA		MF	MP			SE								
	CM-01 Space Station Program (Modular) Specification	CM-02 Space Station Project (Modular) Specification	CM-03 Modular Space Station Project Part I CEI Spec	CM-04 Interface and Support Requirement Document	MA-05 Phase C/D Program Development Plan	MA-06 Program Option Summary Report	MF-01 Space Station Program (Modular) Cost Estimates Document	MP-01 Space Station Program (Modular) Mission Analysis Document	MP-02 Space Station Program (Modular) Crew Operations Document	MP-03 Integrated Mission Management Operations Document	SE-01 Modular Space Station Concept	SE-02 Information Management System Study Results	SE-03 Technical Summary	SE-04 Modular SS Detailed Preliminary Design	SE-06 Crew Cargo Module Definition Document	SE-07 Modular Space Station Mass Properties Document	SE-08 User's Handbook	SE-10 Supporting Research and Technology	SE-11 Alternate Bay Sizes
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2.1 Develop Study Plan and Review Past Effort (MA-01)																			
2.2 Space Station Program (Modular) Mission Analysis								●											
2.3 Modular Space Station Configuration and Subsystems Definition														●					
2.4 Technical and Cost Tradeoff Studies							●												
2.4.4 Modular Space Station Option Summary											●								
2.5 Modular Space Station Detailed Preliminary Design														●					
Mass Properties																●			
2.6 Crew Operational Analysis									●										
2.7 Crew Cargo Module															●				
Mass Properties																●			
2.8 Integrated Mission Management Operations										●									
2.9 Hardware Commonality Assessment													●						
2.10 Program Support					●														
2.11 Requirements Definition																			
Space Station Program (Modular)	●																		
Space Station Project (Modular)		●																	
Modular Space Station Project–Part I CEI			●																
Interface and Support Requirements				●															
2.12 Plans					●														
2.13 Costs and Schedules							●												
2.14 Special Emphasis Task Information Management (IMS)												●							
Modular Space Station Mass Properties																●			
User's Handbook																	●		
Supporting Research and Technology																		●	
Technical Summary													●						
MOD 29																			●
MOD 40						●													

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Section 1

INTRODUCTION

1.1 BACKGROUND

With the advent of the Space Shuttle in the late 1970's, a long term manned scientific laboratory in Earth orbit will become feasible. The shuttle will be used for orbital buildup, logistics delivery, and return of scientific data, enabling the laboratory to provide many advantages to the scientific community and making available to the United States a platform for application to such national problems as ecology research, weather observation and prediction, and research in medicine and the life sciences. The laboratory will be ideally situated for Earth and space observation, and its location above the atmosphere will greatly benefit astronomy.

An orbiting laboratory can take many forms and can be configured to house a crew of up to 12 men. The initial study of the 33-foot-diameter Space Station, launched by the Saturn INT-21 and supporting a complement of 12, has been completed to a Phase B level and documented in the DRL-160 series. Recently completed studies centered around a Space Station comprised of smaller, shuttle-launched modules which could ultimately be configured to provide for a crew of the same size. However, buildup would be gradual, beginning with a small initial crew and progressing toward greater capability by adding modules and crewmen on a flexible schedule.

Phase A study of theModular Space Station results are documented in the DRL-231 series. Phase B study results are documented in series DPD-235, of which this is a volume.

The Space Station will provide laboratory areas similar to facilities on Earth and designed for flexible, efficient changeover as research and experimental programs proceed. Provisions will be included for such functions as data processing and evaluation, astronomy support, and test and calibration of

optics. Zero gravity, desirable for conducting experiments, will be the normal mode of operation. In addition to experiments carried out within the station, the laboratories will support experiments in separate modules either docked to the Space Station or free-flying.

Following launch and activation, Space Station operations will be largely autonomous, and an extensive ground support complex will be unnecessary. Ground activities will ordinarily be limited to long-range planning, control of logistics, and support of the experiment program.

The Initial Space Station (ISS) will be delivered to orbit by three Space Shuttle launches and assembled in space. A crew in the Shuttle orbiter will accompany the modules to assemble them and check interfacing functions.

ISS resupply and crew rotation will be carried out via round-trip Shuttle flights using Logistics Modules (Log Modules) for transport and on-orbit storage of cargo. Of the four Log Modules required, one will remain on orbit at all times.

Experiment modules will be delivered to the Space Station by the Shuttle as required. On return flights, the Shuttle will transport data from the experiment program, returning crewmen, and waste.

The ISS configuration is shown in the frontispiece. The Power/Subsystems Module will be launched first, followed at 30-day intervals by the Crew/Operations Module and the General Purpose Laboratory (GPL) Module. This configuration will provide for a crew of six. Subsequently, two additional modules (duplicate Crew/Operations and Power/Subsystems Modules) will be mated to the ISS to form theGrowth Space Station (GSS) (see frontispiece), which will house a crew of 12 and provide a capability equivalent to the 33-foot INT-21-launched Space Station. GSS logistics support will use a Crew Cargo Module capable of transporting a crew of six.

During ISS operations, five Research Applications Modules (RAM's) will be assembled to the Space Station. Three will be returned prior to completion

of the GSS. In the GSS configuration, 12 additional RAM's will augment the two remaining from the ISS phase. Three of the RAM's delivered to the GSS will be free-flying modules.

During the baseline 10-year program, the Space Station will be serviced by Shuttle-supported Logistics Module or Crew Cargo Module flights.

1.2 SCOPE OF THIS VOLUME

This volume, DR No. MP-01, contains the final analyses conducted on the Modular Space Station in the areas of Experiment, Mission, Operations, Information Management, and Long Life and Safety Analyses. It has been written to collect the outputs of Tasks 2.2.1, 2.2.2, 2.2.3, 2.10.1, and 2.10.2 defined in the Study Plan - Document MA-01. Each of the above subject headings is treated as a major section of this volume and a brief summary of each follows.

1.3 EXPERIMENT PROGRAM SELECTION

The baseline experiment program was prepared by iteratively operating upon Blue Book-derived experiment data, NASA-supplied experiment cost data, estimated Space Station program costs, and the resource capabilities of the Space Station design by means of an MDAC man-in-the-loop computer program (WICK).

The 1971 Blue Book was reviewed and used as the new experiments data base. The experiments were regrouped into 50 candidate Functional Program Elements (FPE's) and the mode of accommodation selections reviewed for each. This resulted in 25 being assigned to be accommodated integrally in the GPL, 17 in Attached Modules and 8 on Free Flying Modules. These candidate FPE's were then scheduled by means of the WICK program. By iteratively considering such factors as those candidate FPE's compatible with the ISS (Initial Space Station) capability, the desire to minimize initial program costs, the proper utilization of the Space Station resources, and the schedule demands of the experiments themselves, the Final Experiment Program, Case 534G, resulted as shown in Figure 1-1. The program begins with experiments being conducted in both the Life Sciences and the

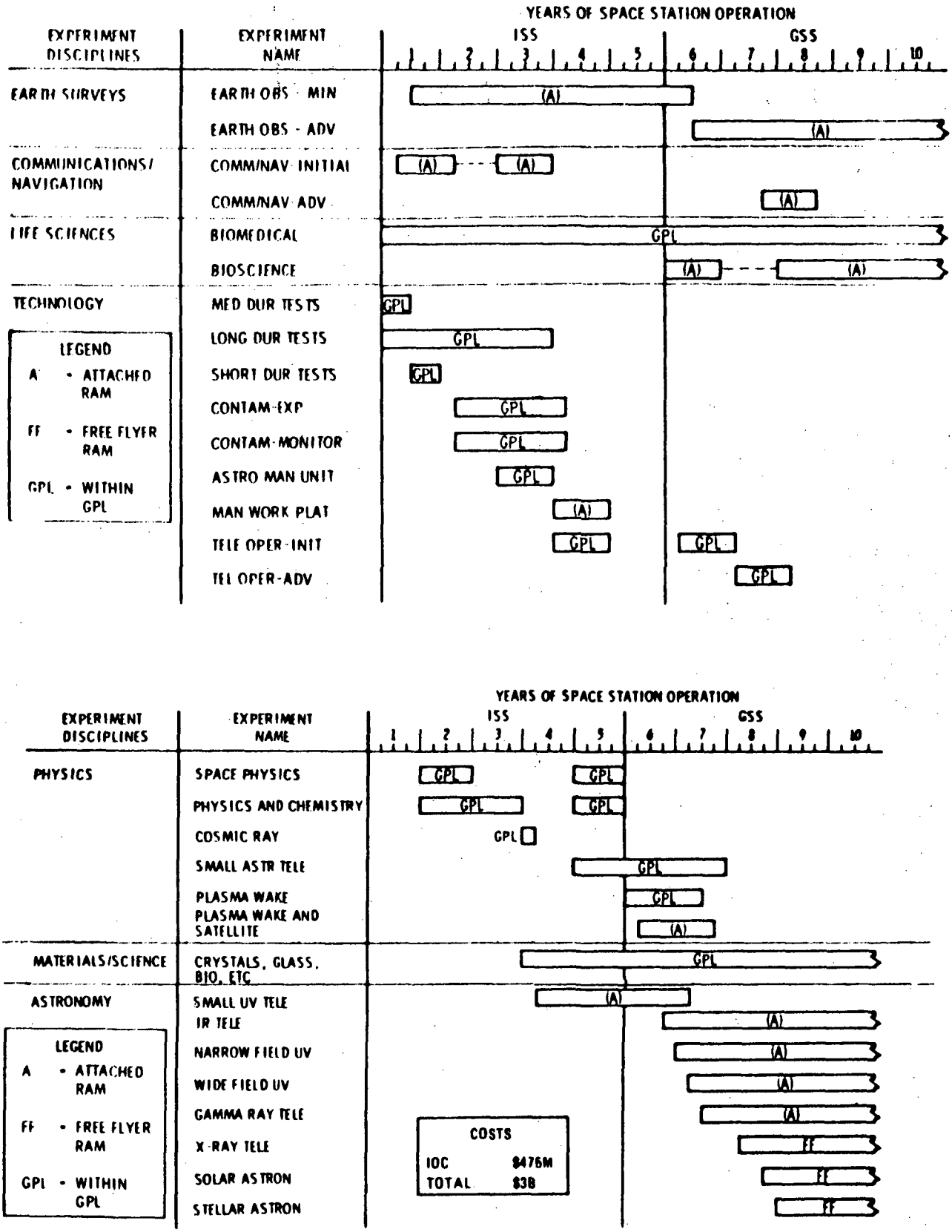


Figure 1-1. Baseline Experiment Program

Technology Areas. During the first year, two RAM's (Comm/Nav and Earth Surveys) are brought up and attached. Experiments are added during the ISS phase so that all major experiment disciplines have been represented. The GSS period is characterized by the addition of more RAM's, primarily astronomy modules. The maximum resource requirements determined during these two program phases are as summarized below.

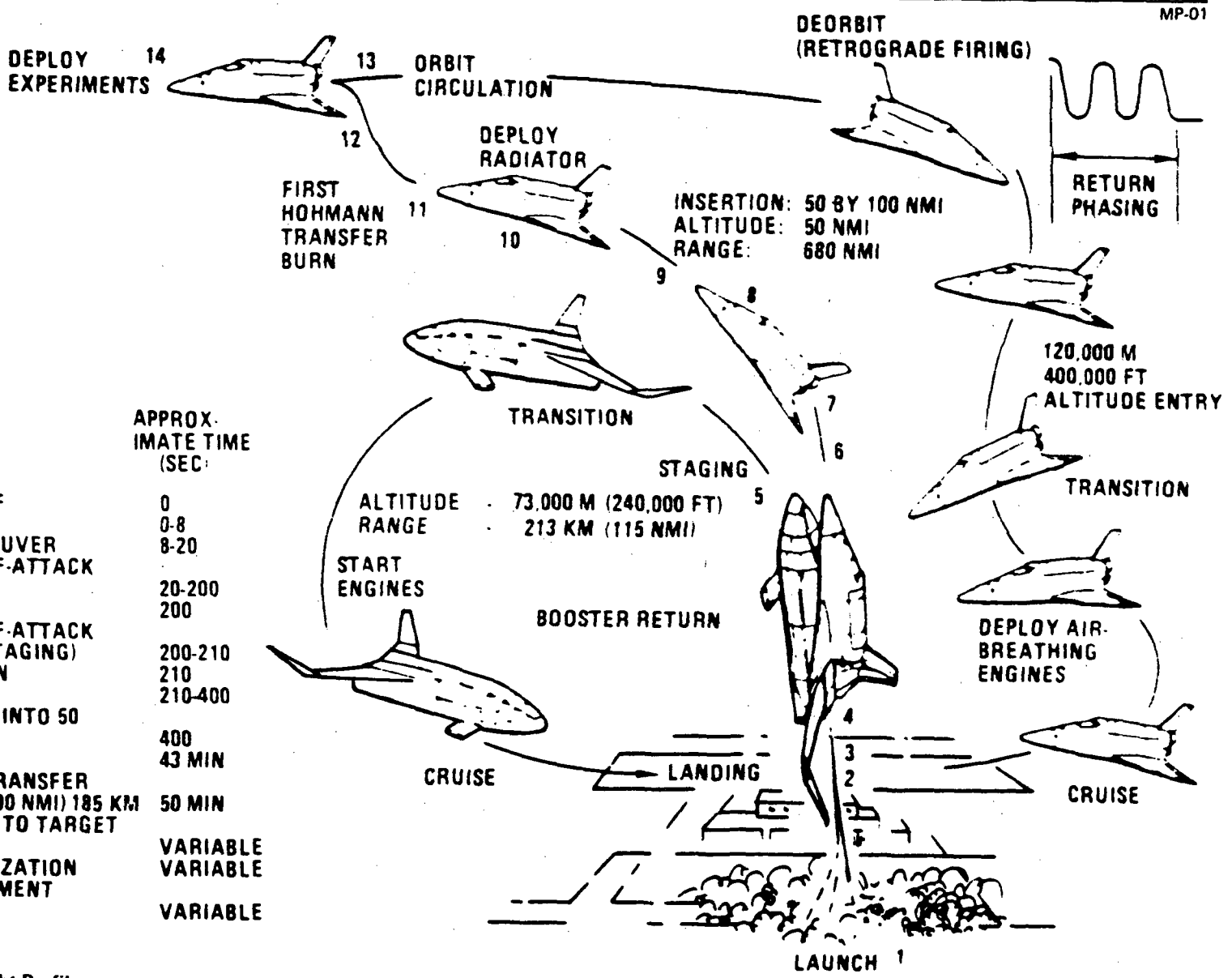
	Cost	Peak Resource Requirements		
		Manpower	Power	Resupply
ISS	$419.15M launch	4.43	4,981 w	31,746 lb/90 days
GSS	$3,222.73M 10 yr	9.45	12,692 w	31,374 lb/90 days

Two alternate experiment programs with emphasis placed on Life Sciences and Astronomy respectively were also developed with the cost constraints removed.

1.4 MISSION ANALYSIS

The Mission Analysis portion of this document, Section 3, presents the mission definition, orbit selection, and supporting analyses conducted on the Space Station program. The Power Module will be initially placed into a 500 km (270 nmi) altitude, inclination using the Phase B defined shuttle. The launch profile for this module and subsequent launches are nearly identical, differing only in the end conditions or final altitude. A typical profile is shown in Figure 1-2. As seen a 93 x 185 km (50 by 100 nmi) orbit is achieved by the orbiter main engines. Subsequent orbit maneuvers are applied by the Orbital Maneuvering System (OMS) engines. OMS engines circularize the shuttle at 185 km apogee where orbit phasing would occur (except for the first launch). The OMS engines then transfer the shuttle to its final orbit altitude by a Hohmann transfer directly or modified by a rendezvous phase as required.

The initial launch, Power Module, is carried to 500 km (270 nm) from where it is allowed to decay down to an operating altitude of 456 km (246 nmi, equivalent to 242 nmi at the equatorial crossing). This technique was used to obviate the need for orbit keeping for the first 160 days of the mission. Eliminating



EVENT	APPROXIMATE TIME (SEC)
1 BOOSTER LIFTOFF	0
2 VERTICAL RISE	0-8
3 PITCHOVER MANEUVER	8-20
4 "ZERO" ANGLE-OF-ATTACK FLIGHT	20-200
5 BOOSTER CUTOFF	200
6 "ZERO" ANGLE-OF-ATTACK COAST PERIOD (STAGING)	200-210
7 ORBITER IGNITION	210
8 OPTIMUM FLIGHT	210-400
9 ORBITER CUTOFF INTO 50 BY 100 NMI ORBIT	400
10 ASCENT COAST	43 MIN
11 FIRST HOHMAN TRANSFER MANEUVER (AT 100 NMI) 185 KM	50 MIN
12 ORBIT TRANSFER TO TARGET ORBIT	VARIABLE
13 ORBIT CIRCULARIZATION	VARIABLE
14 ON-ORBIT EXPERIMENT OPERATIONS	VARIABLE

Figure 1-2. Shuttle Flight Profile

this need resulted in a 226 kg (500 lb) savings for the first module launches which were weight critical (near the 20,000 lb design-to weight constraint).

The baseline orbit of 55 deg inclination and 456 km (246 nmi) was selected by NASA guideline (inclination), and by reaffirming the altitude selection analysis accomplished on the 33-ft-dia Space Station study (altitude). The 456-km altitude selection prevailed because of its Earth viewing capabilities in terms of total Earth coverage (~6 days) and compatibility with experiment sensor field of view and resolution requirements.

The radiation analyses, conducted as part of the Design Support Analyses, concluded that adequate shielding capability is inherent in the Space Station configuration to meet the allowable dose limits. This was determined by analyzing the environment, man model, and Space Station configuration in detail using several MDAC computer techniques. A comparison of the allowable and expected doses for a 90-day exposure duration are shown below. It is suggested that the dose sensitivity to shield material distribution and the effects of environment uncertainties be investigated in future efforts.

	Dose (rem)	
	Allowable	Expected
Skin	105	44
Eyes	52	28
Blood Forming Organs	35	9

The requirements for a film vault were also determined and found to vary dramatically with the type of film used. A film vault of 20 ft^3 capacity would required about 6,200 lb of shielding material to properly protect the films planned for use on the experiment program. Several techniques were offered to reduce this weight.

1.5 OPERATIONS ANALYSES

Space Station Ground and Flight Operations analyses are summarized below.

1.5.1 Ground Operations

Ground operations for the Modular Space Station were influenced by three significant factors: assembly of the Space Station in orbit, resupply capability via Shuttle, and maintaining a 10-year ground support operation. An overriding influence in development of operations concepts was the requirement to minimize program cost.

The modules will be launched by the Shuttle on 30-day launch centers. The flight hardware ground flow is shown in Figure 1-3. Significant points of the concept are:

- Fabrication of a production prototype using qualification hardware to simulate the flight article.
- Assembly of these modules into a cluster (called a Flight Integration Tool or FIT) to verify integrated system operation.
- Interchange of each production flight article with its counterpart in the FIT to verify system compatibility.
- Assembly of flight articles in a cluster to verify operational status.
- Flight articles fully operational and orbit-ready before shipment to the launch site (orbit ready from the factory).
- Only preflight servicing required at the launch site.

This concept minimizes cost by eliminating duplicate testing and substantially reducing the requirement for launch personnel.

The Mission Management concept for the 10-year program is illustrated functionally in Figure 1-4. The responsibilities of each of the four functions are also listed. Autonomy of the Space Station permits a significant reduction of flight operations personnel. The experiment operations function provides a ground contingent familiar with the orbital operations. They will act as an interface with the scientific community. The dynamic planning of missions, resupply, schedules and interfaces requires that a planning function

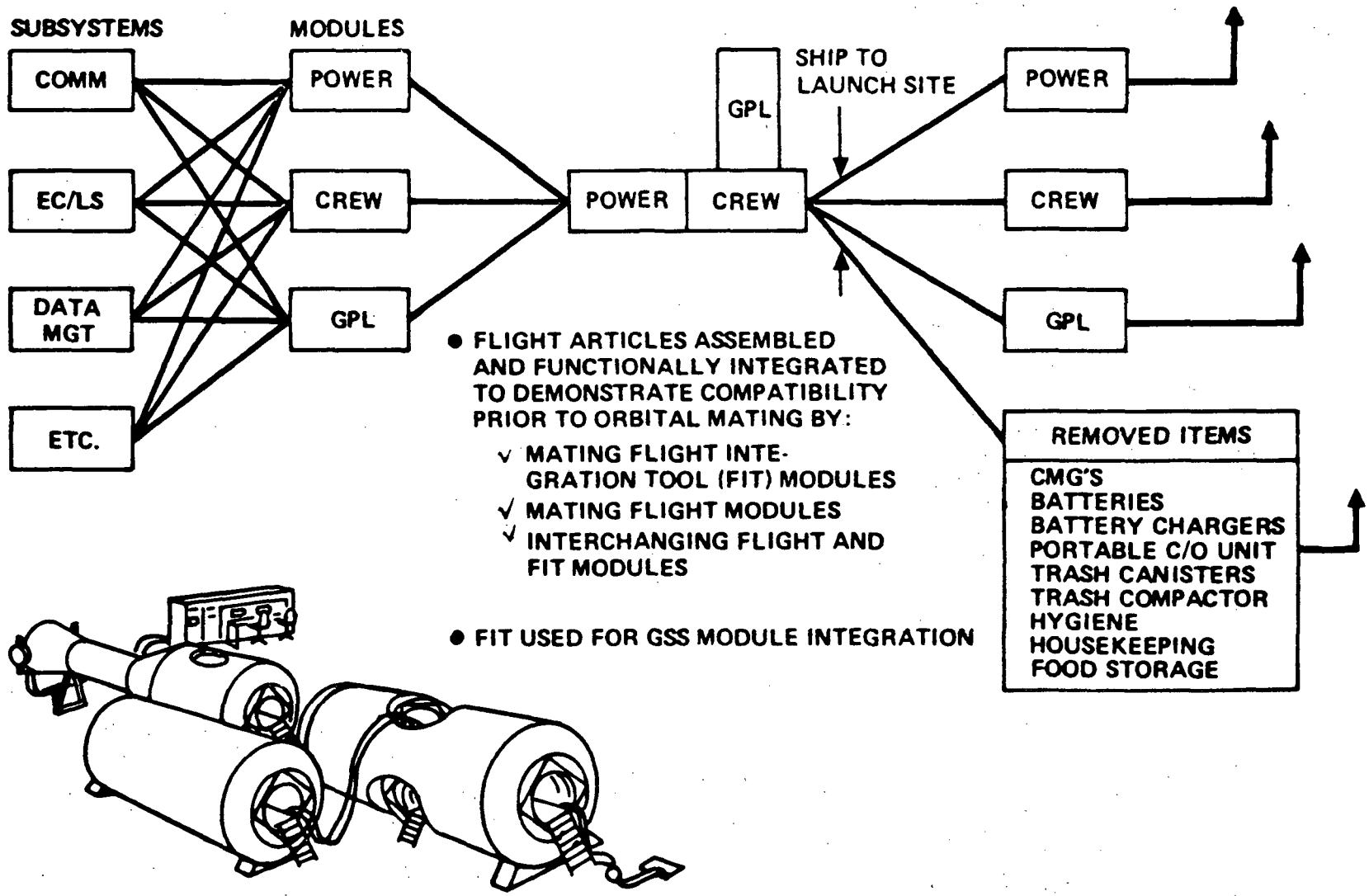
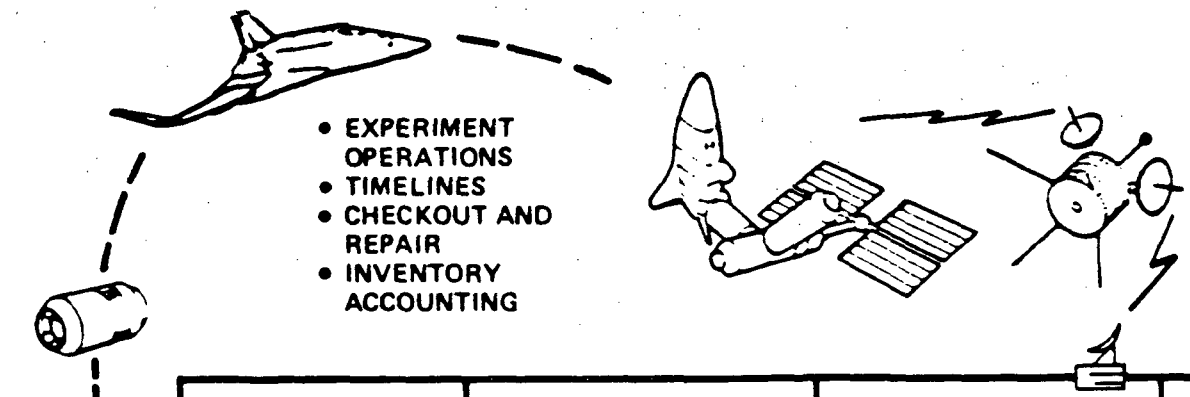


Figure 1-3. Modular Space Station ISS Hardware Flow (Ground)



- EXPERIMENT OPERATIONS
- TIMELINES
- CHECKOUT AND REPAIR
- INVENTORY ACCOUNTING

LOGISTICS OPERATIONS SUPPORT

- INVENTORY
- CONFIGURATION MANAGEMENT
- CARGO HANDLING
- SPARES AND SUPPLIES PROCUREMENT
- NEW MAJOR HDW PROC COORD
- PREFLIGHT TESTING/ CERTIFICATION
- LOGISTIC MODULE
- SPARES REFURB MOCKUPS/FIT
- INTERFACE CONTROL
- PREFLIGHT HDW INTEG
- RETURN CARGO DISPOSITION

MISSION ANALYSIS & PLANNING

- SS PROJECT INTERFACE WITH OTHER PROGRAMS/ PROJECTS
- MISSION PLANS
  - -10 YEARS
  - -90 DAYS
- SCHEDULES
- CONFIGURATION AUTHORIZATION
- LOGISTICS, FLIGHT PLANNING
- CONSULTATION WITH FLIGHT CREW FOR FOR SYSTEM/ EXPERIMENTS
- LONG TERM TREND ANALYSIS

FLIGHT OPERATIONS SUPPORT

- FLIGHT CONTROL
- SIMULATION
- CREW TRAINING
- NETWORK INTERFACE
- HARDWARE DEFINITION

EXPERIMENT OPERATIONS SUPPORT

- EXPERIMENT OPERATIONS
- EXPERIMENT COORDINATION
- DATA EVALUATION
- EXPERIMENT OPERATIONS PLANNING

SHUTTLE PROJECT

Figure 1-4. Space Station Mission Management Operational Functions

be provided to plan, schedule, and establish requirements for the anticipated 10-year experiment program. Since establishment of a static 10-year experiment program will not be possible, this function will continue to analyze proposed changes to the program to ensure that optimum use is made of available resources in accommodation of the experiments.

Since all cargo will be assembled and delivered via Logistics Module launch every 30 days and will be comprised of items from many sources including the scientific community, a single logistic operation will be established to manage the cargo and ensure compatibility of any items with the orbiting station. The Flight Integration Tool used for ground integration of the Space Station as a functional replica of the orbiting station will be used to ascertain compatibility of changes and experiments with the Space Station prior to delivery to orbit.

1.5.2 Flight Operations

The Flight Operations analyses considered ascent, buildup, on-orbit and logistics support operations. The ascent mode was summarized in Section 1.3. The ISS is an on-orbit assembly of three modules (i.e., Power/ Subsystems, Crew Operations, and GPL. Each module is delivered to orbit by the Shuttle on 30-day launch centers, mated to the previously delivered module, and interface/systems verification checks performed.

The buildup and manning sequence is shown in Figure 1-5, for the ISS. Two assembly crewmen will accompany each module to orbit as Shuttle passengers to perform the physical mating of module-to-module interface umbilicals, module(s) checkout, and prepare the orbiting configuration for the next 30 days of unmanned operations. The Shuttle provides a key support role during buildup, including resources, operations, and a base while the crew works in the station modules. Ground support required for buildup includes support to the assembly crewmen for module assembly and checkout, monitor and control of unmanned periods of operation and tracking.

Delivery and checkout of the Power/Subsystem Module requires a mission time of 35 hours from liftoff to Shuttle orbiter return operations. Key events include module habitability verification, solar array deployment,

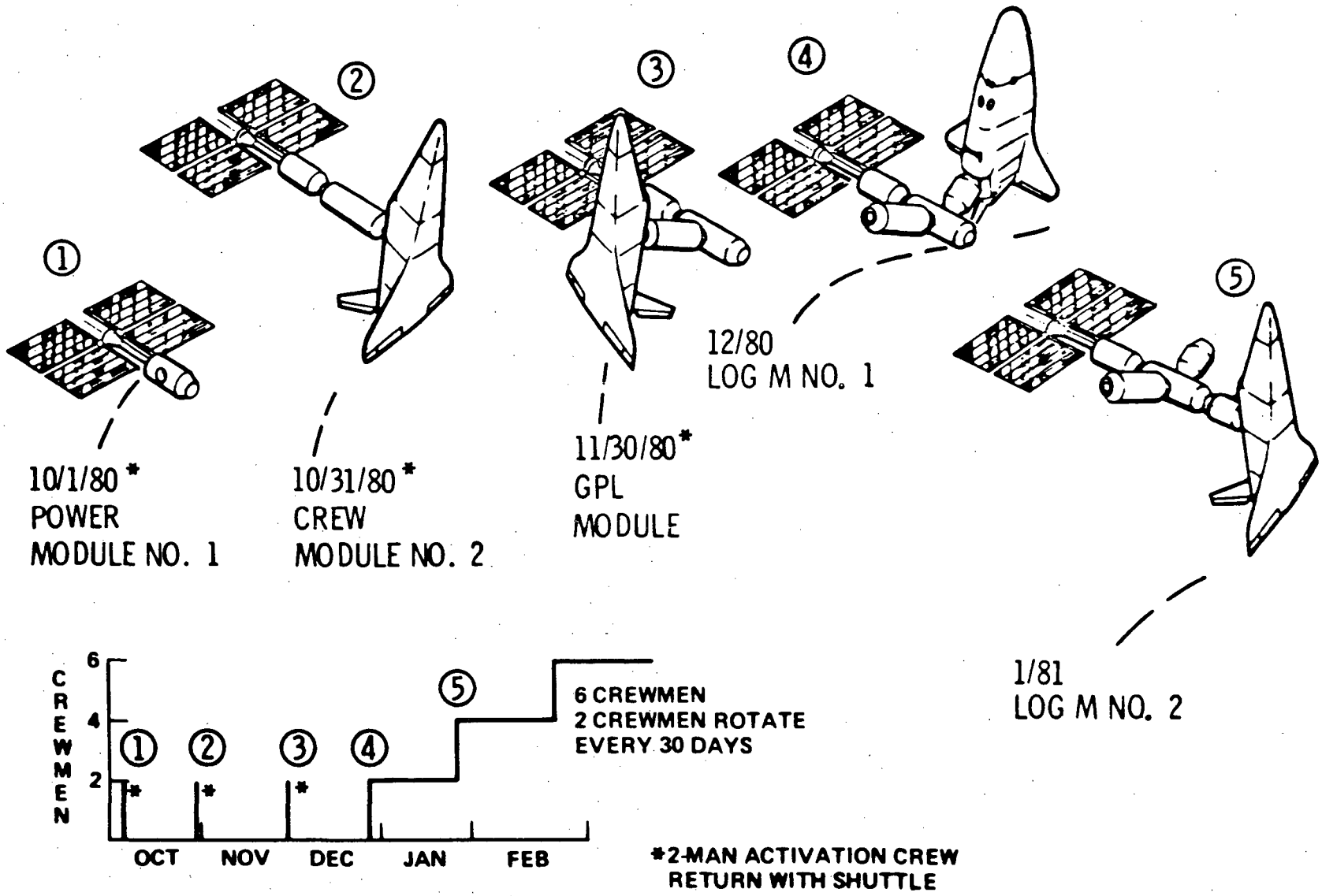


Figure 1-5. Space Station Buildup Operations

power activation, navigation, propulsion, and communications checkout, and other "shakedown" checks. The module remains in an unmanned flight configuration for the next 28 days, controlled and monitored by ground operations. Delivery and checkout of the Crew Operations/Module requires 34 hours. Key events include the mating and verification of 36 interface umbilicals to the Power/Subsystems Module,subsystem checks including the high-gain antennae and VHF and Ku band System operations. GPL delivery and checkout complete the buildup phase requiring 45-1/2 hours from liftoff to orbiter return operations. Key events include mating and verification of 32 interface umbilicals to the Crew/Operations Module, GPL subsystem verifications, and final preparations for the last 30 days of unmanned operations.

Initial manning and final activation begin 90 days after the launch of the Power/Subsystems Module. Three Shuttle flights are required to deliver the full operational crew of six. Each of these Shuttle flights also delivers a Logistics Module which provides the "warehouse" for the initial supplies, experiment equipment, operational consumables, and subsystem noncritical equipment off-loaded from the station modules to meet the 9,072 kg (20,000 lb) Space Shuttle payload liftoff limit. The initial crew installs the subsystem equipment and performs a final Orbital Readiness Test (ORT). Satisfactory completion of this final systems verification places the ISS in an operational readiness status for sustaining operations.

During ISS sustaining operations, the Space Station provides the crew and subsystem support capability for experiment operations to include 4.6 crewmen, 4.8 kw power, 8×10^{11} bpd plus 1.32 min/day TV, 38,000 lb/90 days logistics resupply, 4 RAM docking ports, and steady-state disturbance of 10^{-5} g. The ISS program includes carry-on experiments and attached RAM's. The GPL provides the operations center for the experiments. The crew will be given long-range (30 day) objectives for experiment operation and resulting test data generation. Utilizing the onboard software to analyze the resources available versus the resources required the crew will determine their short range (24 hours or less) operational plans. All FPE and RAM engineering and housekeeping data will be validated and monitored by the

Onboard Checkout System. The crew skill mix will vary from time to time as a function of the experiments in the long-range plan. During GSS operations, experiment operations will include control, servicing, operation of Free-flying Modules. Experiment operations include experiment equipment installation, activation, set-up, operation, calibration, maintenance, repair and checkout. Data operations include data taking, data processing, evaluation, and preparing for return to earth by data dump or shuttle.

Station operations include subsystem operations, inventory control, Logistics Module checkout, resource planning, station maintenance, safety, medical care, food preparation and consumption, hygiene and waste management, physical fitness, and recreation and rest. All the daily routine operations for the Space Station will be automated to the greatest practical extent. A crewman's orbital duty cycle will nominally be 90 days duration.

1.6 EXPERIMENT SUPPORT REQUIREMENTS

The Experiment Support Requirements Analysis, Section 5, is included in four segments: Experiment Definition, Mode of Accommodation, Experiment Support, and Space Station Experiment Interfaces.

A definition of each of the 18 experiment groups was prepared in a brief two-part format. First, the objectives of each respective experiment group were discussed; secondly, the equipment needed for each described.

The mode of accommodation of each experiment area was reviewed and reevaluated because of the reissue of the Blue Book (1971 edition) and the Modular Space Station design. The experiments were subjected to a series of screening procedures (stability, g-level, contamination, and size) to arrive at the accommodation assignments shown in Table 1.1. As seen, of the 50 experiment groups, 25 were accommodated integrally, 17 with attached modules, and 8 with free-flying modules.

The GPL and the Logistics Support needed to accommodate the experiments were determined and are presented in tabular format under headings of

Table 1-1

MODE OF ACCOMMODATION

FPE or Subgroup	Allowable MOA	Attitude Stability	Primary Determining Factors: G-level	Contamination	Size	Remarks
A-1	FF	X		X	X	
A-2	FF	X		X	X	
A-2A	FF	X		X	X	FF – Free Flyer
A-3AA	FF	X		X	X	
A-3CC	FF	X		X	X	
A-4A	AM			Clean	X	
A-4B	AM			Clean	X	AM – Attached Module with approximately one-half volume as airlock accommodates more than one experiment group
A-4C	AM			Clean	X	
A-5A	FF			X	X	
A-5B	AM				X	
A-6	AM			Clean	X	
P-1A, B, C, D, E	I			Clean		I – Integral to station or pressured section of AM
P-2BB	AM				X	
P-2A	I					
P-3	AM				X	
P-3C	I					
P-4A, B, C	I					
ES-1	AM			Clean	X	
ES-1AA	AM			Clean	X	
ES-1G	AM			Clean	X	
C/N-1A, B	AM				X	
MS-3A, B, C, D, E	I				X	

Table 1-1

MODE OF ACCOMMODATION (Continued)

FPE or Subgroup	Allowable MOA	Attitude Stability	Primary Determining Factors			Remarks
			G-level	Contamination	Size	
T-1A, B	I					
T-2A	FF					
T-2BB	FF		X			
T-3A	I					
T-3B	AM				X	
T-4C	I	(Partial)				
T-5	I					
LS-1A	I					
LS-1D	AM				X	
LS-1B, 1C 1D	AM					

subsystems, operations, facilities, equipment, tool, and consumables. In addition the basic interfaces between the experiments and Space Station were defined.

1.7 INFORMATION MANAGEMENT SYSTEM (IMS) ANALYSIS

The information requirements of the baseline experiment program were analyzed and using this data, the basic IMS trade studies performed on the 33-ft-dia Space Station study reviewed. The primary factors effecting these trade studies were: the 1971 issued Blue Book data, the later (1980) launch date, and the Modular Space Station buildup concept. Consideration of these factors resulted in the consolidation of data processing equipment into two multiprocessing computers facilities; one dedicated to subsystem support, the other primarily for experiment operations. In general, the postponed launch date and changes in experiment scheduling would allow the utilization of more capable onboard and ground computing equipment than was considered in the prior study.

1.8 LONG LIFE AND SAFETY ANALYSES

The Long Life and Safety Analyses performed on the Modular Space Station are summarized in the following subsections.

1.8.1 Long-Life Assurance

The results of the Long Life Assurance Task are summarized below, followed by the main conclusions.

Probability for manning at 90 days	ISS	0.97
Probability for mission operations for 120 days	ISS	0.96
Design improvements for redundancy and onboard spares eight to achieve availability	ISS	1,633 Kg(3,600 lb)
	GSS	2,041 Kg(4,500 lb)
90-day resupply of maintenance spares (scheduled replacement and random failures)	ISS	733 Kg(1,550 lb)
	GSS	1,211 Kg(2,670 lb)
Maintenance man-hours per month—corrective and preventive	ISS	65
	GSS	105

The following conclusions were derived from the Long Life Study:

A. The modular concept does not materially affect operational availability; however, there is an increase in maintenance man-hours required over those for a similarly complex large-volume station.

B. Sequential buildup in space represents an appreciable amount of work and the period of unmanned operation materially increase the risk of loss prior to permanent manning over that for a station manned on the next available launch.

C. Packaging of subsystems to provide look-alike installations of common items desired for maintenance efficiency is more difficult than with the 33-foot diameter, 4-level-type station.

D. On-orbit maintenance greatly influences interior arrangements and subsystem design.

E. The possibility of returning any Space Station module to Earth for major maintenance is not precluded by the configuration.

F. The designs presented provide the required access for subsystem and pressure shell maintenance.

The following conclusions from the earlier study of a 10-meter Space Station are still valid:

G. Long-life designs will result from pursuit of good design practices following the characteristic reliability and maintainability concepts. No new technology is required.

H. The limited-life items and mission-critical items identified are amenable to contractor specification and control.

I. Initial spares and resupply requirements are not excessive and can be readily managed. Cost-effective measures must be employed to control ground stocks as well as procurement and repair activities to maximize availability and minimize costs over the 10-year mission period.

J. Maintenance will not cause an inordinate drain on astronaut time. It is expected that no repair task will require a crew response time so short as to precipitate crew error.

1.8.2 System Safety

The approach to achieving an acceptable level of safety for the Modular Space Station has featured retreat-refuge (and recovery) rather than abandonment. Hazards have been minimized throughout design, operations, and configuration. First-level backup provisions permit operation from either either the Crew/Operations Module or GPL with full recovery possibilities if retreat from either module is required. Lower-level alternatives are available by making every module (including RAM's) a safe refuge area for a minimum of 96 hours and if recovery from a contingency is not possible, Shuttle rescue is available as the final backup. The ISS configuration optimizes escape paths and rescue potential to the highest degree. Time-distance to a safe area for any crewman is minimized by providing each module with two escape routes that do not terminate in a common area and providing each module with a minimum of 96 hours life support capability. Size of hatches permits free passage of IVA and EVA suited crewmen, as appropriate.

The risk of meteoroid penetration was minimized by structural wall design (double meteoroid bumper) which provides a no-penetration probability of 0.936, exceeding the Statement of Work requirement of 0.90. Means for detection and a repair kit are provided for the crew if a penetration of the pressure shell does occur.

Potential hazards on the Space Station were minimized by equipment location (e.g., location of high-pressure vessels and propellant tanks in normally uninhabited areas, location of Freon loops outside the pressure compartments, and use of isolation chamber for cryogenics). Least safe equipment is located in minimum crew occupancy areas.

The risks associated with any pressure-suited operation have been minimized by (1) designing to preclude the need for EVA and IVA to the maximum practical extent, and (2) making the pressure-suited operation as safe as possible. The latter was accomplished by providing ready access to the suits, requiring use of the buddy system, multiple IVA umbilical connectors

located in all compartments, time limitation on each EVA, establishing EVA rescue conditions, and defining requirements for lighting, communications, observation and monitoring.

The design and operation of airlocks were examined because of the critical considerations associated with safety. Safety requirements were established and implemented for location, size (minimum of 2 men), operation of doors from each side, pressure relief within the airlock, atmosphere conditions display on each side of doors, etc. An IVA airlock is provided between every adjacent module.

The possible causes of decompression were evaluated to determine the probability of occurrence. Times of decompression for various hole sizes and volumes were determined to ensure that the crew has sufficient reaction time to evacuate or stay and repair. Repressurization capability in the event of loss of atmosphere was examined and it is apparent that the station could sustain a significant loss of pressure without approaching emergency conditions.

The Modular Space Station safety study resulted in the following conclusions:

1) An acceptable level of safety can be achieved with no compromise of operational objectives. The MDAC ISS and GSS configurations satisfy all program safety requirements.
2) Safety is an inherent design parameter and strongly influenced initial concept, configuration, and design selections.
3) Safety is an integrated consideration covering all program aspects, such as hardware, operations, and procedures.

Section 2
EXPERIMENT PROGRAM SELECTION

This section discusses that analysis performed throughout the study phase which resulted in the final definition of the experiment program. This section is divided as follows: Technical Approach, Experiment Sensitivity Analysis, and the Baseline Experiment Program.

2.1 TECHNICAL APPROACH

The technical approach used in this task is shown in Figure 2-1. The major data sources for the accomplishment of the experiment analysis task are the January 1971 version of the Blue Book and the NASA FPE cost data. It was necessary to reaccess the mode of accommodation due to the changes in the Blue Book. This provided data from which the requirements for operation of the MDAC WICK Computer Program were-generated. These requirements, in conjunction with the cost data which were expanded and formatted, were used as inputs to the major portion of the analysis, that of the experiment sensitivity analysis. The results of the experiment sensitivity analysis consist of the experiment resource requirements, the corresponding baseline experiment program, and potential alternative experiment programs. In the following subsections the individual blocks of Figure 2-1 will be further discussed.

2.1.1 January 1971 Blue Book

The January 1971 Blue Book FPE's were regrouped in a logical manner to facilitate the use of the computerized WICK Program. Table 2-1 indicates the titles of the 50 subgroup designations which have been used during the experiment analysis. The coding is such that when identical double letters are indicated, for example the 25th item ES-1AA, Earth Observations Sequential, that many of the Blue Book defined packages have been incorporated into one larger package. For this example, ES-1A, B, C, D, and F

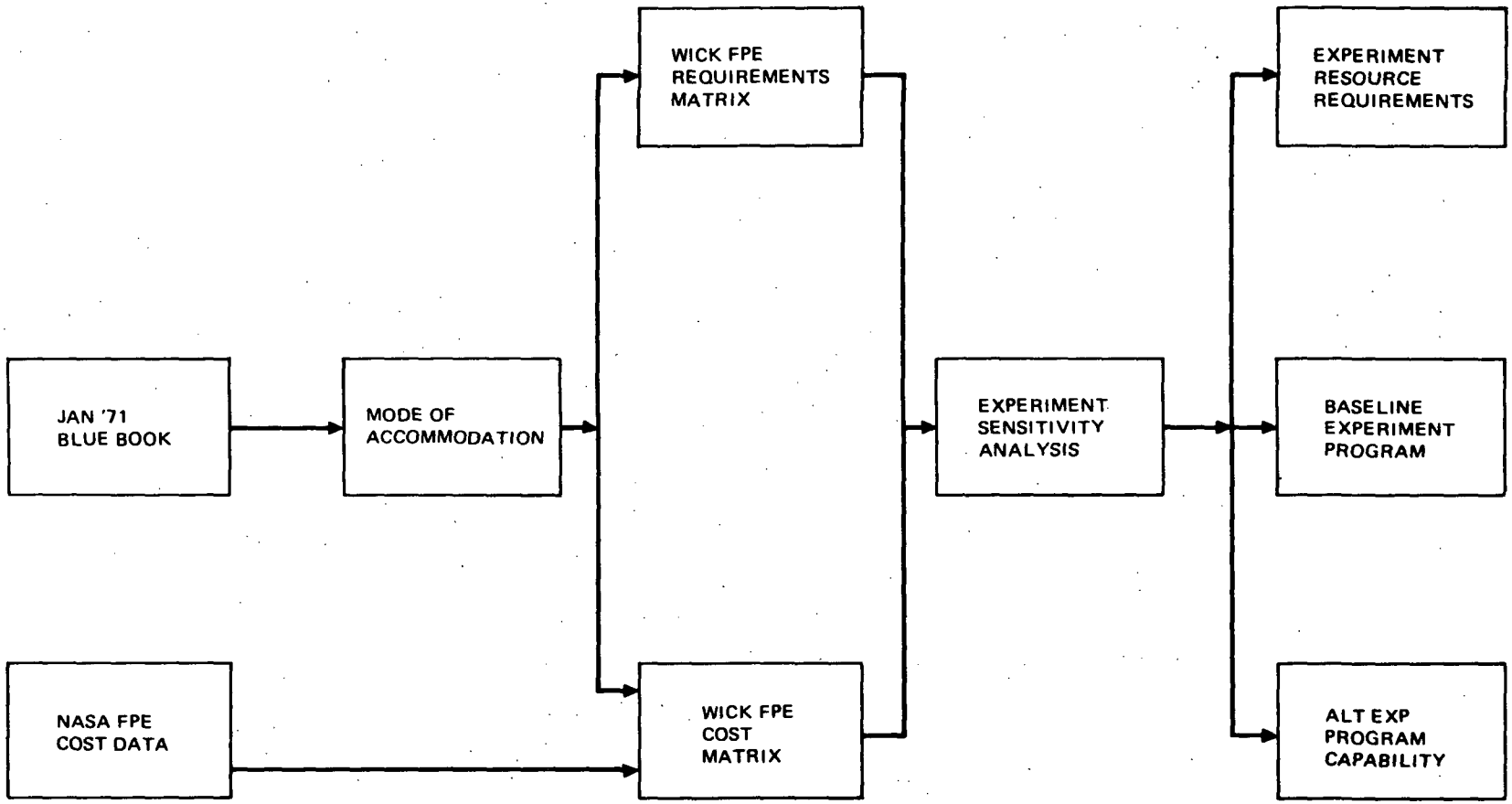


Figure 2-1. Experiment Analysis Logic

Table 2-1

FINAL FPE/SUBGROUP DESIGNATIONS

1.	A-1	X-ray stellar astronomy
2.	A-2	Advanced stellar astronomy
3.	A-2A	Intermediate stellar telescope
4.	A-3AA	Advanced solar astronomy
5.	A-3CC	Atm follow-on
6.	A-4A	0.9m narrow field UV telescope
7.	A-4B	0.3m wide field UV telescope
8.	A-4C	Small UV survey telescope
9.	A-5A	X-ray telescope
10.	A-5B	Gamma ray telescope
11.	A-6	IR telescope
12.	P-1A	Atmospheric and magneto science
13.	P-1B	Cometary physics
14.	P-1C	Meteroid science
15.	P-1D	Thick material meteoroid penetration
16.	P-1E	Small astronomy telescopes
17.	P-2A	Wake measurements from station and booms
18.	P-2BB	Wake, plasma, wave partical, elect, beam
19.	P-3	Cosmic ray physics laboratory
20.	P-3C	Plastic/nuclear emulsions
21.	P-4A	Airlock and boom experiments
22.	P-4B	Flame, chemistry and laser experiments
23.	P-4C	Test chamber experiments
24.	ES-1	Earth observation facility
25.	ES-1AA	Earth observational sequential
26.	ES-1C	Minimum payload (Core)
27.	CN-1	Communications/navigations facility
28.	CN-1A	Communications/navigations subgroup A
29.	CN-1B	Communications/navigations subgroup B
30.	MS-3A	Crystal growth, biological and physical processes
31.	MS-3B	Crystal growth from vapor

Table 2-1

FINAL FPE/SUBGROUP DESIGNATIONS (Continued)

32.	MS-3C	Controlled density materials
33.	MS-3D	Liquid and glass processing
34.	MS-3E	Supercooling and homogeneous nucleation
35.	T-1A	Contamination experimental package
36.	T-1B	Contamination monitor package
37.	T-2A	Long-term Cryogenic storage
38.	T-2BB	Short-term cryogenic storage
39.	T-3A	Astronaut maneuver unit
40.	T-3B	Manned work platform
41.	T-4A	Long-duration system tests
42.	T-4B	Medium-duration tests
43.	T-4C	Short-duration tests
44.	T-5A	Initial flight teleoperator
45.	T-5B	Functional teleoperator
46.	T-5C	Ground control teleoperator
47.	LS-1A	Minimal medical research facility
48.	LS-1B	Minimal life science research facility
49.	LS-1C	Intermediate life science research facility
50.	LS-1D	Dedicated life science research facility

are included in ES-1AA. As will be shown later, manpower, electrical power and cost were the driving parameters. Since the results of the analysis are so dependent upon the basic data, it is of interest to compare the old Blue Book and the new Blue Book data by discipline. Figure 2-2, the comparison for Manpower, indicates that with the exception of Life Sciences, the manpower requirements for the various disciplines have increased considerably for the new Blue Book. Similarly, in Figure 2-3, Power comparison, it can be seen that for the most part the new Blue Book power requirements exceeds that of the old Blue Book with the major exception once again being that of Life Sciences discipline. The cost data, however, as shown in Figure 2-4 is mixed. For example, the cost for Astronomy has

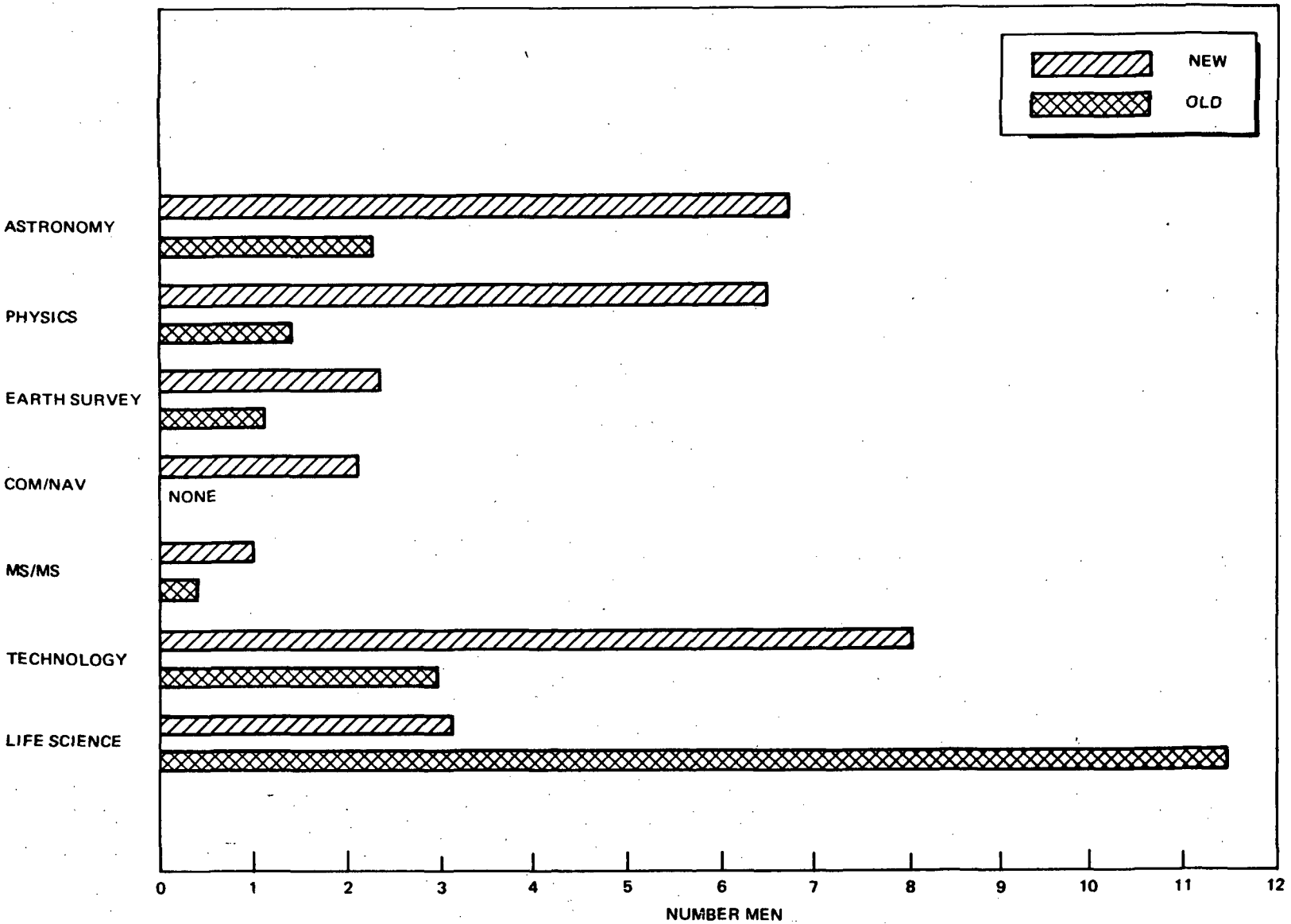


Figure 2-2. Manpower – Old/New Blue Book Comparison

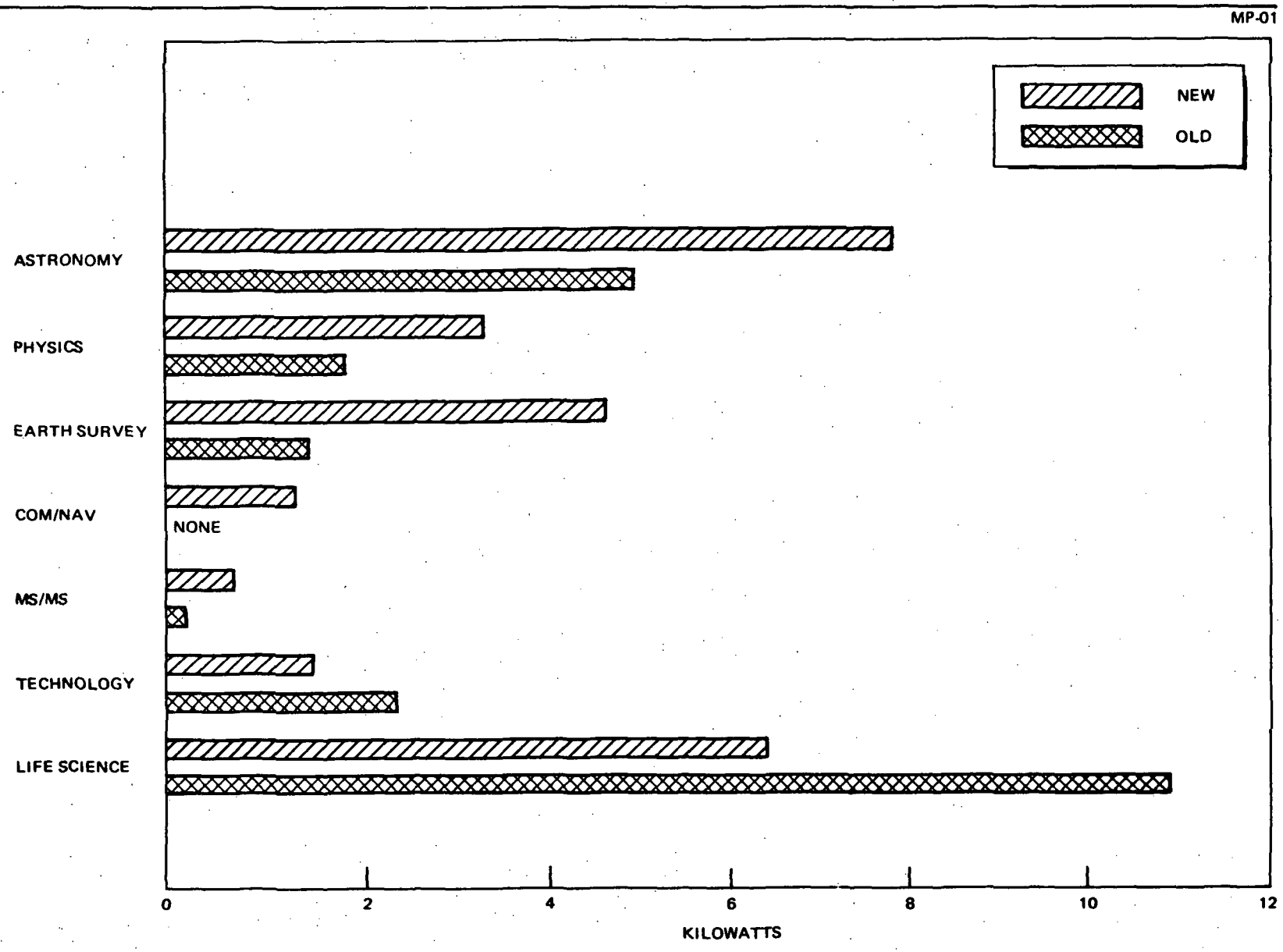


Figure 2-3. Power - Old/New Blue Book Comparison

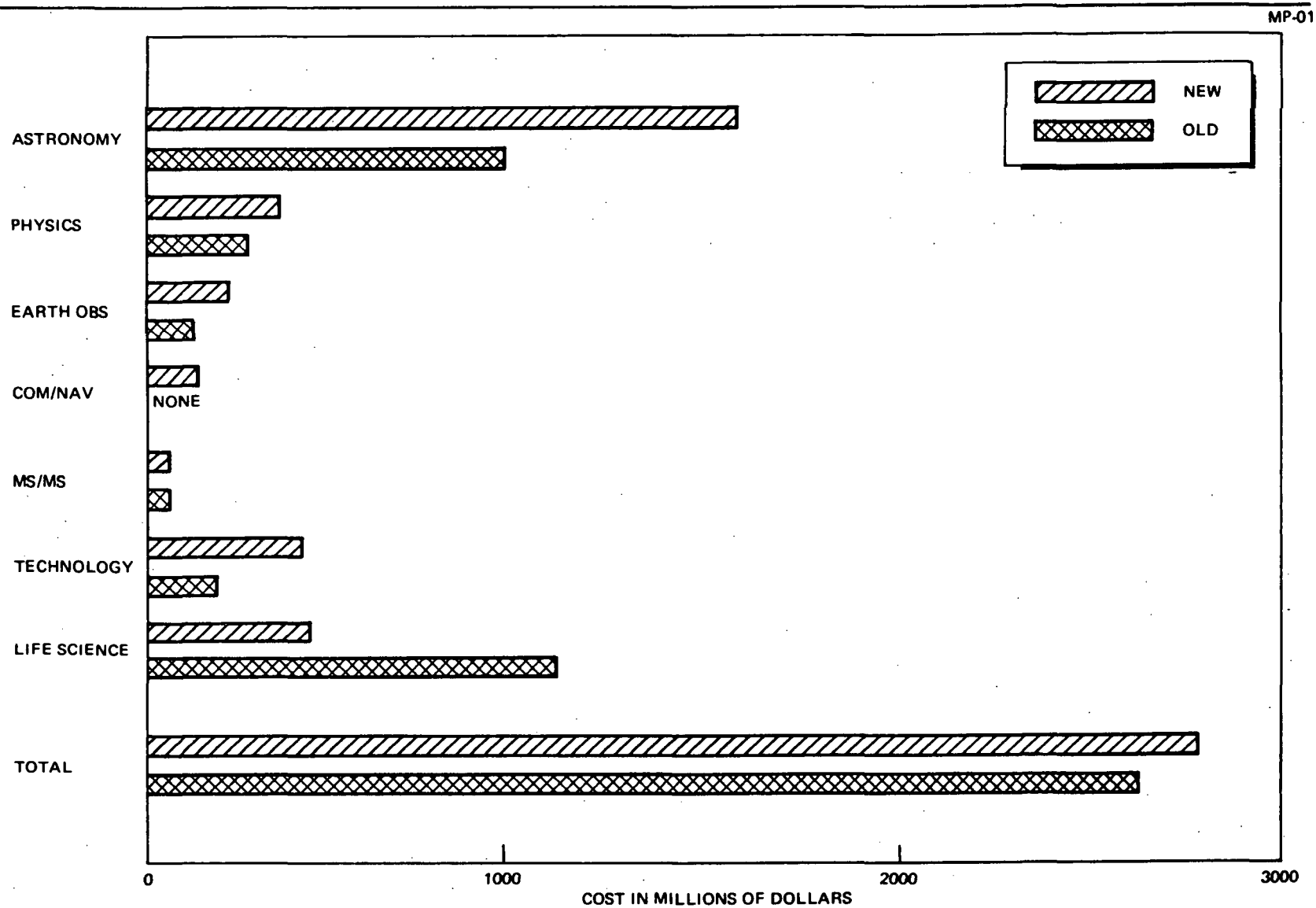


Figure 2-4. Experiment Cost — Old/New Blue Book Comparison

increased because additional FPE's are included. The cost for Life Sciences has decreased due to redefinition of Life Science FPE's. Note that the total cost is approximately the same; however, a major difference in the cost approach between the analysis done here and that done previously on the Modular Space Station study was in all of the analyses presented in this report, operational cost included along with the equipment development cost.

2.1.2 Mode of Accommodation

Due to the change in the Blue Book data, the Mode of Accommodation was updated as indicated in the logic flow of Figure 2-5. As was done in the past, the various FPE's and sub-FPE requirements were played against the Space Station characteristics through a series of mode of accommodation screens, primarily the ones indicated on the chart. For each FPE, a preliminary mode of accommodation was determined. Those FPE's which were determined to be primarily attached modules or attached RAM's or integral FPE's were reviewed once again in terms of vehicle integration to see if they might better be accommodated otherwise. Such was the case in several incidences. Table 2-2, Mode of Accommodation Summary, shows the disposition of the 50 candidate FPE's. Twenty-five of these remain integral, primarily in the GPL, of which 10 were basically Physics and the remaining 14 were either Technology or Material Science. Seventeen of the FPE's preferred to be attached modules, primarily Communication/Navigation, Earth Surveys and Life Sciences. The remaining eight FPE's, primarily Astronomy were necessarily free-flying modules.

2.1.3 NASA FPE Cost Data

The NASA supplied cost data was subjected to the process indicated in Figure 2-6, in which the pertinent FPE and sub-FPE cost and development spreads were determined. Estimates of the complexity in the design required for accommodating the attached and free-flying RAM's were used to determine the module non-recurring cost as well as the module recurring cost. These data were combined to provide the total FPE or sub-FPE cost including operational cost. Table 2-3, the FPE Cost Matrix, is the actual data and format as implemented in the WICK Computer Program.

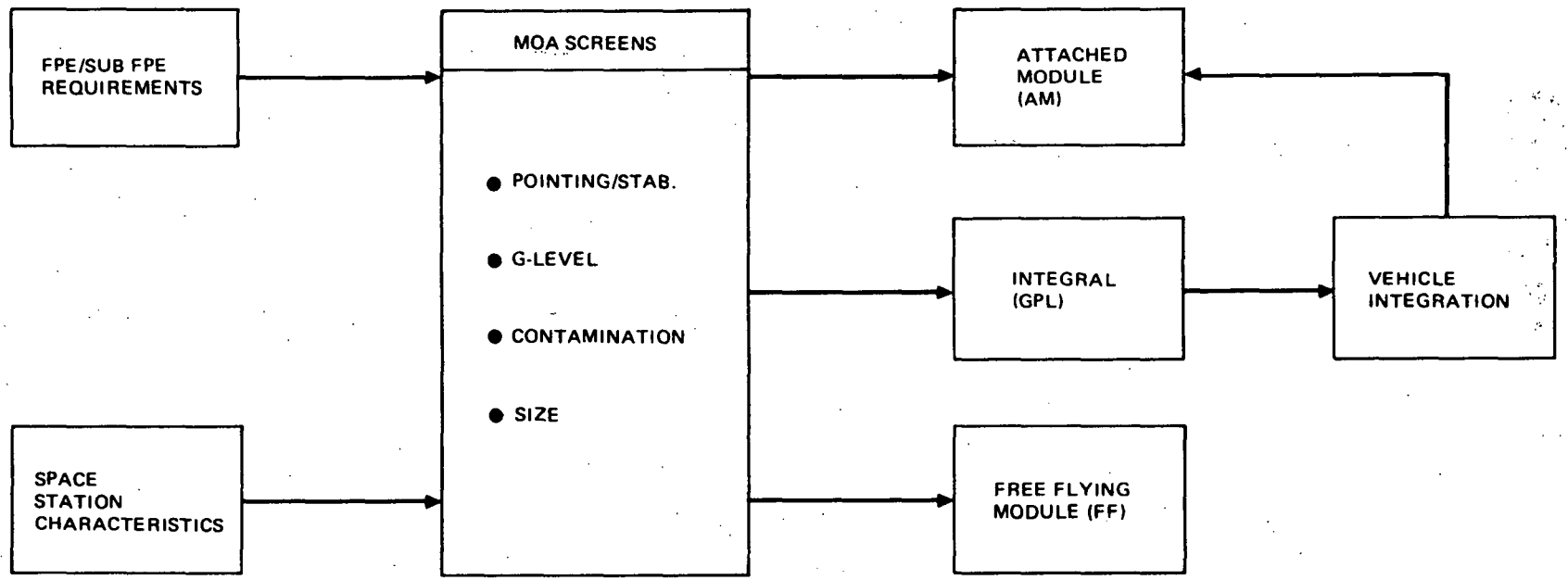


Figure 2-5. Mode of Accommodation (MOA) Analysis

Table 2-2

MODE OF ACCOMMODATION SUMMARY

Integral (GPL) - 25

10 physics

14 technology/materials science

Attached Modules - 17

Primarily communications/navigation, earth surveys, life sciences

Free-Flyer Modules - 8

Mostly astronomy

2 require constant low G

2.1.4 Approach to Experiment Sensitivity Analysis

The subject will be covered in detail in Section 2-2. The approach of the experiment sensitivity analysis was to determine the relationship between ISS costs and the choice of initial experiment crew size. At the same time, parametric data was established for the experiment resource requirements. From this analysis a baseline experiment program was defined and demonstrations of alternate experiment program capability were accomplished. Three main points were emphasized at all times; (1) the determination of the ISS cost and the crew size relationships was determined and used to help choose the ISS portion of the baseline experiment program; (2) the extreme importance of maintaining low initial hardware costs (this factor in itself is the dominating feature of the experiment sensitivity analysis), and (3) the attempt to optimize baseline experiment programs for good resource utilization and program balance.

2.1.5 Outputs

The primary output is the baseline experiment program with appropriate resource profiles. Other outputs include alternate experiment programs which demonstrate the capability of the Space Station to accommodate various groups of FPE's.

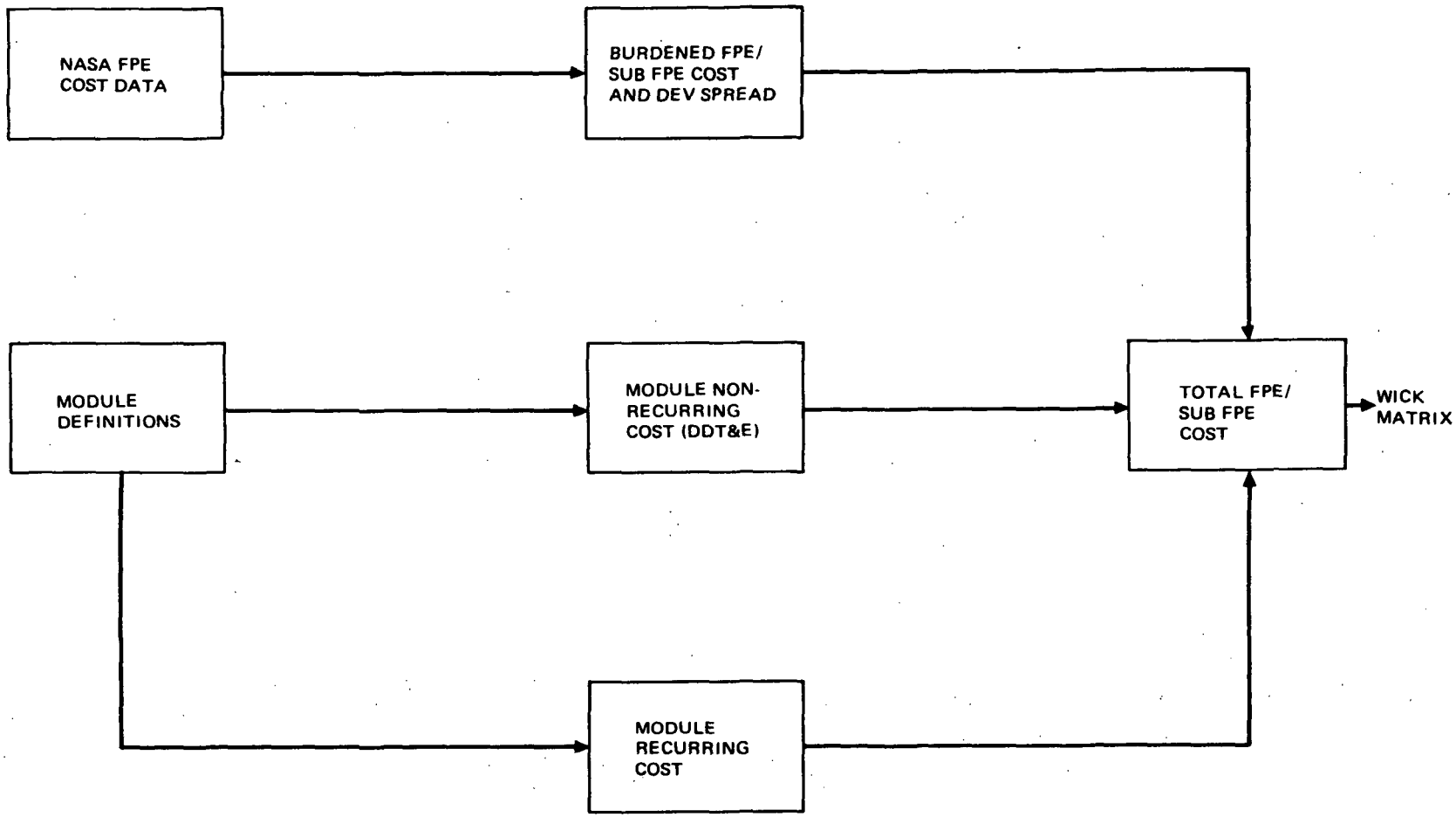


Figure 2-6. FPE Cost Development Process

Table 2-3

FPE COST BASELINE (MILLIONS)

FPE	Mode of ACC-OMM	Manufacture Duration (Years)							Total Costs	Ops/ Year
		1	2	3	4	5	6	7		
A-1	(FF)	12.50	62.70	109.40	118.87	85.96	21.97	0.00	411.40	4.88
A-2	(FF)	15.00	69.40	108.40	92.74	25.10	0.00	0.00	310.64	2.37
A-2A	(FF)	12.30	56.90	90.70	70.66	22.19	0.00	0.00	261.75	2.37
A-3AA	(FF)	9.70	48.80	84.90	93.27	69.56	18.07	0.00	324.30	2.49
A-3CC	(FF)	6.30	31.90	55.70	63.17	50.66	13.67	0.00	221.40	5.16
A-4A	(ATT)	2.90	13.80	24.86	25.16	7.86	0.00	0.00	74.58	2.38
A-4B	(ATT)	2.90	13.80	24.86	25.16	7.86	0.00	0.00	74.58	1.22
A-4C	(ATT)	1.10	7.96	14.96	5.66	0.00	0.00	0.00	29.68	2.03
A-5A	(FF)	4.90	24.50	42.70	50.01	43.45	12.21	0.00	177.77	4.51
A-5B	(ATT)	1.60	9.10	17.20	21.76	20.46	6.16	0.00	76.28	1.58
A-6	(ATT)	2.80	13.90	25.86	26.66	8.46	0.00	0.00	77.68	1.83
P-1A		7.00	6.60	6.40	4.40	1.30	0.00	0.00	25.70	12.20
P-1B		2.50	2.10	1.80	1.00	0.20	0.00	0.00	7.60	4.60
P-1C		2.80	2.40	2.10	1.30	0.30	0.00	0.00	8.90	4.80
P-1D		0.13	0.72	1.02	0.43	0.00	0.00	0.00	2.30	1.20
P-1E		5.00	4.40	4.00	2.50	0.60	0.00	0.00	16.50	9.70
P-2A		3.80	3.10	2.90	1.80	0.50	0.00	0.00	12.10	5.67
P-2BB	(ATT)	18.00	14.70	16.36	15.96	4.96	0.00	0.00	69.98	22.73
P-3	(ATT)	2.30	12.60	24.30	30.00	29.95	22.92	6.25	127.62	9.43
P-3C		0.56	2.20	2.20	0.66	0.00	0.00	0.00	5.62	7.60
P-4A		0.80	4.30	7.60	6.70	2.20	0.00	0.00	21.60	28.00
P-4B		0.50	2.70	4.40	3.70	1.00	0.00	0.00	12.30	18.60
P-4C		0.90	4.30	7.10	5.70	1.70	0.00	0.00	19.70	28.00
ES-1	(ATT)	2.90	13.48	21.03	17.77	4.96	0.00	0.00	60.14	13.33
ES1AA	(ATT)	3.17	14.79	23.58	20.57	6.27	0.00	0.00	68.38	13.33
ES-1G	(ATT)	6.90	31.80	49.16	41.76	10.96	0.00	0.00	140.58	30.82
CN-1	(ATT)	1.63	8.78	17.20	19.01	7.75	0.00	0.00	54.37	0.98

Table 2-3

FPE COST BASELINE (MILLIONS) (Continued)

FPE	Mode of ACC-OMM	Manufacture Duration (Years)							Total Costs	Ops/ Year
		1	2	3	4	5	6	7		
CN-1A	(ATT)	1.50	7.90	17.26	21.96	8.76	0.00	0.00	57.38	9.10
CN-1B	(ATT)	0.33	1.64	3.47	4.23	1.71	0.00	0.00	11.38	12.50
MS-3A		3.30	12.80	14.80	4.70	0.00	0.00	0.00	36.60	3.05
MS-3B		0.60	1.60	1.80	0.80	0.00	0.00	0.00	4.80	0.11
MS-3C		0.20	1.00	1.10	0.30	0.00	0.00	0.00	2.60	0.11
MS-3D		0.10	0.30	0.30	0.10	0.00	0.00	0.00	0.80	0.00
MS-3E		0.10	0.40	0.50	0.20	0.00	0.00	0.00	1.20	0.08
T-1A		0.60	2.70	4.80	4.20	1.40	0.00	0.00	13.70	0.20
T-1B		0.30	1.60	3.30	3.10	1.10	0.00	0.00	9.40	0.00
T-2A	(FF)	0.40	2.40	4.80	12.10	22.26	7.78	0.00	49.74	0.00
T-2BB	(FF)	3.10	15.60	27.30	35.38	36.86	11.08	0.00	129.32	8.00
T-3A		2.00	7.10	4.30	0.00	0.00	0.00	0.00	13.40	1.20
T-3E	(FF)	2.10	12.26	19.56	8.26	0.00	0.00	0.00	42.18	4.90
T-4A		0.60	2.00	0.60	0.00	0.00	0.00	0.00	3.20	0.10
T-4B		1.40	3.70	1.40	0.00	0.00	0.00	0.00	6.50	1.00
T-4C		1.70	4.60	1.70	0.00	0.00	0.00	0.00	8.00	1.20
T-5A		4.10	15.50	15.50	4.10	0.00	0.00	0.00	39.20	4.60
T-5B		4.30	16.30	16.30	4.30	0.00	0.00	0.00	41.20	4.90
T-5C		4.70	18.30	18.30	4.70	0.00	0.00	0.00	46.00	4.90
LS-1A		3.50	16.30	25.70	20.50	5.80	0.00	0.00	71.80	2.31
LS-1B		3.20	16.80	27.60	22.60	14.90	13.90	8.40	107.40	61.50
LS-1C		2.26	11.83	19.76	19.25	16.02	15.93	5.82	90.87	28.55
LS-1D	(ATT)	3.58	20.19	35.32	38.79	38.17	29.55	9.52	175.39	14.17
FF		21.03	29.14	14.03	3.10	2.15	0.00	0.00	69.45	0.00
ATT		24.58	16.39	14.84	1.26	0.17	0.00	0.00	53.24	0.00

2.2 EXPERIMENT SENSITIVITY ANALYSIS

2.2.1 Constraints

A matrix of 20 cases was run in which the two major parameters for ISS portion of the experiment program were cost and experiment crew size. Cost was incremented in four values; 320 million, 400 million, 500 million and 600 million dollars. These costs were for cost of the experiment hardware through Space Station launch. The approximate shapes of the cost constraints are shown in Figure 2-7. A major objective of the analysis was to minimize this cost.

Earlier work in the Modular Space Station study indicated that an experiment crew size of 1.75 men appeared to be the minimum for a viable experiment program. Analysis had shown that for the ISS portion of the program in which the total crew size is 6 men, that 4.75 men might be available for performing experiment operations. Consequently, the crew size was varied by 0.75-man increments from 1.75 to 4.75; 1.75, 2.5, 3.25, 4.0 and 4.75 experiment crewmen. Thus, the matrix of 20 elements established two of the primary constraints for the WICK Scheduling Program.

Another constraint imposed upon the WICK Program, logistics resupply capability for 90 day interval, was constrained to 38,000 lb/90 days for ISS and 29,000 lb/90 days for GSS. This data was based on the amount of payload left over to provide experiments support after servicing of the other portions of the Space Station had been accomplished.

Table 2-4 is a copy of the logic constraints which have been integrated into the WICK Computer Program. As can be seen, four types of logical relationships can exist between groups of FPE's. In the first type, only one of several FPE's is allowed to be scheduled. When that FPE is scheduled, others in the group cannot be scheduled. The second kind of condition is the precursor condition. The logical condition is that of simultaniety or parallel operation. The final logical constraint is that only one from a group can be scheduled at any one time. For example, in Earth Surveys there are three choices; only one of which can fly at any one time.

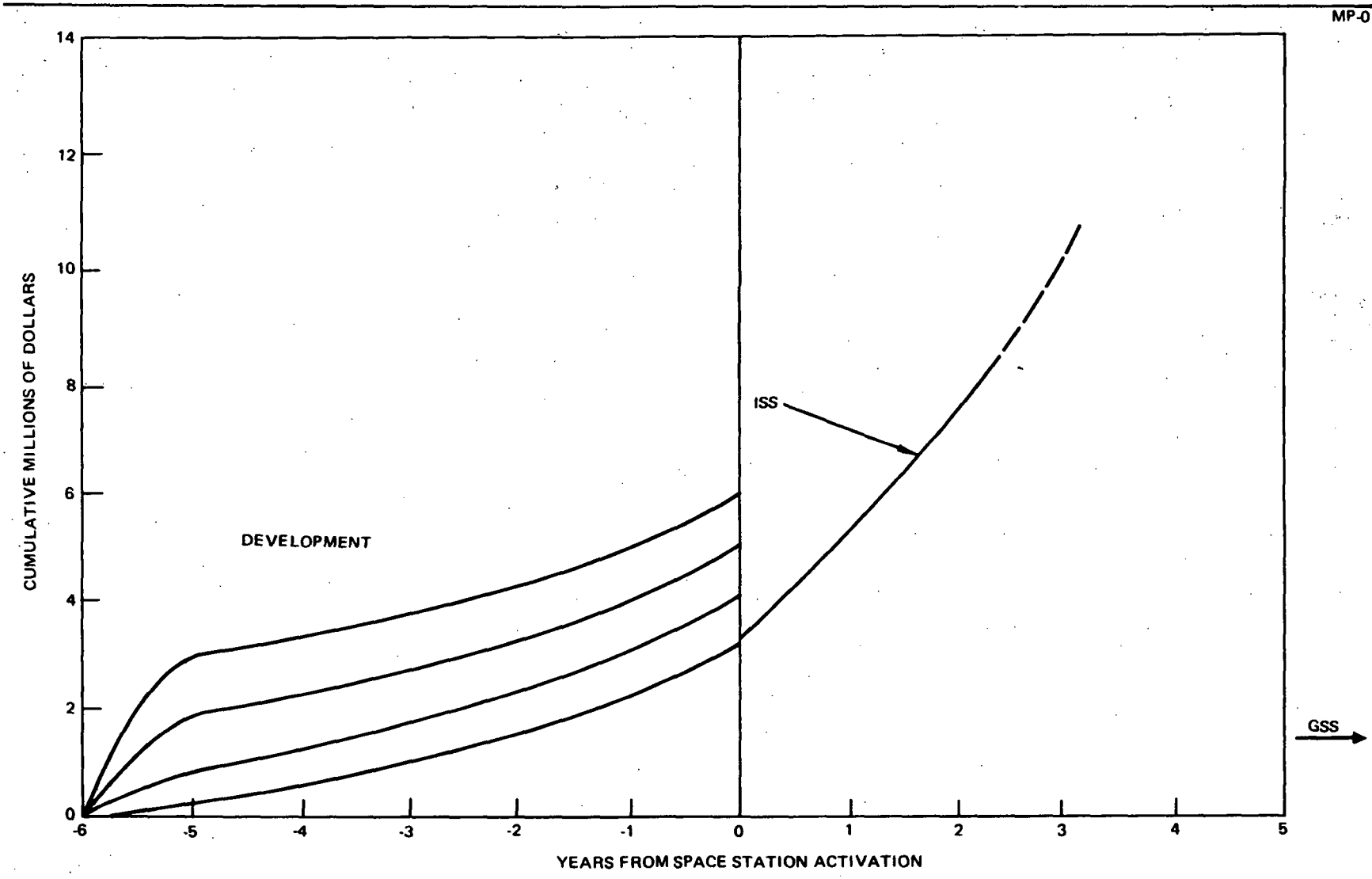


Figure 2-7. Cost Constraints

Table 2-4

LOGIC CONSTRAINTS

Only one of the tasks within the following groups is allowed to be scheduled

A-2 A-2A

The following precurser conditions exist

Task A-4A must precede A-2

Task A-4A must precede A-2A

Task CN-1B must precede CN-1

Task CN-1A must precede CN-1B

Task MS-3A must precede MS-3B

Task MS-3B must precede MS-3C

Task MS-3C must precede MS-3D

Task MS-3D must precede MS-3E

Task T-5A must precede T-5B

Task T-5B must precede T-5C

The following parallel conditions exist

Task P-2BB must operate with P-2A

Task T-1A must operate with T-1B

Only one of the tasks within the following groups can be scheduled at a time

ES-1 ES1AA ES-1G

T-5A T-5B T-5C

A-3AA A-3CC

An important part of the WICK Computer Program is the method in which FPE's are picked by a sequence number and fit against the available resources at a particular time; thus, the lower the sequence number, the more apt that particular FPE is to be chosen. The sequencing was arranged primarily by cost; i. e., the cheapest FPE's were allowed to fly first. Several noteable exceptions were made to this rule. These exceptions

were based on a worth analysis which indicated very high priorities, for LS-1A, the minimum biomedical package, Earth Surveys, and Communications/Navigations. As a result these became the first three sequenced FPE's in every computer case. Also, several adjustments were made in the sequencing to facilitate the computer in implementing precursor relationships between FPE's.

2.2.2 Measures of Effectiveness

Three measures of effectiveness were developed in order to attempt to evaluate the 20 cases produced for the experiment sensitivity analysis. The first measure of effectiveness, that of man-quarters, is the amount of the total work accomplished in an interval. It is computed by multiplying the number of crew available to work times the number of quarters worked.

The second measure of effectiveness, that of percent utilization, is the percent actual work accomplished by a crew compared to the total work that could be accomplished if the crew were operating at 100 percent. For example, if four men were available during an interval to accomplish experiment work and the schedule had only three men working, the percent utilization would be 75.

The third measure of effectiveness, that of ISS $/MΩ is computed by the following formula:

$$\frac{\text{(Number of Crew) (ISS Quarter) (\$2.65 M/MΩ)} + \text{ISS \$ (Hardware)}}{\text{Man Quarters Accomplished}}$$

The first term in this expression, the number of crew times the number of ISS quarters times the equivalent dollar value per manquarter is the measure of the cost of the total work which could be accomplished during ISS for a given crew size. The second term, ISS dollars of hardware, is the cost for the hardware to accomplish that work during ISS. These two cost figures added together are divided by the actual work accomplished during ISS; thus, the lower ISS dollars/MΩ, the more effective the program, i.e., less dollars were spent to accomplish more work during ISS.

Table 2-5, Modular Space Station Experiment Program Analysis, presents the 20 cases run during the sensitivity analysis with some of the measures of effectiveness for each case. Two examples of the measures of effectiveness which apply to the 20 cases constituting the basis of the sensitivity analysis are presented in Figures 2-8 and 2-9, Figure 2-8, the ISS dollars are plotted against ISS dollar/MQ. Since this latter parameter indicates greater effectiveness for a lower value and since it is of paramount importance to minimize the dollars spent on hardware at the Space Station launch, the region of interest is in the lower left-hand portion of the points plotted. The dotted line between the points is simply to facilitate showing cases which correspond to a particular crew level. The region of interest from this has been encircled.

Figure 2-9 employs a similar technique, however, the measure of effectiveness was made a little more complicated. The GSS manquarters of work, that is the total work done in GSS, is divided by ISS dollar/MQ. The more work done in GSS the better, the smaller the parameter of ISS $/MQ the better. Thus, the ratio increases as the program effectiveness increases. Therefore, the region of interest for this plot is low ISS dollars and a high value of the abscissa. There is a good correlation between the points encircled in Figures 2-8 and 2-9. Three dimensional models were constructed which indicated the ISS manpower utilization versus ISS dollars versus crew size available. This clearly gave an indication that large crew sizes and small ISS costs provided the most effective program. The following points were established through this analysis: (1) the ISS experiment accomplishments are relatively insensitive to cost variation at a given crew size; (2) the ISS experiment accomplishment is very sensitive to manpower variation at a given cost, and (3) the apparent effective point is that of the largest crew with fewest ISS dollars. Therefore, Case 526 which had 4.75 men available for ISS crew and had 320 million dollars as the ISS equipment cost was chosen as the point of departure for further analysis and development of the baseline experiment program.

2.2.3 Evolution of the Baseline Experiment Program

As was pointed out in the preceeding sections, Case 526 was the point of departure. From this, the 534 series of cases, with the letter designations

Table 2-5

MODULAR SPACE STATION EXPERIMENT PROGRAM ANALYSIS

Case	Constraints		Effectiveness Measurements					
	Cost (millions of dollars)	ISS Men	ISS Percent Utilization	GSS Percent Utilization	ISS MQ	GSS MQ	Total MQ	Total Percent Utilization
512	320	1.75	85	78	30	147	177	79
514	320	2.50	79	70	40	133	173	72
521	320	3.25	72	66	47	126	172	67
525	320	4.00	66	67	53	128	180	57
526	320	4.75	59	72	57	137	193	68
511	400	1.75	95	76	33	145	177	79
513	400	2.5	90	78	45	149	194	81
515	400	3.25	73	76	48	145	193	76
516	400	4.00	72	67	57	127	183	67
517	400	4.75	65	73	62	139	200	70
524	500	1.75	97	82	34	155	188	84
523	500	2.50	95	75	47	142	189	79
522	500	3.25	85	72	56	136	191	75
520	500	4.00	89	67	72	127	197	73
518	500	4.75	90	59	86	112	197	69
528	600	1.75	97	85	34	161	194	86
529	600	2.50	95	79	47	150	197	82
530	600	3.25	95	75	62	142	203	80
531	600	4.00	95	70	76	134	209	77
532	600	4.75	81	63	77	119	195	68

Notes:

Manpower constraint for GSS is 9.5 men unless otherwise noted.

Logistic R/S constrained to 38,000 for ISS and 29,000 for GSS unless otherwise noted.

*No cost constraint after IOC.

**No cost constraint after IOC.

Also early (320 million) constraint was violated to obtain a better program.

ΔThese cases used increased DT&E module development costs.

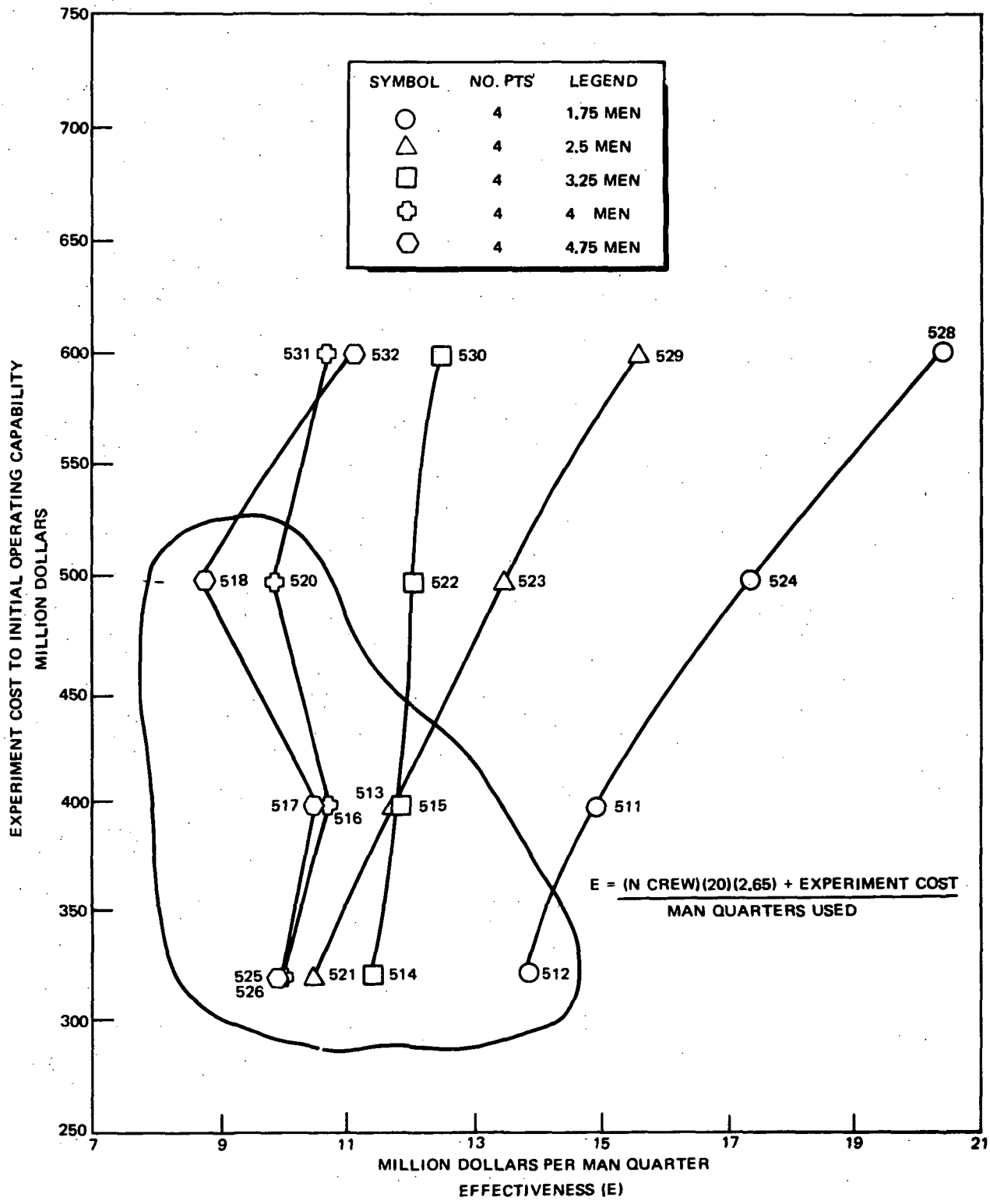


Figure 2-8. ISS Cost Analysis (Wick)

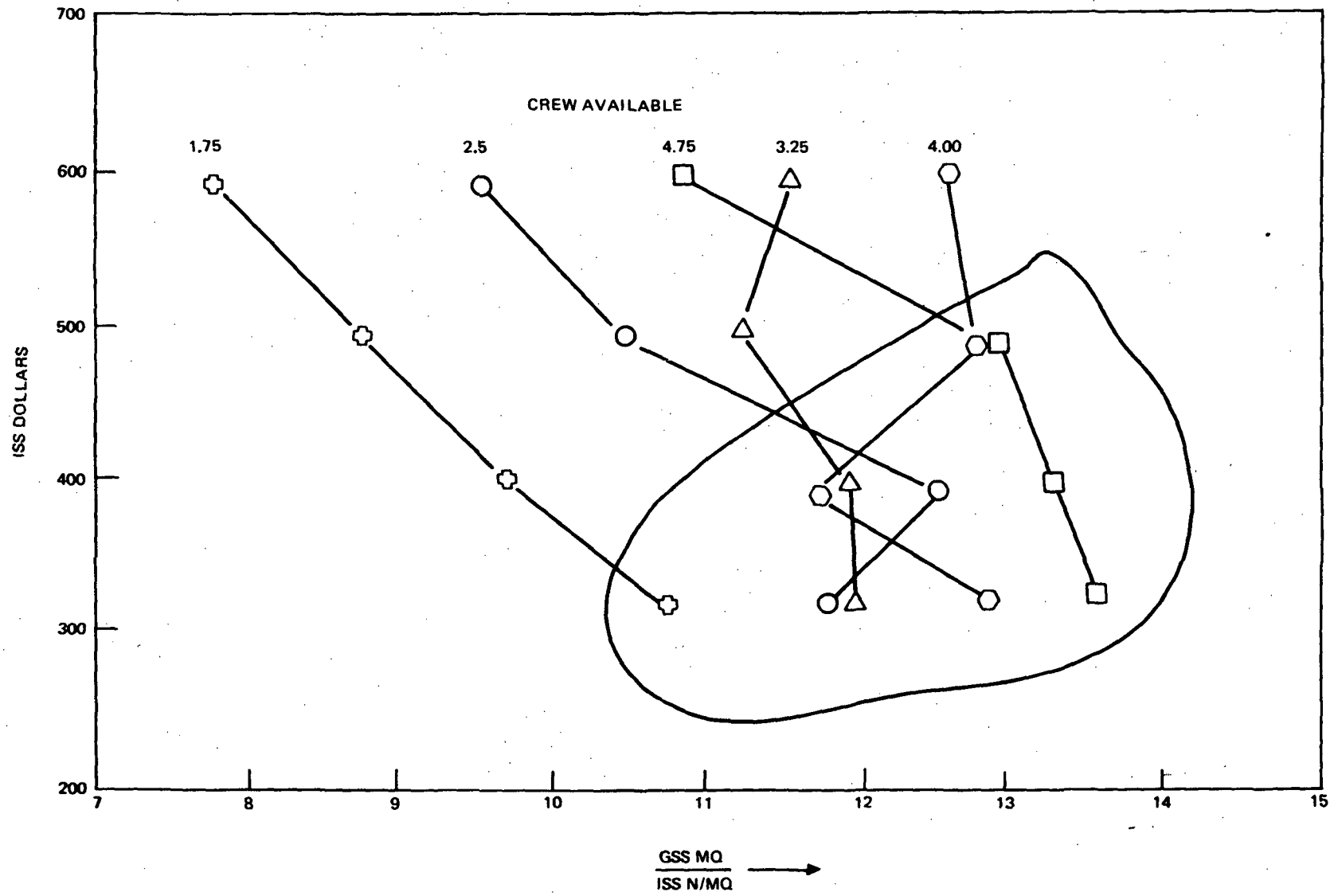


Figure 2-9. Program Effectiveness Versus ISS Dollars

A thru G represented the evolutionary process by which the baseline experiment program was finally determined. In what follows is a very brief description of some of the major changes along the way from Case 534 to 534G which are outlined in order to demonstrate the "fine tuning" which resulted in Case 534G, the Baseline Experiment Program.

Case 534 - The dollar constraints for GSS were removed.

Case 534A - A reexamination of the DDT&E costs were made. P-2A was moved from GSS to ISS and numerous minor changes of RAM launches were made in order to meet the shuttle launch rate constraints.

Case 534B - A-5B and LS-1C were removed from GSS and one free-flyer substituted.

Case 534C - Return P-2A to GSS. Started T-1B earlier, moved T-1A to ISS and returned LS-1C to GSS.

Case 534D - Moved LS-1B to ISS and moved T-3A to GSS.

Case 534E - Minor adjustments were made to facilitate a better ISS power utilization. LS-1B once again changed to GSS.

Case 534F - Delayed CN-1A so that LS-1B could fly in ISS.

Case 534G - Moved CN-1B to ISS primarily due to its high position on the worth analysis. Consequently LS-1B was once again placed in GSS, but at the very start of GSS due to its high priority.

Since the resources looked good, the program balance in terms of all disciplines effecting the "fine tuning" dropped and Case 534G was selected as the baseline experiment program.

2.3 BASELINE EXPERIMENT PROGRAM

2.3.1 Characteristics of the Baseline Experiment Program

Figure 2-10 is the Experiment Flight Schedule for Case 534G, the Baseline Experiment Program. The coding for the FPE can be deciphered by referring to Table 2-1. Thus, it can be seen that LS-1A, the Minimal Medical Research Facility is launched with the Modular Space Station during the first quarter of experiment operations. FPE's marked with X as is LS-1A are

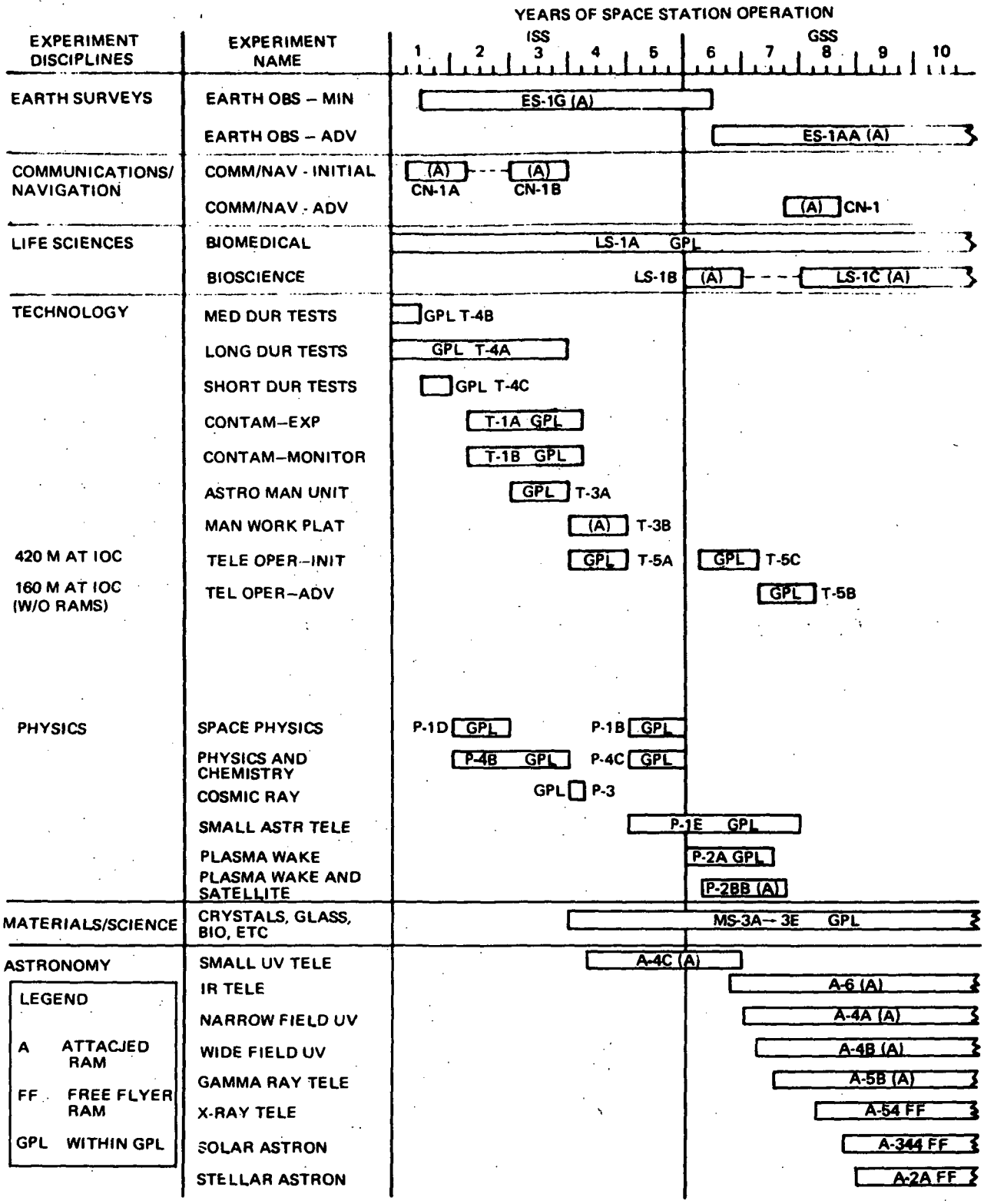


Figure 2-10. Baseline Research and Applications Program

all accommodated in the GPL. Those marked as A are attached RAM's; those marked F are free-flying RAM's. Several technology experiments are also carried up during the first quarter. The first RAM, Communication/ Navigation subgroup A, is brought up the second quarter. During the third quarter the second RAM, ES-1G, Earth Survey Core package is brought up. CN-1A is returned to earth for refurbishment and launched as CN-1B in the ninth quarter. Material Science MS-3A through MS-3E should be considered as one facility brought up incrementally. T1-3B, an attached RAM, is brought up after the conclusion of the Communication/Navigation CN-1B package. Shortly thereafter the UV Astronomy module, A-4C is launched in the 14th quarter. The remainder of the ISS portion of the baseline experiment program continues with the addition of 5 more physics experiments carried in the GPL.

The GSS portion of the Baseline Experiment Program is, for the most part, addition of more RAM's. The launches are staggered to accommodate the ALS restrictions. For the most part these additional RAM's are Astronomy RAM's, especially the last three which are the free-flyers, A-5A, A-3CC, A-2; respectively the X-ray Telescope, the ATM follow-on, and the Advanced Stellar Telescope. Due to the logical constraints discussed earlier, since A-2 flys, A-2A the Intermediate Steller Telescope cannot fly during this program. As was mentioned earlier, the mode of accommodation of FPE's can be adjusted based upon design problems encountered later on. Such was the case with LS-1B and LS-1C, Life Sciences. These have subsequently been reaccommodated as an attached RAM. Figure 2-11 is the docking port load for the Baseline Experiment Program. It can be seen that during the ISS portion three experiment docking ports are required and during the GSS portion of the program eight experiment docking ports are required.

2.3.2 Resource Comparisons

The resources automatically plotted by the WICK Computer Program include cumulative costs, manpower, electrical power and logistics resupply.

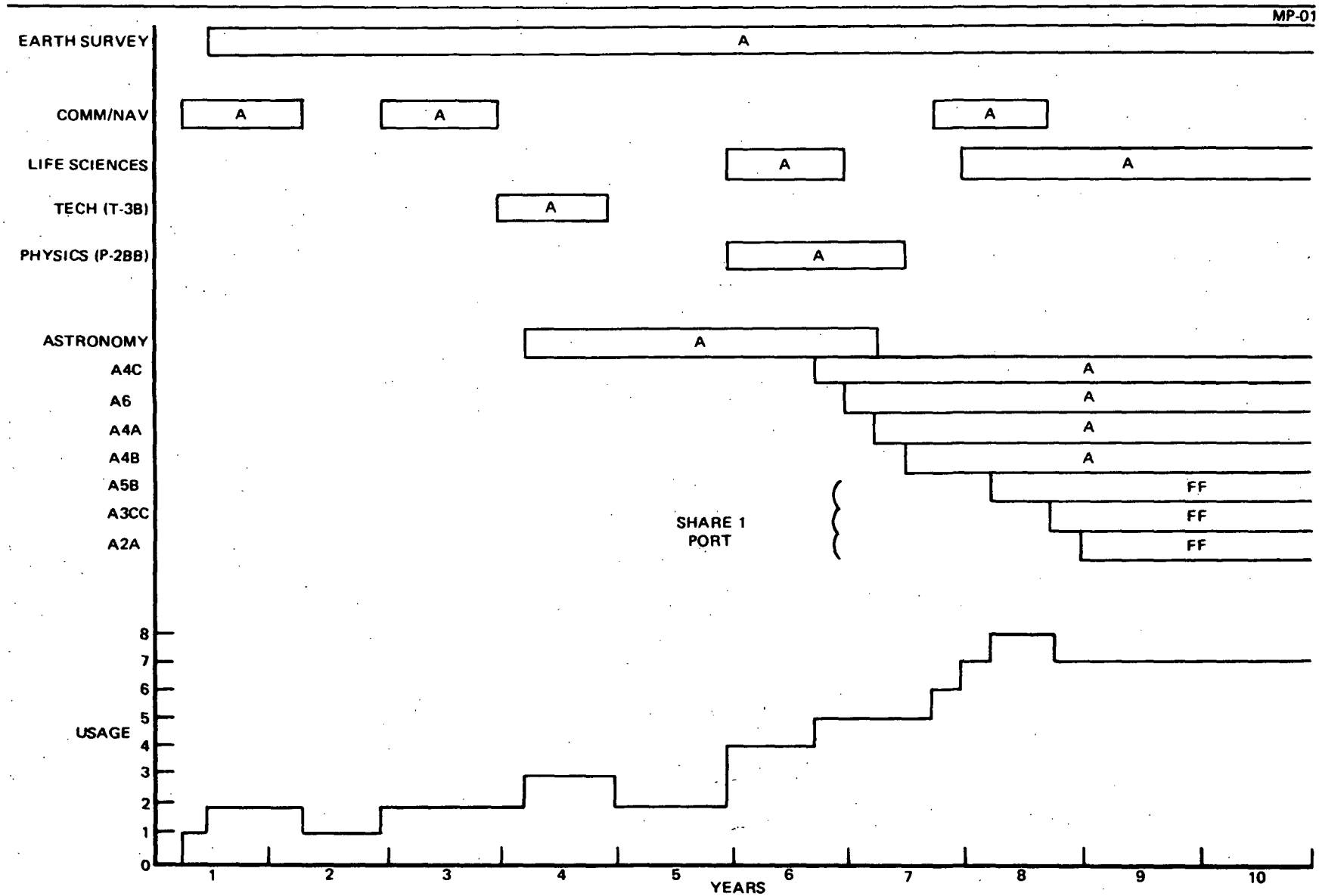


Figure 2-11. Case 534G - Docking Port Utilization

These are shown in Figures 2-12, 2-13, 2-14 and 2-15. Also included is Table 2-6, the data base from which all the requirements were generated. The peak values for the resources were as follows:

Cost	Manpower	Power	Logistics Resupply
$419.15M at launch	4.43 ISS Peak	4981 w ISS Peak	31746 lb/90 days ISS at 13th Quarter (Peak)
$3222.73M at 10 yr	9.45 GSS Peak	12692 w GSS Peak	31374 lb/90 days GSS at 25th Quarter (Peak)

The large peak for logistics resupply is the 13th quarter of ISS was due to the launching of one RAM and three integral or GPL experiments weighing 22,772 lb. The remainder of the 31,000-plus lb was made up by experiment resupply. The 25th quarter GSS peak was due to the 20,861 lb Astronomy Module launched in that quarter plus the resupply, spare parts, etc. for other experiment requirements.

It was determined that the resources did not vary greatly during the ISS portion of the experiment program over a large case sample. This was due to the fact that most of the ISS analysis was done with similar constraints such that data spread was not very large. The GSS varied considerably since it was not as tightly constrained.

2.3.3 Alternate Experiment Programs

By removal of the cost constraint a Life Sciences Emphasis Experiment Program, Case 538B was generated, see Figure 2-16. All other constraints were met as in Case 434G. In the Life Sciences Emphasis Program, both LS-1A (Minimum Medical) and LS-1 (the Minimum Life Science Research Facility) were launched initially. LS-1B was launched up in an attached module. After one year, it was returned to ground for refurbishment, relaunched as LS-1C, the Intermediate Life Science Research Facility. It extended past the end of ISS one year into GSS, and at that time it was joined by LS-1D, the Dedicated Life Science Research Facility, also in an attached module. The primary parameter of interest is the cost at the beginning of ISS, 767 million. A Module Astronomy Emphasis Program was also run as Case 538A. As many modules were made to fly during ISS as were consistent with the resources other than cost. Here the cost at Space Station Launch was 1207 million dollars. This is included as Figure 2-17.

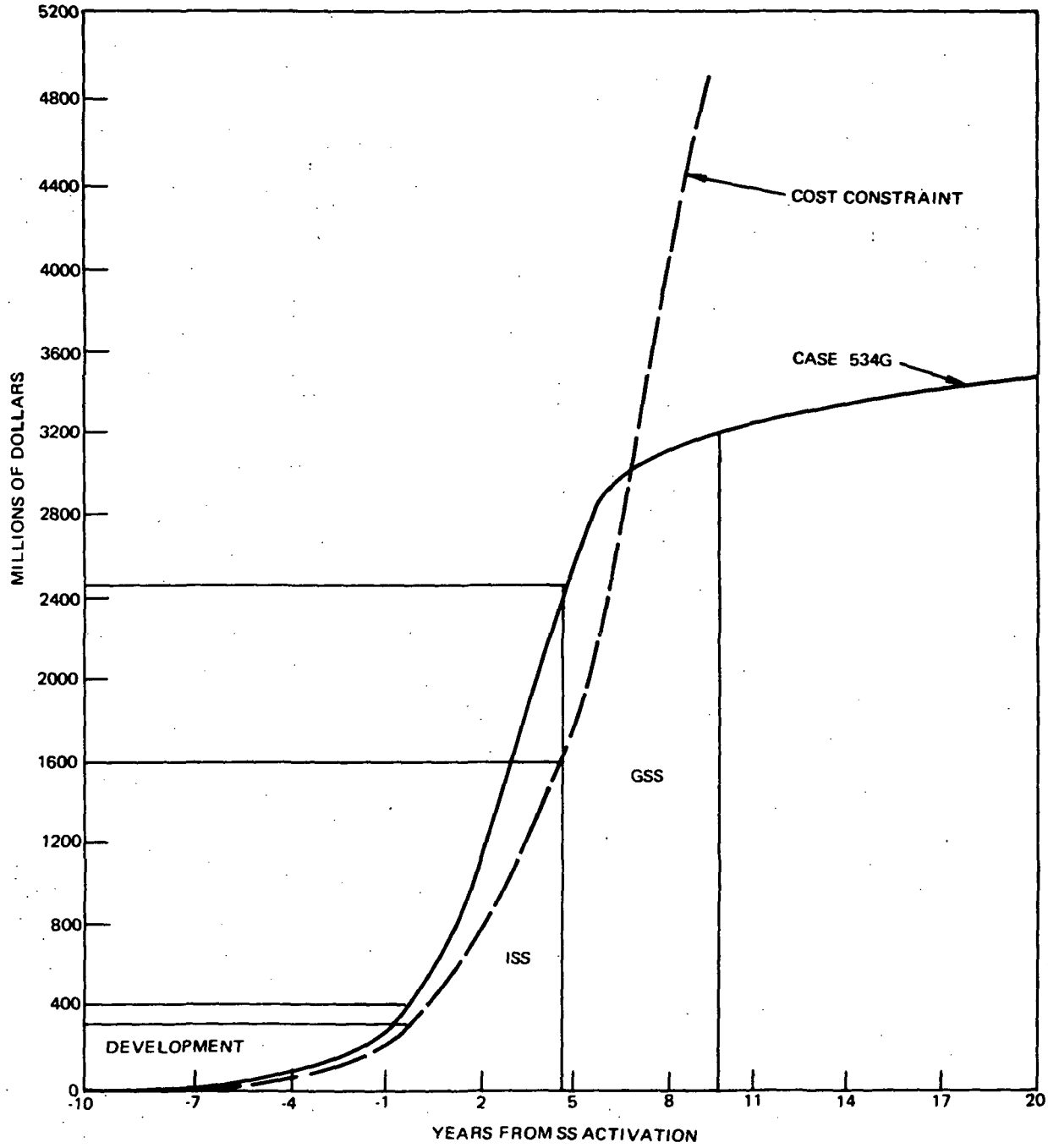


Figure 2-12. Cumulative Costs

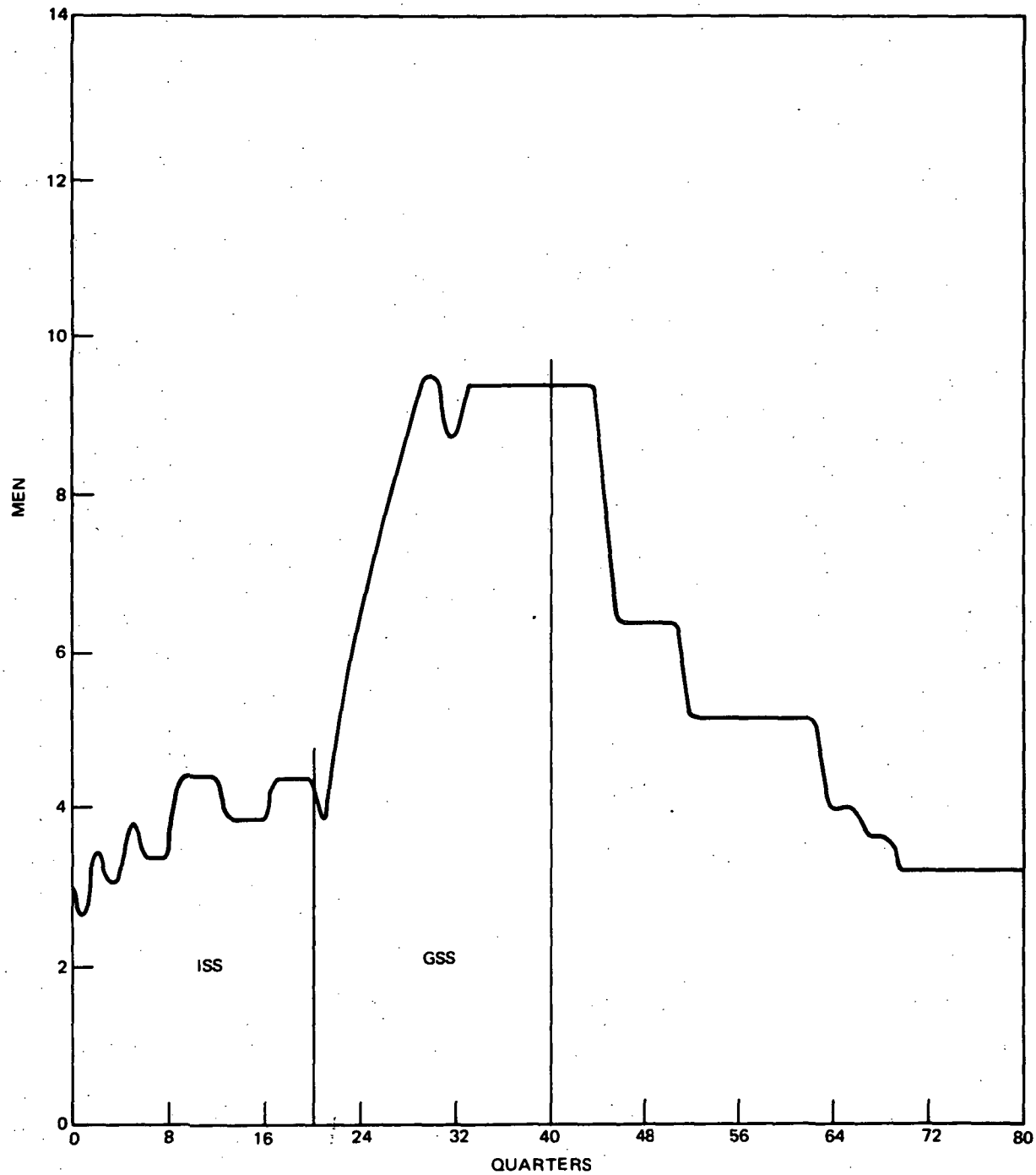


Figure 2-13. Manpower Requirements

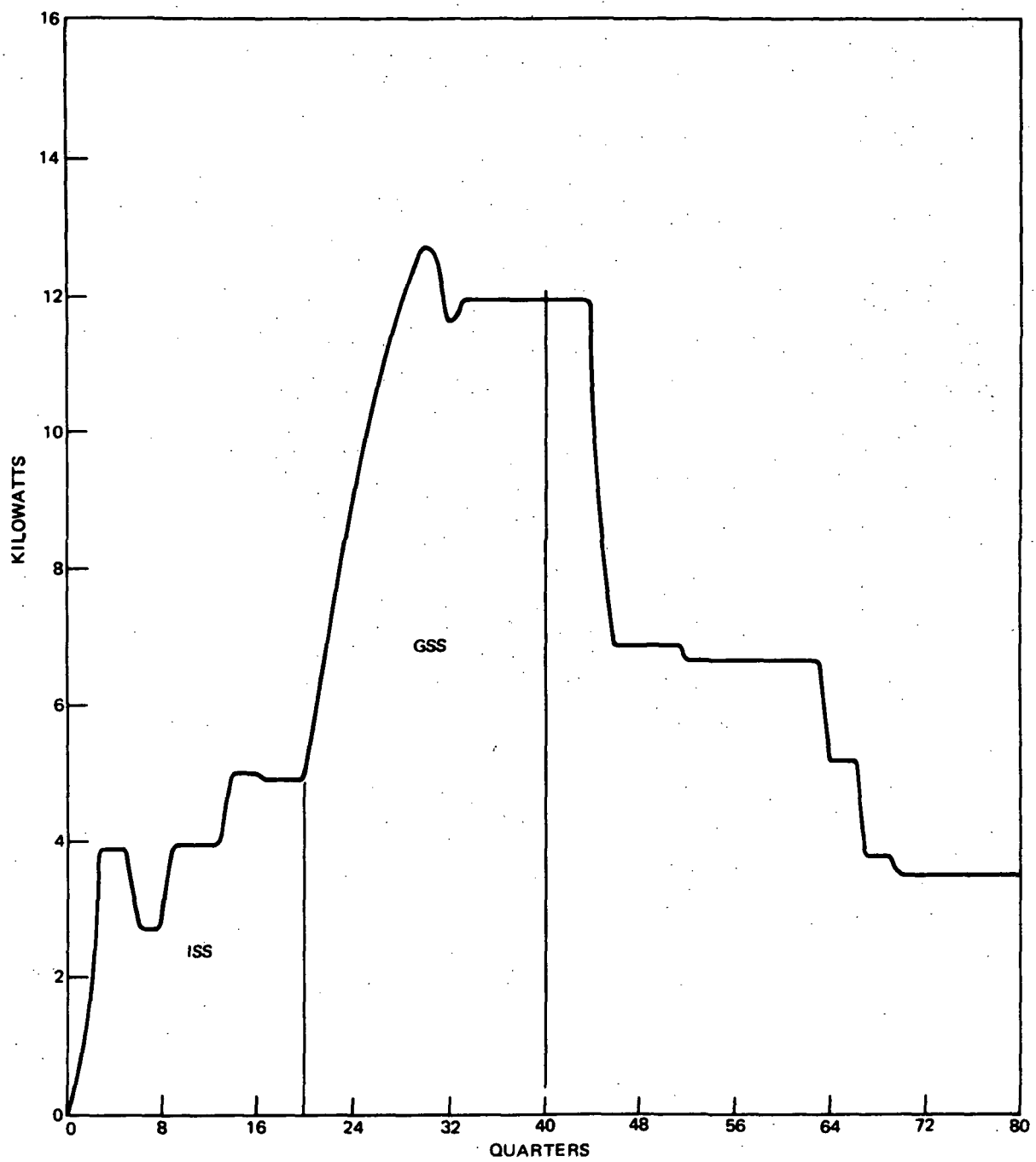


Figure 2-14. Power Requirements

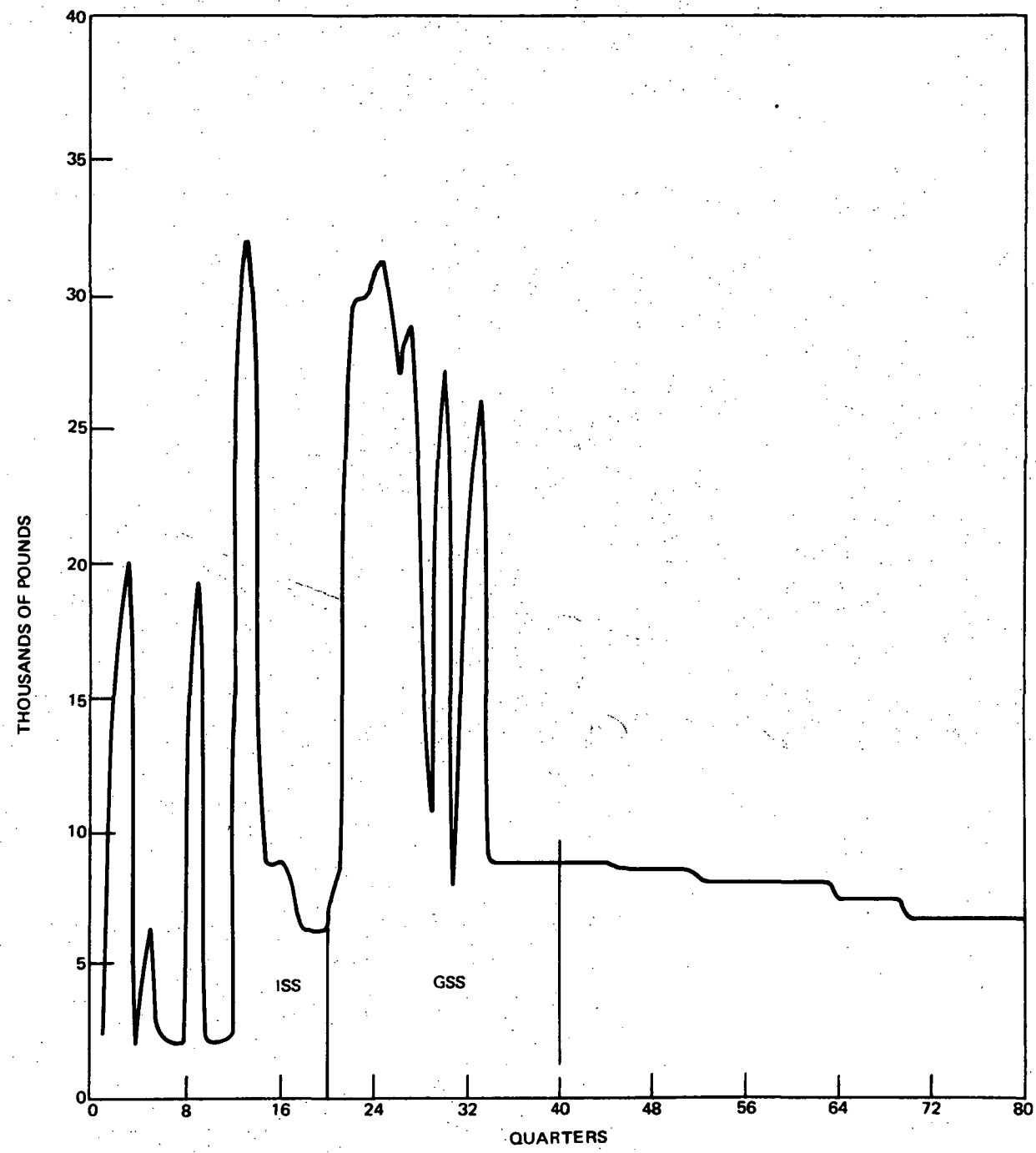


Figure 2-15. Logistic Resupply Requirements

Table 2-6

DATA BASE FOR CASE 534G

FPE	Men	Vol (ft^2)	Logistics (lbs/90 days)	Power (ICW)	Line No.	Sequence	Manufacture Duration (Yrs)	Flight Duration Desired	Exp Wt (lbs) (Quarters)
A-1	0.56	1	642	249	1	50	6	40	20925
A-2	0.81	1	792	247	2	47	5	40	26224
A-2A	0.76	1	650	277	3	46	5	40	17141
A-3AA	1.24	1	1320	266	4	48	6	40	18710
A-3CC	1.21	0	360	249	5	45	6	20	13917
A-4A	0.66	0	77	1420	6	34	5	20	20861
A-4B	1.16	0	100	1472	7	35	5	20	14918
A-4C	0.36	0	100	1142	8	15	4	12	14626
A-5A	0.36	1	730	258	9	43	6	40	18936
A-5B	0.36	0	73	1391	10	36	6	40	18216
A-6	1.16	0	590	1501	11	37	5	40	19806
P-1A	0.13	300	48	13	12	20	5	4	610
P-1B	0.01	275	25	1	13	10	5	4	258
P-1C	0.09	290	25	19	14	11	5	4	118
P-1D	0.01	260	1	1	15	8	4	4	1910
P-1E	0.48	275	13	458	16	16	5	12	223
P-2A	0.20	600	42	10	17	14	5	6	549
P-2BB	1.12	0	3536	927	18	32	5	6	18717
P-3	0.68	0	1720	1867	19	39	7	40	25068
P-3C	0.01	160	264	0	20	40	4	1	308
P-4A	0.88	480	482	8	21	19	5	4	1629
P-4B	1.66	655	812	53	22	18	5	4	2080
P-4C	1.18	240	530	118	23	17	5	4	394
ES-1	2.29	0	3025	4775	24	44	5	40	21493
ES1AA	1.26	0	1798	2590	25	9	5	40	19747

Table 2-6

DATA BASE FOR CASE 534G (Continued)

FPE	Men	Vol (ft^2)	Logistics (lbs/90 days)	Power (ICW)	Line No.	Sequence	Manufacture Duration (Yrs)	Flight Duration Desired	Exp Wt (lbs) (Quarters)
ES-1G	0.86	0	1150	2443	26	1	5	20	17527
CN-1	2.03	0	328	1336	27	33	5	4	15525
CN-1A	0.81	0	202	1241	28	2	5	4	14891
CN-1B	1.02	0	250	1264	29	31	5	4	14955
MS-3A	0.36	925	2858	271	30	21	4	40	3564
MS-3B	0.18	2	277	54	31	22	4	40	40
MS-3C	0.23	2	597	103	32	23	4	40	100
MS-3D	0.09	2	499	56	33	24	4	40	25
MS-3E	0.10	2	66	75	34	25	4	40	25
T-1A	0.27	280	48	80	35	13	5	8	389
T-1B	0.13	260	11	1	36	7	5	8	76
T-2A	0.39	1	9586	232	37	30	6	3	18126
T-2BB	1.26	1	7101	302	38	41	6	2	21532
T-3A	0.84	195	127	11	39	12	3	4	457
T-3B	1.33	0	3223	745	40	28	4	4	17205
T-4A	0.13	275	51	40	41	5	3	12	574
T-4B	2.16	305	78	140	42	4	3	2	890
T-4C	0.93	225	528	48	43	6	3	2	461
T-5A	0.07	160	0	8	44	26	4	4	1455
T-5B	0.21	160	29	4	45	27	4	4	1627
T-5C	0.16	160	0	5	46	29	4	4	1606
LS-1A	0.30	180	31	84	47	3	5	40	739
LS-1B	0.70	250	123	1062	48	38	7	4	1934
LS-1C	1.20	550	207	2081	49	42	7	16	3382
LS-1D	2.83	0	394	6523	50	49	7	40	16510

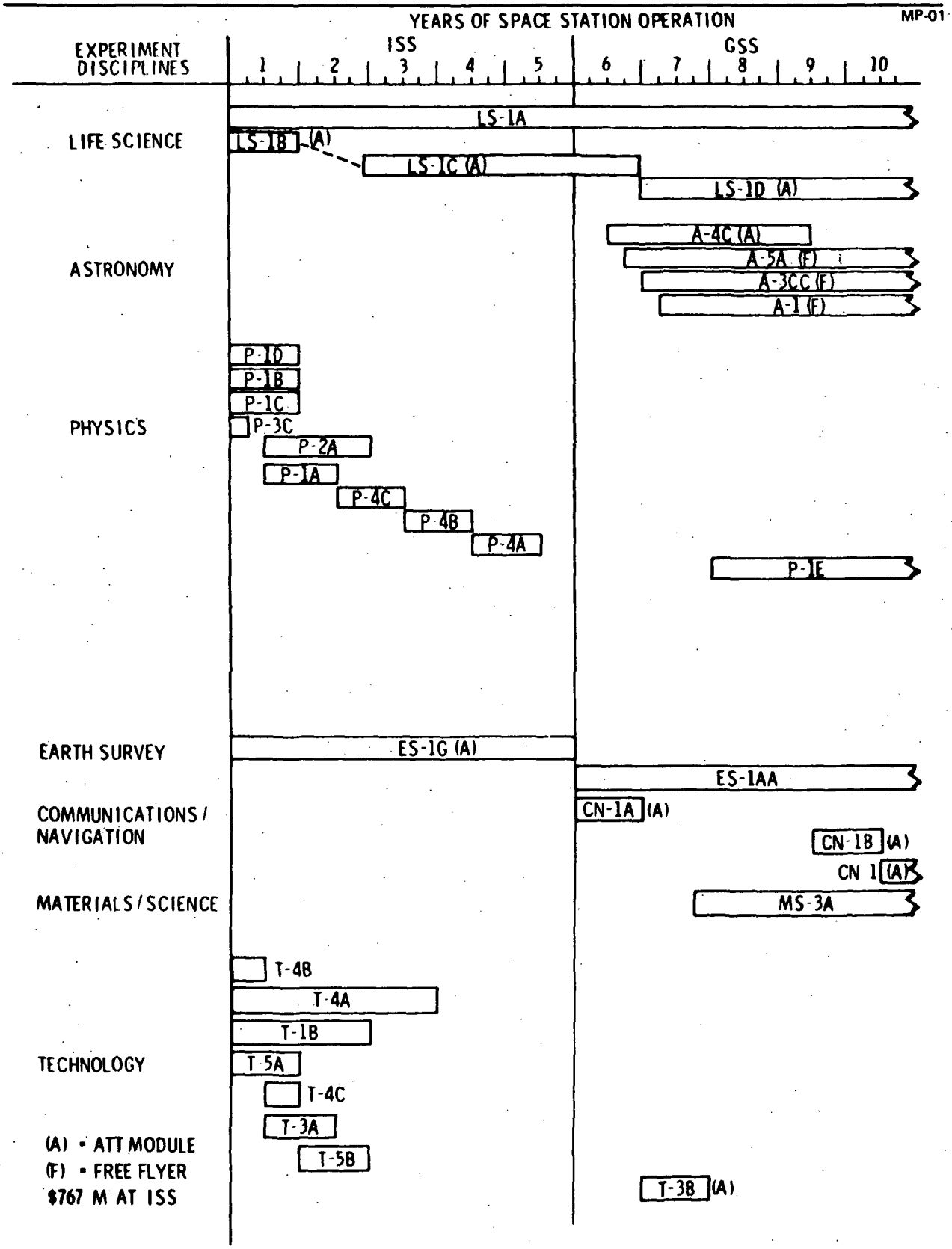


Figure 2-16. Life Science Emphasis

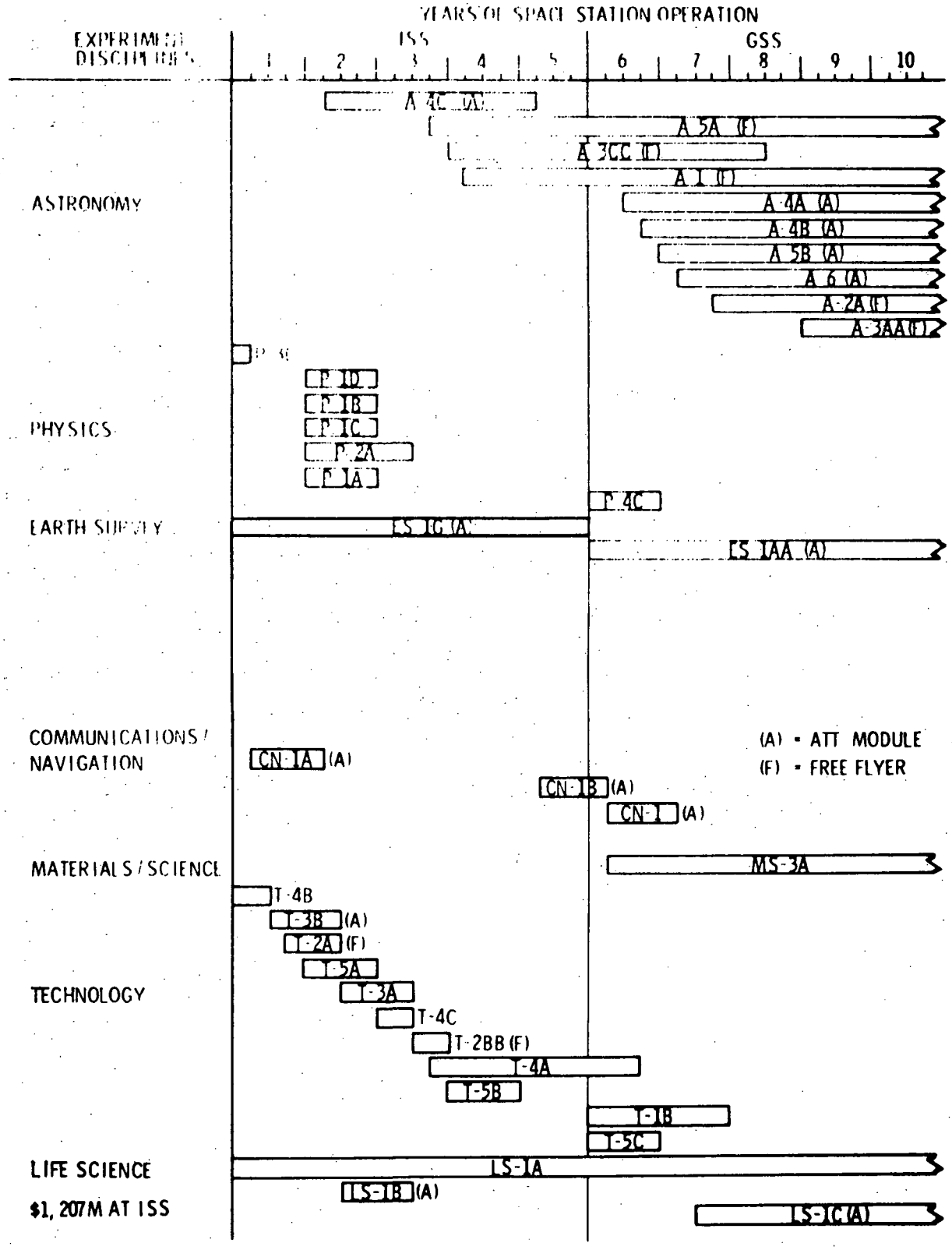


Figure 2-17. Module/Astronomy Emphasis

(A) = AFT MODULE (F) = FREE FLYER

Section 3
MISSION ANALYSIS

The results of the Space Station Mission Analysis, Task 2.2.1.3, are presented in this section. These include analyses conducted to establish basic mission and operational requirements as well as to ensure that the accommodation of these requirements would satisfy the Space Station Program objectives. The analyses presented covers a description of the mission events, orbit selection, orbit evaluation, and related supporting analyses.

The allowable Space Station orbit envelope specified by the NASA was an altitude between 444 km (240 nmi) and 500 km (270 nmi) at an inclination of 55 degrees. The baseline orbit altitude is 456 km (246 nmi) selected primarily to provide reasonable earth coverage opportunities with the new NASA Blue Book sensors. The analysis accomplished to verify this selection is contained herein. The 246 nmi is an average altitude on which most orbital calculations are universally based. It corresponds to an orbit altitude of 242 nmi at the equatorial crossing. The 246 and 242 nomenclature are used interchangeably in this volume.

The 246 nm altitude orbit was evaluated in detail to provide data on orbit keeping requirements and ground coverage and viewing capabilities.

3.1 MISSION DEFINITION

The concept of mission definition employed in this section relates to describing launch, flight, and in-orbit profiles and describing the flight characteristics and performance of the Shuttle as it is used to transport the modules to orbit for modular assembly of the Space Station.

3.1.1 Mission Profile

The shuttle will place the first module of the Modular Space Station, which is the power/subsystems module, into a 500 km (270 nmi) circular orbit

at 55 degrees inclination. This orbit will be allowed to decay down to the 456 km (246 nmi) operational orbit. The orbit decay period without orbit keeping will require approximately 160 days. Orbit keeping will commence when the operational altitude is reached. Figure 3-1 presents the Space Station mission profile history for the first 180 days.

The reason for employing an altitude decay mode for the first 160 days stems from a payload weight limit which has been imposed as a study guideline and constraint. This constraint states that the design-to weight of Shuttle transported modules shall not exceed 20,000 lb (9072 kg) without regard to any particular altitude. The orbit keeping propellant required for 160 days at the baseline altitude is approximately 226 kg (500 lb). However, by taking advantage of this guideline and launching to an initial altitude of 500 km (270 nmi) and eliminating the need for orbit keeping results in saving the 226 kg of propellant. If this fixed weight constraint were changed to allow flights to be loaded up to 80 percent of the Shuttle capability (20 percent margin), all vehicles would be launched directed to 456 km (246 nmi) where they would be maintained.

The launch profile for all the shuttle flights will be nearly identical, differing only in the on-orbit phasing time required to reduce the in-plane phase angle down to an appropriate value where the orbital transfers can be initiated. Both a North-East launch azimuth (nominal flight) and a South-East launch azimuth can be employed to affect an early rendezvous flight.

The orbiter nominal flight profile is shown in Figure 3-2. As indicated, the initial target orbit is a 93 km x 185 km (50 nmi x 100 nmi) orbit obtained by the booster vehicle combined with the burn of the orbiter propulsion system. The time summary of flight events is also shown in Figure 3-2 terminating with orbiter cutoff at the 93 km (50 nmi) perigee point. Upon reaching the 185 km (100 nmi) apogee, the orbiter will circularize and begin orbital phasing pursuant to the terminal rendezvous phase. These data plus those given in Figure 3-3 (dynamic pressure, velocity, flight path angle, axial load factor, and angle-of-attack) define the powered flight conditions during ascent.

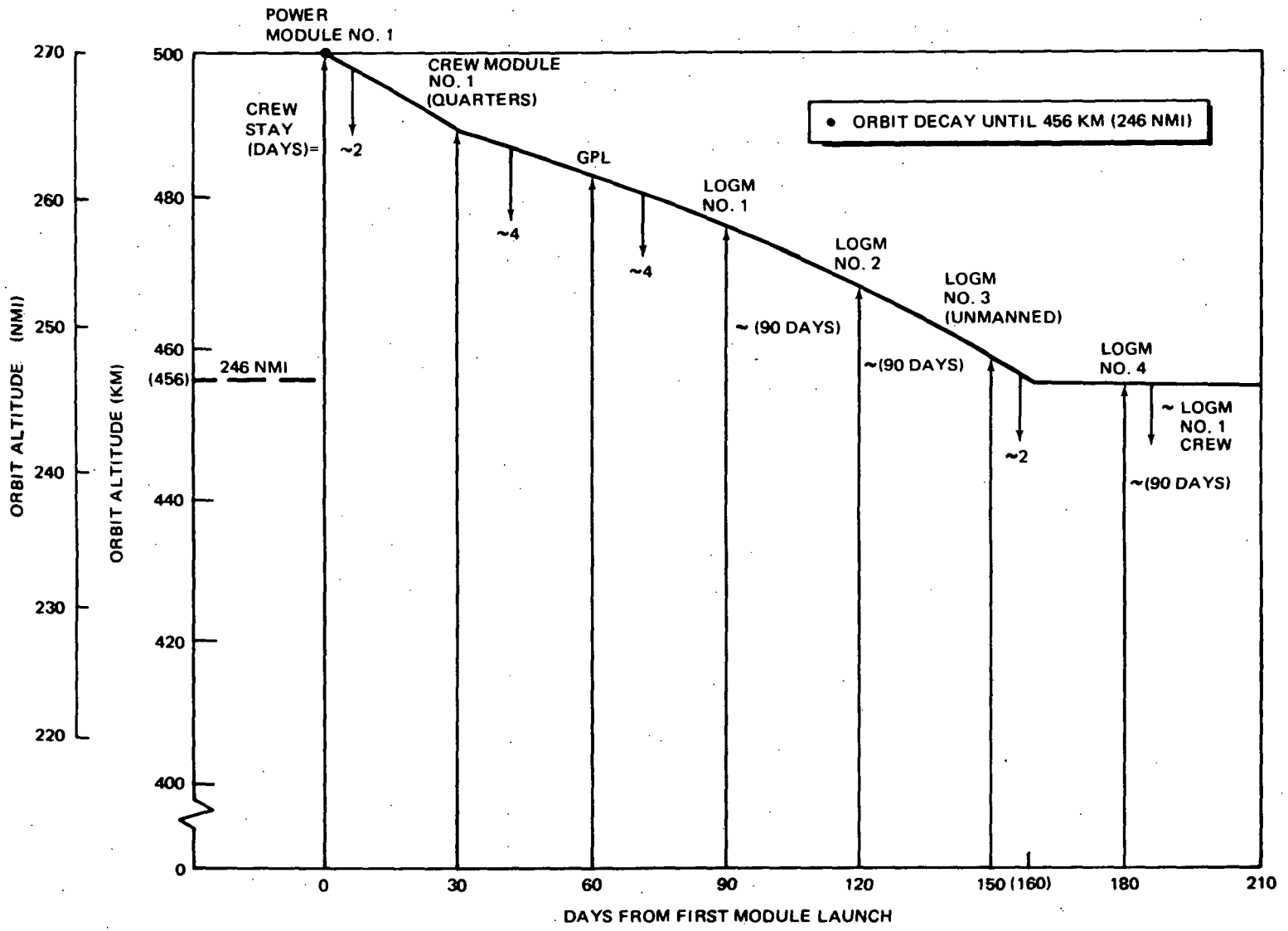
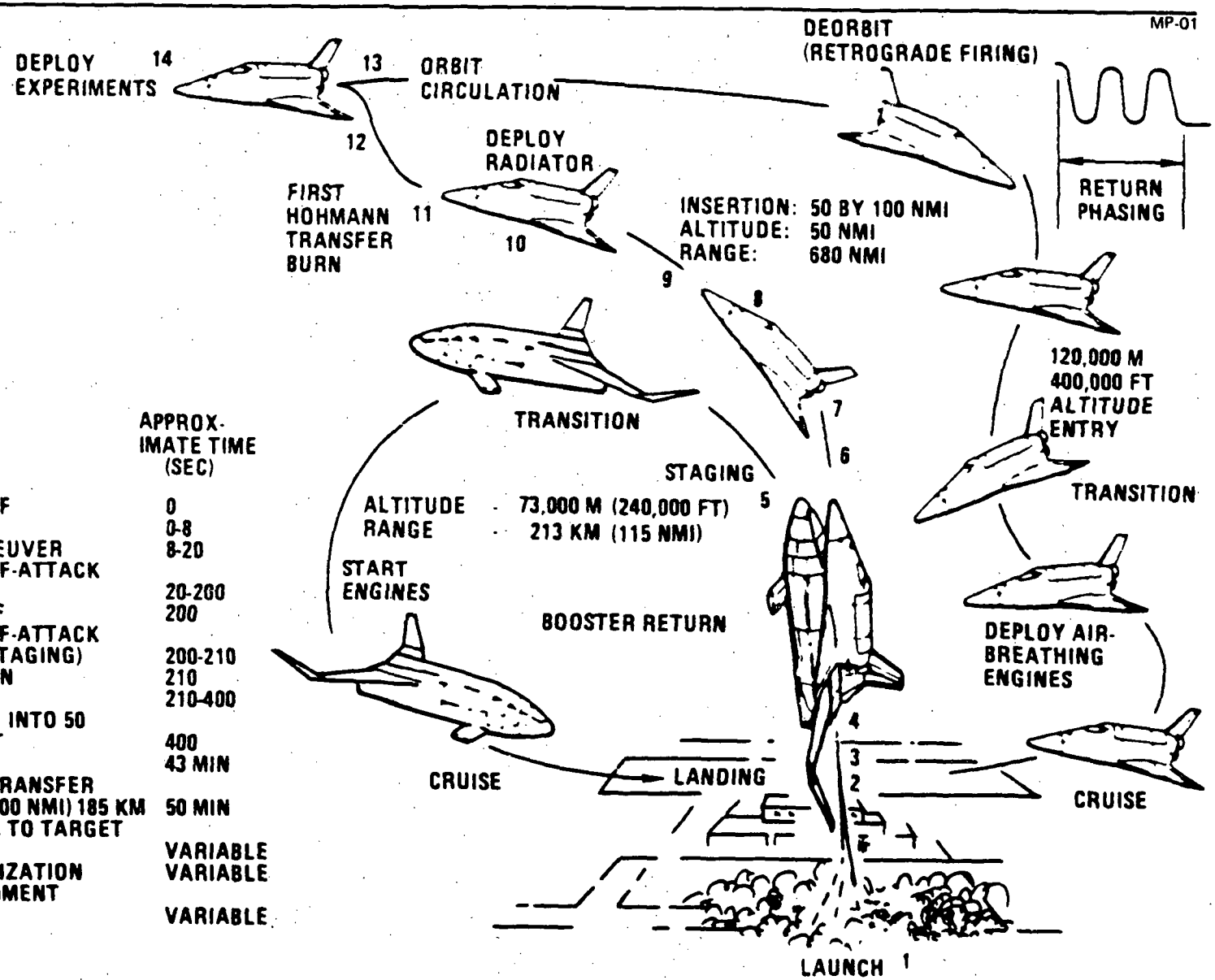


Figure 3-1. Mission History for First 180 Days



EVENT		APPROX-IMATE TIME (SEC)
1	BOOSTER LIFTOFF	0
2	VERTICAL RISE	0-8
3	PITCHOVER MANEUVER	8-20
4	"ZERO" ANGLE-OF-ATTACK FLIGHT	20-200
5	BOOSTER CUTOFF	200
6	"ZERO" ANGLE-OF-ATTACK COAST PERIOD (STAGING)	200-210
7	ORBITER IGNITION	210
8	OPTIMUM FLIGHT	210-400
9	ORBITER CUTOFF INTO 50 BY 100 NMI ORBIT	400
10	ASCENT COAST	43 MIN
11	FIRST HOHMAN TRANSFER MANEUVER (AT 100 NMI) 185 KM	50 MIN
12	ORBIT TRANSFER TO TARGET ORBIT	VARIABLE
13	ORBIT CIRCULARIZATION	VARIABLE
14	ON-ORBIT EXPERIMENT OPERATIONS	VARIABLE

Figure 3-2. Shuttle Flight Profile

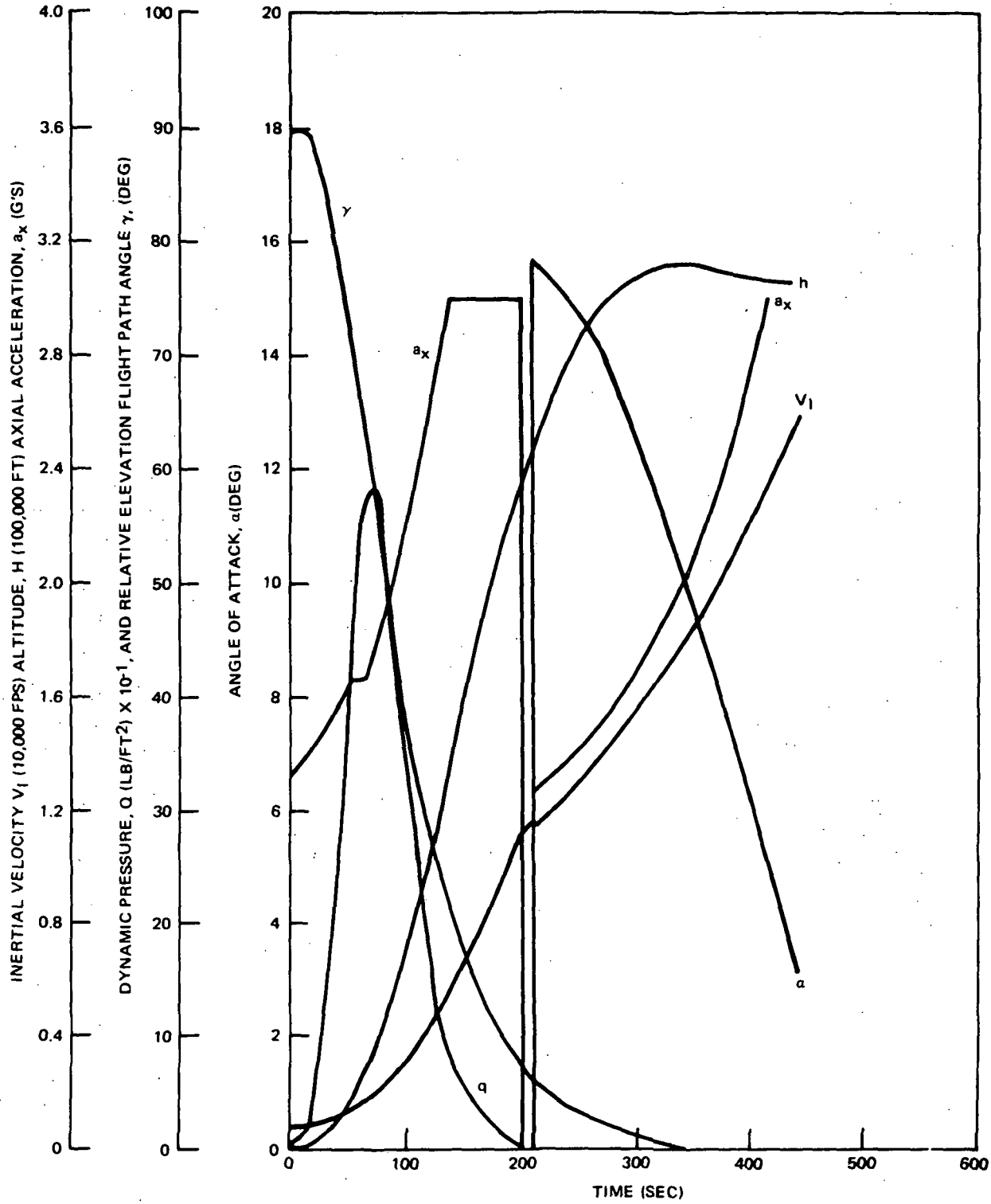


Figure 3-3. Nominal Shuttle Ascent Trajectory

3.1.2 Shuttle Performance

The mission velocity requirements and performance data for the Space Shuttle vehicle are presented in this section. The nominal mission velocity budget is portrayed in Figure 3-4. The generalized mission events are shown in the sketch of Figure 3-5 to illustrate where the velocity increments are applied. It should be noted that the Shuttle Orbiter's main engines are used only during the boost phase to attain the initial 93 km (50 nmi) x 185 km (100 nmi) orbit. The Orbit Maneuvering System (OHS) is used thereafter, starting with a circularization maneuver performed when the orbiter reaches the 185 km (100 nmi) apogee altitude. The velocity required for a rendezvous mission is 46 m/s (150 fps) more than a delivery mission for any altitude.

The velocity requirements for any mission altitude starting from 185 km (100 nmi) are presented in Figure 3-4. As shown, the total velocity required for any altitude is the sum of the fixed requirement of 87 m/s (287 fps) (tabulated in Figures 3-5) and the altitude dependent requirements for orbit transfer and deorbit (assumed to provide a zero perigee altitude).

The baseline shuttle performance at the 55 degree reference inclination for both delivery and rendezvous missions is shown in Figure 3-6 as a function of orbit altitude. The payload sensitivity trade factor with altitude can be seen in Figure 3-6 to be approximately $(\partial W_{PL})/\partial H = -24$ kg/km (-100 lb/nmi). Also indicated on Figure 3-6 is the 9,072 kg, (20,000 lb) "design-to" Space Station module weight constraint. This constraint allows a 20 percent margin or 2,260 kg (5,000 lb) margin over the reference nominal payload 11,340 kg (25,000 lb) to the reference 500 km (270 nmi), 55 degree orbit. The 20 percent margin curve is also indicated in Figure 3-6 and indicates that if allowed 9,800 kg (21,600 lb) would be available at the baseline 456 km (246 nmi) Space Station orbit altitude.

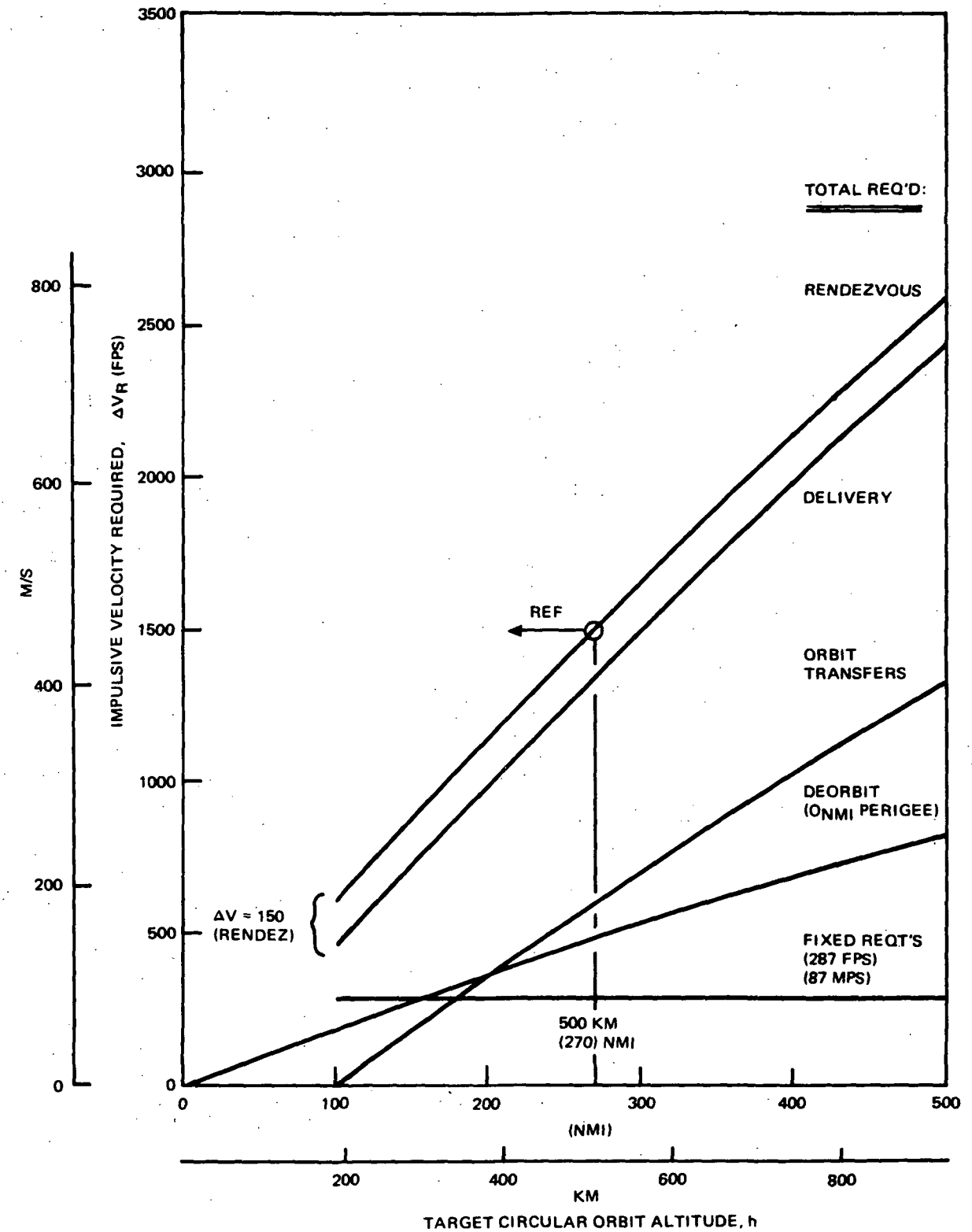
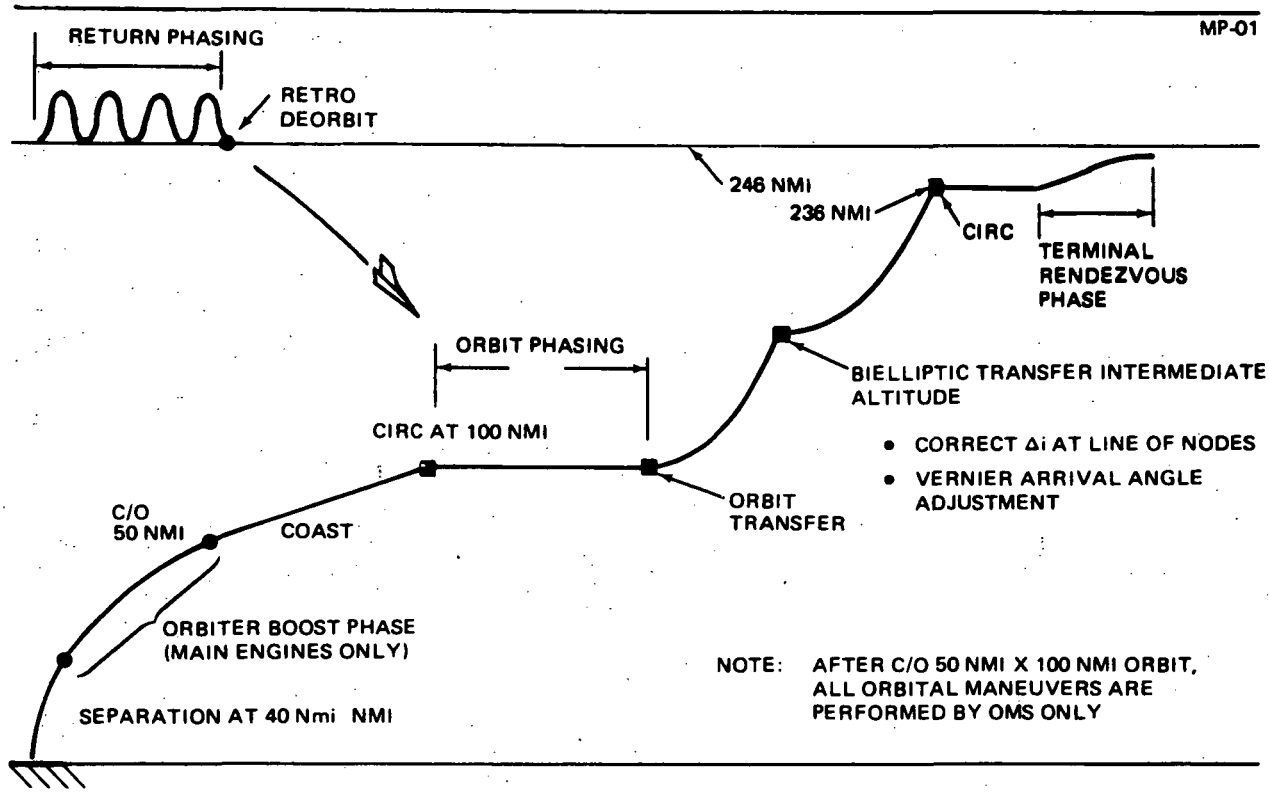


Figure 3-4. Mission Velocity Requirements



		MPS	FPS	MPS	ΔV (FPS)	MPS	FPS
MINIMUM REQUIREMENTS		MISSION AT (246 NMI) 455 KM				REF AT (270 NMI) 500 KM	
• FIXED INCREMENTS		60	(199)			60	(199)
STATION KEEPING, DOCK AND SEPARATION = 9 (30)							
RETURN PHASING = 16 (55)	(199)						
RESERVES = 35 (114)	60						
• INSERTION INTO 100 X 100 NMI 185 X 185 KM		27	(88)			27	(88)
		87	287			87	287
ALTITUDE DEPENDENT REQUIREMENTS							
• ORBIT TRANSFER (ΔV TO TARGET ALT)		157	(512)			181	(593)
• DEORBIT (PERIGEE = 0)		130	(430)			143	(470)
DELIVERY MISSION TOTAL =		374	(1229)			411	(1350)
RENDEZVOUS REQUIREMENTS							
• CLOSING MANEUVERS 18 (60)		46	(150)			46	(150)
• TERMINAL MANEUVER 27 (90) RESERVES							
RENDEZVOUS MISSION TOTAL =		420	(1379)			457	(1500)

Figure 3-5. Nominal Mission Velocity Budget

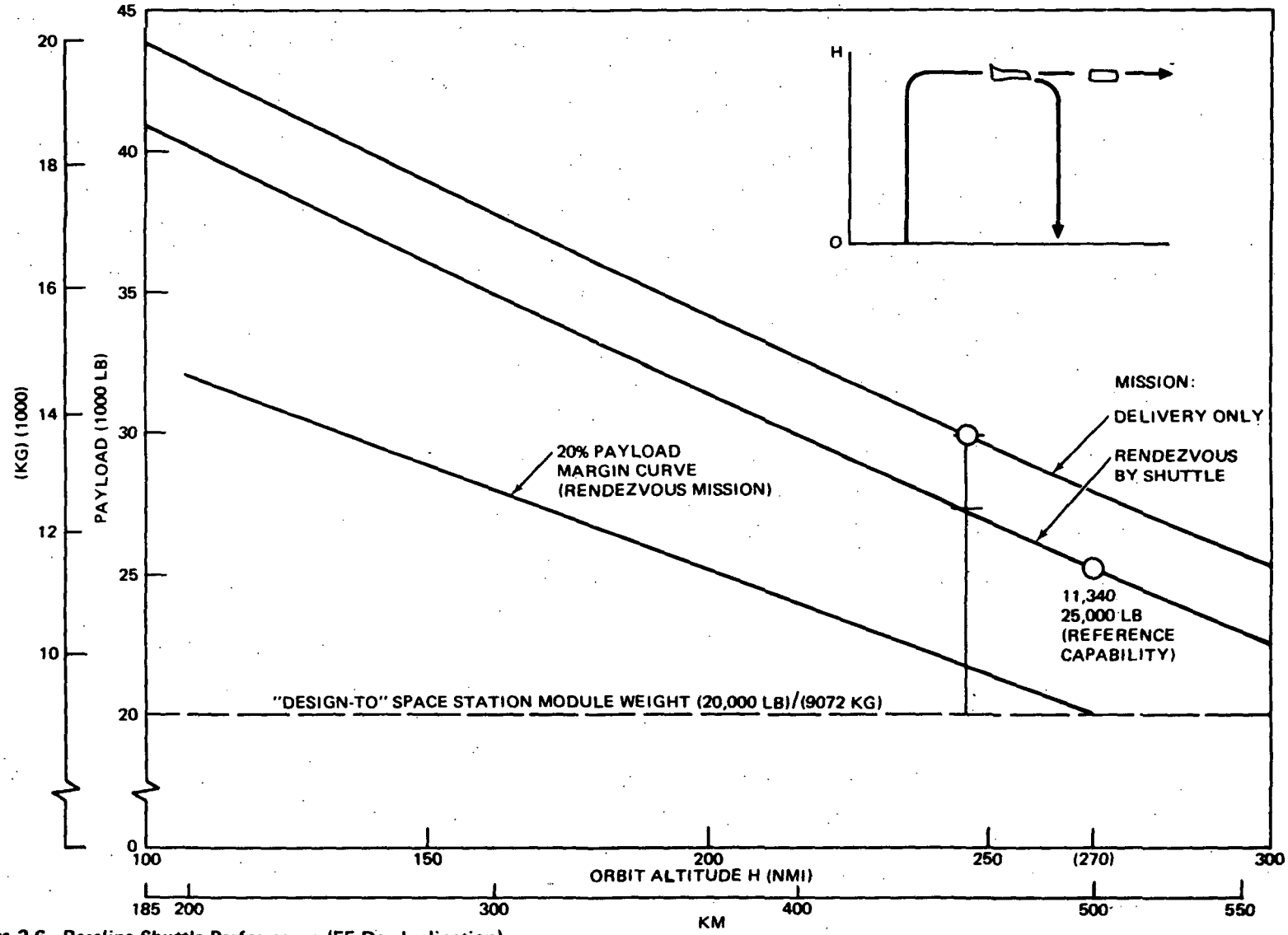


Figure 3-6. Baseline Shuttle Performance (55-Deg Inclination)

3.2 ORBIT ANALYSIS

The orbit analysis activities consisted of performing an orbit selection analysis followed by an evaluation of the selection to determine ground viewing capabilities and to establish orbit keeping requirements.

The orbit selection was approached by scrutinizing the parametric data and analytical rationale which lead to the 33-foot Space Station baseline orbit. From this point the areas potentially affecting the selection of a baseline orbit for the Modular Space Station were reassessed against the new guidelines and configuration concepts.

3.2.1 Orbit Selection

As indicated previously, a Space Station orbit inclination of 55 deg is a study guideline. Another study guideline established that the Space Station must be capable of operating between 444 km and 500 km (240 to 270 nmi).

3.2.1.1 Orbit Selection Considerations

There are many considerations involved in the final selection of an operational orbit for a manned Space Station. An important consideration is the behavior of the orbit in the form of ground coverage sensitivity and its associated performance in providing earth viewing coverage and frequency of observation to an orbital experiment program. Other considerations relate to orbital behavior in the form of operational functions such as rendezvous and communications/observations opportunities which directly affect the total system design of the Space Station.

Typical experiment requirements for an earth orbital Space Station mission are described and operational guidelines defined. These requirements were postulated based on the Space Station Phase B Experiment Program Summary which was developed from the 1971 NASA Blue Book and other current reference data which proposed various ground truth sites, sensors, film resolution ground swaths, etc. Starting with these requirements, the orbit selection techniques are then used to illustrate how an acceptable orbit

regime is selected for a preliminary design. The other considerations reviewed in the orbit selection task are design oriented (radiation and meteoroid environments, drag and orbit keeping propulsion requirements, communications, etc.), and operational oriented (payload performance, rendezvous requirements, etc.).

3.2.1.2 Orbit Behavior

The behavior or performance of potential orbits as they relate to satisfying various Earth viewing requirements can best be determined by evaluating their ground coverage sensitivity. The nature, extent, and frequency of ground coverage of features of the Earth's surface can be evaluated by examining a candidate orbit's trace pattern that is generated on the surface of the rotating earth by the satellite in the course of its orbital motion.

The satellite trace repetition parameter (Q) was established as a useful design tool for evaluating traces. The equation is straightforward.

$$Q = \frac{N}{M} = \frac{360°}{\Delta\lambda_o} = \frac{360°}{(\omega_E - \Omega)\,\tau_n}$$

where

N = Number of nodal revolutions

M = Number of earth rotations relative to the orbit plane

$\Delta\lambda_o$ = Longitudinal shift along the equator per nodal revolution (deg)

ω_E = Earth rotation rate (0.2507 deg/min)

Ω = Nodal regression rate (deg/min)

τ_n = Nodal period (min)

References 3-1, 3-2, and 3-3 provide a more detailed explanation of the satellite repetition parameter and trace pattern development. The satellite trace repetition parameter defines the time it will take for an orbit to complete its cycle and return to an arbitrary starting point and how close the

ground tracks will appear to each other within a given cycle. The distance between tracks is of particular interest with respect to mapping coverage. The satellite repetition parameter sensitivity with altitude is shown in Figure 3-7 for an orbit inclination of 55 deg.

To illustrate the method of interpreting the measure, Q, the value of 15.25 (15-1/4 nodal orbits per "day") can be read from Figure 3-7 at a 55-deg inclination and 432 km (233 nmi) altitude. The lowest integers of N "orbits" and M "days" whose ratio equals the 15.25 value are then the number of orbits and days, respectively, necessary to complete the orbit's coverage or repeatability cycle. In the 432 km (233 nmi) case, the lowest integers are N = 61 and M = 4 or every 4 days. When Q = 15-1/4, expressed with a fractional remainder, the fraction indicates the amount of the daily ground track shift (e.g., one-fourth of the separation between two successive orbits) and the denominator indicates the days required for the orbit to repeat (e.g., 4 days).

The trace behavior of some orbits allows certain Earth truth sites to be directly overflown every M "days". These orbits are called Rendezvous Compatible Orbits (RCO). These "days" are not 24-hour periods because the orbits are precessing (KSC encounters the orbit plane earlier on each succeeding day). For example, RCO altitudes for one to six days are listed in Table 3-1 for a 55 deg orbit inclination and for a 50-deg inclination for comparison.

Table 3-1

RENDEZVOUS-COMPATIBLE ORBITS

M "days" RCO	Q	Altitude i = 50 degrees	nmi	i = 55 degrees	nmi
1	15, 16	502, 202	(270, 109)	508, 210	(274, 113)
2	15-1/2	349	(188)	354	(191)
3	15-1/3, 15-2/3	397, 299	(214, 161)	406, 302	(219, 164)
4	15-1/4, 15-3/4	425, 275	(229, 148)	432, 272	(233, 152)
5	15-1/5, 15-2/5	440, 377	(237, 203)	447, 386	(241, 208)
	15-3/5, 15-4/5	318, 260	(171, 140)	327, 268	(176, 144)
6	15-1/6, 15-5/6	450, 248	(242, 134)	458, 258	(247, 139)

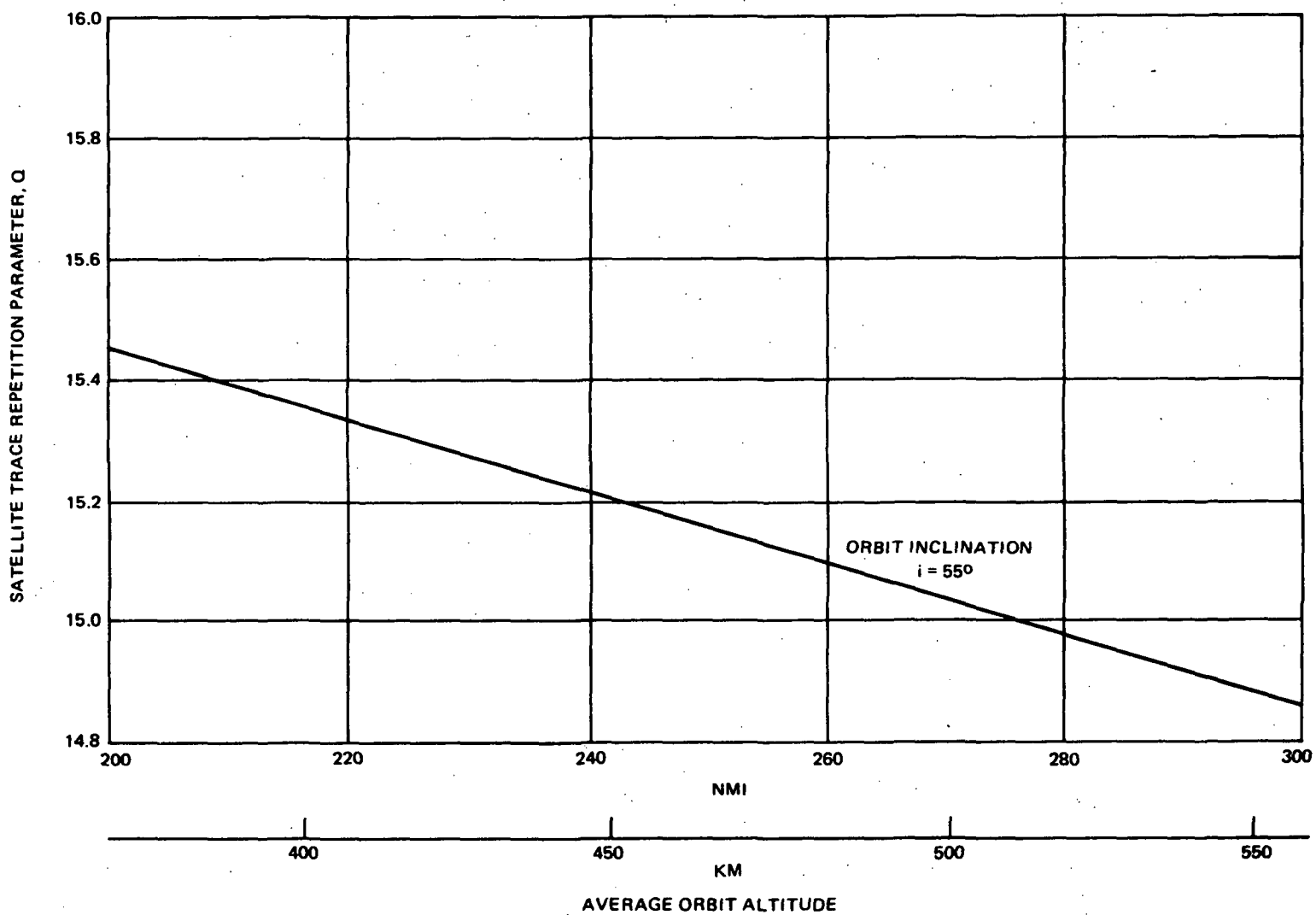


Figure 3-7. Satellite Trace Repetition Parameter

Trace behavior can be represented as shown in Figure 3-8 where the orbits are shown on successive days as they cross the equator on their Northerly or ascending nodes. The parameters considered in the orbit behavior analysis include the following:

$\Delta\lambda_o$ = Ground track longitudinal shift per orbit nodal revolution

$\Delta\Phi_o$ = Daily ground track longitudinal shift (along the equator)

$\Delta\Phi_{o_\perp}$ = Daily "perpendicular" ground track shift

The effect of altitude on the behavior of an orbit can be related to its daily longitudinal path shift at the equator. Figure 3-9 shows the sensitivity of altitude to the daily "perpendicular" path shift ($\Delta\Phi_{o_\perp}$) which is the shift along the equator reduced by the sine of the orbit inclination.

$$\Delta\Phi_{o_\perp} = \Delta\Phi_o \sin i$$

This perpendicular distance is presented here as a reference for mapping rate and separation distance. In using the orbit mechanics data, it is more convenient to use longitudinal and nodal travel measurements but the (Sine i) multiplication must always be made to establish the true mapping separation.

Orbit behavior can be evaluated in terms of the number of days required to repeat the coverage cycle and the distances between the ground tracks on the first and subsequent days. The trace pattern development profiles for those orbits shown in Figure 3-8 were indicated until the first coverage cycle was completed. The initial coverage cycle time (M_o) is the number of nodal days required to sweep across $\Delta\lambda_o$ at the $\Delta\Phi_o$ daily rate and spacing, expressed as:

$$M_o = \frac{\Delta\lambda_o}{\Delta\Phi_o}$$

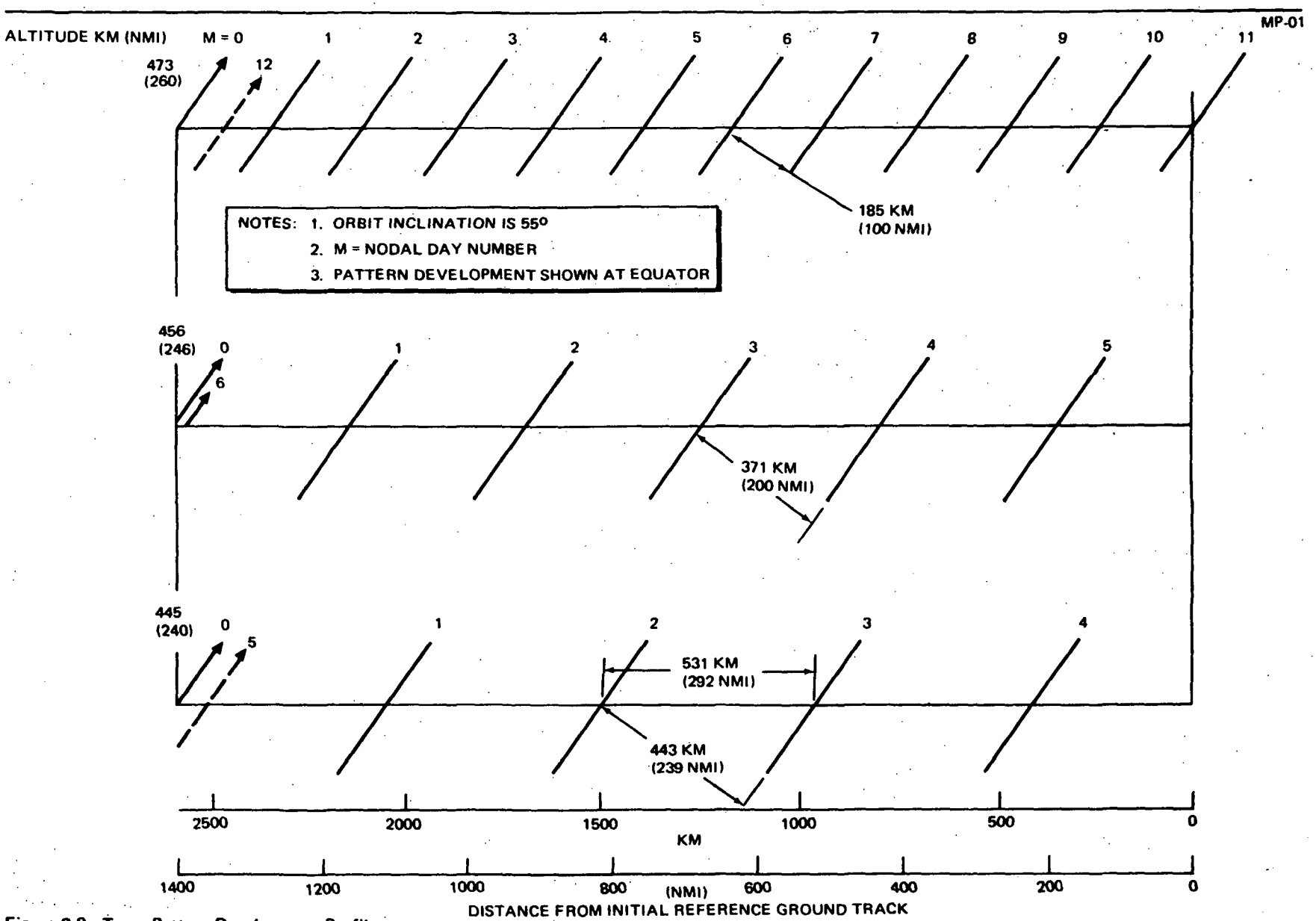


Figure 3-8. Trace Pattern Development Profiles

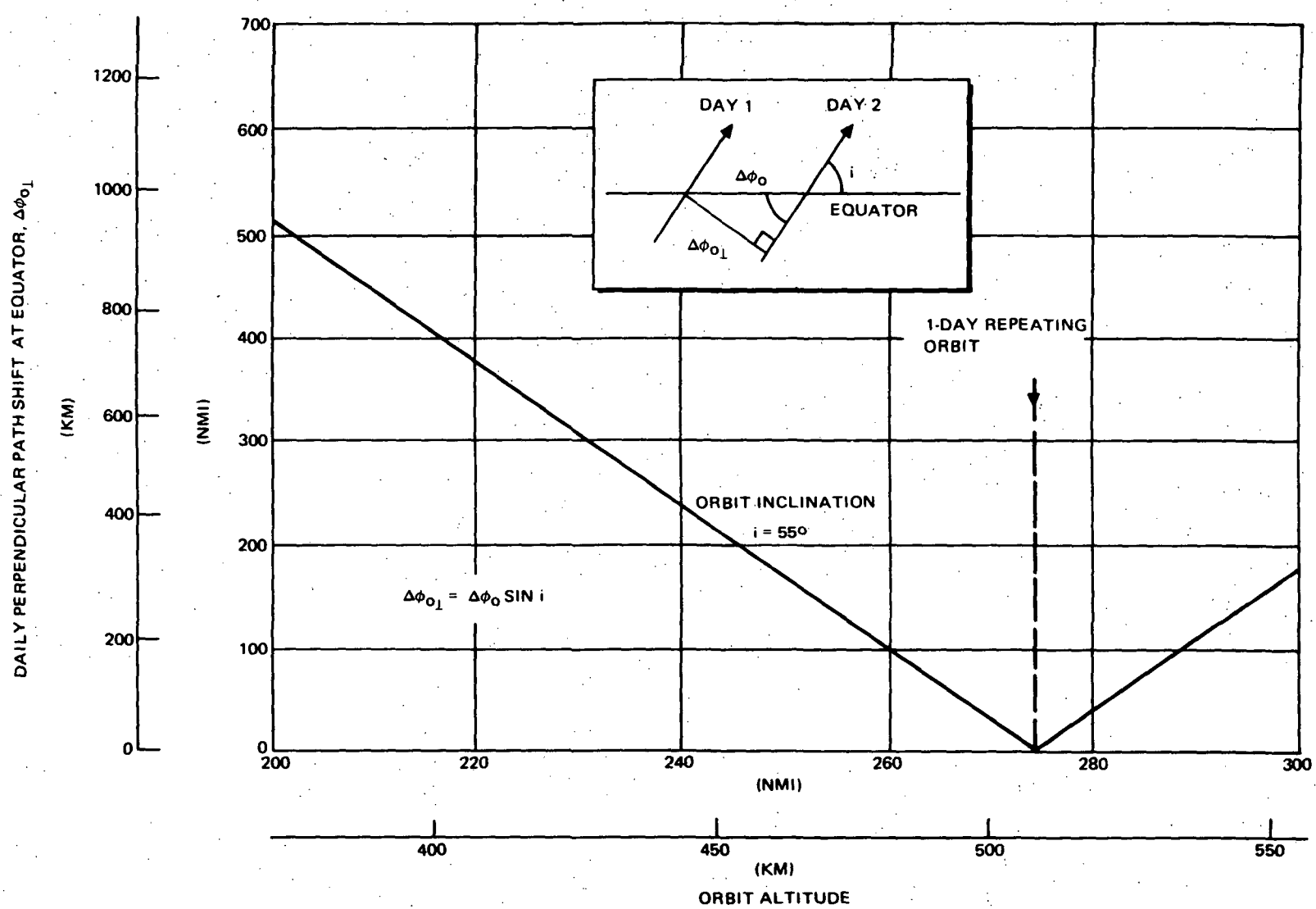


Figure 3-9. Daily Ground Track Separation

This initial coverage time (M_o) is plotted against altitude in Figure 3-10 and emphasizes the sensitivity that was suggested by Figure 3-8. It should be noted that the M_o calculations are for distances measured along the equator and not perpendicular to the ground tracks. Perpendicular measurements such as $\Delta\Phi_o$ (Figure 3-9) are made to determine the actual sensor coverage cycle, which is the time required to complete the initial mapping of total earth coverage (within visible latitudes) down to a specified level. Using Figures 3-9 and 3-10 together, yields both the initial spacing and the time required to obtain initial earth coverage at the daily shift rate.

The trace pattern development profiles portrayed in Figure 3-8 were developed using the fractional remainder of the satellite trace repetition parameter (Q_{FR}) as indicated in the following expression:

$$\Delta\Phi_o = Q_{FR}\ \Delta\lambda_o$$

where, for example, at 445 km (240 nmi) altitude (Q = 15.206):

$$\Delta\Phi_o = (Q_{FR} \sim 0.206)\ (\Delta\lambda_o \sim 2,580 \text{ km},\ (1420 \text{ nmi}))$$
$$\approx 531 \text{ km } (292 \text{ nmi})$$

The trace pattern development characteristics are shown in Table 3-2 for illustration.

Table 3-2

TRACE PATTERN DEVELOPMENT CHARACTERISTICS
(55-deg inclination)

Altitude km (nmi)	Q (Approx Values)	$\Delta\lambda_o$ km (nmi)	$\Delta\Phi_o$ km (nmi)	$\Delta\Phi_{o_\perp}$ km (nmi)	Mo (Nodal Days)
372 (200)	15.45	2590 1398	1160 (628)	954 (514)	2.22
408 (220)	15.33	2610 1409	854 (460)	700 (377)	3.06
445 (240)	15.206	2630 1420	542 (292)	443 (239)	4.86
456 (246)	15.169	2640 1424	453 (244)	371 (200)	5.89
473 (260)	15.086	2654 1432	228 (123)	187 (101)	11.61
502 (270)	15.025	2662 1437	67 (36)	56 (30)	39.92

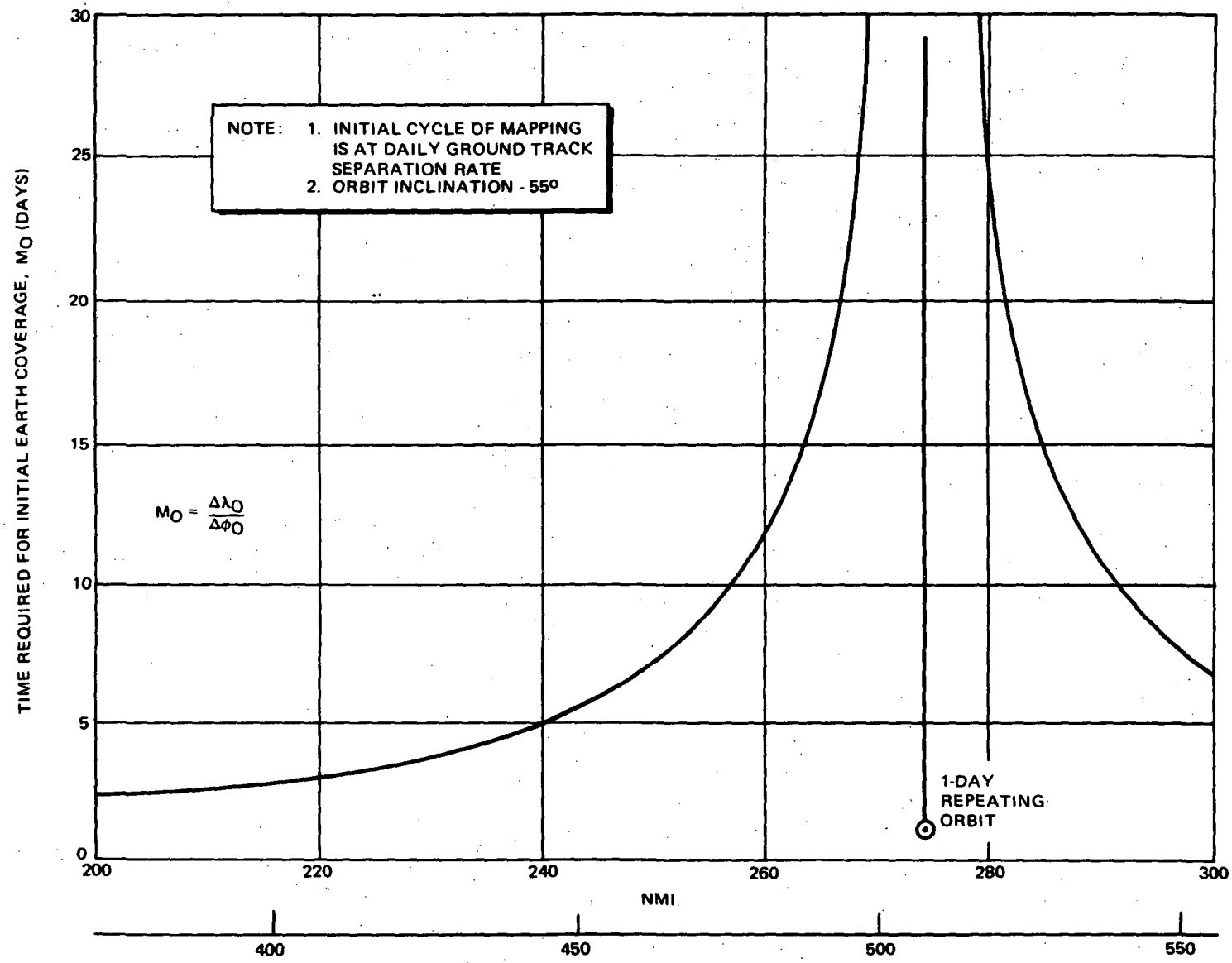


Figure 3-10. Time to Complete Initial Cycle of Total Earth Mapping

3.2.1.3 Experiment Program Altitude Preferences

The baseline Space Station experiment program can of course be accommodated within the Space Station study orbit envelope of 444 km to 500 km (240 to 270 nmi) at a 55-deg inclination. Earth surveys, however, were determined to be the orbit selection driver since their requirements generally overlap the others and providing a satisfactory orbit for them would be acceptable to the rest. In addition, the altitude choice will also affect Earth surveys the most, due to the nature of the ground coverage rate differences with altitude.

The NASA Blue Book defines seven major areas of scientific experimentation; Astronomy, Physics, Earth Observations, Communications/Navigation, Materials Sciences and Manufacturing, Technology, and Life Sciences.

An altitude preference summary of all these disciplines is presented in Figure 3-11. The altitude range which is shaded is the preferred operational range and the dashed lines indicate the acceptable limits. Some disciplines have no hard-and-fast limits listed, such as the last four listed (categories 15 through 18) which prefers an altitude of 185 km (100 nmi), which is usually defined as greater than 185 km (100 nmi). The bar charts for these four as well as for No. 7 and No. 8 are shown with ragged edges to indicate that their limits have not yet been defined.

The orbit and sensor requirements identified by the Blue Book prefer orbit altitudes ranging from 185 km (100 nmi) or lower up to 930 km (500 nmi) but there is no singular altitude or best regime for all. The number of experiment areas satisfied over a 185 km (100 nmi) to 930 km (500 nmi) altitude range is shown to the right of Figure 3-11. The present 456 km (246 nmi) altitude baseline appears near the mean of the distribution with 6 categories satisfied out of a possible maximum of 8. Based on the total combination of preferred and acceptable regions, the dashed distribution, a maximum of 16 categories can be accommodated at an altitude band from 371 km (200 nmi) to 500 km (270 nmi).

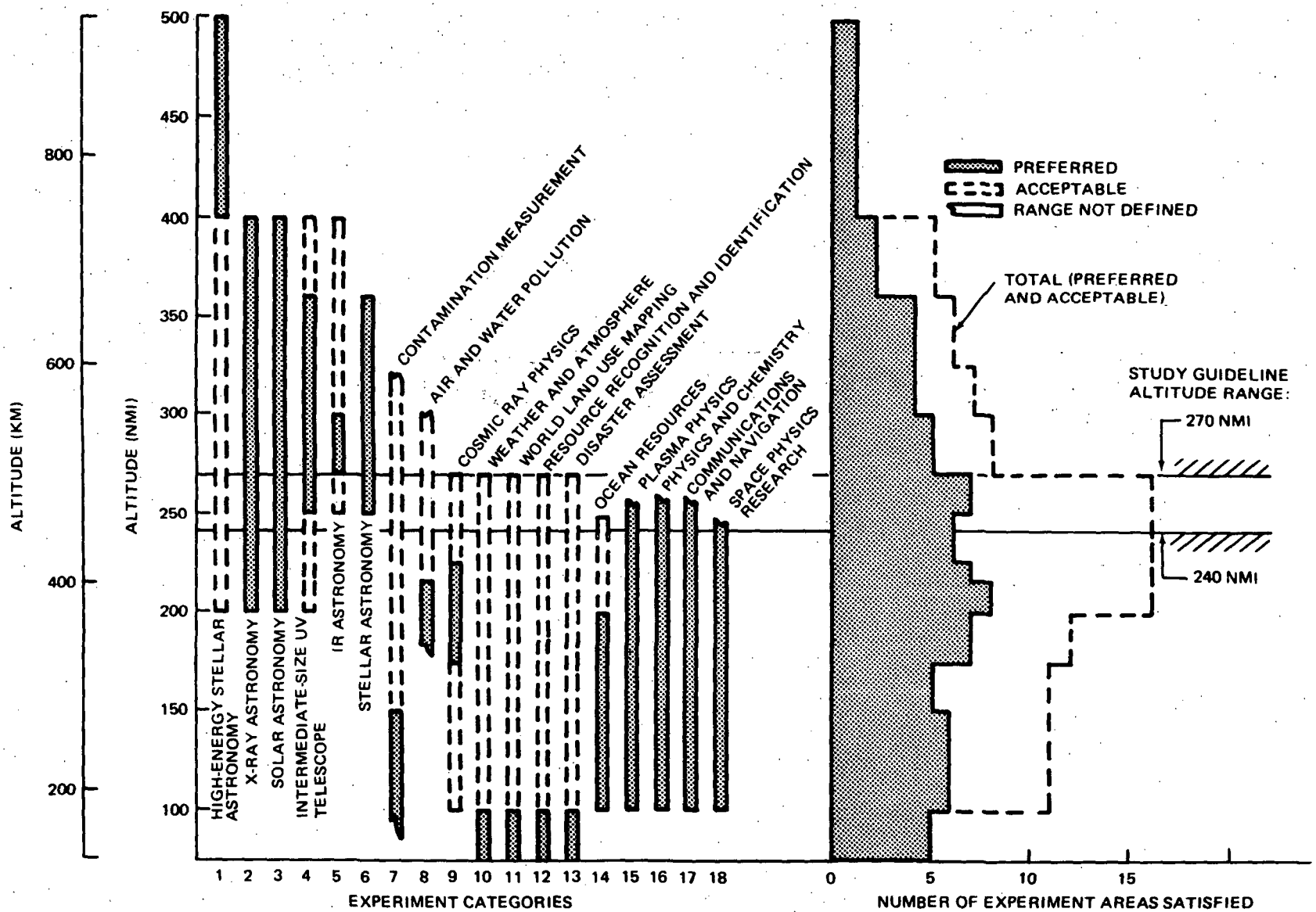


Figure 3-11. Blue Book Experiment Altitude Preference

The problem with some of these experiment category altitude preferences is that the range specified is based on resolution requirements which can be met at the higher altitudes if the cameras or sensors employed greater focal lengths.

There is an insufficient amount of data on ground resolution requirements. The camera/sensor definition does not include lens/film resolution capability (lines per millimeter) or the focal lengths to be employed. The focal length especially determines the altitude versus ground resolution and could assist in orbit selection. A large focal length system (e.g., up to 50 to 70) is a practical solution for bettering the Blue Book resolution requirements. This capability would allow any experiments requiring the higher resolution to be obtained in the 444 km (240 nmi) to 500 km (270 nmi) range.

The sensors proposed for the seven experimentation disciplines together with some of their viewing features are listed in Table 3-3. The typical ground swaths listed in Table 3-3, obtained from a 456 km (246 nmi) altitude, use the field-of-view listed per sensor. The sensitivity of ground swath with altitude and field of view used to obtain these data is plotted in Figure 3-12. The data on this log-log plot terminate when the ground view becomes tangent to the horizon (with fields of view over 100 deg).

3.2.1.4 Orbit Selection Rationale

The Space Station orbit altitude selection rationale is based primarily upon satisfying the experiment program requirements and then subsequently evaluating the operational or design effects that result at that altitude to insure that the station can effectively operate there.

The experiment program (Blue Book) evaluation indicated an average altitude preference for 370 to 500 km (200 to 270 nmi) with Earth Observations preferring 185 to 410 km (100 to 220 nmi) (due to resolution, etc.). There are 17 sensors (each sensor has a unique field-of-view and operational

Table 3-3

SENSORS FOR EARTH OBSERVATIONS

Sensors (Proposed Number)	Field of View (deg)			Scan Range (deg)	Ground Swath from 250-nmi Altitude (nmi)	Earth Observation Categories Requiring Sensor						
	Along Flight Path		Cross-Range			I	II	III	IV	V	VI	VII
Imagers												
1. Metric camera (2)	41	by	62	---	200 x 320	X	X	X	X	X	X	Advanced
1a. Stellar camera (4)		---		---								
2. Multispectral camera (5)	21	by	21	---	94 x 94		X	X	X	X		
3. Multispectral television		10		---	44			X		X	X	Advanced
4. Multispectral scanner		6.6		±6.6	28 (in 60 nmi scan width)		X	X	X	X	X	Advanced
5. Passive microwave scanner	(looks 40 deg ahead of nadir)			±20	90 (in 200 nmi scan width)	X	X	X	X	X	X	
6. Microwave radar	0.001	by	.5	Antenna will look 30 deg to 60 deg to side of ground track	0.004 x 22		X		X	X		
Radiometers												
7. Multispectral (profiler)		0.02		---	0.1	X	X	X	X	X		
8. Multifrequency microwave		1 4.5		---	4 19	X						
9. Scatterometer/radiometer	1.5 (pencil beam)			Along-track scan: 52 deg Cross-track: ±12.5 nominal Scans: ±52 maximum	6 (field of view) 116 (scan nominal) 640 (scan maximum)	X	X				X	
Spectrometer												
10. Multispectral	0.057 viewing center inside telescope with 0.4-deg field of view				0.26 (inside 1.7)	X	X		X			Advanced
11. Aeronomy		0.2		---	0.85	X						
Experimental												
12. Spectral polarimeter		120		---	800	X	X	X	X			Advanced
13. Sferics detector		120		±60	800	X				X		Advanced
14. Absorption spectrometer		1		---	4			X	X			
15. Optical radar (laser altimeter)	0.034			---	0.16							Advanced
Support Specifications												
16. Observation telescope	30 for target acquisition 0.4 for detailed examination			---	142 by 142 1.7 by 1.7	X	X	X	X	X		X
17. Data collector		100			600			X	X	X	X	

*Code: I Meteorology and atmospheric science
II Land use and topographical mapping
III Air and water pollution
IV Resource recognition
V Natural disaster assessment
VI Ocean resources
VII Special research

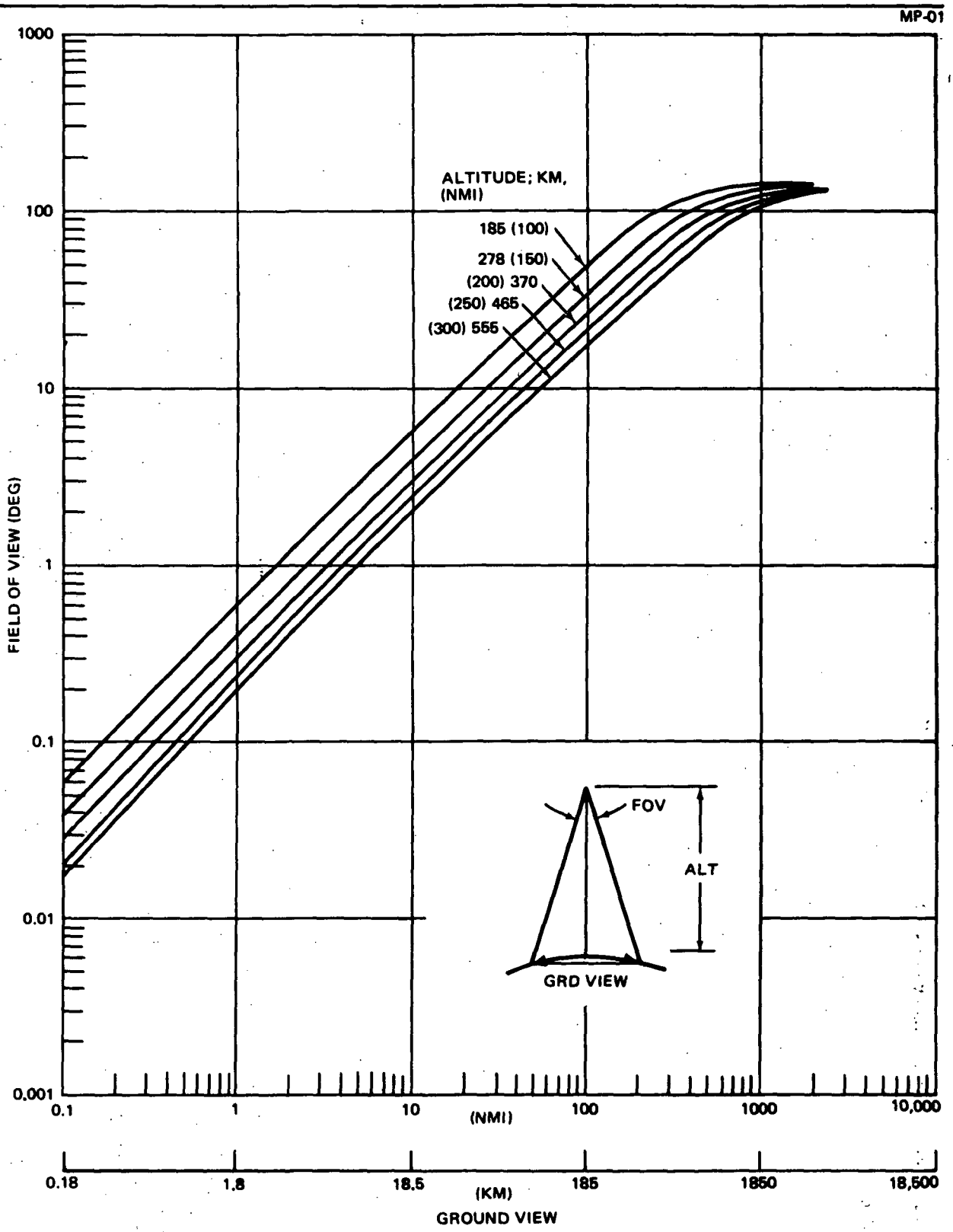


Figure 3-12. Ground Coverage Sensitivity of Field of View With Altitude

requirements or constraints) proposed for use in Earth Observations. Each observation category in turn, uses a different selected set of these sensors and requires certain sun lighting, cloud cover, resolution, etc., conditions.

Two sensors are used in each of the observation categories I through VI (Category VII is Special Research and not a survey use); namely, the Metric Camera and the Passive Microwave Scanner (see Table 3-4). The other sensors possess fields-of-view ranging from horizon-to-horizon down to pencil beams. The metric camera with its 62-deg cross range field-of-view and the passive microwave scanner with its 40-deg cross range field-of-view would experience the coverage performance with altitude as shown in Table 3-4.

The Blue Book suggested that the Metric Camera be operated with a 55 percent stereo overlap of succeeding frames along the ground track. A similar amount of stereo overlap can be provided in the cross track direction if the Space Station altitude is set at 456 km (246 nmi). The amount of time required for the orbital ground track to return or to start another coverage subcycle is indicated in Table 3-4 and indicates that the slow rate at

Table 3-4
SENSOR EARTH COVERAGE PERFORMANCE

Sensor	Altitude (nmi)	Altitude (km)	Ground Swath Width (nmi)	Ground Swath Width (km)	Daily Perpendicular Ground Track Shift (nmi)	Daily Perpendicular Ground Track Shift (km)	First Orbital Coverage (days)	Stereo Cross-Track Overlap Coverage (%)
	270	500	328	608	30	56	~40	82
Metric	246	456	310	565	200	370	~6	55
Camera	240	444	293	544	235	435	~5	40
Passive	270	500	220	407	30	56	~40	73
MW	246	456	200	370	200	370	~6	0
Scanner	240	444	190	352	235	435	~5	-19

a 270 nmi altitude would require approximately 40 days to return to the vicinity of a desired locale, whereas only six days (approximate) are required at 456 km (246 nmi) altitude. The Passive Microwave Scanner can scan approximately 370 km (200 nmi) in cross track from a 456 km (246 nmi) altitude and as indicated in Table 3-4 can obtain almost total viewing coverage on each 6-day orbit coverage subcycle.

A 456 km (246 nmi) Space Station altitude candidate was then established based on mapping rates and daily ground track separation distance (approximately 370 km or 200 nmi, measured at the equator where the greatest separation of ground tracks exist). Another consideration was the avoidance of cloud cover persistence. This consideration requires at least two days between satellite passes over a site to avoid cloud persistence. The additional requirements met at a 456 km (246 nmi) altitude were that the orbit possess a repetition cycle of coverage appropriate to seasonal variations with a nonrepeating orbit specified to allow mapping down to smaller areal coverages.

3.2.2 Space Station Baseline Orbit Behavior

The Earth coverage profile of the Space Station in the baseline orbit is illustrated in Figure 3-13. The ground trace behavior pattern for this orbit along the equator is presented in Figure 3-14. Included in this trace summary are the effects of the north as well as the south nodal crossings of the orbit. The orbit repeat parameter corresponds to a repeat every 5.89 or 58.924, etc., days. Accordingly, the orbit appears to repeat at nearly 59 days. Inherent in this orbit behavior is the operation of a resistojet propulsion system which continuously cancels drag. If the orbit were allowed to decay, the trace pattern development would only be slightly affected over the first 59 days, however, and the coverage behavior would be approximately the same.

3.2.2.1 Orbit Keeping

The orbital decay rate of the Space Station and the velocity requirements to reboost the station back to its initial altitude are presented in this section. The total amount of velocity and the frequency of altitude reboosts depends

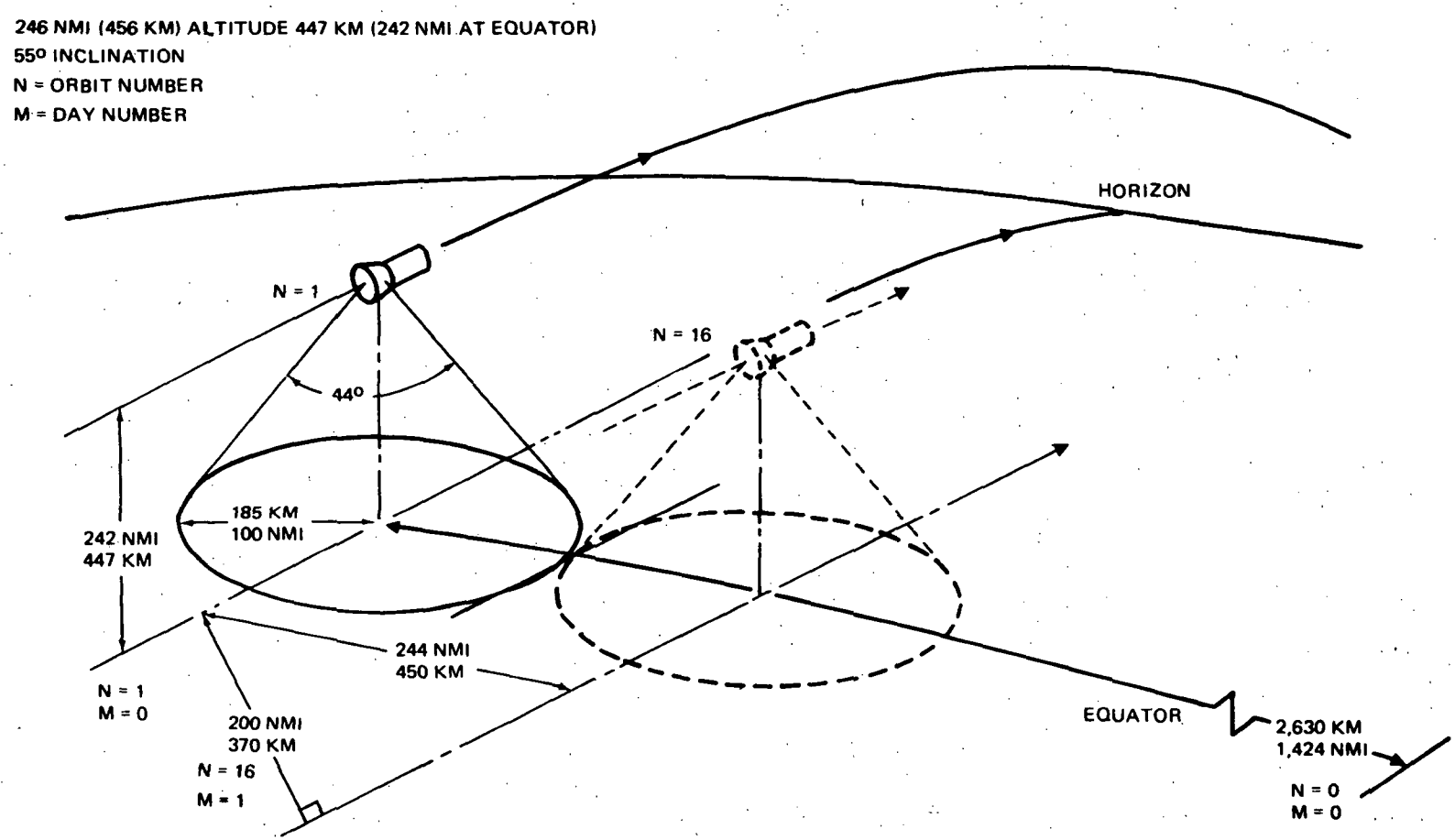


Figure 3-13. Earth Coverage Profile

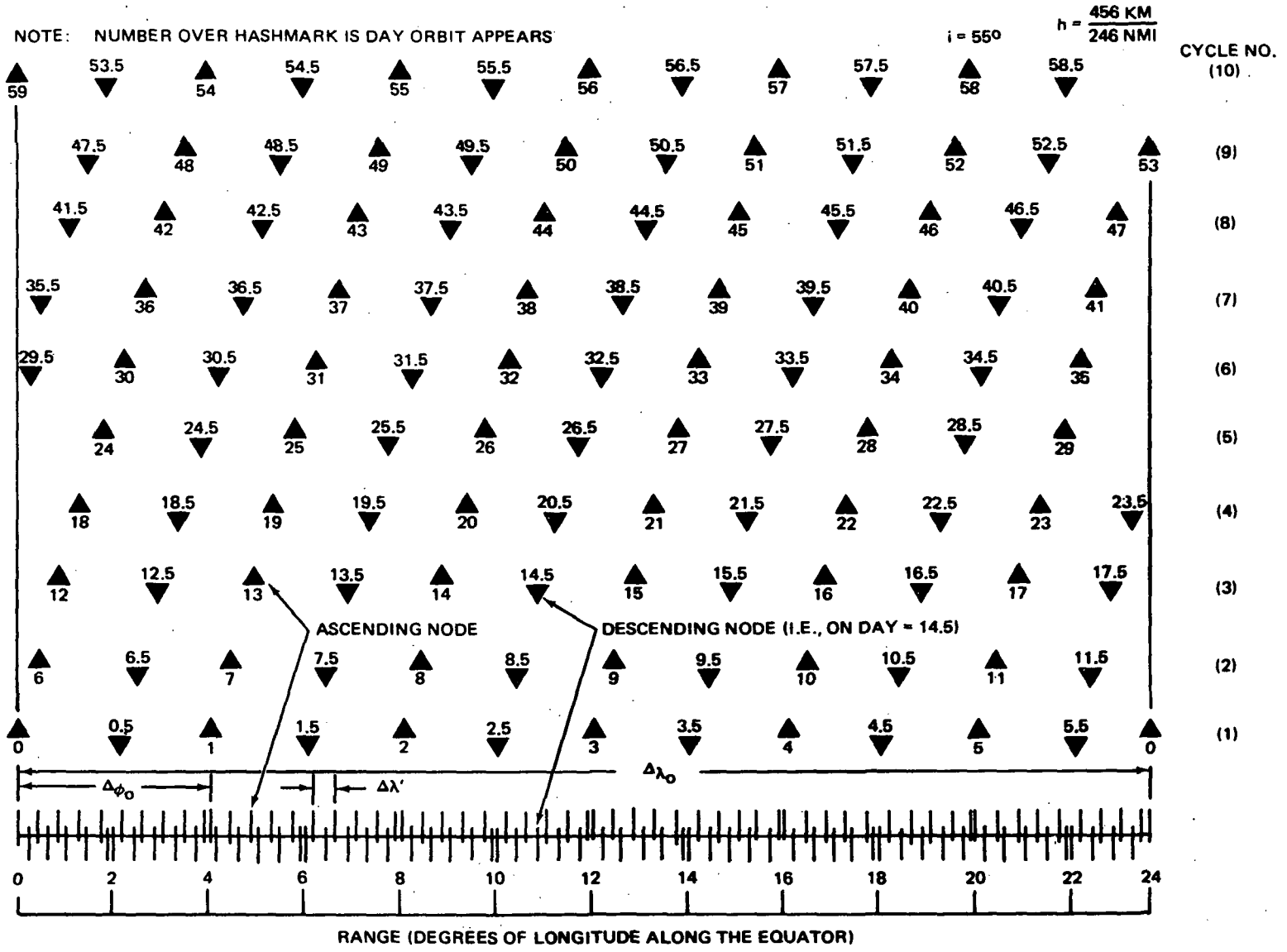


Figure 3-14. Space Station Orbit Trace Pattern Development

upon the initial altitude, the allowable altitude drop increments, the atmosphere environment (year and variation), and the station's ballistic coefficient. The orbit keeping performance of a resistojet system is also presented in this section.

The environment used was obtained from NASA Memorandum TM X-53865, Natural Environment Criteria for the NASA Space Station Program (Second Edition), dated August 20, 1970. The data employed is the $+2\sigma$, 10.7 cm solar flux level as shown in Figure 3-15. The nominal flux level is shown for comparison.

The atmospheric density is presented in Figure 3-16 for the $+2\sigma$ environment at the basic orbit of 55 deg inclination and 456 km (246 nmi) altitude. The $+2\sigma$ average density for the 11 year cycle was determined to be approximately 25×10^{-16} gm/cm^3.

Orbital Drag, Decay, and Propulsion Characteristics

The Modular Space Station has a ballistic coefficient (W/C_DA) value ranging from 79 kg/m^2 (16.2 psf) in the GSS configuration to 140 km/m^2 (28.6 psf) in the ISS configuration. The coefficients are evaluated as shown in Table 3-5 for both configurations.

Table 3-5

BALLISTIC COEFFICIENTS FOR MODULAR SPACE STATION

No. of Modules	Drag Area (C_DA~ft^2) ft^2	m^2	Total Drag Area Including Solar Panel Effects (C_DA ft^2)	m^2	Weight lb	kg	Ballistic Coefficient W/C_DA psf	M/C_DA kg/m^2
ISS Configuration								
5	3,500	325	4,550	423	130,000	59,000	28.6	140
7	6,100	566	7,930	737	165,000	75,000	20.8	101
GSS Configuration								
10	8,150	758	11,410	1,060	240,000	109,000	21.0	103
14	15,000	1,400	21,000	1,950	340,000	154,000	16.2	79

Figure 3-17 presents circular orbit decay rate as a function of solar flux index and altitude. The data were generated for an inclination of 55 degrees and a ballistic coefficient of 25 lb/ft^2 (122 kg/m^2). These data may also be extended to other cases subject to the following approximations:

A. Orbit inclination has little effect on decay rate,
B. Decay rate varies approximately exponentially with altitude, and
C. At least within the range of 98 to 144 kg/m^2 (20 to 30 lb/ft^2), decay rate is very nearly inversely proportional to ballistic coefficient.

As the orbital decay rate changes with changing altitude, the data in Figure 3-17 are of value primarily for determining the impulse requirements of an orbital altitude maintenance system which holds its satellite at a nearly constant altitude.

The atmospheric density between 185 km and 555 km (100 nmi to 300 nmi) is shown in Figure 3-18 for several cases of the third quarter 1979 Modular Space Station launch date environments.

The third quarter 1980 $+2\sigma$ atmospheric density for the 9 am local time condition was computed and shown in Figure 3-18. This curve at 9 am local time represents the average of the variations in atmospheric density encountered at different local times throughout an orbit for this $+2\sigma$ case. This density curve was employed in the orbit keeping and drag force calculations which follow.

The drag force at altitude for the NASA modified Jacchia model $+2\sigma$ atmospheric density at 9 am local time is presented in Figure 3-19 for various drag area (C_DA) values over the range from 185 km (100 nmi) to 555 km (300 nmi). The drag force for a C_DA of 325 m^2 (3,500 ft^2) drops by a factor of two as the altitude changes from 456 km (246 nmi) to 500 km (270 nmi), as shown in Figure 3-18 from 0.029N to 0.015N (0.0066 lb_f to 0.0034 lb_f), respectively. For a C_DA of 930 m^2 (10,000 ft^2) the same approximate

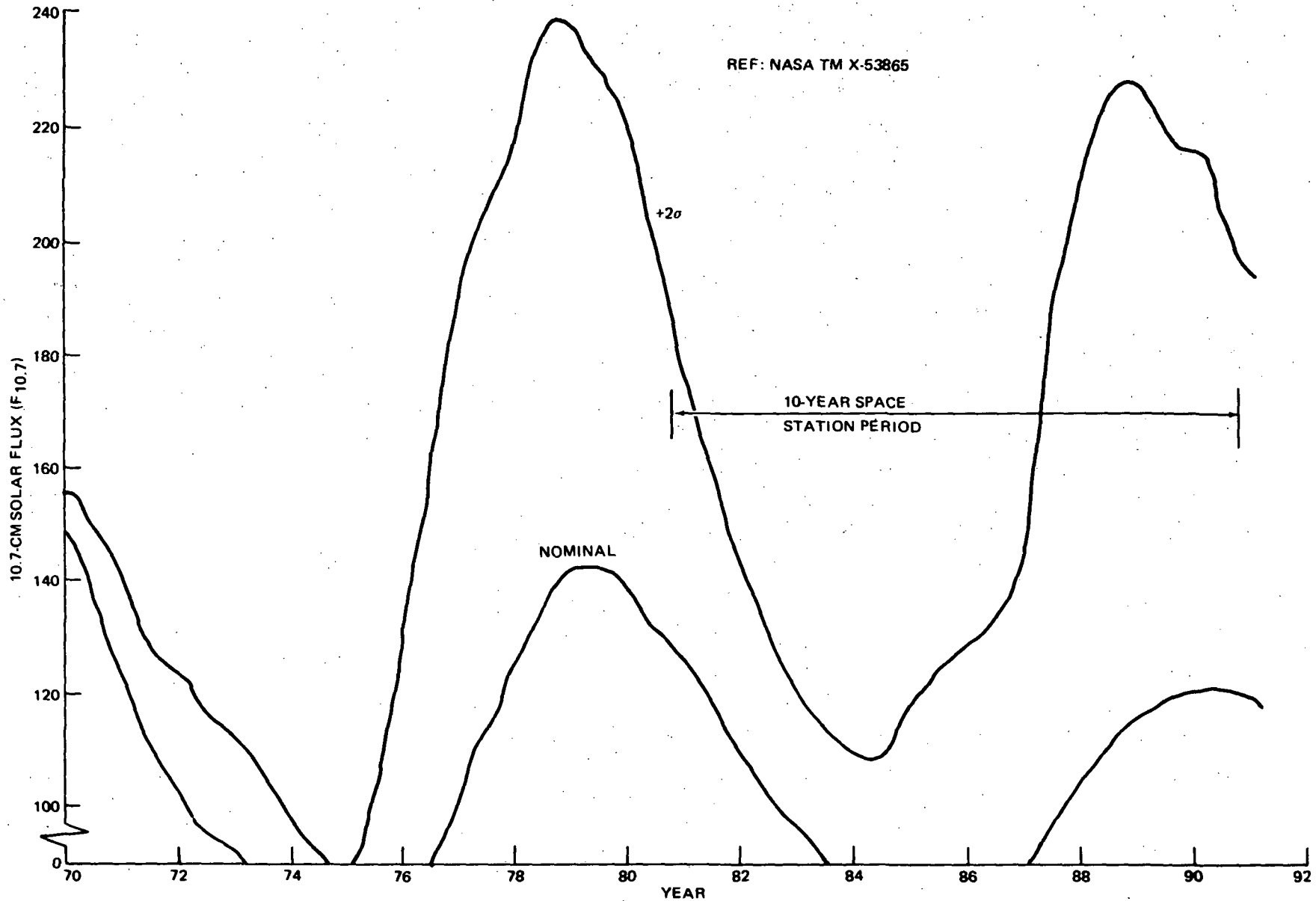


Figure 3-15. Solar Flux Prediction

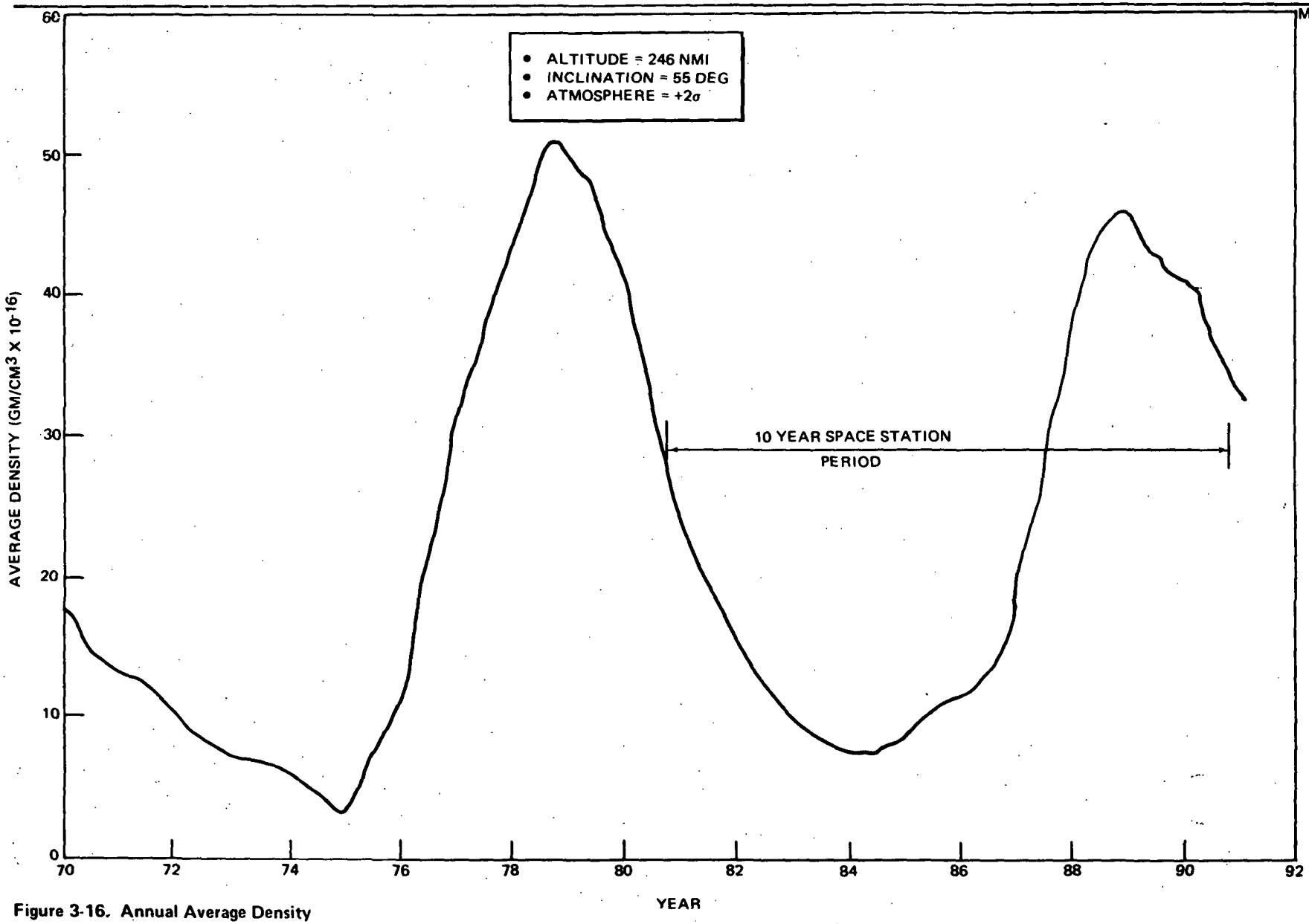


Figure 3-16. Annual Average Density

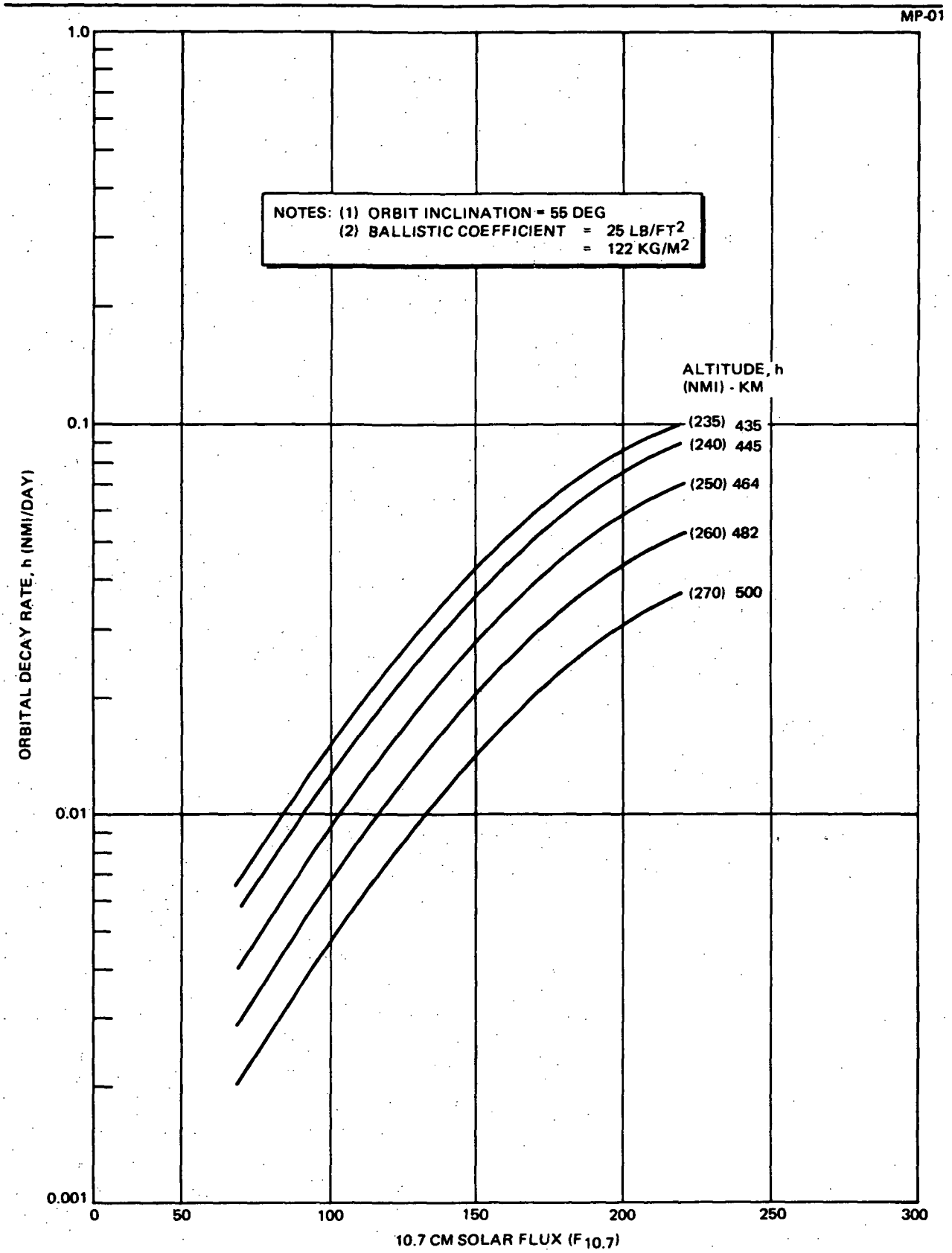


Figure 3-17. Orbital Decay Rate

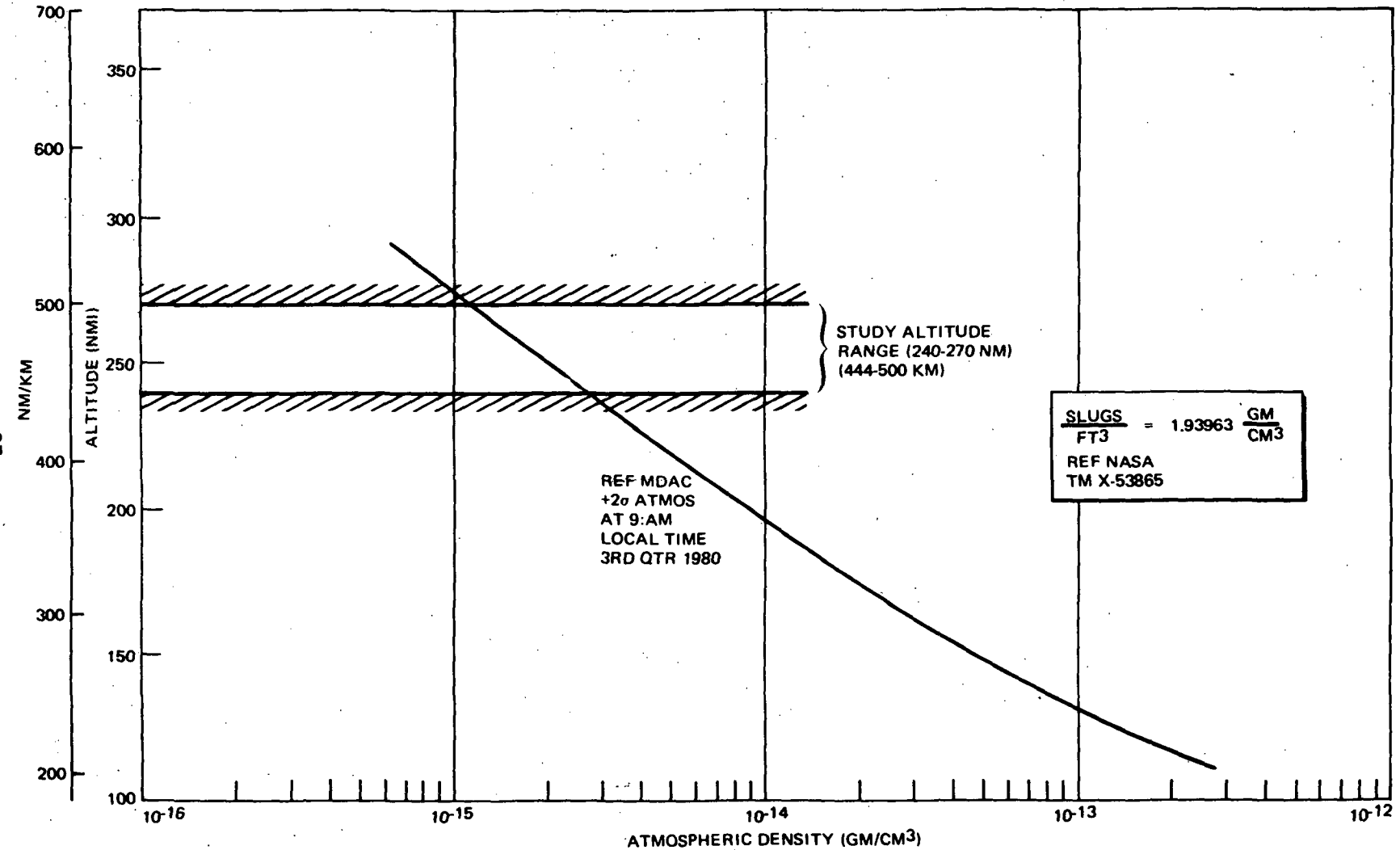


Figure 3-18. Design Atmospheric Density with Altitude

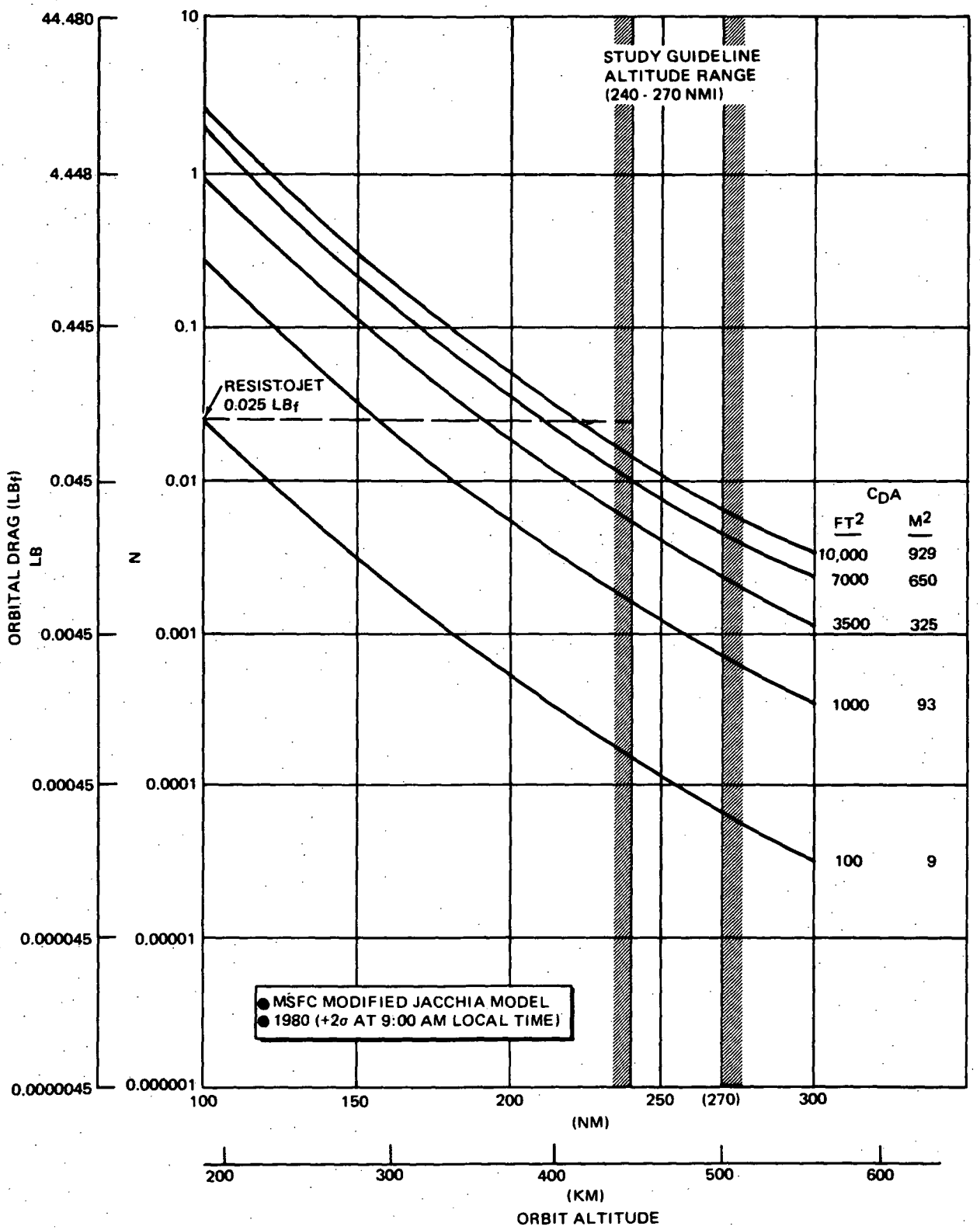


Figure 3-19. Drag Force at Altitude

change from 456 to 500 km (246 to 270 nmi) occurs from 0.08 to 0.044N (0.018 to 0.0098 lb_f). A typical Resistojet thrust level of 0.11N (25 millipounds) per thruster is indicated in Figure 3-19 for comparison.

For example, with a given configuration at altitude with a drag of 0.44N (0.01 lb_f) and an engine I_{sp} (Specific Impulse) of 300 sec, the propellant requirement for a 300 sec flight duration (5 min) would be 0.0046 kg (0.01 lb) of fuel. Per day, this requirement would be 1.3 kg (2.88 lb). During the peak atmosphere period, the difference in orbit keeping propellant per month between 456 km (246 nmi) and 500 km (270 nmi) is about 9.1 to 18.1 kg (20 to 40 lb) of fuel, dependent on total area. For the 30-day interval after launch, the orbit keeping propellant requirements (assuming I_{sp} = 300 sec) would range with total drag areas as indicated in Table 3-6. With other specific impulse, the propellant requirements can be adjusted by factoring (I_{sp} = 300 sec/I_{sp} = new value).

Table 3-6

THIRTY-DAY PROPELLANT REQUIREMENTS

Altitude (nmi)	Altitude (km)	Total Drag Area (C_DA ft^2) (ft)	Total Drag Area (C_DA ft^2) (m^2)	W_{prop} (30 days or orbit keeping lb) (I_{sp} = 300 sec) (lb_m)	W_{prop} (30 days or orbit keeping lb) (I_{sp} = 300 sec) (kg)
246	456	3,500	325	40	18
		7,000	650	77	35
		10,000	930	111	50
270	500	3,500	325	20	9
		7,000	650	41	19
		10,000	930	58	26

+2 σ Atmospheric Density 3rd Quarter 1980 (9 am local time)

Altitude Reboost Requirements

The altitude reboost total velocity requirements over a 10-year mission from the third quarter of 1980 to 1990 are shown in Figure 3-20 for a $+2\sigma$ reference atmosphere environment. Total 10-year mission velocity requirements are presented at various altitudes over the 444 to 500 km (240 to 270 nmi) range as a function of the altitude reboost increment. As indicated, at smaller reboost altitude increments the velocity requirement is less (due to the vehicle spending less time at lower altitudes at denser atmospheres). The minimum velocity requirement at any altitude is obtained if orbit keeping is nearly continuous.

The frequency of reboost can be critical if the thrust employed results in g-levels above minimum experiment thresholds. Table 3-7 presents the altitude reboost frequency for the study altitude range during the $+2\sigma$ maximum 1979 atmosphere.

Table 3-7

FREQUENCY OF ALTITUDE REBOOST OPERATIONS

Altitude (nmi)	Reboost Altitude (km)	(nmi)	Frequency of Reboost (once per)
Environment: $+2\sigma$ Atmosphere of 3rd quarter 1980			
240	1.8	1	~1 week
	9.3	5	~5 weeks
	18.5	10	~10 weeks
	37.0	20	~4 months
270	1.8	1	~2 weeks
	9.3	5	~2 months
	18.5	10	~4 months
	37.0	20	~6 months

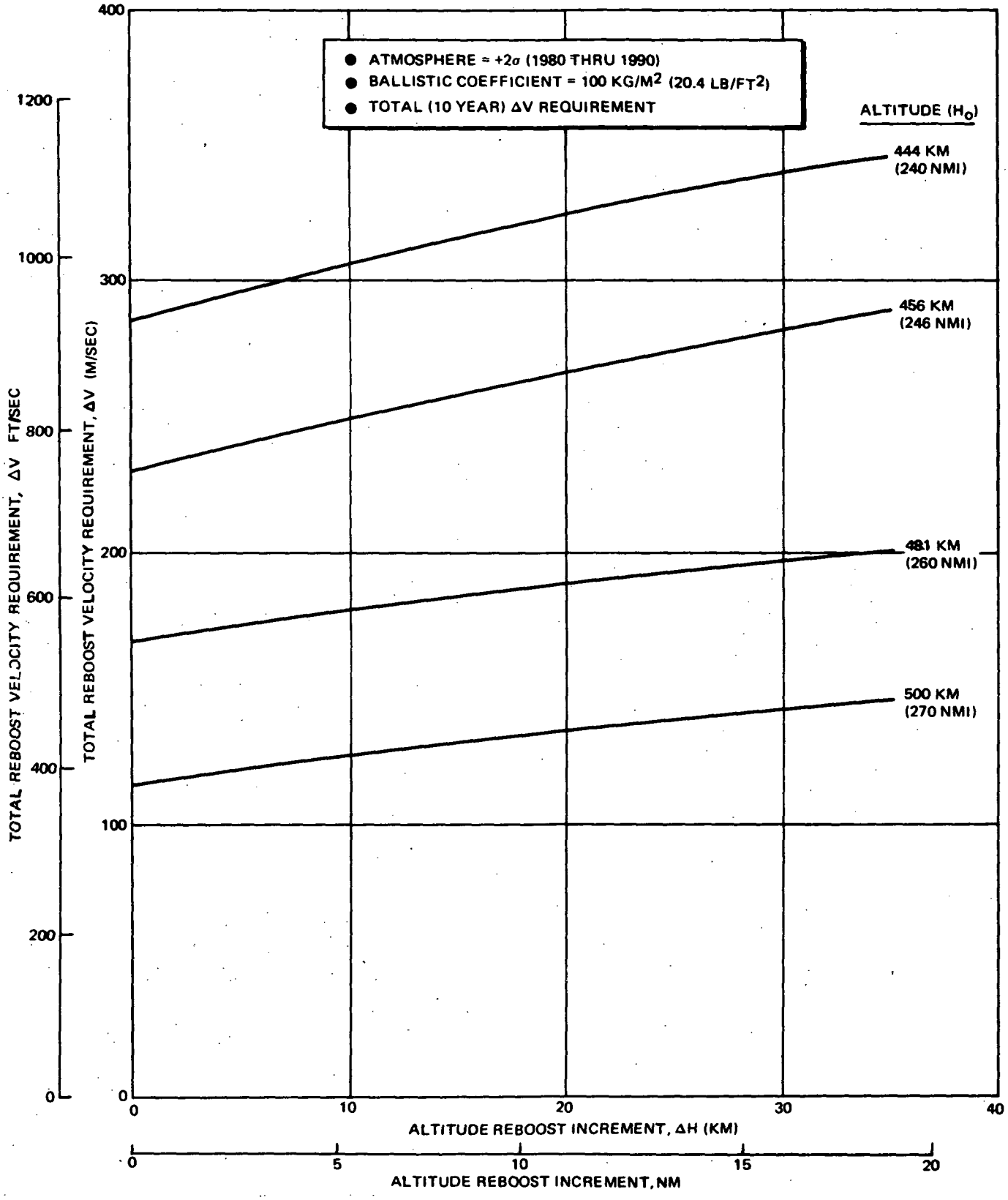


Figure 3-20. Altitude Reboost Velocity Requirements

Orbit Keeping Effect on Net Payload

The reduction of usable Shuttle payload in orbit due to the logistic demands for orbit-keeping propellant is a vital consideration in terms of space station altitude selection and cost of operation. There are several considerations in terms of payload definition. Three payload references at a 55-deg orbit inclination were shown in Figure 3-6 as indicated below:

1. The maximum 100 percent payload capability to orbit (i.e. 11,340 kg (25,000 lb) reference to 500 km (270 nmi)
2. An 80 percent payload capability, 20 percent margin (i.e., 9,072 kg or (20,000 lb) reference to 500 km (270 nmi)).
3. A fixed guideline limit of 9,072 kg (20,000 lb)

The 9,072 kg (20,000 lb) "design to" weight constraint sets a fixed flight hardware weight limit to the Space Station modular elements. This constraint is not expected to preclude the addition of on-board consumables or experiment items which would cause the loaded module to exceed 9,072 kg (20,000 lb) on actual flights; however, if additional payload carrying capability exists on a shuttle flight to a lower altitude as long as a comfortable margin, say 20 percent, exists.

The orbit-keeping effect on net payload as a function of altitude is presented in Figure 3-21 where both the 100 percent and the 80 percent Shuttle payload capabilities are indicated. The total payload capabilities to orbit (with no orbit-keeping propellants removed) are essentially straight lines. The payload loss with altitude can be seen to be approximately -23 kg/km (-94 lb/nmi). The effect of removing the orbit-keeping propellants is shown and indicates the drastic payload reduction at low altitudes. The orbit keeping propellants required were calculated for the $+2\sigma$ 1980 atmosphere using a monopropellant (hydrazine of I_{sp} = 230 sec) to avoid contamination. The two extremes of the Space Station drag areas (C_DA) are presented (ISS minimum and GSS maximum) and these define the expected drag area boundaries to be encountered.

The net payload (total shuttle capability less 30 days' of orbit-keeping propellant) as indicated in Figure 3-21 is per launch assuming the present

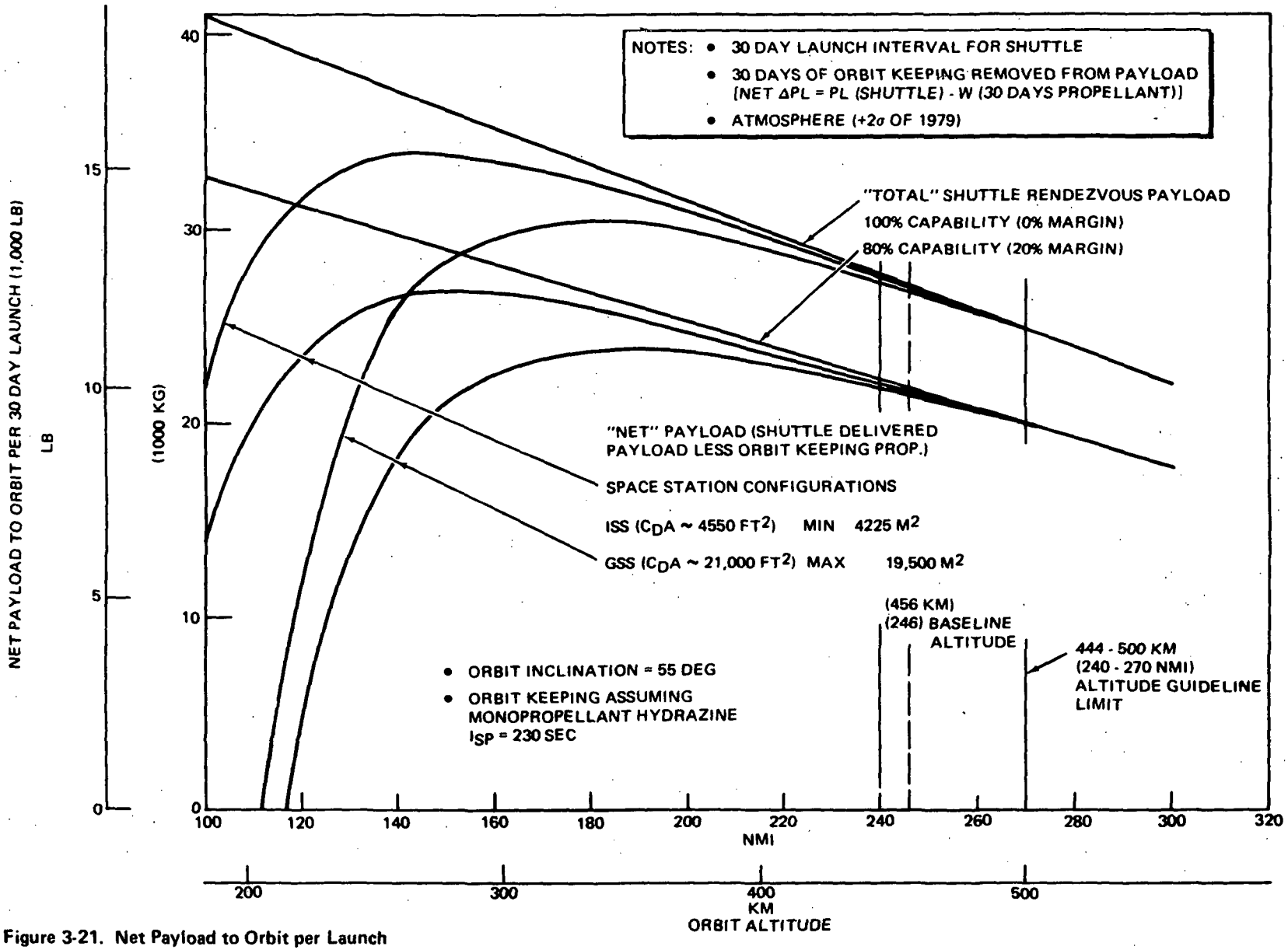


Figure 3-21. Net Payload to Orbit per Launch

monthly shuttle logistics launch interval. This means that on each flight (one per month), the net payload advantage of operating at 456 km (246 nmi) is 910 kg (+2,000 lb) greater than at 500 km (270 nmi) altitude for the 100 percent capability; the advantage is 680 kg (+1,500 lb) per flight for the 80 percent case. In 10 years, the cumulative total is 110,000 kg (+240,000 lb) (100 percent) or 82,000 kg (+180,000 lb) (80 percent capability, or 20 percent margin.

Payload optimum altitudes for the Space Station are indicated in Table 3-8.

Orbit-Keeping with Resistojet System

The resistojet system will be employed to cancel the orbital drag on a nearly continuous basis. With an approximate thrust level of 0.11N (0.025 lb) per thruster, the resistojet will introduce a g-level of 2×10^{-7} g per thruster to the ISS at its lowest weight of 59,000 kg (130,000 lb). The amounts of biowaste collected for the various candidate crew levels are indicated in Table 3-9. For the CO_2 and CH_4 products, a specific impulse (I_{sp}) of 190 sec can be assumed. Using this value of I_{sp}, the weight of orbit-keeping propellant required per year at any altitude assuming the atmospheric density remained constant at each altitude during this peak density year is shown in Figure 3-22. The other variable, total drag area (C_DA) shows the

Table 3-8

OPTIMUM PAYLOAD ALTITUDE FOR SPACE STATION OPERATION

Payload Reference Percent Capability (percent margin)	Configuration and C_DA			Optimum Payload Altitude	
		(ft^2)	(m^2)	(nmi)	(km)
100 (0)	ISS	4,550	4,240	145	269
	GSS	21,000	19,500	180	334
80 (20)	ISS	4,550	4,240	155	288
	GSS	21,000	19,500	190	352

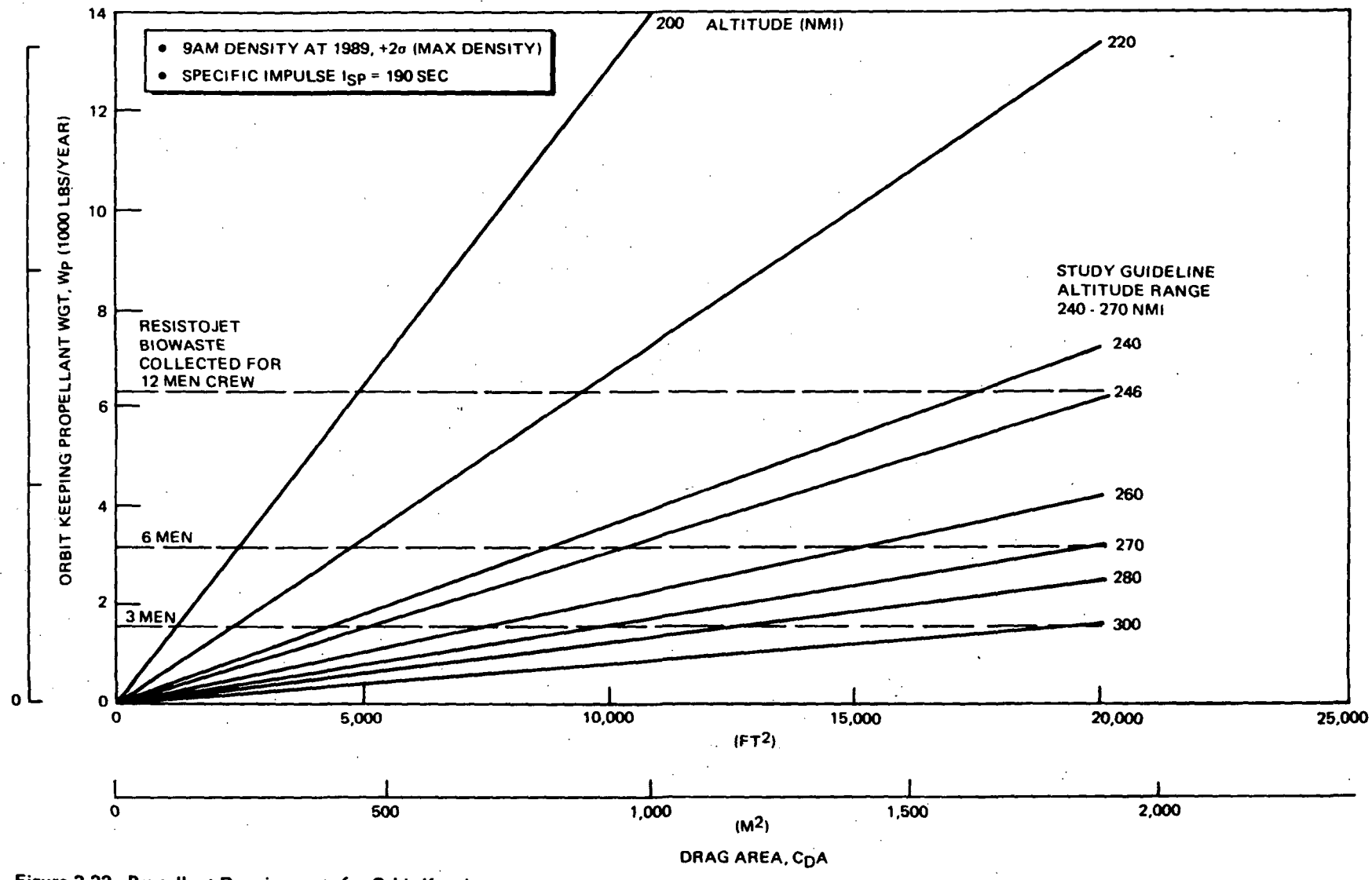


Figure 3-22. Propellant Requirements for Orbit Keeping

effect on annual propellant requirements over a range up to 18,600 m^2 (20,000 ft^2). The resistojet biowaste system capability for three, six, and 12-men crews is shown in Table 3-9 and in Figure 3-22 for comparison and indicates that the maximum drag areas that can be accommodated in a 456 km (246 nmi) orbit at the maximum density year (1989) in a +2 atmosphere. Considering the expected drag areas of the Space Station configurations for the six-man ISS and the 12-man GSS, the biowaste resistojet system is fully capable of cancelling drag throughout its expected range and throughout any succeeding mission year at the 456 km (246 nmi) baseline altitude.

3.2.2.2 Ground Coverage and Viewing Capability

The ground coverage profiles for the Earth Observations sensors are shown schematically in Figures 3-23 through 3-26. In Figure 3-23 the metric camera achieves approximately 55 percent overlap crosstrack coverage from a 456 km (246 nmi) altitude orbit on each succeeding day's adjacent ground track pass. A 55 percent overlap along the track is required in the Blue Book. At higher altitudes, the ground swath width increases, the adjacent ground tracks on succeeding days occur closer together, and the number of days required to return to a target locale increase. The baseline orbit of 456 km (246 nmi) altitude and 55-deg inclination therefore yields a sufficient overlap in near minimum time.

Table 3-9

SPACE STATION BIOWASTE AMOUNTS FOR RESISTOJET ORBIT-KEEPING OPERATION

Biowaste: * CO_2 at 0.95 lb/man-day
CH_4 at 0.49
Total 1.44 lb/man-day (I_{sp} - 190 sec)

Crew Size	Biowaste (lb/day)	Biowaste (lb/year)	Resistojet Impulse (lb-sec/year)
3	4.32	1,577	299,592
6	8.64	3,154	599,184
12	17.28	6,037	1,198,368

*If CH_4 is not generated in the Modular Space Station, the amount of CO_2 for orbit-keeping increased to 2.3 lb/man-day.

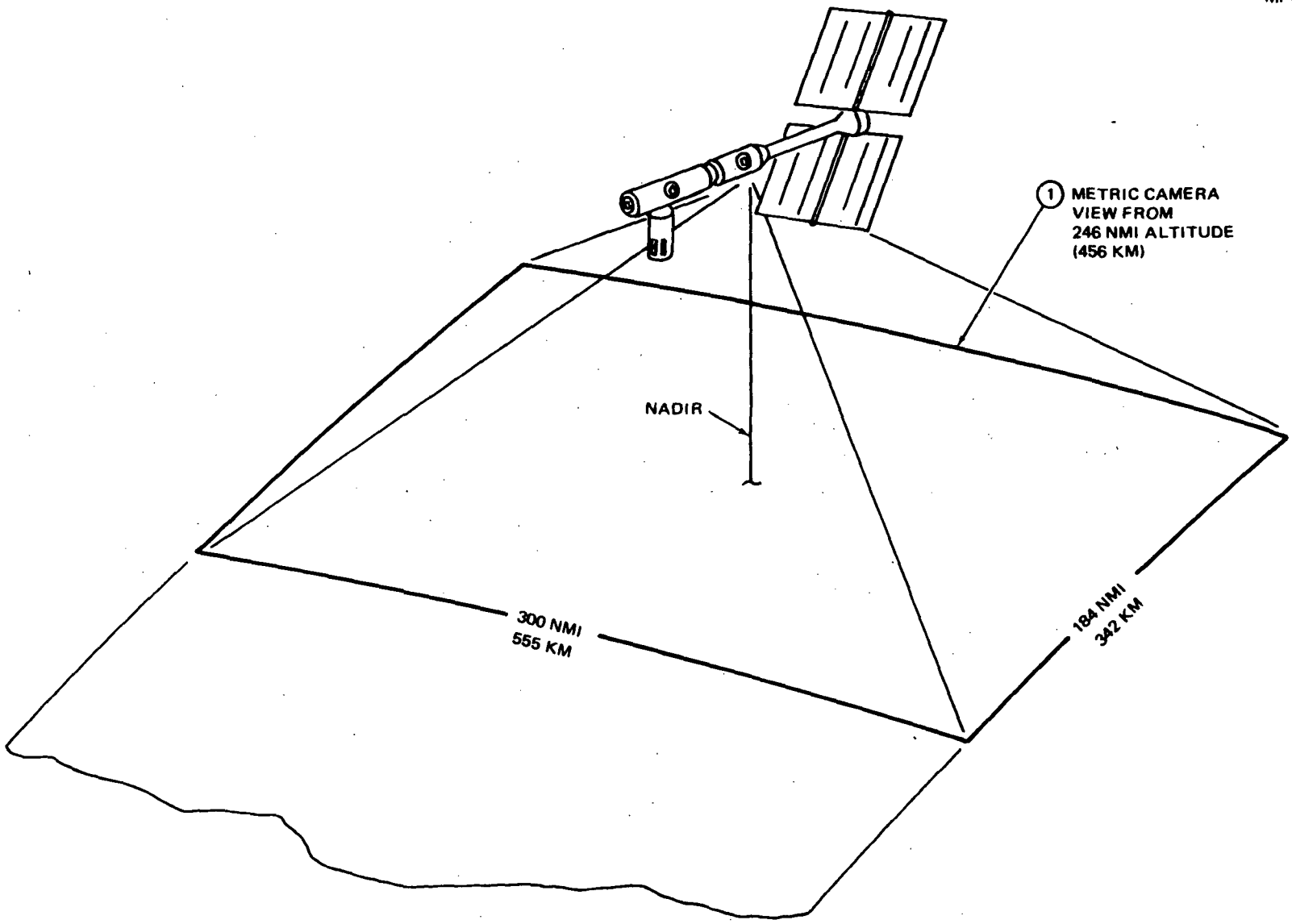


Figure 3-23. Metric Camera Field of View

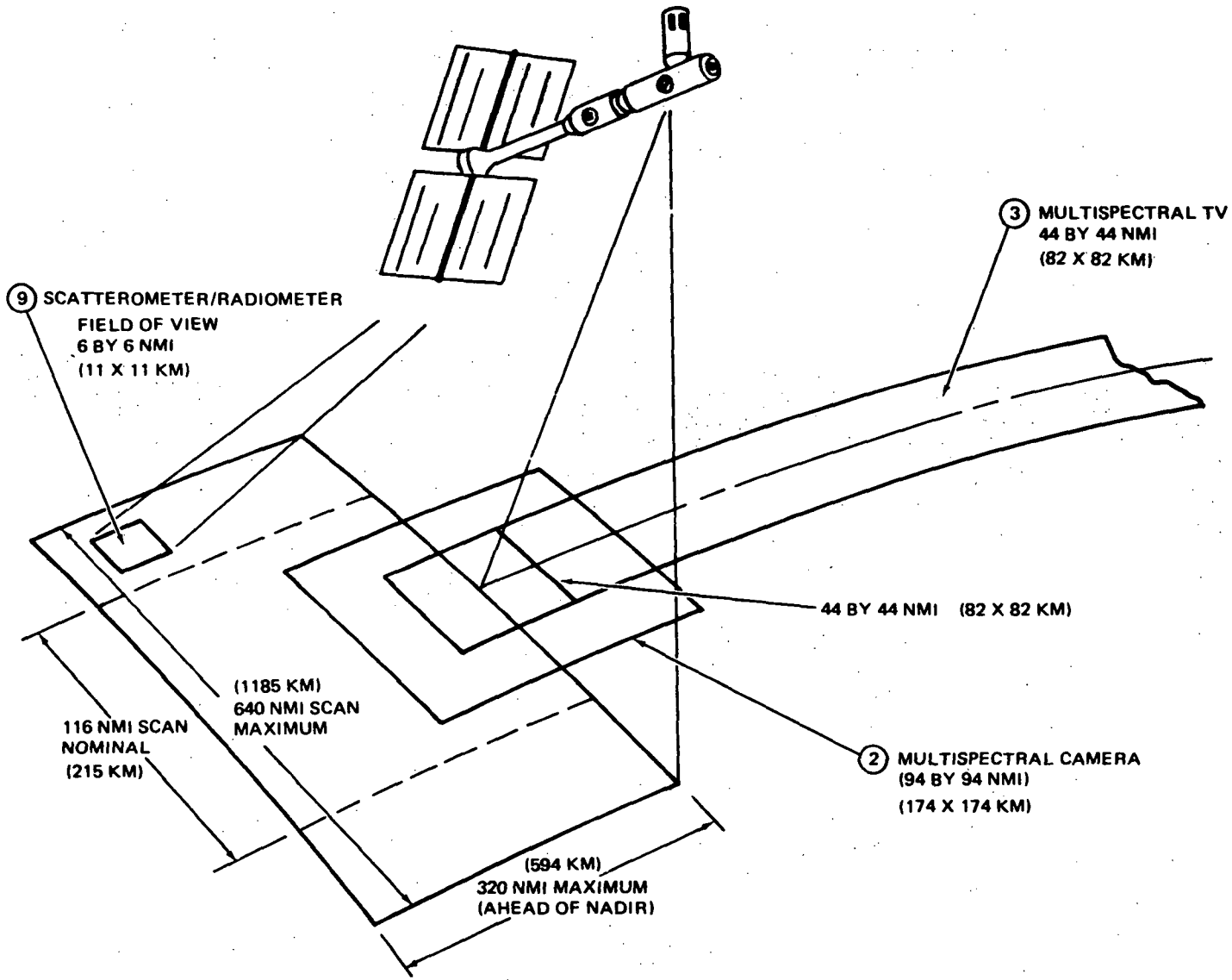


Figure 3-24. Sensor Ground - Coverage Profiles (A)

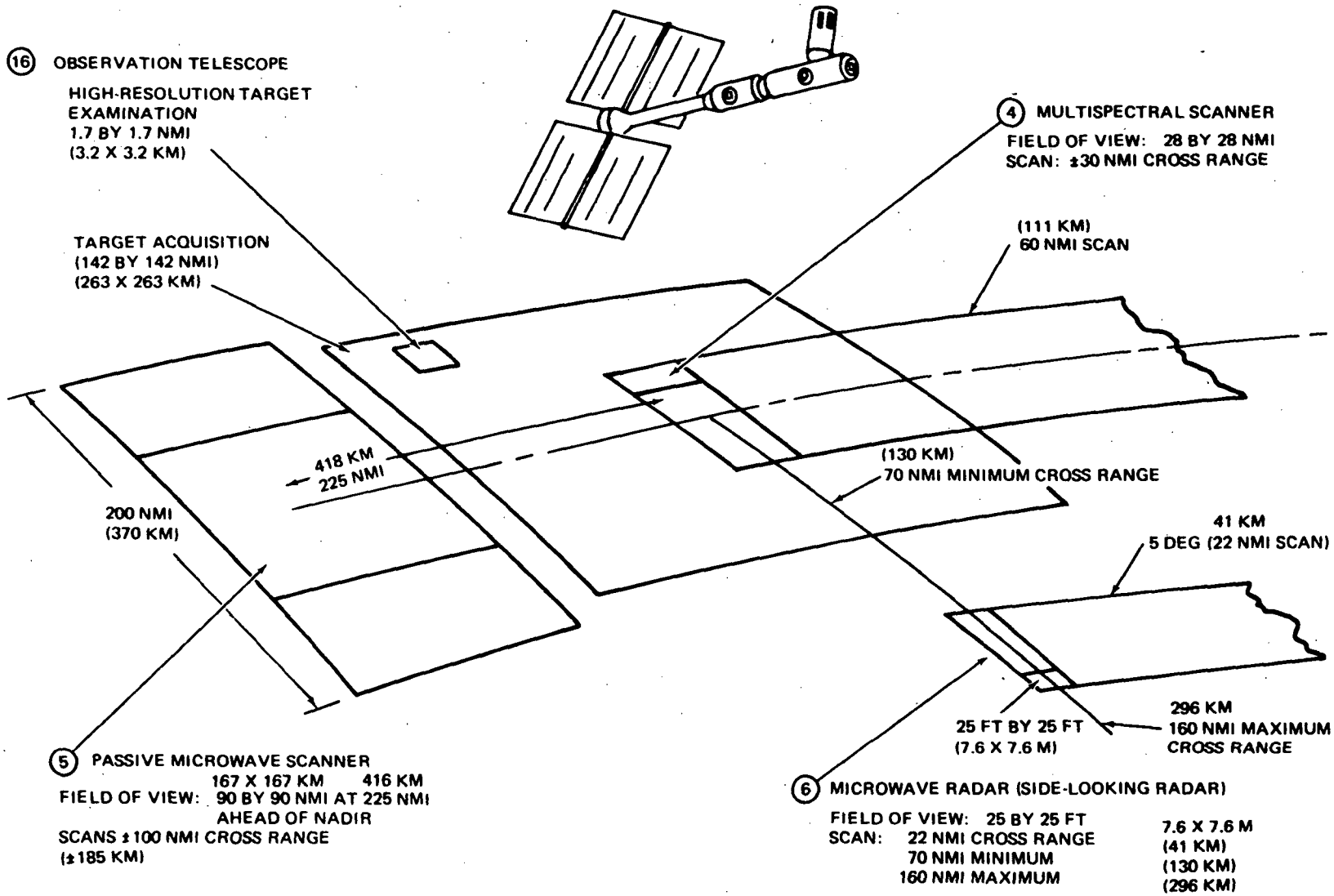


Figure 3-25. Sensor Ground-Coverage Profiles

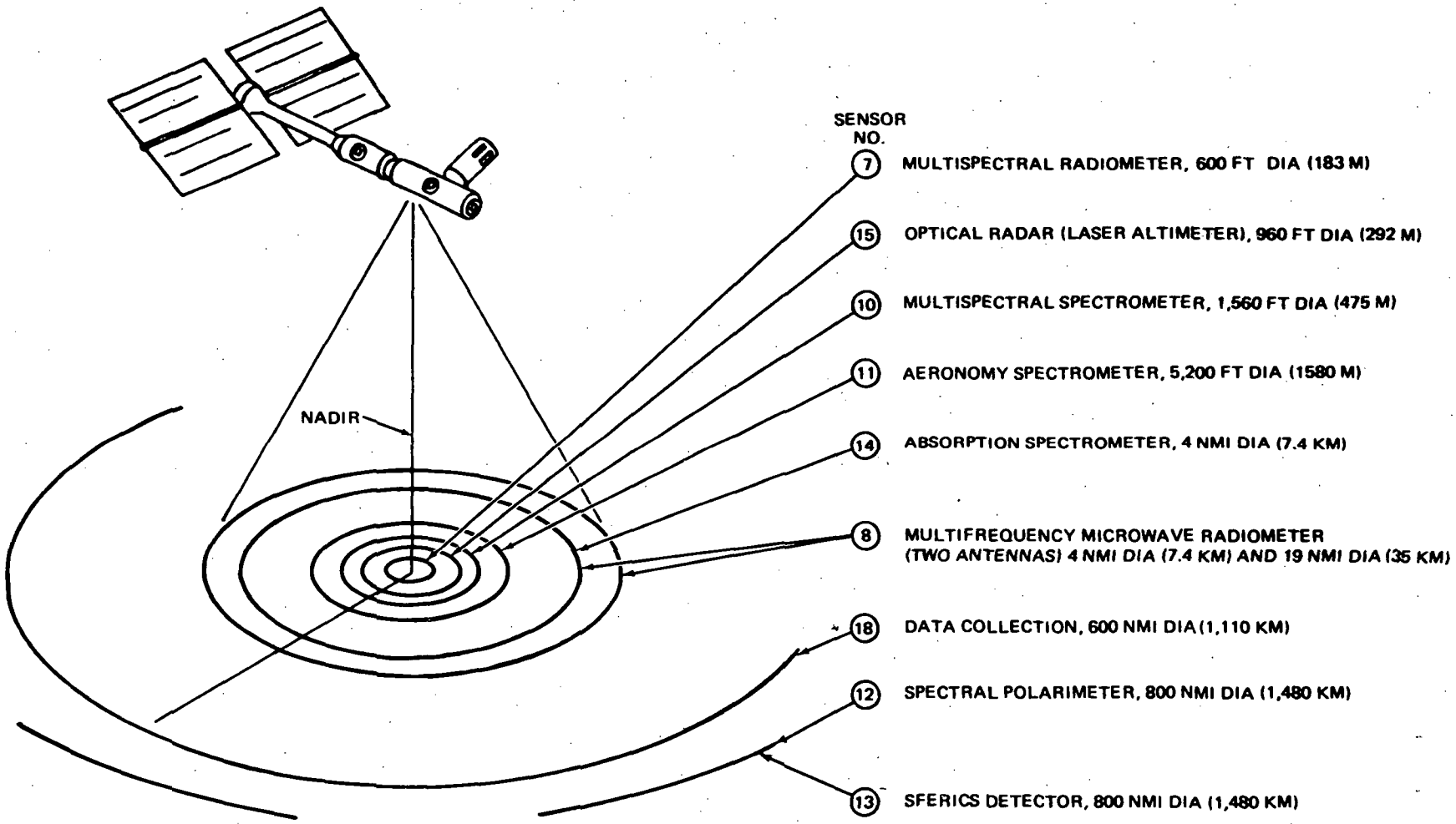


Figure 3-26. Fields of View for Various Sensors

3.3 DESIGN SUPPORT ANALYSES

Two subjects within the areas generally covered by design support analysis activities have been reevaluated for Modular Space Station impacts.

They are the design tradeoff criteria to be used in subsystem tradeoff analysis and the radiation impacts associated with the smaller station modules.

Updating the tradeoff criteria was performed to properly take into account the effect of interim station configurations, multiple launches and the singular use of the reusable shuttle. The radiation analysis which results in the definition of shielding requirements was re-evaluated to determine how the smaller modules would affect the rate of exposure and consequently the shielding needs.

3.3.1 Design Tradeoff Criteria

The system design effort for the Modular Space Station includes multiple design options to satisfy any given functional requirement. These options evolved from both operational alternatives and the list of candidate hardware that could be considered for incorporation into the system. The selection of a preferred or best design from these options is seldom straightforward or limited to single considerations. Rather, the selection process involves a series of tradeoffs and compromises to arrive at the best choice between different performance levels, sizes, shapes, maintenance needs, etc. Further, the very nature of most missions usually provides a direct lead to the problem of placing priorities on the various system parameters and constraints. The design priorities of the subsystems and the constraints and system parameters that are most important or most critical are derived and evaluated in the following subsections. The result is a relative cost equation that can directly assist in subsystem selections.

3.3.1.1 Methodology

Conceptually, the tradeoff criteria are based on cost as a common denominator and several gross-level design parameters that may be considered as experiment resources that are usually tradeable items when alternate design

approaches are available. Three categories of trade factors were identified to account for all the factors that could be involved in a subsystem tradeoff. They are mandatory, quantitative, and qualitative. Mandatory factors encompass those design parameters which must be satisfied and by definition are not tradeable. Quantitative factors consist of those parameters that can be related to each other numerically. Qualitative factors are those equipment attributes that evade quantification but definitely influence the selection process. Flexibility, growth potential, and interface complexity are some of the factors considered in this category.

The technique used in applying the three categories requires, first a determination that mandatory parameters are satisfied. Basic functional performance requirements, for example, must be met before any alternative design can compete in a tradeoff. A judgement is made then, with regard to the pros and cons of the parameters falling into the qualitative category. The parameters to be quantified are then evaluated by means of a relative cost equation and the best design thus indicated.

3.3.1.2 Tradeoff Equation

The basic equation which was developed in the 33-foot Space Station, Phase B study, is repeated below along with the weighting factors that have been updated for the Modular configuration.

$$\Delta C_T = \frac{C(V)}{V} (\Delta V) + \frac{C(W)}{W} (\Delta W)$$

$$+ \frac{C(T)}{T} (\Delta T) + \frac{C(P)}{P} (\Delta T)$$

Volume (V)—expressed in cubic feet
Crew Time (T)—expressed in man-hours
Launch Weight (W)—expressed in pounds.
Electrical power (P)— expressed in watts
C( )—Cost of the parameters, V, T, W, P

Table 3-10 summarizes the cost data and the baseline values for the four principle parameters.

Using these data the following weighting factors (C(X)/X are derived:

Volume $\frac{C(V)}{V}(\Delta V) = \$1,500/ft^3$ $\$52,800/m^3$

Crew Time $\frac{C(T)}{T}(\Delta T) = \$1,940/hr$

Launch Weight $\frac{C(W)}{W}(\Delta W) = \$250/lb$ (550/kg)

Electrical Power $\frac{C(P)}{P}(\Delta P) = \$7,650/w\text{-}10\ yr$

The specific equation for subsystem tradeoff becomes:

$$\Delta C = 250\ [6(\Delta V) + 8(\Delta T) + \Delta W + 30\ \Delta P] \quad \text{[English units]}$$

3.3.2 Radiation Analysis

A parametric study of space radiation dose rates within the NASA Space Station was performed using detailed analytical techniques. The objectives were to improve the accuracy of hand calculated dose predictions, and to determine which compartment provided the best protection against solar cosmic ray (SCR) dose. The calculations considered various combinations of the following parameters:

A. Five astronaut stations
B. Three critical organs: lens of eye, skin, blood forming organs (BFO), the last being treated with two different models.
C. Various cylindrical wall thicknesses for the Space Station

Table 3-10

TRADEOFF WEIGHTING FACTORS

Launch Weight

Launch cost/flight = $\$5 \times 10^6$
Payload - 20,000 lb

Volume

Structure/mechanical cost/module = $\$8.1 \times 10^6$
Structure/mechanical weight/module = $\$2.25 \times 10^6$
V(C) = $\$10.35 \times 10^6$

Volume/module = 6900 ft^3

Electrical Power

Launch weight cost	$\$5 \times 10^6$
Resupply weight cost	$\$15 \times 10^6$
Production cost	$\$155 \times 10^6$
Volume cost	$\$ 16 \times 10^6$
V(P)	$\$191 \times 10^6$
Total Power	25 kw - 10 yr

Crew Time

Crew support-equipment costs	$\$190 \times 10^6$
Volume and weight costs	27
Flight operations cost	70
C(T)	$\$287 \times 10^6$
Crew hours	147,600 hr

These analysis results were then extended to determine parametric film vault requirements.

3.3.2.1 Radiation Environment

The radiation environment data used in this study were updated from those used in previous investigations. The environment models are those specified by NASA in reference document TMX-53865, Aug. 20, 1970 edition, the

Vette 1968 electron model, the Thede proton model, and the NASA SCR model. The current NASA SCR free-space model is a factor of 2 lower than that specified in the earlier edition of the reference document; also the earlier recommendation that free space fluxes be reduced by a factor of 15 to correct for geomagnetic cutoff in the particular orbit has disappeared. In the present work both factors were applied, resulting in the SCR in-orbit flux being a factor of 30 below the free-space values originally recommended by NASA. One model flare was assumed for a 90-day stay time as specified in the environment reference.

The dose attenuation data for trapped electrons and protons are given in Figure 3-27, the SCR dose attentuation data in Figure 3-28.

The galactic cosmic ray (GCR) dose rate of 0.002 rad/day, used previously, was obtained by applying a geomagnetic attenuation factor of 0.09 to the maximum free-space dose rate of 8 rad/year. The GCR dose is unattenuated by the Space Station structure.

3.3.2.2 Configuration Model

The Space Station model used for this analysis is shown in Figure 3-29 to include a Crew Module with a Power Module fixed to one end and a Logistics Module residing at the other end half time. The Power Module was assumed to be a homogeneous cylinder weighing 23, 197 lb. The 20, 000-lb Logistics Module was similarly simulated, but was considered present only one third of the time. Although the Logistics Module averages half-time residency at the position shown in Figure 3-29, it occurs on a 30-day cycle, thus, conservatively, it would be absent the first and last 30 days of a 90-day crew stay. In the analysis to follow, the occurrence of a solar cosmic ray event was assumed with the Logistics Module absent. The shielding potential of the radially docked modules (varying from two to six) was ignored to simplify the calculations and to remain conservative.

The Crew Module was apportioned into five working segments as shown in Figure 3-29. The residency percentage of a typical crewman based in crew quarters one is also shown. Crew quarters one residency was used as

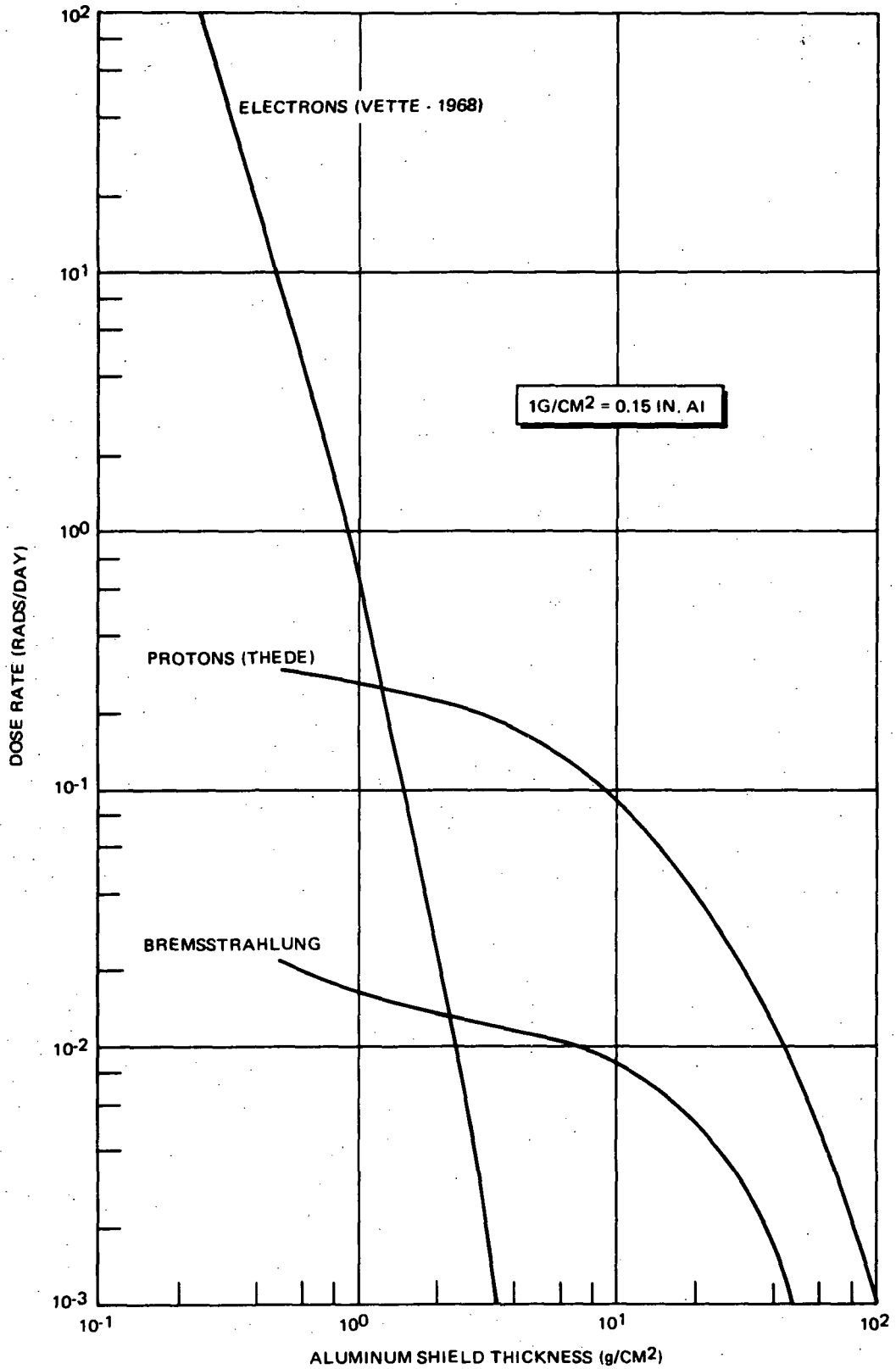


Figure 3-27. Radiation Dose Attenuation (246-NMI, 55-Degree Circular Orbit)

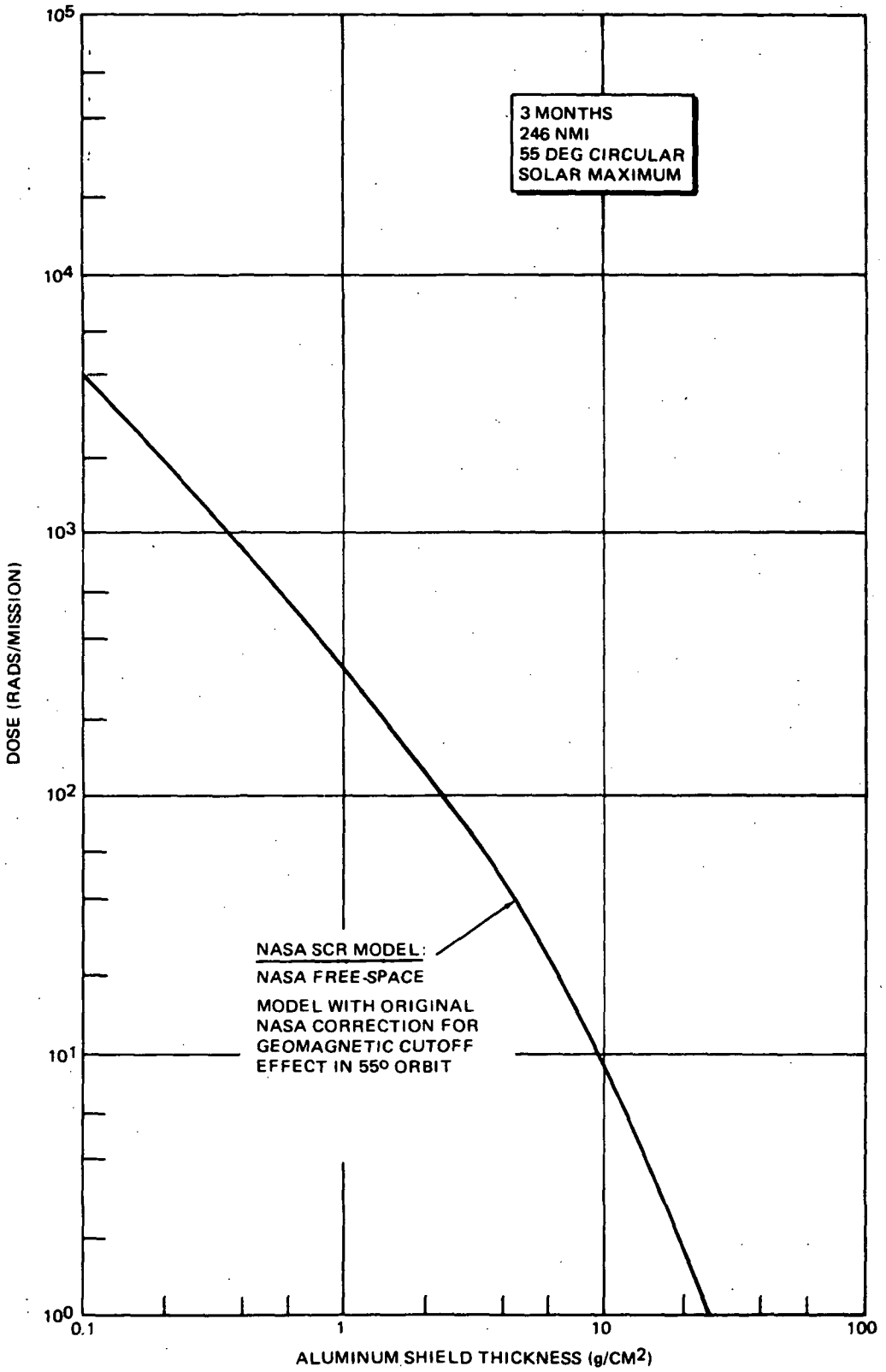


Figure 3-28. Solar Cosmic Ray Proton Dose Transmission

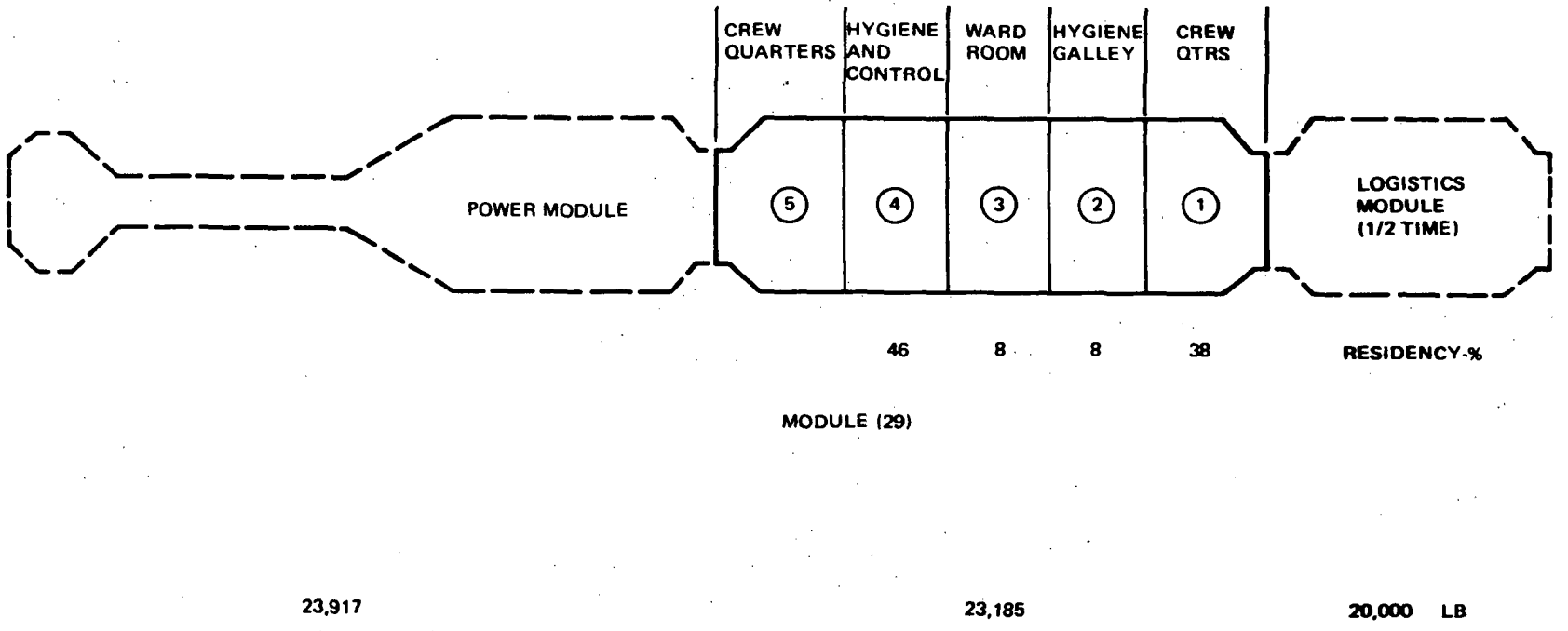


Figure 3-29. Space Station Configuration

typical since it is the least shielded end with the Logistics Module being absent 60 of the 90 days. The typical crewman spends 83 percent of his time within the Crew Module as shown and the remaining 17 percent in one of the radially docked modules. Examination revealed that the crew stations in the radially docked modules would be similar in terms of shield capability with the control station in the Crew Module. Therefore, this 17 percent residency time was added to the control station section time for a total of 46 percent residency in that section.

The mass distribution for the Crew Module is shown in Figure 3-30 in equivalent thickness of aluminum. The structure includes the paint, meteoroid bumpers, insulation and pressure wall. The miscellaneous structure includes the wiring, tubing, ducting, atmosphere, and other similar items. The equipment includes the remainder of the Crew Module contents. In addition to the sidewall thickness shown in Figure 3-30, end caps of 0.51 in. were included on the Crew Module for completeness.

The structure details are shown in Figure 3-31. As shown the basic structure sums up to a minimum thickness of 0.103 inch. The mass equivalent thickness, $\bar{t}$, of these items is 0.157 in. and the equivalent thickness, $\bar{t}$, of the miscellaneous structure items adds another 0.09 in. for a 0.247-in. total.

3.3.2.3 Man Model

The CARS man model (Reference 3-4) was used for the basic man model. The dose points were positioned in the model as follows: lens of the eye 3 mm deep in head, skin 1 mm deep in the trunk, and BFO 5 cm deep. A BFO distribution recently determined by MDAC was also used. It is an average distribution which accounts for the diverse spatial extent of the bone marrow in the body. Path distributions were constructed for many points in the marrow, and combined using the fraction of the total mass of marrow represented by each point. The doses calculated using this model are necessarily higher than those from the conventional 5 cm depth, since it shows a 22 percent probability of paths less than 5 cm.

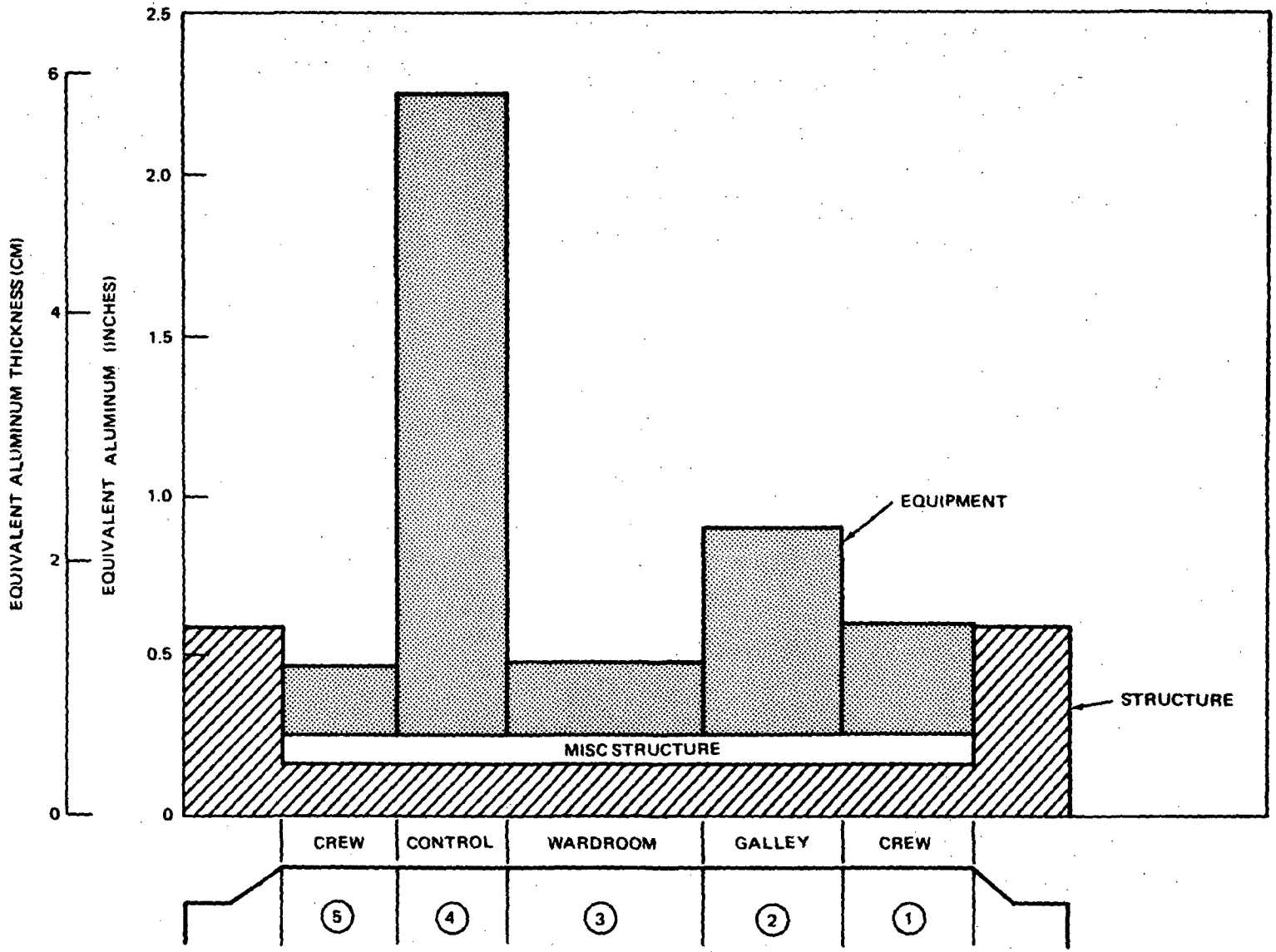


Figure 3-30. Configuration Shield Model

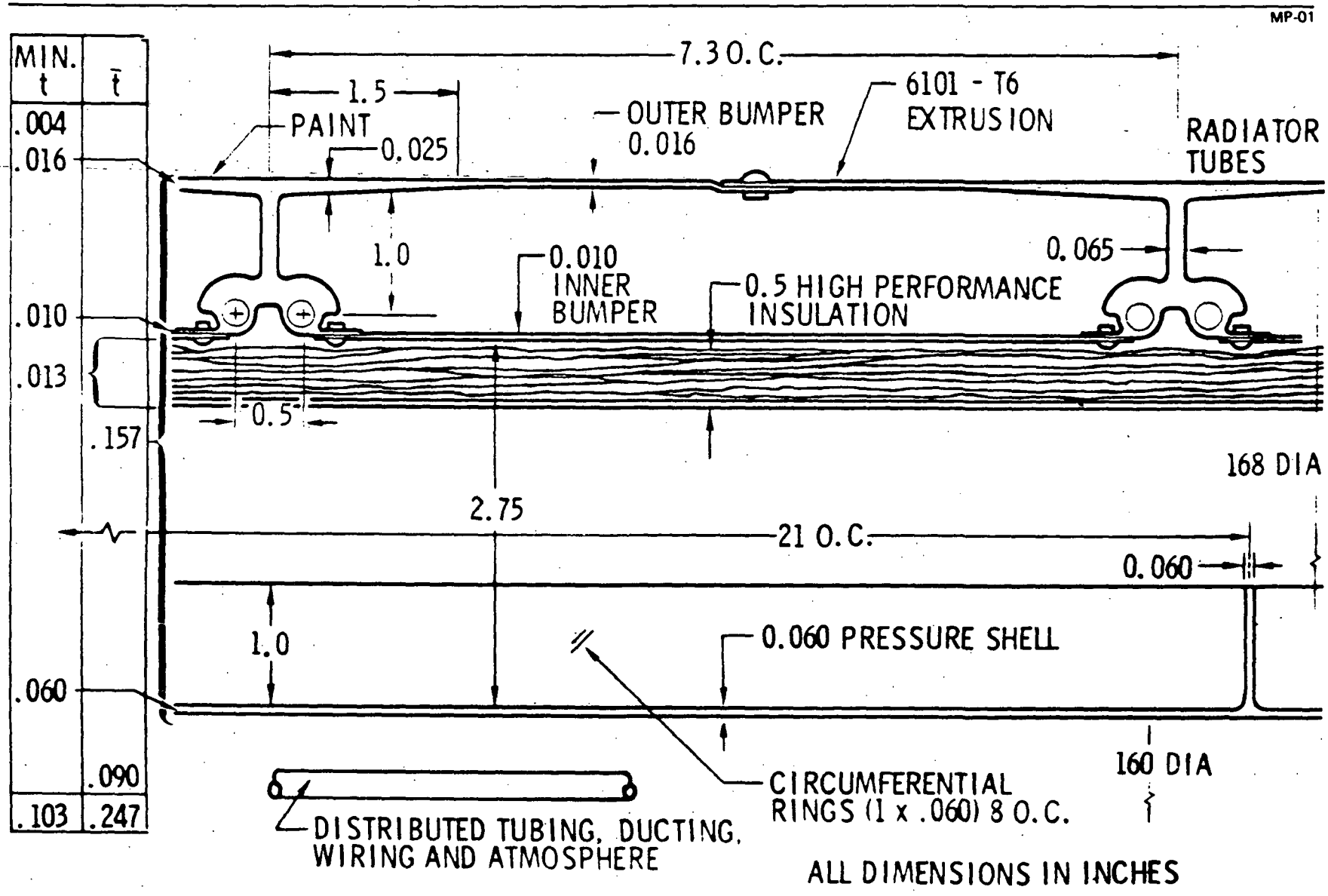


Figure 3-31. Structural Details

The allowable dose levels used are shown in Table 3-11, repeated from the Program Requirements Document. The quarterly allowables were used for the analysis since that is the planned crew on-orbit stay time. These allowable doses apply to the man model discussed above.

3.3.2.4 Analysis

The dose analysis was accomplished using established MDAC computer programs (SIGMA, CHARGE, SWORD, et al.). Recent improvements resulting from IRAD work on these programs have allowed a significant improvement in the capability to perform space radiation dose analyses in detailed, complex geometric systems. The essential difference from the previous conventional approach is the decoupling of space vehicle and astronaut geometries in a manner that appreciably increases accuracy by permitting much more detail to be incorporated.

The dose evaluation techniques are incorporated in the SIGMA code which now traces rays from a dose point within the geometric system describing the vehicle and constructs a probability distribution of attentuation path lengths. This distribution is then integrated with a dose attenuation kernel

Table 3-11

ALLOWABLE DOSE - REM

	30 day	Quarterly	Yearly
Skin			
0.1 mm	75	105	225
Eyes			
3.0 mm	37	52	112
Marrow (BFO)			
5.0 cm	25	35	75

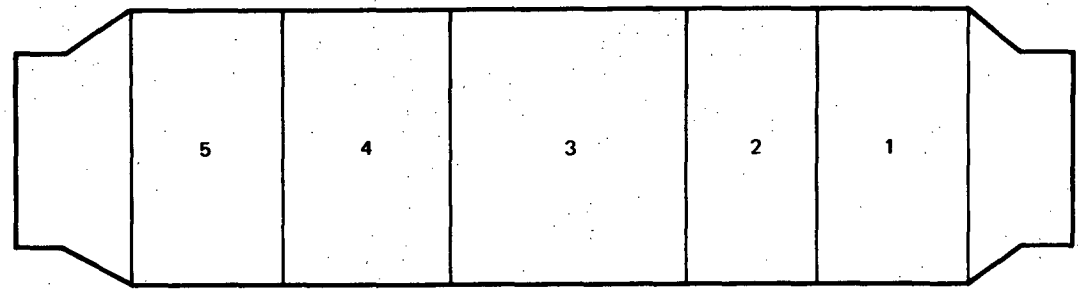
to evaluate the dose instead of performing geometric ray tracing. These distributions are constructed for the vehicle at each dose location, and then convoluted with distributions for various dose points in the astronaut. This technique provides random orientation of the astronaut in the vehicle, eliminating the artificial assumption of a fixed orientation. Experience with this technique to date has implied a factor of approximately 100 in reduced computer time over conventional techniques when realistic levels of geometric detail are incorporated in both astronaut and vehicle.

The results of this analysis are shown in Figure 3-32 which includes the 90-day doses received by the three dose points (skin, eyes, and BFO) when located within each of the five Crew Module compartments. Each compartment dose can then be factored by the residency percentages shown to arrive at the total doses received. Two shield cases are included. The first is for the exterior shield only including the basic and miscellaneous structure ($\bar{t}$ = 0.247 in.). The second case includes the shield effect of the equipment distributed within the Space Station as described in Figure 3-30.

The total doses received are compared to their respective allowables in the right hand columns of Figure 3-32. The dose received in the first case (exterior structure only) is less than allowable for the skin and BFO. The eye dose is exceeded by 12 rem for this case. When the total shield capability, including the equipment (Case 2), are considered, the skin, eyes, and BFO doses are 44, 28, and 9 rem, respectively, well within the respective allowables of 105, 52, and 35.

The detailed dose contributions from each source for these two cases are presented in Table 3-12 for reference. The BFO dose received using the integrated model is seen to be about a factor of two higher than that received by standard 5 cm depth model.

The dose analysis was pursued to determine the location that would best serve as a biowell (place to reside during a solar cosmic ray event). Figure 3-33 lists the dose data received for the total shield case (exterior



RESIDENCY-%		0	46	8	8	38	
						TOTAL DISTRIBUTED DOSE	ALLOWABLE
SKIN							
	EXTERIOR SHIELD	99	62	63	64	119	83
	TOTAL SHIELD	70	15	27	21	86	44
EYES							
	EXTERIOR	62	62	53	64	71	64
	TOTAL	36	18	29	24	42	28
BFO							
	EXTERIOR	14	16	16	16	16	15
	TOTAL	9	7	9	9	11	9

105

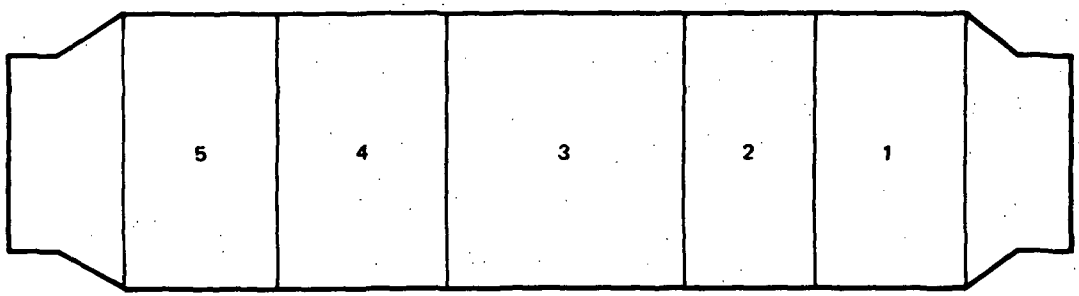
52

35

Figure 3-32. Dose Analysis Summary

Table 3-12
DETAILED DOSE DATA

	Case 1—Exterior Shield—0.247 in.					Case 2—0.247 in. Plus Equipment (Figure 3-30				
Receptor Position	5	4	3	2	1	5	4	3	2	1
Residency (%)	0	46	4	4	38	0	46	8	8	38
Dose Point/Source										
Eyes (Allowable 52)										
Electrons	0.3	0.3	0.3	0.3	0.5	0.1	0.01	0.003	0.01	0.3
Bremsstrahlung	0.8	0.9	0.9	0.9	0.9	0.7	0.6	0.7	0.7	0.8
Trapped Protons	10.4	11.2	11.4	11.4	11.2	7.8	6.1	8.2	7.9	8.7
SCR Protons	50.1	49.1	50.3	50.9	58.8	27.0	10.9	19.9	15.2	32.1
Total	61.6	61.5	62.9	63.5	71.9	35.6	17.6	28.8	23.8	41.9
Skin (Allowable 105)										
Electrons	0.8	0.6	0.6	0.6	1.03	0.3	0.01	0.01	0.01	0.5
Bremsstrahlung	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.6	0.6	0.6
Trapped Protons	8.0	8.5	8.8	8.8	8.6	6.1	4.8	6.4	6.2	6.9
SCR Protons	89.7	52.2	53.3	54.0	109.0	63.4	10.1	19.8	14.2	78.4
Total	99.2	62.0	63.4	64.1	119.3	70.3	15.4	26.8	21.0	86.4
BFO (Point)(Allowable 35)										
Electrons	0	0	0	0	0	0	0	0	0	0
Bremsstrahlung	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.4	0.4	0.4
Trapped Protons	3.2	3.5	3.6	3.6	3.5	2.5	2.1	2.6	2.7	2.9
SCR Protons	2.2	2.4	2.5	2.5	2.5	1.4	1.0	1.4	1.4	1.7
Total	5.9	6.4	6.6	6.6	6.5	4.2	3.5	4.4	4.6	5.0
BFO (Integrated)(Allowable 35)										
Electrons	0	0	0	0	0	0	0	0	0	0
Bremsstrahlung	0.6	0.6	0.7	0.7	0.6	0.5	0.4	0.5	0.5	0.6
Trapped Protons	5.5	5.9	6.0	6.0	6.0	4.2	3.5	4.4	4.4	4.8
SCR Protons	8.1	9.0	9.2	9.3	9.5	4.4	2.8	4.5	3.9	5.4
Total	14.3	15.6	15.9	10.0	16.1	9.1	6.7	9.4	8.8	10.7



RESIDENCY-%	0	46	8	8	38		
SKIN (105 ALLOWABLE)						DISTRIBUTED BIOWELL	DOSE (REM) NO BIOWELL
FLARE	63	10	20	14	78	10	44
TOTAL	70	15	27	21	86	16	
EYES (52)							
FLARE	27	11	20	15	32	11	28
TOTAL	36	18	29	24	42	21	
BFO (35)							
FLARE	4	3	5	4	5	3	9
TOTAL	9	7	9	9	11	8	

Figure 3-33. Effect of Biowell on Radiation Dose

shield plus equipment) both for the SCR contribution and the total dose received at each compartment. The lowest SCR dose is received at the control station of the Crew Module. Therefore, if it is assumed as the biowell location with the total flare dose received there and the remaining dose from the background sources received according to the residency distribution shown, the total doses are seen to be 16, 21, and 8 rem for the skin, eye, and BFO dose points, respectively. These show a marked reduction from the totally distributed doses of Figure 3-32, thus the appropriateness of a biowell is apparent.

The duration of a typical major solar flare would vary from one to four days. To take maximum advantage of the biowell concept, the crew should remain in the biowell for the duration. Short excursions would increase the dose proportional to the same spent outside the biowell. These should obviously be limited in nature but are certainly allowed.

It should be pointed out that the above analysis should be viewed with some degree of reserve because of the manner in which the equipment and structure was assumed to be distributed. An adequate amount of material is inherently available for the needed radiation shielding; it must be properly distributed. It appears that the problem of actually implementing this distribution in final design coupled with an analysis of environment uncertainties would warrant future study.

3.3.2.5 Film Vault Analysis

The basic dose data generated during the above analysis was used to determine film vault requirements. Figure 3-34 shows the film dose received as a function of vault thickness for electron, Bremsstrahlung, trapped proton, and SCR proton sources. The latter intermittent source provides the major portion of the dose. The allowable dose levels for typical film planned for use on the Space Station mission are shown along the left side of Figure 3-34. These are based upon the amount of film exposure (in terms of density) allowed for each individual film use. As noted the allowable radiation doses vary from 0.3 to 300 rad for a 90-day mission with a corresponding variation in vault thickness required of from less than one-half to over 10 in. The weights of variously sized spherical aluminum film vault are

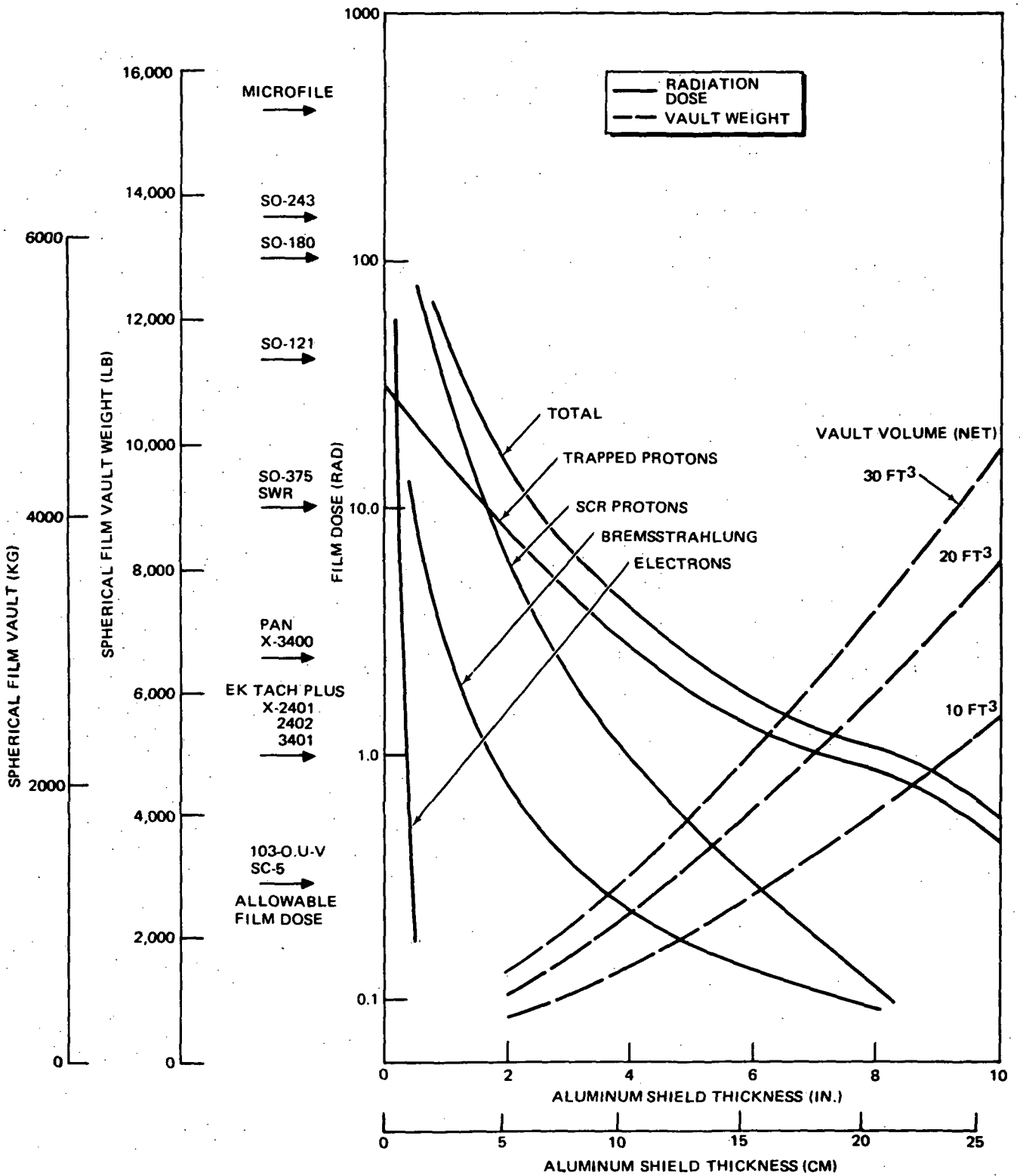


Figure 3-34. Film Vault Shield Requirements (90 Day Dose)

also shown in Figure 3-34. For the example shown, Ektachrome has a 90-day allowable dose of 1.0 rad which requires a vault thickness of 8.2 in. The vault required to store 20 ft^3 would then weigh 6200 lb as shown. It appears that films with allowable radiation dose levels below 1.0 rad should not be used since the vault requirements become very large.

Prior to the final design of a film vault other considerations should be made which would tend to reduce the weight required. These would at least include the following:

A. Space Station shielding - The Space Station shielding effects were ignored in this analysis; when accurately included these would slightly reduce the vault thickness required.

B. Film Stacking - A 20 ft^3 volume is large enough that the film could be arranged such that the least sensitive film would provide additional shielding for the center packed more sensitive types. Careful design and inventory control would be required to maintain this advantage.

C. Solar Flare Cosmic Ray (SCR) Considerations - Since the SCR events are random and seldom occur (~1 per year) at the model level assumed, the vault could be designed for background sources only. This, however, may impair or ruin some of the film data taken during the occurrence of the intermittent SCR. The weight savings using this technique for a 20 ft^3 vault would be about 1200 lb.

D. Design for a film resupply cycle of 30 days. This would reduce the exposure time and the weight of a 20 ft^3 vault by about 3,000 lb or one half.

E. Experiment Schedule - The film use schedule could be programmed to use the sensitive film early in each resupply cycle, develop it, and thus reduce its effective exposure time to radiation.

F. Temperature - The storage or vault temperature could be reduced since the sensitivity of film to radiation varies inversely with temperature.

G. Image Processing - Investigate image processing techniques where the known or predictable effects of radiation on the film can be recognized and eliminated or dealt with sufficiently to allow the retention of the desired data.

3.4 REFERENCES FOR SECTION 3

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3-2 Kirkland, V., Space Station Program Definition, DRD-8, Vol II - Mission Analysis, MDC G0605, June 1970, McDonnell Douglas Corporation, Huntington Beach, California.

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Section 4
OPERATIONS ANALYSIS

The operations analyses performed on the Modular Space Station are reported here. Section 4. 1 presents the Ground Operations in summary form—the full discussion is included in MP-03—while the Flight Operations Analysis is included in Section 4. 2.

4. 1 GROUND OPERATIONS

Analysis of ground operations as a part of the Modular Space Station integrated mission management would normally address launch site, prelaunch, and launch operations with little mention of operations prior to delivery to the launch site. However, the unique possibilities for streamlining operations and reducing operational costs inherent in the Modular Space Station concept require a much broader overview of the ground operations prior to launch if the prelaunch and launch operations at the launch site are to be fully understood. Hence, the following discussion of Space Station module operations delves deeper into predelivery activities and overall test philosophy than would be expected ordinarily. Also included in the discussion are prelaunch and launch activities related to experiments and experiment modules (RAM's), logistics modules (Log Modules), Crew Cargo Modules (CCM's), mission operations support and flight crew activities.

The discussion is divided into five sections, as follows:

- 4. 1. 1 Space Station Operations
- 4. 1. 2 Logistics/Crew Cargo Module
- 4. 1. 3 Experiments
- 4. 1. 4 Mission Support
- 4. 1. 5 GSE and Facilities

4. 1. 1 Space Station Operations

Space Station operations include all launch site activities necessary to activate the site, and to process (receive, service, install in orbiter, and launch) all modules required to complete the orbital buildup of the Space Station. These modules will be of three different types: power, crew, and general purpose laboratory (Figures 4-1, 4-2, and 4-3, respectively). Three modules launched first (see Figure 4-4, overall launch schedule) will comprise the ISS shown in Figure 4-5, while a second group of two modules that may be launched five years later would provide for growth to the full 12 man capability or GSS shown in Figure 4-6. The operations will span several years. Hence, the concepts for training and maintaining of ground personnel and the disposition of GSE form an important part of prelaunch and launch operations. Note that KSC is assumed to be the launch site for this analysis.

4. 1. 1. 1 Test Philosophy

Although prelaunch and launch operations begin with the first module activity at the launch site and end when the last Space Station module has been launched, the discussion must also consider integration of the modules which could be performed prior to delivery to the launch site and transportation to the launch site. The test philosophy developed for the Space Station embraces all aspects of testing in the categories of development tests, qualification tests, acceptance tests, prelaunch and launch tests, and on-going mission tests. Some of the most important guidelines of the test philosophy are as follows:

A. Imposed environment testing, both development and qualification, will be concentrated at the assembly and subsystem hardware level. All hardware will be environmentally tested at some hardware level, but only one environmental demonstration will be required.

B. There will be no environmental testing at higher hardware levels.

C. Testing of assembled modules and/or assembled clusters will be limited to the following:

Design-Development tests utilizing a functional model (FM) that is an electrical/electronic/data subsystem breadboard of the ISS modules.

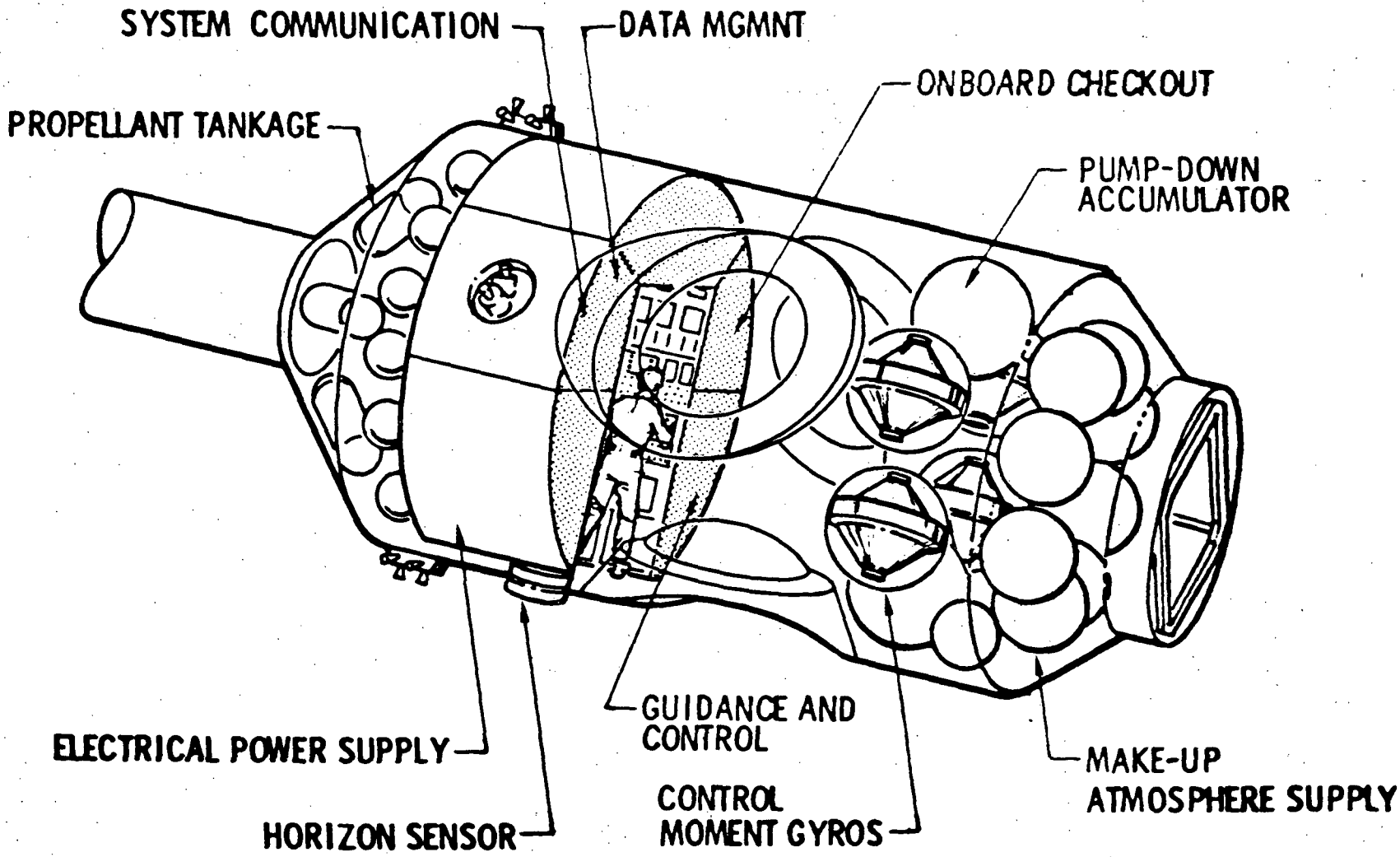


Figure 4-1. Power/Subsystems Module

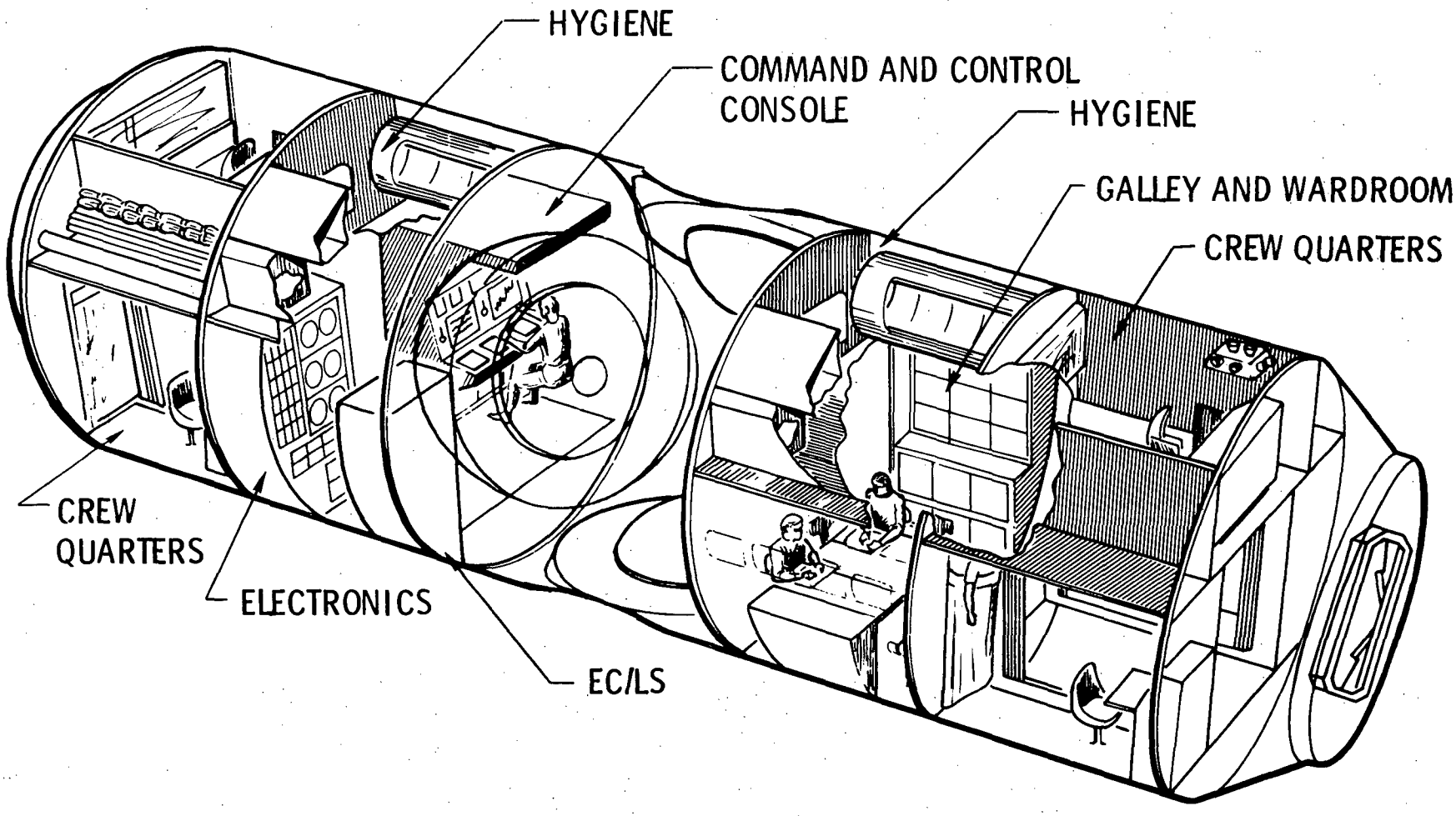


Figure 4-2. Crew/Operations Module

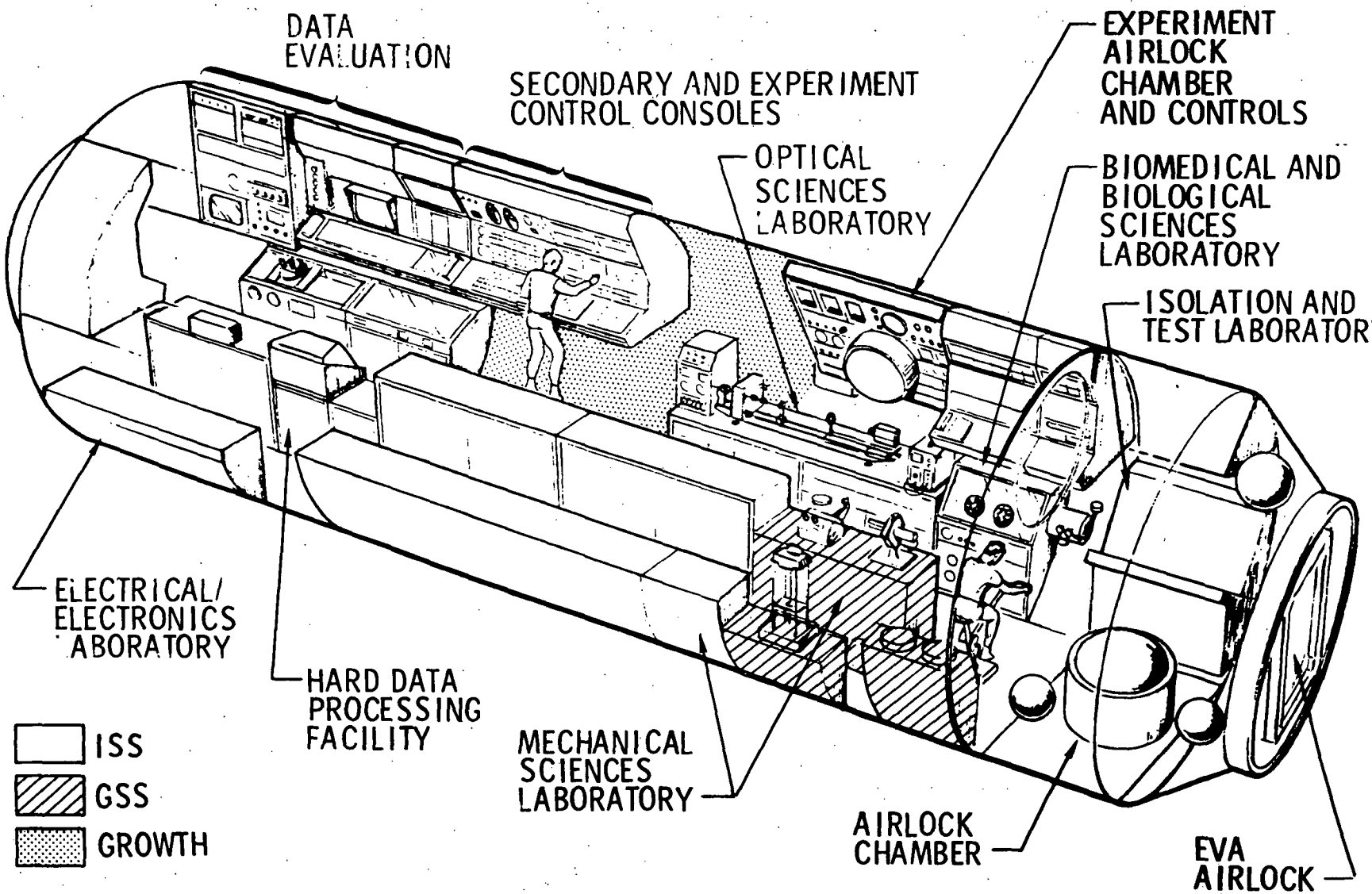


Figure 4-3. Baseline General Purpose Laboratory

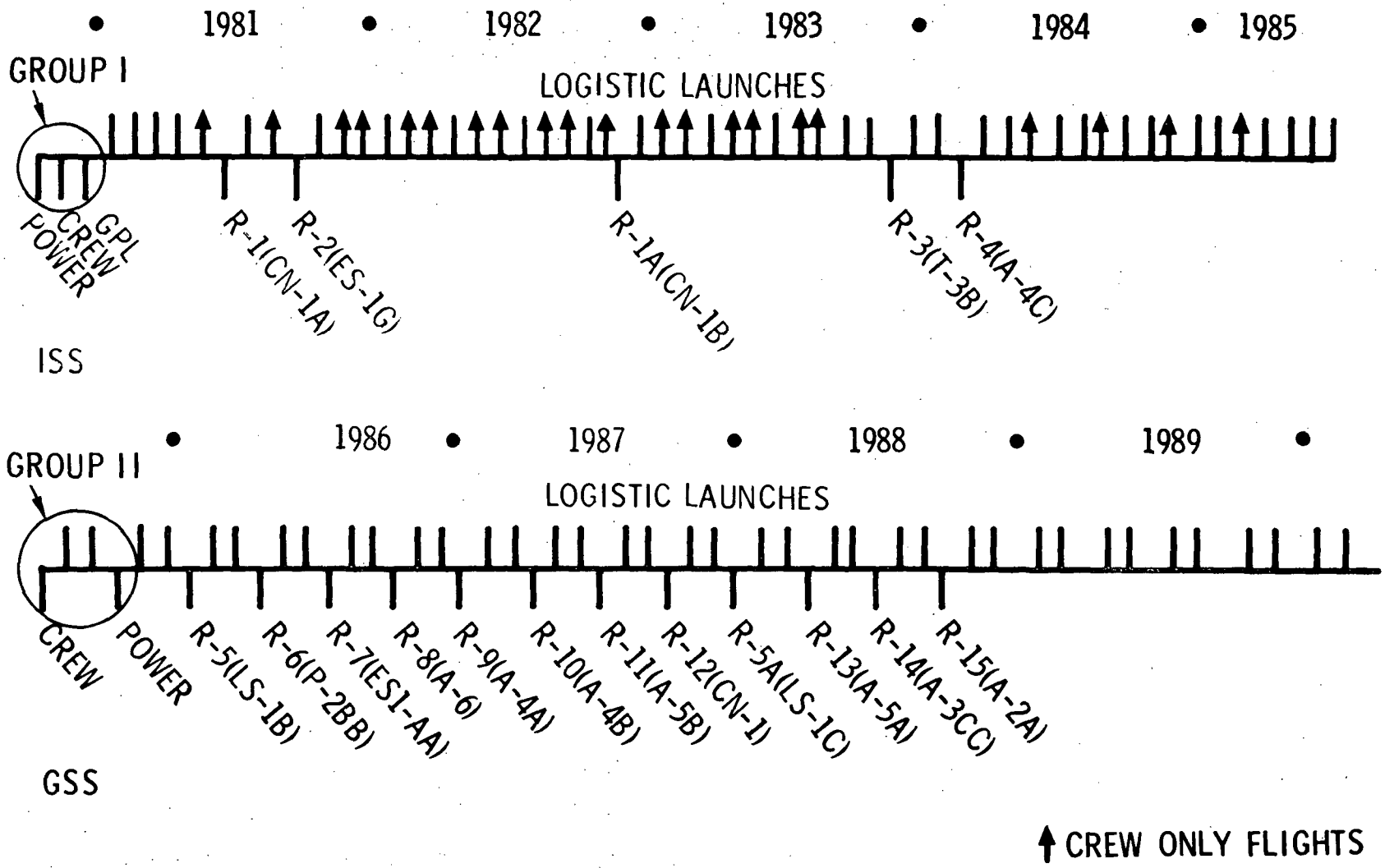
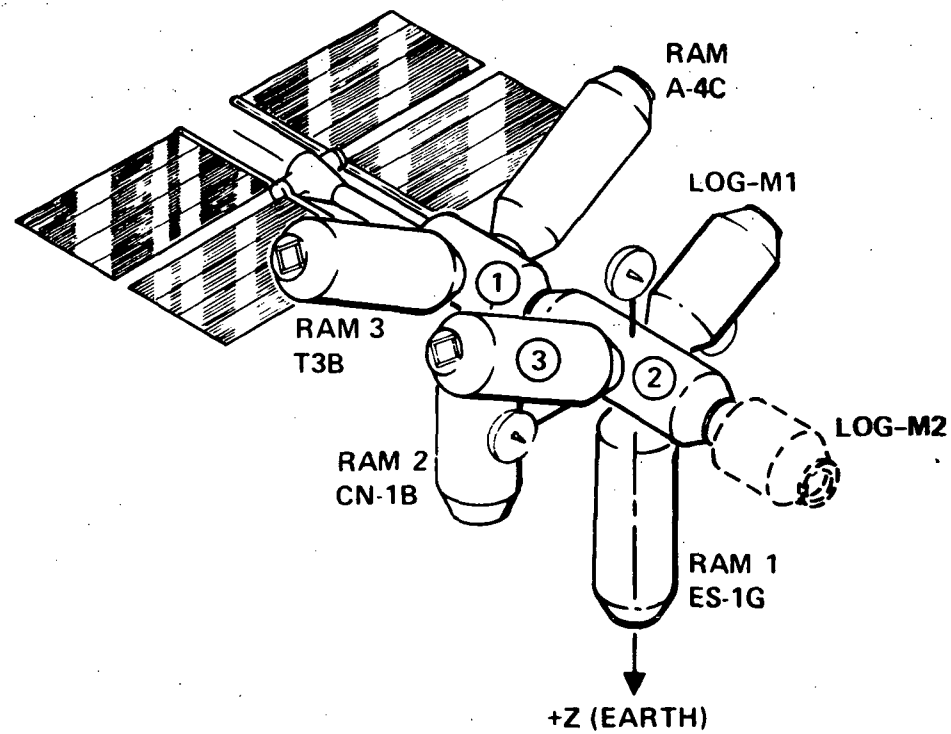


Figure 4-4. Space Station Buildup Module Delivery Schedule

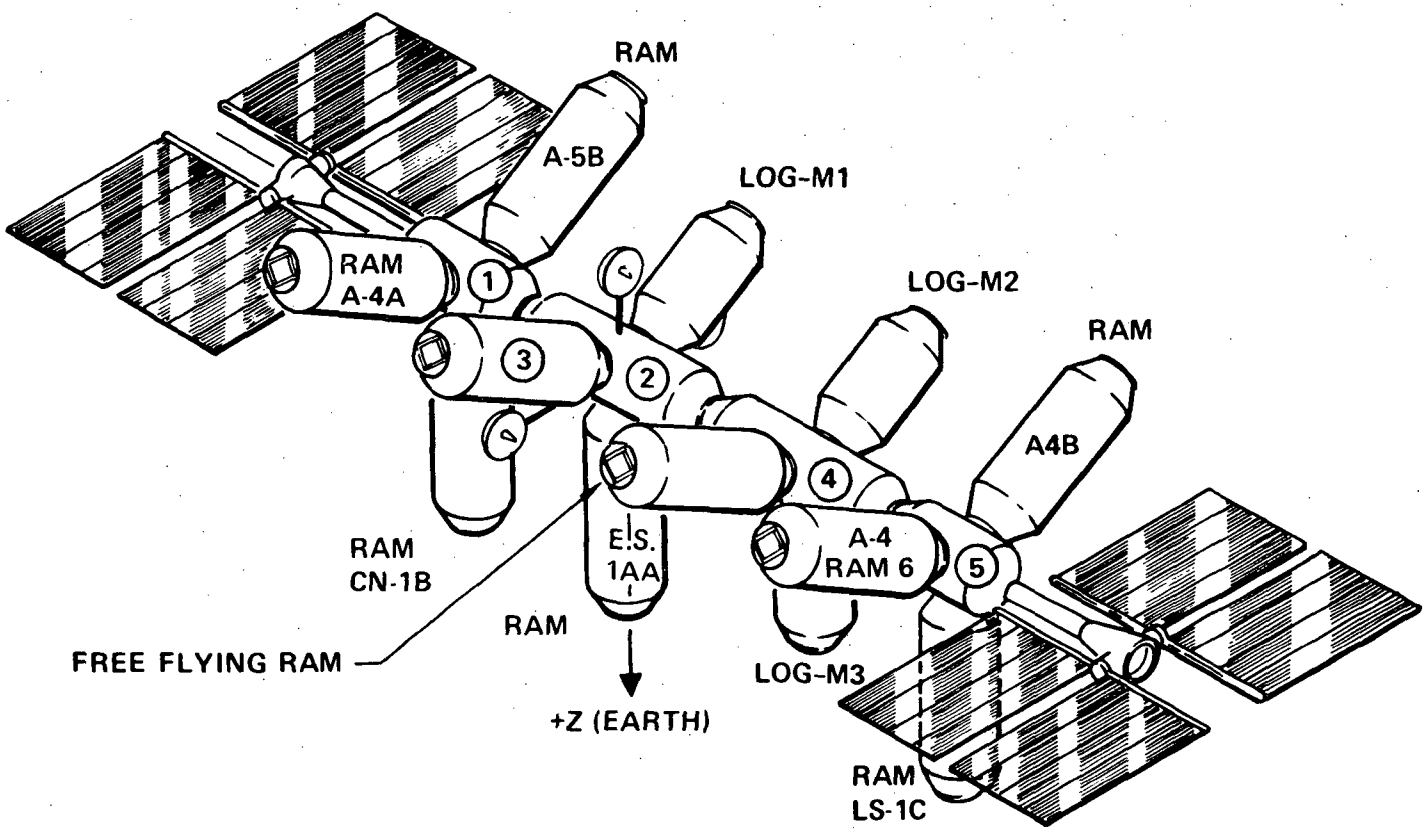


LAUNCH SEQUENCE/MODULE	1*	2*	3*	
PRIMARY FUNCTION	POWER/ SUBSYS	CREW/ OPNS	GPL	LOG M
CREW LAUNCHED	0	0	0	2

* 2 MEN ACTIVATION CREW POTENTIAL FOR SHUTTLE ORBITAL DURATION

Figure 4-5. Initial Space Station (ISS) (Maximum Cluster Size During Quarter 13)

R277



LAUNCH SEQUENCE/MODULE	1	2	3	4	5
PRIMARY FUNCTION	POWER / SUB/SYS	CREW / OPS	GPL	CREW / OPS	POWER SUB/SYS
MINIMUM LAUNCH WT (LB)	18,932	17,562	18,378	16,562	18,932
			ISS		GSS

Figure 4-6. Growth Space Station (GSS) (Maximum Cluster Size During Quarter 28)

Design-Qualification demonstrations utilizing an integration fixture that is a physical/functional replica of the ISS modules (also used for sustaining support of mission operations, discussed later).

Hardware-Acceptance tests of flight modules.

Implicit in this test philosophy is the intent to eliminate environmental mission profile qualification testing at the module level or above, and to minimize undue repetition of integrated systems tests, whether performed at the factory or launch site.

D. A policy of shipping an orbit-ready module from the factory will be followed with regard to launch site testing. However, should any launch site testing be unavoidable, it will be confined to and no more rigorous than acceptance testing performed at delivery of at the factory. Tests shall be en-to-end. Major disassembly and tests at lower levels of assembly will not be permitted in the field except when necessary to isolate malfunctions. Launch checkout shall be accomplished with onboard checkout instrumentation (although complete onboard checkout capability does not exist in single modules, and the instrumentation will have to be supplemented with external GSE for control and monitoring purposes).

E. Tests shall be assembled into an overall test plan covering all aspects of testing such that; (1) tests conducted a lower hardware levels are not repeated at higher levels unless inherent in hardware operation and unavoidable, and (2) development testing shall be constructed so that sensors and parameters which will ultimately be used for acceptance testing will have a credible data base. Similarly, acceptance and prelaunch testing will be constrained to those sensors and parameters properly explored, and previously developed in the development qualification testing programs.

4. 1. 1. 2 Space Station Integration

Before considering the specifics of individual module processing operations at the launch site, it is necessary to discuss the overall problem of Space

Station integration, and verification of integrated Space Station operations on the ground as the technique used will have significant impact on launch site operations. Note that integration can be separated into two distinct but related categories; ground activities designed to ensure the orbital compatibility of Space Station modules and their successful buildup into the complete station and activities devoted to ensuring successful integration and implementation of new hardware/software (both station and experiment) and any hardware/software change throughout the 10-year mission duration.

Module Integration, Orbital Compatibility

Figure 4-7 illustrating the interface between the ISS modules readily shows the necessity to verify the integrated operations on all the modules prior to first module launch. The need is especially evident when the nature of the data bus is considered, i. e., a dynamic data link between subsystems within the modules and between modules for the transmission of control commands and feedback data, communications, status monitoring and checkout, etc. Several alternative techniques for verifying integrated operation of Space Station modules exist. These include: (1) mating the initial cluster of modules together and verifying integrated operation of them, then treating the remaining modules five years later by another method; (2) mating each module with a breadboard of the complete station and verifying integrated operation of module and breadboard; (3) mating each module with a physical and functional replica of the station and verifying integrated operation of the module and replica; (4) using interface substitutes, considering each module an individual payload; and (5) analysis of engineering drawings and procedures.

Other variations may also be possible but the four analyzed illustrate the basic principles involved, and point out the relative merits of various concepts. The advantages and disadvantages of each of these four approaches to integration are listed in Table 4-1. The foremost considerations in judging the desirability of a technique are the fidelity of integration, or confidence in integration, and the additional cost of implementing the technique.

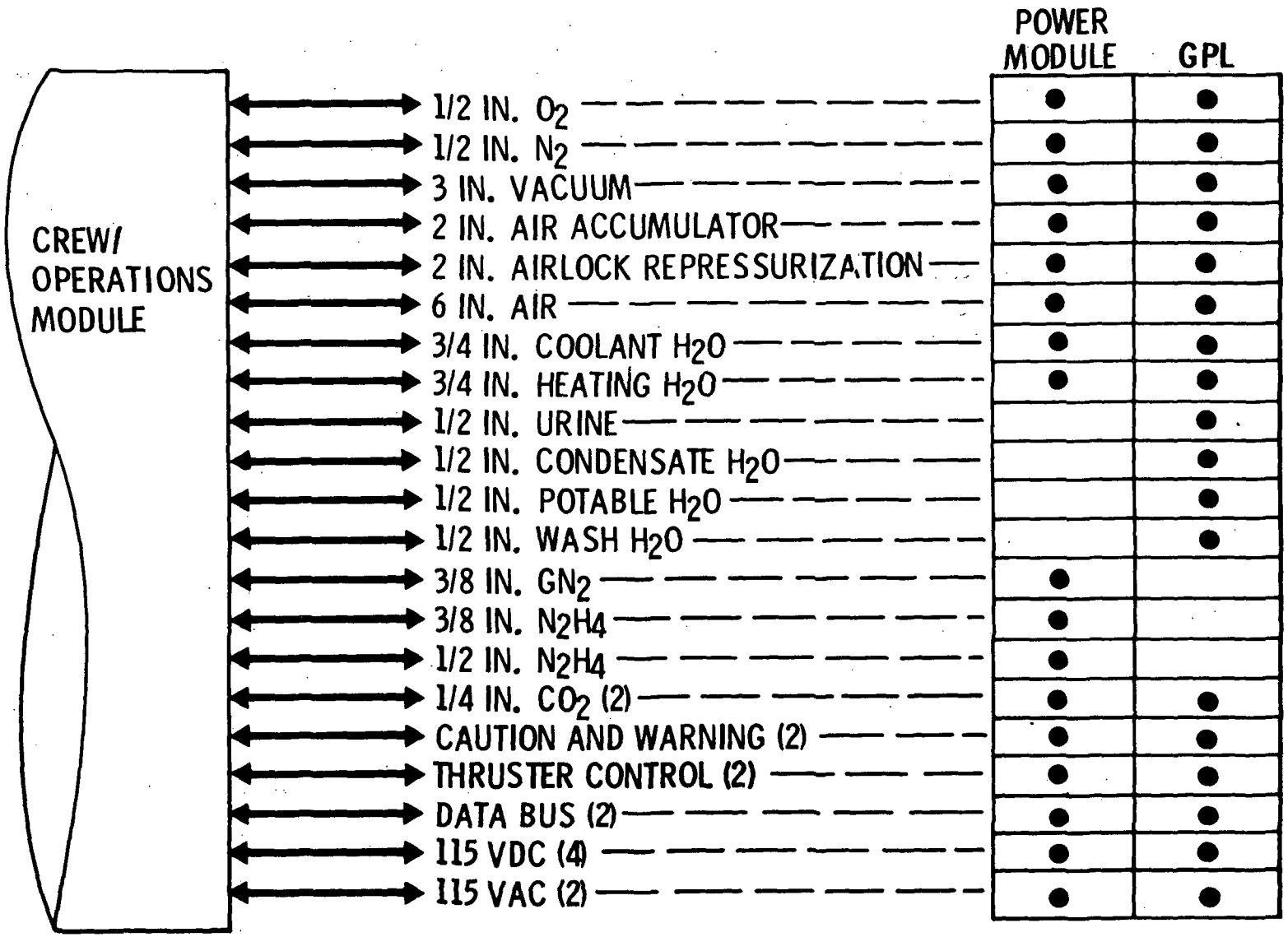


Figure 4-7. Module-to-Module Interfaces

More detailed discussions of the four integration options and Continuing Mission Support Integration are contained in Section 2 of MP-03, Integrated Mission Management Operations.

Recommended Module Integration Concepts

The concept recommended for satisfying integration requirements (illustrated in Figure 4-8) is a hybrid of flight module mating and use of physical/functional replica or flight integration tool (FIT). Key points regarding the concept are as follows:

A. Qualification hardware, flight article spares, and integration structures will be used to assemble replicas of the ISS and GSS flight modules.
B. Assemble FIT for final development of software and hardware and later for continuing mission support activities.
C. Mate the FIT modules in the ISS configuration.
D. Soft-dock the modules to reduce facility and access GSE requirements, to aid easy substitution of modules and increase flexibility.
E. Use a standard docking port tool to verify mechanical compatibility of modules.
F. Interchange flight modules with FIT counterparts and verify operations.
G. Mate flight modules and verify operations.
H. Remove items to be offloaded due to Shuttle payload limitations and ship separately to launch site for delivery of lst two logistics flights.
I. Disassemble cluster and send individual modules to launch site.

The overall concept and any program/schedule constraints are presented in the following paragraphs.

The three ISS modules will be launched 30 days apart over a 60-day period. Current weight estimates require that items not critical to buildup or initial operations be offloaded to reduce each module to the current payloads weight limit of the Shuttle orbiter. Though the subsystems will be divided among

Table 4-1

INTEGRATION METHOD COMPARISON MATRIX

Method	Advantages	Disadvantages	Method	Advantages	Disadvantages
Initial Cluster Mating	• The initial cluster of flight modules (the most important toward ensuring success) would actually be operated together before flight, giving highest confidence possible in flight performance. • Onboard checkout system (OCS) could be used extensively, since a workable system will exist in the three modular clusters. • No additional hardware cost.	• Flight interfaces between modules would be demated after integrated testing, thereby invalidating the real advantage of mating, which is the verification of integrated operation through the actual interfaces. • Another method would have to be used to verify integration of the latter three modules launched in six years. • Continuing mission support functions would have to be accomplished by separate means.	Physical Functional Replica Mating (FIT)	• High-fidelity integration of modules would give highest confidence in integration results. • Onboard checkout system could be used extensively in conducting tests, thereby reducing GFE requirements. • All continuing mission support functions and final development functions could be accomplished as well as the module integration functions. • Qualification test hardware and integration structures could be used to obtain replica modules at little extra cost to the program.	• Program cost may be increased since integration structures for every module may not be available, i. e., two structurally identical modules would not both have wire and tube run development; thus, an additional structure would have to be manufactured, or obtained elsewhere for the Flight Integration Tool • A replica would be an overly sophisticated GSE system if its sole purpose were to verify module compatibility for on-orbit mating. • Actual flight interfaces would never be mated and verified. • A special facility would be required for the program duration.
Breadboard Mating (Functional) Model)	• The basic Functional Model (FM) as an integration tool would be available at little additional cost to the program, since it is a product of engineering development of the Space Station design. • Additional GSE requirements would be minimized since the combined breadboard and module would have OCS capability. • Some continuing mission support functions could be partially accomplished using the FM, i. e., functional configuration control, troubleshooting, functional integration of hardware and software, maintenance plan and procedure development and revision, and software qualification, although not as well as if an FM were used.	• Development hardware would not necessarily be equivalent to flight hardware in design performance or reliability and could not be expected to last long enough to be used with the latter modules, especially if the Functional Model is also used for mission support. Hence, fidelity of integration would be only fair for early modules, with no guarantee for future modules. • A Functional Model typically represents electrical functions only; therefore, fluid functions would have to be added to it at extra cost. • Some continuing mission support functions would have to be accomplished by other means. Those that could be accomplished are done with a loss of capability, and with dubious validity, e. g., troubleshooting on development hardware may lead to erroneous results due to differences between development and flight hardware design. • Actual flight interfaces would never be mated and verified. • A special facility would be required for the duration of the program.	Interface Substitutes	• GSE could be obtained at no extra development cost, since it would be needed anyway for individual module acceptance testing.	• Additional sets of GSE at extra cost would be required if integration is accomplished at other than the manufacturing and acceptance location. • Onboard checkout system would not be used for checkout; hence, its operational capability to determine and isolate faults would not be verified. • Fidelity of integration testing would be the lowest of any of the alternatives. • Actual flight interfaces would never be mated and verified. • Continuing mission support functions would have to be accomplished by other means.

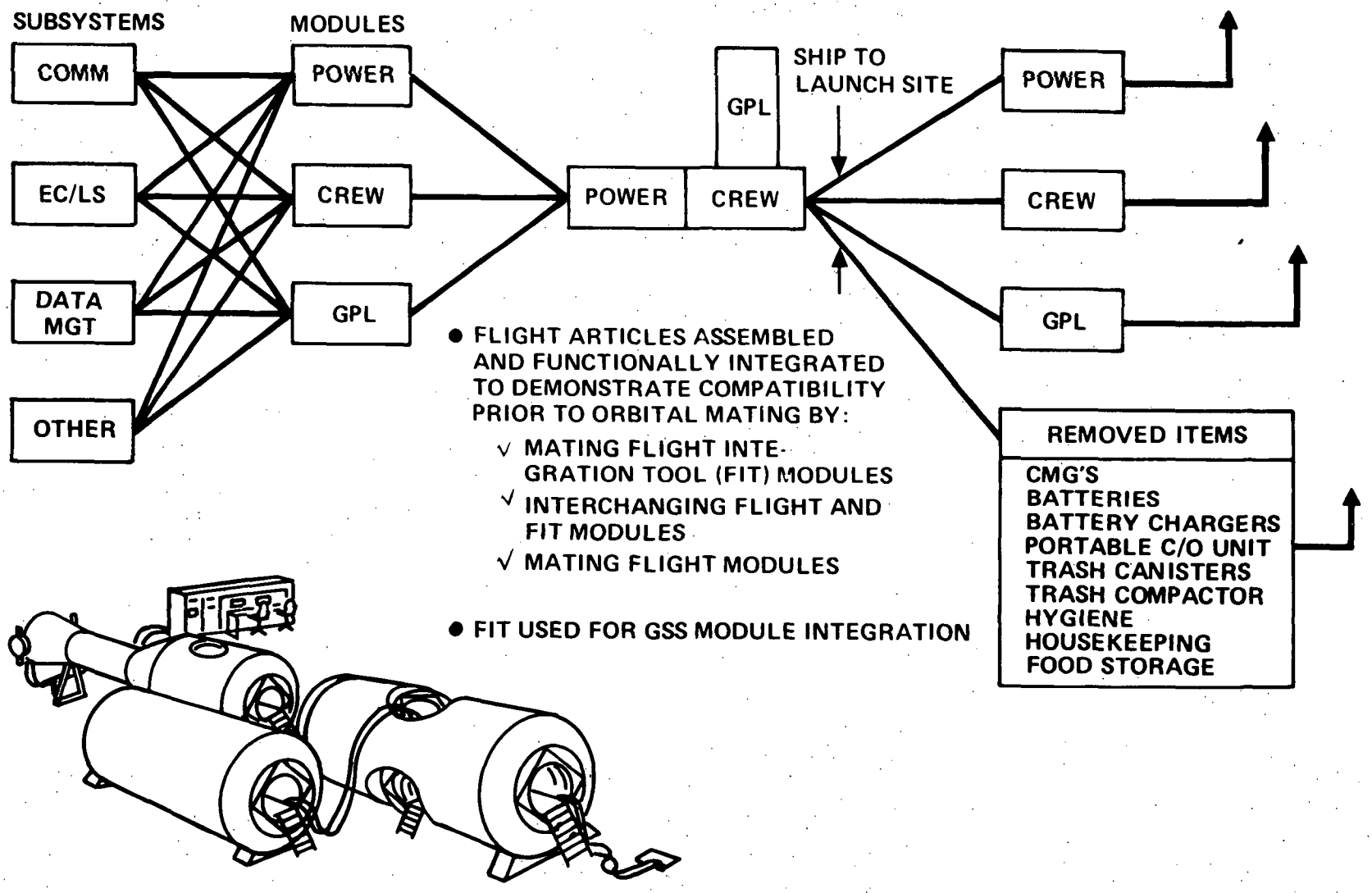


Figure 4-8. Modular Space Station ISS Hardware Flow (Ground)

the three modules for ISS, they will be designed, developed, tested, and delivered as complete subsystems. Once delivered, these subsystems will be separated and the appropriate portions installed in the designated module. Both the concurrent subsystem delivery and the close launch dates of the modules eliminate any benefit in staggering the module production, testing, etc.; thus the selected integration concept can be based on the three ISS modules being completed at the same time.

The first articles off the production line will be all three FIT modules. At this stage of development they are used as production prototypes to develop cable and wire runs, assembly techniques, etc. Each of these modules will be tested utilizing production GSE after which it will be substituted for its counterpart in the functional model. After all three have been substituted in the FM, they will be assembled into the ISS configuration utilizing the split interface adapters shown in Figure 4-9. The production flight articles will be next off the production line. They will be substituted for the FIT modules, one by one, and operations verified. The flight articles will be assembled into the ISS configuration and integrated operation verified. By this technique, both the FIT modules and the flight articles are proven to operate as assembled ISS configurations. The interchange of modules between the two verifies the intermodule interface and overall operation of the flight articles and the FIT, the latter of which will support the 10-year program on the ground for integration of subsequent changes and/or new hardware.

After this integrated test which must verify readiness for orbital operations, the modules will be disassembled, the items to be offloaded removed and the modules individually shipped to the Shuttle launch site for loading in the orbiter and subsequent launch.

Mating of the ISS flight modules for integration could be performed at one of several sites, i.e., a site convenient to the overall Space Station contractor; at an integration facility at the launch site; or at an independent integration facility situated at neither the launch site nor the manufacturing location. Mating at the launch site would allow integration to be accomplished immediately before launch of the first module without cross-country transportation

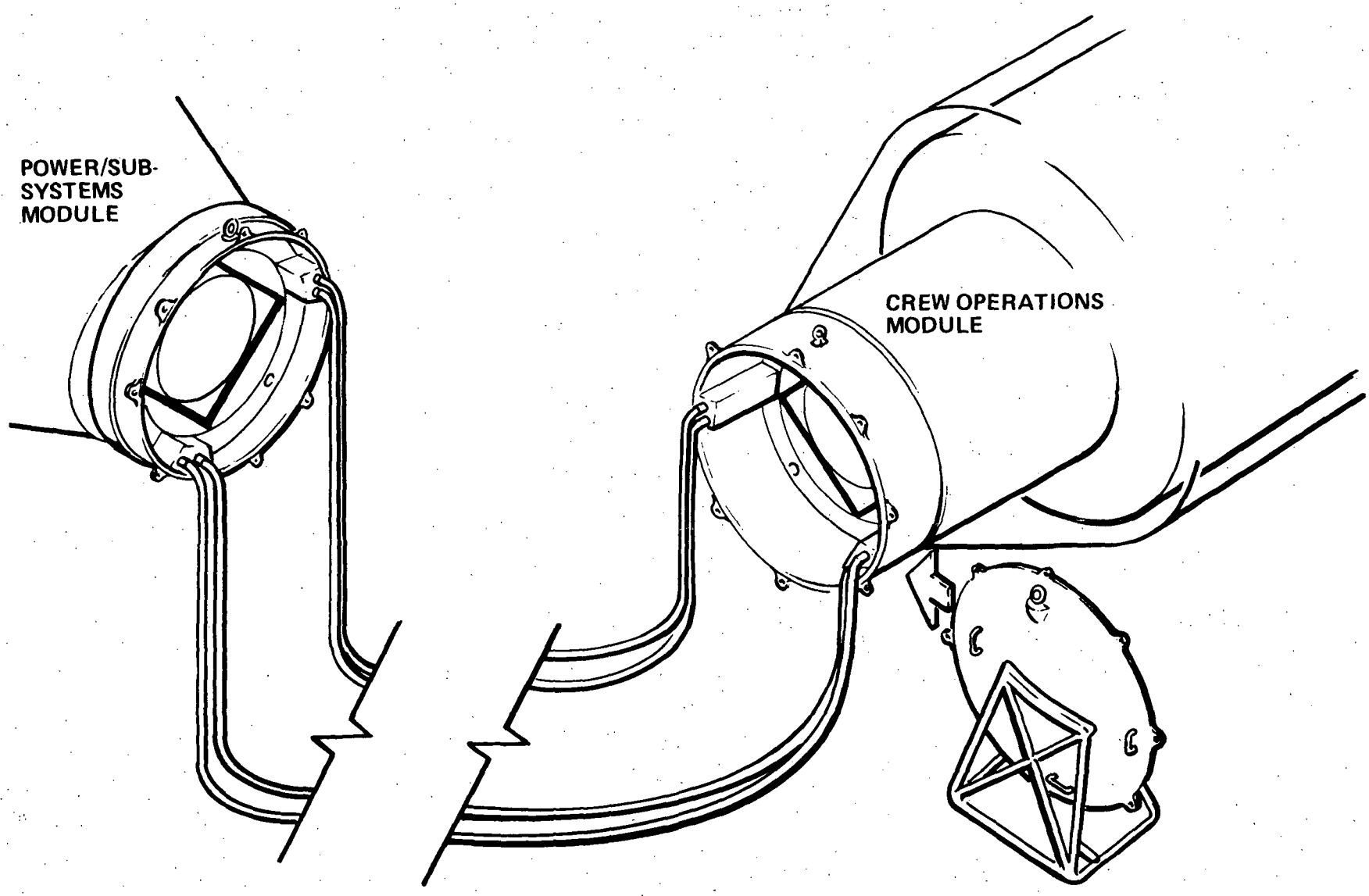


Figure 4-9. Interface Verification Using Split Interface Adapter

between integration and launch, and the accompanying possibility of transportation effects damaging the modules or invalidating integration test results. Mating at an independent site doubles the transportation requirements, i. e., factory to independent site to launch site instead of factory to launch site. Another concept requires the integration to be accomplished at the manufacturing site which minimizes program cost development risk. To realize the economics and advantages of this concept, the flight articles must be orbit-ready when they leave the manufacturing site. Mating the modules and verifying ISS integrated operation at the manufacturing site is recommended; however, in order to minimize costs, as no damage or invalidation of results would be expected unless modules are subjected to severe transportation environments which can be easily measured.

Failure to do this will move duplicate operations to the launch site with the resultant manpower increases, schedule extensions and resultant launch date slip. Unfortunately, this has been the experience in part programs. This condition has been caused by early establishment of a specific ship date tied heavily to payment incentives and a multitude of late changes by both the customer and contractor, thus forcing the bidding contractor to plan for this contingency and expect to ship the flight article with missing or non-functional elements (i. e., ship short) and deliver this article to a launch site crew of significant size in facilities specifically prepared to complete the manufacture and perform acceptance tests. Admittedly, if the vehicle is not ready on the planned ship date from the manufacturing site, the launch date could slip; however, any operation that must be accomplished prior to launch can be performed faster with existing personnel, equipment, etc., at the manufacturing site, rather than shifting operations, personnel, and equipment to the launch site and dedicating modifying facilities to perform these tasks. Lead times on launch site facility preparation preclude a last minute decision to perform any task at the launch site and preplanning such activity would expend manpower and money to perform a function at the launch site that may not be required.

An alternative scheme would be to perform the integration at both the factory and launch site; however, this would duplicate testing and require the off-loading to be done at the launch site where the installation experience does

not exist. Performing the flight module integrated testing only at the launch site invites schedule slip and cost increase in that the flight modules would be assembled first there and any difficulties encountered in initial assembly of modules would have to be accomplished remote from the engineering and production sites where presently all the integrated module GSE will be retained at the manufacturing site and only necessary module GSE would be shipped to the launch site, this would require all the GSE to operate the FIT and flight module cluster would have to be shipped to the launch site and set up in a specific facility.

The FIT could also be located at one of the three types of site indicated above. However, development of the Space Station (particularly software) will require extensive use of the FIT by engineering personnel during final development phases for the initial cluster of modules. Thus, from a development view, locating the FIT at the manufacturing site is the logical choice. Otherwise, development engineering personnel would have to be temporarily assigned to the FIT location thereby increasing development costs. Therefore, it is recommended that the FIT be located at the manufacturing site until final development of the ISS has been completed.

After ISS development the FIT should be located at a site that most conveniently accommodates the majority of continuing activities. Note that locating the FIT at other than the manufacturing site does not materially interfere with development of the GSS modules since they should be essentially identical in design to their ISS counterparts and would require no additional hardware development. Integration of GSS modules and new changed GSS software is included in the continuing mission functions. However, locating the FIT at other than factory or launch site will double transportation risks for GSS modules similarly to ISS modules as mentioned above. If the FIT were only used to verify hardware just prior to delivery to orbit, it would be best located at the launch site, however, the FIT has other functions both in the development cycle and the 10-year program. It will be used for SS and experiment change verification and will be used to verify future RAMS, in addition to the mission management uses listed in Table 4-2.

Table 4-2

MISSION SUPPORT FUNCTIONS FOR
THE FLIGHT INTEGRATION TOOL

Aid real-time configuration control and tracking of the orbiting Space Station.
Aid trouble-shooting of orbital problems which cannot be solved be the flight crew.
Provide for functional and physical integration of new or modified Space Station flight hardware, experiments, and experiment modules (RAM's).
Provide for functional integration of new or modified software.
Aid flight crew proficiency training (although training requirements are considerably reduced since cargo modules are no longer docked under station control).
Provide for verification of the Space Station/flight control center functional interface.
Aid in development and revision of maintenance plans and procedures.
Aid principal investigator orientation.
Qualification testing of software.
Indoctrination of the scientific community.

Development of new software programs will also utilize the FIT. Contractors or NASA centers that are involved in experiment integration might require the FIT at their facility. New hardware delivery will probably be subjected to acceptance testing on the FIT and in this case the location at a contractor facility could reduce the number of personnel and hardware to be relocated to perform this function at other than a contractor site. In summary, the location of the FIT should be left open until the requirements of the Space Station, RAM and Shuttle projects can be integrated. These requirements should be made available to the bidding contractors who should be permitted the option of proposing a locating where their resources and implementation planning indicates would be most cost-effective for the program.

Note that if flight module mating and integration or FIT operations were to be performed at the launch site, then the MSOB checkout area would be an ideal

facility, i. e., a suitable environment, more than adequate space, adjacent offices, overhead cranes, etc., requiring little modification to its present configuration. Space would be adequate for both flight modules and FIT simultaneously. Other existing facilities, e. g., PIB, could also accommodate these activities if suitably modified.

4. 1. 1. 3 Space Station Module Transportation

Modules will be surrounded by a protective cover having either an active or passive environmental control system (S-IVB as used on 10 m (33 ft) station). Modules will be protected from excessive shock and vibration during transportation and will be provided with shielding which protects against accidental impact. On completion of acceptance test, removal of items to be offloaded, and preparation for shipment at their assembly and integration areas modules will be shipped to KSC.

During preparation for shipment activities conducted at the final assembly and integration area, the modules will be installed on its transporter and a prime mover attached. The module will then proceed from that area over a predetermined route to the aircraft loading areas. The module will move via convoy consisting of a prime mover; a transporter maintenance vehicle; and leading and following vehicles equipped with wideload signs, flashing amber lights, and communications. In addition, equipment will be available as necessary to perform emergency road maintenance. The speed of the module and transporter will be held to a minimum to prevent traffic accidents and to minimize shock and vibration transmitted to the module. The route will be selected to ensure safe, smooth, unobstructed passage to the module and transporter envelope and to minimize traffic interference. Transportation will be during periods of low traffic activity.

On arrival at the aircraft loading area the module and transporter will be positioned to best advantage for loading and the prime mover disengaged. Loading will be accomplished in such a manner to reduce shock/vibration transmitted to the module to acceptable limits.

Contractor personnel will accompany the module during transportation to KSC. They will be charged with monitoring the environmental status of the module and inspecting the condition of the protective covering, tie-down, transporter, and attendant equipment to further assure safe transportation of the module.

On arrival at KSC, the module and transporter will be unloaded as a unit and placed on the ground where a prime mover will be attached. This combination will then proceed over the launch site ramp and roadway system to the Shuttle maintenance area where receiving inspection will be accomplished.

4. 1. 1.4 Prelaunch and Launch Operations

Prelaunch and launch operations include all launch site (KSC) activities required to prepare and launch the Space Station modules. It is assumed that launch will be from Complex 39 (LC-39) by Shuttle launch vehicle (LV). Space Station operations described herein have been developed according to the overall test philosophy and integration concepts delineated in subsections 4. 2. 1. 1 and 4. 2. 1. 2. The three ISS modules equipped with the integral experiment hardware installed in the GPL will be fully assembled and a complete integrated test performed at the manufacturing site. The entire Space Station will be acceptance tested, the three modules demated, and pre-established items off-loaded to bring the module gross weight within the Shuttle cargo weight limit. The off-loaded items will be limited to those which will not impair Space Station buildup or initial operation.

The modules will be transported by air, and since the modules were fully operational at the factory in integrated test, they will be serviced for flight, loaded in the Shuttle orbiter and interfaces verified.

The launch of the ISS Space Station is essentially a one-time launch and as such does not warrant the buildup of a field station crew to repeat testing that that should be performed at the manufacturing site where facilities, equipment, procedures, and manpower already exist to perform this function. Since the Space Station is only the first of many closely scheduled launches

in the Space Station Program, shipment on nonflight-ready hardware to the field station is an unacceptable alternative both from a cost and schedule point of view.

The result, combined with the influence of the manned/recoverable Shuttle launch vehicle, is a departure from past programs in that the flight article is shipped from the manufacturing site in an orbit-ready state.

Three basic types of modules will be launched. The capabilities of each module at the time of launch will differ considerably as shown in Table 4-3. The overall general operational flow for each type of module (Figure 4-10) will be identical, nevertheless, differing only in details. This results from delivering to the launch site fully checked and integrated modules that are orbit-ready except for preflight servicing. Note that the offloaded items (refer to Figure 4-10) are delivered to orbit later in logistics modules. The launch site operations will range from 15-21 days from landing at the launch-site to lift-off. At present the power module requires the longest time due to battery installation at the launch site.

More detailed prelaunch operations are contained in Section 2.1.5.1 of MP-03, Integrated Mission Management Operations.

4.1.1.5 Ground Crew Staffing and Training

Space Station associated Shuttle launches will occur approximately every 30 days, as shown in Figure 4-4.

This suggests that a general-purpose or universal prelaunch and launch operations crew could be assembled to handle all Shuttle payload modules. Applying this principle to the station related modules indicates a virtually constant relatively small, direct employee work force can be established and maintained as shown in Figures 4-11 and 4-12. In order to accommodate the idiosyncrasies and special problems associated with individual modules, a special traveling crew would be established for each module to supplement the permanent crew. This traveling crew would participate in factory checkout and Space Station integration operations as well as prelaunch and launch operations. The crew would be comprised of personnel drawn from the permanent universal prelaunch and launch operations crew, and from factory personnel. The factory personnel will be selected from personnel who have been responsible for Space Station design, test procedure

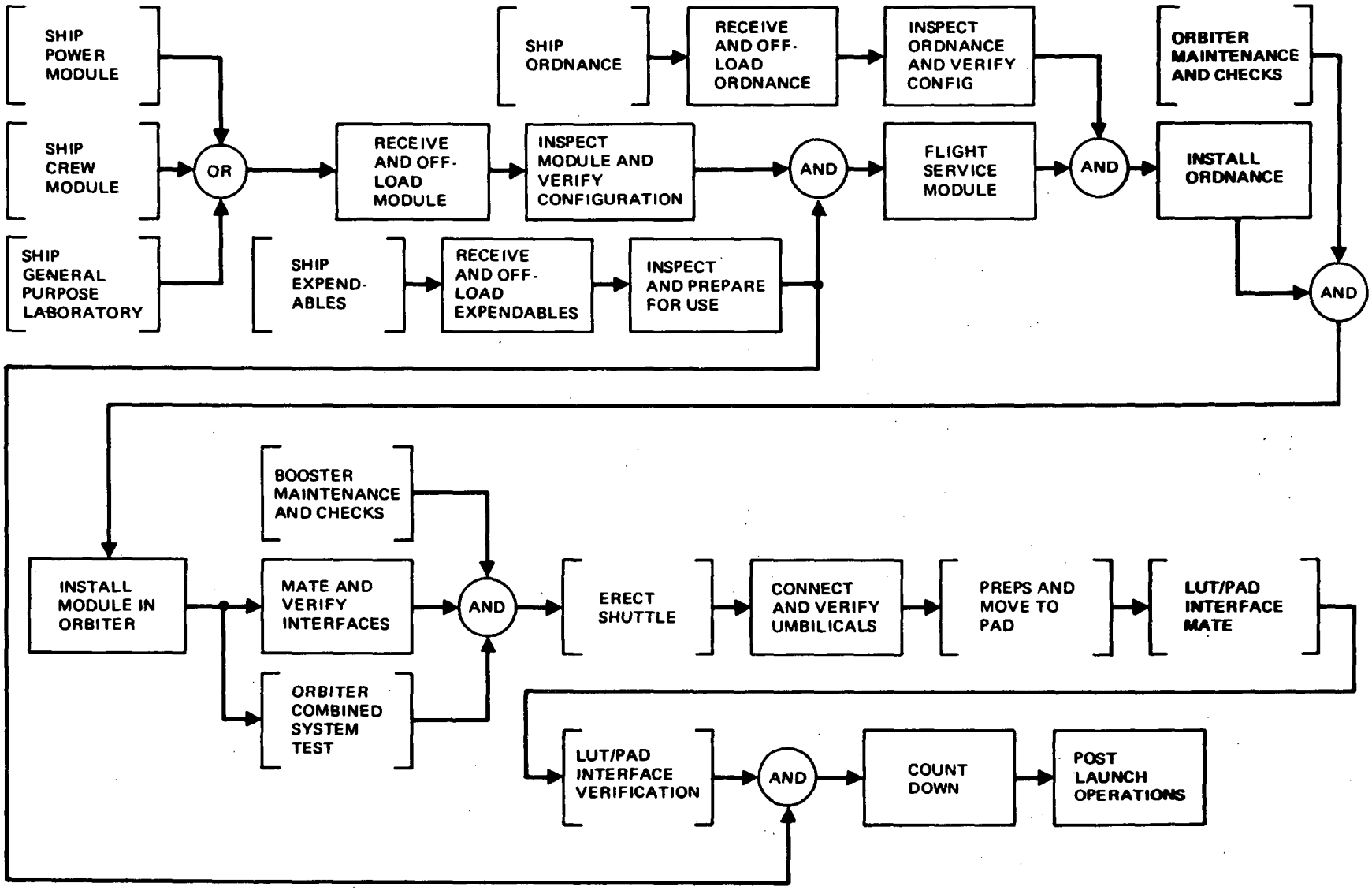


Figure 4-10. Typical Module Operational Flow

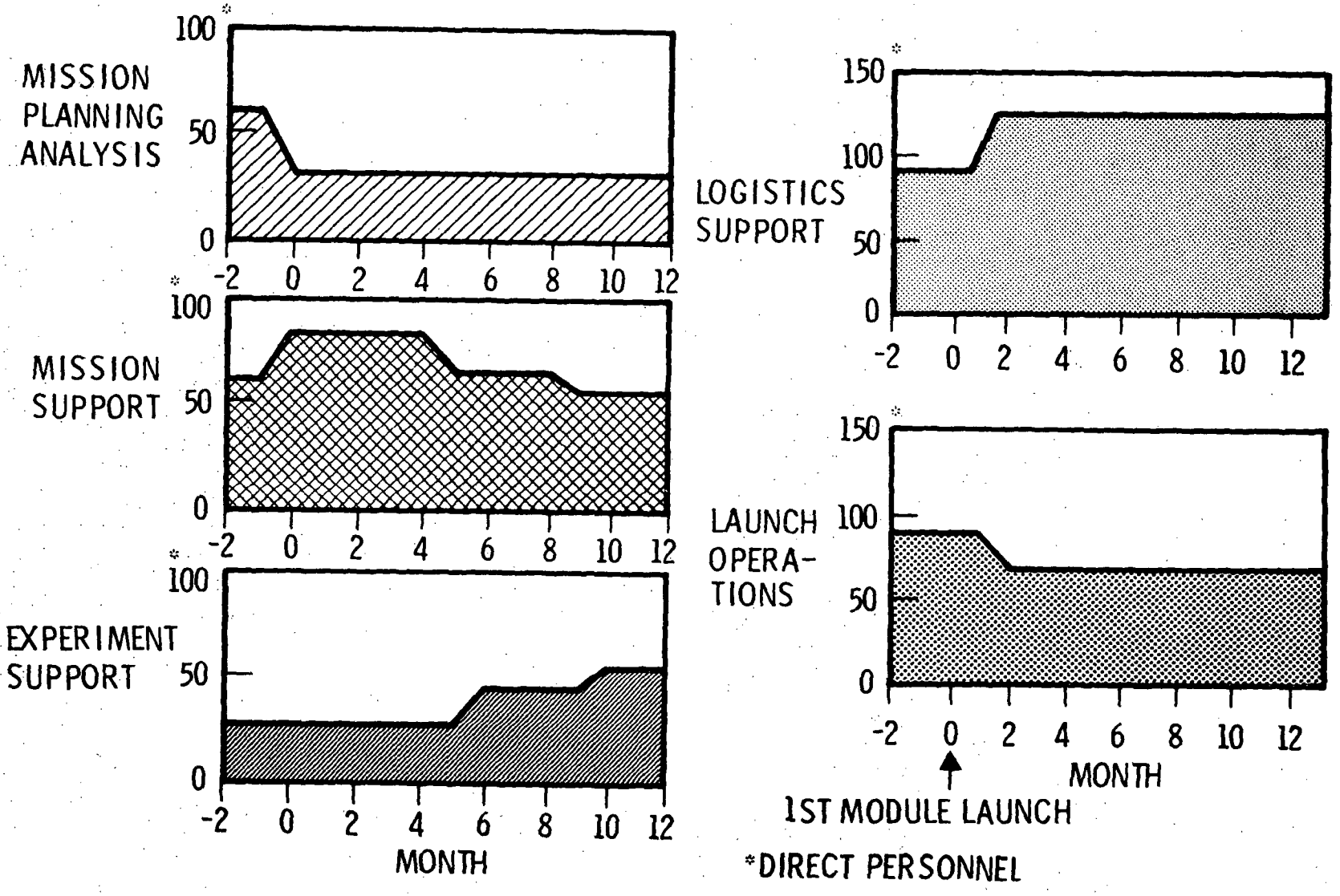


Figure 4-11. Mission Management Manning in Buildup

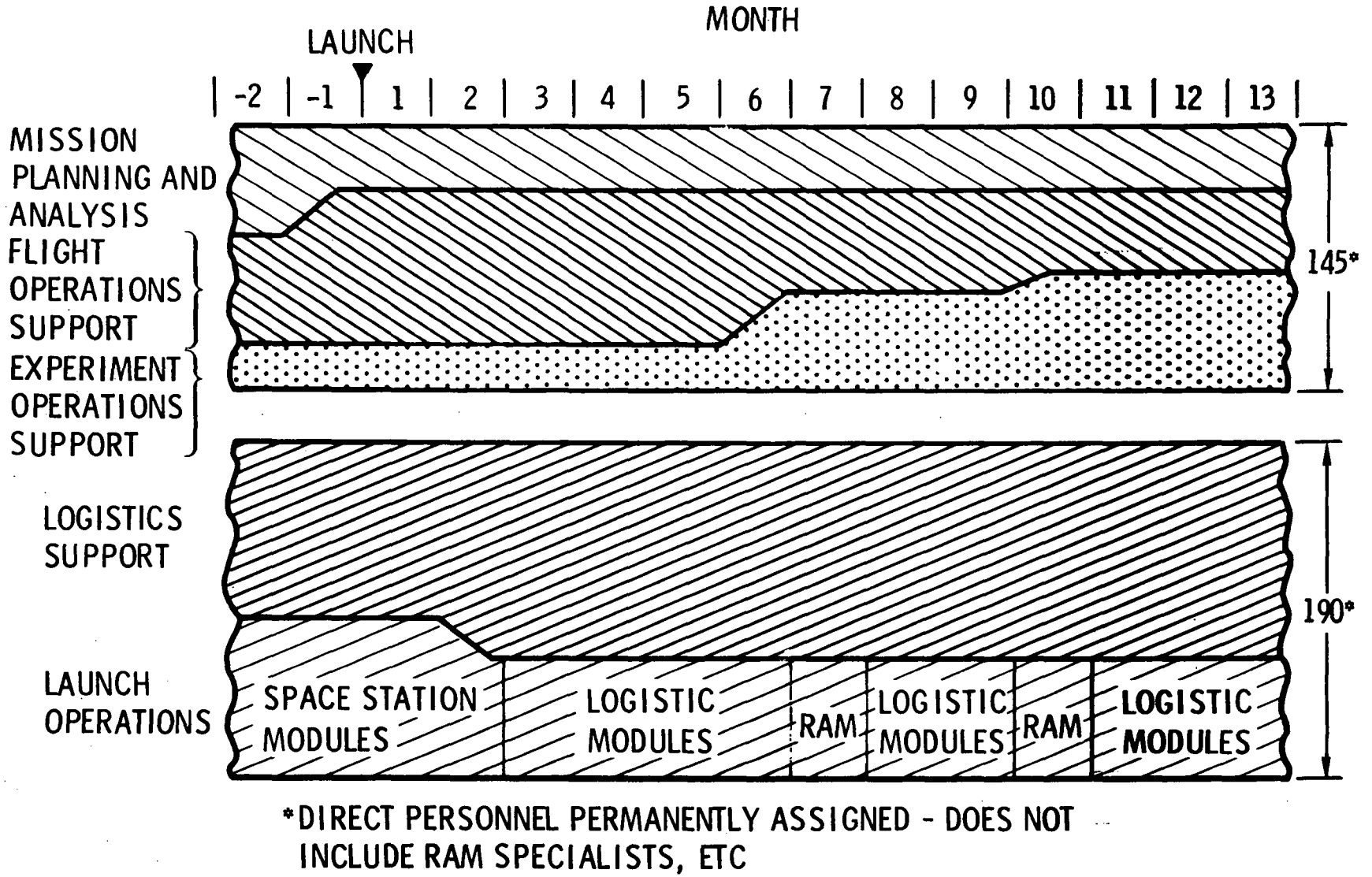


Figure 4-12. Phasing of Mission Management Functions

Table 4-3

SPACE STATION CAPABILITY
DURING BUILDUP

Subsystem	Launch/Module				
	First/ Power	Second/ Crew	Third/ GPL	Fourth/ Logistics	Fifth/ Logistics
Habitability	Shirtsleeve shuttle air	Six-man EC/LS	Six-man EC/LS	Repressur-ization gas	
Power	Solar array No. 1 battery set			Nos. 2 and No. 3 battery sets	Nos. 4, 5, and 6 battery sets
Attitude Control	RCS No. 1	RCS No. 2		Four CMG's	
Communications	VHF S-band	Wideband			
Data Management	Central computer	Control and display	Redun-dant data Manage-ment		
Onboard Checkout	Central computer, portable C/D			Three portable C/D units	
Thermal Control	Operable for each module				

generation, flight crew handbook inputs, and test technique development. Hence, they will be thoroughly familiar with the module for which they will be responsible. The result will be a prelaunch and launch crew that will combine the expertise of the factory checkout and launch operations and that will maintain continuity of operational knowledge.

In addition to launch operations described, four functions of mission support operations, described in Section 4. 1. 4 of this volume, are as follows: Mission

Planning and Analysis, Logistics Operations Support, Flight Operations Support, and Experiment Operations Support.

Of these four, most of the functions of Logistics Operations Support should be at the launch site due to critical schedules and the actual cargo to be delivered to orbit. The Space Station module supplemental crew decreases after the third module launch and the launch crew for the Logistic Modules is increased in anticipation of the first of many Logistics Modules. This provides an essentially flat-loaded task between the logistics and single launch crews.

The other three functions of mission support also tend to flat-load the manpower. Mission planning and analysis at first launch will settle down to a smaller crew than that required for preflight planning. Flight operations support increases at first launch and settles down after shakedown operations and arrival of the first two RAM modules. Experiment operations support, a project oriented function with a mix similar to the orbiting scientific crew, will increase at the arrival of each of the first two RAM modules than stabilize.

4.1.1.6 Space Station Ground Operations Requirements Summary
Ground operations will impose a number of requirements upon the Space Station and, in turn will be constrained by the Space Station design and the design of existing facilities. These requirements and constraints, either implied or stated explicitly in the preceding subsections, are summarized in this subsection.

1. Space Station module launches shall be from the Shuttle launch site.
2. No checkout shall be performed at the launch site.
3. Modules shall be shipped to the launch site fully flight-ready with the the exception of expendables and batteries that must be loaded at the launch site. Shipping short shall not be permitted. The only permissible missing hardware items in the modules shall be those items deliberately removed at the factory to meet Shuttle payload weight limitations, and planned for later delivery to orbit by a logistics flight.

4. Required Space Station module operations shall be performed in the orbiter maintenance area.
5. The Mobile service structure shall not be used.
6. Space Station modules shall accommodate performance of all ground processing, prior to Shuttle stacking, in a horizontal position, and after stacking in a vertical position.
7. Space Station modules shall provide for direct attachment of hoisting GSE while in the orbiter cargo bay (with orbiter horizontal or vertical, although attach points need not be the same for each orientation).
8. Space Station module umbilical connections shall be accessible through access doors provided in the orbiter skin after module installation in the orbiter.
9. Interior panels, displays, and controls shall have, as a goal, a heads-up orientation with the module in a horizontal position.
10. The Space Station modules shall not require a clean room environment. If special cleanliness protection is required by some module hardware, provisions shall be built into the module to protect the sensitive equipment, or individual covers shall be provided.
11. Non hazardous fluid serving equipment shall be portable, and shall be temporarily located in the orbiter maintenance area during Space Station prelaunch and launch operations.
12. Servicing equipment for hazardous fluids shall be located on pad.
13. It shall be possible, although not normally done, to open all docking port hatches during ground operations except when modules are in the Shuttle.
14. Space Station module subsystems shall operate in a 1-g environment with the module horizontal or vertical.
15. Active thermal control of module subsystems shall not be required on the ground when the subsystems are off.
16. Any ordnance arming or connecting points shall be accessible with the module installed in the orbiter on pad.
17. Module design shall not require installation of flight hardware on pad (except ordnance igniters if used).

18. Access to the vicinity of modules during ground processing shall be controlled and limited.
19. No access to module interiors shall be permitted except in an emergency, or for loading power module batteries.
20. Hazardous liquids and gases shall be loaded on pad.
21. Integral experiment equipment launched with the GPL shall be installed and checked at the factory.
22. Flight interfaces previously mated and functionally verified at the factory shall not be demated at the launch site unless necessary to effect repairs. In this case, interfaces shall be completely reverified after remating.
23. Modules shall be designed for transportation in a horizontal position, i.e., the long-axis horizontal.
24. Space Station module subsystems shall be used to accomplish ground functions whenever possible.
25. GSE shall supplement module subsystems for:
    A. Handling and transportation
    B. Servicing
    C. Module subsystems turn-on and status verification during countdown.
    D. Checkout of repaired subsystems in the event of a malfunction during normal operations.
26. Perishables shall not be launched in Space Station modules.
27. All prelaunch and launch operations shall be controlled by detailed procedures (manual, automatic, or both).
28. The same GSE shall be used at the factory and launch site when possible.
29. No less than two people (buddy system) shall be allowed in the power module during battery installation, or any module during emergency repairs.
30. Space Station ground operations shall comply with the safety requirements of the launch site (KSC) and range (ETR).

4.1.2 Logistics/Crew Cargo Module Operations

Two types of modules will be used with the Space Station Program for logistics. The first, the Logistics Module (Figure 4-13), used during ISS operations, will be unmanned while in the Shuttle and will be docked to the orbiting station by the Shuttle. Two Space Station crewmen will ride in the Shuttle passenger compartment each flight to effect crew rotation. The second type, the Crew Cargo Module, will be used during GSS operations and will be similar to the first except it will contain a life support system and carry six passengers to accommodate rotation of the larger crew. In both cases the subsystems onboard are simple, requiring little in the way of ground checkout. The basic concept for Logistics and Crew Cargo Module operations is similar to that developed for the 10-m (33-ft)-dia station, i.e.,

A. Existing facilities will be used for Log Module and CCM operations (the VAB low bay area).
B. Log Module and CCM operations will be a continuing effort for the duration of the Space Station Program (with up to one launch per month except when superceded by a Space Station module or research and applications module (RAM) launch).
C. There will be no flight operations support impact (in terms of Log Module and CCM mission control facilities and GSE) beyond that required for Space Station and Shuttle mission control operations.

The nature of Log Module and CCM activities at KSC is described in more detail in the following paragraphs.

4.1.2.1 Logistics Module Transportation

On completion of acceptance test and preparation for shipment at their assembly and integration areas, modules will be shipped to KSC.

During preparation for shipment at the final assembly and integration area, the module will be installed on its transporter and a prime mover attached. The module will then proceed from that area over a predetermined route to the aircraft loading areas. The module will move via convoy consisting of a prime mover; a transporter maintenance vehicle; and leading and following vehicles equipped with wideload signs, flashing amber lights, and communications. In addition, equipment will be available as necessary to perform

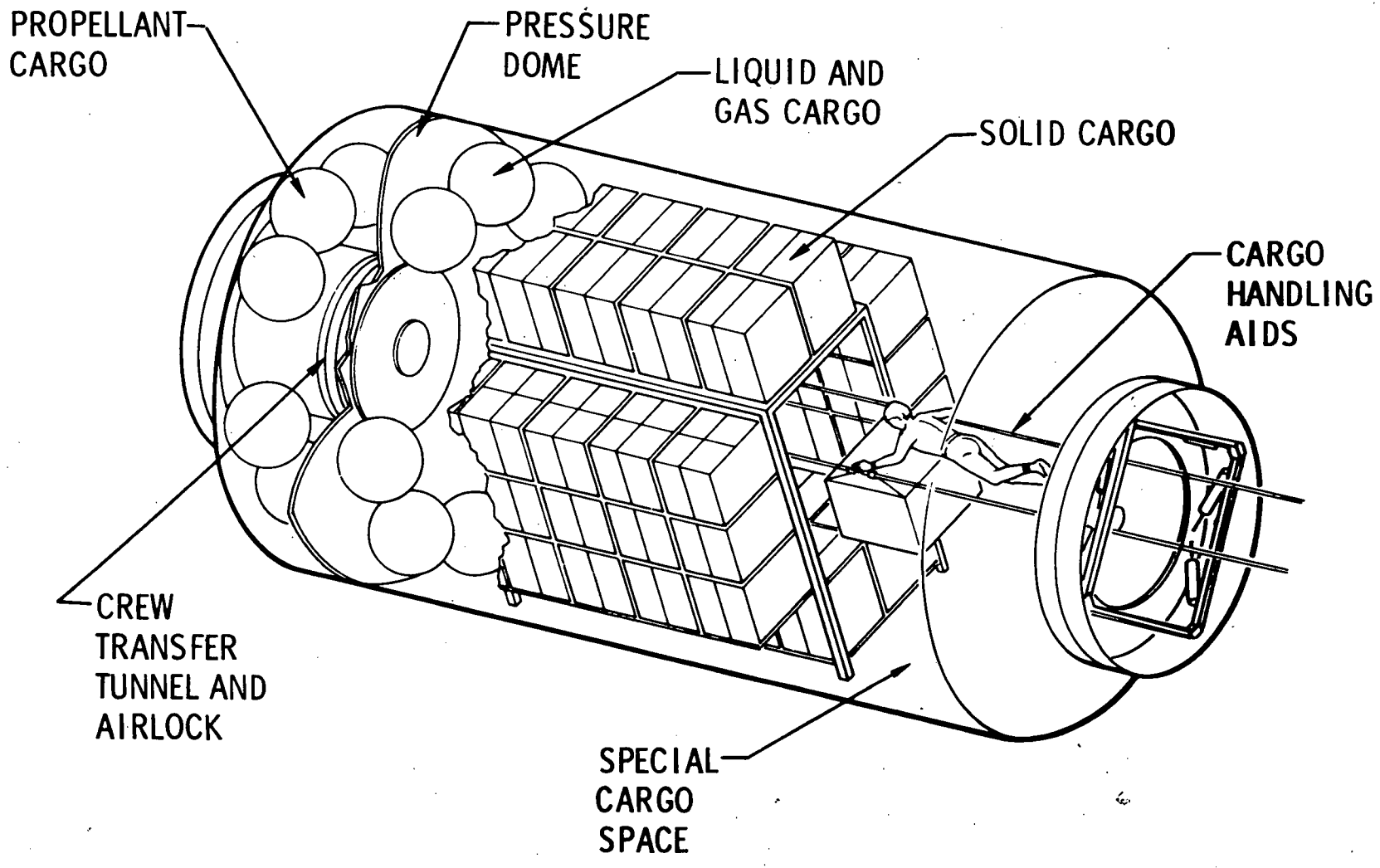


Figure 4-13. Logistics Module

emergency road maintenance. The speed fo the Log Module and transporter will be held to a minimum to prevent traffic accidents and to minimize shock and vibration transmitted to the module. The route will be selected to ensure safe, smooth, unobstructed passage to the module and transporter envelope and to minimize traffic interference. Transportation will be during periods of low traffic activity.

On arrival at the aircraft loading area, the module and transporter will be positioned to best advantage for loading and the prime mover disengaged. Loading will be accomplished in such a manner to reduce shock/vibration transmitted to the module to acceptable limits.

Contractor personnel will accompany the module during transportation to KSC. They will be charged with monitoring the environmental status of the Log Module or CCM inspecting the condition of the protective covering, tie-downs, transporter, and attendant equipment to further assure safe transportation of the module.

On arrival at KSC, the module and transporter will be unloaded as a unit and placed on the ground where the prime mover will be attached. This combination will then proceed over the launch site ramp and roadway system to the refurbishment and turn-around area in the VAB low bay area where receiving inspection will be accomplished.

4.1.2.2 Logistics Module Prelaunch and Launch Operations

Logistics Module operations at KSC have several unique features which depart significantly from previous manned and unmanned spacecraft programs. The modules will carry a large quantity of cargo relative to its overall size (4.3 m (14 ft)/dia by approximately 9 m (30 ft) long). It will be placed in orbit by the Shuttle orbiter, and on return from orbit cannot reenter the atmosphere unilaterally, but must be returned to earth by the Shuttle Orbiter. It will be returned to KSC after its mission. It will be reusable being returned to orbit many times during its lifetime. In addition, the later versions (CCM's) for use with the GSS will provide life support for six crewmen for several days.

As a result, Log Module ground operations must consider post orbiter landing activities, i.e., refurbishment and maintenance, cargo loading and unloading in addition to the more familiar prelaunch and launch operations associated with any launch. The operational flow typical of Log Module processing at KSC, and illustrating these features is summarized in Figure 4-14. Operations interfacing with Log Module operations are shown for reference (connected with dashed flow lines). Note that Log Module operations marked with an asterisk are new to KSC and will have significant impact.

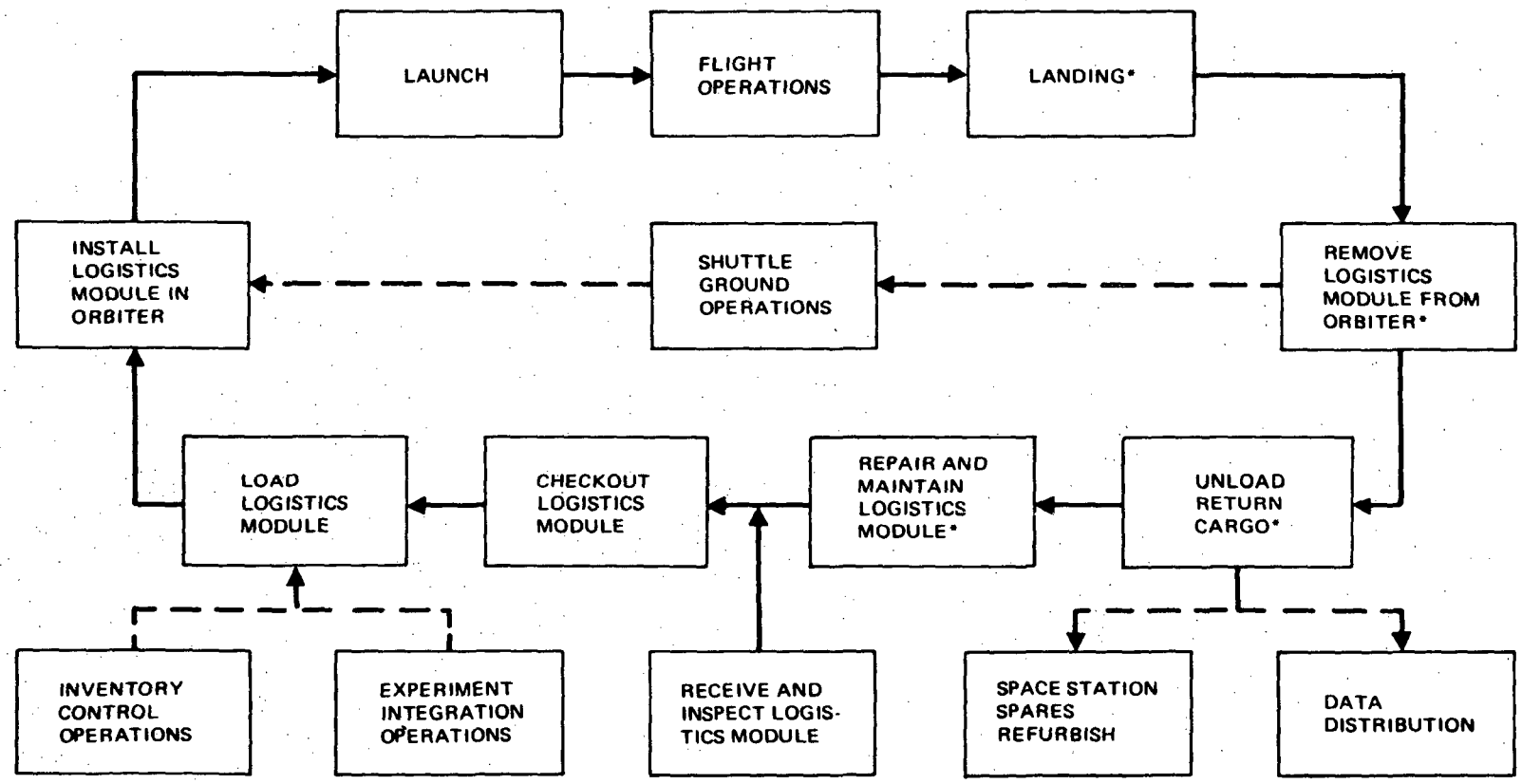
Log Module ground operations must be accomplished efficiently, as the launch rate will approach one every 30 days on the average.

Operational Flow

Overall operational flow proposed for the Log Module at KSC, and the related cargo handling flows are shown in Figure 4-15. Note that the flow shows three major branches; the flow for the initial flight of a Log Module, originating at the factory with manufacturing and shipment to KSC; the flow for repeated flights of a Log Module returned from orbit; and the flow for cargo and supplies to be loaded on the Log Module. These branches converge to a common flow for later stages of Log Module operations, beginning with final checkout of the Log Module and terminating with launch.

Significant features of the operational flow which should be noted include:

A. First flight flow branch for the unmanned Log Module is extremely simple, i.e., it is received and off-loaded, inspected, verified for proper configuration, and given very limited checks (since there are few functional subsystems on the Log Module. No unique requirements are evident for this phase of Log Module operations other than facilities necessary for accomplishment of the operations. The nominal means of shipping the Log Module to KSC will be by air, although other means will be possible. The facility proposed for conducting operations is the VAB low bay.



*NEW TO KSC

Figure 4-14. Logistics Operations Summary

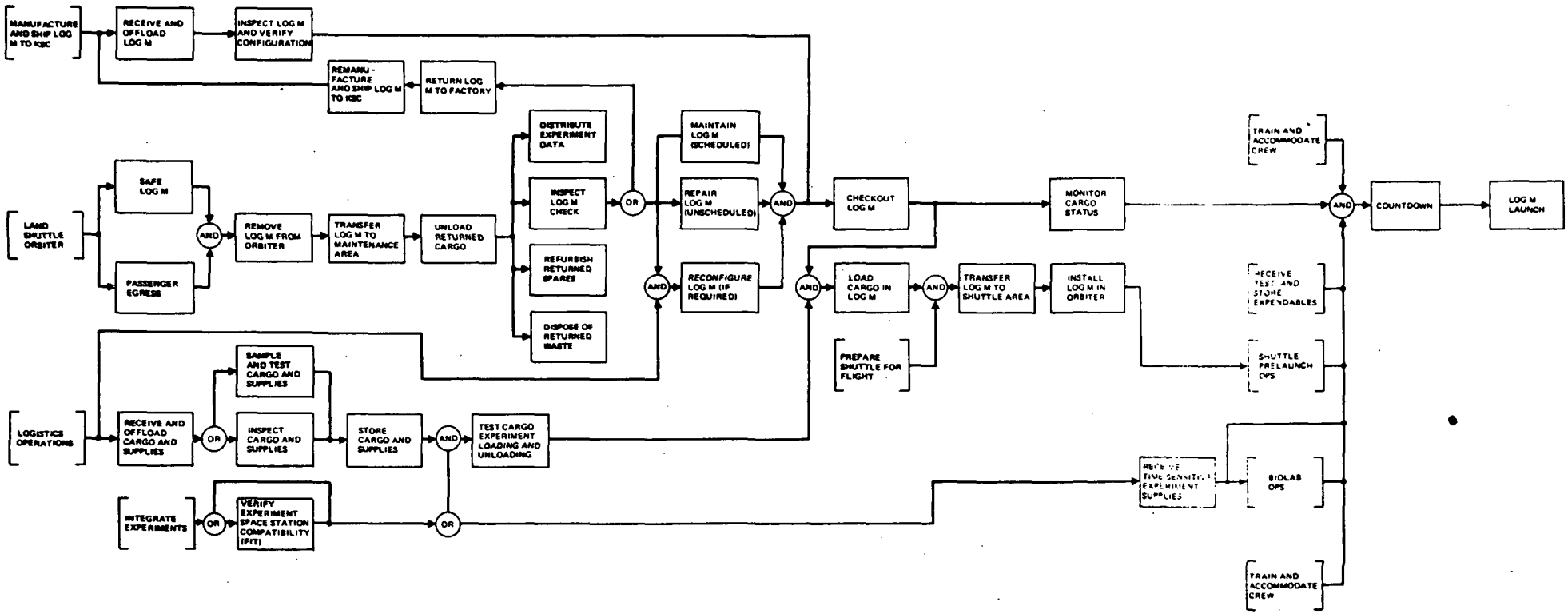


Figure 4-15. Logistics Module Prelaunch and Launch Operations

B. A Log Module may be severely damaged as a result of a shuttle landing mishap, or may require major overhaul after (TBD) flights. The Log Module would be returned to the manufacturer or to KSC shops with remanufacturing capabilities in this case, and treated as a new Log Module arriving at KSC for its first flight when it is returned to operational status.

C. The repeat flight flow branch for the Log Module has several unusual features:

1. The Log Module will be returned to KSC by the shuttle orbiter. Time-critical data will be removed as soon as the shuttle orbiter rolls to a stop. Returning Space Station crew members will also egress from the Shuttle passenger compartment at this time. Portable stairs similar to those used by airlines or other means for passenger removal will be required at the shuttle rollout area. It is assumed that the Shuttle will provide any equipment for crew ingress and egress.
2. The Log Module must be safed when it arrives (lands) at KSC since it will contain residual Space Station propellants and EC/LS expendables and residual experiments expendables. This will be accomplished as soon as the Shuttle crew and passengers have left and the Shuttle has cooled. Log Module servicing equipment will be required at end of the Shuttle runway for Log Module safing.
3. It will contain cargo of various types (experiment data and samples, Space Station parts which have malfunctioned, waste, reusable packaging, etc.) which must be unloaded and given proper disposition. Unloading will be accomplished more easily after Log Module removal from the orbiter, since access to all hatches will then be possible.
4. A postflight inspection and check of the Log Module will be performed to determine if there are any malfunctions or defects which must be repaired in addition to scheduled maintenance. Subsystem tests will ensure that all repairs and reconfiguration have been successfully accomplished, and that the Log Module is again flight ready except for loading.

5. Log Module reconfiguration will be required occasionally as dictated by changes in cargo mix. Therefore, Log Module design must be capable of quick change accommodation of different types cargo, e.g., palletized fluid tank complexes.

D. Operations occurring in the common part of the flow also have several unique features:

1. Log Module cargo status (e.g., expendable tank pressures, valve positions) will be continuously monitored after checkout has been completed until countdown and liftoff.
2. Cargo loading will include loading of all solid and fluid cargo except time sensitive, and hazardous items which will be loaded during countdown. Weight and cg equipment must be located at the cargo loading area to verify the actual weight and cg of the flight loaded Log Module.
3. The Log Module will be top loaded in the shuttle orbiter while it is still horizontal in the shuttle maintenance area, although it will be possible to load the Log Module into the orbiter with the orbital vertical in the VAB high bay.
4. Shuttle operations pace the Log Module operations after it is installed in the orbiter.
5. Log Module countdown will be integrated with the shuttle countdown. Log Module activities during this period will include loading of propellants, cryogenics, and other hazardous fluids, activation of Log Module flight systems and verification of status, and time sensitive cargo ingress.

Several operations which interface with Log Module operations are shown as reference blocks on the diagram. Experiment integration includes mating experiments with the FIT before delivery to the Log Module. Logistics control operations track supply usage, plan procurement of cargo and supplies, and determine cargo mixes as described in subsection 4.1.4.2. Shuttle operations include refurbishment and preparation of both booster and orbiter for the next flight, erection and stacking, and shuttle countdown. Space Station replacement crew and the returned crew are processed through the crew training and accommodation operations block. Finally, biological laboratory

operations care for live experiment specimens until launch (as described in subsection 4. 1. 3. 3) and support orbital experimentation by performing control experiments on the ground in parallel with orbital experiments.

Figure 4-16 is an estimated timeline of Log Module operations. Note that approximately 18 working days (3. 6 weeks) will be required from time of arrival of the module through liftoff to turn a module around.

Ground Handling Approach

It is obvious that handling and transporting of a Log Module returned from orbit will be necessary considering the impracticality of accomplihsing Log Module repair, checkout, and cargo loading, while it is in the Shuttle cargo bay. A number of module handling options were investigated during earlier study efforts, (refer to DRL 160, Line Item 22, Appendix 0). The option which results in the least handling, and hence the least risk of damage during ground operations, is one in which the module is shipped installed on a transporter or dolly or installed on one immediately upon removal from the Shuttle, and remains on this transporter throughout all subsequent operations until it is loaded into a shuttle craft.

Turnaround and Maintenance Activities

Logistics Modules will be maintained through an airline method of operation as illustrated in the flow, i. e., preflight and postflight checks, correction of malfunctions experienced during flight, and periodic maintenance. However, this ideal, as in the case of aircraft, cannot be realized initially. Early repeat flights of the Log Module will require extensive post/preflight testing similar to that required for the first flight. These early flights are analogous to certification flights of aircraft before they are put in regular service. As experience and confidence in test procedures is gained, the amount and complexity of inspection and test will be reduced.

Corrective maintenance of fluid cargo handling equipment can be performed on the modules during flight as well as during postflight turnaround. Certain

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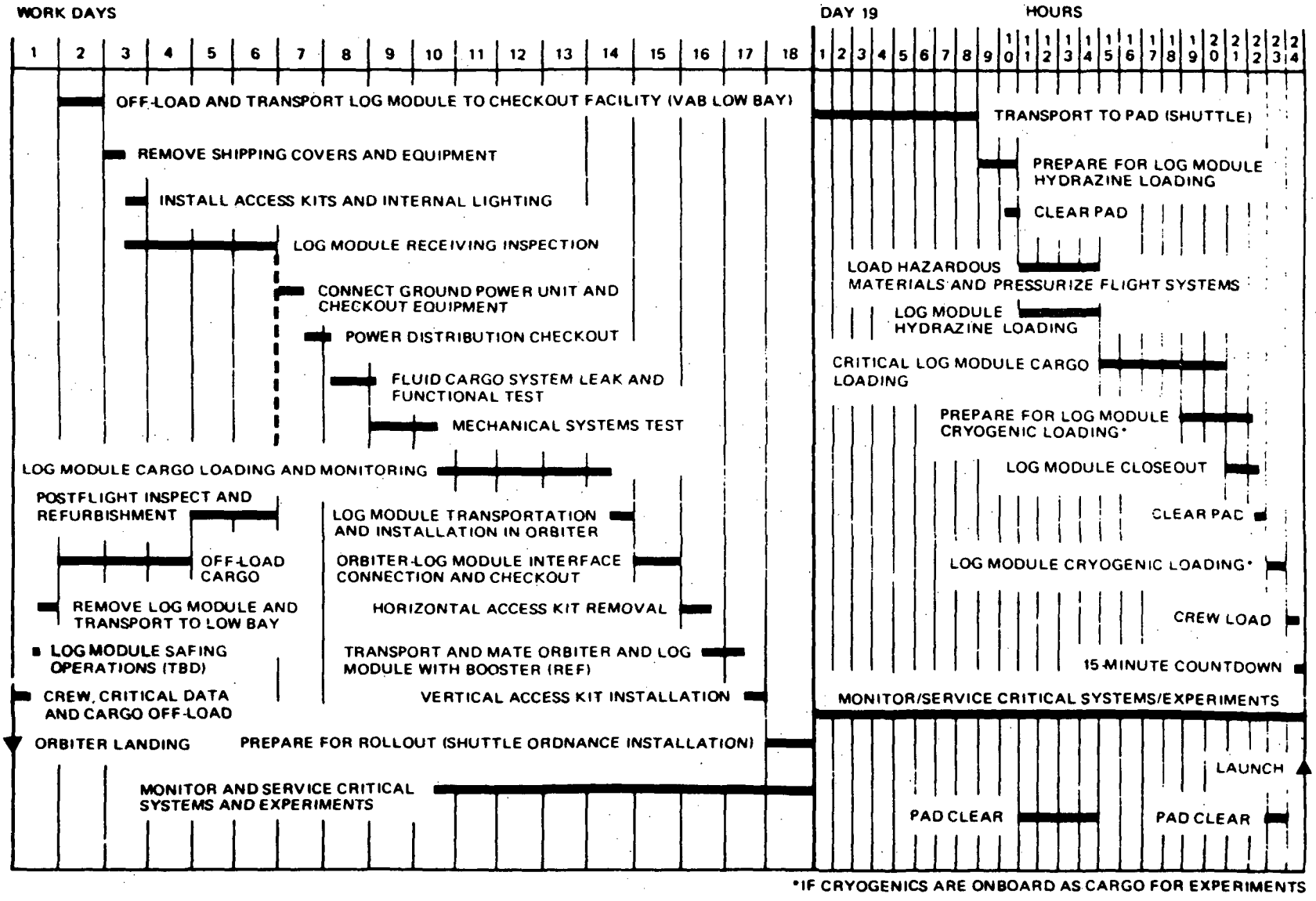


Figure 4-16. Preliminary Master Schedule Logistics Module

critical spares will be carried onboard the Log Module and the Space Station to allow inflight removal and replacement. The bulk of preventive and corrective maintenance performed on the modules will be accomplished on the ground between flights. Regardless as to where maintenance is accomplished, removed hardware will be inspected and refurbished if possible.

Refurbishment operations include the activities necessary to rework, repair, and recommission Log Modules subsystems and subassemblies or components thereof which have been removed because of failure or limited-life considerations.

The items to be refurbished will be sent to inventory control and then shipped to the refurbishment centers operated by contractors or by the Government.

Refurbishment begins with receipt and inspection of the returned items at the refurbishment centers. This activity will determine the reusability of the item and its future disposition. Some returned equipment will have been so badly worn or damaged that it will only be used in further destructive testing and analysis, for display, and to satisfy other needs. Other equipment will be in such a condition that it can be returned to serviceability after some repair or rework. On determination that the returned equipment can be returned to serviceability, it will be sent to either contractor or Government repair and rework agencies. Factors influencing selection of the rework and repair agency will include capability to handle the job relative to personnel, equipment, and facilities; cost; and time required to return the item to the spares inventory.

Returned items will be repaired and reworked to the same specifications as when first produced. Standards and testing will be the same to assure that the refurbished item will perform as satisfactorily as a new item. All items will undergo final acceptance testing.

New facilities and equipment will be developed only if repair and rework requirements are heavier than originally estimated.

On completion of repair and rework and after acceptance testing, the items will be delivered to the Inventory Control Complex. This facility will provide storage for the items until they are required at log module maintenance areas or on orbit. A capability for further testing the newly received spares to verify that they have not been damaged during transportation from the refurbishment locations will be available at the Inventory Control Complex or log module turnaround/maintenance area.

After the spares have been returned to the Inventory Control Complex for storage and have been certified by further testing that they qualify as in-commission, they will be returned to the in-commission status and assigned to the available spares inventory. This will consist of an accounting function which simply adds the particular item to the listing of available spares. The spares will remain in the Inventory Control Complex until required during ground maintenance or until required to be carried onboard the log module or Space Station as inflight spares.

4.1.2.3 Crew Cargo Module Prelaunch and Launch Operations

Crew Cargo Module prelaunch and launch operations will be essentially the same as those for the Log Module. The primary difference will be the additional servicing and checkout required for the six man EC/LS subsystem on board. In this case, approximately 23 working days (4.6 weeks) will be required to turn around a module. The additional week (over and above the 3.6 weeks required for Log Module is a direct result of accommodating the six passengers.

4.1.2.4 Logistics Module Ground Operations Requirements Summary

A number of requirements and constraints for both the ground system and Log Module are inherent in this operational concept and are listed below. Note that some of these requirements were not stated explicitly in the preceding analysis, but are necessary to implement the recommended concept.

A. Log Modules shall accommodate performance of all ground processing in a horizontal position.

B. Log Modules shall provide for direct attachment of hoisting GSE while in the orbiter cargo bay (with orbiter horizontal or vertical—although attach points need not be the same for each position).

C. Log Module servicing (umbilical) connections shall be accessible for Log Module servicing when the Log Module is installed in the shuttle orbiter, with the orbiter vertical (for loading of hazardous fluids on pad and final top off of others during countdown), and with the orbiter horizontal (for safing after landing and initial servicing).

D. Interior equipment, cargo stowage racks, etc., shall be in a heads-heads-up position during ground processing of the Log Modules in the horizontal position.

E. The Log Modules shall be provided with a cargo loading hatch (or hatches) other than docking ports for loading and unloading cargo pallets.

F. The Log Modules shall not require a clean room environment.

G. Log Module design shall be such that reconfiguration due to cargo mix changes will be minimal; i. e., the Log Module cargo carrying accommodations shall be as independent of cargo mix as practical.

H. Reconfiguration of Log Modules, when necessary, shall be easy to implement. Access to all joints and interfaces which must be broken or mated shall be provided. Simple standarized interfaces shall be a goal.

I. Readily accessible test connectors shall be provided for checkout. It shall not be necessary to disconnect flight connectors during ground processing (except for repairs).

J. Umbilical connections shall be provided for monitoring CCM system status after checkout has been completed.

K. Log Module fluid cargo servicing equipment shall be located at the shuttle landing site, the pad, or shall be portable.

L. All Log Module assembly, integration, and acceptance testing shall be accomplished prior to delivering the Log Module to KSC.

M. Log Module interior arrangements and provisions shall allow ground personnel easy access, in a 1-g environment, to all cargo securing and tie down areas, and all maintenance areas.

N. It shall be possible to open all Log Module docking ports and hatches during ground operations except when the Log Module is installed in the Shuttle orbiter.

O. Active Log Module equipment shall operate in the 1-g Earth environment with the Log Module horizontal or vertical.

P. Special atmospheric cleanliness provisions, i.e., clean-room type air conditioning, shall not be required for Log Module exterior and interior access in the VAB. Air presently supplied in the VAB as follows shall be adequate:

1. Humidity: 0 to 100 percent, adjustable to a specific desired value to within ±5 percent.
2. Temperature: 40°F minimum, adjustable to a specific desired value to within ±5°F.
3. Particulate Matter: Standard office-type air conditioning filtration for interior. Exterior shall require no special air treatment.

Q. Active thermal control of the Log Module shall not be required on the ground.

R. Any ordnance arming or connecting points shall be accessible with the Log Module installed in the orbiter on pad.

S. The Log Module design shall not require installation of flight hardware on pad (except ordnance igniters).

T. Prelaunch testing of the Log Module shall be structured to duplicate actual launch and flight operation to the extent practical.

U. Log Module checkout procedures shall be standardized to the extent possible for use at the factory, at KSC, and on orbit.

V. Access to the Log Module during ground processing shall be controlled and limited.

W. Log Module preventive and corrective maintenance shall be accomplished by the removal and replacement of "plug-in" modules.

X. Installation/loading of hypergolics, cryogenics, and ordnance initiator devices in the VAB shall not be permitted. Installation of any ordnance should be planned as late as possible in the processing flow.

Y. Ground access shall be provided for loading live specimens and perishables in the Log Module while on the launch pad.

Z. Hazardous liquids and gases shall be loaded in the Log Module on the launch pad.

4.1.3 Experiments Operations

The experiments analyzed in this study of impact on KSC were derived from the Reference Earth Orbital Research and Applications (Blue Book), NHB 7150.1, preliminary edition dated January 15, 1971. Consideration was given to available data and the baseline experiment flight schedule generated in the Modular Space Station, Phase B Extension study.

The January Blue Book identified experiments in seven discipline areas of research as follows:

- A - Astronomy
- P - Physics
- ES - Earth Observations
- C/N - Communications/Navigation
- MS - Materials Science and Manufacturing
- T - Technology
- LS - Life Sciences

In the Modular Space Station study, 77 FPE's and FPE subgroups were identified in these seven disciplines. Finally, these were reduced to 50 FPE's and subgroups for determining accommodations modes and scheduling in an experiment flight plan. Refer to Table 4-4. As noted in the introduction (Section 1.2), Case 534G was assumed as baseline for this analysis. The accommodation rationale which selected Case 534G for the Modular Space Station is described in Section 2 of MP-01, Space Station Program (Modular) Mission Analysis.

4.1.3.1 Experiments Operations Analysis

The study approach for FPE's or FPE Subgroups and experiment modules consisted of three major steps:

A. Determine the requirements that must be provided for each FPE or FPE Subgroup in established categories of pertinent KSC operations. Then identify groups of GPE's or FPE Subgroups having similar general KSC requirements.

Table 4-4

FPE/SUBGROUP IDENTIFICATION AND ACCOMMODATION TYPE (CASE 534G)

Final FPE/Subgroup Designations (WICK)		Original FPE/Subgroup Designations		Type of Accommodation
A-1	X-Ray Stellar Astronomy	A-1	X-Ray Stellar Astronomy	Free Flying Module (Not Scheduled)
A-2	Advanced Stellar Astronomy	A-2	Advanced Stellar Astronomy	Free Flying Module (Not Scheduled)
A-2A	Intermediate Stellar Astronomy	A-2A	Intermediate Stellar Astronomy	Free Flying Module
A-3AA	Advanced Solar Astronomy	A-3A	1.5 m Photoheliograph/ 0.25 m Spectroheliograph 0.5 m X-Ray Telescope	Free Flying Module (Not Scheduled)
		A-3B	Solar Coronagraph	
A-3CC	ATM Follow-On	A-3C	Photoheliograph	Free Flying Module
		A-3D	X-Ray Spectroheliograph	
		A-3E	UV Long Wave Spectrometer	
A-4A	0.9 m Narrow Field UV Telescope	A-4A	0.9 m Narrow Field UV Telescopes	Attached Module
A-4B	0.3 m Wide Field UV Telescope	A-4B	0.3 m Wide Field UV Telescopes	Attached Module
A-4C	Small UV Survey Telescope	A-4C	Small UV Survey Telescopes	Attached Module
A-5A	X-Ray Telescope	A-5A	Lower-Energy Experiment	Free Flying Module

Table 4-4

FPE/SUBGROUP IDENTIFICATION AND ACCOMMODATION TYPE (CASE 534G) (Continued)

Final FPE/Subgroup Designations (WICK)		Original FPE/Subgroup Designations		Type of Accommodation
A-5B	Gamma Ray Telescope	A-5B	Higher-Energy Experiment	Attached Module
A-6	IR Telescope	A-6	IR Telescope	Attached Module
P-1A	Atmospheric and Magneto Science	P-1A	Atmospheric and Magnetospheric Science	Integral (Carry-On)
P-1B	Cometary Physics	P-1B	Cometary Physics	Integral (Carry-On)
P-1C	Meteoroid Science	P-1C	Meteroid Science	Integral (Carry-On)
P-1D	Thick Material Meteoroid Penetration	P-1D	Thick Material Meteoroid Penetration	Integral (Carry-On)
P-1E	Small Astronomy Telescopes	P-E	Small Astronomy Telescopes	Integral (Carry-On)
P-2A	Wake Measurements from Station and Booms	P-2A	Wake Measurements from Station and Booms	Integral (Carry-On)
P-2B	Wake, Plasma, Wave Particle, Electron Beam	P-2B	Wake Measurements from Subsatellites	Attached Module
		P-2C	Plasma Resonances	
		P-2D	Wave Particle Interactions	
		P-2E	Electron and Ion Beam Interaction	
P-3	Cosmic Ray Physics Laboratory	P-3	Cosmic Ray Physics Laboratory	Attached Module (Not Scheduled)

Table 4-4

FPE/SUBGROUP IDENTIFICATION AND ACCOMMODATION TYPE (CASE 534G) (Continued)

Final FPE/Subgroup Designations (WICK)		Original FPE/Subgroup Designations		Type of Accommodation
P-3C	Plastic/Nuclear Emulsions	P-3C	Plastic/Nuclear Emulsions	Integral (Carry-On)
P-4A	Airlock and Boom Experiments	P-4A	Airlock and Boom Experiments	Integral (Carry-On)
P-4B	Flame Chemistry and Laser Experiments	P-4B	Flame Chemistry and Laser Experiments	Integral (Carry-On)
P-4C	Test Chamber Experiments	P-4C	Test Chamber Experiments	Integral (Carry-On)
ES-1	Earth Observation Facility	ES-1	Earth Observation Facility	Attached Module (Not Scheduled)
ES-1AA	Earth Observation Sequential	ES-1A	Meteorological and Atmospheric Science	Attached Module
		ES-1B	Land Use Mapping	
		ES-1C	Air and Water Pollution	
		ES-1D	Resource Recognition	
		ES-1E	Natural Disasters	
		ES-1F	Ocean Resources	
ES-1G	Minimum Payload (Core)	ES-1G	Minimum Payload	Attached Module
C/N-1	Communications/ Navigations Facility	C/N-1	Communications/ Navigations Facility	Attached Module

Table 4-4

FPE/SUBGROUP IDENTIFICATION AND ACCOMMODATION TYPE (CASE 534G) (Continued)

Final FPE/Subgroup Designations (WICK)	Original FPE/Subgroup Designations	Type of Accommodation
C/N-1A Communications/ Navigations Subgroup A	C/N-1A Communications/ Navigations Subgroup A	Attached Module
C/N-1B Communications/ Navigations Subgroup B	C/N-1B Communications/ Navigations Subgroup B	Attached Module
MS-3A Crystal Growth, Biological and Physical Growth	MS-1IIIA Space Station Group	Integral (Carry-On)
MS-3B Crystal Growth from Vapor	MS-1IIIB Space Station Group	Integral (Carry-On)
MS-3C Controlled Density Materials	MS-1IIIC Space Station Group	Integral (Carry-On)
MS-3D Liquid and Glass Processing	MS-1IIID Space Station Group	Integral (Carry-On)
MS-3E Supercooling and Homogenous Nucleation	MS-1IIIE Space Station Group	Integral (Carry-On)
T-1A Contamination Experimental Package	T-1A Contamination Package No. 1	Integral (Carry-On)
T-1B Contamination Monitor Package	T-1B Contamination Package No. 2	Integral (Carry-On)
T-2A Long-Term Cryogenic Storage	T-2A Long Term Cryogenic Storage	Free Flying Module (Not Scheduled)

Table 4-4

FPE/SUBGROUP IDENTIFICATION AND ACCOMMODATION TYPE (CASE 534G) (Continued)

Final FPE/Subgroup Designations (WICK)		Original FPE/Subgroup Designations		Type of Accommodation
T-2BB	Short-Term Cryogenic Storage	T-2B	Short Term Cryogenic Storage	Free Flying Module (Not Scheduled)
		T-2C	Slush Propellant	
		T-2D	Non Cryogenes 1	
		T-2E	Non Cryogenes 2	
T-3A	Astronaut Maneuver Unit	T-3A	Astronaut Maneuver Unit	Integral (Carry-On)
T-3B	Manned Work Platform	T-3B	Manned Work Platform	Attached Module
T-4A	Long-Duration System Tests	T-4A	Long-Duration Systems Tests	Integral (Initial GPL)
T-4B	Medium-Duration Tests	T-4B	Medium-Duration Tests	Integral (Initial GPL)
T-4C	Short-Duration Tests	T-4C	Short-Duration Tests	Integral (Carry-On)
T-5A	Initial Flight Teleoperator	T-5A	Initial Flight	Integral (Carry-On)
T-5B	Functional Teleoperator	T-5B	Functional Manipulation	Integral (Carry-On)
T-5C	Ground Control Teleoperator	T-5C	Ground Control	Integral (Carry-On)
LS-1A	Minimal Medical Research Facility	LS-ST/A	Minimal Medical Research Facility	Integral (Initial GPL)
LS-1B	Minimal Life Science Research Facility	LS-ST/B	Minimal Life Science Facility	Attached Module

Table 4-4

FPE/SUBGROUP IDENTIFICATION AND ACCOMMODATION TYPE (CASE 534G) (Continued)

Final FPE/Subgroup Designations (WICK)		Original FPE/Subgroup Designations	Type of Accommodation
LS-1C	Intermediate Life Science Research Facility	LS-ST/C Interim Life Science Facility	Attached Module
LS-1D	Dedicated Life Science Research Facility		Attached Module (Not Scheduled)

B. Determine a typical sequence of operations at KSC for each group identified above.

C. Identify GSE and supporting facilities required at KSC for each group.

The approach was based on the following ground rules and assumptions:

A. The Modular Space Station GPL will include equipment for FPE Subgroups P-1D, T-4A, T-4B, and LS-1A on the initial launch. This equipment will be installed during module fabrication. Therefore, these subgroups were not included in these experiments analyses, but were considered in the requirements for the GPL module.

B. The Case 534G Experiment Flight Schedule is baseline for schedule and accommodations mode.

C. Checkout and test of experiment modules will include those subsystems and functions that are critical to achieving a satisfactory rendezvous and docking with the Space Station.

D. Checkout and test of experiments will be determined for each FPE considering the criticality of the function to orbit operations, the difficulty or impossibility of adjustment or repair on orbit, and the validity of a ground verification exercise.

E. The philosophy of orbit-ready from the factory is considered a goal and will be followed where technically feasible.

In the first step of the approach, established criteria were applied to the FPE's for grouping experiments with common or similar KSC requirements. These criteria and their rationale were as follows:

A. Specialized or Unique Facilities

Are specialized or unique facilities such as laboratories, clean rooms, or shops required? FPE's requiring special or unique launch site facilities significantly impact program planning because of the long lead time associated with the design, construction, and activation of new facilities.

B. Maintenance of Unique Protective Environment

Does the FPE or module require continuous maintenance of a protective environment not normally provided by launch site facilities?

Experiments in this category must be continuously monitored, replenishment consumables provisioned, and operational and maintenance procedures are required.

C. Test and Checkout Requirements
Is test and checkout required at the launch site? If test and checkout is required (consistent with the "orbit ready from the factory" philosophy) facilities must be provided or modified and provisions must be made to accommodate associated GSE.

D. Prelaunch Servicing of Consumables
Is prelaunch servicing of comsumables required? If servicing is required, consumables must be stored and GSE may be required.

E. Lift-Off Status
Is the FPE or module active at lift-off? If the equipment is active at lift-off, countdown activities requirements must be defined.

F. Installation During Countdown
Is installation during the launch countdown required? Requirements for installation during the launch countdown imply interfaces with KSC launch pad facilities and require integration with other program elements.

G. Program-Peculiar Functions
Are program peculiar functional activities required? Requirements for experiment electrical and mechanical interface verification with the Flight Integration Tool (FIT) must be met and coordinated with FPE installation in the module carrier.

These criteria were applied individually to each of the FPEs or FPE Subgroups scheduled in the Case 534G Flight Plan, except those launched integrally with the GPL. (FPEs launched with the GPL were considered as a subsystem of the station and accordingly were included with the GPL for impact on KSC.) The result of applying these criteria is shown in Table 4-5. When the FPEs and FPE Subgroups are rearranged and grouped according to common criteria, six distinct groups become apparent as shown in Table 4-6. A summary of significant factors and commonalities of these groups is shown in Table 4-7.

The second part of the study approach was to determine a typical sequence of operations at KSC for each of the groups. This analysis resulted in functional flow block diagrams that are presented in Subsection 2.3.3 of MP-03 (Integrated Mission Management Operations) together with descriptions of the activities that will be required.

The third part of the approach, to identify the supporting facilities and GSE required at KSC, was then accomplished. Data derived in this analysis are presented in Sections 3 and 4 of MP-03, Integrated Mission Management Operations. A summary is presented in Section 4 of this document.

4.1.3.2 Experiment Prelaunch and Launch Operations

The detailed prelaunch and launch operations for the six experiments are presented in Section 2.3.3 of MP-03. Since the operations descriptions are extensive due to the variety of experiments, they are not repeated in this volume.

4.1.3.3 Experiments Ground Operations Requirements Summary

Prelaunch and launch operations for experiments will normally be confined to the monitoring of certain critical parameters such as inert gas blankets on optical systems. Specific exceptions and associated launch site operational concepts are as follows:

Space Biology Experiments – The operational activities associated with the specimens for the space biology experiments represent the major impact of the experiment program on the launch site. A biological laboratory must be provided for specimen storage, care, feeding, and flight preparation. It is desirable that this facility duplicate as far as possible the orbital configuration. This similarity has the following inherent advantages:

A. Minimize transients imposed on specimens in transition from one facility to another.
B. The ground unit can serve as a configuration control article.
C. The ground facility can serve as the required one-g experiment control laboratory.

Table 4-5

GENERAL CATEGORIZATION ANALYSIS

Category / FPE Subgroup	I Specialized or Unique Facilities	II Maintenance of Protective Environment Not Normally Provided by Launch Site Facilities	III Test and Checkout Required at Launch Site	IV Prelaunch Servicing of Consumables	V FPE Subgroup or Module Active at Lift-off	VI Installation During Countdown Required	VII Program Peculiar Functions Required
A-1 X-Ray Stellar Astronomy		Refrigerated storage for X-ray polarimeter; inert gas blanket	Electrical; OCS; controls and displays checkout; docking electrical interface	LN_2 loading for cryostat; monopropellant			
A-2 Advanced Stellar Astronomy		Inert gas blanket	Electrical; OCS, controls and displays checkout; docking electrical interface	Monopropellant			
A-2A Intermediate Stellar Astronomy		Inert gas blanket	Electrical, OCS, controls and displays checkout; docking electrical interface	Monopropellant			
A-3AA Advanced Solar Astronomy		Inert gas blanket	Electrical, OCS, controls and displays checkout; docking electrical interface	Monopropellant			
A-3CC ATM Follow-on		Inert gas blanket	Electrical, OCS, controls and displays checkout; docking electrical interface	Monopropellant			
A-4A 0.9M Narrow Field UV Telescope	UV Instrument Laboratory; Optics Laboratory	Inert gas blanket	Electrical, OCS, controls and displays checkout; docking electrical interface				
A-4B 0.3M Wide-Field UV Telescope	UV Instrument Laboratory/ Optics Laboratory	Inert gas blanket	Electrical, OCS, controls and displays checkout; docking electrical interface				
A-4C Small UV Survey Telescope	UV Instrument Laboratory; Optics Laboratory	Inert gas blanket	Electrical, OCS, controls and displays checkout; docking electrical interface				

Table 4-5 (Continued)

GENERAL CATEGORIZATION ANALYSIS

Category / FPE Subgroup	I Specialized or Unique Facilities	II Maintenance of Protective Environment Not Normally Provided by Launch Site Facilities	III Test and Checkout Required at Launch Site	IV Prelaunch Servicing of Consumables	V FPE Subgroup or Module Active at Lift-off	VI Installation During Countdown Required	VII Program Peculiar Functions Required
A-5A X-Ray Telescope	Optics Laboratory	Inert gas blanket	Electrical, OCS, controls and displays checkout; docking electrical interface	Monopropellant			
A-5B Gamma Ray Telescope	Optics Laboratory	Refrigerated service for gamma ray spectrometer	Electrical, OCS, controls and displays checkout; docking electrical interface	Service cryogenics loop			
A-6 IR Telescope	Optics Laboratory	Refrigerated storage for IR sources; inert gas blanket	Electrical, OCS, controls and displays checkout; docking electrical interface	Service cryogenics loop LHe and LNe			
P-1A Atmospheric and Magneto Science	Optics Laboratory	Refrigerated storage for IR spectrometer	Electrical, OCS, controls and displays checkout	LHe			Mechanical and electrical interface with FIT; CCM integration
P-1B Cometary Physics							Mechanical and electrical interface with FIT; CCM integration
P-1C Meteoroid Science	Optics Laboratory		Electrical, OCS, control and displays checkout				Mechanical and electrical interface with FIT; CCM integration
P-1E Small Astronomy Telescopes	Optics Laboratory		Electrical, OCS, controls and displays checkout				Mechanical and electrical interface with FIT; CCM integration
P-2A Wake Measurements from Station and Booms	Particle source and vacuum chamber for calibration	Storage environment control	Electrical, OCS, controls and displays checkout				Mechanical and electrical interface with FIT; CCM integration

Table 4-5 (Continued

GENERAL CATEGORIZATION ANALYSIS

Category / FPE Subgroup	I Specialized or Unique Facilities	II Maintenance of Protective Environment Not Normally Provided by Launch Site Facilities	III Test and Checkout Required at Launch Site	IV Prelaunch Servicing of Consumables	V FPE Subgroup or Module Active at Lift-off	VI [illegible]	VII Program Peculiar Functions Required
P-2BB Wake, Plasma Wave Particle, Electrical Beam	Particle source and vacuum chamber for calibration	Storage environment control	Electrical, OCS, control and displays checkout; docking electronic interfaces	N_2 Subsatellite fuel			
P-3 Cosmic Ray Physics Laboratory		Storage environment control	Electrical, OCS, controls and displays checkout; docking electrical interfaces	Argon/Methane LN_2 and LH_e			
P-3C Plastic/ Nuclear Emulsions			Electrical, OCS, controls and displays checkout				Mechanical and electrical interface with FIT; CCM integration
P-4A Airlock and Boom Experiments			Electrical, OCS, controls and displays checkout	N_2, O_2, He			Mechanical and electrical interface with FIT; CCM integration
P-4B Flame Chemistry and Laser Experiments		Storage environment control	Electrical, OCS, controls and display checkouts	Various oxidizer gases; various gas/liquid fuels; inert gases			Mechanical and electrical interface with FIT; CCM integration
P-4C Test Chamber Experiments		Storage environment control	Electrical, OCS, controls and displays checkout	LHe, N_2, H_2O Freon			Mechanical and electrical interface with FIT; CCM integration
ES-1 Earth Observation Facility		Storage environment control	Electrical, OCS controls and displays checkout; docking electrical interface	LN_2 coolant			
ES-1AA Earth Observation Sequential		Storage environment control	Electrical, OCS, controls and displays checkout; docking electrical interface	LN_2 coolant			

Table 4-5 (Continued)

GENERAL CATEGORIZATION ANALYSIS

Category / FPE Subgroup	I Specialized or Unique Facilities	II Maintenance of Protective Environment Not Normally Provided by Launch Site Facilities	III Test and Checkout Required at Launch Site	IV Prelaunch Servicing of Consumables	V FPE Subgroup or Module Active at Lift-off	VI Installation During Countdown Required	VII Program Peculiar Functions Required
ES-1G Minimum Payload (Core)		Storage environment control	Electrical, OCS, controls and displays checkout; docking electrical interface	LN_2 coolant			
CN-1 Communications/ Navigation Facility	Optical, microwave, laser and supporting laboratory	Storage environment control	Electrical, OCS, control and displays checkout; docking electrical interface				
CN-1A Communications/ Navigation Subgroup A	Optical, microwave, laser and supporting laboratory	Storage environmental control	Electrical, OCS, control and displays checkout; docking electrical interface				
CN-1B Communications/ Navigation Subgroup B	Optical, microwave, laser and supporting laboratory	Storage environmental control	Electrical, OCS, control and displays and checkout; docking electrical interface				
MS-3A Crystal Growth, Biological and Physical Processes		Refrigeration for biological materials					Mechanical and electrical interface with FIT; CCM integration
MS-3B Crystal Growth from Vapor							Mechanical and electrical interface with FIT; CCM integration
MS-3C Controlled Density Materials							Mechanical and electrical interface with FIT; CCM integration
MS-3D Liquid and Glass Properties							Mechanical and electrical interface with FIT; CCM integration

Table 4-5 (Continued)

GENERAL CATEGORIZATION ANALYSIS

Category / FPE Subgroup	I Specialized or Unique Facilities	II Maintenance of Protective Environment Not Normally Provided by Launch Site Facilities	III Test and Checkout Required at Launch Site	IV Prelaunch Servicing of Consumables	V FPE Subgroup or Module Active at Lift-off	VI Installation During Countdown Required	VII Program Peculiar Functions Required
MS-3E Supercooling and Homogeneous Nucleation							Mechanical and electrical interface with FIT; CCM integration
T-1A Contamination Experiment Package	Optical and cleaning laboratory		Electrical, OCS, displays and control checkout				Mechanical and electrical interface with FIT; CCM integration
T-1B Contamination Monitor Package	Optical and cleaning laboratory		Electrical, OCS, displays and control checkout				Mechanical and electrical interface with FIT; CCM integration
T-2A Long-Term Cryogenic System			Electrical, OCS, displays and control checkout; docking electrical interface	LH_2 servicing Monopropellant			
T-2BB Short-Term Cryogenic System			Electrical, OCS, displays and control checkout; docking electrical interface	LH_2 servicing Monopropellant			
T-3A Astronaut Maneuver Unit			Electrical, OCS, displays and control checkout; leak check with O_2	N_2 pressurization			Mechanical and electrical interface with FIT; CCM integration
T-3B Manned Work Platform			Electrical, OCS, displays and control checkout; leak-check, helium; docking electrical interface	Hydrazine loading			

Table 4-5 (Continued)
GENERAL CATEGORIZATION ANALYSIS

Category / FPE Subgroup	I Specialized or Unique Facilities	II Maintenance of Protective Environment Not Normally Provided by Launch Site Facilities	III Test and Checkout Required at Launch Site	IV Prelaunch Servicing of Consumables	V FPE Subgroup or Module Active at Lift-off	VI Installation During Countdown Required	VII Program Peculiar Functions Required
T-4C Short-Duration Tests			Electrical, OCS, control and displays checkout				Mechanical and electrical interface with FIT; CCM integration
T-5A Initial Flight Teleoperator			Electrical, OCS, controls and displays checkout; leak-check helium	N_2 loading			Mechanical and electrical interface with FIT; CCM integration
T-5B Function Teleoperator			Electrical, OCS, controls and displays checkout; leak-check helium	N_2 loading			Mechanical and electrical interface with FIT; CCM integration
T-5C Ground Control Teleoperator			Electrical, OCS, controls and displays checkout; leak-check helium	N_2 loading			Mechanical and electrical interface with FIT; CCM integration
LS-1B Minimal Life Science Research	Biological laboratory	Environmental control and life support; nutrients for specimens	Electrical, OCS, controls and displays checkout; docking electrical interface	Life support commodities	Environmental control and life support; specimen restraints verification	Specimens	
LS-1C Intermediate Life Science Research Facility	Biological laboratory	Environmental control and life support; food, water for specimens	Electrical, OCS, controls and displays checkout; docking electrical interface	Life support commodities	Environmental control and life support; specimen restraints verification	Specimens	
LS-1D Dedicated Life Science Research Facility	Biological laboratory	Environmental control and life support; food, water for specimens	Electrical, OCS, controls and displays checkout; docking electrical interface	Life support commodities	Environmental control and life support; specimen restraints verification	Specimens	

Table 4-6

KSC REQUIREMENTS GROUPING SUMMARY

KSC Requirements Group	FPE Subgroup / Category	I Specialized or Unique Facilities	II Maintenance of Protective Environment Not Normally Provided by Launch Site Facility	III Test and Checkout Required at Launch Site	IV Prelaunch Servicing of Consumables	V FPE Subgroup or Module Active at Liftoff	VI Installation During Countdown Required	VII Program Peculiar Functions Required
A	A-1		X	X	X			
	A-2		X	X	X			
	A-2A		X	X	X			
	A-3AA		X	X	X			
	A-3CC		X	X	X			
	ES-1		X	X	X			
	ES-1AA		X	X	X			
	ES-1G		X	X	X			
	P-3		X	X	X			
	T-2A			X	X			
	T-2BB			X	X			
	T-3B			X	X			
B	A-4A	X	X	X				
	A-4B	X	X	X				
	A-4C	X	X	X				
	A-5A	X	X	X	X			
	A-5B	X	X	X	X			
	A-6	X	X	X	X			
	CN-1	X	X	X				
	CN-1A	X	X	X				
	CN-1B	X	X	X				
	P-2BB	X	X	X	X			
C	P-3C			X				X
	P-4A			X	X			X
	P-4B		X	X	X			X
	P-4C		X	X	X			X
	T-3A			X	X			X
	T-4C			X				X
	T-5A			X	X			X
	T-5B			X	X			X
	T-5C			X	X			X

Table 4-6 (Continued)

KSC REQUIREMENTS GROUPING SUMMARY

KSC Requirements Group	Category: FPE Subgroup	I: Specialized of Unique Facilities	II: Maintenance of Protective Environment Not Normally Provided by Launch Site Facility	III: Test and Checkout Required at Launch Site	IV: Prelaunch Servicing of Consumables	V: FPE Subgroup or Module Active at Liftoff	VI: Installation During Countdown Required	VII: Program Peculiar Functions Required
D	P-1A	X	X	X	X			X
	P-1B							X
	P-1C	X		X				X
	P-1E	X		X				X
	P-2A	X	X	X				X
	T-1A	X		X				X
	T-1B	X		X				X
E	MS-3A		X					X
	MS-3B							X
	MS-3C							X
	MS-3D							X
	MS-3E							X
F	LS-1B	X	X	X	X	X	X	
	LS-1C	X	X	X	X	X	X	
	LS-1D	X	X	X	X	X	X	

Table 4-7

EXPERIMENT GROUP DESCRIPTION

Group A Modules	Five astronomy, three Earth observations, one physics, and three technology FPE subgroups, Free-flyer or attached module accommodation, Driver was module accommodation mode and status of equipment during countdown and at lift-off. Group A differs from Group B mainly in that specialized laboratories or facilities are not needed for Group A, but are required for Group B.
Group B Modules	Six astronomy, three communications/navigation, and one physics FPE subgroups, Attached or free-flyer module accommodation, Driver was module accommodations mode; status of equipment during countdown and at lift-off and requirement for specialized laboratories or facilities.
Group C Carry-On	Four physics and five technology FPE subgroups, Launched in a logistics module for carry-on to space station GPL, Driver was requirement for electrical and mechanical checkout with FIT. Group C differs from Group D mainly in that specialized laboratories or facilities are not needed for Group C, but are required for Group D.
Group D Carry-On	Five physics and two technology FPE Subgroups, Launched in a logistics module for carry-on to space station GPL, Driver was requirement for electrical and mechanical checkout with FIT and requirement for specialized facilities.
Group E MS/MS Carry-On	Five materials science and manufacturing FPE Subgroups, Launched in a logistics module for carry-on to space station GPL, Driver was no requirement for checkout and servicing, except for verification with FIT.
Group F Life-Science Modules	Three life-sciences FPE Subgroups, Attached module accommodation, Driver was needed for specialized facilities, installation of specimens during countdown, and life-support equipment active at lift-off.

Since the specimens are time-sensitive, they must be installed in their flight containers at the launch pad. Transportation at KSC will be within the flight cage or specimen container, serviced by a portable life support system. The flight life support system must be kept active at all times subsequent to specimen installation in the launch vehicle. Permanent accommodations for space biology principal investigators will be required at the launch site.

Continuous Active Support Required—Four of the FPE detectors will require continuous active support. One of the detectors in both FPE A-1, Grazing Incidence X-ray Telescope, and A-5B, Gamma Ray Telescope, must be kept at dry-ice temperatures when not operating and must operate at LN_2 temperatures. The crystals will be transported in dry ice and installed at KSC after activation and functional verification of the cryo loops. In addition, a continuous GN_2 blanket will be maintained on the optical trains of many FPEs (See Table 4-5 Category II) to meet environmental requirements for cleanliness and humidity.

Time-Sensitive Installations—All films and emulsions will be received at the launch site and stored in a refrigerated and radiation-shielded vault. These items will be installed just prior to flight carrier/orbiter mate.

The impact of the Case 534G flight schedule on KSC for preflight operations is shown in Figure 4-17. The postflight impact is shown in Figure 4-18.

4.1.4 Mission Support Operations

Mission support operations, as exemplified by the mission management concept and requirements derived during the original 10 m (33 ft) Space Station Phase B study, are also applicable to the modular Space Station. The impact of these mission support operations, if they were all to be located at KSC, was determined during the KSC impact study supplement to the original Phase B study (DRL-160, Line Item 22, Analysis of Space Station Impact on KSC, Volume 1, dated December 1970). The operations will impact KSC similarly

F	E	D	C	B	A	EXPERIMENT GROUP	KSC FACILITY
ALL				ALL	ALL	EPIC	
ALL						LSBL	
		ALL		ALL		KSC LABS	
				ALL	ALL	O & C	
ALL	ALL	ALL	ALL	ALL	ALL	FIT	
	ALL	ALL	ALL			LOG MOD LOAD	
ALL	ALL	ALL	ALL	ALL	ALL	SHUTTLE MAIN AREA	
ALL	ALL	ALL	ALL	ALL	ALL	SHUTTLE PAD	
				CN-1A		1	
			T-4C		ES-1G	2	
						3	
			P-4B			4	
		T-1A				5	
		T-1B				6	
						7	
			P-4A			8	
			T-3A	CN-1B		9	
						10	
						11	
			P-3C			12	
MS-3A, 3B, 3C, 3D & 3E			T-5A	A-4C	T-3B	13	
						14	
						15	
		P-1A P-1B				16	FLIGHT PLAN 534G
		P-1C P-1E	P-4C			17	LAUNCH SCHEDULE
						18	BY QUARTERS
						19	
						20	
LS-1B		P-2A				21	
			T-5B	P-2BB		22	
					ES-1AA	23	
				A-6		24	
				A-4A		25	
			T-5C	A-4B		26	
				A-5B		27	
				CN-1		28	
LS-1C						29	
				A-5A		30	
						31	
					A-3CC	32	
					A-2A	33	
						34	
						35	
						36	
LS-1D					A-1		
					A-2		
					A-3AA		
					ES-1	NOT SCHEDULED	
					P-3		
					T-2A		
					T-2BB		

Figure 4-17. KSC Facility Utilization - Preflight

ALL ALL	ALL	ALL ALL	ALL ALL	ALL ALL	ALL ALL	LANDING SITE KSC LABS LSBL	KSC FAC
F	E	D	C	B	A	EXPERIMENT GROUP	
						1	
						2	
						3	
			T-4C			4	
				CN-1A		5	
						6	
						7	
			P-4B			8	
						9	
						10	
			P-4A			11	
		T-1A	T-3A	CN-1B		12	
		T-1B	P-3C			13	
						14	
						15	
			T-5A		T-3B	16	
						17	
						18	
		P-1A, P-1B				19	
		& P-1C	P-4C			20	
						21	
					ES-1G	22	
						23	
						24	
LS-1B						25	FLIGHT PLAN 534G
			T-5B	A-4C		26	RETURN SCHEDULE
				P-2BB		27	BY QUARTERS
		P-1E				28	
			T-5C			29	
						30	
				CN-1		31	
						≈	
LS-1C				A-4A		44	
						≈	
					A-3CC	51	
						≈	
				A-6		63	
				A-4B		64	
						65	
						66	
				A-5B		67	
						68	
						69	
				A-5A		70	
						71	
						72	
						73	
						74	
						75	
						76	
						77	
						78	
	MS-3A, 3B,				ES-1AA	79	
	3C, 3D & 3E				A-2A	80	

Figure 4-18. KSC Facility Utilization - Post Flight

should they all be located there for the modular station. It may be, however, that some mission support functions will be performed at KSC, and some at other locations such as MSC. Therefore, part of the following discussion emphasizes how the mission support functions as defined by the earlier study efforts could be logically split between the Shuttle launch site and other locations if required.

4. 1. 4. 1 Mission Support Operations Requirements

The 10-year continuous operation of the orbiting Space Station, the multiple project interfaces and the capability for continued resupply generated a requirement for a different form of mission management to that employed in the past. The Shuttle-supported Space Station Program is compared to the expendable booster-single mission payloads in Table 4-8.

Mission management for the Space Station must address the areas of orbital and support operations. Before developing these functions within the Space Station Program, the relationship to other projects/programs and NASA functions must be established. Figure 4-19 identifies the overall relationship of the Space Station to the mission management of other programs, the directive relationship to program management and the influence of program hardware development on the operations functions. As indicated, the scientific program interfaces directly with program management and for experiments which are established to be flown with the Space Station or the Shuttle, the relationship is then established at a working level within mission management to implement the requirements.

As indicated in Figure 4-20, the scientific programs are independent of the support elements shown on the right. The Space Station supports only a part of the scientific payloads. The common denominator is the ground network which will provide and process all data for the scientific program management and provide mission data to the support agencies. The Integrated Scientific Orbital Program Management does not exist as shown, but does consist of the illustrated functional elements. Mission management then must support the appropriate scientific payloads.

Table 4-8

COMPARISON OF SPACE STATION TO EXPENDABLE BOOSTER PROGRAMS

Space Station		Expendable Booster Payloads
Multiple projects over long mission-multiple support and multipayload capability	vs	Minimal interproject involvement after booster separation, i. e., independent payload
Continuing resupply	vs	No resupply
Dynamic planning of missions, resupply, schedule, interfaces	vs	Essentially preplanned single missions
High autonomy on-orbit with smaller ground crew in-flight operations	vs	Minimal to no autonomy in orbit
Assembly in-orbit of initial and subsequent hardware	vs	Launched integral functional unit
Integration of new hardware and repair on orbit	vs	No resupply

Space Station mission management must provide for mission planning, logistics resupply and orbital operations support. The latter must recognize the support for the Space Station itself as well as the support of the scientific payloads.

4. 1. 4. 2 Mission Support Operations Concept Summary

As shown earlier, the Space Station Program is unique with respect to current manned space flight program. It must operate as an orbiting operational facility (as opposed to an R&D program) that is both economical and convenient to use by the scientific community, commercial enterprise, and anyone else who might need to perform activities in an orbital environment. It must provide this operational facility for ten years. Obviously, the ten year operations cannot be accurately predicted to any depth in advance; shifting emphasis in national goals, new techniques, scientific breakthroughs (perhaps brought about by the experiments onboard the station), and new equipment that may

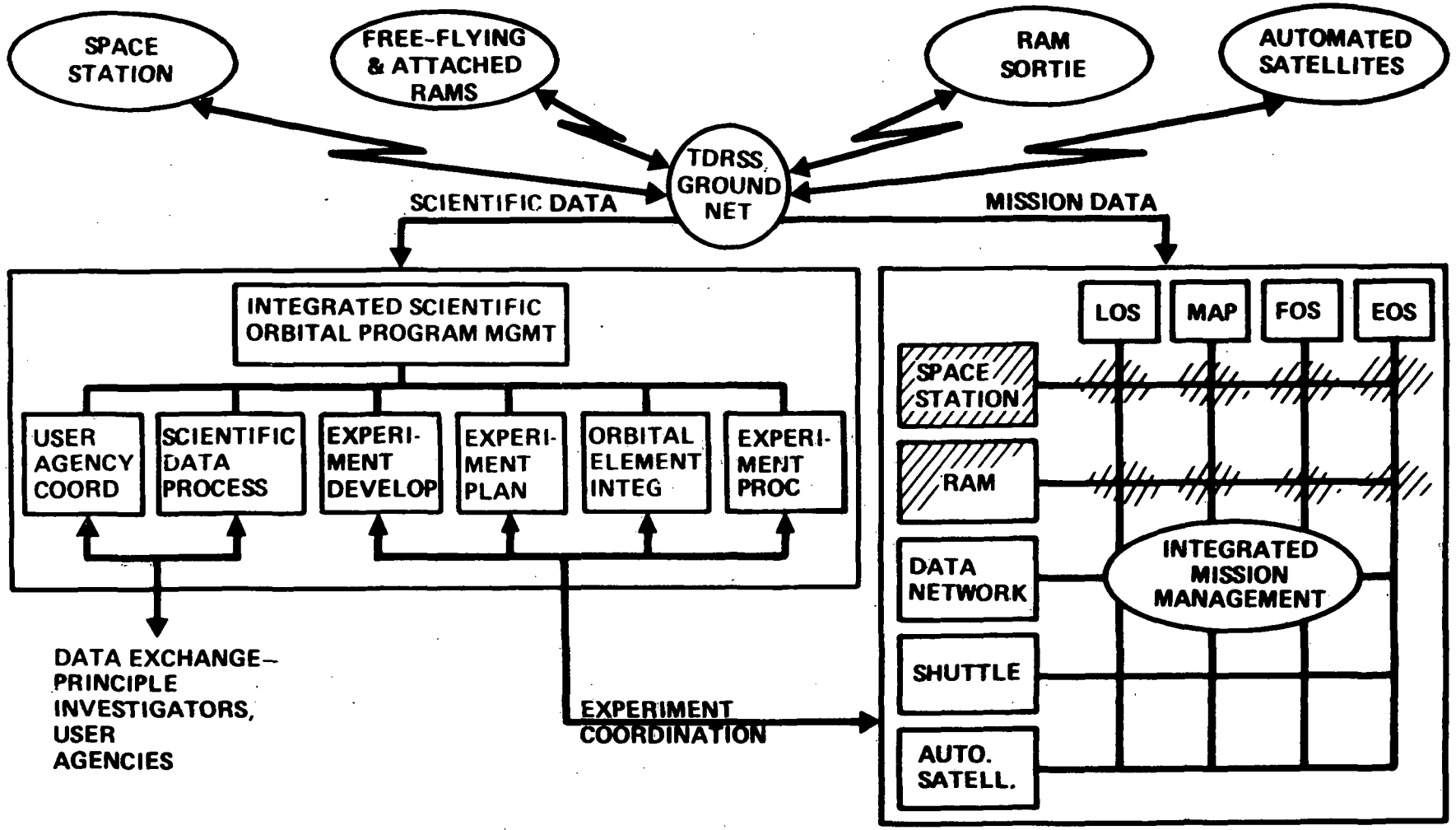


Figure 4-19. Support Elements of an Integrated Scientific Orbital Program

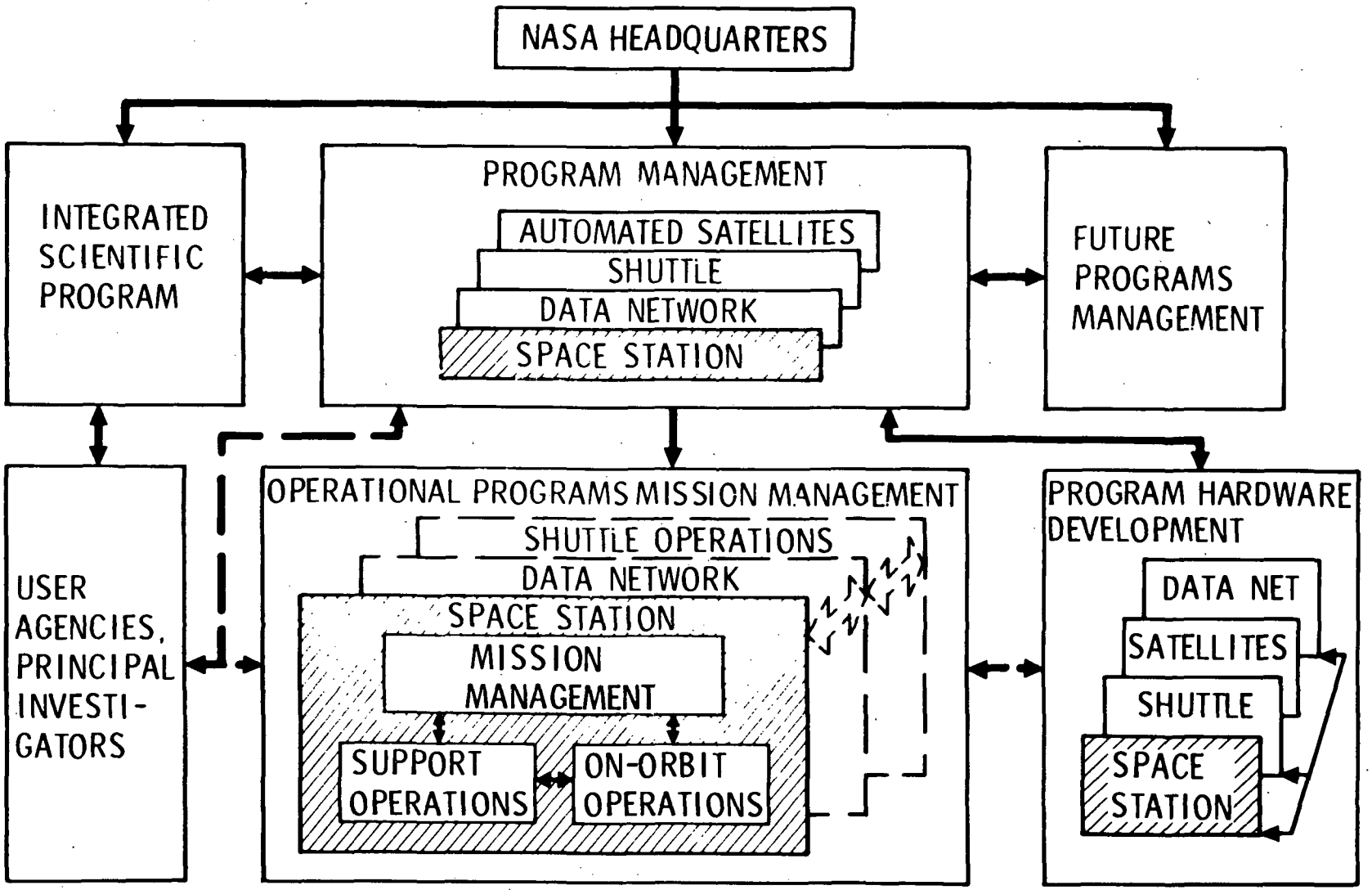


Figure 4-20. Space Station Program and Mission Management

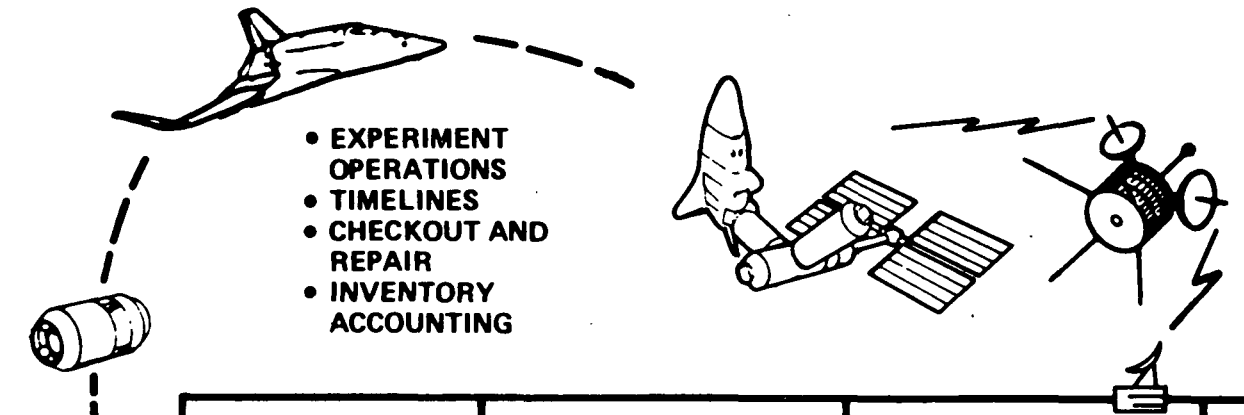
become available will result in a dynamic program characterized by change. Therefore, an overall mission management concept is required that will integrate all Space Station mission support operations in a manner that will be responsive to any program changes that may develop during the ten year program.

There are three separate activities associated with management of the operational Space Station program. The first is coordination with user agencies, the second is development of new program elements, and the third is conduct and support of the active program. Orderly accomplishment of these activities will require an overall Space Station Program management structure whose job will be to plan and control the future directions of the program. The first two are the responsibility of NASA program management. It is the third activity, however, that has significant potential impact on KSC, and is the subject of the following discussion on Space Station mission management.

As shown in Figure 4-21, the task of managing the active conduct of the program will consist of ground operations support, and performance of the on-orbit activities. Ground operations support will be further subdivided into; (1) logistics operations support, (2) mission analysis and planning, (3) flight operations support, and (4) experiment operations support. A summary of the requirements for the four ground support functions is given in Table 4-9.

LOGISTICS OPERATIONS SUPPORT

Logistics operations support includes inventory management to insure that all required crew, materials, and supplies are delivered to the Space Station at the proper time and in the proper quantity so that the mission can always be conducted at maximum capability to provide disposition of all returned cargo as shown in Figure 4-22. The logistics support operations will provide configuration management so that there will always be knowledge, on the ground, of what the exact orbital configuration is including experiment hardware. The logistics operations also will perform the more classical logistics



LOGISTICS OPERATIONS SUPPORT

- INVENTORY
- CONFIGURATION MANAGEMENT
- CARGO HANDLING
- SPARES AND SUPPLIES PROCUREMENT
- NEW MAJOR HARDWARE PROC COORD
- PREFLIGHT TESTING/ CERTIFICATION
- LOGISTICS MODULE
- SPARES REFURB
- MOCKUPS/FIT
- INTERFACE CONTROL
- PREFLIGHT HARDWARE INTEGRATION
- RETURN CARGO DISPOSITION

MISSION ANALYSIS AND PLANNING

- SS PROJECT INTERFACE WITH OTHER PROGRAMS/ PROJECTS
- MISSION PLANS
  - 10 YEARS
  - 90 DAYS
- SCHEDULES
- CONFIGURATION AUTHORIZATION
- LOGISTICS, FLIGHT PLANNING
- CONSULTATION WITH FLIGHT CREW FOR SYSTEM/ EXPERIMENTS
- LONG-TERM TREND ANALYSIS

FLIGHT OPERATIONS SUPPORT

- FLIGHT CONTROL
- SIMULATION
- CREW TRAINING
- NETWORK INTERFACE
- HARDWARE DEFINITION

EXPERIMENT OPERATIONS SUPPORT

- EXPERIMENT OPERATIONS
- EXPERIMENT COORDINATION
- DATA EVALUATION
- EXPERIMENT OPERATIONS PLANNING

SHUTTLE PROJECT

Figure 4-21. Space Station Mission Management Operational Functions

Table 4-9

SUMMARY OF GROUND SUPPORT REQUIREMENTS

Ground Support Functions Category	Support Requirements
Flight operations	Mission coordination
	Monitor and control of Space Station (unmanned phases)
	Cognizance of space systems status
	Central point for flight/ground contact
	Ground management for acquiring systems and trajectory specialists support
	Long-term space systems parameter trands analysis
	Data and information uplink transmission management
	Communication configuration control
	Trajectory support
	Operations data processing control
	Simulation
	Crew training
	Space Station flight control personnel
	Space Station ground experiments control personnel
	Flight operations support personnel
	Personnel onboard orbiting Space Station
	Operations data processing control
	Flight support software
	Space Station flight software verification
	Integrated data management system

Table 4-9

SUMMARY OF GROUND SUPPORT REQUIREMENTS (Continued)

Ground Support Functions Category	Support Requirements
Experiment operations support functions	Experiment operations
	Quality checking of experiments data
	Time tagging of experiments data
	Merging of SS status and dynamics data
	Calibration of data
	Sorting of FPE and user
	Experiments data analysis processing
	Data reconstruction
	Image enhancement
	Real-time program modification
	Batch processing
	Experiments data base management
	Storage
	Retrieval
	Maintenance
	Display processing for ground principal investigators
	Command and display request processing
	Correlation of physical data
Mission analysis and planning support functions	Mission design
	Mission operations planning
	Flight planning
	Resource utilization planning
	Trajectory analysis

Table 4-9

SUMMARY OF GROUND SUPPORT REQUIREMENTS (Continued)

Ground Support Functions Category	Support Requirements
	Crew rotation scheduling
	Training planning
	Experiments integration and utilization planning
Logistics support functions	Support on-orbit inventory control
	Support return cargo mass control
	Spares and supplies procurement
	New major hardware procurement coordination
	Transportation
	Maintain configuration control
	GSE and ground facility maintenance
	Cargo/advanced logistic system compatibility responsibility
	Inventory management and control
	Preflight testing/certification
	Maintain mockups/FIT
	Interface hardware integration
	Return cargo disposition

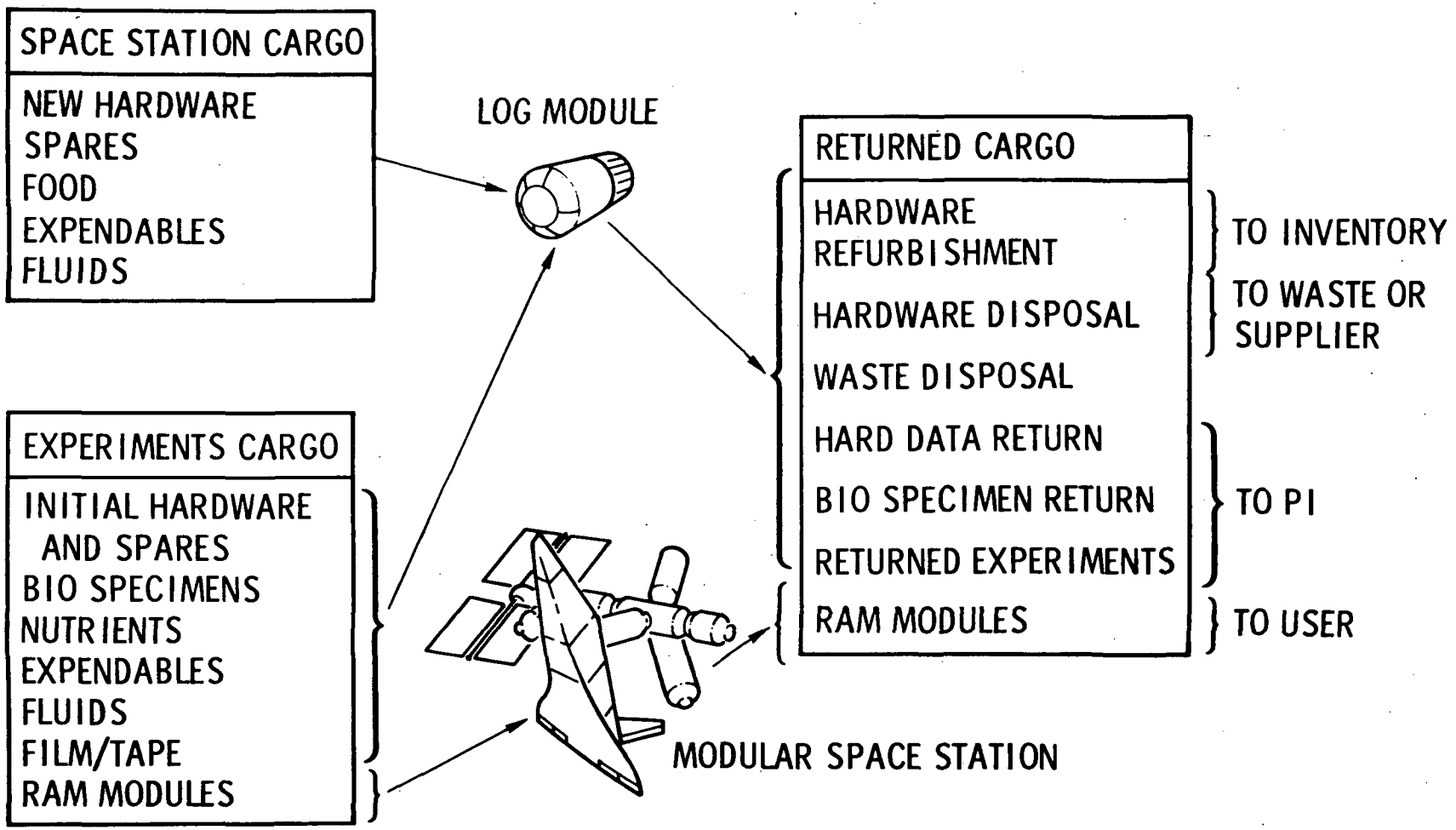


Figure 4-22. Space Station Cargo Flow

functions of cargo handling, packaging, procurement, and transportation. The Space Station hardware will be procured by this function were in the case of experiment hardware coordination with their procuring agency is required to assure program hardware and software compatibility. Another function of logistics is testing, particularly testing or certification of new equipment to make sure that it will fit and that it will function properly. In the case of experiment hardware, adequate certification of testing for compatibility is required.

Spares refurbishment will be provided on Space Station hardware as required. The experiment hardware will be refurbished separately but the configuration and compatibility with other Space Station hardware must be verified. All the hardware to be flown with the Space Station is subject to interface control under the Space Station. Verification will be by preflight hardware integration on the FIT. Return cargo disposition for all orbiting elements will be accomplished by Logistics Operations Support. Hard data, returned spares, waste, etc., must all be accounted for an disseminated to the appropriate destination.

The total accountability of these returned items is key to successful inventory control and accounting. The Logistics Module refurbishment, loading, and launch operation falls entirely in this function. As items under configuration control and hardware integration, both the mockups and FIT are under the change of logistics operations support to assure that changes either to on-orbit configuration or to future additions to the on-orbit configuration are reflected.

Centralized logistics control is a management function performed in parallel with flight operations support, mission planning and analysis, and experiment operations support. It will consist of inventory control, material, maintenance, transportation, configuration control, and personnel management subelements. Included are any hardware that physically interfaces with the Space Station. Each of these subelements is charged with management and control of its particular activities and for integration and interfacing with other technologies within and external to the logistics structure.

Elements and tasks which collectively fulfill the complete logistic obligation for the Space Station support are further identified under several functional disciplines; provisioning of spares, source coding, technical orders, high-value time identification and control, hardware and software improvement, packaging, preservation, warehousing, inspection, skill requirements, and training and associated curriculum and equipment.

Inventory Control

Continuation of Space Station operations from phase to phase, year to year, will be largely dependent on the logistics network providing the correct quantity and mix of resupplies. To achieve maximum operational efficiency of the Space Station and transfer operations from crew to crew, it will be imperative that precise information be known as to the amount and type of spares, expendables, and consumables onboard the Space Station and what additional logistics payload is required to continue operations for the next mission phase. The success of these goals will be dependent on the ability of the crew, together with supporting ground operations, to maintain and track the utilization of spares; and of the ground crew, in coordination with experiment operations, to adequately identify the resupply requirements for new equipment scheduled for the next mission phase. This will be necessary since the limited storage space onboard the Space Station will not permit large inventories to backup operations.

Inventory Control will be responsible for those specialized activities dealing with tracking of Space Station utilization of consumables and expendables and providing necessary resupplies to permit continuous operations. Inherent in this responsibility is a close interrelation with other program elements—Shuttle and Experiments—and the command, communications, and data functions. Effective control will be dependent on timely and accurate knowledge of use rates and stores inventory from the Space Station.

Material

Procurement of Space Station resupplies will be one of the major functions of the logistic process. Originally conceived plans and estimates of resupplies will have to be very accurate to preclude shortages or overstocks. Some long-lead ordering will be accomplished prior to the Space Station being

placed on-orbit. Sufficient spares will be kept in inventory to allow contingency resupply before their normally scheduled preventive maintenance cycle. Procurement of items of this nature will consider premature failure contingencies, later to be influenced by actual case histories. Lead time for procuring resupply items will be the aggregate time from when they are loaded on the logistics vehicle back through preparation for shipment, transportation, manufacture, production, test, design (if necessary), to procurement contract negotiation. Experiment hardware including spares is procured via a separate agency; however, the Space Station logistics function must coordinate configuration, schedule, testing, etc., to assure compatibility with the orbiting station.

Maintenance

Maintenance control will be established as a management subelement directly under logistics management. Maintenance control's responsibility will include scheduling preventive maintenance, tracking of failures and trends, planning, and supporting maintenance activities.

Transportation

Space Station Program transportation will be responsible for identifying and providing for transportation and shipping needs. Major Space Station Program elements require special handling, equipment, and means of transportation.

Configuration Control

Configuration control will track, supervise, and establish the Space Station hardware and software configuration at any given point in time during the operational program. Space Station subsystem and experiment hardware will change configuration through the 10-year mission as a function of:

A. Subsystem design changes to improve performance and reliability.
B. New or modified subsystems to incorporate new technology or advanced state-of-the-art design.
C. New or modified subsystems to maintain compatibility with new experiment subsystems and hardware.
D. Failure of Space Station or experiment hardware requiring a change in hardware configuration (wiring, plumbing, etc.) to continue operations.

Long-range mission planning may include the installation of modification kits during certain phases as a result of one or more of the above functions. Serialization of orbital equipment will be maintained and all changes are tracked as a result of periodic maintenance reports from the flight crew.

A condition requiring change coordination and control may arise when an equipment change is proposed to a module or experiment which is in orbit. If the change is approved, it will first be installed and verified on the FIT. The mission Planning and Analysis function will be advised of the time span required to make the change, the recommended experiment time phase in which to implement the change, and the earliest Shuttle flight which could deliver the mod kit to the Space Station. From this information, the appropriate 90-day mission plan will contain a work schedule for installing the change.

Personnel

Personnel management within logistics will be responsible for recruiting, and accommodating flight crew personnel. Also included in this responsibility are the specialized ground support personnel who are involved in launch and orbital sustaining operations.

MISSION ANALYSIS AND PLANNING

Mission planning will involve all planning, working documentation, and procedures required to support the total program including operations, ground and vehicle resource utilization, simulation, logistical functions and the experiment program. These planning functions will begin at the mission design level and continue until the mission is terminated; and will involve development of and modifications to mission rules and constraints, hardware and software. As data are collected, the performance of the crew, system hardware, and experiments will be continuously evaluated to verify that program goals and objectives are being satisfied. Real-time reprogramming of the experiment activities will be performed by the appropriate principal investigator but will be coordinated with mission planning.

The approach followed for Space Station mission analysis and planning will be split into two levels; first, there will be a 10-year plan which will generally structure the total Space Station mission. This 10-year plan will be broken down into 90-day segments, each one of which, for planning purposes, will be considered a separate mission. The 90-day plan, comprising the second level, will establish what the objectives for that mission are and what has to be done to accomplish these objectives. The on-orbit crew, as a result of their high degree of autonomy, will not be working to pre-determined timelines but to this mission plan, which will provide them with general requirements for conduct of the mission from which they will develop their own timelines every 24 to 48 hours. The crew will also perform maintenance functions such as checkout and repair as required and will participate in overall inventory control. Automated techniques will be used to the maximum cost effectiveness, through use of computerized mission planning models. If required, these models will be adaptable for use in on-line or realtime planning functions in support of the overall program.

Mission Design

Mission design will commence with the development of requirements to conduct a mission. Objectives will be stated, candidate vehicles selected, crew complement (mix) determined, and general mission guidelines established. The iterative process of comparing mission objectives to the constraints and guidelines will result in the modification of objectives and the revision of constraints. Analyses will be performed to establish priorities of objectives; determine the validity of the constraints related to flight systems, crew, and mission and ground support elements; and determine mission schedule feasibility. The results of this analysis and planning will constitute a preliminary reference mission design from which mission operations planning will be able to proceed.

Mission Operations Planning

The planning and analysis functions required to effect an optimum mission will involve the task of integrating all mission elements into an operational mission with the greatest probability of success to accomplish the established

objectives. The major task, essentially, will be that of optimizing the use of the total mission resource including the flight systems, crew and ground support element. The following major detail plans, which must be developed prior to flight, will be continuously monitored to ensure timely implementation and current applicability of the mission operations plan:

A. Hardware and software development and acquisition plan (as applicable).
B. Mission activity timeline.
C. Alternative (contingency) mission operations plan (as applicable).
D. Mission operations priority plan.
E. Crew flight plan (involves task simulations and crew/systems integration planning).
F. Ground support operations plan.
G. Training and simulations plan:
    1. Crew
    2. Ground personnel
    3. Systems test.

Mission Planning During Flight Operations

Planning functions will be accomplished during mission operations and will provide the means for modification or revisions to the plans developed before the next mission. These changes would be a result of near real time assessment by the crew and ground of the mission status and would include the following major planning tasks:

A. Resource utilization planning:
    1. Crew and flight systems.
    2. Ground support elements (personnel, equipment, and facilities).
    3. Communications and tracking plans.
B. Trajectory:
    1. Rendezvous planning for logistics vehicles and unmanned modes.
    2. Planning for emergency return and recovery operations.
C. Assessment of objective priorities and alternative plans development and planning for integration of new experiment elements into mission operations.

The above tasks will require a coordinated, on-line effort between the onboard personnel (operations and experimenters) and their ground support counterparts. To effect the autonomy goals of Space Station operations, many of the above tasks must be accomplished by the onboard crew. For example, a real-time modification of the flight plan decision must lie with the Space Station commander (within major mission rules); however, the long-range assessment of the impacts of this modification could best be accomplished by the ground element and its resources.

FLIGHT OPERATIONS SUPPORT

During the orbit operations phase Flight Operations Support will perform what has in the past been called the mission control functions; supporting on-board status monitor and fault isolation/analysis. The Space Station flight crew will be utilized in the flight and experiment operations support. Flight Operations will also coordinate all systems status and trend data for crew training, simulation, and other activities associated with preparation for flight operations.

Flight operations will have the primary goal of maximizing the utilization of mission resources. This function will begin during the prelaunch phase and continue throughout the life of the Space Station Program. However, the duties performed and the number of personnel required vary according to mission phase. During the prelaunch and launch phases the primary duties will be to support systems integration and flight readiness testing, verify status of that portion of the tracking capability which has been called up to support the mission, verify the capability of the communications system to support the mission, and participate in the generation of launch and flight mission rules and procedures. It will provide a means of analyzing long-term performance trends and Space Station trajectory data.

Early Orbit Operations

From lift-off through early orbit, the flight operations personnel will perform limited flight control duties. The mission director and his staff will run the mission during buildup operations and until the first operational flight crew boards the Space Station and has it fully operational. During the powered

flight and early orbit phases, trajectories will be monitored to verify that the Space Station achieves the desired orbit. After initial manning, the flight operations personnel will revert to a low activity level and after the first year only periodic ephemeris updates will be prepared for comparison with onboard data. Subsystem status will be monitored for long-term trend analysis and consumables management.

Flight Operations

Space Station flight operations support will provide capabilities for communications configuration control, telemetry, and ground tracking data processing; Space Station systems status parameters processing; receipt, storage, and routing of data; uplink data processing; and information presentation required by the various mission operations support groups. It will accept inputs from the mission operations support groups in form of display information requests, systems configuration control commands, and space vehicle uplink data. It will also provide for the storage and analysis for scientific data generated by experiments.

Experiment systems data will be received in raw and/or status form for analysis by experiment specialists for predicting long-term systems health. Support of integration of newly developed experiment systems into the Space Station will be provided. This involves support of checkout and testing of new hardware and software items prior to flight and during on-orbit installation.

In the event of contingency situations, the flight operations support personnel will serve as consultants to the flight crew and assist them in fault isolation and maintenance tasks. They will also contact individual experts to bring their knowledge to bear.

Simulation and Training

The simulation requirements, plans, and programs will be developed for flight simulation and part-task trainers by this element of the flight support effort. All simulation and training for both flight crews and ground personnel will be performed utilizing ground simulation equipment.

EXPERIMENT OPERATIONS SUPPORT

The fourth function of mission management is experiment operations support whose prime function is to plan experiments, establish their procedures, and provide the capability for Principal Investigators to participate (on the ground) in real-time activities of their experiment while it is in orbit.

The experiment operations will provide the bulk of the requirements for storage and analysis of data which will be downlinked by the Space Station-to-ground communication link. Reception and storage of these data will be a nearly continuous real-time function. Ground-based computers will store and reduce data to allow real time analysis of it by principal investigators.

The experiments data systems will receive experiment systems data in raw and status form which will be analyzed by experiment module specialists to predict long-term failures. Ground support of experiment modules may be more critical than Space Station Systems data because of the developmental nature of the experiment modules.

4.1.4.3 NASA Functions in Space Station Mission Management

The activities described in Section 2.5.1 and 2.5.2 are envisioned as the day-to-day operations and could most logically be done by contractor(s) and the flight crew performing ground operations on a rotational basis. The successful accomplishment of these functions depends on the administrative and management relationship of the Space Station mission management to other projects/programs and the scientific community.

These NASA administrative and management functions for each of the elements of mission management are described below.

Mission Operations Support—Includes NASA effort required to administer the mission operations support function comprised of Mission Analysis Planning, Flight Operations Support, Experiment Operations Support and Logistics Operations Support. Included are:

A. Administrative and Management Functions.
B. Project planning and interprogram/agency planning.

Mission Analysis and Planning—Includes the NASA effort required to administer the planning function for the Space Station project. This includes:

A. Coordination with NASA Center, users, etc.
B. Establishment of priorities.
C. Mission planning and scheduling direction.
D. Overall requirements of mission operations.

Flight Operations Support—Includes the NASA effort required to provide the real-time ground support of the Space Station orbital operations and crew training. This includes:

A. Administration of flight operations function.
B. Ground network provisioning and operations.*
C. Data acquisition.*
D. Hardware change authorization.
E. Flight crew training (personnel and hardware provisioning).
F. Simulation provisioning.
G. Data distribution.**

Experiment Operations Support—Includes NASA effort required to provide real time ground support of Space Station orbital operations. This includes:

A. Coordination with user agencies and NASA Center.
B. Direction of experiment operations function.

Logistics Operations Support—Includes NASA effort required to replenish expendable supplies and equipment needed to maintain ground and orbital operations. This includes:

A. Management of logistics operations support.
B. Facility operations.
C. Procurement Administration.
D. Inter- and intraprogram coordination for logistics functions.
E. Establishment of Shuttle schedules and availability of services for Space Station.

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*Ground network costs provided by NASA.
**Hard-copy data distributed by Logistics Operations support function. Soft data reduced and distributed as ground network costs provided by NASA.

4.1.5 GSE and Facilities

The GSE and Facilities for the Space Station Program are contained in Sections 3 and 4, respectively, of MP-03, Integrated Mission Management Operations.

4.1.5.1 Ground Support Equipment

The production GSE for the Space Station flight articles will be used at both the factory and launch site where possible. This reduces the amount of launch site peculiar GSE which is desirable for essentially a single launch system. The production GSE will be used with the flight integration tool both in production and for 10-year mission support.

The GSE for the Logistics Module is relatively simple due to the limited function requiring checkout; consisting mainly of handling and access equipment to support a heavy traffic of recycling modules over a 10-year program.

The experiments GSE consisting of a wide variety of speciality equipment to support the experiments. There is little commonality in the GSE due to the significant differences in flight hardware, possible but unknown schedule conflicts and high probability that the flight experiment equipment will be built by many different suppliers.

4.1.5.2 Facilities

The Space Station facilities for manufacture of the modules present no particular challenge to existing facilities. The orbit-ready from the factory concept reduces the need for facilities at the launch site in that preflight servicing can be performed in existing facilities in the Shuttle maintenance area or low bay of the VAB.

The Crew Cargo Module will be housed in low bays of the VAB which is near the Shuttle maintenance area. The cargo for the Log Module will be accommodated as a part of the Mission Management facilities.

The experiment modules and experiment hardware will be hous ed in the MSOB high bay. This will provide the clean area, vacuum chambers and adequate space for required offices and laboratories. This would also be the location of the FIT if located at KSC. The location of the FIT for the 10-year mission support is still undetermined. Alternate locations were previously discussed.

The Biological Laboratory must be located at the Shuttle launch site because of the live specimens and will be located in the MSOB.

Mission Management for the 10-year ground support of the Space Station will require facilities, however, the location for some functions is still open (see Section 2.5.3 of MP-03, Integrated Mission Management Operations).

The cargo will be stored in the Supply, Shipping and Receiving Building behind the MSOB. If located at KSC, the FIT, which is used for configuration control, etc., will be located in the MSOB high bay.

The management of Logistics, Mission Planning and Analysis, and both management and operational elements of flight operations support and experiment operations might be located at KSC, however, during buildup operations which includes 60 days of predominantly unmanned operations, the function could be located at MSC where ground network ties, etc., presently exists. For the continued support of a 10-year program there could be economies resulting from location of all elements of Mission Management at KSC. Were these functions to be at KSC, all would be located in the MSOB including Flight Operations Support and Experiment Operations Support. The CIF computer capability would be required in support of Mission Management.

4.2 FLIGHT OPERATIONS

The flight operations of the Modular Space Station have been divided into four major areas for documentation. These areas are primarily concerned with the Space Shuttle flight support required for the delivery and buildup of the Space Station; detailed operational activities associated with the buildup and initiation phases of the Space Station mission; the Space Station sustained on-orbit operations during the 10-year mission duration; and the logistics support required throughout the mission.

4.2.1 Ascent

The ISS is composed of three modules (Power/Subsystems, Crew Operations, and General-Purpose Laboratory). These modules are delivered to orbit on 30-day launch centers. In order to conserve the propellent required for the Space Station during the 60-day buildup period, the Space Station is placed in a 500 km (270 nmi) orbit and then the orbit of the configuration is allowed to decay, to the nominal operational altitude of 456 km (246 nmi). This is equivalent to 242 nmi at the equatorial crossing. The first Space Station module, the Power/Subsystems module, ascent will be to a circular orbit of 500 km (270 nmi), 55-deg inclination. The ascent of the Crew Operations module will be to a circular orbit of 491 km (265 nmi), for rendezvous and docking to the Power/Subsystem module. The GPL module ascent will be to a circular altitude of 484 km (261 nmi) for docking to the orbiting Space Station configuration. (See Figure 3-17 for Orbit Decay Profile.)

The ascent operations of the Space Shuttle during the Power/Subsystem module delivery mission includes Space Shuttle booster flight and orbiter burn to an insertion orbit of 93 x 185 x km (50 x 100 nmi) altitude. Approximately 42 min later, the orbiter OMS engine thrust raises the orbital apogee to approximately 461 km (249 nmi). Forty-five minutes later, at apogee, the main engines of the orbiter are fired again to raise the perigee to 461 km (249 nmi) and the apogee to the target altitude. Approximately 47 min later a co-elliptic burn raises the perigee to the target altitude. Circularized at the target altitude, the on-orbit operations for the Power/Subsystem module activation begins. During the ascent of the Crew Operations module, 30 days later, the Space Shuttle will perform phasing at the

185.3 km (100 nmi) orbit for a period of approximately 3.5 hours. The GPL module, launched 60 days after the Power/Subsystems module, will require a phasing period of approximately 8.5 hours during its ascent and rendezvous mission. A trajectory events summary of the Space Shuttle ascent flight is presented in Table 4-10.

Throughout the delivery operations of the delivery operations of the Space Station modules, the Space Shuttle will provide an average power of 500 watts to the payload module, with peak load requirements not to exceed 800 watts. Summary power profiles for the modules are presented in Figure 4-19. Also, during the ascent operations, the Space Shuttle will monitor critical payload parameters through the data bus umbilical supplied at the Space Station module interface. These parameters will be displayed on the Space Shuttle payload caution and warning indicators located in the Space Shuttle cabin.

During the ISS portion of the Space Station mission, the Space Shuttle will carry two Space Station crewmen as passengers on each flight. The Shuttle will be required to provide 14 man-days of life support for these crewmen on all missions. During the buildup operations these crewmen will be assembly and checkout technicians, and these crewmen will return with the Space Shuttle to the earth. Once the activation operations begin, the crew will be the nominal Space Station crewmen.

4.2.2 Buildup and Activation

The buildup and activation of the Modular Space Station presented new problems in operations. For the first time in manned space flight, a complete integrated space system will be required to be divided and launched in descrete parts and assembled in Earth orbit. In addition to the problem of assembly, the Space Shuttle launch constraint of no more than one launch every 30 days requires that the Space Station be operated in an unmanned mode until the orbiting configuration is completed and manned for sustained operation.

The Space Shuttle launch weight constraint of 9,072 kg (20,000 lb) required that some limited equipment of the Space Station modules be off-loaded for

Table 4-10
SPACE STATION ORBIT RENDEZVOUS

Event	Time of Initiation, hr:min:sec GET	Δt Between Events, hr:min:sec	Propulsion System	Total ΔV, fps	Resultant h_a/h_p, nmi	Position Latitude, deg	Position Longitude, deg	Altitude, nmi	Phase Angle, deg
Insertion	00:07:34		NA	NA	100/TBD	TBD	TBD	TBD	23.3
		00:41:41							
Phasing	00:49:15		Main engines	350	249/100	31.1S	89.6E	100	9.8
		00:45:32							
Height	01:34:47		Main engines	279	260/249	31.2N	101.9W	249	3.0
		00:46:59							
Coelliptic	02:21:45		Main engines	26	260/260	31.3S	66.2E	260	1.7
		01:29:11							
TPI	03:50:56		Main engines	22	270/260	16.3S	30.3E	260	0.3
		00:34:10							
Braking	04:25:06		RCS	45[a]	270/270	23.9S	171.7E	270	0.0
		00:30:00							
Docking	04:55:06		RCS	10	NA	55.0N	94.4W	270	NA
		14:58:24							
Separation	19:53:30		RCS	10	270/265	55.0S	134.7W	270	NA
		03:00:00							
Deorbit	22:53:30		Main engines	495	270/-10	36.7S	120.0E	270	NA
		00:32:00							
Entry	23:25:30		NA	NA	NA	6.0S	105.0W	65.8[b]	NA
		00:40:00							
Landing	24:05:30		NA	NA	NA	28.5N	80.6W	0	NA

[a]Theoretical TPV ΔV is 28 fps; [b]400,000 feet

launch and then delivered, using the Logistics Module, for installation on orbit. This off-loading scheme was devised to minimize the total number of Space Station modules required for the orbiting vehicle, in order to minimize the Space Station DDT&E costs. This period of assembly of off-loaded equipment, along with the crew buildup to six crewmen, is called the activation phase of the mission.

4.2.2.1 Buildup

The delivery, mating, and checkout of the three Space Station modules is termed the buildup phase of the mission. As presented on Figure 4-23, this phase of the mission covers the first 60 days (three launches) of the Space Station Program. During this phase of the mission, two assembly crewmen will accompany each of the Space Station modules to orbit as passengers in the Space Shuttle. These assembly crewmen will perform the interface mating, checkout, and operational verification functions on the Space Station, while the Space Shuttle remains attached to the configuration. During their orbital stay, these crewmen will derive their life support from the Space Shuttle, eating and living on the Shuttle, and working in the Space Station module(s).

Power Module

The first Space Station module launched is the Power/Subsystems module. This module is equipped with one set of batteries which provide the necessary electrical power until solar array deployment and checkout. The power module also supplies its own atmosphere with oxygen and nitrogen storage provided onboard the module. This atmosphere is controlled by partial pressure sensors and a control module. While the power and atmosphere capability provide for assembly crew shirtsleeve entry into the module, for a conservative approach, the mission requirements were analyzed assuming that the assembly crew will enter this module (and the other two modules during buildup) suited in helmets and gloves, and prepared for possible decompression.

The Power/Subsystems Module buildup timeline is presented in Figures 4-24, 4-25, 4-26, and 4-27. As shown on these figures, at approximately four

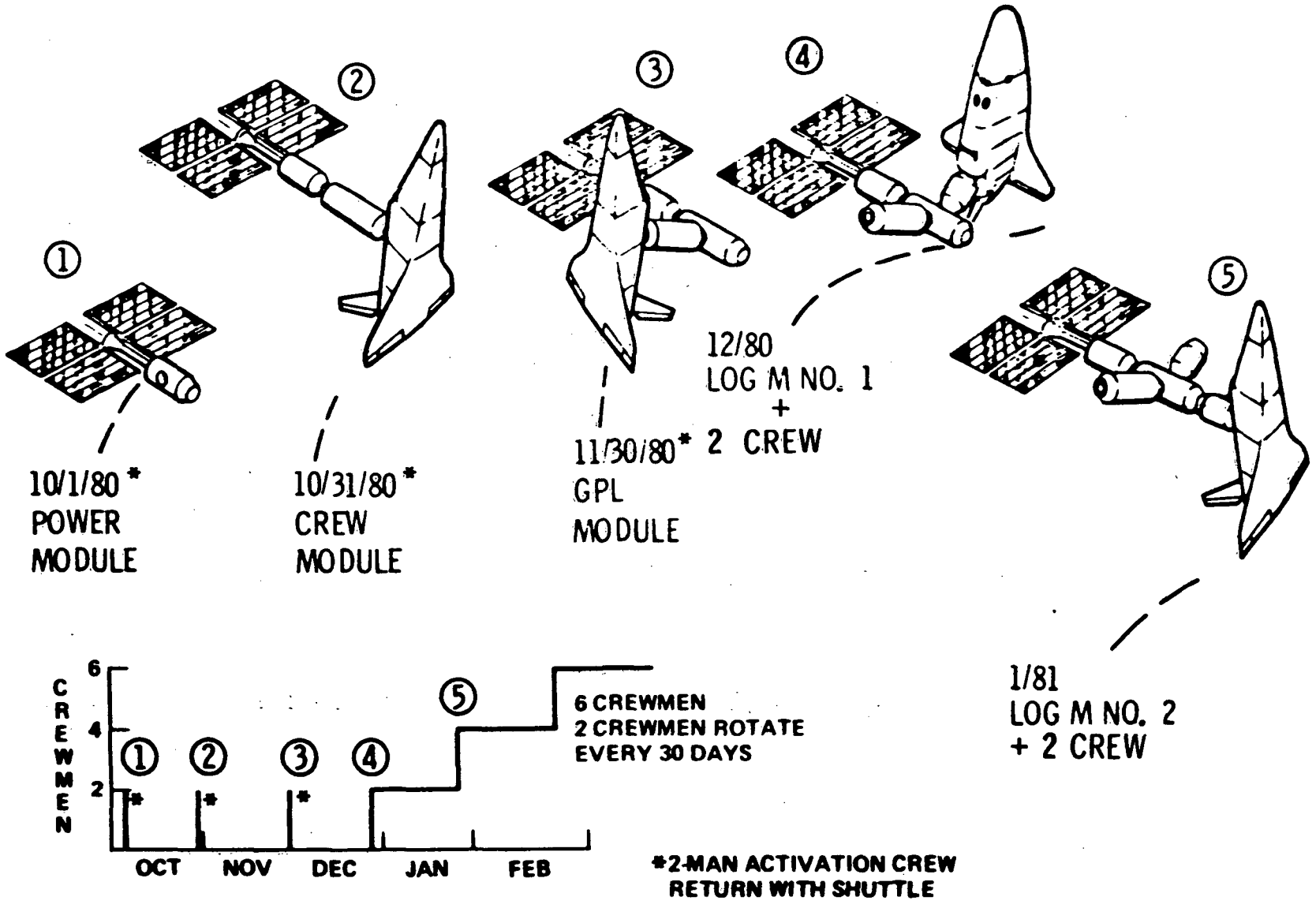


Figure 4-23. Space Station Buildup Operations

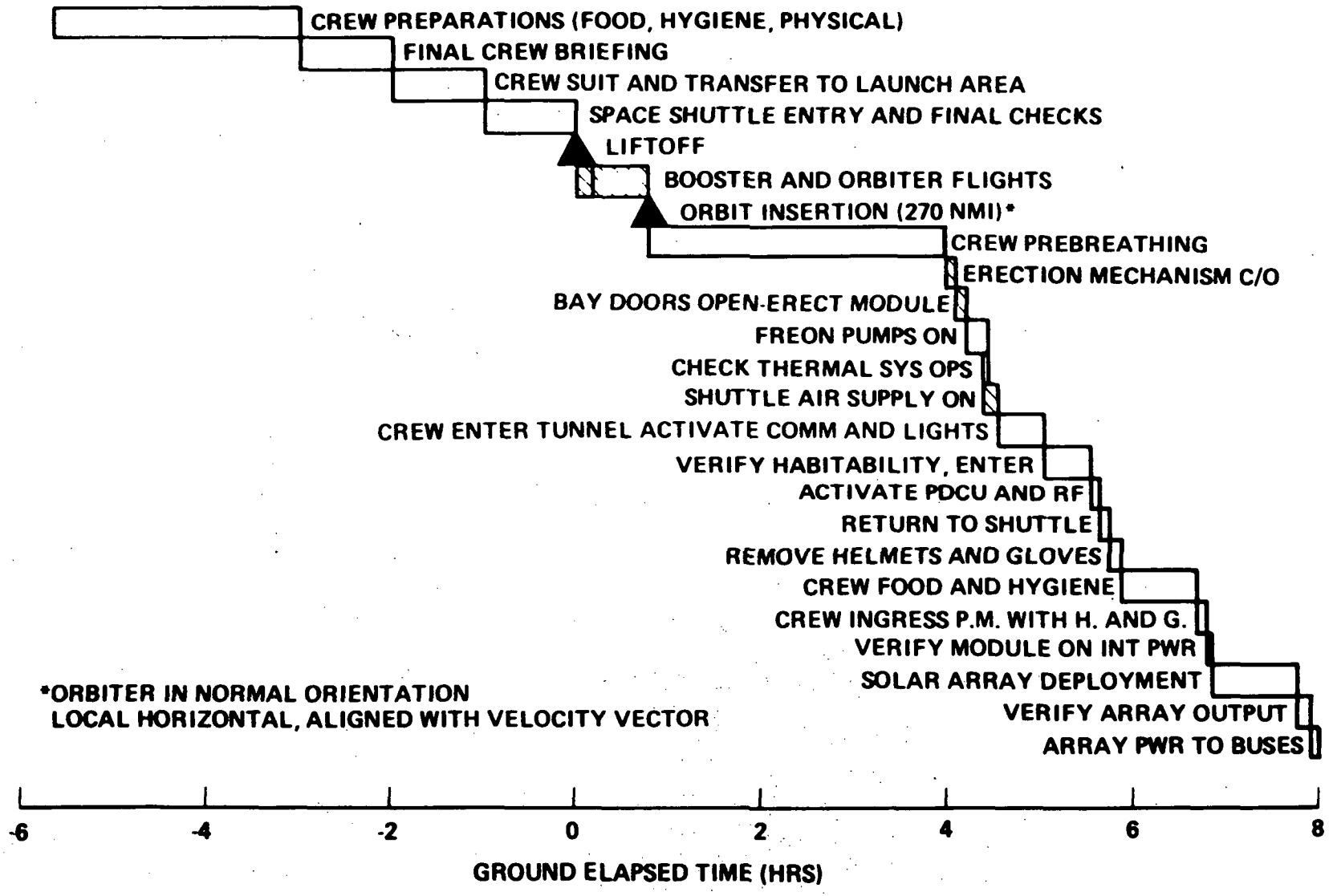


Figure 4-24. Buildup Timeline - Power Module

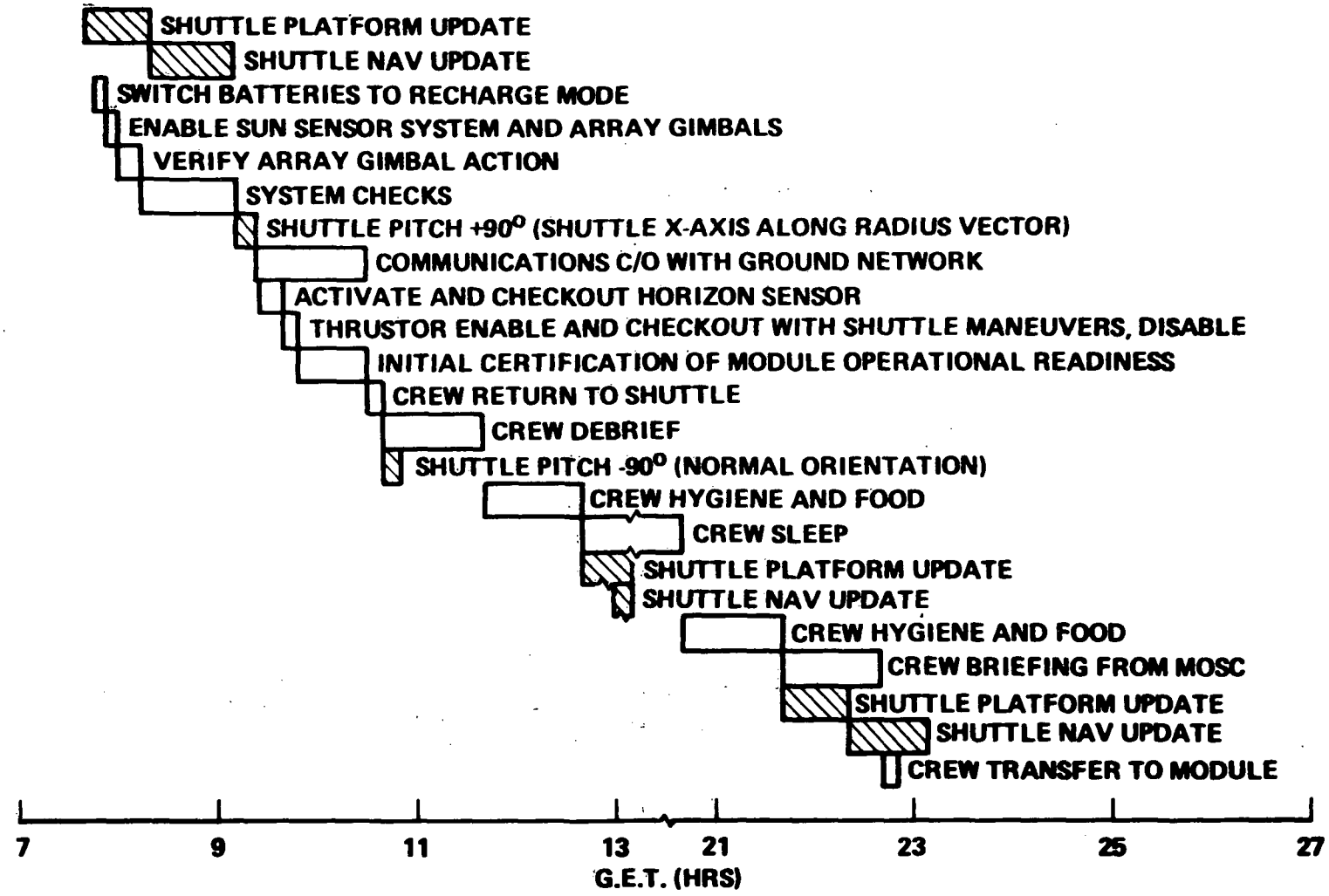


Figure 4-25. Buildup Timeline - Power Module

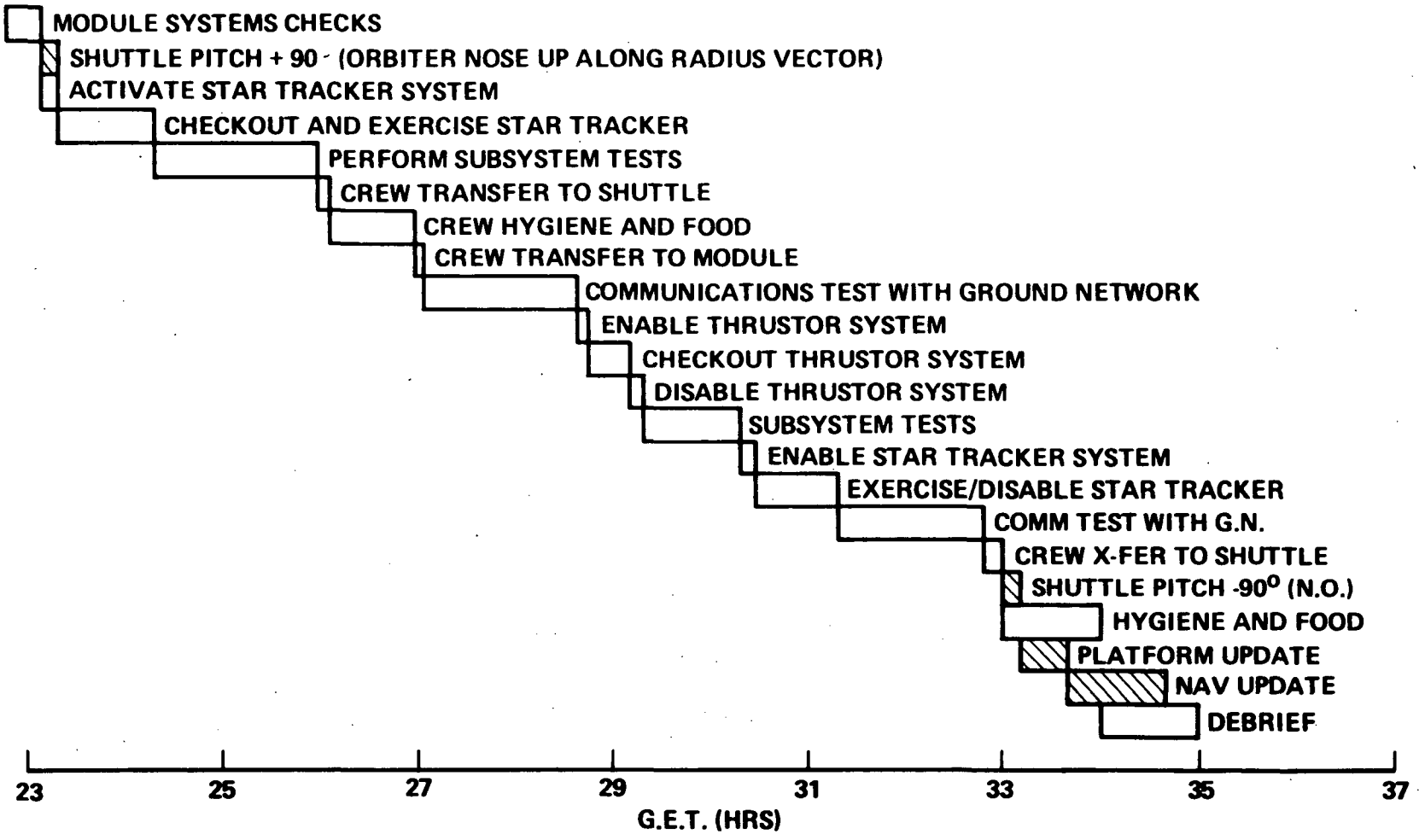


Figure 4-26. Buildup Timeline - Power Module

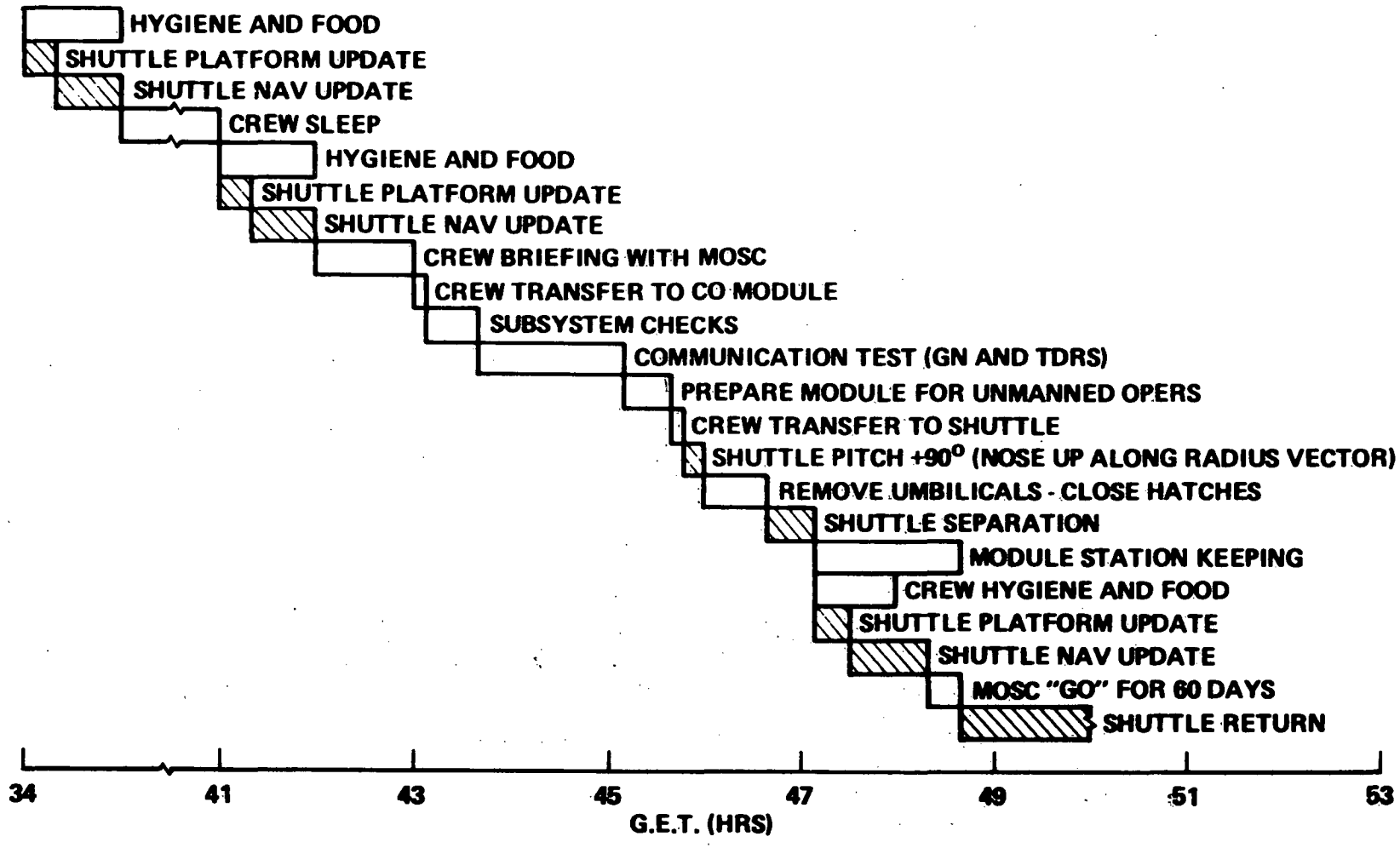


Figure 4-27. Buildup Timeline--Crew/Operations Module

hours ground elapsed time (GET) the Space Shuttle bay door will be opened and the module will be deployed on the payload interface pallet. During ascent, the module internal water loop is operating. Once the module is deployed from the Shuttle bay, the module radiator loop (freon) is activated by turning on the circulation pump. Once the operation of the thermal system has been verified, the crew prepares the module subsystems and the Space Shuttle airlock for crew entry to the payload module. At this point in time, the Space Shuttle crew will activate the atmosphere supply flow from the Space Shuttle into the module, through the payload interface. This air supply will utilize the nominal atmosphere distribution system in the module, retaining the onboard atmospheric supply for backup.

The two assembly crewmen then enter the Space Shuttle airlock in their IVA suits (see Figure 4-28). An expandable tunnel is used for crew transfer from the Space Shuttle to the Power/Subsystems hatch. At the module hatch, there is a viewing window and a habitability verification readout station. The crew can equalize pressure across the entry hatch at this location, and can activate the internal communication systems and lighting systems of the module.

Once the habitability of the module has been verified the crew opens the hatch and enters the module. Following entry, the crew will use the portable display and control unit (PDCU). This unit is shown in Figure 4-29. It operates with the data management system computer and has the functional capabilities of the control and display console scheduled for delivery in the Crew Operations Module. This unit operates in a manual, command at a time, mode. The PDCU can thus be used for command activities and with diagnostic routines for fault detection and isolation. Following these activities the crew returns to the Shuttle, removes their helmet and gloves, and completes a food and hygiene cycle.

The crew will then reenter the power module in shirtsleeves and begin the checkout operations. The first activity commanded by the crew is deployment of the solar array system shown in Figure 4-30. During ascent, the array support housings are stowed along the array boom. These arrays are

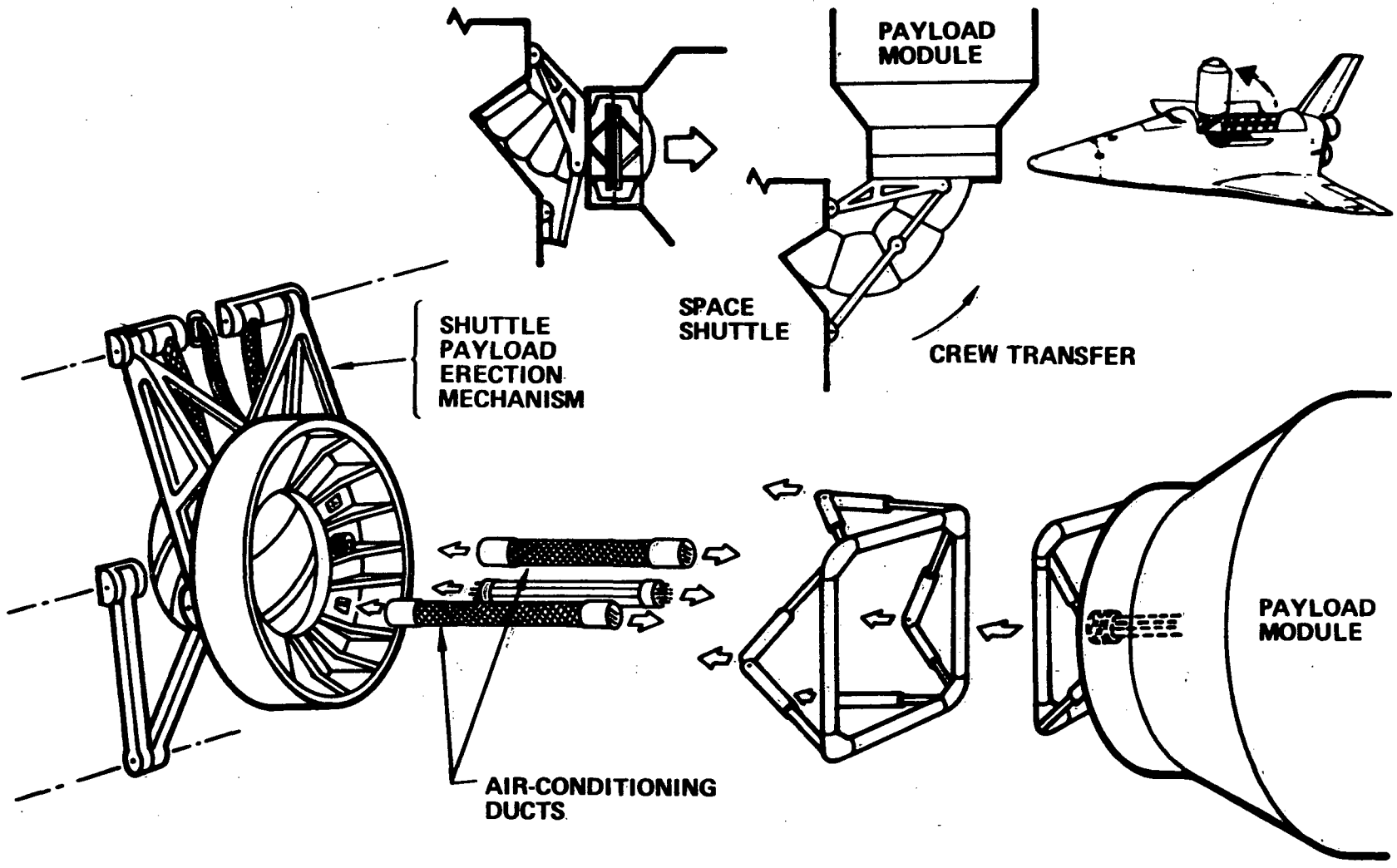


Figure 4-28. Shuttle/Module Interface

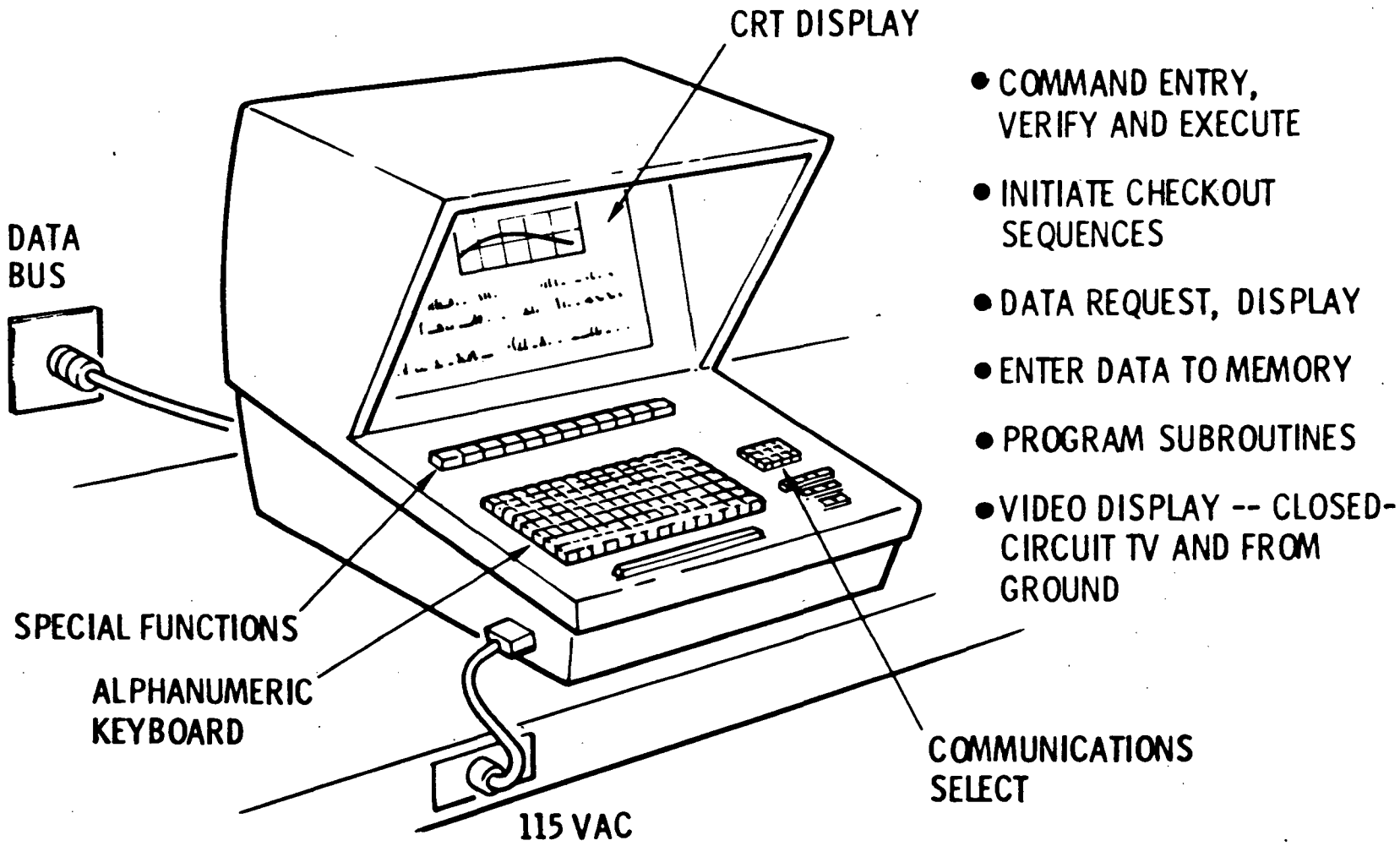


Figure 4-29. Portable Display and Control Unit

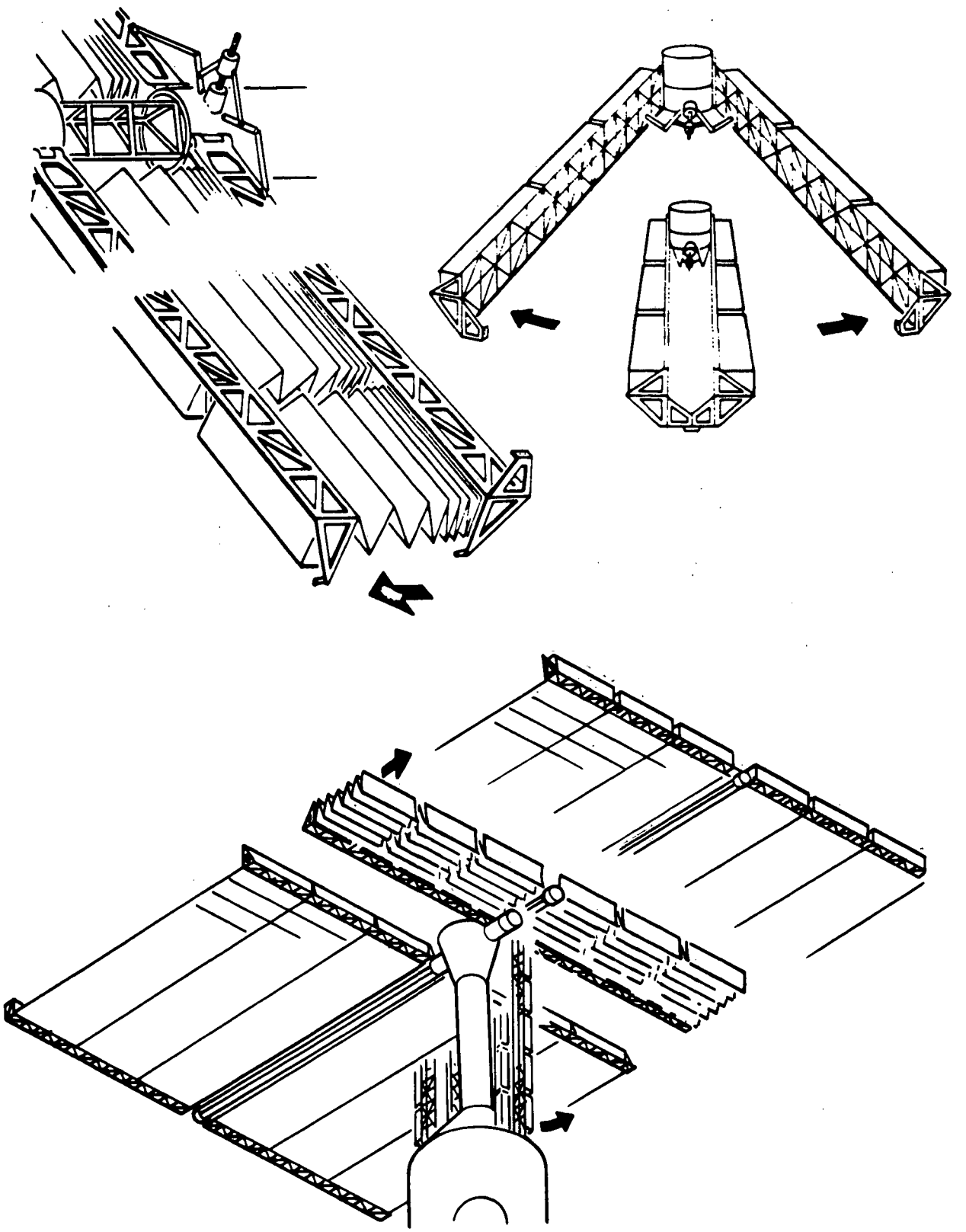


Figure 4-30. Solar Array Support Structure and Solar Array Mast/Panel Deployment

released at their outboard attach fittings and are then rotated outward by means of a motor-driven screw jack. Once the array support beams are in place and held by removable over-center locks, the twelve array panels are deployed by means of the Astromast assembly. This assembly consists of a collapsed truss beam which snaps into place, one section at a time, thereby extending the sections ahead of it. This entire deployment operation can be done manually if a failure should preclude the deployment sequence; however, the manual operation would require EVA and thereby require the crew to suit and prebreathe for the operation.

Once the arrays are deployed, the crew checks the power generation capability of the system and then switches the power source to the arrays. The batteries onboard the module are then switched to the recharge mode, initiating normal power system operation. At this point in time the solar array orientation control system is activated and checked out. Proper system response and panel operation can be evaluated by the crew while the Space Shuttle maintains orbital rate of the total configuration.

With the module on solar array power, the assembly crew begins a communication test on the VHF and S-Band systems with the ground network. While one crewman is performing these tests, the second crewman begins the next activation sequence for the high-thrust, N_2H_4 propulsion system. A simplified schematic of this system is presented in Figure 4-31. The power module is launched with approximately 317 kg (700 lb) of propellant onboard to maintain control for 120 days. This propellant loading is provided for buildup operations with the first resupply flight scheduled 90 days following the launch of the first Space Station module. The propulsion system is checked by the crewman by means of a series of controlled tests that are repeated several times to accumulate a reasonable amount of operating time in the space environment. The checkout test consists of having the Shuttle fly a predetermined attitude profile, while the crewman ascertains that proper error signals, valve commands, and engine firings results onboard the Space Station module. With verification of this system operation, the

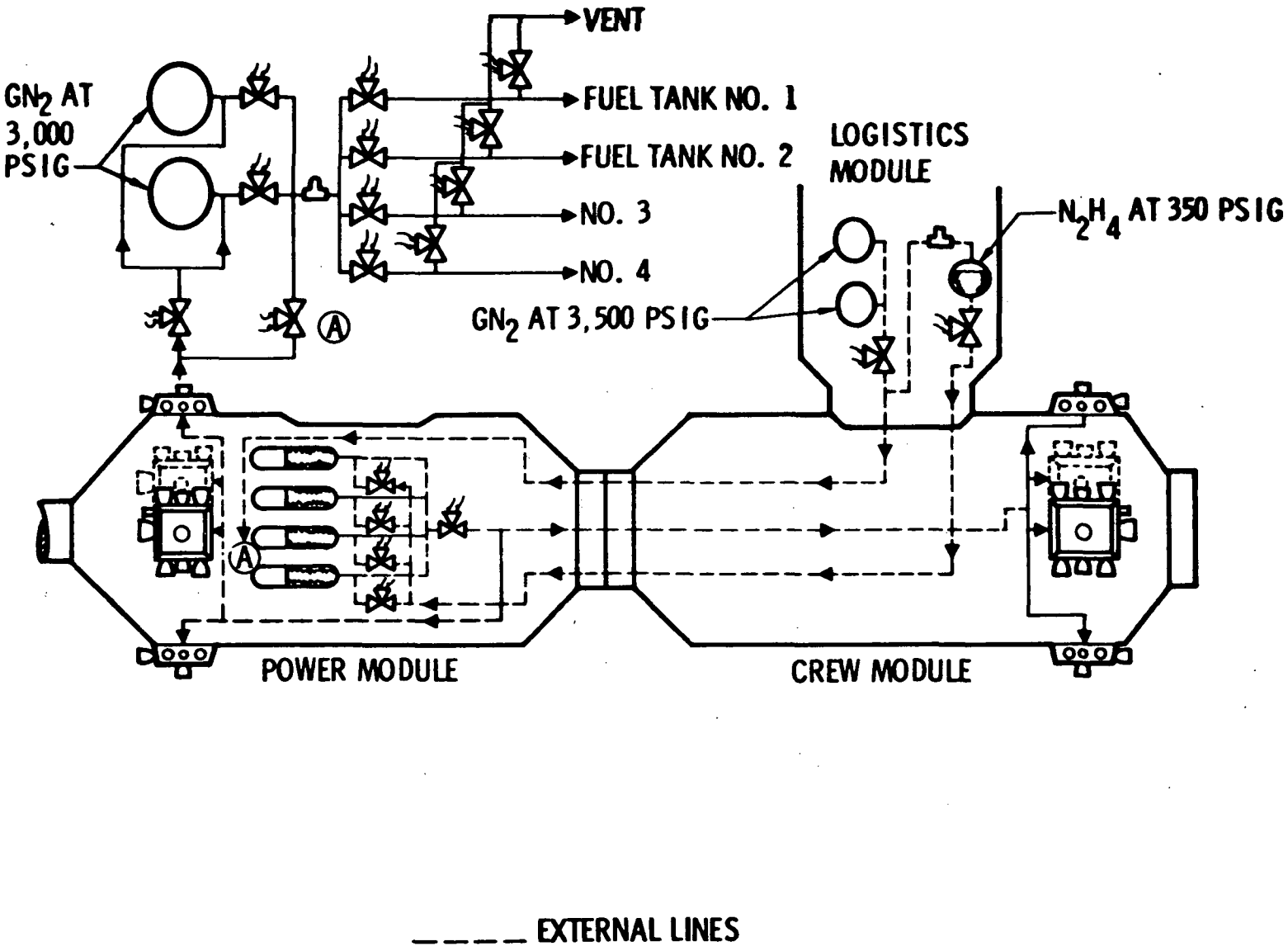


Figure 4-31. High-Thrust Attitude Control Fuel Transfer and Distribution System

system is deactivated and the initial certification of the module operational readiness is attained. The crew returns to the Shuttle, debriefs with mission operations support on the ground, and prepares for a sleep cycle onboard the Shuttle.

During the buildup operations, the Space Shuttle will require platform and navigation updates. The frequency of this Shuttle operation is determined by the accuracy desired of the Space Shuttle guidance and navigation system. As shown, in Figure 4-24, this operation has been presently baselined for approximately once every 10 hours.

Each time the assembly crew reenters the module, a system test will be performed to ascertain any anomalies which have occurred during their absence. During the crew sleep cycles, the mission operations support personnel on the ground will also monitor the module systems to ascertain any system anomaly trends.

On the second day, the crew will reenter the power module to check the horizon sensor and star tracker systems. During the unmanned phases of buildup, between delivery of modules, the Space Station configuration will be oriented with the longitudinal axis aligned with the velocity vector and the solar arrays in a trailing position. This orientation will exercise the module attitude control system in an operational mode similar to the nominal operations mode. The horizon sensor operation will be required to support this operation, and the checkout performed by the assembly crew will establish the operational readiness of this system. During this test, the Space Shuttle will be required to orient the configuration such that the system can be checked. Once this test is completed, the Space Shuttle will return to its normal orientation, along the velocity vector with the wings perpendicular to the radius vector. Following completion of this test the crew will perform periodic tests on the module subsystems, similar to a shakedown cruise.

Following 24 hours of shakedown cruise, the crew will prepare for release of the module and return of the Space Shuttle. This operation will begin

once the on-orbit crew and the ground have established the module's readiness for 60 days of unmanned operations. The Power/Subsystems module will be configured for unmanned operations by activation of the atmosphere supply onboard the module. The crew will then transfer to the payload tunnel area and secure the module hatch. After this, the crew will disconnect the umbilicals across the interface and then enter the Space Shuttle airlock, securing the tunnel hatch. The tunnel will then be depressurized and the Shuttle will orient the module to its separation attitude. Once the desired attitude has been attained, the Space Shuttle will separate from the Power/Subsystems Module. Following separation the module propulsion system will be activated and the hatch cover closed over the exposed docking port by RF command from the Space Shuttle. For one orbit (or more), the Shuttle will station-keep with the module monitoring subsystem operation. At the proper time, the Space Shuttle, with the assembly crewmen onboard, will initiate the retrofiring for return to Earth and completion of the first phase of the buildup operations.

Crew Operations Module

The second flight of the Space Station buildup operations will be the delivery of the Crew Operations Module and the mating of this module to the Power/Subsystems Module. Figure 4-32 presents a summary of the interfaces between the Crew Operations module and those modules included in the Space Station initial configuration. As shown in this figure, once the Crew Operations Module is delivered to orbit and docked to the longitudinal docking port of the Power Subsystems Module, 36 interfaces will be mated between the two modules. To perform the operations of mating these module-to-module interfaces and checkout of system operations, two assembly crewmen will accompany the Crew Operations Module to orbit, as Space Shuttle passengers.

This second flight of the buildup operations also includes the first direct docking operations of one module to another, utilizing the Space Shuttle systems. The technique for direct docking utilizes manual control by a Space Shuttle crewman located at the docking station in the Space Shuttle airlock.

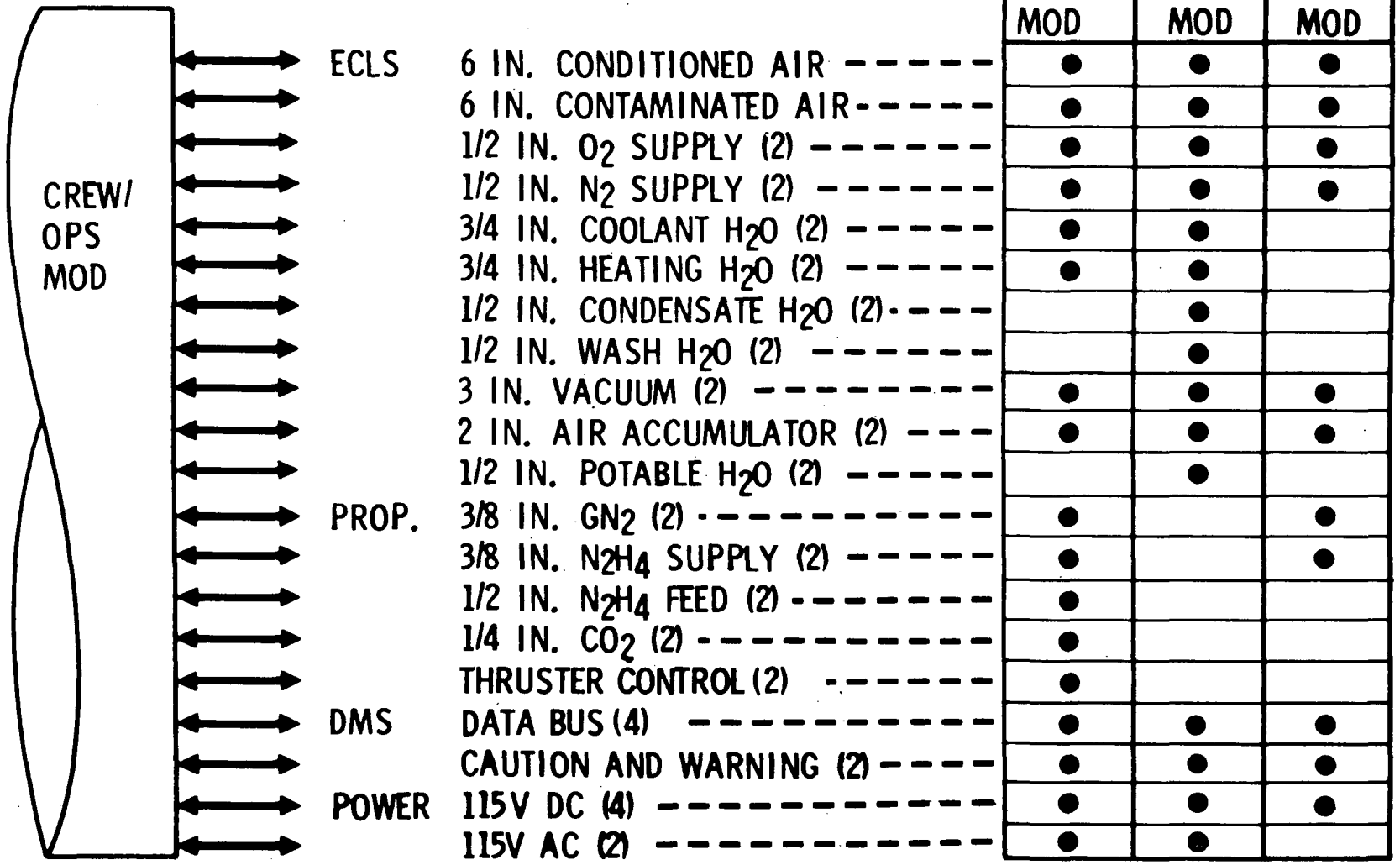


Figure 4-32. Module-to-Module Interfaces

With the defined Shuttle orbiter capabilities and docking aids, a simulation was conducted during the Phase B study to assess the acceptability of the manual mode. The results verified that the direct docking mode is acceptable, and controlling final contact errors to an acceptable value presents no serious difficulty. While not directly related to buildup operations, concern also existed over a possible side collision resulting from the various configurations of the Space Station, while attempting to dock modules of various lengths to the Space Station radial ports. The simulation included investigation of this problem, and the results established that clearance was more than adequate for the Space Shuttle. However, to ensure collision avoidance, a lighting system for the Space Station, similar to the running lights on a boat, was developed to provide a positive cue to the Shuttle, should the Shuttle inadvertently maneuver to a position where collision is possible. This lighting system, along with the selected docking aid is presented in Figure 4-33.

The docking aid chosen to apprise the pilot of displacement errors is a T-Bar device. The T-Bar is located above the target docking hatch and, when viewed through the Space Shuttle docking telescope, its image will yield information relative to lateral and vertical displacement of the Space Shuttle. In addition, target image diameter calibrations will yield data relative to distance-to-the-docking-interface-plane. The T-Bar and the target circle are both electroluminescent, and the Space Shuttle will provide lights for docking illumination, to relieve lighting constraints on docking operations. In addition, the collision lights have a slight (4 deg) inward cant so that at distances greater than 91.5 m (300 ft) the lights may be seen at all times as acquisition and rendezvous aid.

The selected docking mechanism is shown in Figure 4-34. This mechanism consists of a docking collar with two protruding guide arms on one module, and an identical collar on the other module with two guide arms in opposite corners to provide a neuter type of arrangement. The guide arms force alignment in the lateral, vertical, and roll positions during final closure. At closure, capture links located on the guide arms hold the collars together while the collars are retracted by collapsing their hydraulic energy

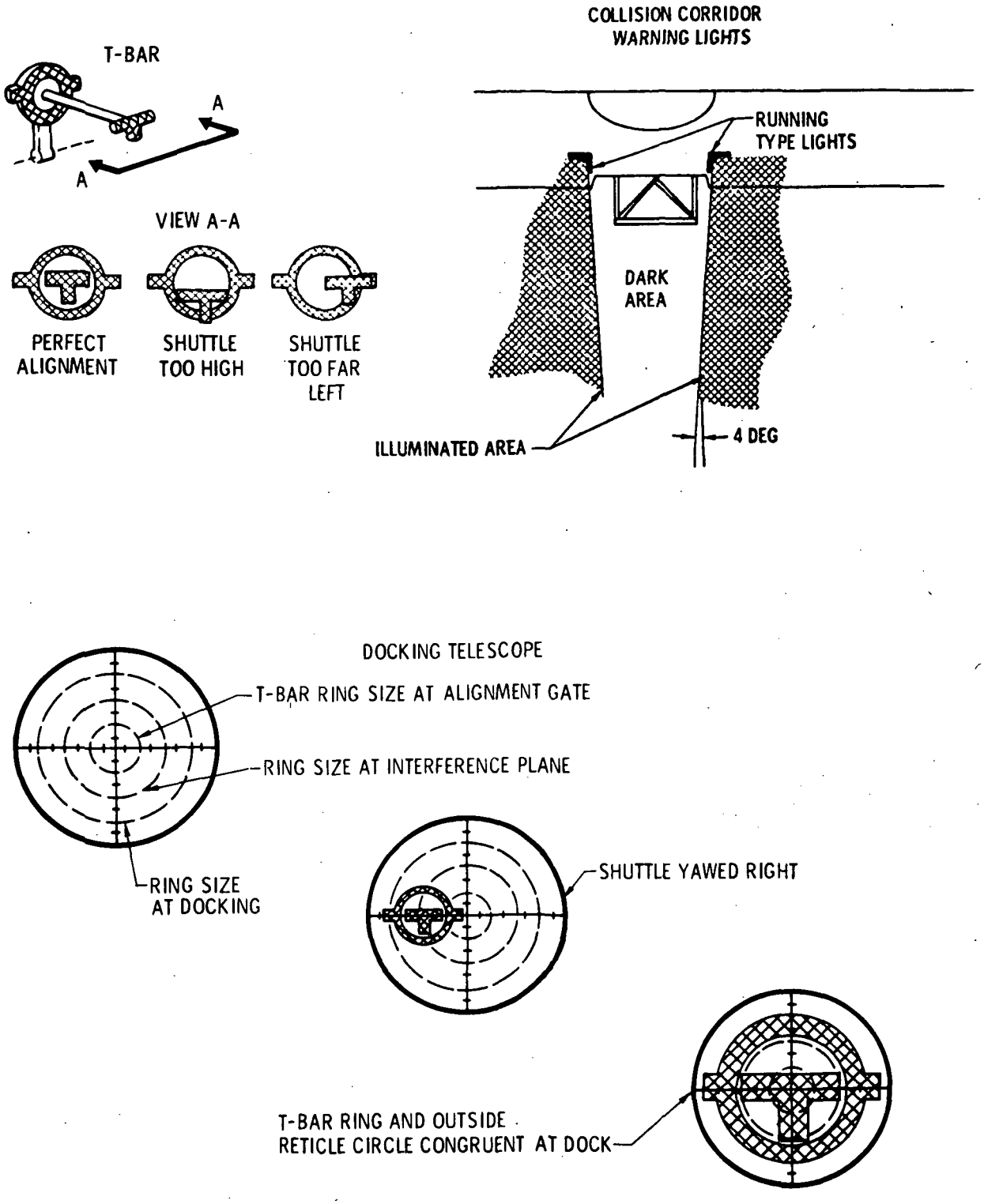


Figure 4-33. Docking Aids

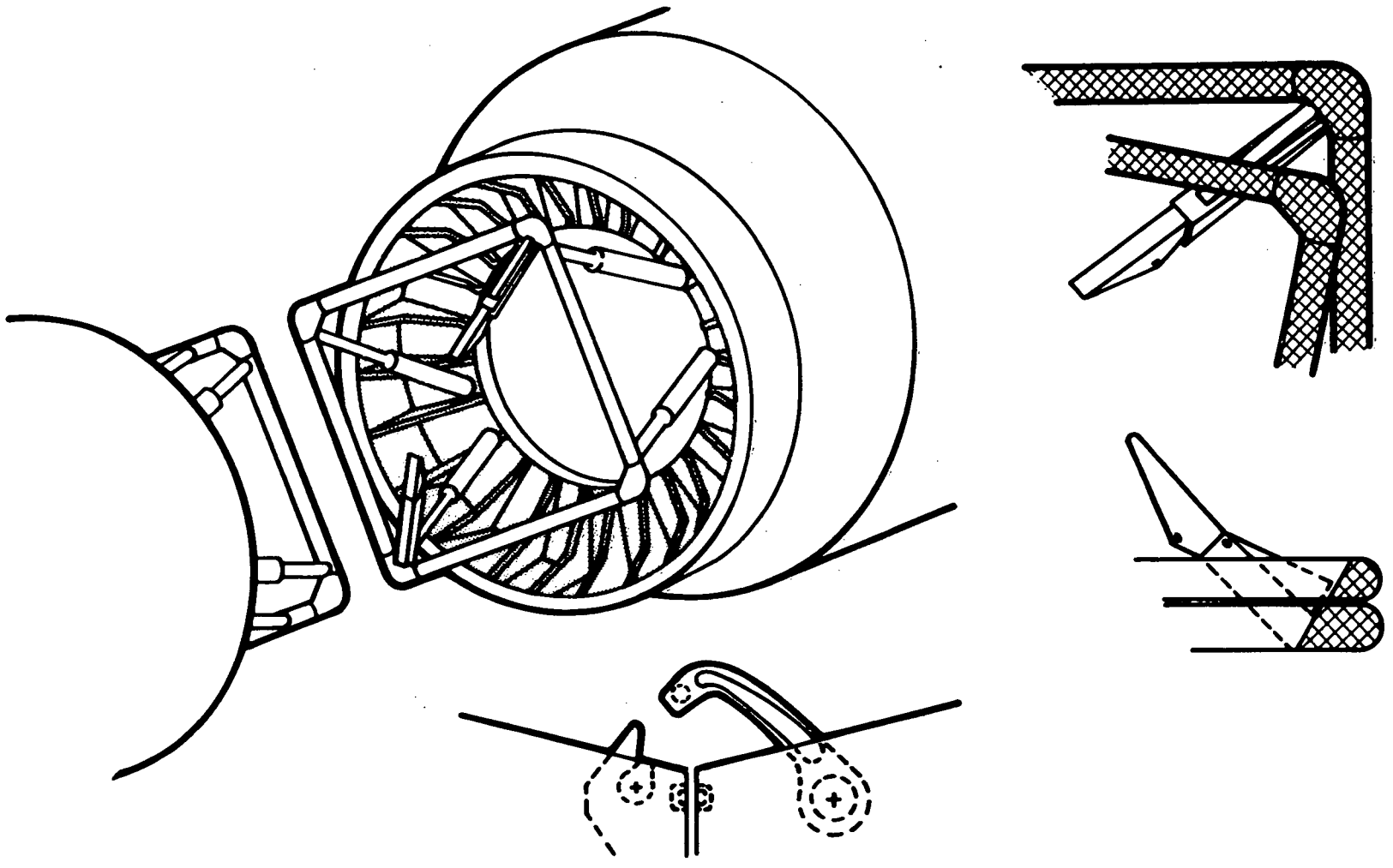


Figure 4-34. Docking Mechanism

absorbing members. When the two mating surfaces are in contact, 24 interdigitated hooks (12 on each module) are engaged, and redundant seals are pressurized to seal the docking interface.

Figures 4-35 through 4-38 present the timeline for the Crew Operations Module buildup mission. As shown, at a ground elapsed time of approximately 5 hours, the Space Shuttle will have completed rendezvous with the Power/Subsystems Module and the Shuttle bay door will be opened and the module deployed for docking. As during the Power/Subsystems module delivery mission, the freon loop of the Crew Operations Module will be activated following module deployment from the Shuttle payload bay. During the ascent of the Space Shuttle, the mission operations support personnel will activate the rendezvous and docking aids and deploy the hatch cover over the target docking port using the RF command loop.

Before initiating the terminal docking maneuver, the high-gain antenna located on the Crew Operations Module must be rotated to the docking orientation shown in Figure 4-39. This orientation eliminates any interference with the docking operation, including the docking pilot's view. Also, the RF link between the Space Shuttle and the Power/Subsystems Module will be verified, as it is required for the nominal docking operation.

At a ground elapsed time of approximately six hours, the docking operation will be completed. Immediately following docking completion, the Space Station attitude control system will be deactivated and the orbiting configuration attitude orientation will be controlled by the Space Shuttle until completion of the on-orbit activities. Once this system has been deactivated, the crew will transfer to the Shuttle airlock and enter the crew transfer tunnel. Once the two assembly crewmen arrive at the entry hatch into the Crew Operations Module, they will activate the module lighting and intercomm systems and perform visual checks to establish the habitability of the module.

The Crew Operations Module contains the atmosphere control system and sufficient oxygen and nitrogen for 12 man days of habitation; however, this

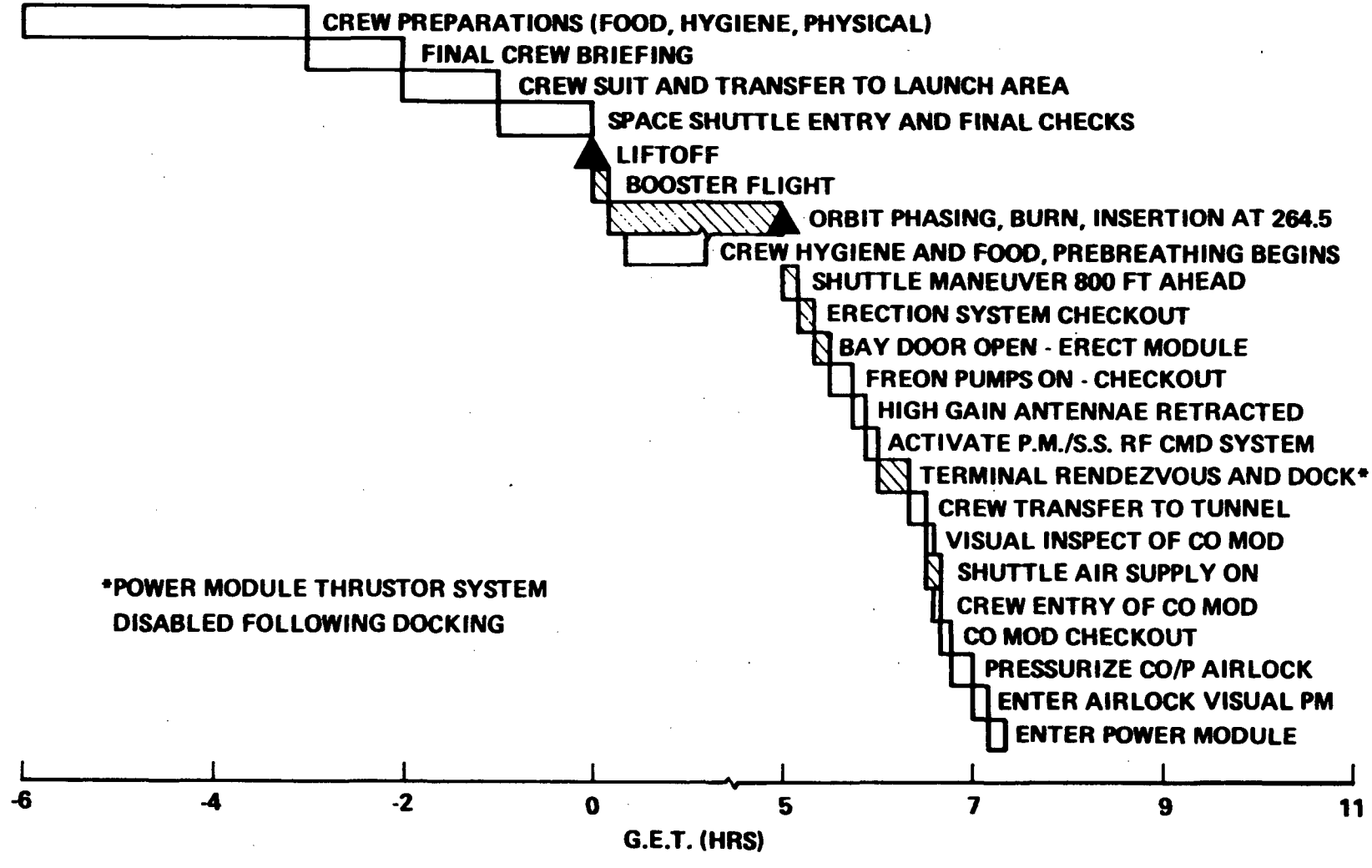


Figure 4-35. Buildup Timeline - Crew/Operations Module

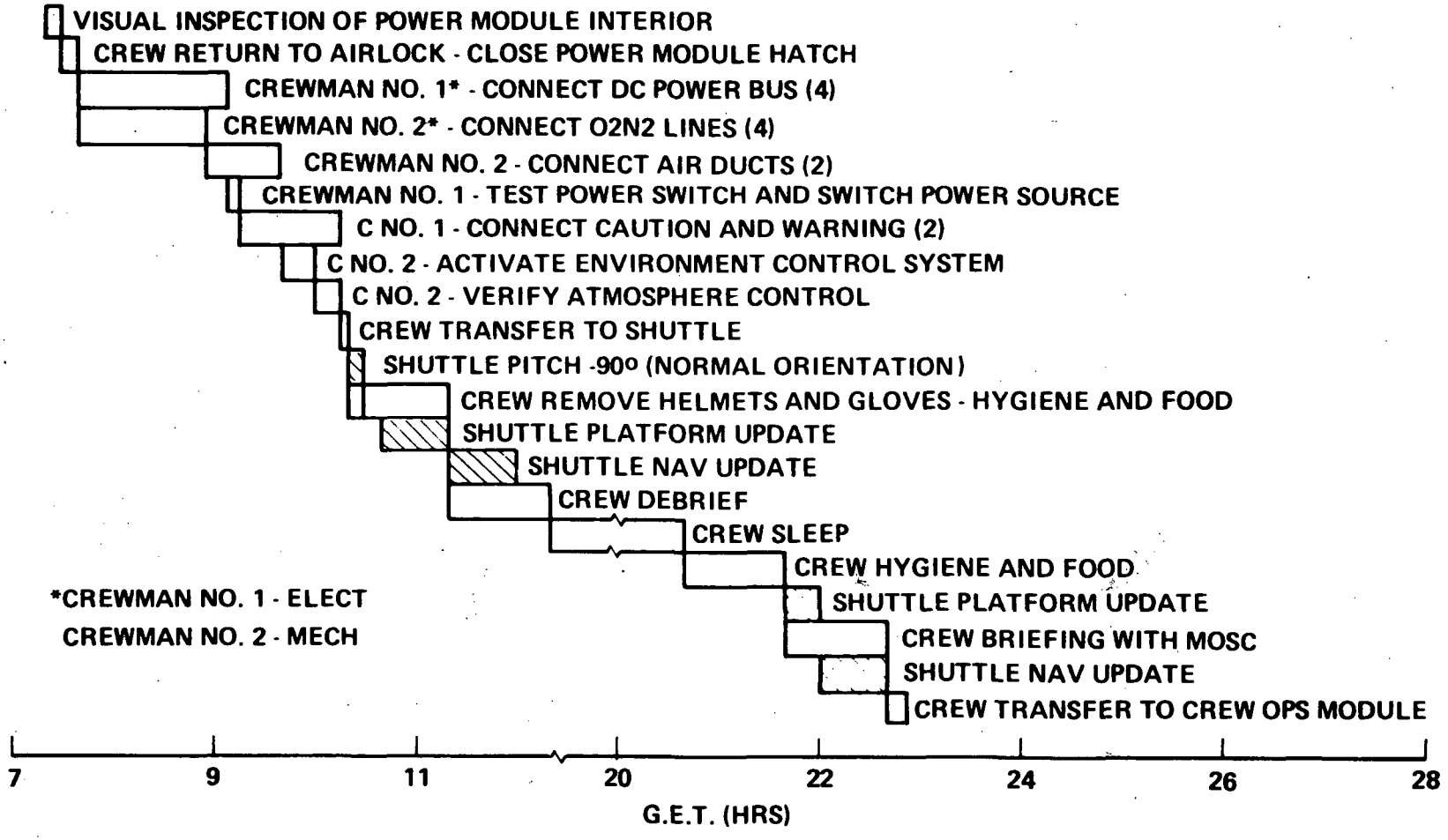


Figure 4-36. Buildup Timeline - Crew/Operations Module

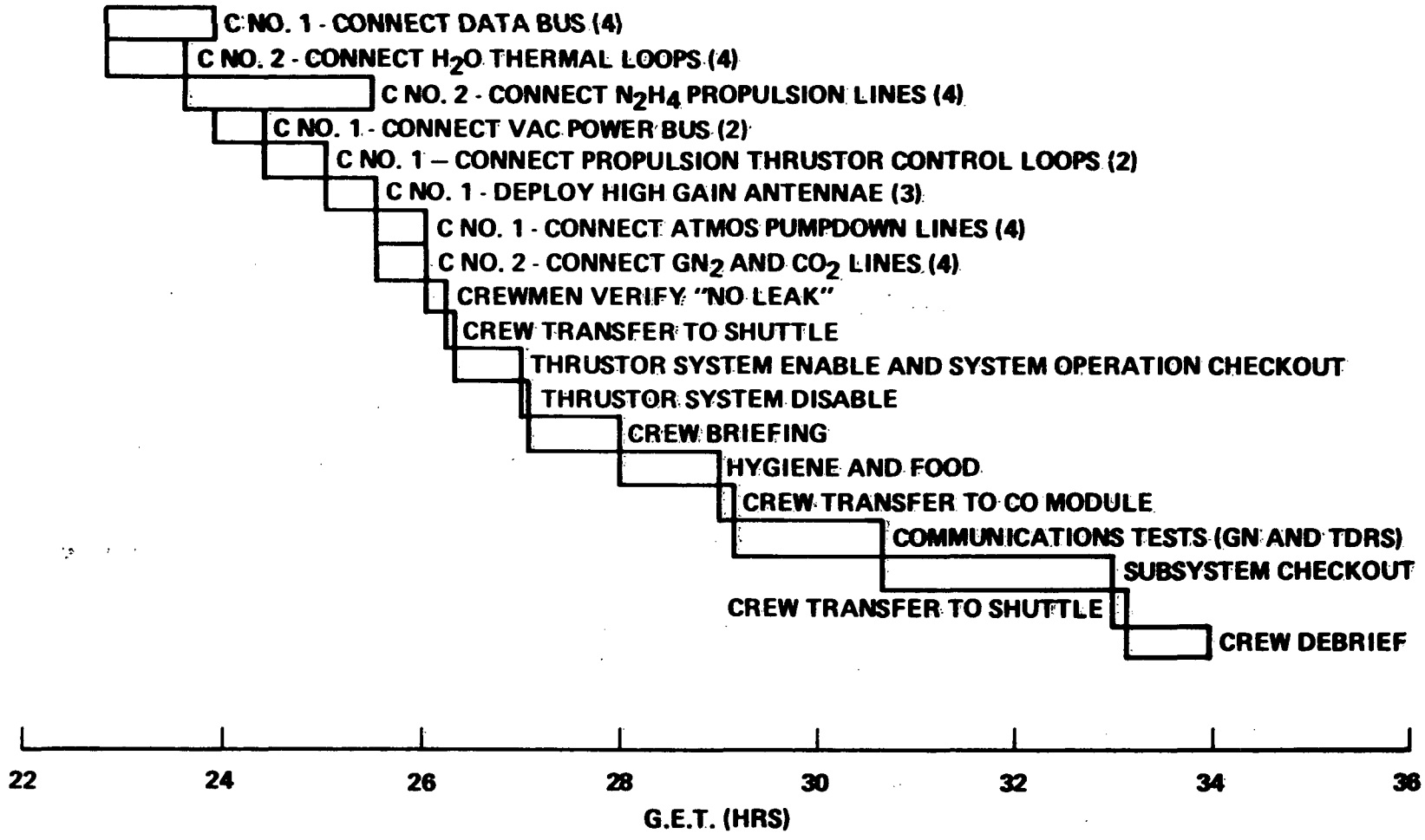


Figure 4-37. Buildup Timeline - Crew/Operations Module

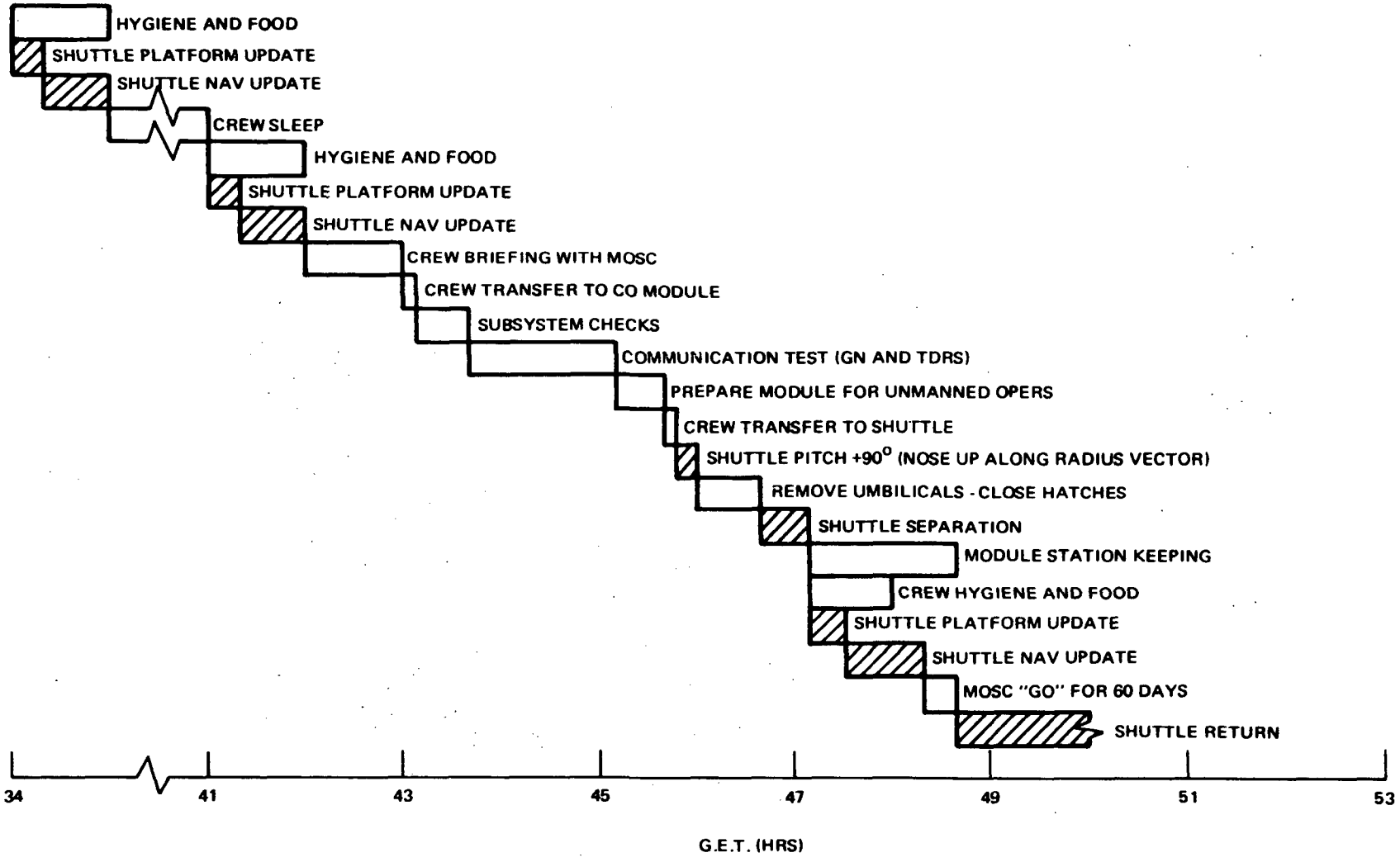


Figure 4-38. Buildup Timeline - Crew/Ops Module

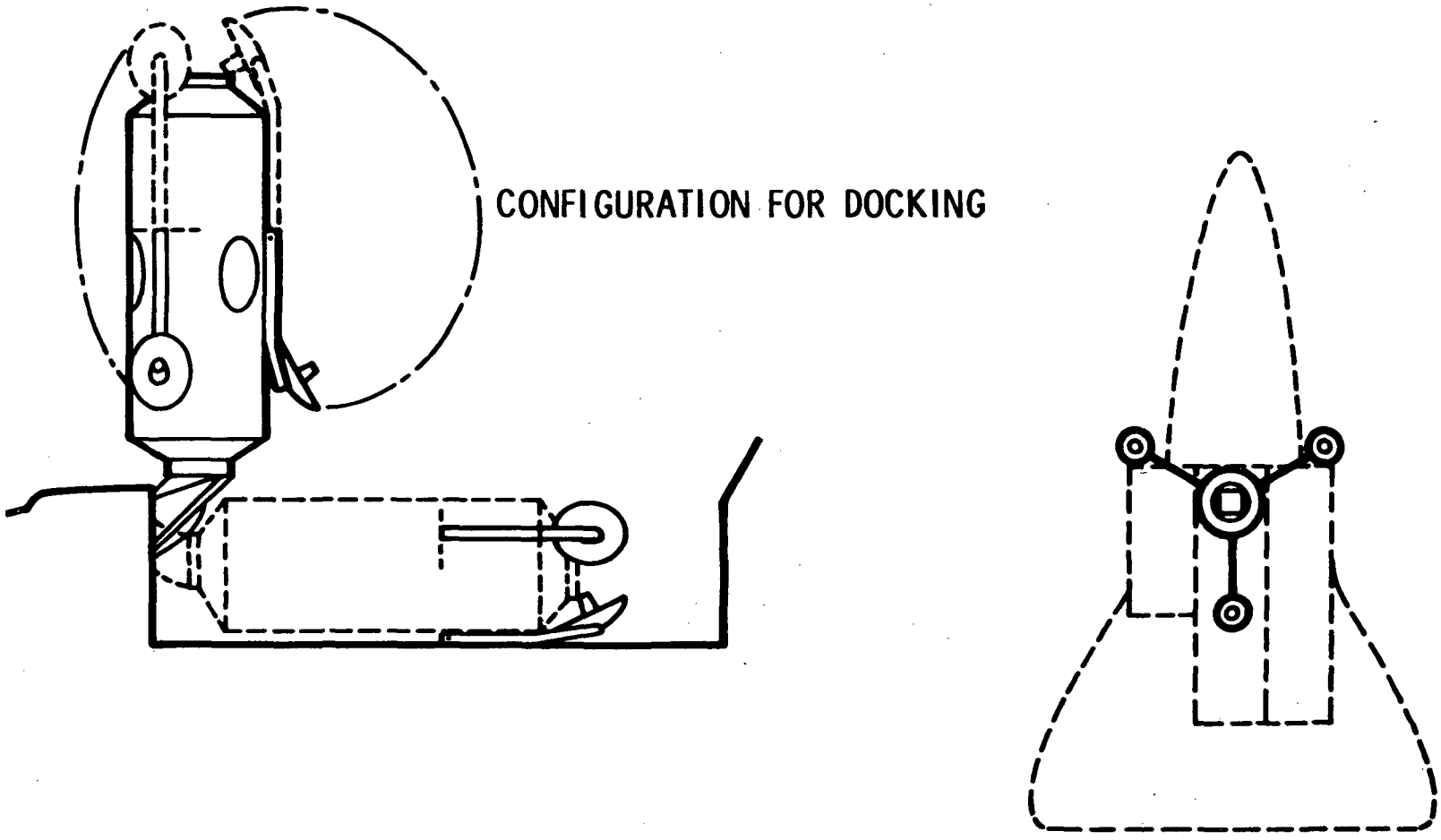


Figure 4-39. High-Gain Antenna Installation

will be kept in reserve, and the module(s) will be supported by the Space Shuttle ECS. The crewmen will equalize pressure across the hatch, enter the module (once again, for conservatism, it is assumed in their IVA suits, with helmets and gloves) and perform a visual check at the Crew Operations Module-Power/Subsystems Module interface. They will equalize pressure in this natural airlock between the modules, and then enter this airlock. In this position, the crew will perform visual checks of the Power/Subsystems Module through the view port in the hatch. The crew will then enter the Power/Subsystem Module and visually inspect the module.

Following visual inspection the two assembly crewmen will return to the Crew Operations Module to begin mating the interface, securing the hatch into the Power/Subsystems Module. Until the electrical power interfaces are mated and checked out, the Crew Operations Module is dependent on the Space Shuttle for its electrical supply. This supply is limited to 500 watts nominal and 800 watts peak, with a total energy of 20 kwh. Therefore, the dc power bus interface connectors will be the first items to be mated. Figure 4-40 presents a typical electrical interface connector. All electrical connectors are standard except the power plugs which incorporate a nonarcing feature in case of accidental demating. By incorporating a high-resistance outer sheath, such as a carbon rod with an appropriate inert binder, as an extension to the regular pincontact, the power plug will automatically eliminate arcing during mating and demating. While the first assembly crewman (an electrical technician) is completing the power interface, the second assembly crewman (an electromechanical technician) will mate the oxygen, nitrogen, and air ducting interfaces. Approximately two hours following the initiation of the interfacing mating, the Crew Operations Module will be on the Space Station power source.

The times required for the interface matings are presented in Table 4-11. The values shown in the first column represent estimates of the time required to complete the mating of the connection type of interface listed in the lefthand column of Table 4-11. These times were then corrected for the space environment, depending upon whether they could be done in IVA

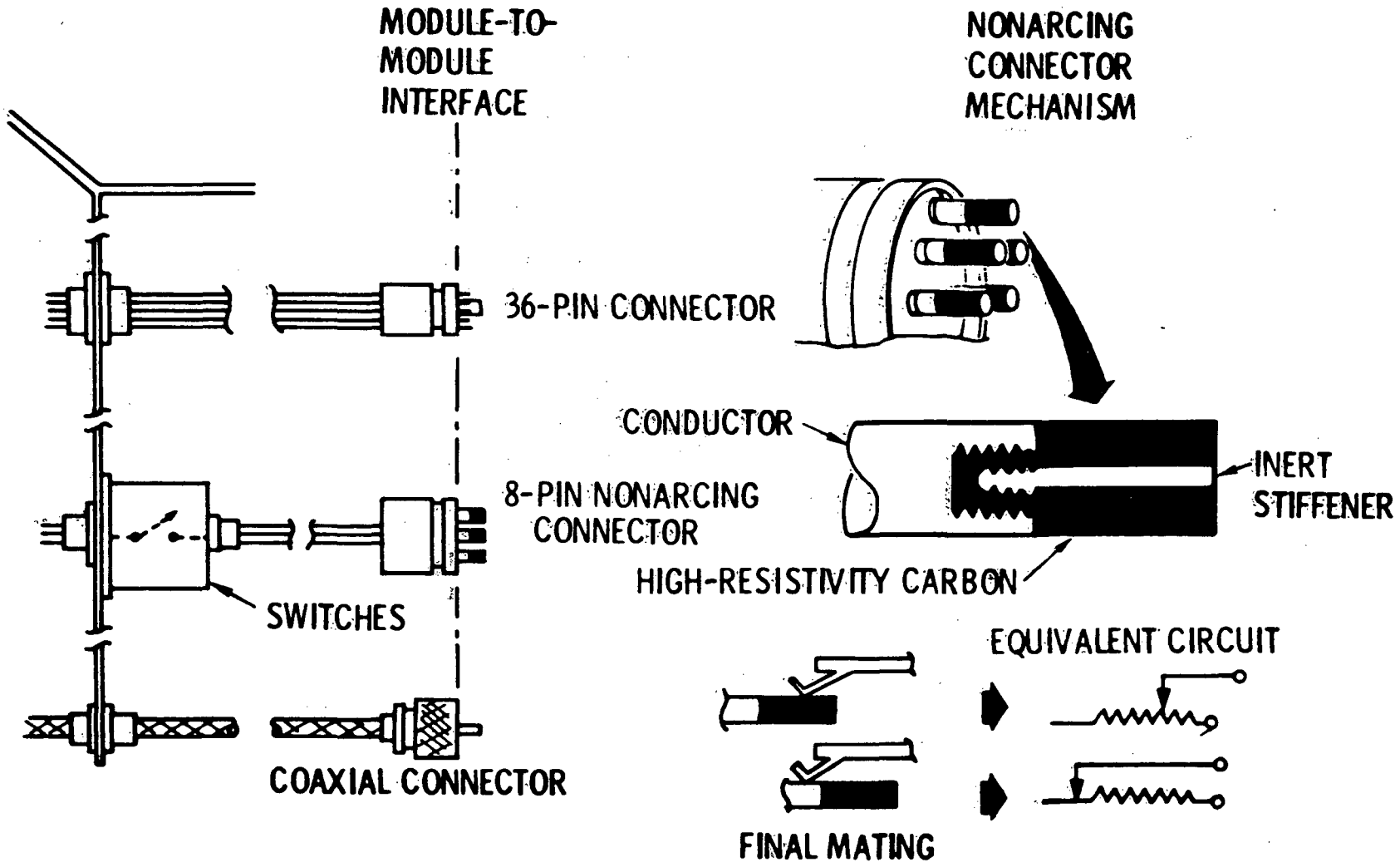


Figure 4-40. Electrical Interface Connection Concepts

Table 4-11

DETAIL ESTIMATES–INTERFACE CONNECTIONS

Connection	Unstow, Mate, Torque, Secure Time (min)	Correction for Space Environment*	Hookup Time (min)	Test and C/O Time (min)	Total Connect Time (min)
Air ducts	6	3.5	21	3	24
Gas lines (O_2, N_2)	4	3.5	14	3**	17
Fluid lines (H_2O)	4	1.5	6	5**	11
Fluid lines (N_2H_4)	18	1.5	27	10**	37
Power bus (vdc)	5	3.5	17.5	5	22.5
Power bus (vac)	5	1.5	7.5	5	12.5
Data bus	6	1.5	9	10	19
Caution and warning	6	3.5	21	10	31
Gas lines (pumpdown)	4	1.5	6	3	9

*Correction factors: 3.5 (avg) for space suit; 1.5 (avg) for zero-g

**120-min leak test adequate for all fluid systems

suits or were more probably to be accomplished in shirtsleeves. The third data column presents the corrected time for the interface mating and the final column presents the total connection time, including the test and checkout requirements.

Table 4-12 presents the detailed requirements for interface connections between the Power/Subsystems Module and the Crew Operations Module, in time required for total subsystem. As shown in Figure 4-41, the low-pressure interfaces employ quick disconnects with interlocks to the shutoff valves for emergencies. To detect leakage of non toxic fluids and gases at these interfaces, the joints are encased in transparent bags, which by condensation or swelling will signify leakage.

Once the atmosphere interfaces are mated and the Crew Operations Module is on Space Station power, the crew will activate the environmental control system and verify proper atmospheric control. Following these operations, the crew would return to the Space Shuttle, assuming they are in their IVA suits, remove their IVA suits, debrief, and perform a food and sleep cycle.

The second day, the crew will brief with the support personnel on the ground to identify any anomalies which occurred during their sleep cycle, and then reenter the Crew Operations Module to continue the buildup operations. One of the first activities to be completed on the second day is the mating of the hydrazine propulsion lines. This interface is shown in detail in Figure 4-42. Since N_2H_4 is considered a hazardous fluid, it is transferred inside an evacuated sleeve. The interface surfaces of both the fluid line and the outer sleeve are joined by appropriate means of bolts, V-band clamps, etc. The outer sleeve can be retracted for ease of connection of the inner line. Following completion of the interface mating, the crew returns to the Crew Operations Module and secures the hatch, isolating the interface volume from both modules. By proper valve manipulation the N_2H_4 lines are evacuated, and the propellant lines are filled from the source tanks in the Power/Subsystem Module. After the outer sleeve is evacuated, a burst disk is inserted in the vacuum line to detect an N_2H_4 leak into the evacuated sleeve volume.

Table 4-12

POWER/CREW–DETAIL INTERFACE ESTIMATES

Connection	Number	Hookup Time (min)	Checkout Time (min)	Total Time (min)
Air ducts	2	42	6	48
Atmosphere supply	4	64	12	76
Power (vdc)	4	70	20	90
Caution and warning	2	42	20	62
H_2O thermal	4	24	20	44
Atmosphere pumpdown	4	24	12	36
Propulsion (N_2H_4)	4	72	40	112
Propulsion (GN2, CO_2)	4	24	12	36
Data Bus	4	24	40	64
Power (vac)	2	10	20	20
Thruster control	2	18	20	38
			Total time = 636 man-min	

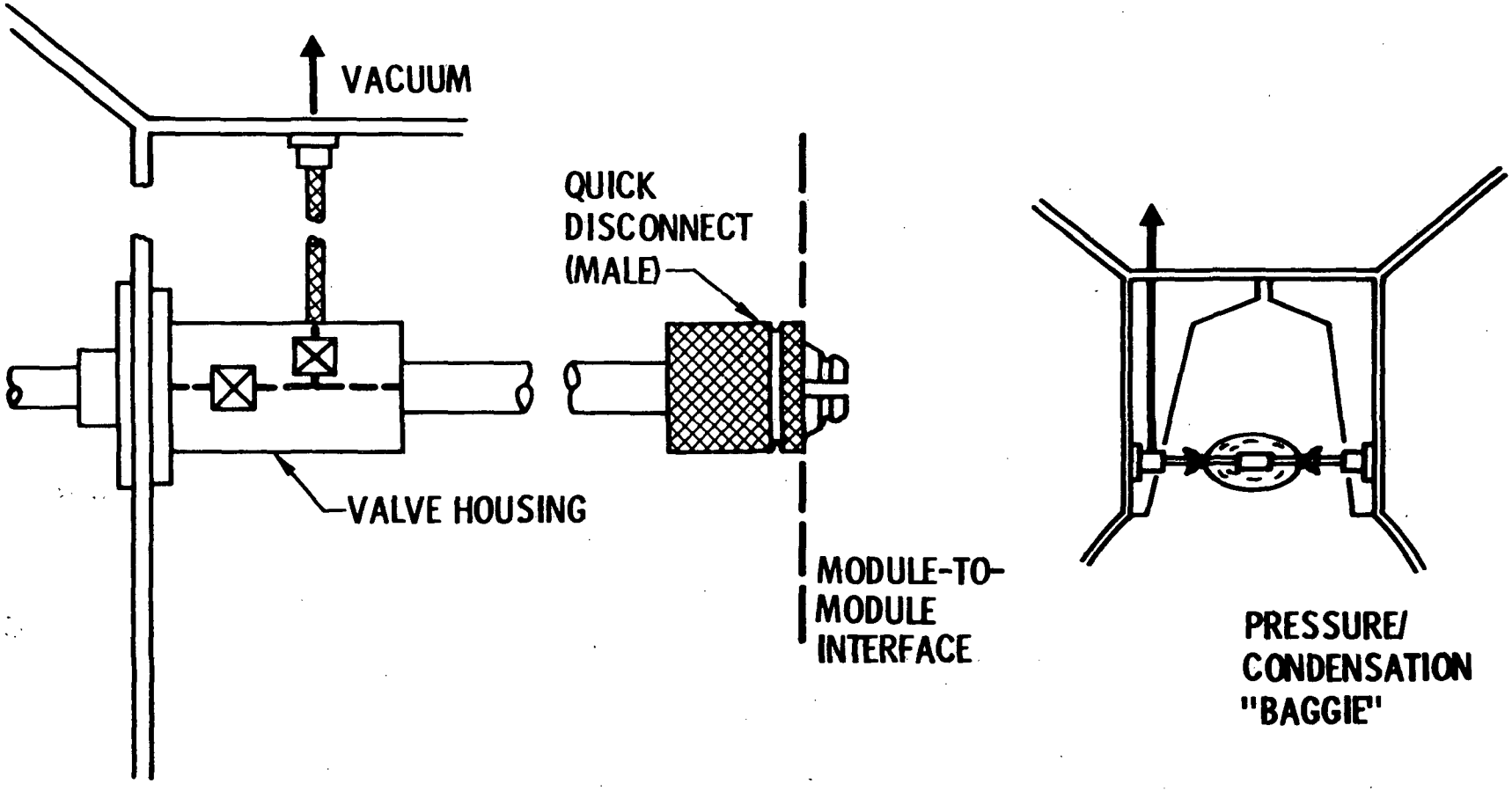


Figure 4-41. Low-Pressure/Fluid-Interface Connection Concept

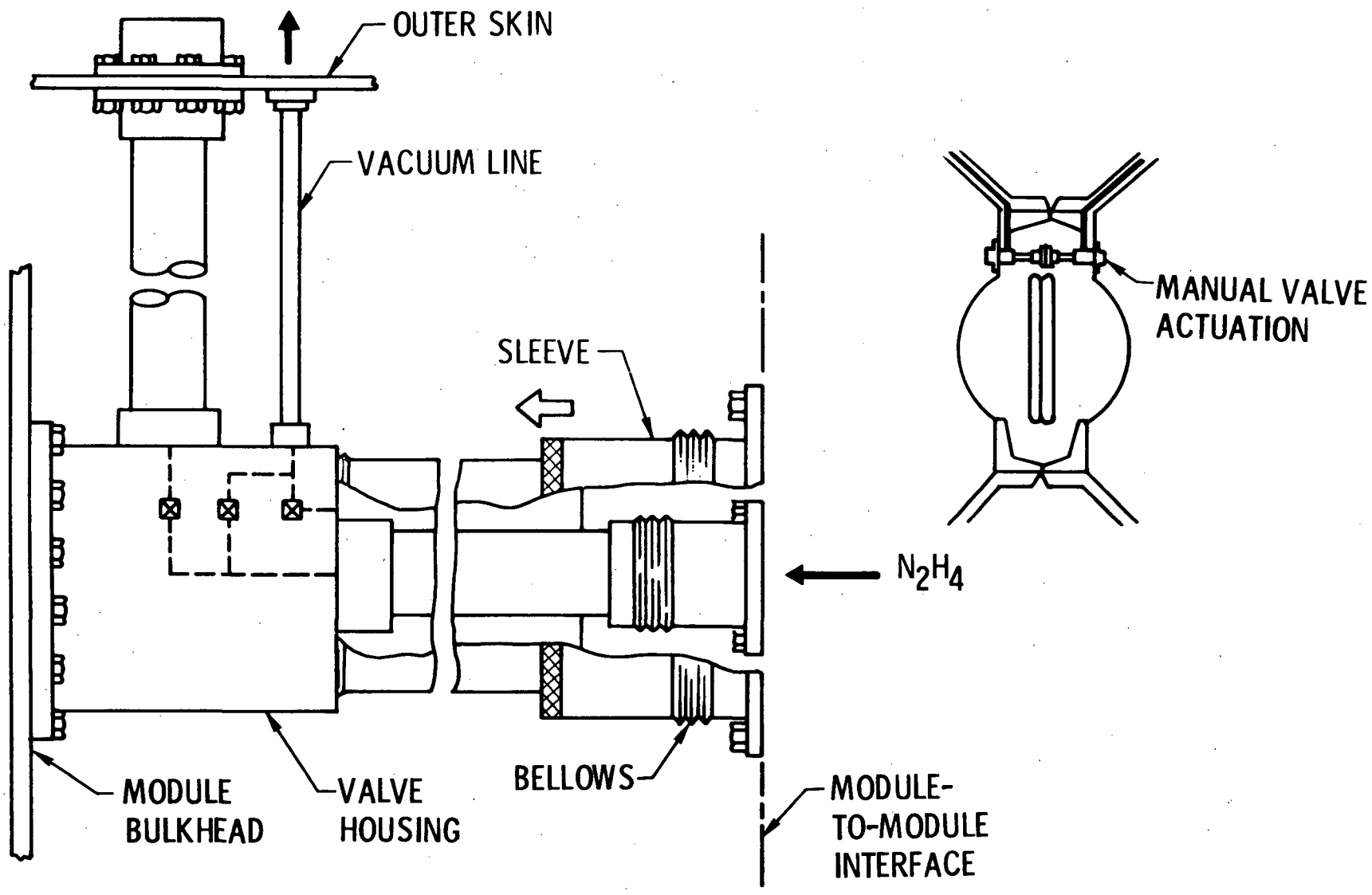


Figure 4-42. N_2H_4 Interface Connection Concept

The high-gain antennas located on the Crew Operations Module are then deployed to their normal position, from the stowed positions utilized during docking. Following this operation, the crewmen again verify no leaks in the N_2H_4 feed lines and then transfer to the Space Shuttle. Once in the Space Shuttle, the thruster system is enabled and the propulsion system on the Crew Operations Module is operated to verify system integrity. Following completion of the test, the crew will deactivate the system and perform a food and hygiene cycle on the Space Shuttle.

The crew will then transfer into the Crew Operations Module, verify the habitability of the Crew/Power interface airlock, and begin the communications tests with the high-gain antennas. Figure 4-43 presents a representation of the relative orientations between the orbiting configurations and the Tracking and Data Relay Satellites. Because the Space Shuttle structure tends to obscure the antennas, the Shuttle orientation of the cluster must change to permit continuous viewing for checking acquisition and handover operations. This can be accomplished by orienting the cluster as noted in the figure, the actual orientation depending on the position of the orbit relative to the satellites.

Following the initial communications tests, the assembly crew will perform a total of 10 hours of subsystems tests on primary, redundant, and backup systems to establish the operational readiness of the two modules. Typical of the subsystem activation and checkout operations is that one associated with the urine recovery system presented in Figure 4-44. The first step in activating the urine recovery system is to verify that all manual isolation valves are in the position and that the thermal fluid from the solar collector is present at the heat exchanger. One of the chemical treatment tanks is then activated. During normal operation, when one storage tank is filled the second starts to accumulate urine while the first is automatically switched to the wick system. The circulating air system drives air through the heat exchanger and across the wicks, evaporating the water which is subsequently condensed in the two stage condenser. The water is then filtered through charcoal and bacterial filters and transferred to the water management storage units. During the checkout operations, purified water will be used to simulate urine, to provide the operational test. Principal

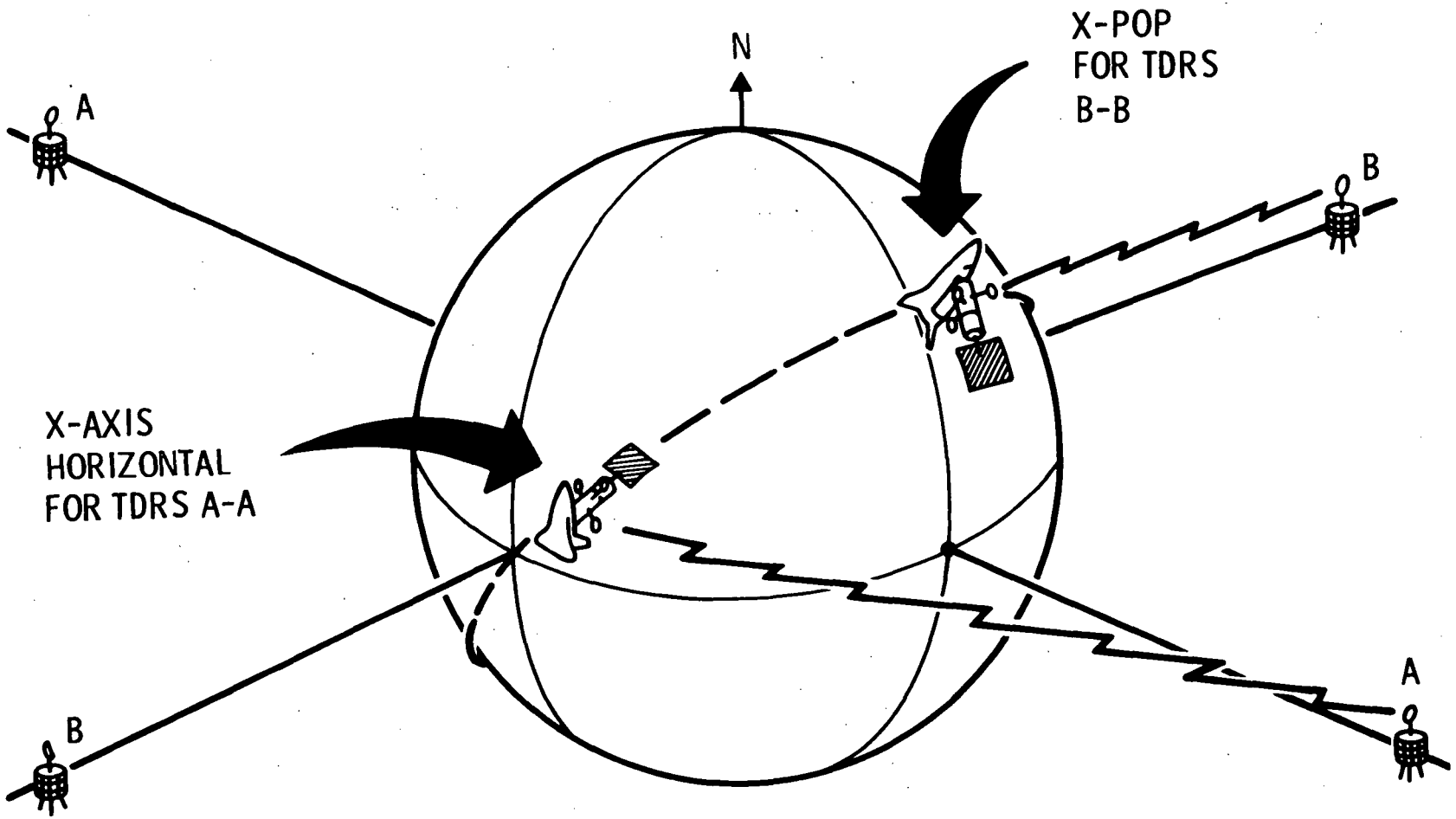


Figure 4-43. High-Gain Antenna Checkout Shuttle/TDRS Relative Orientation

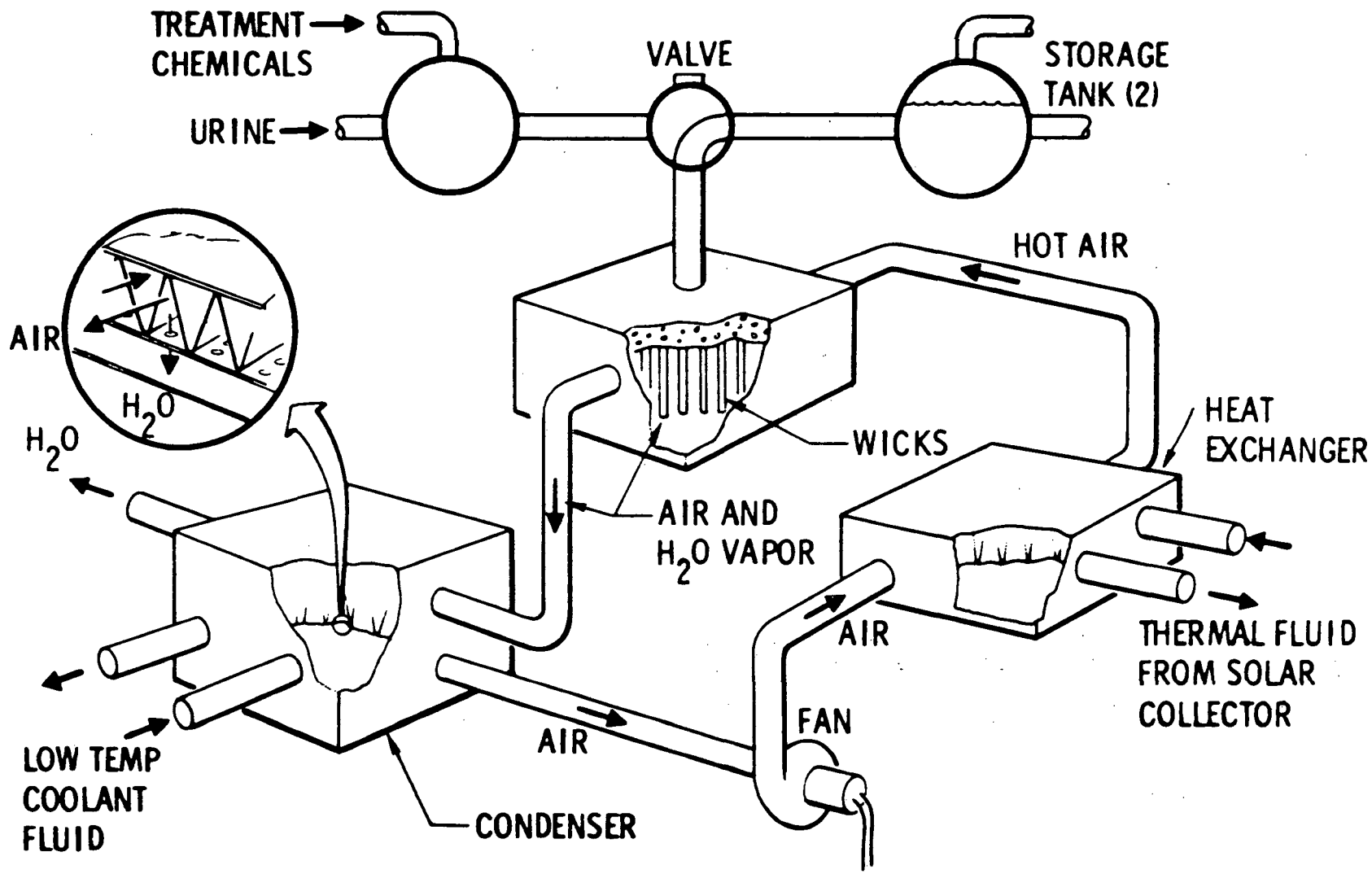


Figure 4-44. Urine Recovery System

monitor parameters are heat exchanger outlet temperature, fluid level in the storage tanks, and quantity of remaining treatment chemicals and system balance.

Once the operational readiness of the modules has been established, the crew will prepare the module systems for operations and then transfer to the payload tunnel area and secure the Crew Operations Module hatch. Following this, the crew will disconnect the umbilicals from the Shuttle to the module, and then enter the Space Shuttle airlock. The tunnel will then be depressurized and the Shuttle will orient the module cluster to its separation attitude. Once the attitude is attained, the Shuttle will separate from the modules. Then, using RF command the Shuttle will activate the configuration/propulsion system, and close the hatch cover over the exposed hatch. For one orbit (or more), the Shuttle will station-keep with the modules, and at the proper time return to the Earth, completing the second phase of the buildup operations.

General-Purpose Laboratory

The third and final flight of the buildup operations is the delivery and mating of the GPL to the Crew Operations Module. Table 4-13 presents a detail summary of the interfaces between the GPL and the Crew Operations Module. As shown, once docking has been completed, 32 interface connectors will be mated between the two modules.

The buildup operations timeline for this mission is presented in Figures 4-45 through 4-48. As shown, the Space Shuttle terminal rendezvous is completed at a GET of approximately 10 hours. The GPL is deployed for docking at a GET of 14 hours. Once deployed, the module's freon pump is turned on, and docking is completed 15 hours following liftoff. Due to the extensive phasing requirement during the ascent portion of the mission, the crew will perform an 8-hour sleep cycle during ascent.

Following docking, the two assembly crewmen transfer to the Space Shuttle airlock and tunnel, to the GPL test and isolation chamber hatch. At this position the crewmen verify the habitability of the chamber, activate the

Table 4-13

CREW/GPL–DETAIL INTERFACE ESTIMATES

Connection	Number	Hookup Time (min)	Checkout Time (min)	Total Time (min)
Air ducts	2	42	6	48
Atmosphere supply	4	64	12	76
Power (vdc)	4	70	20	90
Caution and warning	2	42	20	62
H_2O thermal	4	24	20	44
H_2O life support	6	36	30	66
Atmosphere pumpdown	4	24	12	36
Data bus	4	24	40	64
Power (vac)	2	10	20	30

Total time = 516 man-minutes

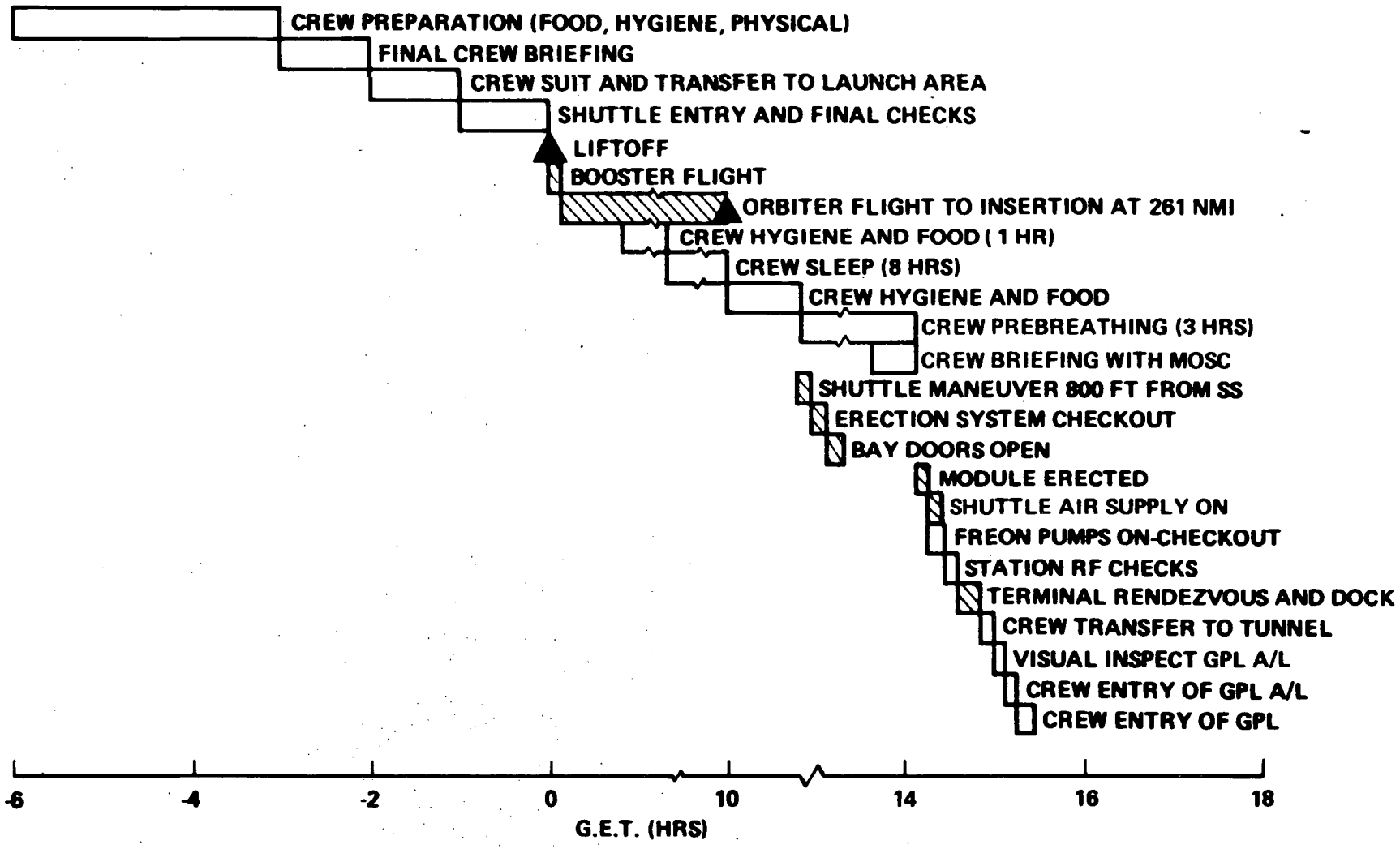


Figure 4-45. Buildup Timeline - GPL Module

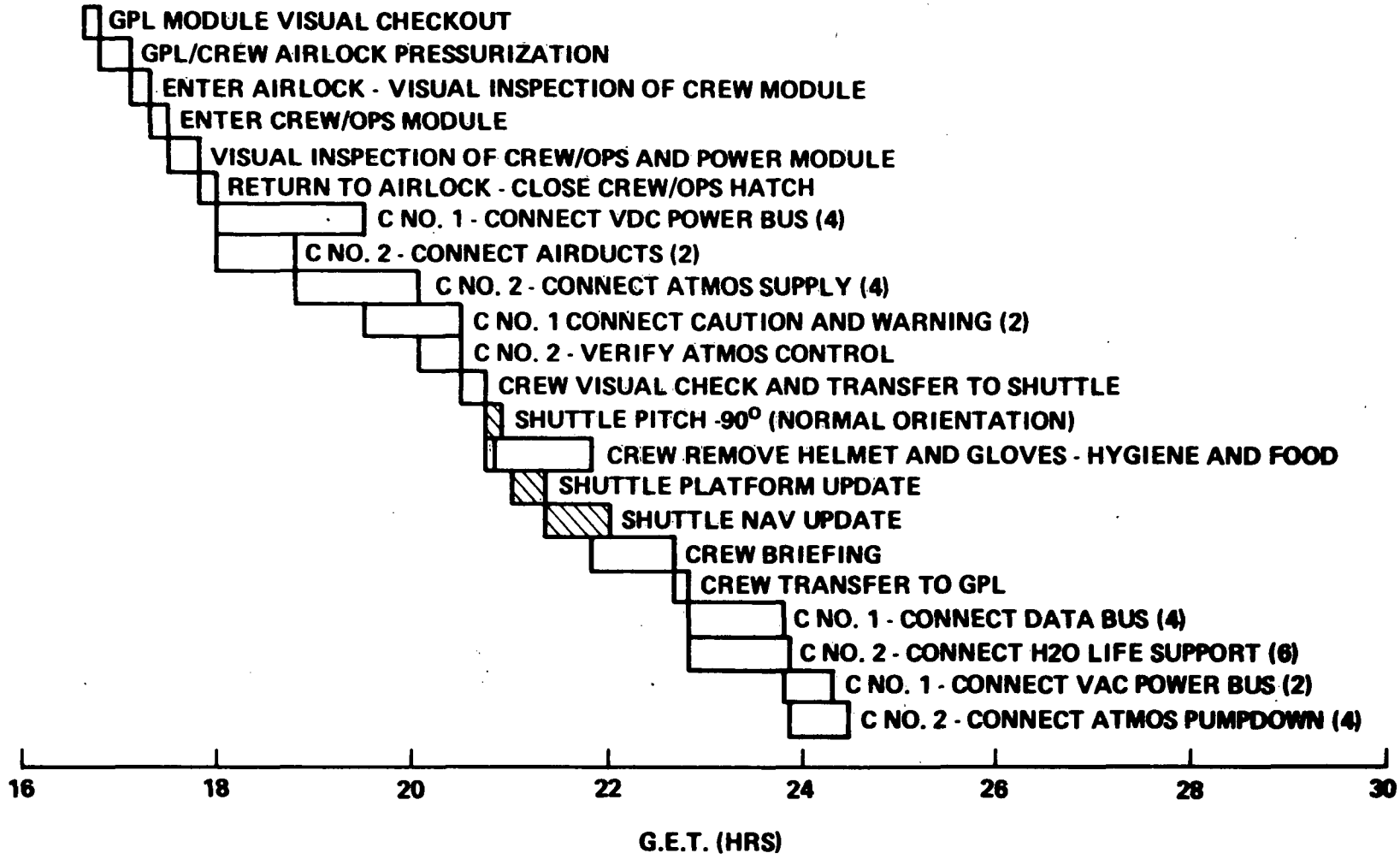


Figure 4-46. Buildup Timeline - GPL Module

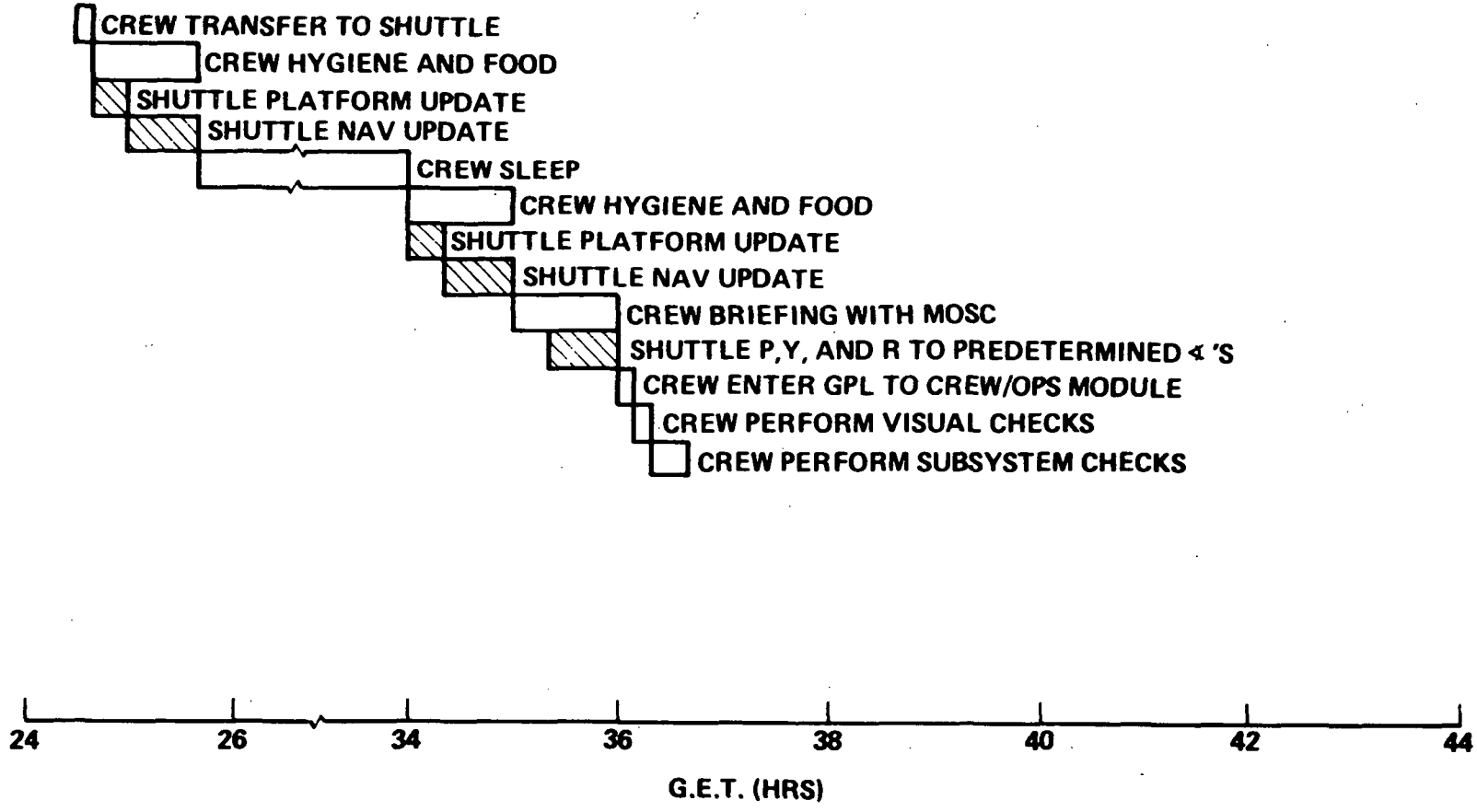


Figure 4-47. Buildup Timeline - GPL Module

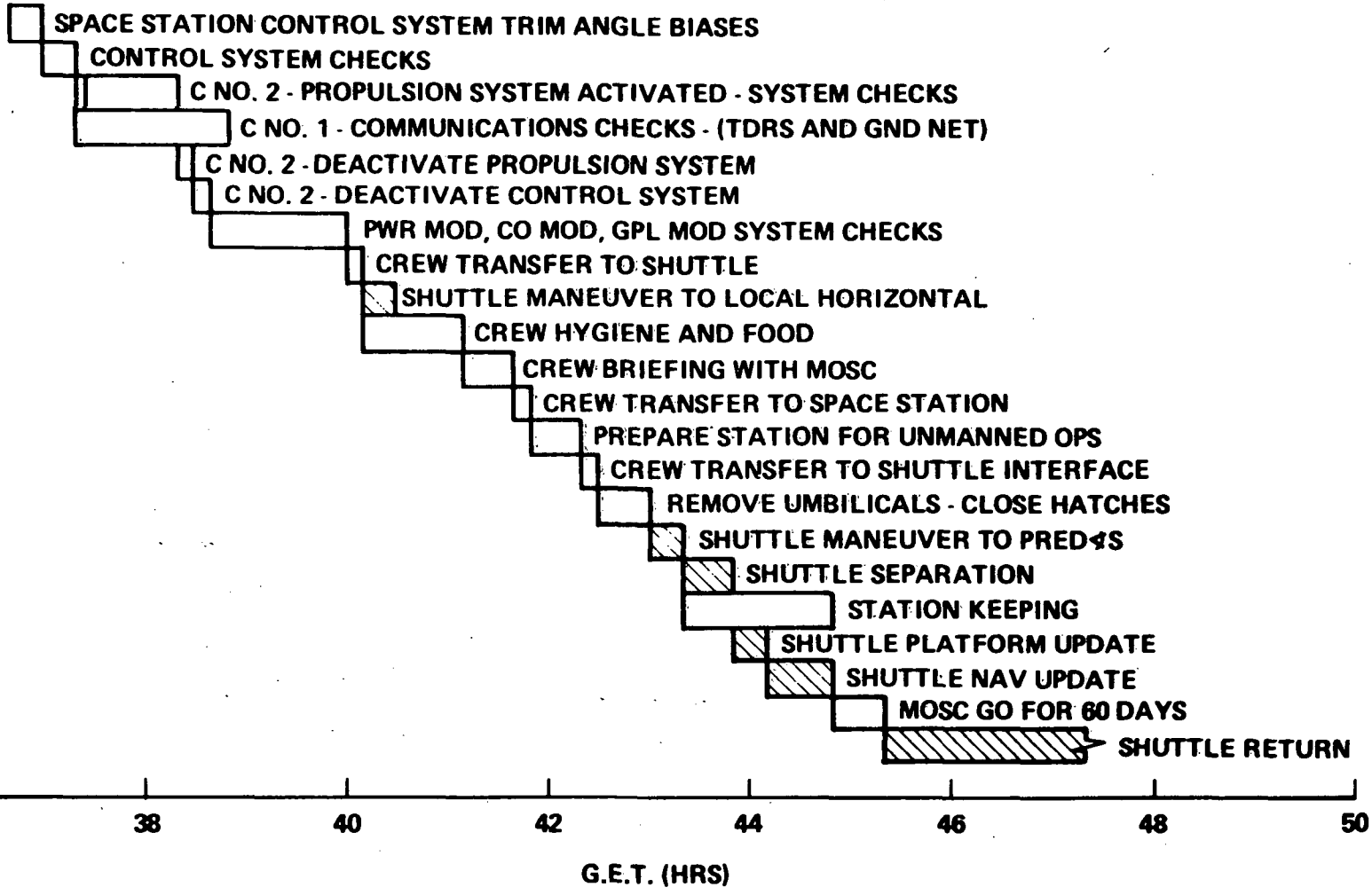


Figure 4-48. Buildup Timeline - GPL Module

lighting system and the intercom system, and enter the chamber (assumed to be in IVA suits with helmet and gloves on). The crew performs a visual inspection of the chamber and then transfers to the GPL hatch. The crew establishes the habitability of the GPL and then enters the laboratory portion of the module for visual inspection. Following inspection, the crew will transfer to the GPL hatch located at the GPL-Crew Operations Module interface. The two assembly crewmen then pressurize the natural airlock at the interface, equalizing pressure across the hatch, and they enter the airlock. Following a visual check of the Crew Operations Module through the viewing window in the hatch, the crew equalize the pressure across the Crew Operations Module hatch and enter the Crew Operations Module. Following a visual inspection of that module, the crew returns to the GPL, securing the Crew Operations Module hatch.

The two crewmen then begin the required interface mating operations, which require a total of six hours and 30 minutes. Once the interface mating has been completed, the crewmen transfer to the Space Shuttle for normal food, hygiene, and sleep activities. Following these activities the crew transfers to the GPL and performs 10 hours of subsystem operations and checkout to verify the operational readiness of the configuration. Following these activities, preseparation operations are begun. The remaining Crew and Space Shuttle activities parallel those described previously for separation, station-keeping, and return.

The Space Shuttle will provide a maximum capability of 14-man-days of mission support. As shown in Table 4-14, the buildup operation requirements are significantly below this maximum capability of the Shuttle. In addition, Tables 4-15 through 4-17 present the detailed electrical power support required from the Space Shuttle. The Power/Subsystem Module power support requirements from the Space Shuttle represent backup only, since this module will provide its own electrical power. As is shown in Figure 4-49, the power requirements are well below the 800-watt power maximum and 20 kwh energy of the Space Shuttle. As shown in Figure 4-50, the propellant requirements the buildup operations place on the Space Shuttle are also within the Space Shuttle system capability.

Table 4-14

BUILDUP TIMELINE SUMMARY

Mission	Duration for Completion* (Day: Hr)
Power/Subsystems Module	2:04
Crew Operations Module	1:23
General Purpose Laboratory	1:21

* Includes nominal phasing requirements

During the buildup operations, a crew duty cycle day of 20 hours was utilized. The short duration of the missions indicated that the crew did not require the nominal four-hour recreation period each day; therefore, none were scheduled. This approach enables greater utilization of the crew time on-orbit; however, during sustained operations, with the crew on-orbit for extended periods, the recreation and relaxation periods should be and are included in the daily schedules.

Growth Space Station

The Modular Space Station Program includes growth to a 12-man Space Station five years following the first launch of the initial six-man Space Station. The growth step includes the on-orbit addition of two Space Station modules; a Crew Operations Module, and a Power/Subsystem Module (identical to those used for ISS). The detail analyses and design performed on the Initial Space Station were not performed on the Growth Space Station; however, the growth concepts were developed and are presented herein.

The buildup to the GSS will occur during ISS operations. During the final year of ISS operations, a second Crew Operations Module ;will be delivered to orbit and docked to the longitudinal docking port of the first Crew Operations Module. This module will be identical to the ISS Crew Operations Module, with the exception of the high-gain antenna. The on-orbit ISS crew will perform the interface mating of the second Crew Operations Module to

Table 4-15

POWER MODULE BUILDUP

Activ Time (hr)	Subsystem	Item	No. of Items	Load Per Item (w)	Total Load (w)	Total Power (w-hr)
40	GN&C	Gyros	2	45	90	702
40	EC/LS	Water Pump	1	60	60	468
4.3		Freon Pump	1	76	76	380
L/O	Power	Sensors	(Partial)	12	12	94
L/O		DC Dist	1	2	2	16
7		Tunnel Drive	1	50	50	40
7		Mast Drive	1	50	50	40
7		Sun Sensor	1	3	3	2
L/O	Data Management	Computer	(Partial)	240	240	1872
L/O		Data Acquisition	(Partial)	125	125	975
5.5		PDCU	1	20	20	46
L/O	Propulsion	Press Storage	1	10	10	78
L/O		Press Control	1	5	5	39
L/O		Prop Tanks	4	15	60	468
4.6	Communications	VHF Assembly	1	22	22	70
4.8		S-Band	1	18	18	51
4.6		Low Gain	1	3	3	10
4.6		Intercom	1	6	6	19
4.6	Lighting	Interior	30	4	120	984
4.6		Handrails	20	3	60	192
7		Exterior	2	1	2	2

Table 4-16

CREW MODULE BUILDUP*

Activ Time (hr)	Subsystem	Item	No. of Items	Load Per Item (w)	Total Load (w)	Total Power (w-hr)
-	GN&C	None	-	-	0	0
-	Propulsion	None	-	-	0	0
L/O	EC/LS	Water Pump	1	60	60	552
5.6		Freon Pump	1	76	76	274
L/O	Data Management	Terminals	(Partial)	24	24	221
L/O		PDAU's	(Partial)	20	20	184
6.8		PDCU	(Partial)	20	20	48
L/O	Power	Dist Control	(Shuttle Partial)	22	22	202
6.0	Communications	High Gain Antenna	(Retract/Docking)	60	60	10
6.0		Intercom	(Partial)	6	6	19
6.2	Lighting	Interior	48	4	192	576
6.2		Handrail	25	3	75	225
6.2		External	2	1	2	6

*Crew Operations Module placed on Solar Array/Space Station Power at GET of 9 hr 10 min

Table 4-17

GPL MODULE BUILDUP*

Activ Time	Subsystem	Item	No. of Items	Load Per Item (w)	Total Load (w)	Total Power (w-hr)
-	GN&C	-	-	-	0	0
-	Propulsion	-	-	-	0	0
L/O	EC/LS	Water Pump	1	60	60	1152
14.2		Freon Pump	1	76	76	380
L/O	Data Management	Terminals	(Partial)	24	24	461
L/O		RDAU's	(Partial)	20	20	384
L/O		Command	1	2	2	38
L/O	Power	Dist and Control	(Shuttle Partial)	22	22	422
15.0	Communications	Intercom	(Partial)	6	6	25
14.6	Lighting	Internal	45	4	180	828
14.6		Handrails	25	3	75	345
14.6		Exterior	2	1	2	9

*GPL Module placed on Solar Array/Space Station Power at GET of 19 hr, 10 min

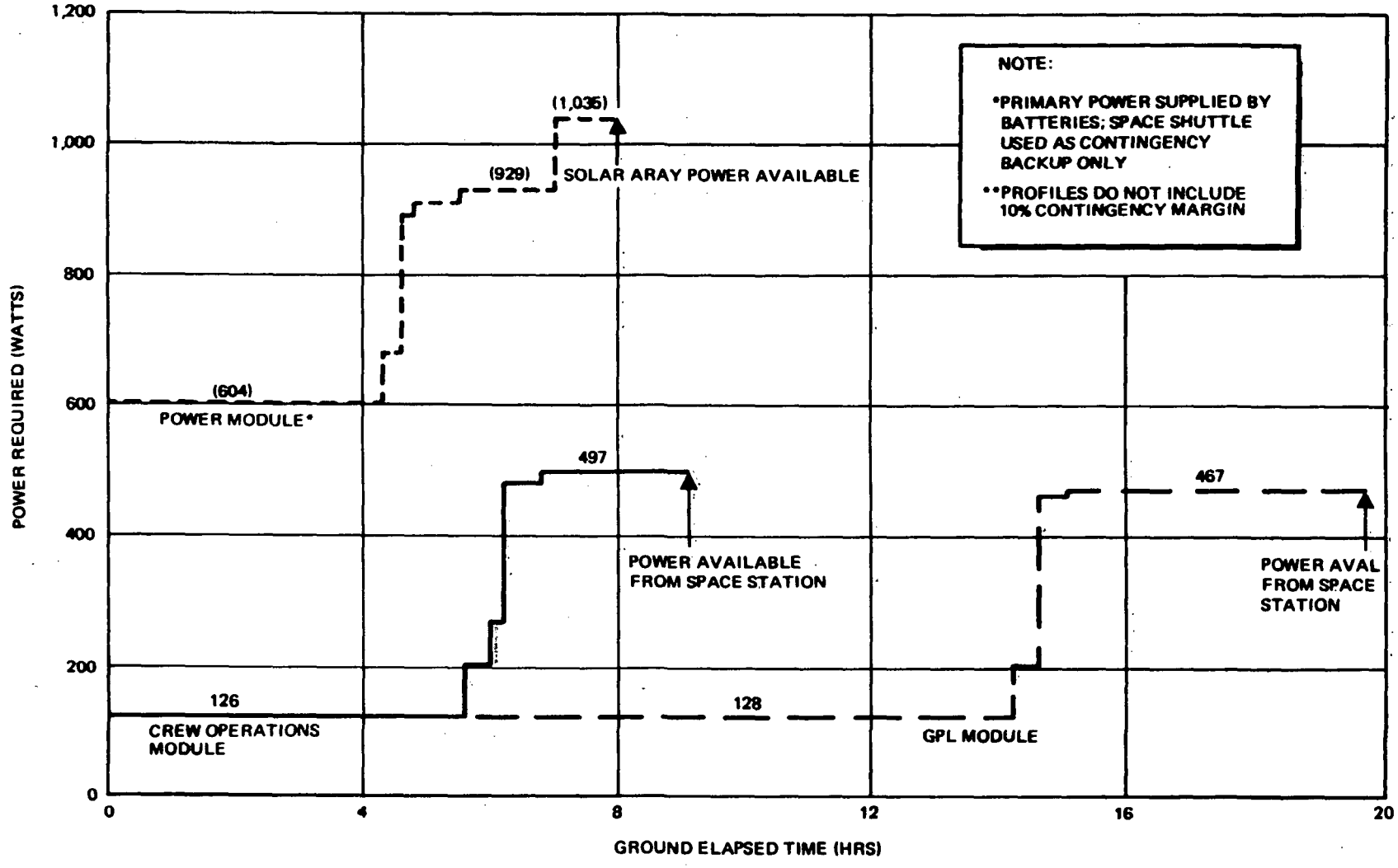
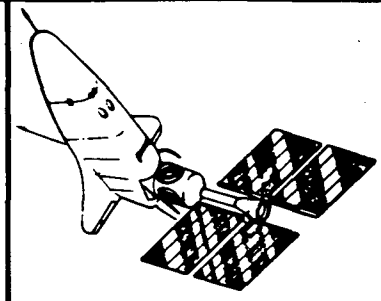
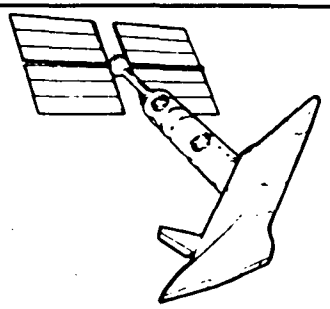
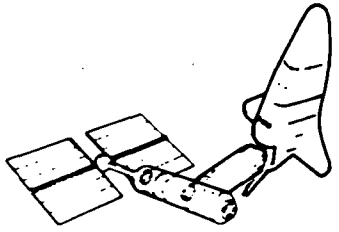


Figure 4-49. Space Station Buildup Operations – Space Shuttle Power Required**

R277

CONFIGURATION / MANEUVER ΔV (FPS)	POWER MODULE	CREW MODULE	GPL MODULE
			
ASCENT	766	766	766
RENDEZVOUS & DOCKING	-	149	149
ORBITAL MANEUVERS	56	25	55
CLUSTER CONTROL	22	24	26
ARRAY CHECKOUT	15	-	-
ANTENNA CHECKOUT	-	21	-
STAB. & TRIM CHECKOUT	20	21	23
SEP. & STATION KEEP	50	50	50
DESCENT	452	452	452
TOTAL	1,381	1,508	1,521

ORBITER NOMINAL OMS & ACPS PROPELLANT LOADING EQUIVALENT TO 1,630 FPS

Figure 4-50. ISS Delivery Maneuvering Requirements

the first. Ninety days following the delivery of the second Crew Operations Module, a second Power/Subsystems Module will be delivered to the Space Station. Prior to docking this module, the Space Shuttle will deploy the module, activate its attitude control system, and then release the module. The Space Shuttle will then dock to the docking port on the solar array tunnel of the second Power/Subsystems Module, deactivate the module's attitude control system, and dock it to the longitudinal docking port of the second Crew Operations Module. The on-orbit ISS crew will then perform the interface mating and checkout between the second Crew Operations Module and the second Power/Subsystems Module.

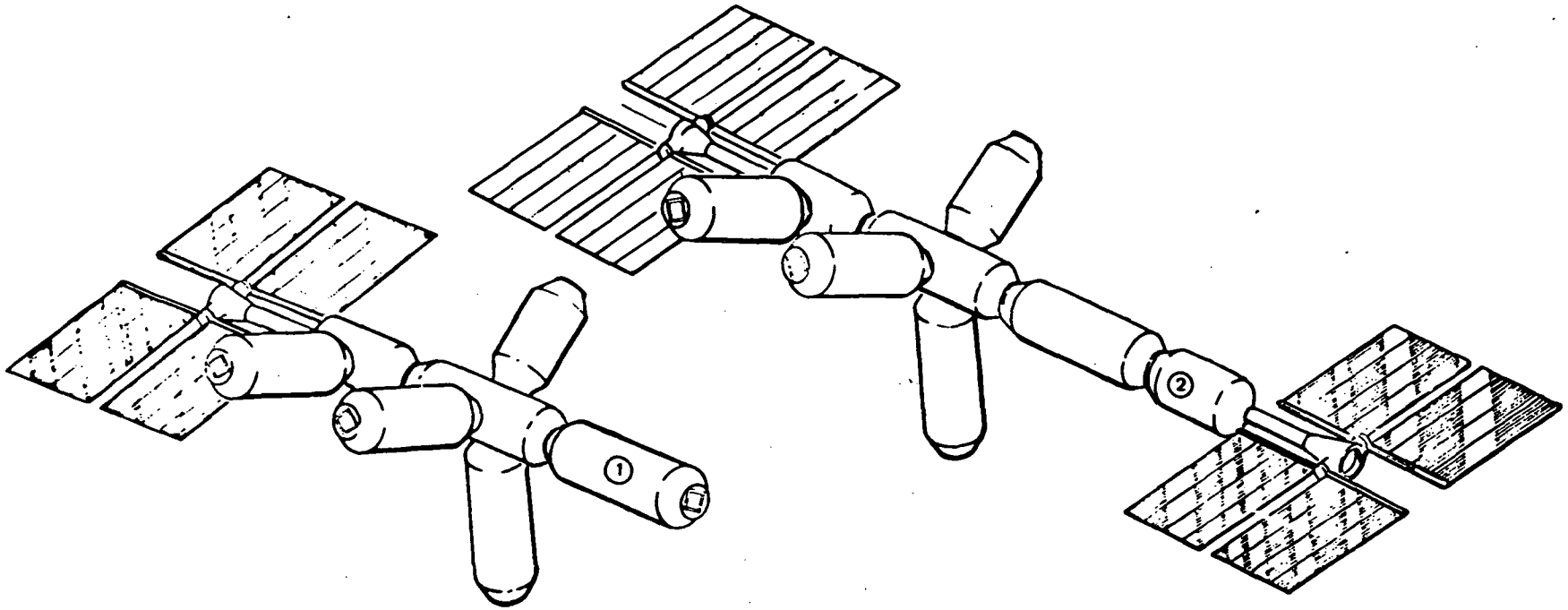
Following the configuration buildup to GSS, the next two logistics flights, 30 days apart, will deliver Crew Cargo Modules with six crewmen onboard each module. These operations will buildup the on-orbit crew to the GSS level. Thirty days later, a logistics flight of the Log Module will deliver the off-loaded equipment and spares inventory buildup, completing the buildup operations to the GSS.

Figure 4-51 presents a summary of these GSS buildup operations. The ISS operations exist over a period of five years, from October 1980 to October 1985. The ISS buildup operations duration results in a total of four years, seven months of sustained ISS operations, with the GSS operational level reached by November 1985.

4.2.2.2 Activation

As previously discussed, the activation phase of the Space Station mission includes the first three launches (30 days apart) of the Logistics Modules, building the on-orbit crew in two-man increments to the total operational level of six men. During this phase of the mission, certain noncritical equipment, which was off-loaded from the Space Station modules to meet the 9072 kg (20,000 lb) Space Shuttle launch limit, will be delivered to orbit on the logistics flights for assembly into the modules.

The fourth launch of the Space Station Program will be the first Log Module with two sustained operations crewmen carried as passengers in the Space Shuttle. Following docking to the Crew Operations Module, the interfaces



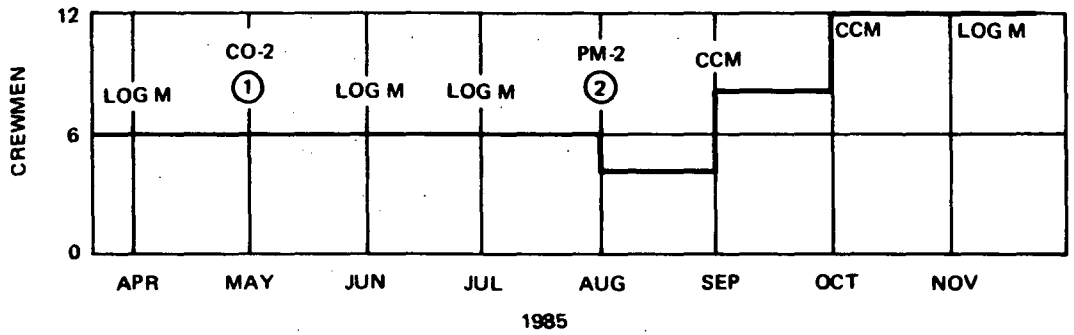


Figure 4-51. Growth Space Station Buildup

presented in Table 4-18 will be mated, the systems checked out, and then the off-loaded equipment will be carried onto the Space Station and installed at the proper location. Any items which weigh in excess of 90.7 kg (200 lb) will require two men for transfer.

As presented in Figures 4-52 through 4-58, rendezvous with the orbiting Space Station occurs approximately seven hours following lift-off. Following deployment of the Logistics Module from the Shuttle payload bay to the docking position, the Log Module is docked to the Crew Operations Module. The Space Station crewmen transfer from the Shuttle, through the tunnel, to the Log Module hatch. Following the establishment of habitability of the module, and activation of the lighting and communications system, the two crewmen enter the Log Module. After completing a visual check of the Log Module interior, the crewment ransfer to the Log Module hatch at the Log Module-Crew Operations Module interface, and equalize pressure across the hatch into the natural airlock.

The crewmen enter this airlock and equalize pressure into the Crew Operations Module. Once this operation has been completed, the crewmen enter the Crew Operations Module and perform a visual check of the Space Station interior. They then return to the Log Module and begin the interface mating between the Log Module and the Crew Operations Module. Once the power and atmosphere control interfaces have been mated, the Log Module is switched from Shuttle support to Space Station subsystem support. The crew then returns to the Space Shuttle and, with habitability verification, they remove their helmets and gloves and perform a hygiene, food, and sleep period.

Following a briefing period with the ground support personnel, the crew transfer to the Log Module to complete the interface mating required between the logistics vehicle and the Space Station. Once the interface operations have been completed, the crew begins transfer of equipment off-loaded from the Space Station Modules for launch. Typical off-loaded equipment is presented in Table 4-19 indicating the items which are candidates for off-loading from the Space Station Modules, the number of these items which

Table 4-18

LOG MODULE CREW - DETAIL INTERFACE ESTIMATES

Connection	Number	Hookup Time (Min)	Checkout Time (Min)	Total Time (Min)
Air ducts	2	42	6	48
Atmosphere supply	4	64	12	76
Power (VDC)	4	70	20	90
Caution and warning	2	42	20	62
Data bus	4	24	40	64
Propellant N_2H_4 supply	2	36	20	56
Propellant GN_2 supply	2	12	6	18
Gas lines (pumpdown)	4	24	12	36
		Total time = 450 man-minutes		

could be off-loaded, and the module they would be installed in. Also, an approximate distance and time for transfer is shown, along with the estimated installation time. One typical piece of equipment is the battery. As shown in Figure 4-59, individual batteries are dropped into cold-plate bays and then secured with a screw-type locking clamp. The whole unit is installed in battery set cases which in turn are connected to the power system. Since each battery set weighs approximately 176 kg (389 lb), two crewmen will be required to transfer each set. The total transfer time for the batteries for the Power/Subsystem Module is 624 man-min.

Following the transfer and installation of the off-loaded items, the newly installed equipment will be checked out and its operability verified. As shown in Figures 4-52 through 4-58, at approximately 75 hours GET, the crew will begin to utilize the Space Station for their food, hygiene, and sleep cycles. At the end of the build-up phase, the orbiting configuration is certified as ready to support a long term scientific program based on an accumulation of operational data on the various subsystems previously exercised.

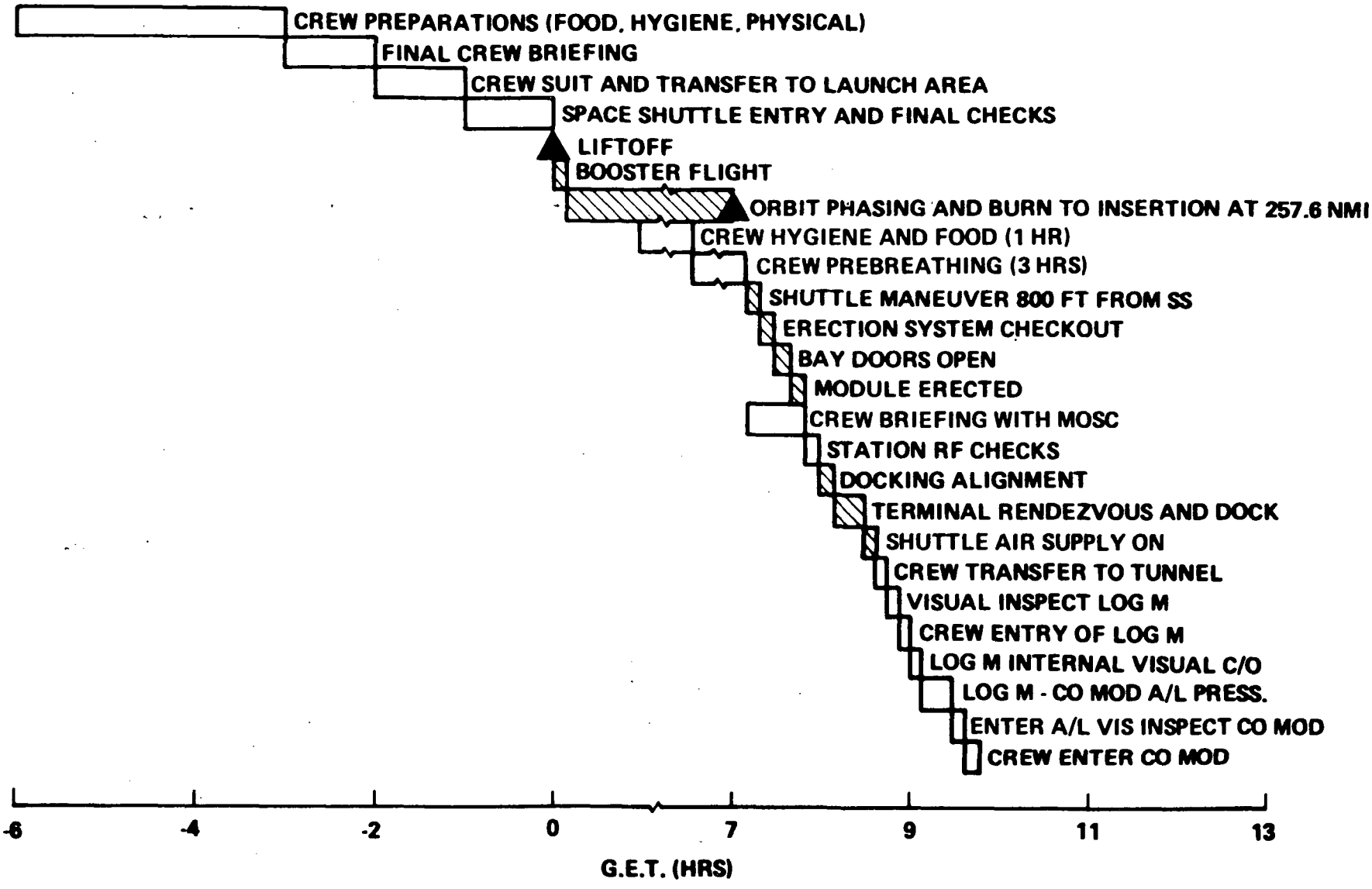


Figure 4-52. Buildup Timeline - Logistics Module

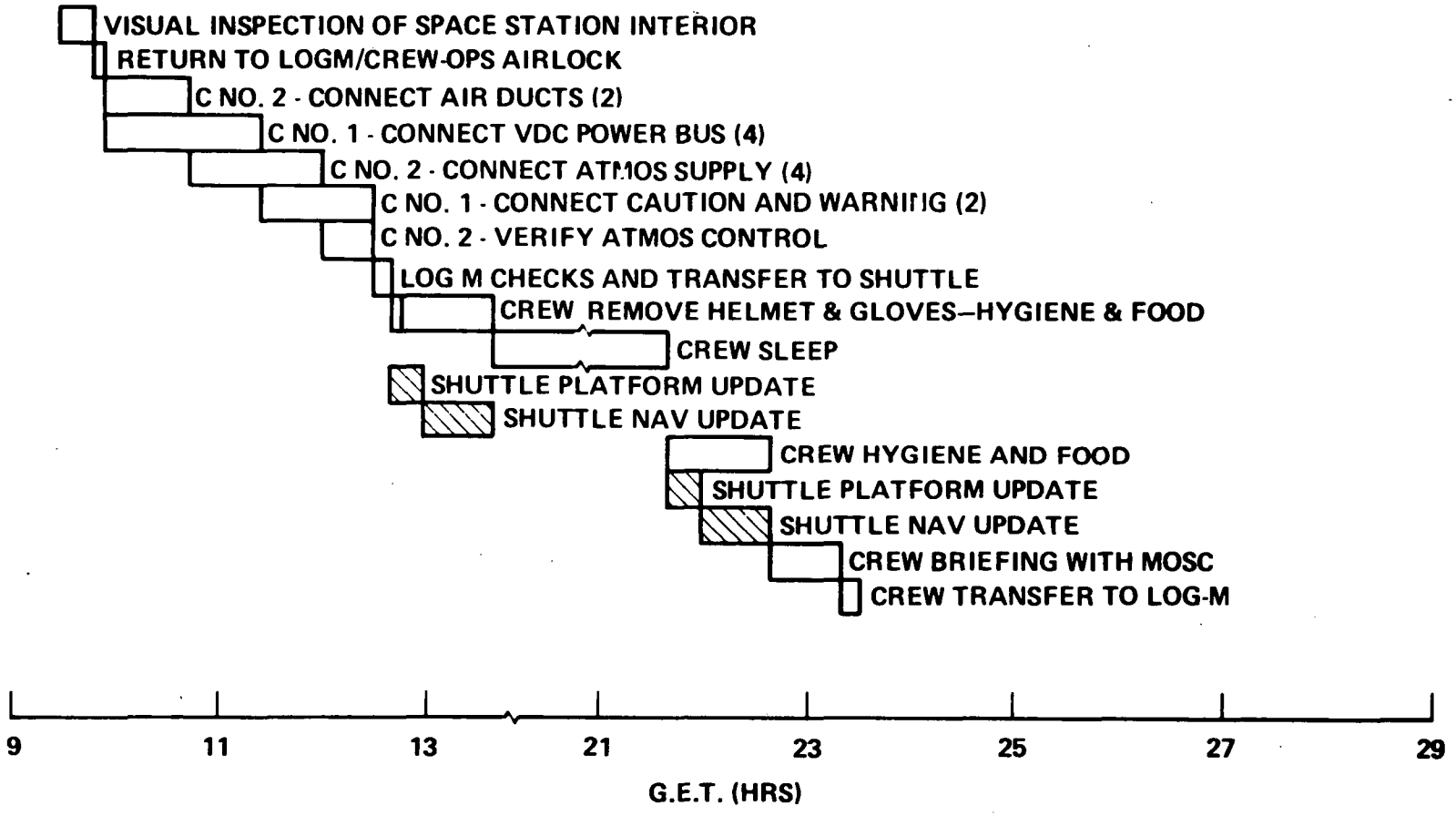


Figure 4-53. Buildup Timeline - Logistics Module

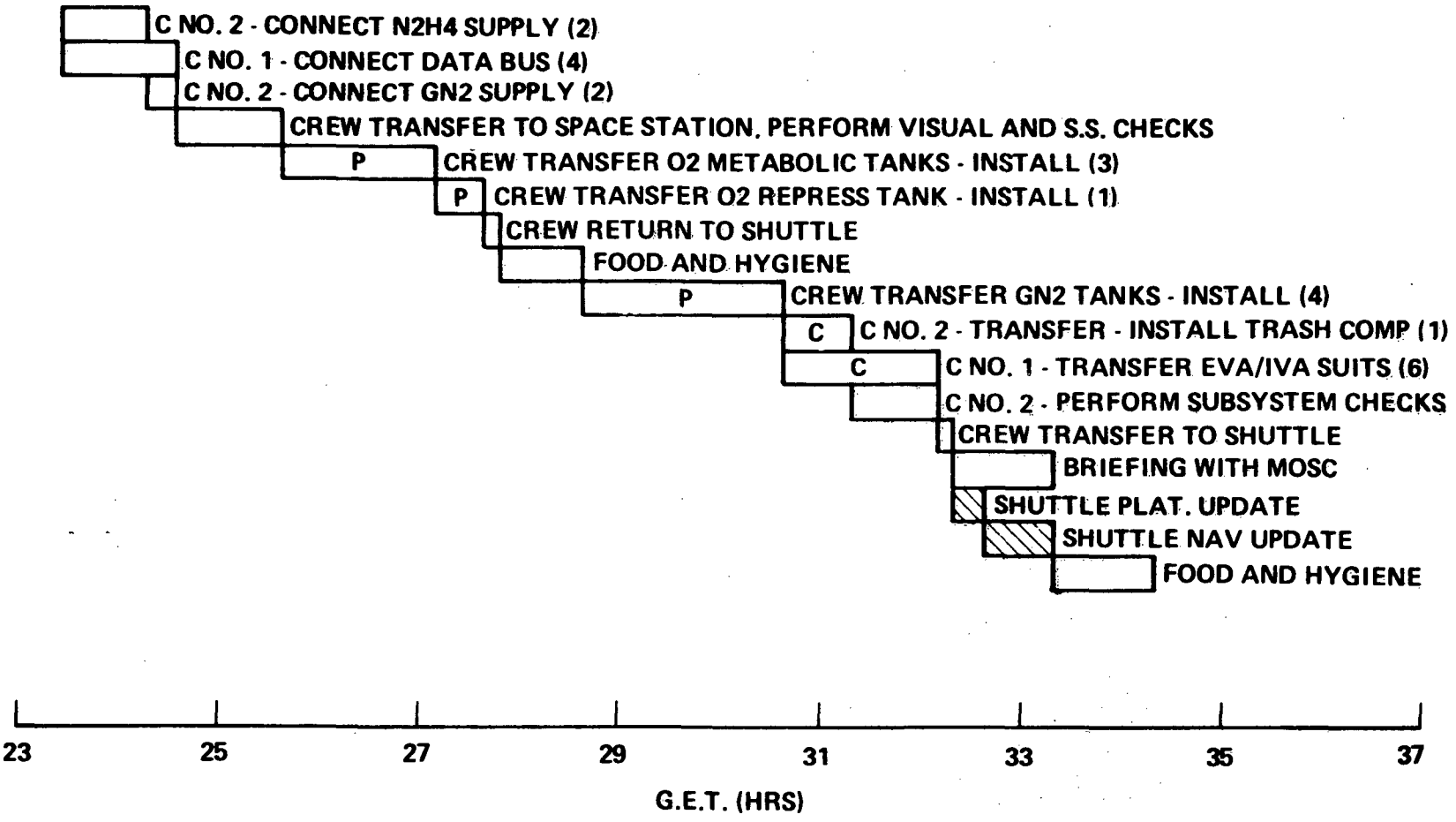


Figure 4-54. Buildup Timeline - Logistics Module

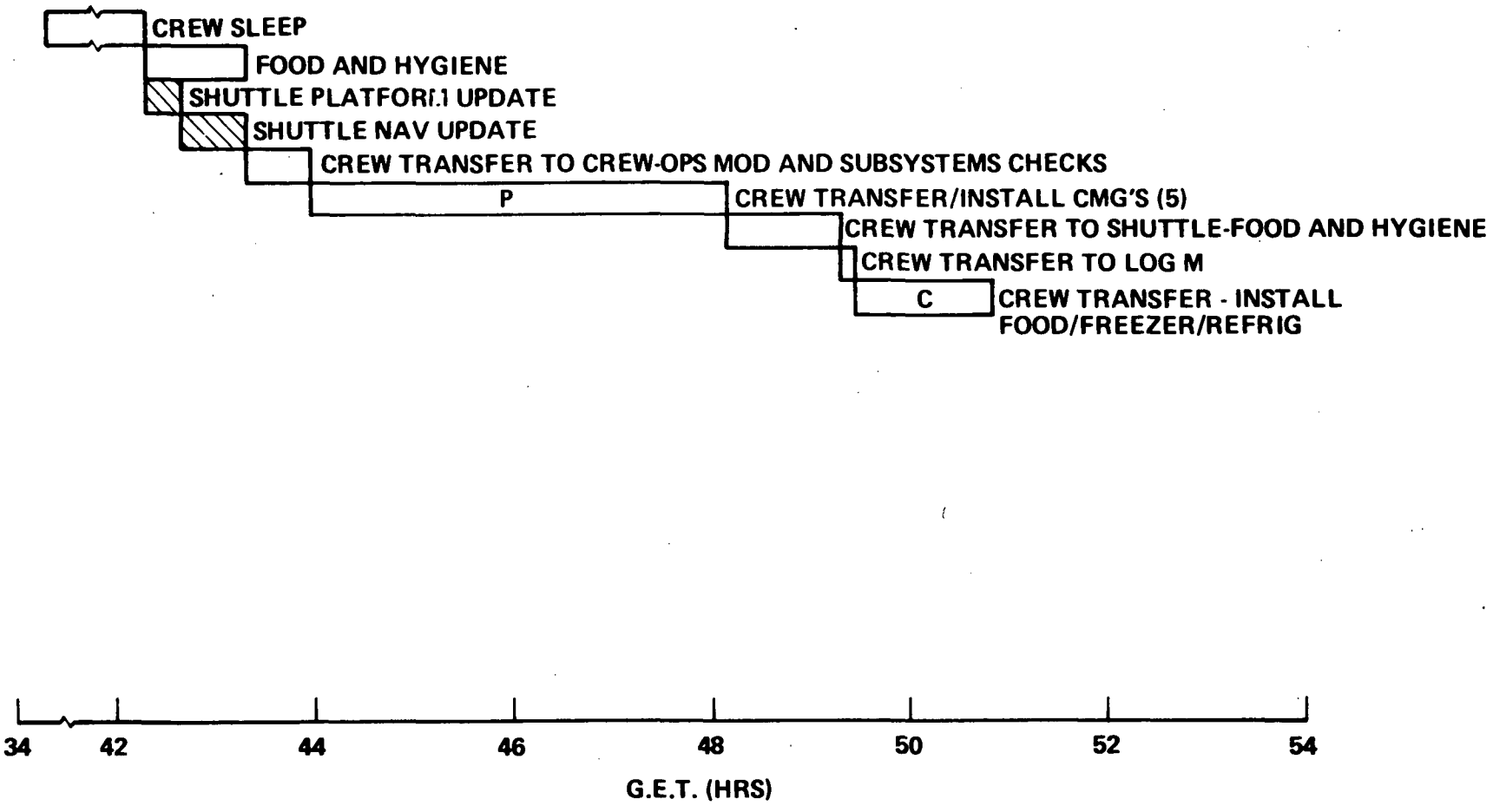


Figure 4-55. Buildup Timeline - Logistics Module

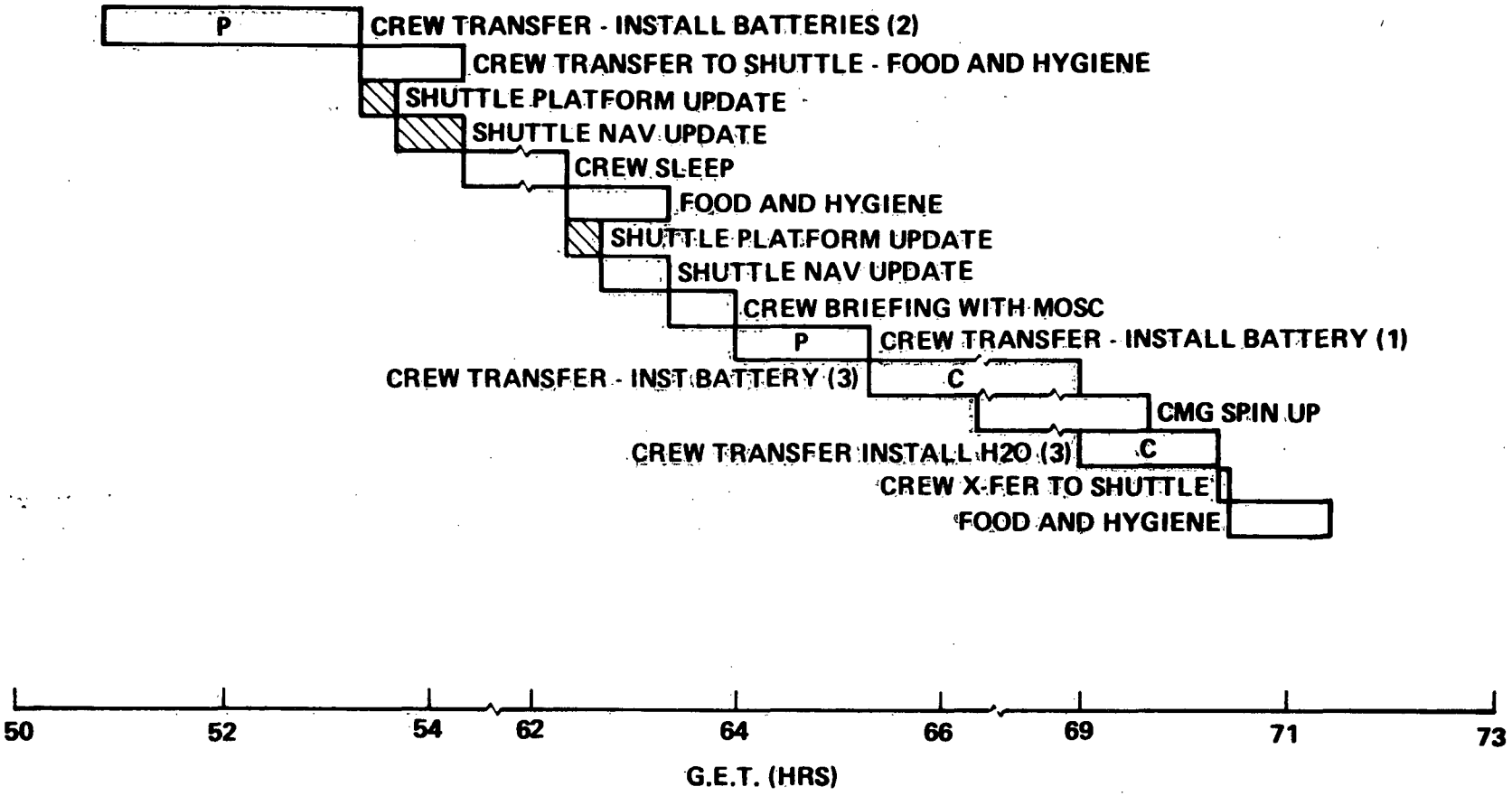


Figure 4-56. Buildup Timeline - Logistics Module

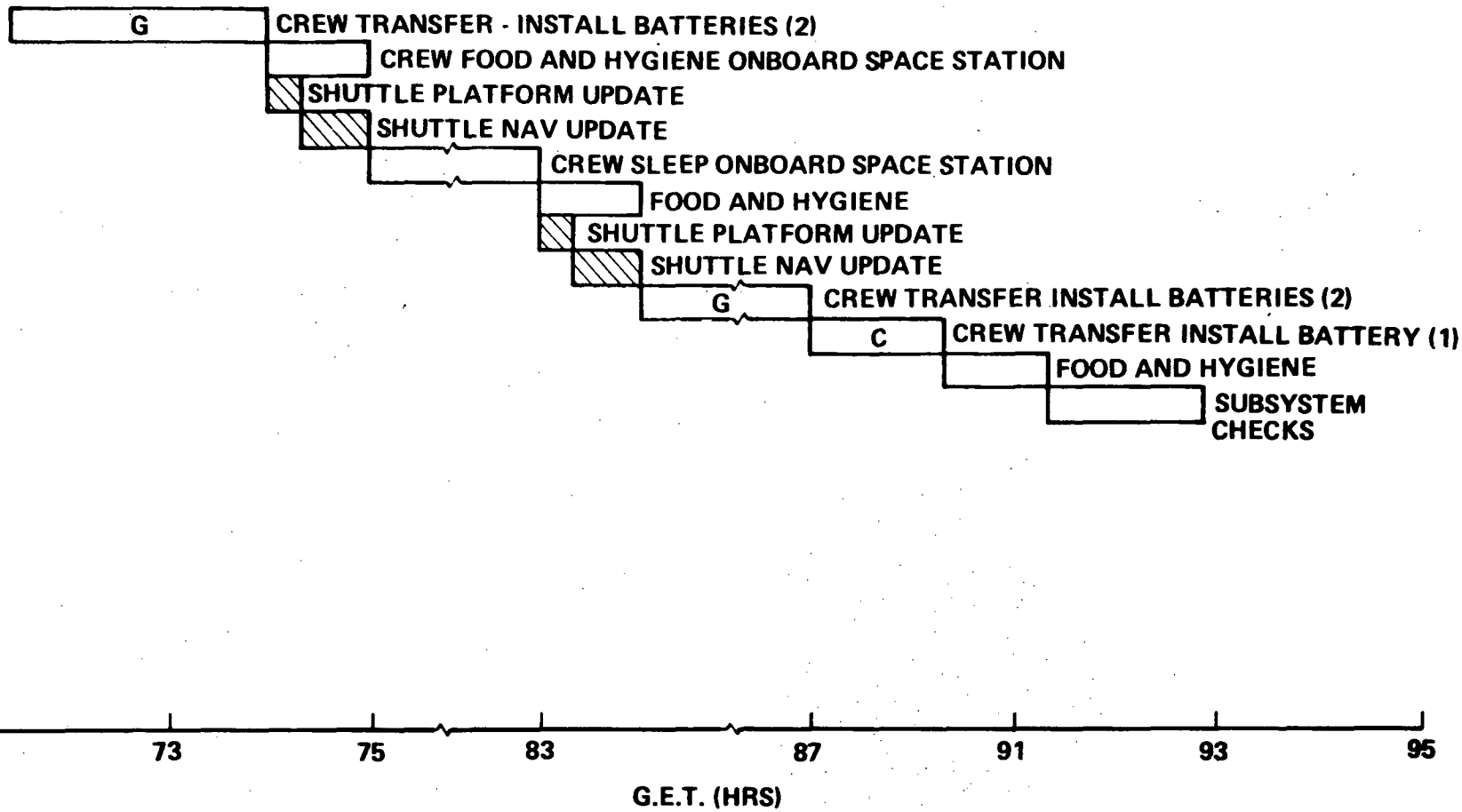


Figure 4-57. Buildup Timeline - Logistics Module

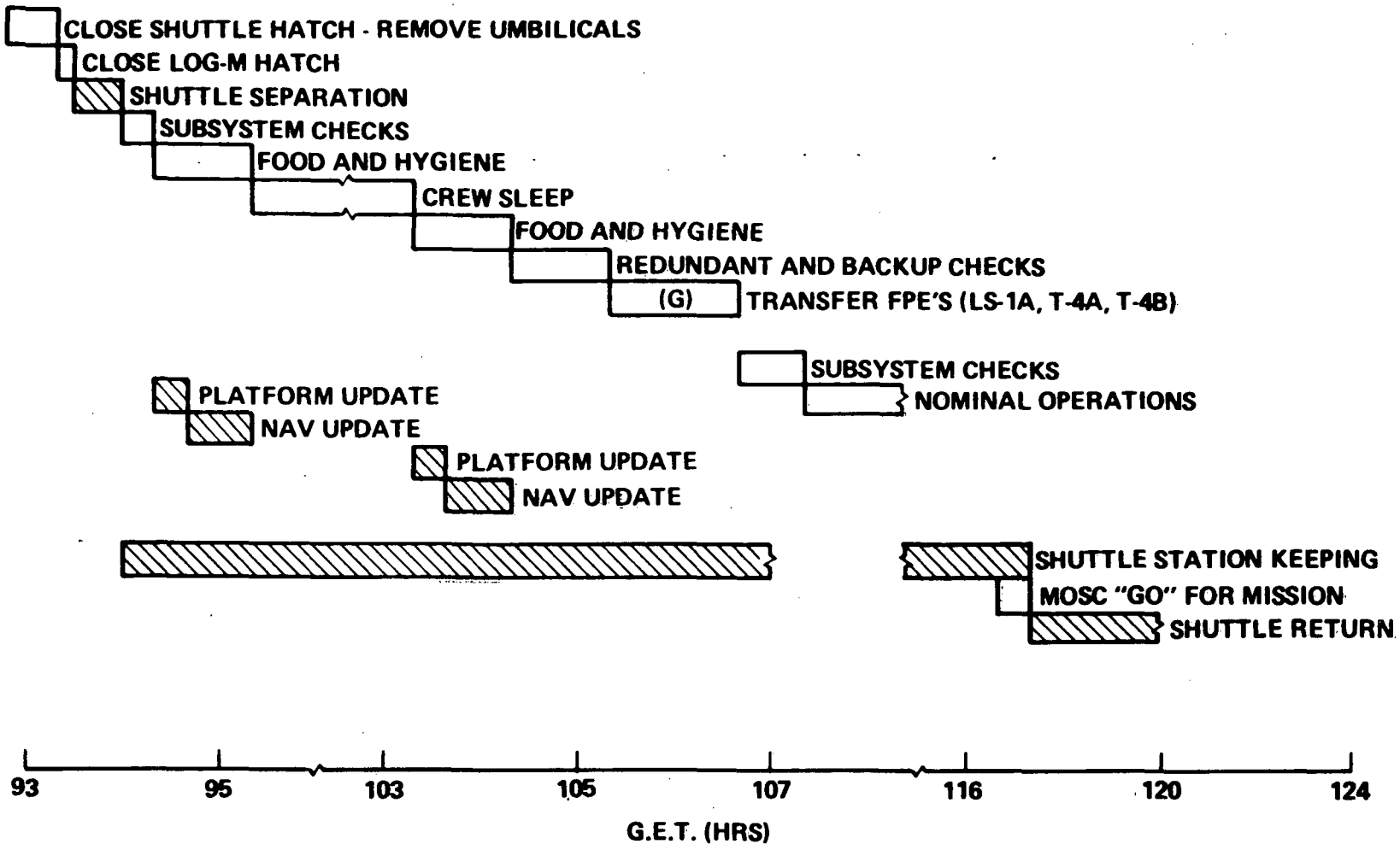


Figure 4-58. Buildup Timeline - Logistics Module

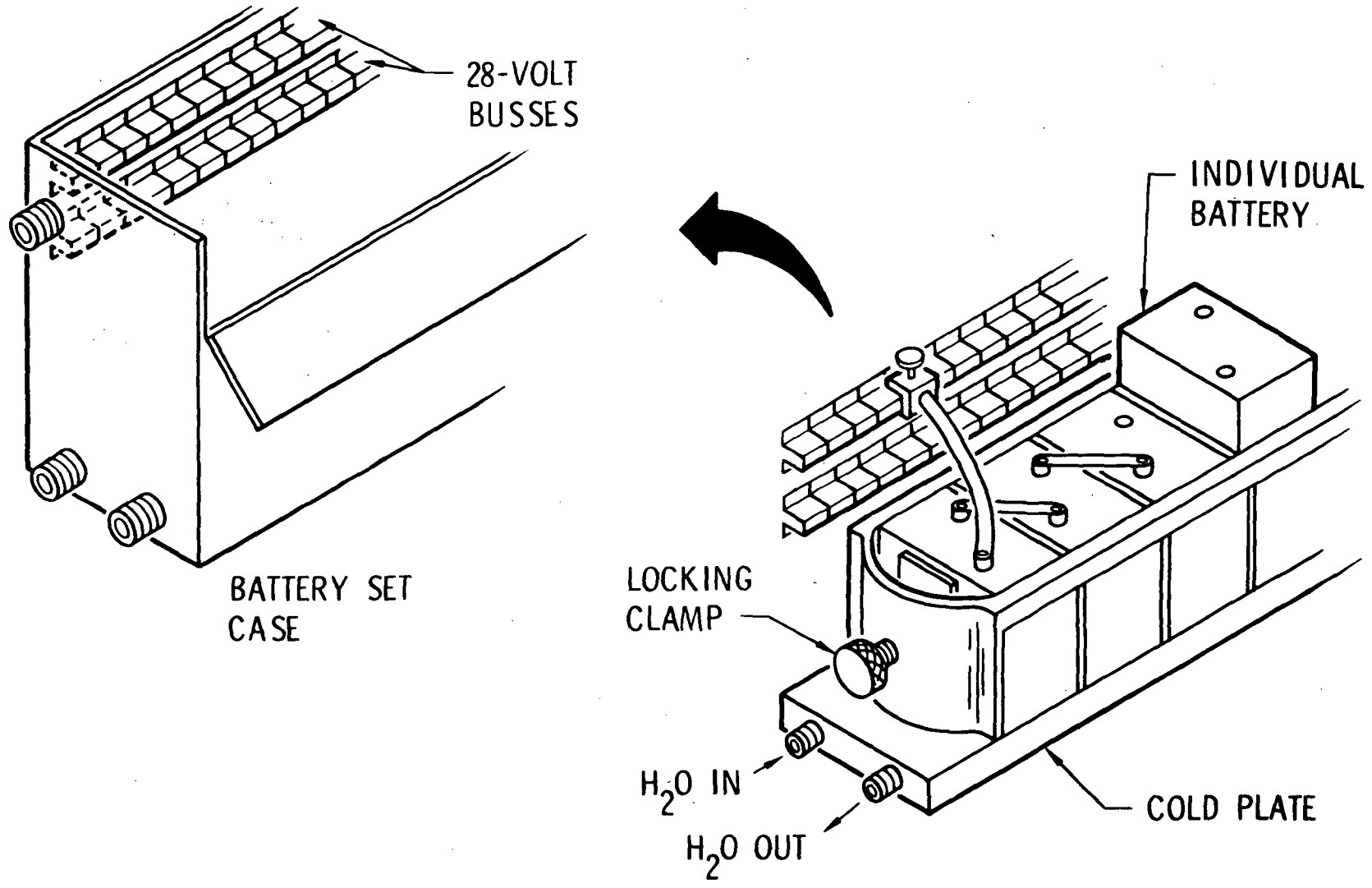


Figure 4-59. Battery Installation

Table 4-19

EQUIPMENT TRANSFER/INSTALLATION

Item	Quantity	Module	Transfer Distance (ft)	Time Per Unit Transfer (min)	Unit Install Time (min)	Total Time (min)	Unit Weight (lb)
CMG	5	Power	(38)	20	30	250	400
Battery	4	Power	(50)	18	60	312	389
O_2 (Repress)	1	Power	(33)	15	15	30	289
GN_2 (Repress)	4	Power	(33)	15	15	120	277
O_2 Tank (Metabolic)	3	Power	(33)	15	15	90	289
Battery	8	Crew	(18)	15	60	600	389
Water Tank	3	Crew	(22)	12	15	81	386
Trash Compactor	1	Crew	(26)	15	25	40	110
Food (Freezer/ Refrigerator)	4	Crew	(15)	10	10	80	228
IVA/EVA Units	6	Crew	(28)	10	5	90	74
Battery	8	GPL	(34)	18	60	624	389

Verifying the readiness of the Space Station to support a 10-year operational program is based on criteria in three categories.

1. The overall configuration of the station must be compatible with long-term operations. This is established through build-up records that indicate all interfaces are mated and checked, equipment is installed, and inventory is at the operational level. This activity will be performed on-orbit and verified by the ground-support elements. Successful completion of early time-line activities also will verify configuration.
2. An Orbital Readiness Test (ORT) will be performed to establish operability of subsystems, including back-up modes. Also, the software routines will all be checked by operational tests. The subsystem operating records from the various in-situ tests will be examined with ground support for further confidence in subsystem status.
3. Certification on the ground of the operational readiness of all ground-support elements.

One of the most critical tests which leads up to operational verification is the Orbital Readiness Test that is performed subsequent to final assembly. In this test, the activation crew runs through the entire set of onboard checkout routines to verify the operability and status of each subsystem. The Station cannot be certified as operational until all subsystems are functioning properly.

The culmination of the entire verification program is a formal certification of the operational readiness of the Space Station to support a long-term, scientific program in space. This certification occurs on an orbiting vehicle but is a cooperative effort with the ground. Assuming the Space Station program satisfies the criteria for configuration, subsystems and supporting elements, the Space Station is declared operational, the Shuttle departs the Space Station leaving the on-orbit crew alone for the first time, and a 10-year scientific and applications program commences.

Approximately 93 hours following liftoff, the Space Shuttle will separate from the Space Station, leaving the two crewmen onboard the Space Station to begin nominal operations. After station-keeping for approximately one day on-orbit,

the Space Shuttle will return to Earth. A total of three of these missions is required to complete the activation operations and build the on-orbit crew to a six-man level. These Flights are 30 days apart, resulting in completion of buildup and activation five months after the first Space Station launch.

The first logistics flight requires the greatest amount of Space Shuttle mission time, four days and 21 hours. This is well within the Space Shuttle mission duration capabilities, and provides a margin of two days on-orbit for any contingency operations which might occur.

4.2.3 On-Orbit Sustained Operations

The sustained operations of the Space Station have been divided for documentation purposes into two categories, experiment operations and station operations. In general, the experiments and their operations represent the Space Station mission, while the station operations represent those support activities on-orbit which are required for mission accomplishment. In the Phase B design study of the Modular Space Station, the subsystem selections were driven to achieve the lowest cost at initial launch, while the subsystem sizing was driven primarily by the experiment requirements resulting from the studies and data presented in Section 2. of this document.

4.2.3.1 Experiment Operations

The experiment operations associated with the Space Station were analyzed for the baseline experiment schedule, Case 534G, presented in Figure 4-60. These experiments, listed on the left, were groups and subgroups of those FPE's presented in the 1971 Blue Book. As discussed in Section 2, the purpose of the experiment analysis was to develop a representative set of experiment groupings to evolve into a representative set of experiment requirements against the Space Station facility. The operations analysis was similar. In general, the approach was driven toward developing a general set of operations capabilities on the Space Station for any experiment or set of experiments which could be flown during the Space Station era.

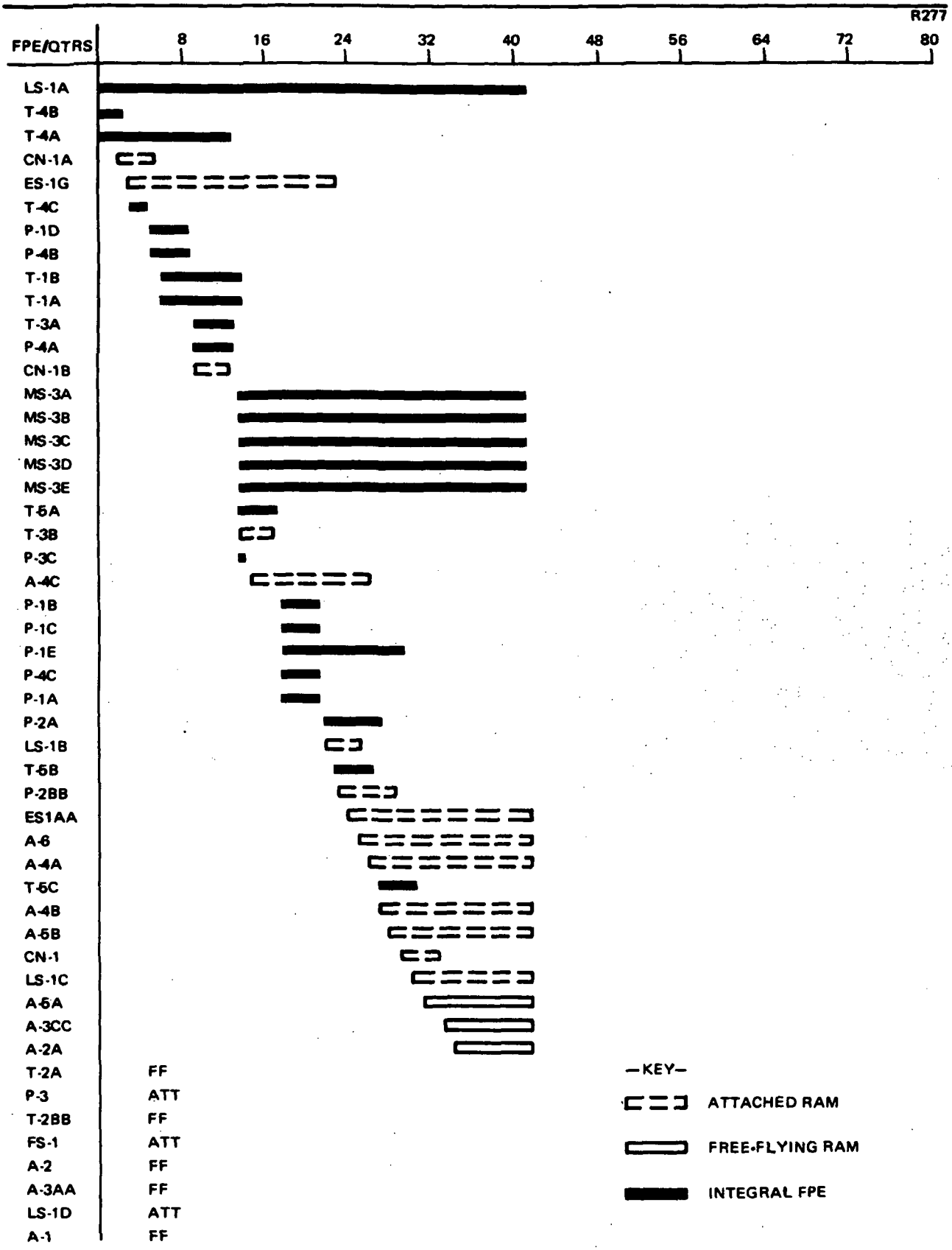


Figure 4-60. Experiment Flight Schedule

The Space Station provides those subsystem support capabilities presented on Table 4-20. As shown, during ISS, the equivalent of 4.6 crewmen (276 manhours per week) is available for the experiments, out of the total crew of six men. A total of 4.8 kw of electrical power is also provided for experiment operation, along with 17,237 kg (38,000 lb) of logistics resupply. The logistics support will be discussed in detail in Section 4.2.4.

The ISS program includes carry-on experiments and RAM experiments. The carry-on FPE's will be delivered to the Space Station by the Log Module. These FPE's will be transferred to their assigned location in the GPL and installed for operation. The RAM's will be delivered as Space Shuttle payloads. They will be docked to their assigned port utilizing the direct docking mode of operation of the Space Shuttle. The ISS configuration provides docking facilities for four of these RAM's.

The General Purpose Laboratory provides the operations center for the experiments. Located in the GPL, the experiment control console (shown in Figure 4-61) provides the control and scheduling facility on-orbit for the experiments. As a general rule, the ISS crew will be given long-range (30-day) objectives for experiment operation and resulting test data generation. Utilizing on-board software to analyze the resources available versus resources required for various experiments, the crew will determine their short-range (24 hr or less) operational plans. The complexity of combining the potential targets-of-opportunity, available crew, available equipment, and available subsystem resources for the determination of this short-range schedule will be a sizable task for the experiment operations officer on-board the station. In addition this console will provide the notification of Space Station and experiment requirements conflicts for resolution.

Table 4-20

SPACE STATION EXPERIMENT RESOURCE SUMMARY

Function	ISS	GSS
Crew (men)	4.6	9.5
Power (kw)	4.8	12.1
Data		
Digital (BPD)	8×10^{11}	8×10^{11}
TV (min/day)	1,320	1,320
Logistics (lb/90 days)	38,000	29,000
Docking ports	4	8
Orientation	All	All
Steady-state disturbance (g)	10^{-5}	10^{-5}

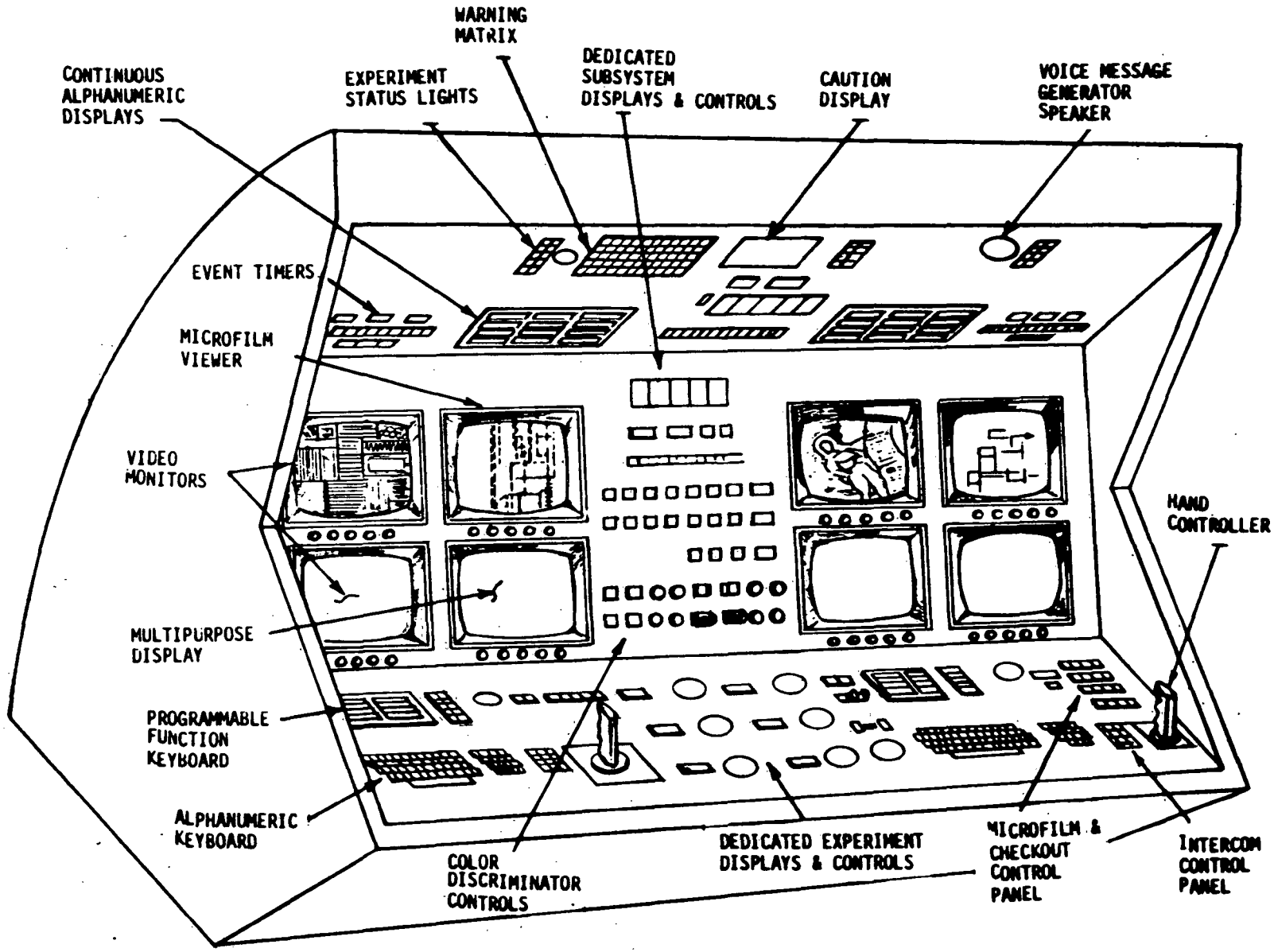


Figure 4-61. Secondary Command and Control Console

The attached RAMs which require manned operation and control of experiments will have a significant amount of their display and control provided locally. Their data will be available on the data bus, and will be transferred by the data bus to the data management computer for processing, formatting, and any executive actions required.

All FPE and RAM engineering and housekeeping data will be validated and monitored by the Onboard Checkout System. Space Station data such as state vector information will be available to the experiment computer, located in the GPL, for collation required for planning and operations. Detailed experiment computations requiring a large amount of storage or processing time will also be performed by the experiment computer.

During the course of the five-year ISS mission duration, experiment additions, deletions, refurbishment, and reverification will be required as new experiments become available, are operated, and then returned to Earth. To provide sufficient volume for the total complement of the experiments, each experiment, upon completion of its operational duration, will be returned to Earth at its earliest opportunity. Should unplanned maintenance be required on an experiment opportunity. It was assumed that an FPE other than the one under repair would also be inoperative due to the limitation of crew time available. For major failures, the decision to repair on-orbit versus return to Earth and repair on the ground will be considered from a cost-effectiveness point of view at the time of the failure.

Those RAMs which require atmosphere pumpdown for sensor exposure to the environment will utilize the Space Station accumulator capability of 23.7 cu m (840 cu ft) at 1.03 kg/cm^2 (14.7 psia). RAMs which require greater volume capacity will be required to provide their own accumulator storage facility; however, these RAMs may utilize the Space Station pump for this function on a noninterference basis with Space Station requirements. The accumulator provided by the Space Station has been sized for the Test and Isolation chamber located in the GPL.

Growth to the GSS operational level is accomplished five years after the first Space Station launch. The resources provided to the experiments at GSS are shown in Table 4-20. As shown, 570 man-hours of crew time, and 12.1 kw of power are provided for experiment operations. In addition, eight docking ports (two equipped for servicing free-flying RAMS) are also provided for experiment support.

The free-flying RAMs will be delivered to the Space Station as Space Shuttle payloads, and docked to the Station using the direct docking mode of the Shuttle. Once at the docking port, the RAM systems and experiment equipment will be checked out using the Onboard Checkout System of the Space Station. The guidance and control, data management, and thermal control systems of the RAM will be activated. The experiment systems will then be activated and secured for undocking and transfer to the operations orbit. The RAM will then be undocked and transferred to its operational orbit using Space Station tracking, RF control, and RAM propulsion.

After deployment is complete, the RAM's guidance and control system will be initialized by RF command to provide the required attitude stabilization, solar panel pointing, and sensor control. In its operational orbit, station-keeping maneuvers will be commanded from the Space Station. These propulsive maneuvers will be managed by the Space Station guidance and control subsystem.

Following completion of its experiment operation cycle (may include more than one pass through the station-keeping loop), the RAM will rendezvous and dock to the Space Station, under Station control, for maintenance. While docked to the Space Station, experiments will be inspected, data will be retrieved, and expendables will be resupplied. The systems and experiments will then be reactivated and the RAM deployed for another operational duty cycle. These operations will continue until the RAM mission is completed, at which time it will return to the Space Station and await Space Shuttle return to Earth.

The remainder of experiment operations in the GSS will be similar to the ISS activities. The Space Station GPL has been sized with volumetric capability to increase the experiment complement with the crew size.

4.2.3.2 Space Station Operations

The Space Station sustained operations are initiated with the third Log Module flight, five months following first launch, when the ISS crew is increased to six men. ISS operations continue until four years and seven months later when the Space Station crew is increased to 12 men. Over the Space Station program duration, a total of approximately 275,000 man-hours of productive operations are provided on-orbit. Of these, 88,000 are provided during ISS operations.

The Space Station crew is delivered to orbit during ISS as passengers onboard the Space Shuttle. Once docking has been completed, the two crewmen enter the Shuttle airlock, transferring through the expandable tunnel to the payload Log Module interface. The crewmen then equalize the pressure across the Log Module hatch, open the hatch, and transfer through the Log Module airlock and the Log Module to the Space Station. The exit of crewmen returning to Earth is the reverse operation along the same path. The GSS crews are delivered to orbit as passengers in the Crew Cargo Module, inside the Space Shuttle cargo bay. Once docking has been completed, the six crewmen pressurize the natural airlock between the CCM and the target docking port, and transfer through the airlock into the Space Station.

The Space Station design approach has paid careful attention to minimizing crew tasks and complexity associated with housekeeping and maintenance activities to provide the maximum possible number of manhours on-orbit for productive operations.

Experience with Space Station operations will be required of the operational crew and highly desirable and beneficial to the experiment crew. The general crew functions for the on-orbit crew include the following:

A. Space Station Operations
   1. Subsystem operations,
   2. Inventory control,
   3. Logistics vehicle checkout and operation,
   4. Resource planning,
   5. Station maintenance,
   6. Safety and medical care,
   7. Experiment interfaces.

B. Crew Special Duties
   1. Food preparation and consumption,
   2. Hygiene and waste management,
   3. Physical fitness,
   4. Recreation and rest.

C. Experiment Operations
   1. Space Station interfaces,
   2. Experiment scheduling,
   3. RAM control and operations,
   4. FPE checkout and operation,
   5. Objective accomplishment.

All of the daily routine operations for the Space Stations will be automated to the extent practical. A typical example is the monitoring of critical parameters and activation of appropriate warning devices for out-of-tolerance conditions. The actuation of appropriate response to warnings will be a crew responsibility; however, system switching to redundant or backup systems will be automated as much as possible. During each duty shift, one crewman will be assigned the responsibility of the control console located in the Crew Operations Module (shown in Figure 4-62). When operations are minimal at this position, the console operator will perform other duties, but will be available if malfunction or emergency conditions arise requiring his attention.

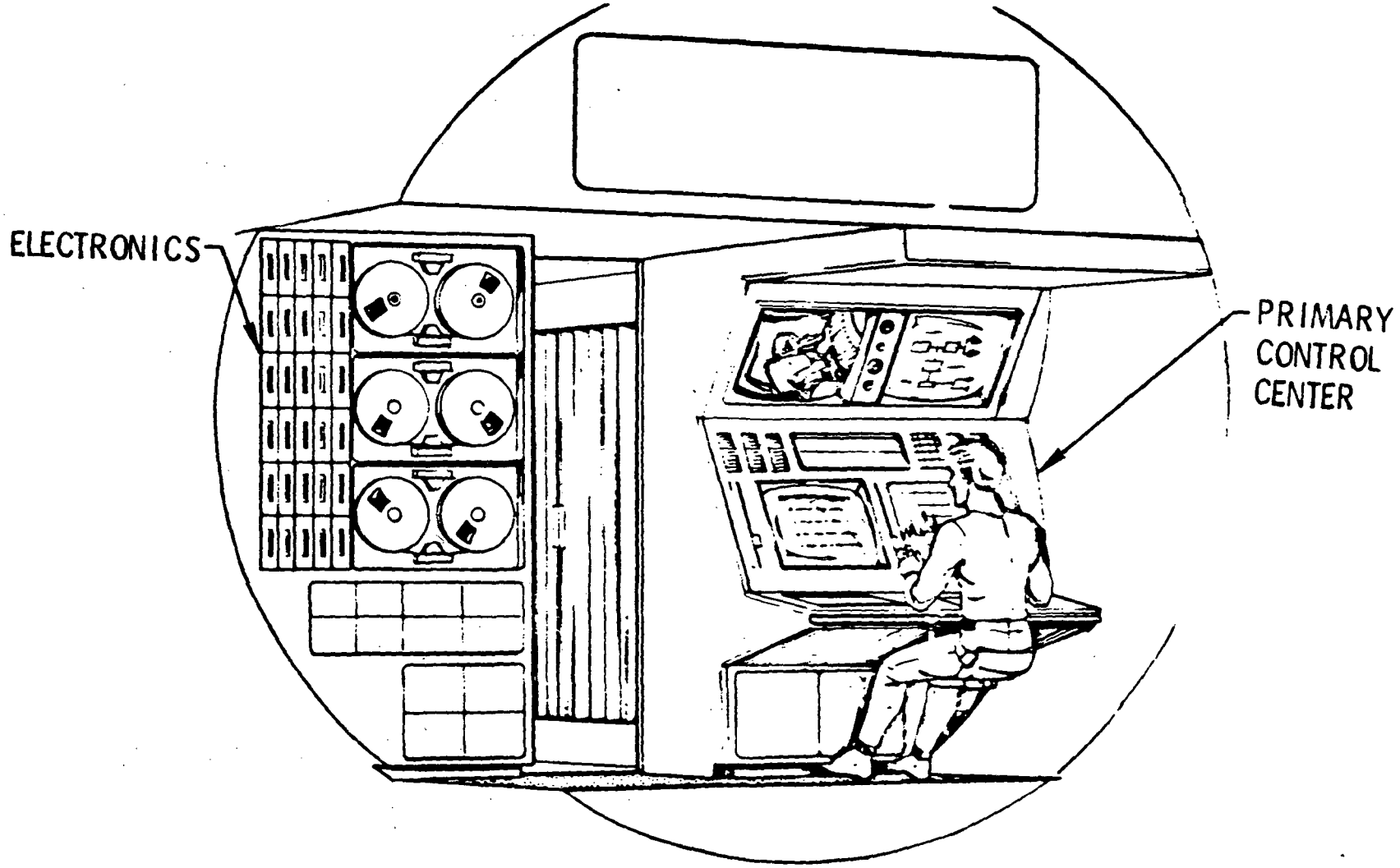


Figure 4-62. Control Center - - Crew/Operations Module

The general crew complement will be required to accommodate a changing experiment program. This flexibility will require a broad range of scientific background in order to minimize detailed instruction impacts to the overall training program. As shown in Figure 4-63, during ISS one crewman is assigned the responsibility for Space Station operations and maintenance: he is the Space Station Commander. A second crewman, the Experiment Officer, is primarily responsible for all experiment operations and partially responsible for Space Station operations. The four remaining crewmen are assigned to the experiment operations. Principal investigators may be included in the group of four experiment operations personnel. The scientific crew will require a minimum of astronaut training; primarily, the Space Shuttle passenger responsibilities, and Space Station safety, emergency, and personal crew training (waste management, hygiene, etc.). At GSS the crew is structured according to the organization previously developed for the MDAC Phase B 33 ft diameter Space Station.

The crewman's duty cycle on-orbit will nominally be 90 days in duration. Crew overlap during crew rotation is nominally planned for 12 hours, though this period could be reduced if required. The crew is recruited for continuous support of the program with a maximum of one on-orbit duty cycle every year. The balance of the year will be spent in mission preparation, proficiency training, debriefings, and as mission operations support personnel on the ground. As mentioned previously, each crewman will be trained in more than one skill to provide backup operational capabilities on-orbit. Table 4-21 presents a crew requirements summary for comparison between the three various types of crewmen.

The Space Station subsystems have been designed to provide the capability for single or dual shift operations on-orbit. As shown in Figure 4-64, the separation of the crew quarters provides for three crewmen working, while the other three are resting. At the same time the galley and wardroom are sized to accommodate all six crewmen at one time. Evaluation of various duty cycles, work loads, power distributions, responses to emergencies, consolidation of tasks, peak loading on common equipment, and targets of opportunity indicates that a two-shift day cycle is the more efficient approach. This two-shift cycle would be comprised of two 12-hour

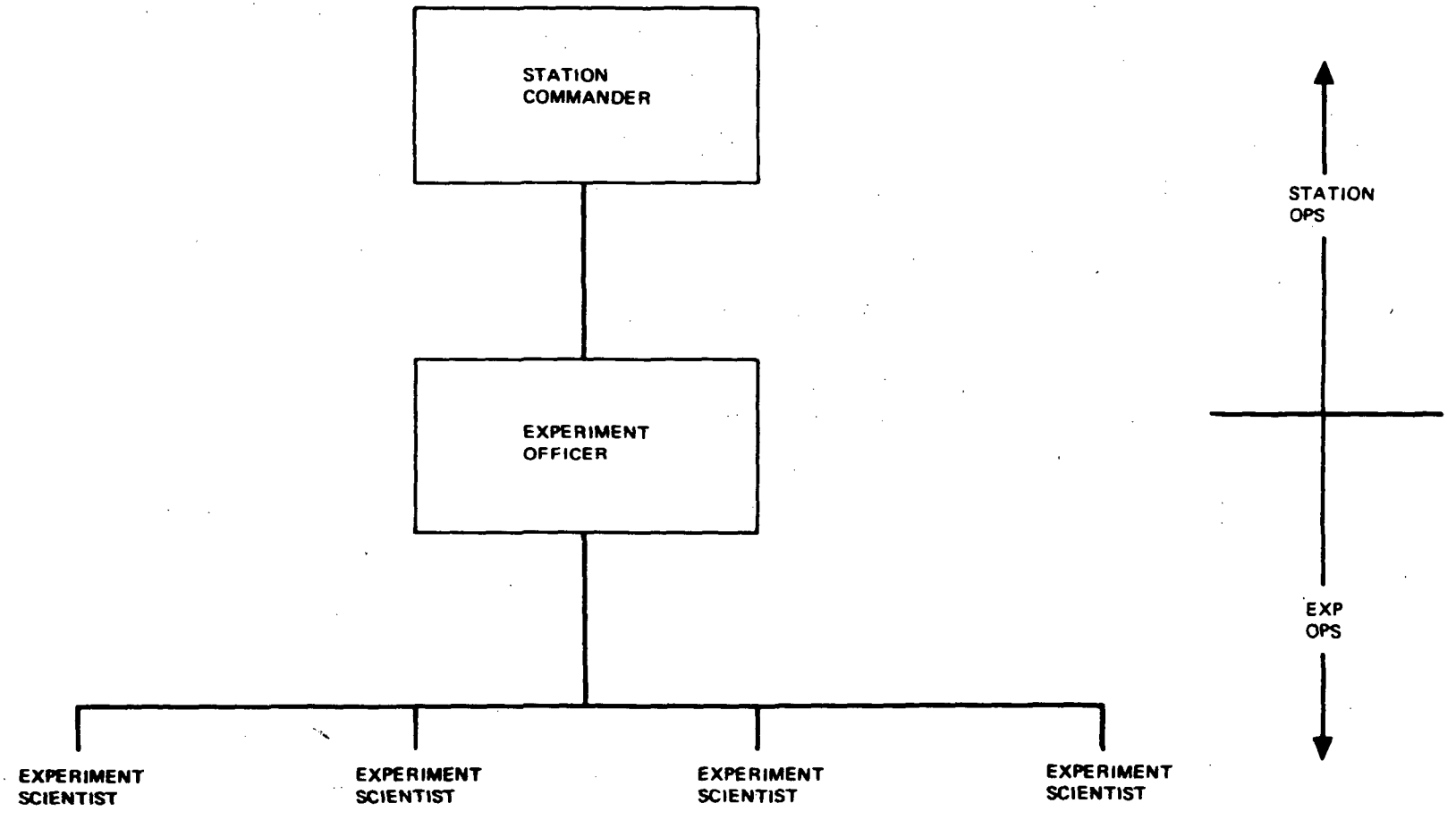


Figure 4-63. ISS Space Station Organization

Table 4-21

CREW OPERATIONS SUMMARY

Astronaut	Experiment/Scientist	Principal Investigator
Continual flights	Several flights	One or two flights
Operation of subsystems	Operations of scientific equipment	Operation of one type of equipment
General training	General training and proficiency training in selected areas	Limited training on Space Station required activities
Duty scheduled on 90-day centers 270 days apart	Duty scheduled on FPE groupings	Duty scheduled with special equipment

tours of responsibility, with each crewman performing a 10-hour tour of duty in one of the two shifts. More specifically, it would assign 12 hours of responsibility to one-half the crew, with freedom to perform the assigned hours of duty and other individual tasks while remaining available to respond to any contingency. The individual's requirements for sleep, shower, medical examination, and exercise would be performed during the 12 hours off responsibility.

The two-shift assignment also promotes greater application to duty through normal reaction to responsibility. Flexibility is inherent to meet varying duty time requirements. Only four meal periods would be required, two of which will provide a schedule activity interface bringing both shifts together to promote camaraderie. This approach also consolidates food preparation and cleanup for minimizing required crew time.

The information management system plays a key role in the Space Station operations, from the initial buildup through the 10-year mission. Figure 4-65 presents a summary of the various communications elements in the Space Station program. Along with the Space Station internal communications loops, the configuration includes S-Band, VHF, and K_u-Band links between various elements.

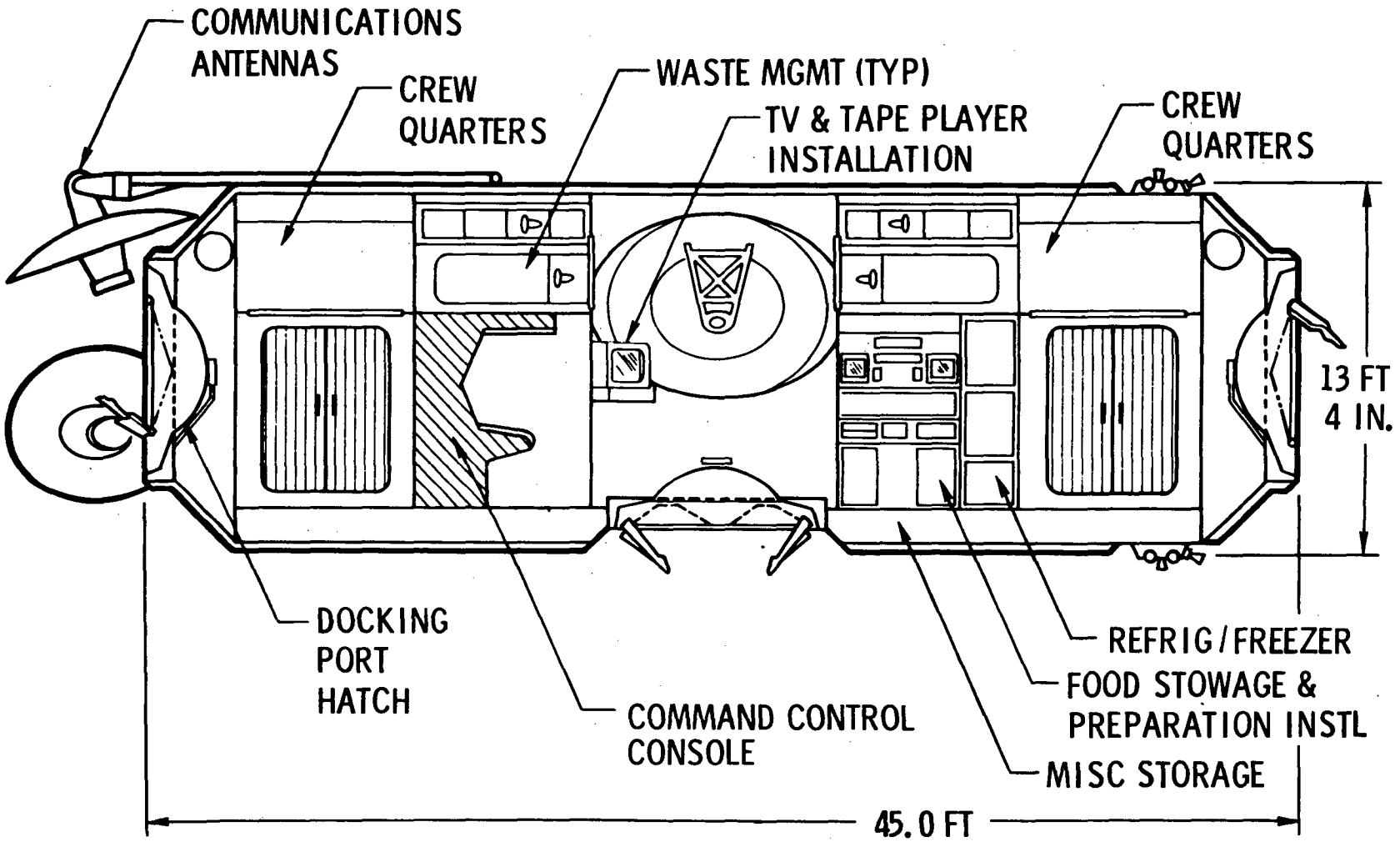


Figure 4-64. Modular Space Station Crew/Operations Module

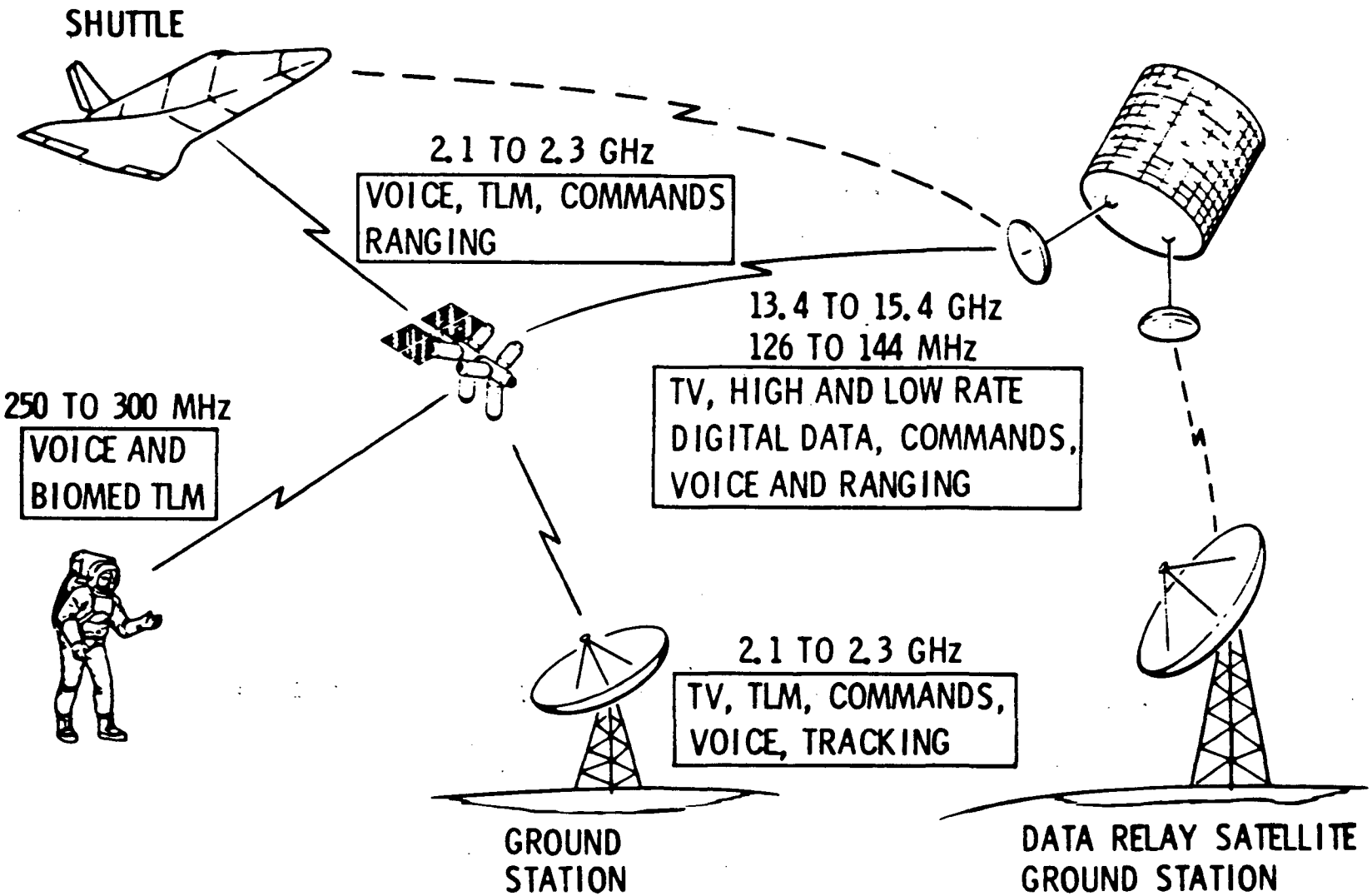


Figure 4-65. Communications Elements

During buildup operations, voice communications will be provided between crewmen in the Space Station module and the Shuttle orbiter crew. The baseband voice channel nominally utilized for public address or emergency voice communications provides this capability, and it is available in all of the modules. Prior to crew entry into the Power/Subsystems Module, the VHF and S-Band transmitters, receivers, and low gain antenna system will be checked to insure the systems operability. Following the entry of the assembly crew into the module, the S-Band RF link will provide a backup to the hardline voice loop.

During buildup operations of the Crew Operations and GPL modules, the hardline voice loop will be available. The backup RF link will not be available until the interface mating operations are completed and each module is linked to the S-Band receivers on the Power/Subsystem Module.

During Space Shuttle rendezvous and docking operations with the unmanned Space Station, the Space Station will be capable of receiving command and control information, transmitting telemetry status data, and ranging information at ranges up to 300 km (166 nmi) over the S-Band link. Following docking of the Space Shuttle to the Space Station, the S-Band RF system provides the backup voice loop as previously discussed. Near-continuous two-way data communications contact with the ground is available via the VHF link through the Tracking and Data Relay Satellite System (TDRSS). The operation of the high-gain (K_u-Band) system is not required during buildup, because of the low data rates generated during buildup.

During the unmanned Space Station operations, there are two methods available for communication control. The first method includes leaving the VHF and S-Band receivers in a standby or a totally "on" mode. The transmitters may then be energized by ground command for system operation. The second method involves storing programmed commands to cycle the system operation on for ground commanding interface. A combination of the two methods will be employed on the Space Station.

During nominal operations the IMS provides the following capabilities:

A. Direct to ground network
   1. Command, voice, ranging reception.
   2. Telemetry, voice, ranging transmission.

B. TDRSS Link
   1. Television, multiple voice, entertainment, digital data, ranging reception.
   2. Television, experiment data, multiple voice, digital data, ranging transmission.

C. Space Shuttle Orbiter
   1. Voice, command, ranging reception.
   2. Voice, telemetry, ranging transmission.

D. EVA
   1. Voice, biomedical data reception.
   2. Voice transmission

The direct ground link will be utilized primarily for Space Station tracking and the transmission of state vector update information. The capabilities for command, voice, telemetry, and experiment data dump may be utilized during TDRSS blackout or failure periods.

The TDRSS link, utilizing the high-gain antenna system shown in Figure 4-66 is primarily for experiment operations support. The wideband capability provided by the K_u-Band is only required for the FPE's flown on the Space Station. The transmission of experiment data will be controlled on a scheduled basis by the data management system; however, the capability will exist for a VHF voice link callup for data transmission through the TDRSS. This wideband RF link will require a cooperative acquisition procedure.

During the sustained operations, the TDRSS VHF link will be utilized for administrative and procedural types of voice and low data rate traffic between the Space Station and mission operations support on the ground. A capability for simultaneous voice, data, and ranging between the Space Station and Space Shuttle will be provided at ranges up to an approximate maximum of 200 km (108 nmi).

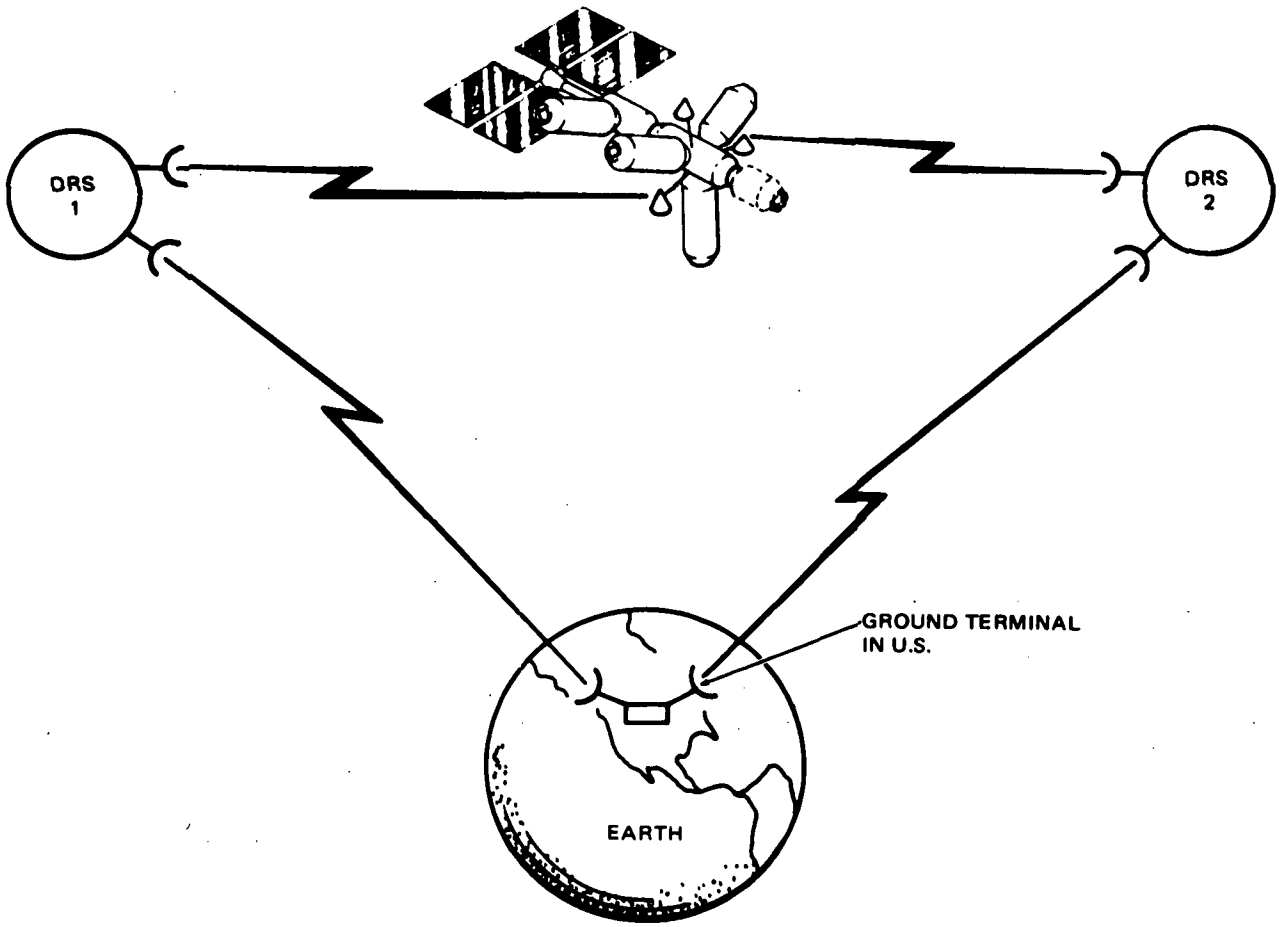


Figure 4-66. Data Relay Satellite Network

The EVA operations communications, duplex voice, and biomedical data are provided to the Space Station. The pressure suit and biomedical data can be displayed on the operations consoles in either the GPL or the Crew Operations Module.

Voice communications are provided within all the modules by the internal communications system. An onboard telephone system is provided which is comparable to a telephone system on Earth. A capability for public address and individual module paging is also provided.

During contingency operations, the crew will be provided the capability to communicate with ground personnel on an intermittent basis with the S-Band system, or on a near continuous basis using VHF through the TDRSS. The operation of these systems can be controlled either by the portable display and control units or by controls located at each docking port. Voice communications are available from any of the modules by the use of audio terminals which access the transmitters and receivers through the analog data bus. Additional voice capability (hardwired) to the VHF and S-Band systems is available at each docking interface.

Following growth to the GSS phase of the Space Station mission, an additional requirement is levied on the IMS, support of the free-flying RAM FPE's and modules. The relative trajectory of the RAM's to the Space Station will determine the maximum range of the Space Station antenna system. The total number of free flying RAM's operating simultaneously will also dictate the number of receivers required. As presently included in the baseline, the GSS IMS will provide the following capabilities for these free-flying RAM's:

A. Transmission of command, control, and ranging information.
B. Reception of the ranging code for generation of range and range rate data.
C. Reception of video and digital data related to the FPE and the RAM.

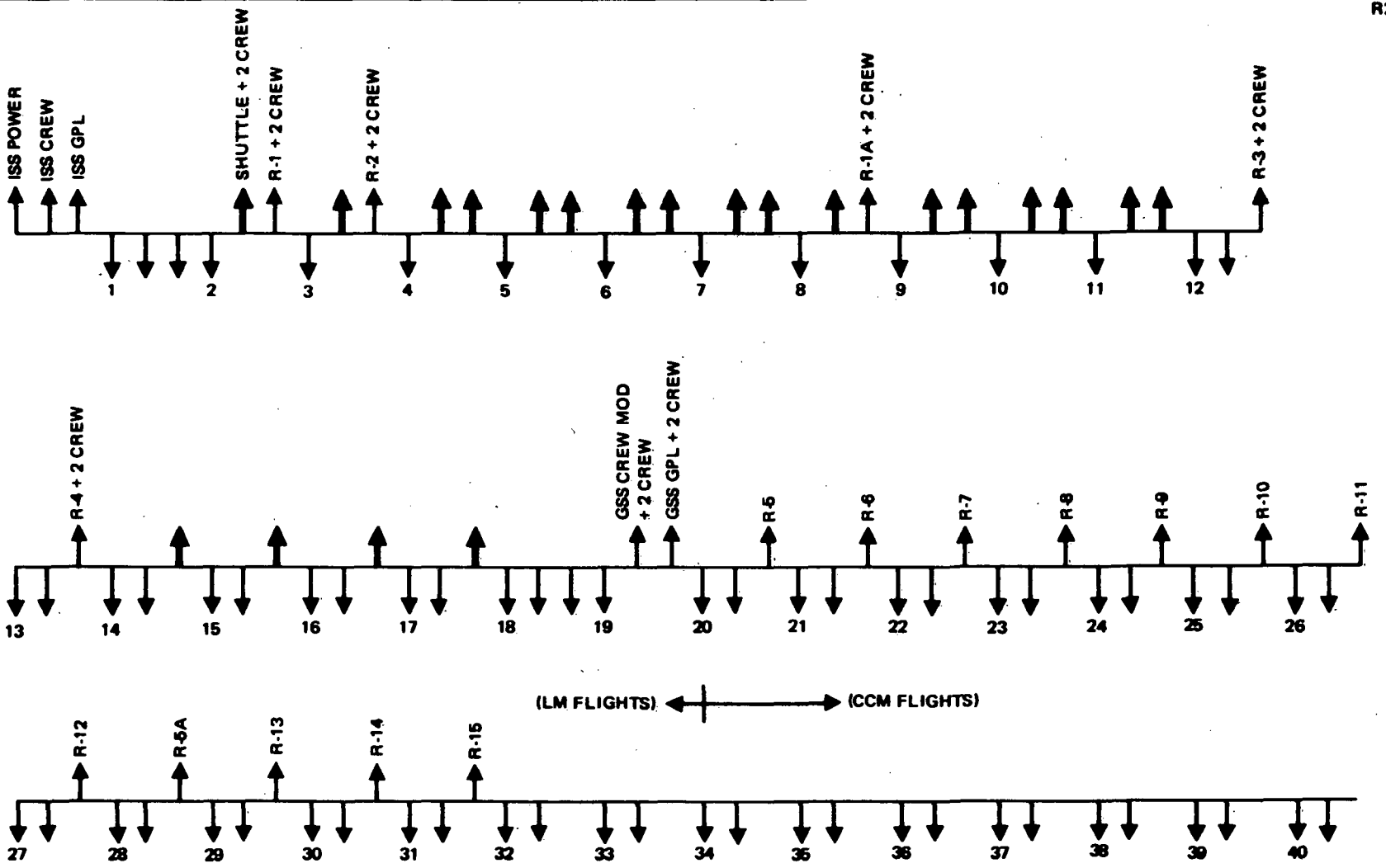
4.2.4 Logistics Support

4.2.4.1 Flight Schedule

The Shuttle vehicle will provide the transportation system to deliver and return the crew, RAM's, experiment equipment and supplies to the Modular Space Station. An analysis of crew rotation requirements, Space Station subsystem resupply cargo, and experiment (RAM's, equipment, samples, data, and resupply) cargo was accomplished to identify the flight requirements for the ISS and GSS operations. The other key drivers identified during the study that were integrated with the cargo requirements to establish the flight schedule, (Figure 4-67) are:

A. The Shuttle delivery and return payload capability is 9,072 kg (20,000 lb).
B. The maximum Shuttle launch frequency is every 30 days.
C. The Shuttle can accommodate a maximum of two passengers.
D. Crew rotation cycles are based on a nominal frequency of every 90 days.
E. The maximum cargo payload accommodation of a Logistics Module is 6,350 kg (4,000 lb).
F. The maximum cargo payload capability of a Crew Cargo Module is 4,990 kg (11,000 lb).
G. The Modular Station initial buildup and on-orbit assembly logistics support shall include the delivery of off-loaded subsystem equipment and a large inventory of spares over and above the nominal resupply requirements.
H. Resupply cycles are scheduled on nominal 90-day centers.
I. Experiment Case 534G will be used to establish a flight schedule. The results of the analysis impacting the ISS flight schedule include a total cargo weight of 115,000 kg (254,000 lb) delivered to the ISS Station during five years of operation.

A detailed description of Station subsystem and experiment cargo requirements including cargo mix of gases, liquids, and solids by weight and volume is presented in SE-06.



*BASED ON EXPERIMENT CASE 534G

ISS	-	LM FLIGHTS	29
ISS	-	SHUTTLE (2 CREW ONLY)	21
ISS	-	CCM FLIGHTS	2
GSS	-	CCM FLIGHTS	40

Figure 4-67. LM Flight Profile

Figure 4-67 shows five Shuttle flights required to deliver the Space Station modules and five flights to deliver RAM's. The first three Log Module flights in Quarter 1 are required to establish the initial inventory, initial six-man crew, subsystem equipment for activation, and the first quarter of a year of operational supplies. Quarters 12 through 20 require two Log Module flights very 90 days to deliver required supplies while Quarters 2 to 12 require only one Log Module. A Shuttle flight every 30 days is required to rotate two crewmen; thus, 21 additional Shuttle flights are required during ISS for crew isolation operations.

The GSS logistic support shows 42 Crew Cargo Module flights and 12 RAM flights required. All cargo resupply requirements can be delivered on the crew rotation flights for Case 534G.

A total of 126 flights is required for the 10-year Modular Station Program. Figure 4-68 presents a return flight schedule.

4. 2. 4. 2 Cargo Loading Philosophy

The on-orbit pantry concept developed during the 33-ft station study was reevaluated for the modular station design and operation. The reevaluation concluded that the pantry concept continued to provide the best concept and operational mode for on-orbit storage, inventory control, cargo transfer (loading and unloading) and daily utilization by the crew. Tradeoffs emphasized crew time, storage requirements aboard the station, and scheduling of cargo tasks. The pantry concept continues to provide the minimum on onboard storage requirements for other station modules, minimum crew time required for cargo transfer, and allows the transfer of cargo on an as needed basis or non-interference scheduling with experiment operations.

The Space Station is required to provide 30 days of consumables past the next scheduled resupply for support of on-orbit operations. The technique employed to satisfy this requirement is to store 30 days of operating spares, consumables, and expendables onboard the Space Station, and to store the logistics required until the next logistics appointment onboard the Log Module. As shown in Figure 4-67, the time between Log Module flights during ISS varies from 30 to 90 days. The Log Module has been designed for

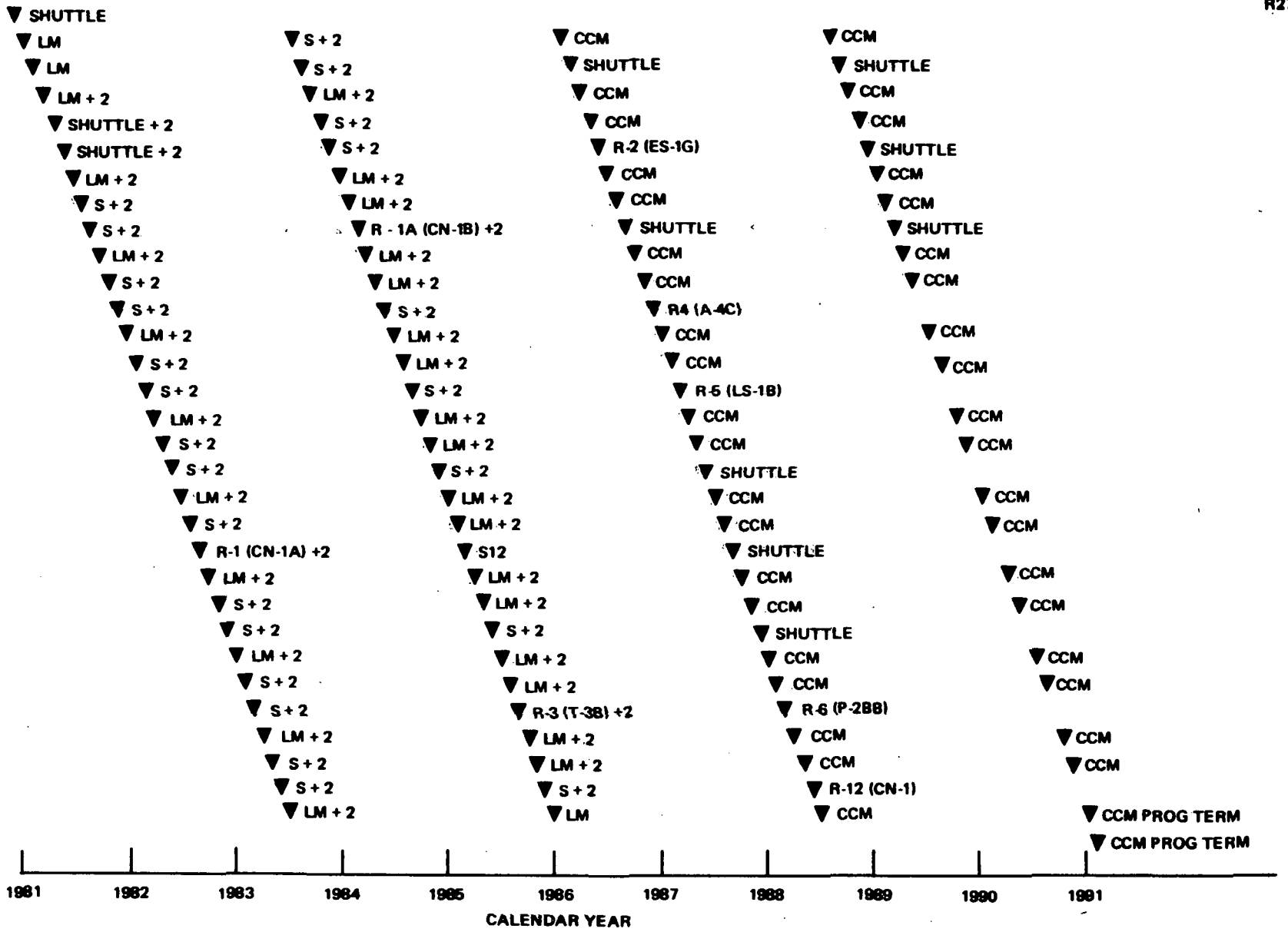


Figure 4-68. Return Flight Schedule

capacity loading of 90 days of supplies. This sizing allows the module to respond to the maximum requirement during the ISS mission phase.

In actuality, the Log Module will be loaded with logistics sufficient to support the Space Station until the next Log Module flight. Therefore, in Quarter 8 (for example) the Log Module will be loaded with 90 days of supplies, while in Quarter 12, the first Log Module will be loaded with 30 days of logistics and the second will be loaded with 60 days. Requirements for transfer of unused equipment from the Log Module to the Space Station or return to Earth of unused supplies will be held to a minimum with this approach.

GSS operations require the rotation of 12 crewmen every 90 days. This will be accomplished using a Crew Cargo Module which provides for the delivery of logistics and six crewmen. A minimum of two flights will be required each 90-day period to rotate the 12 crewmen. Analysis of resupply requirements during GSS indicated that the logistics capability of two CCM's every 90 days will be sufficient to support the Space Station operation.

4. 2. 4. 3 Cargo Transfer Operations

Selected liquids and gases are transferred from the Log Module (by a system controlled from the Space Station command control console) to the subsystem using point (RCS, RAM, GPL, et.) throughout the station. The fluid or gas is pumped or gas pressure fed to effect transfer. Each neuter docking port on the Modular Space Station has the interface connectors and capability to mate to the logistic modules for these transfer operations.

All cryogenics are transferred manually by the crew from the Logistics Module to the GPL or RAM. The study emphasis for low ititial cost eliminates all large quantities of cryogenics for controlled transfer by pumping. Current technology has not developed an operational system or technique for cryogenic transfer in zero g. DDT&E costs to develop a system for cryogenic transfer would exceed the study guidelines for low initial cost.

Small quantities of special fluids or gases required for experiment operations will be transferred the same as solid cargo. Solid cargo transfer will primarily be accomplished by the crew hand controlling and translating each item on an as-needed basis or scheduled periodically. The majority of solid cargo items can be safely handled and transferred by the crew from the Log Module or CCM to the Power/Subsystems Operations, Crew, or GPL modules without the aid of a cargo handling system. However, the characteristics of a new items exceed the capability of a crewman to safely control and constrain the movement of the item without the assistance of a mechanical aid or cargo handling device. These characteristics include size or shape, moment of inertia, and safety precaustion (example - transfer of high pressure gas tanks). Some of the items are resupplied periodically throughout ISS and GSS operations and will require a transfer from the Log Module to a station module. The experiments will also require the periodic delivery and transfer of equipment or resupply of cargo having the characteristics requiring a transfer system to assist the crew. Since the usage rate of the transfer system is periodic rather than routine with each resupply flight, a simple system that can be easily installed and removed for onboard storage is desired rather than a more sophisticated and permanent system throughout the station. A proposed concept for a minimum system is presented in the following paragraphs and would be delivered to the station on the first Log M.

A dual cable cargo moving system is depicted in Figures 4-69 and 4-70. The system features include the following:

A. Two cables are attached to attachment fixtures located in the aisle ways of each station module and Logistics Module. Separate cables are attached on each side of the aisle to provide directional control of the cargo transfer.
B. The cables are anchored at convenient intervals.
C. No fittings are required on the cable.
D. Removable cable trackers are easily and quickly installed by a crew member.
E. A deadman brake is provided on the tracks.
F. Anchor pins seize continuous cable run.
G. Corners can be conveniently traversed.
H. System easily adaptable to cargo continer design.

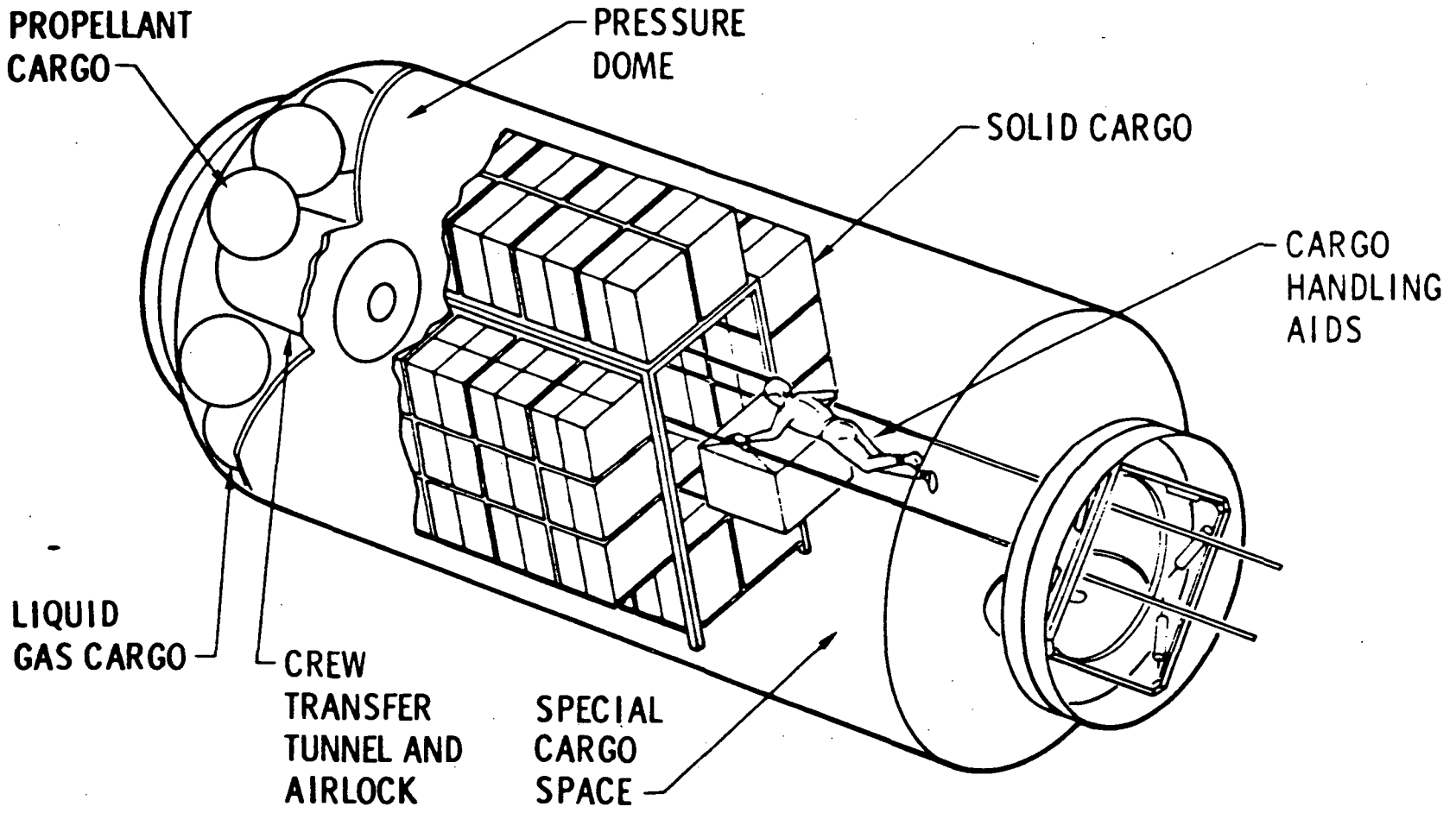


Figure 4-69. Logistics Module

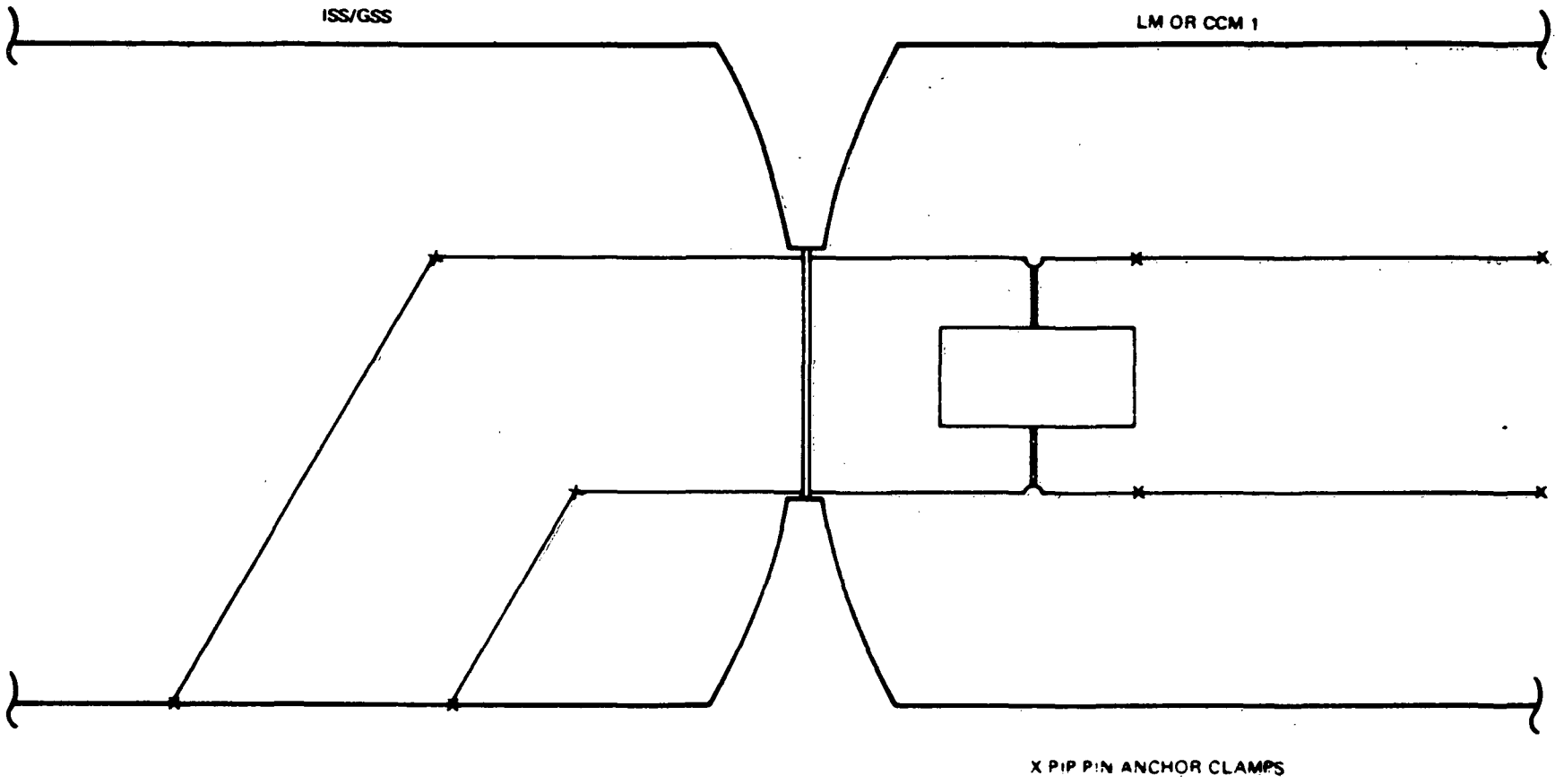


Figure 4-70. Transfer Cable System

I. No maintenance required.

J. Minimum storage on station required.

K. Minimum crew time for installation or removal.

Equipment requiring use of the system during ISS activation would include those described in Table 4-22.

Table 4-22

CANDIDATE EQUIPMENT REQUIRING TRANSFER SYSTEM

Item	Quality	Transfer From Logistics Module To
CMG's	4	Power/Subsystem Module
Repressurization Gas		
O_2	1	Power/Subsystem Module
GN_2	4	Power/Subsystem Module
Metabolic Gas		
O_2	2	Power/Subsystem Module
O_2	2	Crew Operations Module
Pumpdown Accumulators	2	Power/Subsystem Module
Water Tanks	2	Crew Operations Module
Batteries	1 set	Power/Subsystem Module
	2 sets	Crew Module
	2 sets	GPL
	2	Crew Module
	2	
Trash Compactor	1	Crew Module

To operate the system the crew would attach the cable runs from the Log Module to the equipment location aisle zone in the station module where the equipment or item is to be transferred. The crew would then proceed to the storage rack of the Log Module and attach one cable tracker to the cable. The tracker is clamped and locked onto the cable and is normally spring-loaded to the brake position. The crew depresses the trigger mechanism releasing the brake and the tracker is free to slide along the cable. Releasing the trigger automatically engages the tracker brake.

With one tracker installed, the crew would then attach an adjustable cargo constraint cable. One end anchors to the tracker and the other end attaches to the cargo packaging fitting. The tracker and anchor to remove the cargo holding constraints (bolts, straps, etc.) releasing the cargo from its storage rack. The cargo item is pulled into the aisle-way sufficient to allow installation of the second tracker and guide cables are then adjusted to the proper tension to constrain the cargo. The crew is now ready to translate the cargo along the cable run.

Each crewman releases the tracker brake and the crewmen provide the force to translate the item. The crew performs the reverse procedure to remove and install the item at its destination point. Figure 4-71 further demonstrates the use of the proposed system. The system provides a very simple, easy to operate and store, minimum maintenance and cost compared to other systems evaluated.

4.2.4.4 Spares

A reliability and maintainability analysis was performed to determine the requirements for subsystem spares during the 10 years of operations. Figure 4-72 demonstrates the results of the analysis showing the effect of wieght of spares stored onboard the Station and the weight required to achieve 0.96 probability for 120 days of operation. The nominal 90-day spares resupply weight is the estimated weight of spares required to replenish the inventory for each 90-day period of operations. The initial inventory for ISS subsystems operations required 1,814 kg (4,000 lb) and 1.7 m^3 (60 ft^3)

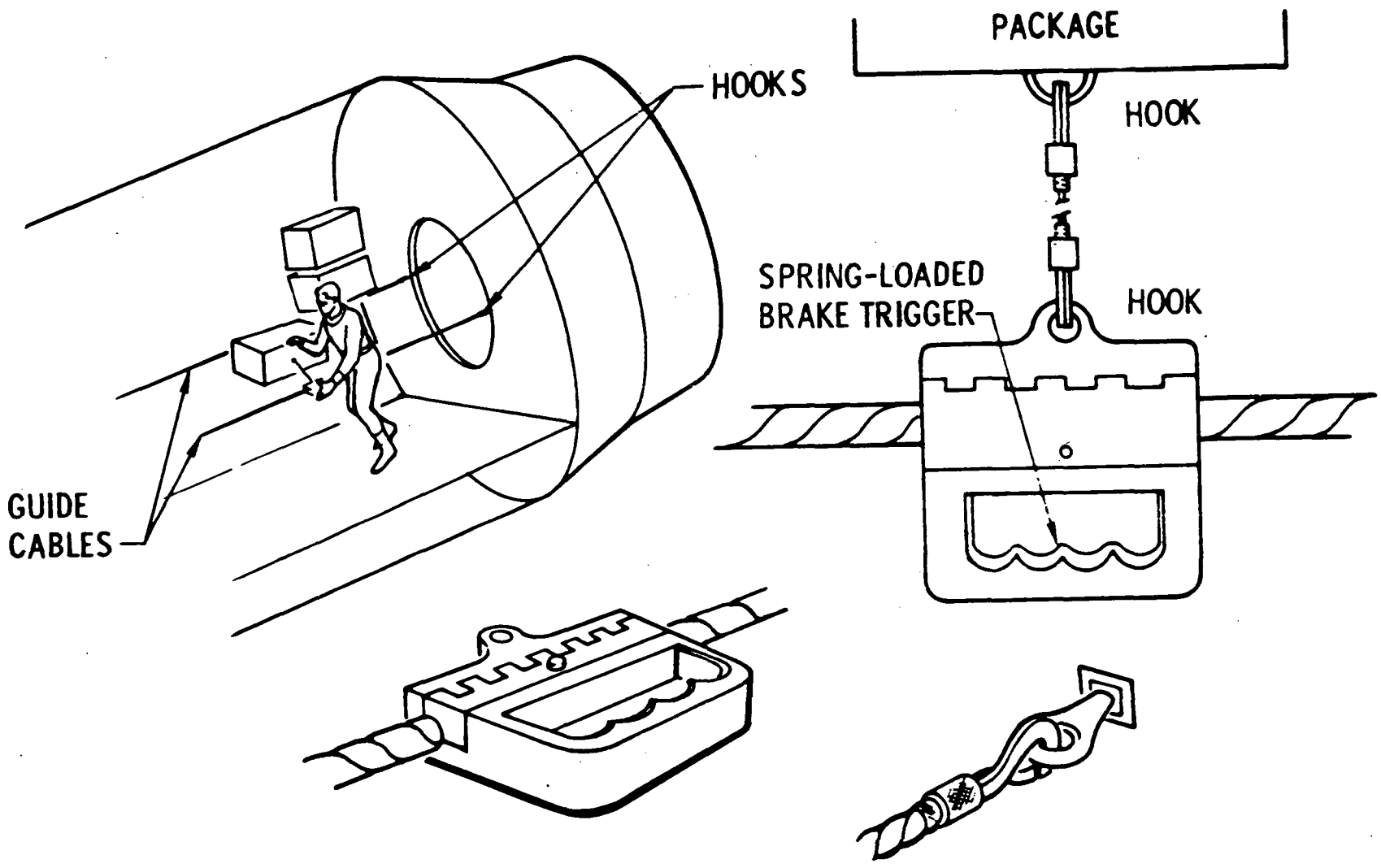


Figure 4-71. Cargo Handling System Components

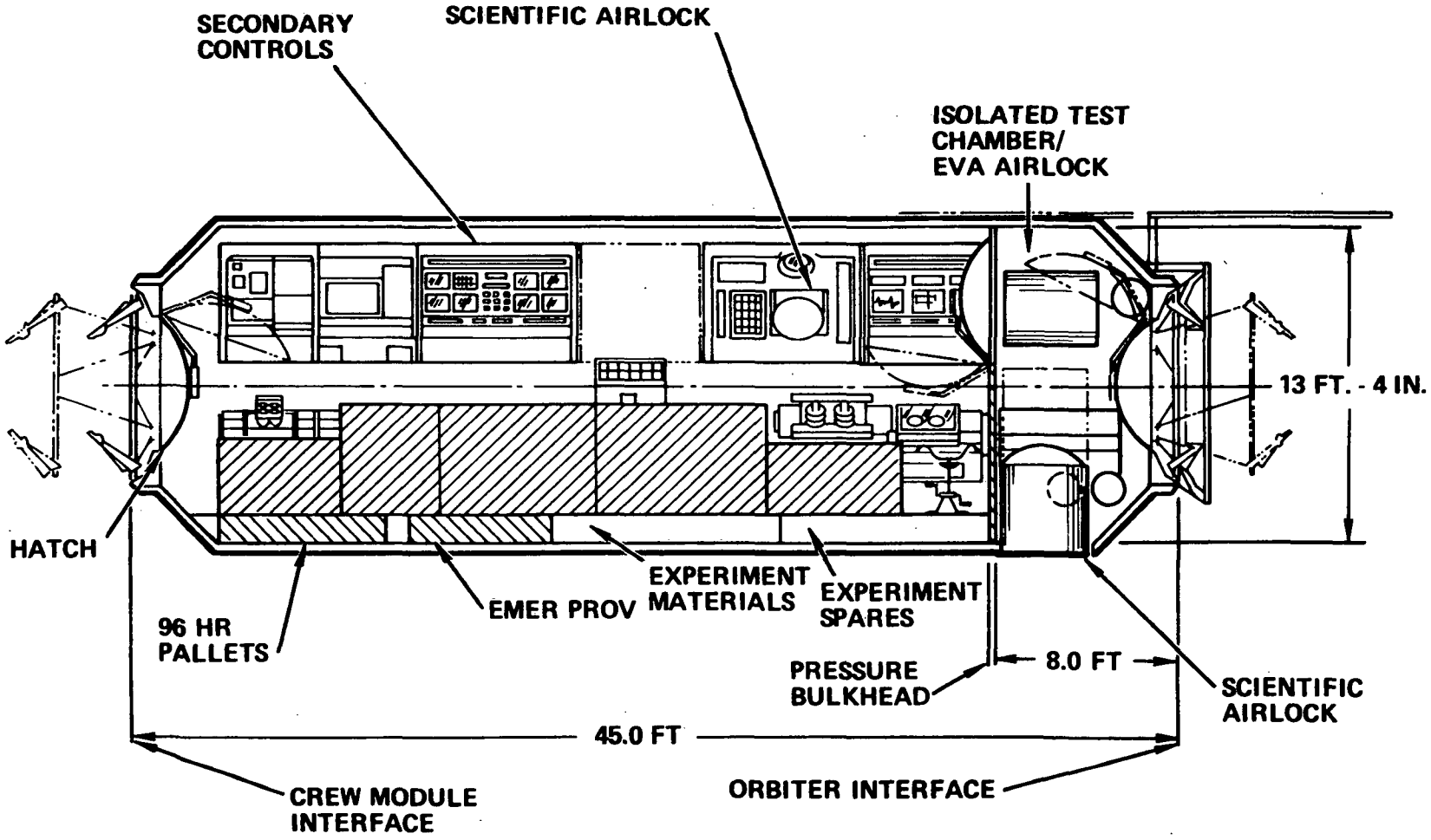


Figure 4-72. General Purpose Laboratory - - Inboard Profile

of onboard storage. Figures 4-73 and 4-74 depict the storage location of the inventory onboard the station. An average value of 150 kg (330 lb) of spares are delivered each 90 days as replacement items to the inventory. The inventory is established by the first three Log Module flights in the program. GSS inventory requirements are 2,450 kg (5,400 lb) and 2 m^3 (72 ft^3). For more detail on spares definition and requirements, refer to Section 7.1.2.

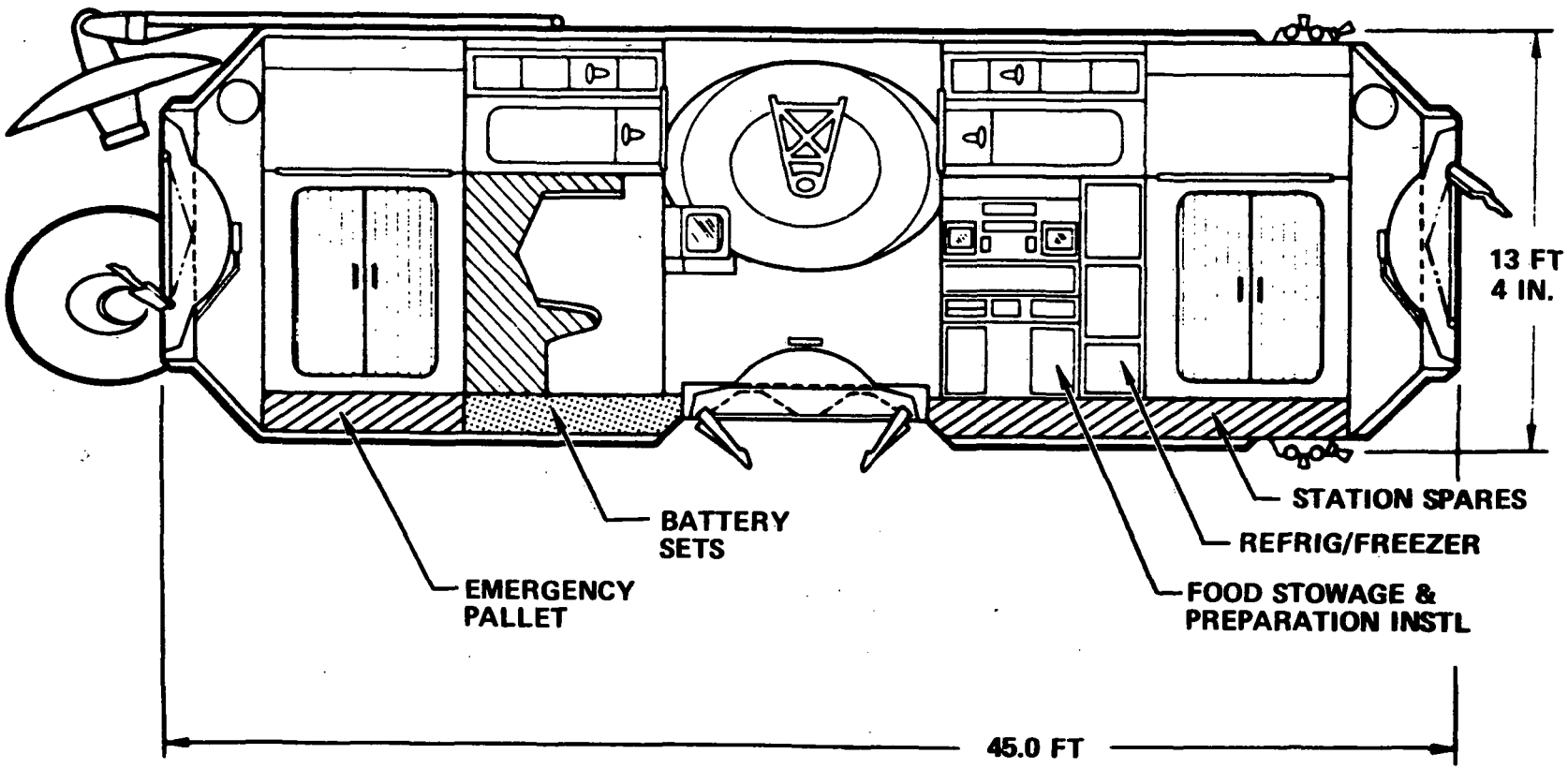


Figure 4-73. Crew/Operations Module - - Inboard Profile

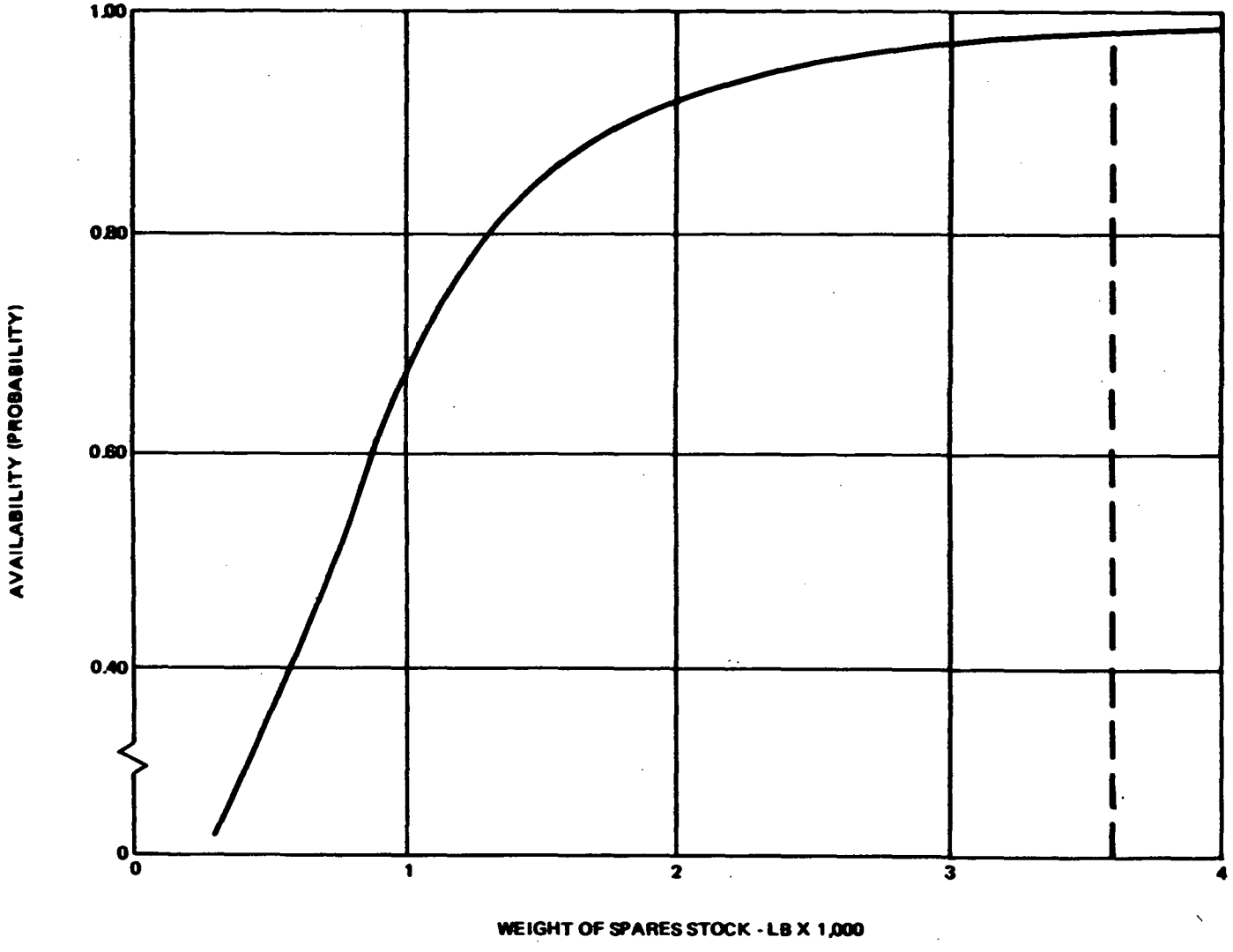


Figure 4-74. Availability Growth with Addition of Spares -- 120 Days

Section 5
EXPERIMENT SUPPORT REQUIREMENTS ANALYSIS

This section includes the analyses accomplished in the area of Experiment Support. It is discussed in four segments, as follow: 5. 1, Experiment Definition; 5. 2, Mode of Accommodation; 5. 3, Experiment Support; and 5. 4, Space Station Experiment Interfaces.

5. 1 EXPERIMENT DEFINITION AND DESCRIPTION

A brief description of the objectives of the candidate experiments for the Space Station is included in this section along with a discussion of the potential hardware utilized for conducting the experiments.

The experiments consist of seven disciplines or FPEs (Functional Program Elements), divided into 18 groups, and subsequently into 60 subgroups as shown in Table 5-1. The subgroups have been derived as packages which are compatible to operate with the Space Station resources and within program restraints.

A brief objective and description format follows for each of the 18 groups.

FPE A-1 X-RAY STELLAR ASTRONOMY

Objectives and Description

1. Objectives

The X-ray Stellar Astronomy FPE will provide capabilities for extending the range of observable objects to extreme cosmological distances with improved angular, spectral (energy level), flux level, and polarization measurement resolution. The objectives of the X-ray Stellar Astronomy experiment are:

A. Identification, location and angular size of soft X-ray sources in the 10^{-10} to 10^{-8} meter (1 to 100 angstrom) spectral range

Table 5-1

FPE, GROUP, AND SUBSYSTEM RELATIONSHIPS

FPE	Group	Subgroup	Title
Astronomy	A-1		X-Ray Stellar Astronomy
	A-2		Advanced Stellar Astronomy
		A-2A	Intermediate Stellar Telescope
	A-3		Advanced Solar Astronomy
		A-3A	1.5m Photoheliograph/ 0.25m XUV Spectroheligraph/ 0.5m X-Ray Telescope
		A-3B	Solar Coronagraph
		A-3C	Photoheliograph
		A-3D	X-Ray Spectroheliograph
		A-3E	UV Long Wave Spectrometer
	A-4		Intermediate Size UV Telescopes
		A-4A	0.9m Narrow Field UV Telescopes
		A-4B	0.3m Wide Field UV Telescopes
		A-4C	Small UV Survey Telescopes
	A-5		High Energy Astronomy
		A-5A	Lower Energy Experiment
		A-5B	Higher Energy Experiment
	A-6		IR Telescope
Physics	P-1		Space Physics Research Laboratory
		P-1A	Atmospheric and Magneto Science
		P-1B	Cometary Physics
		P-1C	Meteoroid Science
		P-1D	Thick Material Meteoroid Penetration

Table 5-1

FPE, GROUP, AND SUBSYSTEM RELATIONSHIPS (Continued)

FPE	Group	Subgroup	Title
Physics (Continued)		P-1E	Small Astronomy Telescopes
	P-2		Plasma Physics and Environmental Perturbation Laboratory
		P-2A	Wake Measurements from Station and Booms
		P-2B	Wake Measurements from Subsatellites
		P-2C	Plasma Resonances
		P-2D	Wave Particle Interactions
		P-2E	Electron and ION Beam Interaction
	P-3		Cosmic Ray Physics Laboratory
		P-3A	Laboratory Without Total Absorption Device
		P-3B	Laboratory With 1/2 Total Absorption Device
		P-3C	Plastic/Nuclear Emulsions
	P-4		Physics and Chemistry Laboratory
		P-4A	Airlock and Boom Experiments
		P-4B	Flame Chemistry and Laser Experiments
		P-4C	Test Chamber Experiments
Earth Survey	ES-1		Earth Observation Facility
		ES-1A	Meteorological and Atmospheric Science
		ES-1B	Land Use Mapping
		ES-1C	Air and Water Pollution
		ES-1D	Resource Recognition

Table 5-1

FPE, GROUP, AND SUBSYSTEM RELATIONSHIPS (Continued)

FPE	Group	Subgroup	Title
Earth Survey (Continued)		ES-1E	Natural Disasters
		ES-1F	Ocean Resources
		ES-1G	Minimum Payload
Communications/ Navigation	C/N-1		Communications/Navigations Facility
		C/N-1A	Communications/Navigations Subgroup A
		C/N-1B	Communications/Navigations Subgroup B
Materials Science and Manufacturing	MS-1		Materials Science
		MS-1IIIA	Space Station Group
		MS-1IIIB	Space Station Group
		MS-1IIIC	Space Station Group
		MS-1IIID	Space Station Group
		MS-1IIIE	Space Station Group
Technology	T-1		Contamination Measurements
		T-1A	Contamination Package 1
		T-1B	Contamination Package 2
	T-2		Fluid Management
		T-2A	Long-Term Cryogenic Storage
		T-2B	Short-Term Cryogenic Storage
		T-2C	Slush Propellant

Table 5-1

FPE, GROUP, AND SUBSYSTEM RELATIONSHIPS (Continued)

FPE	Group	Subgroup	Title
Technology (Continued)		T-2D	Noncryogenic 1
		T-2E	Noncryogenic 2
	T-3		EVA
		T-3A	Astronaut Maneuver Unit
		T-3B	Manned Work Platform
	T-4		Advanced Spacecraft Systems Test
		T-4A	Long-Duration Systems Tests
		T-4B	Medium-Duration Tests
		T-4C	Short-Duration Tests
	T-5		Teleoperations
		T-5A	Initial Flight
		T-5B	Functional Manipulation
		T-5C	Ground Control
Life Science		LS-ST/A	Minimal Medical Research Facility (Station)
		LS-ST/B	Minimal Life Science Facility (Station)
		LS-ST/C	Interim Life Science Facility
		LS-ST/D	Dedicated Life Science Facility

B. Determination of the amount and distribution of the energy associated with such sources;

C. Detailed spectral information enabling determination of the physical mechanisms responsible for X-ray emissions;

D. Information enabling continuing technology development;

E. Simultaneous correlated observations and measurements enabling studies of image and spectral variations.

2. Description

The X-ray astronomy facility consists of six independent X-ray collection and direction-sensing assemblies: (a) a high resolution (1000 cm^2) X-ray telescope, (b) a large area (5000 cm^2) moderate resolution X-ray telescope, (c) a proportional counter array, (d) a scintillation counter assembly, (e) a flat crystal spectrograph, and (f) a transient X-ray phenomena detector. Although the assemblies are independent of each other, correlation of the data when all six are operated simultaneously yields data over an energy spectrum from 0.1 keV to 10 keV and provides a basis for analysis of interfering signals.

FPE A-2 ADVANCED STELLAR ASTRONOMY

Objectives and Description

The Advanced Stellar Astronomy FPE will provide capabilities for greatly improved angular, spectral, photometric and polarization measurements resolution and accuracy in the 1 μm to 0.09 μm spectral range.

1. Objectives

Diffraction-limited images from a large telescope in space can provide a significant increase in our knowledge of the spatial structure of astronomical objects and permit the detection of fainter objects than is presently possible from the ground, because of increased angular resolution. Large telescopes in space will also allow higher spectral resolution to be achieved more efficiently by instruments employing dispersive optical systems. The advanced stellar astronomy goals in space are:

A. Improved observation of stellar objects in the 10^{-5} to 9×10^{-7}m (10,000 Å to 900 Å) spectral region by imaging, spectrometry, photometry, and polarization measurement.

B. High resolution spectrometry and imaging of planetary bodies.

C. Acquisition of operational information enabling evaluation of design philosophies and operational techniques for candidate manned (or man-controlled) space telescopes. The more immediate goal is to obtain sufficient design information and experience with a typical large telescope that would enable better definition and combination of user, observer, and scientist/astronaut requirements for a National Astronomical Space Observatory telescope.

D. The long term goal of observational astronomy in the short wavelength IR, visible light, and UV portions of the spectrum is to obtain an operational high resolution large diameter telescope in space by the the early 1980's. Such a telescope would enable maximum state-of-art observational capabilities with minimum limitation from Earth atmosphere, sky brightness, cloud obscuration, and atmospheric varying refraction effects.

2. Description

The facility equipment for the advanced stellar astronomy functional program element (FPE) will consist of a telescope which will be operated experimentally in space prior to establishment of a more permanent telescope for National Astronomy Space Observations (NASO). This telescope may be either two or three meters in diameter at the aperture and will be arranged to accommodate various optical technology experiments as well as engaging in scientific stellar observations. All telescope options considered for advanced stellar astronomy will allow for attachment or retrofit of various instruments at one of the foci or beam split optical points to enable accommodation of instruments for a number of investigators. The telescope will be capable of being monitored and remotely controlled from the ground as well as from a nearby Space Station or a logistics (Shuttle) service vehicle.

FPE A-3 ADVANCED SOLAR ASTRONOMY

Objectives and Description

The Advanced Solar Astronomy FPE will provide capabilities for more continual observation in the 1.1 um (11,000 Å) to 2 x 10^{-10}m (2 Å) spectral region with better spectral, angular, temporal, and magnetic field resolution than is obtainable from large solar observatory sites on Earth.

1. Objectives

The objectives of manned orbital advanced solar astronomy are:

A. Extremely high resolution visible and UV studies of the solar granular structure and areas of high solar activity.

B. Correlated XUV and X-ray observations with higher spatial and spectral resolution using larger apertures, more efficient reflective surfaces, and improved instrumentation.

C. Development of solar astronomy facilities designed to take maximum advantage of man's presence (some of these modules may operate detached from the Space Station).

D. A long-lifetime solar information acquisition system capable of being efficiently and conveniently operated either from a Space Station or the ground. (Such an information acquisition system will possibly involve the use of advanced communication satellites for real-time ground control.)

2. Description

The advanced solar astronomical facilities are expected to consist of two groups of instruments: one group which is intended to be used to examine phenomena in solar granular structure and areas of high activity with best-available spectral and spatial resolution, and a second group which measures phenomena in the region of the solar corona.

FPE A-4 INTERMEDIATE SIZE UV TELESCOPES

Objectives and Description

The Intermediate-Size UV Telescopes FPE provide an early means for testing stabilization, electronic imaging, and spectrometry approaches in a less costly size as well as continuing development of UV wide-field observations for diffuse or widely distributed sources.

1. Objectives

Principal scientific objectives of the ultraviolet experiments or observations with the intermediate UV telescopes are:

A. Spectrally selective ultraviolet imaging of galactic emission and reflection nebulae.

B. Spectrally selective ultraviolet imaging and photography of star clusters. Ultraviolet photometry of cluster stars will permit more accurate derivations of stellar evolutionary sequences, particularly for massive stars requiring large bolometric corrections.

C. Direct ultraviolet imaging and photography of galaxies. Images of nearby galaxies will improve the delineation of spiral structure due to increased contrast between star groups and dust lanes at shorter wavelengths.

D. Slitless spectrography in the ultraviolet of selected large planetary nebulae. This technique will provide the means of obtaining monochromatic ultraviolet spatial images of essentially dust-free pure emission gas systems.

E. Slit spectrography of specific features in large emission nebulae. These observations will be used to study collisional, radiative, and processes in the nebulae.

F. Spectrographic and photographic observations of the brighter quasars and novae.

G. Concurrently with these specific observations and measurements, observations will be continued with a wide-field all-reflective telescope to accomplish the following:

1. Conduct an ultraviolet survey of the sky.
2. Obtain spectra in the ultraviolet region from selected strong ultraviolet sources and from the entire celestial sphere.

3. Provide survey data of selected areas for detailed investigation by the larger instrument.
4. Develop an ultraviolet technology base and determine man's potential in support of space astronomy.

Objectives of the narrow field UV telescope experiments are as follows:

A. Spectrally selective imaging of galactic emissions, star clusters, and nearby galaxies, as well as planets of the solar system.
B. Slitless spectrography of planetary and emission nebulae.
C. Spectrometry of selected stars, brighter quasars and novae.
D. Information on performance of the 0.94-meter gimballed telescope enabling further development of the design for interplanetary spacecraft use.

Wide-field UV telescope survey experiment objectives are:

A. Imaging of objective-grating stellar spectra in the 9×10^{-8} to 2×10^{-7}m (900 to 2000 Å) wavelength region, with a wavelength resolution of 2×10^{-10}m (2Å) or better.
B. Moderate-resolution far-ultraviolet direct-imaging of selected objects and Milky Way fields.
C. Development of instrument technology and in-flight procedures of potential value in the efficient wide-area surveys.
D. Extension of photographic spectroscopy in the region of the Lyman series of atomic and molecular hydrogen (primary goal of this FPE).

2. Description

The ultraviolet stellar survey facility items consist of a narrow-field 0.94-meter (37 inch) Ritchey-Chretien Cassagrainian type of telescope and a 0.3-meter wide-field UV telescope. The narrow-field UV telescope and its associated experiments form an ultraviolet energy gathering and processing system. The system is capable of accepting ultraviolet radiation from stars or nebulae and performing direct-field photography or spectrography. The pictures may be taken by either electronic or photographic processes.

FPE A-5 HIGH-ENERGY STELLAR ASTRONOMY

Objectives and Descriptions

The High-Energy Stellar Astronomy FPE provides pointed-observation capability for time-correlated (simultaneous) measurements in the energy spectrum from 0.1 keV to 30 GeV to obtain more complete information on the nature of physical processes occurring at these sources with improved energy, polarization, and temporal resolution.

1. Objectives

This group of experiments obtains information to enable accomplishment of stellar X-ray and gamma ray astronomy studies. This program element will enable multispectral correlation of stellar X-ray and gamma ray source data which can be analyzed immediately by the astronomical community.

The Low Energy X-ray Telescope experiment objectives include measurement of selected sources at the same time that higher energy instruments in other experiments are utilized for observation in higher energy portions of the spectrum.

FPE A-6 INFRARED ASTRONOMY

Objectives and Description

The IR Astronomy FPE provides greatly improved capabilities for survey and detailed observation of cosmic, galactic, planetary and diffuse IR sources in the 100 um to 1 um spectral region at better sensitivities than possible from aircraft in the atmosphere or ground-based sites.

1. Objectives

Infrared studies promise new ways of studying the nature and structure of the universe.

Unbiased surveys of essentially all the sky are necessary to understand what kinds of infrared objects exist. Surveys at wavelengths longer than 20 um will probably be effective in finding entirely new types of infrared objects, such as extra-galactic objects. A second essential study is a survey to determine the luminosities of a large number of sources. Since there are objects which emit a major fraction of their energy in the infrared, broad-bank measurements which lead to accurate total luminosities are required for all types of galactic and extra-galactic objects.

2. Descriptions

The IR telescope is unique among the astronomy instruments in that it must be cooled in its entirety to very low cryogenic (27.6°K) temperatures. The detectors in IR telescopes, at the focus of the optical path, must be kept at even lower cryogenic temperatures. To suppress "noise" in the detection and recording system, temperatures as low as 2°K are desired in some cases. Note that these extremely low temperatures apply only to the detectors and objects in the detector field of view and not to the telescope as a whole.

The IR telescope consists of a straightforward Cassegrainian optical system which is superinsulated to reject radiation from both the sun and earth. The IR instrumentation section containing an interferometer and an IR detector array is mounted directly behind the primary mirror of the Cassegrainian optics. IR detector array may be used for IR survey (scanning) and radiometry. An auxiliary optical telescope, for simultaneous visible-light imaging, is mounted to the IR telescope outside the superinsulation.

FPE P-1 SPACE PHYSICS RESEARCH LABORATORY

Objectives and Description

1. Objectives

The purpose of the Space Physics Research Laboratory (SPRL) is to provide flexible facilities in space for conducting experiments relating to:

A. Atmospheric and magnetospheric science (including aurora)
B. Cometary physics
C. Meteoroid science
D. Astronomy (small telescopes)

The objectives of the Space Physics Research Laboratory are:

A. To investigate the chemical and energy conversion processes which control the structure of the thermosphere and through simultaneous measurement of its structural properties, the energy input parameters which control these properties and the airglow parameters which provide information on the rates of controlling aeronomic process.
B. To study such complex processes as quiet-time auroral precipitation and the dynamics of the magetospheric substorm.
C. To investigate the physical mechanism or mechanisms responsible for the production of the observed radicals and ions in comets.
D. To determine meteoroid mass, velocity, composition, trajectory and origin.
E. To compliment and supplement the astronomical investigations to be conducted with its larger cousins, such as the Advanced Astronomy Module, or the UV Stellar Survey Module of the Space Station.

2. Description

The instruments necessary to accomplish the above objectives are grouped into five categories as follows:

A. Optical Sensors such as a Photometric Cluster, a Scanning Grating Spectrometer, and a Image Isocon Television.

FPE P-1 SPACE PHYSICS RESEARCH LABORATORY
(Continued)

B. Ambient Environment Sensors such as Mass Spectrometers, Magnetometers and Electric Field Probes.

C. Energetic Particle Sensors such as an aluminum foil exposure device.

D. Gaseous Release Devices

FPE P-2 PLASMA PHYSICS AND ENVIRONMENTAL PERTURBATION LABORATORY

Objectives and Description

1. Objectives

Historically satellite experiments to study the magnetosphere have been passive observations. Although much useful data has been obtained, the complexity and interaction of the physical processes involved has precluded the understanding of the controlling mechanisms. Active stimulation of individual parameters will greatly aid the separation of cause and effect.

There are four main experiment areas considered:

A. Wake Measurements. A wake is produced in the ionsphere by the Space Station which is moving at a velocity between that of the electrons and ions. Particle and fields distribution over the wake will be measured for comparison with theoretical predictions. The wake of "geometrically-clean" bodies will be also measured using inflatible balloons.

B. Plasma Resonances. For many years electron density profiles had been obtained by probing the ionosphere with topside sounders. After pulsing a swept low frequency electromagnetic source, numerous resonances have been observed that are a function of electron and ion density and geomagnetic field strength. Both the resonance measurements noted and transmission measurements will be made in this experiment covering a wide frequency range, for differing geomagnetic field and velocity vector directions and changing ionospheric conditions.

C. Wave/Particle Interactions. Whistler-mode waves have been observed triggered by lightning and other natural sources. These emissions, produced by wave-particle interactions, will be studied by controlled stimulation using high powered VLF radiation from the station and possibly from the ground. This data will aid in establishing the validity of magnetospheric VLF-wave amplification theories.

D. Electron and Ion Injection. Rocket experiments have demonstrated the feasibility of artifically producing aurora and reflecting particles from the magnetic conjugate point using electron beam injection. Data obtained using high power electron and ion beams coupled with the VLF radiation available from the previous experiment will aid in understanding electron precipitation phenomena producing aurora. Particle injection in the geomagnetic field also gives information on the field configuration and on trapping mechanisms producing the radiation belts.

FPE P-3 COSMIC RAY PHYSICS LABORATORY

Objectives and Description

1. Objectives

The Cosmic Ray Physics Laboratory is primarily an astrophysical observatory for high energy particles. The parameters of interest are the electron, positron and nuclei flux, isotopic composition, energy spectra and directionality. The highest energy particles measurable offer the only direct samples of stellar material available and at lower energies gives information on propogation in the intervening region. Previous measurements have been limited to energies below about 10^{10} ev. even with an earlier flight of the unmanned High Energy Astronomy Observatory (HEAO) the laboratory will offer a substantial increase in geometric factor and energy resolution. Manned operation makes possible timely maintenance and reconfiguration allowing a long operational life.

The observation program contains five major experiments.

A. Charge and Energy Spectra of Cosmic Ray Nuclei. The cosmic-ray flux directionality, charge and energy spectra will yield information on the stellar processes and characteristics of the intervening medium. With reference to Figure P-3, these measurements will be accomplished with Channel I the TAD, TASC and magnetic spectrometer and the Channel III double ended TAD configuration. Channels are discussed in the description below and shown in the figures.

B. Electron and Positron Energy Spectra and Anisotropics experiment measures the algebraic charge and mementum of electrons and positrons using the TASC and magnetic spectrometer in the Channel I experiment group.

C. Isotopic Composition of Light Elements up to at least beryllium is measured with Channel II instruments including the magnetic spectrograph and the large liquid Cerenkov detector.

D. Search for Nucleonic Antimatter will be conducted using both Channel I and Channel II instruments. The magnetic spectrometer detects the negative charge of the antimatter and the TASC detects the cascade shower resulting from annihilation products.

E. Extremely Heavy Nuclei are measured by tracks in plastic and nuclear emulsion plates.

2. Description

The laboratory has been broken down into subgroups to facilitate launch and build-up to full capability. The 24 klb TAD could be removed for the initial launch, delaying experiments A) and D) above. The next step in the buildup includes the addition of one-half the TAD. On-orbit assembly is feasible since the TAD is composed of 350 lb segments and highly accurate concentration is not required. Experiments A) and B) may be run with less accurate energy measurement than with the final buildup to total TAD. The plastic/nuclear emulsion sheets are broken out as a separate subgroup since they can be flown without the other laboratory hardware.

FPE ES-1 EARTH OBSERVATION FACILITY

Objectives and Description

1. Objectives

The Earth Observations Facility will include provision for data acquisition, sensor maintenance and repair, sensor control and display, and data analysts. Its function is to provide scientists in universities, industry and government the means for making observations of Earth by utilizing the unique capabilities that man can provide to a laboratory in space. The facility is research and development in nature with a potential for operational applications.

Data acquisition is primarily by the sensors located aboard the facility. These sensors fall into three groups that have general applicability and a fourth group that is unique to the particular research. Included in the first groups are imagers, radiometers and spectrometers, and included in the latter group are polarimeters, sferics detectors and optical radar.

Sensor controls will provide the means to operate several sensors simultaneously or to select various portions of the total passband of multi-spectral sensor. The performance displays will enable the crew to check the sensors for proper operation and to monitor all of the raw data for electronic quality and selected data for quick-look evaluation.

The data analysis unit should have the capability to store, call up, and display all data. It will utilize the capabilities of man to reduce the amounts of redundant, superfluous, or low-quality data that is collected or transmitted.

2. Description

The Earth Observation Facility consists of 15 Earth observation sensors and seven pieces of support equipment. The sensors operate in a variety of wavelengths, from ultraviolet through visible and infrared to microwave.

FPE ES-1 EARTH OBSERVATION FACILITY (Continued)

Groups of sensors operate simultaneously to conduct experiments in the following areas:

A. Meteorology and the Atmospheric Sciences,
B. World Land Use Mapping,
C. Air and Water Pollution,
D. Resource Recognition and Identification,
E. Natural Disaster Assessment and Anomalies,
F. Ocean Resources,
G. Special Research.

FPE C/N-1 COMMUNICATIONS/NAVIGATION RESEARCH FACILITY

Objectives and Description

1. Objectives

The goals of this functional program element (FPE) are to facilitate continued and expanded application of space technology and satellite systems. Man's unique capabilities as a research scientist in space may be used to provide for increased national and international needs for communications with and between earthbound airborne and spaceborne terminals, and to improve continually the capabilities for terrestrial, air, and space vehicle navigation and traffic control.

Several continuing broad objectives guide the description of the Communications/Navigation Research Facility to serve its intended goals. These are:

A. Develop and demonstrate satellite system and spacecraft technology applicable to space communications, navigation, and traffic control needs.

B. Optimize the use of the electromagnetic spectrum for communications and navigation satellite systems.

C. Provide fundamental understanding of the space communications and navigation sciences to permit NASA to fulfill its role as space communications and navigation consultant to government and industry.

2. Description

The Com/Nav Research Facility will support three distinct types of activities: (1) experimentation, (2) data processing, and (3) maintenance and troubleshooting.

The proposed experiment program consists of active and passive elements, spanning the range from VHF through optical frequencies.

FPE MS-1 MATERIALS SCIENCE AND MANUFACTURING IN SPACE

Objectives and Description

1. Objectives

The basic objective of the program will be to secure scientific results that will expand our knowledge of physical and chemical processes in materials and provide a sound basis for new process inventions. Some of the latter will no doubt concern new or improved processes for use on the ground, but many are expected to be for processes that work to unique advantage in free fall. These will be developed toward commercial-scale production as the scale of space operations expands, in parallel with an aggressive continuing program of exploratory research. When it appears that one or more new processes can be practiced profitably in space, arrangements will be made for commercial exploitation or, where appropriate, for production under Government auspices.

2. Description

Materials Science and Manufacturing payloads for missions in the post-Skylab period must provide very flexible and general capabilities for research and development work in the MS/MS program's chosen technical areas, because the MS/MS experiment program will be open-ended, evolving from exploratory research in its early phases to product development and pilot production in later years.

The equipment inventory is broken down into four general classes of apparatus:

A. Basic Units, which are large items with an average weight of the order of 100 Kg (220 lb) and an average volume of 1 m^3 (35 ft^3). These include seven large pieces of experimental apparatus and three systems that provide control functions and utilities.

B. Internal Units, which are smaller items of apparatus to be mounted in the large basic units to configure them for specific experiments. Most of the internal units have no unique location and can be used interchangeably in several basic units.

C. External Units, which perform functions simular to those defined for internal units, but which are to be mounted on the outside surfaces of basic units and therefore affect the outline dimensions of equipment configurations.

D. Support Units, which fall in the same size range as the basic units but are used for general supporting functions such as servicing and sample evaluation.

FPE T-1 CONTAMINATION MEASUREMENTS

Objectives and Description

1. Objectives

The objectives of Contamination Measurement Experiments are to:

- **A. Identify the types, quantities, spatial distributions, and effects of contaminants in the spacecraft-induced external environment.**
- **B. Provide operational support to the manned Earth orbital experiment program.**
- **C. Develop the design data needed to control or eliminate contamination effects on future spacecraft and instruments.**

2. Description

The FPE is comprised of a set of measuring instruments and exposure apparatus which are employed to:

- A. Measure the amount of light scattering due to environmental contamination, to identify "good-seeing" conditions, and to provide calibrations for other viewing experiments.
- B. Measure the amount of material deposited on optical components, windows, and thermal control surfaces, and evaluate its effects and identify its composition.
- C. Monitor the composition of the spacecraft's external environment and determine how contaminants move after they are released.
- D. Evaluate techniques devised to remove contamination.
- E. Evaluate contamination control measures.

FPE T-2 FLUID MANAGEMENT

Objectives and Description

1. Objectives

The purpose of these experiments are to obtain parametric information over the entire range of flows, temperatures, acceleration levels, heat transfer rates, etc., for advanced spacecraft fluid systems. Specific objectives include the following under low g conditions:

A. Observe the behavior of fluid interfaces in tanks.
B. Obtain data on fluid boiling and thermal stratification.
C. Investigate the performance of capillary devices.
D. Investigate the fluid dynamics and thermodynamics of condensers.
E. Define characteristics of two-phase flow.
F. Investigate the fluid dynamics and thermodynamics of propellant transfer.
G. Obtain basic fluid dynamics and thermodynamics data on vessels for long-term storage of cryogenic propellants.
H. Determine the thermodynamic behavior of slush propellant in tanks.
I. Investigate bubble characteristics in a nucleate boiling process and two-phase flow in a pipe.
J. Investigate the characteristics of fluid behavior in channel flow systems.
K. Describe the characteristics of liquid buildup and transport on a conical surface due to condensation and the behavior of fluid in a cyclonic separation.

2. Description

Experiment equipment items for Fluid Management range in size from small "carry-on" packages to large cryogenic storage tanks. Interconnecting plumbing will provide flow control between tanks. Pumps and mixers will be used to move and mix fluids as necessary. All of the experiments require sustained acceleration periods at specified levels between 10^{-3} and 10^{-5} g. Some require orientation of flows parallel, across, and counter to gravity.

Measurements include temperatures and pressures with crew observation and film and TV recording.

FPE T-3 EXTRAVEHICULAR ACTIVITY

Objectives and Description

1. Objectives

The goal of this FPE is to provide guidelines for the development of advanced extravehicular systems which will effectively perform the tasks required during manned orbital extravehicular activity (EVA). The FPE includes experimental equipment to supplement manned EVA. The objectives of these experiments are to:

A. Assess and develop man's capability to control and use the maneuvering systems in performing extravehicular tasks.

B. Develop the hardware and procedures required for future extravehicular manipulations.

2. Description

The two experiments included in this FPE are the Astronaut Maneuvering Unit (AMU) and the Maneuverable Work Platform (MWP). The AMU is a backmounted unit containing a life support system and multiple fixed-position cold-gas (O_2) thrusters.

The MWP experiment allows evaluation of a hard-suited astronaut's ability to perform selected tasks such as cargo transport, docking and grappling. The MWP is an open structure, unpressurized, hydrazine-propelled vehicle with variable cargo-bed geometry.

FPE T-5 TELEOPERATION

Objectives and Description

1. Objectives

The objective of this FPE is to evaluate an experimental teleoperator (T/O) system. Such a system would be precursor to an operational system and would provide a means for evaluating teleoperator performance, safety, and suitability for performing various tasks in space.

2. Description

The experimental T/O system consists of a small, free-flying T/O spacecraft and a control station. A two-way RF link provides commands to the T/O spacecraft and feedback information to the control station. Attitude control and translational capability are provided by a cold gas (N_2) system.

The T/O manipulator arms duplicate the motions of a human controller operating the master manipulator at the control station. The control station may be located in a parent spacecraft or in a ground installation.

LIFE SCIENCES

The NASA Life Sciences Program encompasses all of the individual program areas covering:

A. Medical and behavioral questions associated with manning and operating an Earth-orbital research facility or facilities.
B. Development, testing, and incorporation into such facilities of the advanced technology for life support and protective systems.
C. Fundamental biological and biomedical research.

The most effective pursuit of this program depends upon a Life Sciences Space Laboratory consisting of:

A. A matrix of common operations research equipment/facilities (CORE) serving a broad spectrum of experimental areas in several FPE's.
B. Supplemental facilities and instrumentation relating to a smaller number of FPE's or experiments, but which are sufficiently specialized to be removed from CORE.
C. FPE or experiment-peculiar items ancillary to one or both of the preceeding more general categories.

The CORE facility consists of the Visual Records and Microscopy Unit; Data Management Unit; Life Science Experiment Support Unit; Preparation, Preservation and Retrieval Unit; Biochemical/Biophysical Analysis Unit; Maintenance, Repair and Fabrication Unit; and Ancillary Storage. FPE peculiar hardware is listed in the following FPE descriptions.

5.2 MODE OF ACCOMMODATION

This mode of accommodation (MOA) study developes the logic for determining the preferred carriers for the experiment groups. These include:

A. Integral—in general purpose laboratory.

B. Airlock Module—Module with approximately half pressurized volume and half depressurizable volume.

C. Dedicated Module—Attached module dedicated to a single experiment.

D. Free-Flying Module—Module that operates detached from station.

5.2.1 Screening Techniques

The total process for selection of the MOA required two steps. First, the resource requirements for each FPE and experiment subgroup were screened according to selected resource requirement limits as shown in Figure 5-1. Table 5-2 is a summary of the results or the mode of accommodation screening. The primary criteria are those limits that have an effect at the individual experiment level, i.e., the five primary screens shown have the greatest influence on allowable accommodation modes. Emphasis is placed on these and not on the secondary factors that do not determine the MOA but

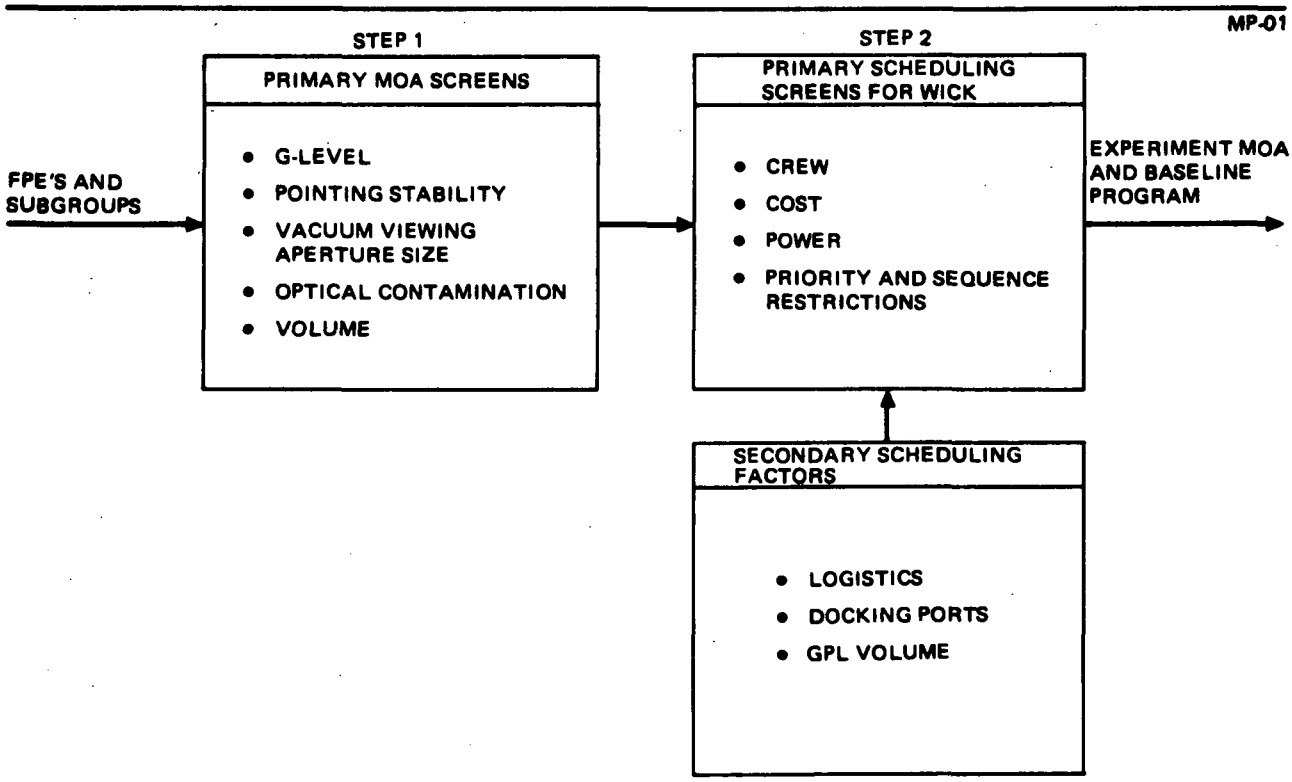


Figure 5-1. Mode of Accommodation and Program Selection Screens

Table 5-2

MODE OF ACCOMMODATION

FPE or Subgroup	Allowable MOA	Primary Determining Factors				Remarks
		Attitude Stability	G-level	Contamination	Size	
A-1	FF	X		X	X	
A-2	FF	X		X	X	
A-2A	FF	X		X	X	FF – Free Flyer
A-3AA	FF	X		X	X	
A-3CC	FF	X		X	X	
A-4A	AM			Clean	X	
A-4B	AM			Clean	X	AM– Attached Module with approximately one-half volume as airlock accommodates more than one experiment group
A-4C	AM			Clean	X	
A-5A	FF			X	X	
A-5B	AM				X	
A-6	AM			Clean	X	
P-1A,B, C,D,E	I			Clean		I – Integral to station or pressured section of AM
P-2BB	AM				X	
P-2A	I					
P-3	AM				X	
P-3C	I					
P-4A,B,C	I					
ES-1	AM			Clean	X	
ES-1AA	AM			Clean	X	
ES-1G	AM			Clean	X	
C/N-1A,B	AM				X	
MS-3A,B, C,D,E	I				X	
T-1A,B	I					
T-2A	FF					
T-2BB	FF		X			
T-3A	I					
T-3B	AM				X	

Table 5-2

MODE OF ACCOMMODATION (Continued)

FPE or Subgroup	Allowable MOA	Primary Determining Factors				Remarks
		Attitude Stability	G-level	Contamination	Size	
T-4C	I	(Partial)				
T-4A, B	I					
T-5	I					
LS-1A	I					
LS-1D	AM				X	
LS-1B, 1C 1D	AM					

only the module subsystems selection and structural design. Final selection of the appropriate mode results from the scheduling analysis and requires a compilation of cumulative resources as a function of the program buildup. This second step is accomplished with the WICK resources allocation program and is covered in Section 2 of this report.

5.2.2 Gravity Level

Acceleration produced by crew motions on the station sets a bound on ambient acceleration levels (gravity level). As the station mass increases with buildup from ISS to GSS, the gravity level decreases from 1.4×10^{-4} to 1.2×10^{-4}g. These screens are shown on Figure 5-2 plotted across the acceleration sensitive experiment requirements. LS-3, the plant research facility, represents greatest divergence from capability with a requirement for less than 10^{-5}g for 90 percent of the time and 10^{-4} g for 10 percent of the time. The P-4B combustion experiments require 10^{-4}g and the Material Science experiments desire 10^{-5}g but will accept 10^{-3}g. Given the alternative of operating in a free-flying module, it is highly unlikely that any of these experiments would accept the option due to increased cost, delayed flight opportunity, and the elimination of manned accessibility. Shock mounting of material science and plant experiments offers a solution to this problem. If required, shock mounting could also be used for the P4B combustion experiments. The acceleration levels set for astronomy are primarily determined by the stringent attitude stability limitations. The astronomy experiments requiring less than 10-4g require free flyers to satisfy other criteria and the attached module astronomy acceleration is within station limits.

The fluid physics experiments require continuous discrete acceleration levels from 10^{-5} to 10^{-3}g for long time periods (approaching 5,000 hr). A free-flying module must be used since it is not practical to accelerate the station.

5.2.3 Pointing and Stability

The station pointing accuracy remains constant through the buildup at 0.25 deg with an 0.1 deg attitude stability once pointed. The stability rate for the ISS configurations is 0.005 deg/sec, decreasing to 0.002 deg/sec for

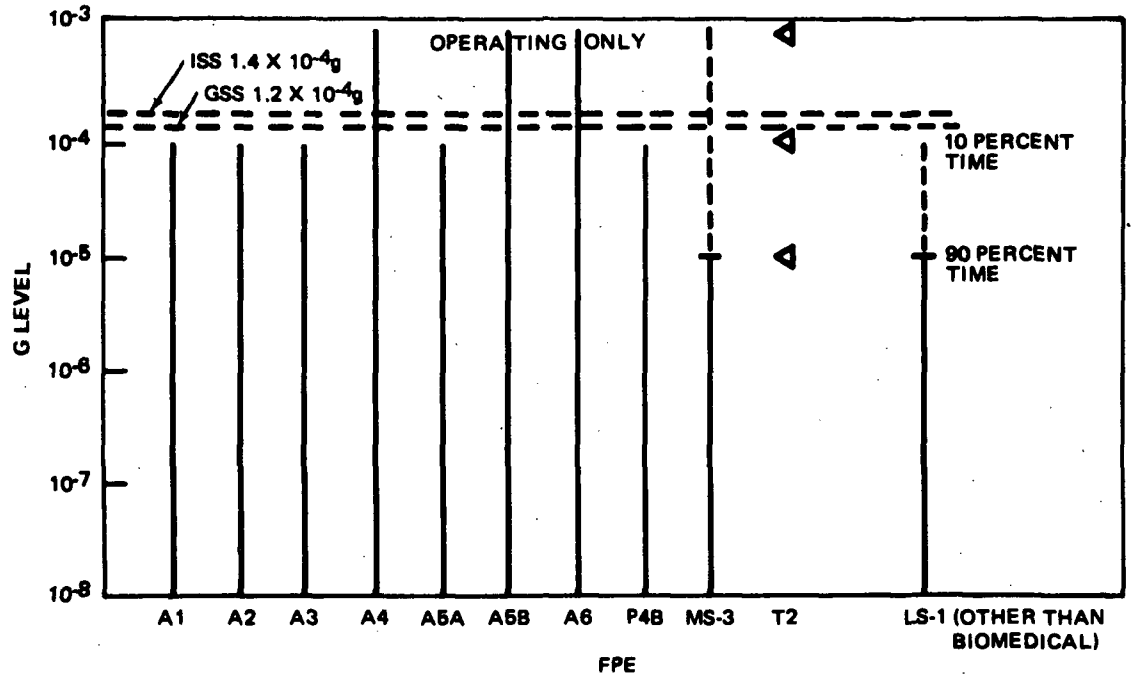


Figure 5-2. Mode of Accommodation – Gravity Level

the GSS. As shown in Figure 5-3, these pointing and stability limits are adequate for all but Astronomy, Com/Nav and the Advanced Guidance System Evaluation that is flown piggyback on the Advanced Stellar Astronomy Module. The UV survey, high energy, and IR astronomy experiments can be pointed from the station if a gimbal system with accuracy 2.5 times better than the Apollo Telescope Mount is available. The Com/Nav experiments also require a gimbal, but one with much less stringent requirements.

The Advanced X-ray, Stellar and Solar experiments have attitude stability requirements that are far in access of state-of-the-art gimbal capability. The use of accurately stabilized free-flying modules is estimated to approach that required for the A-1 and A-3 telescopes.* The addition of a switch mirror in the A-2 telescope with a jitter-removal system should solve the most stringent stability problem if basic module stability proves inadequate. These conclusions can be summarized as follows.

*J. Purcell at NASA, Goddard Space Center, has stated that OAO can achieve at least 0.01 arc second attitude stability.

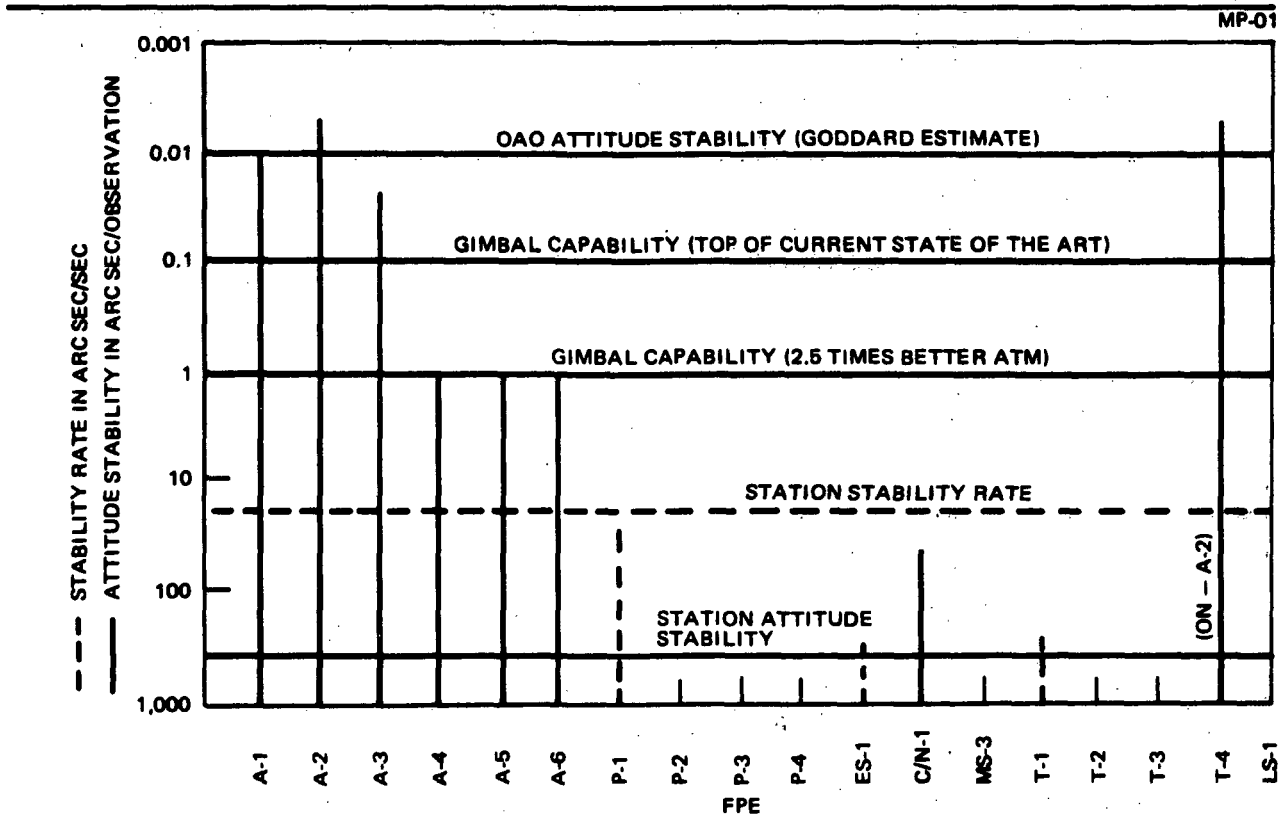


Figure 5-3. Attitude Stability and Stability Rate

Pointing stability—MOA screen conclusions experiments with attitude stability requirements fall into three classes:

A. Within basic station capability
   1. All physics.
   2. Earth observations.
   3. Technology (except for A-2 Module piggyback).

B. Within factor of 2.5 times better than ATM gimbal.
   1. Intermediate UV telescopes, A-4.
   2. High-energy astronomy, A-5.
   3. IR astronomy, A-6.

C. Requiring free flyer
   1. X-ray stellar astronomy, A-1.
   2. Advanced stellar astronomy, A-2.
   3. Advanced solar astronomy, A-3.

5.2.4 Size

A critical experiment envelope parameter is the size of the pressurable compartment doors required for vacuum viewing experiments. Figure 5-4 shows the aperture size for EVA, experiment field of view and deployable gimbal or platform clearance. The maximum diameter of an outward opening door in a module is 4.1 m (13.4 ft) and an inward opening door is 2.65 m (8.7 ft.) The inward opening door is much lighter, less complex and more reliable than the outward opening door. The smaller stellar and IR telescopes, i.e., primary optics, 1 meter or less in diameter can be accommodated with inward opening doors. Several of the technology experiments are too large for scientific airlocks and therefore also use depressurizable chambers with inward opening doors.

The size of the experiment platform required to deploy all of the ES-1 instruments simultaneously requires a dedicated depressurizable module. The sequentially deployed sensor subgroup ES-1AA and the seven-sensor core group can be accommodated in an airlock as can the physics experiments. The integral candidate experiments are those not requiring large depressurizable volumes or very large dedicated facilities. Large experiments requiring a dedicated pressurized module include the cosmic ray physics

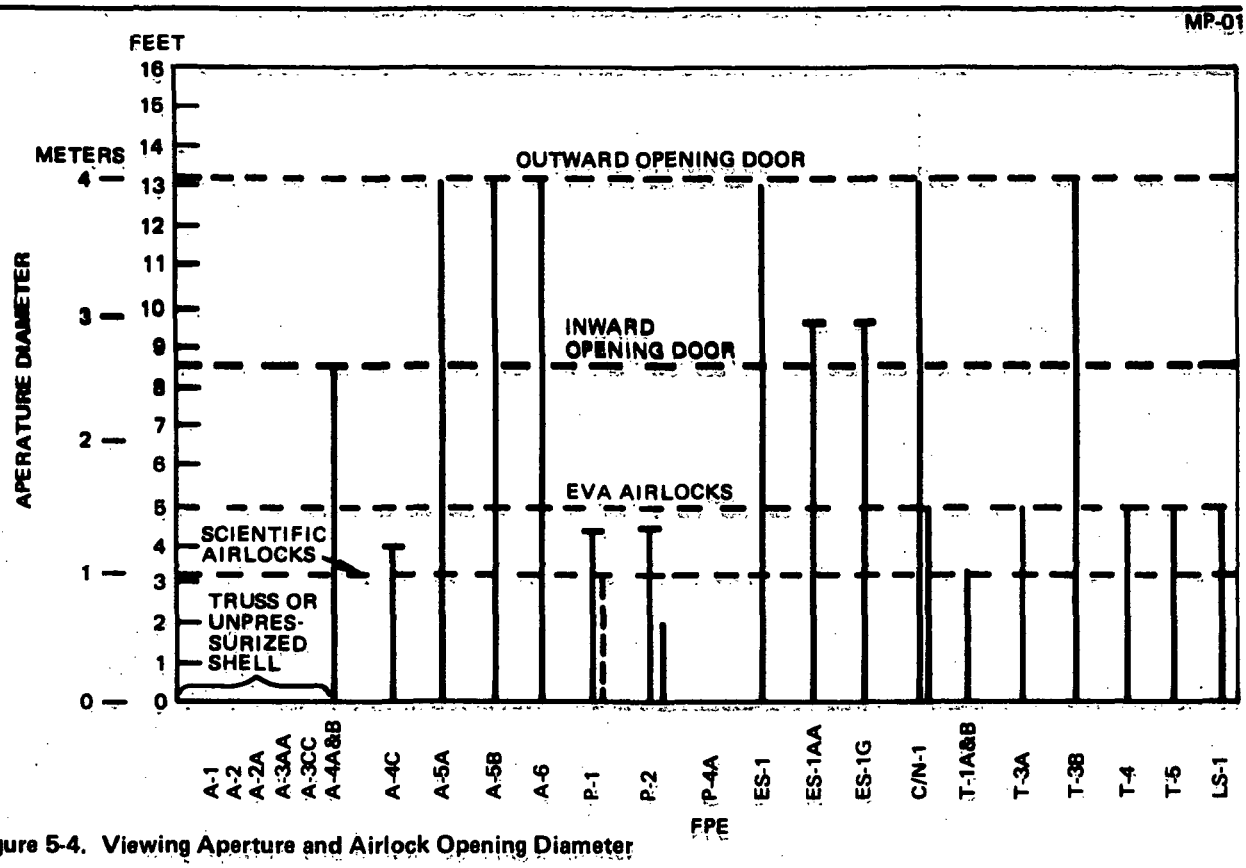


Figure 5-4. Viewing Aperture and Airlock Opening Diameter

laboratory P-3 and the total Life Sciences Facility LS-1D. The Space Station integral volume for experiments and GPL equipment is 168 m (6,010 ft^3) at ISS. This volume allocation is worked as the experiment program is scheduled. The common equipment in the Material Sciences Laboratory is placed in the GPL, the remaining equipment brought up as required. These size-related conclusions are shown below.

Vacuum Viewing Aperture Size - MOA Screen Conclusions

A. Experiments requiring 0.5 to 1 M airlocks
   1. Space physics research lab, P-1.
   2. Plasma physics and environmental perturbation lab, P-2.
   3. Contamination experiment, T-1.

B. Experiments requiring EVA airlocks
   1. Space physics research laboratory, P-1.
   2. Technology experiment T-3, T-4, T-5.

3. Modules with unpressurizable experiment chambers A-1, A-2, A-3.
4. Com/Nav, C/N-1.

C. Experiments using inward opening pressure doors
1. Intermediate size UV-telescopes, A-4A and B.
2. Plasma physics experiments using subsatellite, P-2BB.

D. Experiments using outward opening pressure doors
1. X-ray and gamma ray telescopes A-5A, A-5B.
2. IR astronomy, A-6.
3. Earth observations ES-1, ES-1AA, ES-1G.
4. Com/Nav C/N-1A, C/N-1B

E. Truss or unpressurized shell modules
1. X-ray stellar astronomy, A-1.
2. Advanced stellar astronomy A-2, A-2A.
3. Advanced solar astronomy A-3AA, A-3CC.

Volume - MOA Screen Conclusions

A. Dedicated life science facility, LS-1D and cosmic ray physics laboratory, P3 require pressurized dedicated modules.

B. Earth surveys (total sensor deployment) ES-1 requires depressurizable dedicated module.

C. Volume not a primary consideration in free-flyer selection.

5.2.5 Contamination

Optical contamination effects produce one of the most important screens, however the lack of detailed and definitive on-orbit test data makes any study of contamination controversial. Data from such programs as Skylab, TO-27, previous Space Station studies, and other existing studies have been reviewed and the applicable information on contamination sources, effects and countermeasures compiled.

Conclusions are presented as a function of primary optics size and operating wavelength. As shown in Table 5-3 x-ray imaging instruments have the severe sensitivity to contamination due to the refraction and absorption by very thin contamination layers on grazing incidence optics. At the far

Table 5-3

CONTAMINATION SUSCEPTIBILITY AND COUNTERMEASURES

Instrument Wavelength	Susceptibility to Condensables	Susceptibility to Scattering	Replacement	Active Cleaning	Calibration
X-ray (imaging)	Extreme	Low	Alignment very difficult	Difficult without degrading surfaces	Difficult due to weak sources
Ultraviolet	Absorption high for shorter wavelengths	High	Ok for small optics, if provided in design	Promising concepts (most require vacuum) Slight degradation must be recalibrated	Observe standard stars or built-in sources
Visible	Moderate	High	Ok for small optics	Techniques available (use solvents in pressurized envelope)	Observe standard stars or built-in sources
Infrared	Low (but increased rate with cryogenic mirror)	Low	Ok for small optics	Techniques available (use solvents in pressurized envelope)	Observe standard stars or built-in sources

UV end of the spectrum photoelectric absorption in the region of k edges of low Z contaminants also produces extreme absorption. At wave lengths in near UV and visible spectra the susceptibility to condensables become moderate. At IR wavelengths, the effects are low but the use of cryogenically cooled mirrors greatly increases the sticking coefficient and therefore the contamination buildup rate.

Degradation produced by scattering from the contamination cloud surrounding the station is worst in the UV, visible and IR wavelengths. The cloud exists for at least several orbits after a substantial ECLS dump or RCS dump. The time for dispersal is substantially extended by condensation on cool space station surfaces with subsequent vaporization when reheated by solar radiation.

The most promising countermeasures include replacement, active cleaning, and calibration to take account of changes in reflectivity or transmissibility. Replacement of x-ray grazing incidence optics is difficult due to extreme alignment accuracies required and the absence of strong stellar calibration sources. Replacement of small UV visible and IR optics, i.e., on the order of 3 (1-ft) diameter or less, is feasible if provision is made in the design. Calibration can be supplemented using built-in or standard stellar sources.

Active cleaning techniques for x-ray optics do not appear feasible due to the complexity of structures such as the grazing incidence venetian blind collinator. The x-ray mirror surface finish is unacceptably roughened by active cleaning techniques that are sufficiently vigorous to remove most contaminants. There are several promising active cleaning techniques for UV reflectors; for example, ion bombardment. At visible and IR wavelengths, solvent cleaning procedures can be used if the optics are in pressurizable carriers. The major conclusions of the contamination mode of all-in-datum screen are:

Optical Contamination - MOA Screen

A. Grazing incidence X-ray optics cannot be effectively cleaned. Therefore, the A-1 and A-5B x-ray telescopes require free flyers.

B. Cleaning of large high-resolution telescopes questionable. Therefore A-2 stellar and A-3 solar telescopes also require free flyers.

C. Cleaning techniques promising for smaller optics—intermediate UV and IR telescopes, physics and earth observation optics—attached operation, ok.

Note: The cryogenically cooled IR-telescopes must be warmed prior to cleaning and then recooled, thereby increasing the complexity of the operation and requiring additional refrigeration or liquid nitrogen.

5.3 EXPERIMENT SUPPORT REQUIREMENTS

5.3.1 GPL Support of Subsystems

The general purpose laboratory has been designed so that with common equipment it can meet the subsystem and experiment support requirements. Space Station subsystems have the requirement for on orbit maintenance, part replacement, and contingency repair. To accomplish these on orbit, tasks certain equipment and facilities are required. These facilities and equipment are supplied by the GPL. Table 5-4 is a listing of each subsystem and the support it requires from the GPL. Small tools and instruments are stored in the GPL where they are most likely to be utilized (i.e. small mechanical tools in the Mechanical Sciences Laboratory). Large support units become an integral part of the general-purpose laboratory support equipment. (i.e. brazing facility in Mechanical Sciences Laboratory Box) Section 4.4 of DRL SE-04 (preliminary design or space station subsystems) analyzes in detail the commonality aspects of the GPL support of subsystems. The detailed analyses shows that the same equipment that is required to support subsystems also supports the experiment program.

5.3.2 Logistic Support Requirements

This section presents requirements for Operational Consumables and Spares and Maintenance Consumables. These requirements were derived from analyses of the experiments needs, with consideration for the mission duration and shuttle flight frequency. In addition, estimates of repair and

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS

Subsystem	Operations	Facility	Equipment	Tools
Data Management	Cable/plug repair	Storage in test facility		Wire strippers Flat cable strippers Wire printer Diagonals Long nose pliers Portabin volt-ohmmeters Solder gun Connector/pin tools Terminal crimper Screw drivers Allen wrenches
	Equipment analysis and repair	test facility	Power supplies Oscilloscope Digital multimeter Digital counter Function generator Vacuum/nitrogen source Fluke/null meter Ultrasonic cleaner Micro search terminal Signal sources	
Onboard Checkout	Component removal and replacement	Storage		Circuit card puller Screw driver Standard removal tools (depends on package concepts)

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Onboard and Checkout (Continued)	Cable/plug repair	Storage	Volt-ohmmeter	Wire strippers Flat cable strippers Wire printer Wire cutters Needle-nose pliers Connector/pin tools Crimping tools Screwdriver Allen wrenches
	In-place equipment analysis and fault isolation	Electrical/ electronics laboratory	Same as below	Circuit card extender/ puller Test leads Breakout box
	Bench-level equipment analysis	(multiinstrument test bench)	Multichannel oscilloscope Volt-ohmmeter Multifunction signal generator Power supplies Electronic counter Oscilloscope camera	Circuit tap plug Screwdriver Test leads Alligator clips Pliers Holding device Mallet Magnifier
S/AC	Sensor replacement[1]	Deploy/retract pressurizable compartment	Volt-ohmmeter Oscilloscopes Power supplies	Standard

1 Includes the following sensors: Horizon sensor, gyros,

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
S/AC	Electronics module replacement[2]	Electronics test laboratory	Oscilloscope, signal generator, etc.	Standard
S/AC	CMG replacement	NA	Mechanics tools	Standard
S/AC	CMG repair	NA	Mechanics tools, bearing puller	Standard
G/N	Sensor replacement[3]	Deploy/retract pressurizable compartment	Volt-ohmmeter Oscilloscopes Power supplies	Standard
G/N	Electronics module replacement[4]	Electronics test laboratory	Oscilloscope, signal generator, other	Standard
Electrical Power Solar Array and Orientation	Replacement of solar panels (feasibility TBD - requires EVA)	Storage	Special handling tools to transport panels	Wrenches Torque wrench

2 Includes the following electronic assemblies: sensor interface electronics, CMG electronics, control electronics and jet drivers, power conditioners.

3 Includes the following sensors: star trackers, star sensors, rendezvous radars.

4 Includes the following electronic assemblies: Sensor interface electronics.

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Electrical Power Solar Array and Orientation (Continued)	Replacement of motors, bearings and dynamic seals, pumps	Storage	Special puller for exposing bearings and seals	Wrenches Torque wrench
Energy Storage	Replacement of battery modules	Storage		
T/C/D and Control	Connect/disconnect electrical umbilicals	None		Special electrical disconnect tool
	Replacement of black boxes, inverters, battery chargers, battery load regulators, and shunt regulators	Storage		Screw drivers Torque wrench Electrical disconnect tool Plug pin tools
Subassemblies-Components	Switches Circuit Breakers Limiters Relays Motors Instruments Sensors Lights Circuit cards Brushes Cable Battery modules	Magnifier Circuit card vise Clean box Storage Test facility	Oscilloscope VTVM Load box Tachometer meters Circuit card tester	Allen wrenches Screw drivers Inspect mirror Nylon gloves Torque wrench Side cutters Solder gun Continuity test light Circuit card puller Plug pin tools

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Communications	Normal maintenance and replacement			Connector pliers Mounting rack tool Other small hand tools*
	Replacement of coaxial cables, connectors	Communications equipment test facility	Signal generators, oscilloscope, spectrum analyzer, multimeter, power meter	
Propulsion Checkout Leak check Valves/ bellows Connections		Gas supply	Gas bottle Hand valves Pressure gauges Bubble soap solutions	Miscellaneous hand tools
Subsystem	Visual display (P;T)			
Functional Valve control Sequence checks	Propellant control panel Visual display (P_1 events)			

* Tools chosen for data management may also be used for emergency repairs at lower levels.

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Checkout (Continued) Instrumentation Calibration		Instrument calibration and functional check	Gas supply Pressure gage Temperature sensors Voltammeter/current tester Ohmmeter	Miscellaneous electrical and mechanical hand tools
Electrical Continuity Function Resistance Check		Component test areas	Gas supply Pressure gages Hand valves Voltammeter/Current traces Ohmmeter	Miscellaneous electrical and mechanical hand tools
Regulator	Strip charts (P)			
Response Thruster Valves	Strip charts (Volts) Strip chart (events)	Contingent test area	Gas supply Pressure gages Hand valves Voltammeter/Current traces Event recorder	Miscellaneous electrical and mechanical hand tools
Heaters Resistance Functions	Strip chart (temperature)	Component test area	Temperature control box Temperature sensors Ohmmeter Voltammeter/Current traces	Miscellaneous electrical hand tools

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Replacement Components/ inst Tankage (load or unload) Thrustor modules Umbilicals Instrumentation		Space storage Cleaning (liquid) Hazard Storage Cleaning (liquid) Cleaning (liquid) as noted above	 Handling dolly/ fixture Handling fixture 	Miscellaneous hand tools EVA tethers Hand tools Hand tools PLSS PSA
Cleaning/ decontamination		Purge gas	Built-in capability	Hand tools
Line repair		Argon purge gas cooling water cleaning (liquid)	Brazing equipment Tube benders	Braze heads Tube cutters/deburrers
Propellant Check NO, FE, H_2O particle content		Propellant laboratory	Propellant sampler (bottle and valves) Filters Laboratory equipment	Hand tools
EC/LS	Component replacement of valves fans pumps compressor connectors	Storage bin	Conventional portable checkout equipment, such as volt-ohmmeter oscilloscope electronic counter	Conventional hand tools modified for zero-gravity use, tubing wrenches screw drivers pliers allen wrenches

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
	sensors heaters filters canister electronic control separator motor hoses		Special portable plug-in equipment, such as flow meter temperature meter pressure sensor Portable leak detector Plumbing repair equipment (contingency) tube cutters tube flare, etc. (same as propulsion)	
	Module replacement of Heat exchanger subassembly tank subassembly membrane module			
	Radiator repair		Brazing (contingency)	Wrenches

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Housekeeping Equipment	Replace Repair Adjust	GPL	Pneumatic system leak detector	Continuity test light Phillips screwdrivers (3- and 6-inch)
Recreation equipment	Repair Adjust	GPL	None	Allen wrench, size to be determined
Radiation and meteoroid Detection equipment	Repair Adjust	None	Calibration instrument	Circuit card tester Circuit card puller Continuity test light
Maintenance equipment	None	None	None	None
Food and food management equipment	Repair Replace Adjust Sensors, elec. unit	None		Repair kit contents
Religious worship provisions	Repair	None	None	
Emergency equipment	None	None	None	Special emergency equipment repair kit
EVA support equipment		None	None	Special EVA repair kit

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Pressure suit assembly support equipment	PSA monitor panel	None	None	Special PSA repair kit
Damage control and safety	None	None	None	Hole plug kit
Medical equipment	None	None	None	Special medical equipment repair kit
Mechanical	Maintenance of mechanical systems; i.e., gimbal rollers, hydraulic systems, elevators, and cargo-handling devices	Tool-storage areas, mechanical assembly/ disassembly areas	Holding fixtures	Wrenches
	Docking shock struts; door mechanisms, door seals, window seals			Torque wrenches, allen wrenches Glove box
Personal equipment	Repair	GPL	None	Circuit card tester Soldering gun Soldering needle Continuity test light

Table 5-4

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Restraint Equipment	Replace/repair restraint locking clamping device and fabrics	GPL	None	Allen wrench (size to be determined) Fabric mending kit (contents to be determined)
Exercise Equipment	Repair of mechanical linkage-cables, electrical alternator load control	None	Volt-ohmmeter	Socket set with 3/8 drive, and 3/8, 7/16, 1/2, 9/16, Sockets Same as personal equipment
Hygiene Equipment	Adjust Repair	GPL		Same as personal equipment Allen wrench, 5/32 Phillips screwdrivers, (3- and 6-inch) B-nut wrench, to be determined

replacement needs were made, depending on the type of equipment and duration of operations. Figure 5-5 is a brief flow diagram of the Shuttle/Space Station logistics operations. Table 5-5 lists the logistic requirements of the Space Station candidate experiments.

Information shown in the columns is as follows:

Operational Consumables Type—Identifies the commodity or item that must be provided for each experiment.

Initial Weight and Volume—Indicates the amounts of expendables that must be launched on the flight that initiates the experiment. Expendables packaged with experiment equipment and included with experiment weights and volumes are excluded from these requirements.

Resupply Weight and Volume—Indicates the amounts of expendables that must be provided each 30 days to support the continued performance of the experiment.

Return Weight and Volumes—Includes data tapes, specimens, etc., as well as expended equipment to be returned to ground for analysis, corrective action, and disposition.

Spares and Maintenance Consumables Initial Weight and Volume—Includes the amounts of these expendables that must be launched on the flight that initiates the experiment.

Resupply Weight and Volume—Shows the spares and maintenance items estimated to be required each 30 days to support the continued performance of the experiment.

Return Weight and Volume—Shows the spares and maintenance items that will be returned each 30 days during performance of the experiment.

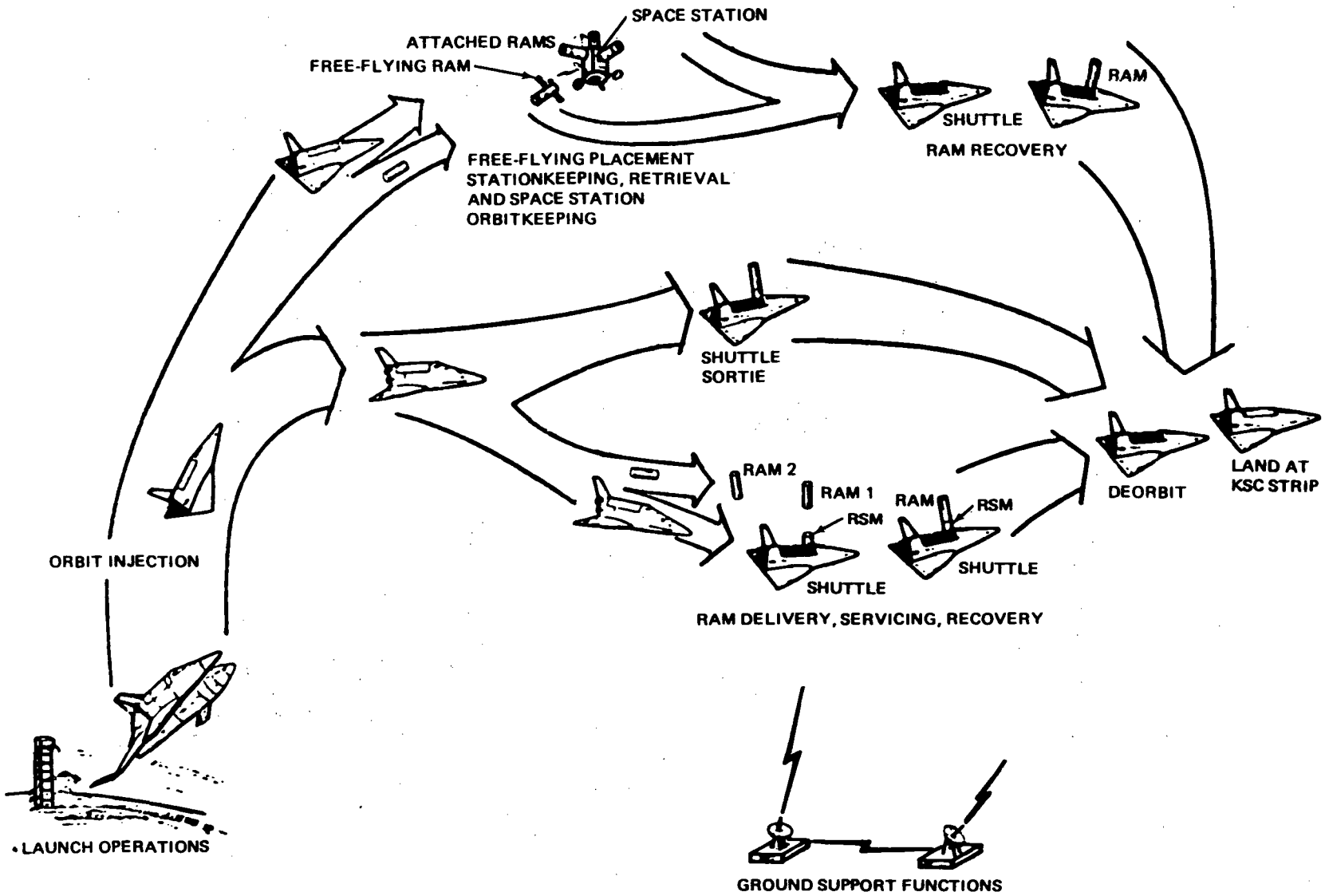


Figure 5-5. Logistics Support Requirements

Table 5-5

LOGISTIC SUPPORT REQUIREMENTS

FPE / Requirements	Type	Operational Consumables						Spares and Maintenance Consumables						Remarks
		Initial		Resupply (30 Days)		Return (30 Days)		Initial		Resupply (30 Days)		Return (30 Days)		
		Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	
A1 X-Ray Astronomy														
High res telescope	None	0	0	0	0	0	0	25.2 (56)	0.06 (2)	12.6 (28)	0.03 (1)	12.6 (28)	0.03 (1)	
Large area telescope	Cryogenic	20 (44)	0.03 (1)	3.3 (7.3)	0.005 (0.14)	0	0	22.2 (48.8)	0.06 (2)	11.1 (24.4)	0.03 (1)	11.1 (24.4)	0.03 (1)	
Supplementary experiments	None	0	0	0	0	0	0	0	0	0	0			
A2 Advanced stellar astronomy	Film	37 (81)	0.06 (2)	37 (81)	0.06 (2)	37 (81)	0.06 (2)	2.3 (5)	0.01 (0.3)	2.3 (5)	0.01 (0.3)	2.3 (5)	0.01 (0.3)	Update of exp will require about 306 kg (675 lb); 1.3 m^3 (26.3 ft^3) per year
A3 Advanced Solar Astronomy														Note: Operational consumables listed are to support a film system, if used.
1.5M photoheliograph		76 (167)	0.12 (4.1)	76 (167)	0.12 (4.1)	76 (167)	0.12 (4.1)	12.5 (27.5)	0.02 (0.67)	12.5 (27.5)	0.02 (0.67)	12.5 (27.5)	0.02 (0.67)	
XUV spectroheliograph		15.3 (34)	0.03 (1)	15.3 (34)	0.03 (1)	15.3 (34)	0.03 (1)	6.7 (14.7)	0.01 (0.33)	6.7 (14.7)	0.01 (0.33)	6.7 (14.7)	0.01 (0.33)	
X-ray grazing incidence		2.5 (6.6)	0.006 (0.02)	2.5 (6.6)	0.006 (0.02)	2.5 (6.6)	0.006 (0.02)	7.5 (16.5)	0.01 (0.35)	7.5 (16.5)	0.01 (0.35)	7.5 (16.5)	0.01 (0.35)	
Solar coronagraph		10.7 (23.3)	0.02 (0.5)	10.7 (23.3)	0.02 (0.5)	10.7 (23.3)	0.02 (0.5)	3.3 (8.2)	0.005 (0.17)	3.3 (8.2)	0.005 (0.17)	3.3 (8.2)	0.005 (0.17)	
A4 Intermediate Size UV Telescopes														
0.94m narrow field	355mm film	33.6 (74)	0.057 (2.0) 600 ft reel	5.7 (12.3)	0.017 (0.6) 600 ft reel	5.7 (12.3)	0.017 (0.6) 600 ft reel	----	----	----	----	----	----	
0.3m wide field	150mm film	33.6 (74)	0.057 (2.0)	9.1 (20)	0.017 (0.6)	9.1 (20)	0.017 (0.6)	----	----	----	----	----	----	
A6 Infrared Astronomy														
MSS	Cryogenics L Ne	273 (600)	0.23 (8)	45.5 (100)	0.04 (1.4)	----	----	0 0	0 0	0 0	0 0	0 0	0 0	
	L He	227 (500)	1.53 (54)	38 (83.4)	0.25 (8.8)	----	----	0 0	0 0	0 0	0 0	0 0	0 0	

Table 5-5

LOGISTIC SUPPORT REQUIREMENTS (Continued)

Requirements / FPE	Type	Operational Consumables						Spares and Maintenance Consumables						Remarks
		Initial		Resupply (30 Days)		Return (30 Days)		Initial		Resupply (30 Days)		Return (30 Days)		
		Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	
P1 Space Physics Research Laboratory		*13.5 (29.8)*	*0.13 (4.6)*	*8.03 (17.9)*	*0.07 (2.6)*	*8.03 (17.9)*	*0.07 (2.6)*	*19.53 (44.6)*	*0.18 (2.6)*	*9.82 (23.3)*	*0.09 (3.16)*	*8.8 (19.3)*	*0.06 (2.16)*	
P2 Plasma Physics and Environmental Perturbation Laboratory	Polaroid film Balloons Batteries Subsat fuel	881 (1,937)	0.64 (22.5)	516 (1,135)	0.53 (18.9)	207 (455)	0.53 (18.5)	37 (81)	0.05 (2.0)	19 (41)	0.02 (1.0)	19 (41)	0.02 (1.0)	Polaroid film weight 17 lb. Magnetic tape for data recording determined separately as part of data management study
P3 Cosmic Ray Physics Laboratory	Argon/ methan for spark chambers, nuclear emulsions and magnet/ dewar	66 (146)	1 (35.2)	186 (410)	1.2 (40.5)	151 (333)	1.2 (40.5)	273 (600)	0.57 (20)	60 (150)	0.14 (5)	68 (150)	0.14 (5)	
		Emulsions and magnet/dewar included in exp launch weight		Magnet/dewar, once per year 1,360 (3,000)	5.6 (197)	680 (1,500)	5.6 (97)							
P4 Physics and Chemistry Laboratory	Film, mag tape, etc., gas, fuels, oxidant	225 (500)	0.364 (13.0)	112 (250)	0.364 (13.0)	45 (100)	0.028 (1)	37.6 (83.0)	0.227 (8.1)	18.8 (41.5)	0.114 (4.1)	18.8 (41.5)	0.114 (4.1)	
ES1 Earth Observation Faility	Mag tape, film	197 (437)	0.31 (10.1)	197 (437)	0.31 (10.1)	197 (437)	0.31 (10.1)	368 (820)	0.57 (20.5)	368 (820)	0.57 (20.5)	368 (820)	0.57 (20.5)	
5 Day shuttle	*Not a payload for a five-day shuttle (see subgroup requirements)*													
C/N1 Com/Nav	Film Mag tape Re-entry vehicles*	28.6	0.03	28.6	0.03	28.6	0.03	30	0.21	15	0.11	15	0.11	Host vehicle supplied*
MS1 Materials Science and Manufacturing in Space	Experiment materials	650 *(1,432.2)*	0.16 *(19.95)*	650 *(1,432.2)*	0.16 *(19.45)*	412 *(906.4)*	0.22 *(7.72)*	393 *(865)*	2.41 *(86.3)*	314 *(692)*	1.94 *(69.2)*	157 *(346)*	0.97 *(34.6)*	

Table 5-5

LOGISTIC SUPPORT REQUIREMENTS (Continued)

FPE / Requirements	Type	Operational Consumables						Spares and Maintenance Consumables						Remarks
		Initial		Resupply (30 Days)		Return (30 Days)		Initial		Resupply (30 Days)		Return (30 Days)		
		Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	Weight kg (lb)	Volume m^3 (ft^3)	
T1 Contamination Measurements	Film	1.8 (4)	0.011 (0.4)	0.9 (2)	0.006 (0.2)	0.9 (2)	0.006 (0.2)	7.7 (17)	0.044 (1.6)	3.8 (8.5)	0.022 (0.8)	3.8 (8.5)	0.022 (0.8)	
	N_2	4.5 (10)	0.018 (0.64)	2.27 (5)	0.009 (0.32)	0	0							
	Samples (optical and	0	0	1.8 (4)	0.02 (0.8)	1.8 (4)	0.02 (0.8)							
T2 Fluid Management Station	Liquid hydrogen	0	0	450 (985)	11 (391)	0	0	54.7 (132.5)	0.046 (1.55)	10.2 (27)	0.007 (0.25)	54.7 (132.5)	0.046 (1.55)	Spares and electronic and mechanical parts
T3 EVA Logistics Spares		493 (1,084)	0.44 (15.8)	462 (1,015)	0.44 (15.1)	23.2 (51)	0.006 (0.2)	97 (213.6)	0.62 (22.3)	31.5 (69.3)	0.12 (4.4)	31.5 (69.3)	0.12 (4.4)	
T4 Advanced Spacecraft Systems Tests	ACS fuel	0	0	75 (165)	0.08 (3)	0	0	30 (65)	0.045 (1.6)	15 (32.5)	0.022 (0.8)	15 (32.5)	0.022 (0.8)	Spares and electronic and mechanical parts
T5 Teleoperation		137 (307)	4.14 (148)	30 (67)	0.45 (16)	0	0	52 (116)	0.33 (11.9)	13.6 (30)	0.09 (3.1)	39.1 (86)	0.25 (8.8)	
Life Sciences	Gas, food, charts, containers, samples	30 (64)	0.1 (3.5)	30.0 (3.0)	0.1 (3.0)	1.0 (22.0)	0.06 (2.2)	100 (220)	0.3 (12.0)	25 (55)	0.05 (2.5)	3 (150)	0.02 (0.75)	

5.3.3 Space Station Experiment Capability

The resources provided by the Space Station to support experiment programs are:

A. Power level of 4.8kw at 115 vdc is provided for experiments and experiment support with growth to 8.5kw.

B. A scientific complement of 4.75 men (average) with growth to 9.5 men (average).

C. Color TV, high resolution black-and-white TV, high bit-rate digital data (approx. 10^9 bps), analog data, high resolution film (black-and-white, color, infrared, ultravioled).

D. The ability to transmit digital, analog and TV data in real time to Earth.

E. Payloads up to a five-to-dia sphere and up to 2,000-lb initial weight with growth capability to 8,000 lb.

F. Three initial attached applications modules with growth to eight.

G. All orientation capability (i.e., Earth-oriented, inertial, solar, gravity gradient, etc.)

H. An attitude hold capability of ±0.02 deg in the Earth-oriented mode and ±0.05 deg in the inertial mode.

I. A stabilization rate of ±0.001 deg/sec.

J. A gravity level down to 4×10^{-5}g (quiescent) to 1×10^{-4}g (crew movement).

These were determined to be adequate for a general experiment program. The specific support required is a function of the specific experiment program flown.

The individual experiment support requirements are presented in Section 5.4.

5.3.4 Special Design Features

Some special features are provided to accommodate the Space Station experiment program. These features are primarily designed into the general-purpose laboratory and are required to perform the candidate experiments. Table 5-6 is a listing of these special design provisions required by the experiments and accommodated in the individual laboratories and facilities.

Table 5-6

SPECIAL DESIGN FEATURES

Facility	Requirements	Major Interfaces	Remarks
Hard Data Process Facility	Fluid Tight Equipment Filter System Light Tight Closure	Water System, ECLS, Power	
Electronics/ Electrical Laboratory	Power to Electronic Equipment, High Voltage and Power Safety	Power	
Mechanical Laboratory	X-Ray Safety, Cleaning and Purging, Glove Box Mechanical Assembly/Disassembly, Metals Testing, Storage Space for FPE Equipment	Power, ECLS, Waste Management	Experiment and Test Isolation Facility in Mechanical Laboratory
Experiment and Test Isolation Facility	Isolation for Pressurized Gases, Fluids and Cryogenics. Air-lock with Heat Exchanger, Hydraulic/Pneumatic Test Bench, must take reverse pressure	ECLS, Power	Remove Detection for Environment Required
Optics Facility	Light Closure, Storage Space for FPE Equipment, Heat Exchanger for High Energy Light Sources. Rigid Optical Flat and Optical Bench	Power Filter	Airlock and Viewport in Facility

Table 5-6

SPECIAL DESIGN FEATURES (Continued)

Facility	Requirements	Major Interfaces	Remarks
Airlock Facilities	Airlocks with Deployment Mechanisms. Viewing Ports into Airlock, for Airlock to look outside Station. Heat Exchanger on Airlock in Experiment and Test Isolation Facility. Remote monitoring and Control of Airlock in Experiment and Test Isolation Facility	Power, ECLS	Airlock in Experiment and Test Isolation Facility. Airlock in Optics Facility
Data Evaluation Facility	Fluid Tight Equipment, Filter System, Light Closure	Data Management, ECLS, Power	

5.4 SPACE STATION EXPERIMENT INTERFACE DEFINITION

This section provides definition of the general requirements of the experiment to Space Station interface outlined below.

A. Power
B. Communications and Data Management
C. Atmosphere Control
D. Orbit, Attitude Control and Stability
E. Crew Skills and Manpower

The data includes both module and experiment data. The basic experiment data is based on the Experiment Requirements Summary (Green Book) an appendix of this report.

5.4.1 Integral Experiment Interfaces

5.4.1.1 Electrical Power

The Space Station provides 115 ± 3 vdc to all experiments with an average power of 4.8 kw at ISS with a growth capability to 12.1 kw. The experiment power requirements are listed in Table 5-7.

5.4.1.2 Communications and Data Management

The communications requirements for integral experiments are covered in Table 5-8 under the Disposition of Data column.

Experiment data acquisition and management requirements are given in the first two columns of Table 5-8 under Data Acquisition and Operation.

5.4.1.3 Environmental Control and Life Support

The operating environmental control and life support requirements for experiments are tabulated in Table 5-9.

5.4.1.4 Orbit, Attitdue Control and GNC Requirements

Table 5-10 contains the experiment guidance, navigation and control requirements. The definitions of each column heading are as follows.

Table 5-7

POWER REQUIREMENTS

FPE / Requirements	Average Operation Power Each (Watts)	Operation Duration or Duty Cycle (Hours/Day)	Daily Average Power Per Number Days Per Cycle (Watts)	Peak Power (Watts)	Peak Duration or Duty Cyc E (Watts)	Remarks
A1 X-Ray Astronomy						
Hi-Res Telescope	172	3.24/9.5	105 w/day	254	sec	Daily average include 72 watts when in standby
Large Area Telescope	220.9	9.5/9.5	220.9 w/day	223.9	sec	Example average power calc: $\frac{3.24\,(172) + 6.26\,(72)}{9.5} = 105$ w
Supplementary Experiments	88.1	9.5/9.5	88.1 w/day	88.1	Continuous	
A2 Advanced Stellar Astronomy						
3 Meter Telescope	1. 1,465 2. 1,285 3. 1,265 4. 1,765 5. 1,317 6. 1,350 7. 1,465	1. 0.9 2. 0.7 3. 4.0 4. 4.0 5. 4.6 6. 0.7 7. 9.1	Average is 1445 watts for 24 hr each day	1. 1,950 2. 1,446 3. 1,295 4. 1,765 5. 1,325 6. 1,350 7. 1,465	1 + 6 min 7 - 9.1 hr	The daily average of 1385 w considers one sequence of 14.9 hours plus standby for 9.1 hours. Numbers 1 to 7 refer to experiments.
A3 Advanced Solar Astronomy						
1.5 M Photoheliograph	215 Operate 175 Standby	54 min/90 min 36 min/90 min	199 Avg/orbit	245	20 sec	
XUV Spectroheliograph	55 Operate 70 Standby	54 min/90 min 36 Min/90 min	61 Avg/orbit	70	36 min	Exp operate continuously (16 orbits dwg)
X-Ray Crazing Incidence	450 Operate 260 Standby	54 min/90 min 36 min/90 min	384 Avg/orbit	595	2 min	
Solar Coronagraph	60 Operate 35 Standby	54 min/90 min 36 min/90 min	50 Avg/orbit	60	Continuous	
A4 Intermediate Size UV Telescopes						
0.94 M Narrow Field	141 266 300	20 percent 70 percent 10 percent	28.2 186.2 244.4 30	300.0	10%/day	
0.30 M Wide Field	120 320 325	10 percent 85 percent 5 percent	12 272 300.3 16.3	325.0	5%/day	
A5 High-Energy Stellar Astronomy						
All Seven Experiments	300	23.75 (98.967.)	297	482	0.25 hr/24 hr (1.04 percent)	
A6 Infrared Astronomy						
Station	254 (300 w/50 min) (200 w/42 min)	24	254	300	13.2 hr (55 percent)	
P1 Space Physics Research Laboratory	477w	24	477 w	4 kw	17 min/event 10 times/yr	

Table 5-7

POWER REQUIREMENTS (Continued)

FPE / Requirements	Average Operation Power Each (Watts)	Operation Duration or Duty Cycle (Hours/Day)	Daily Average Power Per Number Days Per Cycle (Watts)	Peak Power (Watts)	Peak Duration or Duty Cyc E (Watts)	Remarks
P2 Plasma Physics and Environmental Perturbation Laboratory Station			55W - 372W 215 W Averaged Over 10 days	789	1.7 percent max	
P3 Cosmic Ray Physics Laboratory Station	690 160 (Magnet)	Continuous 1 Day/Week	713 Continuous	850	1 day/week	
P4 Physics and Chemistry Lab	220	10	92 w/21 days per mo	2,615	0.17	30 Day cycle
ES1 Earth Observation Facility	6,572	7.1	1,940, 7 days	8,227	1.0	-
C/N1 Comm/Nav	944	1.0	51W/365/1 Yr 40/day (3 mo)	1,945	1 hr/ occurrence	
MS1 Materials Science and Manufacturing in Space	44.47 KW	See Subgroup Requirements		94.65 kw	See Subgroup Requirements	
T1 Contamination Measurements	225 W (worst case)	4 hr/mo	81/day over 30-day period	400	5 sec/hr	Daily average is average of all experiments and is not based on worst case shown in average operation power and operation duration.
T2 Fluid Management	1,327 w 750 w	6 Continuous	332 - 2 days	4,000 w	6 hr	-
T3 EVA (Worst Case)	330	9 hr/3 days	122 every 3 days	400	9 hr/3 days	
T4 Advanced Spacecraft Systems Tests	1,140 w	Continuous	190	4,100	100 hr	
T5 Teleoperation (Worst Case) All Missions	300	3 hr/3 days	73 3 days	300	3 hr/3 days	
Life Sciences Station (Dedicated Life Science Module) *(Include Reduced Facilities for* LS-1 Through LS-7)	4,257	9	4,257	8,540	8 hr	Power requirements are dependent on experiment selection. Typical values are given.

Table 5-8

EXPERIMENT DATA REQUIREMENTS

FPE	Requirements	Data Acquisition: Measurement Source	Data Acquisition: Output Form (D.A. Film)	Data Acquisition: Data Rate (bps, Hz)	Operation: Duration (Min)	Operation: No. Of Operations Per Day	Operation: Daily Total (Bit kHz, Frame)	Disposition of Data (Approx Percent): Real-Time Transmit (%)	Disposition of Data (Approx Percent): One Orbit Dump (%)	Disposition of Data (Approx Percent): 1 to 7 Days Return (%)	Disposition of Data (Approx Percent): Shuttle Return	Disposition of Data (Approx Percent): On-Orbit Display	Remarks
A1	X-Ray astronomy												
	Hi res telescope	Sec Vidicon (Prim)	D	2.5×10^4 1.1×10^4	100 100	2.52	5.44×10^8	0	0	0	100	1	Used for target verification
	Large area telescope	Sec Vidicon (Prim)	D	5.4×10^3	400	2.52	3.24×10^8	0	0	0	100	100	
	Supplementary experiments	Exp	D	6.7×10^3	continuous	continuous	5.8×10^8	0	0		100	1	
A2	Advanced stellar astronomy	Imaging data	D	7×10^6 bits/ image	5 image/ operation	2	70×10^6	100				100	Data needed for focus, assignment and target acquisition
	3 Meter telescope		D	1.12×10^8 bits/ image	1 image/ operation	2 2	2.24×10^8 7×10^6	10			90	10	Approx 10 percent of data would be required real time by control crew
			D	7×10^5 bits/ image	5 image/ operation			10			90	10	
		Nonimaging hskp and scien	D	2×10^3 bps	continuous	2	1.73×10^8	5			95	5	
A3	Advanced solar astronomy												
	1.5 M photoheliograph focus and alignment	Vidicon	A	2.9 MHz	15	16	2.9 MHz (4 hr)	100			100	100	Need real time for focus and alignment
	Obs location	Vidicon	A	2.9 MHz	2	16	2.9 MHz (32 min)	100			100	100	
	Echelle	Vidicons	D	3.85×10^9 bits per data set	10 sec per data set	32	1.23×10^{11} bits		10		100		Need for periodic verification
	H- ; WL, UV	Vidicons	A	3.9 MHz	4 sec	160	3.9 MHz		10		100		
	Magnetograph	Processor	D	1.34×10^8 bits per data set	10 sec	32	(40 sec) 14.3×10^9 bits				(100		
	Totals	Vidicon	A	2.9 MHz	17	16	2.9 MHz (272 min)	100			100	100	Data rates are based on limited operation of experiment instruments (20 sec operation/orbit)
		Vidicon	A	3.9 MHz	40 sec	16	3.9 MHz (640 sec)		10		100	100	
			D	4.0×10^9	20 sec	16	1.27×10^{11}		10		100		

Table 5-8

EXPERIMENT DATA REQUIREMENTS (Continued)

FPE	Requirements	Data Acquisition			Operation			Disposition of Data (Approx Percent)					Remarks
		Measurement Source	Output Form (D, A, Film)	Data Rate (bps, Hz)	Duration (Min)	No. of Operations Per Day	Daily Total (Bit kHz, Frame)	Real-Time Transmit (%)	One Orbit Dump (%)	1 to 7 Days Return (%)	Shuttle Return	On-Orbit Display	
A3	XUV Spectroheliograph	Vidicon	D	1.75×10^8 bits/data set	2 sec	160	2.8×10^{10}				100		Data rates are based on limited operation of experiment instruments (20 sec operation/orbit)
	X-Ray grazing incidence	Vidicon	D	1.93×10^7 bits/data set	2 sec	160	3.1×10^9				100		
			D	10×10^3 bps	40 sec	16	0.64×10^6				100		
	Housekeeping and other data		D	8.2×10^3 bps	continuous	continuous	7.1×10^7				100		
	Solar coronagraph	Vidicon	D	3.23×10^7 bits/data set		160	5.16×10^9				100		
	Advanced solar astronomy (total FPE)	Vidicons	A	2.9 MHz	17	16	2.9 MHz (272 min)	100			100	100	
		Vidicons	A	3.9 MHz	4 sec	160	3.9 MHz (640 sec)		10		100		
		Vidicons (Prim)		4.23×10^4	see above		1.63×10^{11}				100		
A4	Intermediate size UV telescopes 0.94 M Narrow field	Electronic imaging camera	D	54	2.5	72	5.7×10^8			100		5	Data handling and storage performed on supporting vehicle (2.5×10^8 bits)
		TV monitor	D (A)	8×10^6 (400 kHz)	6 min	16	46×10^9 (400)	100 96 min				100	1 to 7 days return desired, shuttle return acceptable
		Film camera	Film	6F/45 min	90 min	16	96 frames				100	5	
		Nonimaging data	D	2.2 K	400	1.8	0.95×10^8	10		100		10	
	0.3 M Wide field	Electronic imaging camera	D	2.8×10^6	40 sec	9.5	10.7×10^8			100		5	Data handling and storage performed on supporting vehicle (2.5×10^8 bits)

Table 5-8

EXPERIMENT DATA REQUIREMENTS (Continued)

FPE	Requirements	Data Acquisition: Measurement Source	Output Form (D, A, Film)	Data Rate (bps, Hz)	Operation: Duration (Min)	No. Of Operations Per Day	Daily Total (Bit kHz, Frame)	Disposition of Data (Approx Percent): Real-Time Transmit (%)	One Orbit Dump (%)	1 to 7 Days Return (%)	Shuttle Return	On-Orbit Display	Remarks
A4	Intermediate size UV telescopes (continued)												
		TV monitor	D (A)	$8x10^6$ (400 kHz)	6 min	9.5	$27.4x10^9$ (400)	100 57 min				100	1 to 7 days return desired, shuttle return acceptable
		Film camera	Film	If/ operation	120	4.9	4.9				100	5	
		Nonimaging data	D	1.1	72	4.9	$0.24x10^8$	10.0		100		10	1 to 7 days return desired, shuttle return acceptable
A5	High energy stellar astronomy												
	Lower energy experiments	Imaging det	D	26	10%	1	$2.3x10^8$			100		100	
		Nonimaging	D	11.1	100%		$9.6x10^8$			10	100	1	
	Higher energy experiments	Nonimaging	D	11.9	100%	1	$10.3x10^8$			10	100	1	
	Align/calibrate/acquire	Imaging	D (A)	$7x10^6$ (353 kHz)	2%	1	$121x10^8$	100				100	
		Nonimaging	D	3.4	3.5%		$0.11x10^8$	100				5	
A6	Infrared Astronomy												
	Station	Aspect sensor - field viewing imager	D	$7x10^6$	10	16	$68x10^9$	100				100	Aspect sensor data related to experiment operations center for brief periods (10 min) of time
			A (Alternate)	(0.35 MHz)	(10)	(16)	(0.35 MHz/ 2.7 hr)						
		Detector array scanning	D	9.5	50	16	$0.456x10^9$			10	100	20	Primary data-taking function
		Radiometry	D	300	12.5	2	$4.5x10^5$			100	100	5	Special sequence possible
		Spectroscopy	D	1.3	12.5	2	$19.5x10^5$			100	100	5	Special sequence possible

Table 5-8

EXPERIMENT DATA REQUIREMENTS (Continued)

FPE	Requirements	Data Acquisition: Measurement Source	Data Acquisition: Output Form (D, A, Film)	Data Acquisition: Data Rate (bps, Hz)	Operation: Duration (Min)	Operation: No. Of Operations Per Day	Operation: Daily Total (Bit kHz, Frame)	Disposition of Data (Approx Percent): Real-Time Transmit (%)	Disposition of Data (Approx Percent): One Orbit Dump (%)	Disposition of Data (Approx Percent): 1 to 7 Days Return (%)	Disposition of Data (Approx Percent): Shuttle Return	Disposition of Data (Approx Percent): On-Orbit Display	Remarks
P1	Space physics research laboratory	Airglow, Aurora, Ambient Env, ICN and NH_3 fluorescence, meteoroids and stellar observations	Digital	120 (worst case)	720	1	5.2×10^9				100	10	Daily total bit rate is a subgroup total assuming sequenced operation
			Analog	330 kHz	180	1/day for 10 days per 2 mo					100	10	
			Film								100	0	
			Impact plates								100	0	
P2	Plasma physics and environmental perturbation laboratory station	Plasma parameters measured with particle and field sensors, Aurora with TV	Digital				3.6×10^9	4*	5		100	20	*Real time transmission is needed only if high altitude and conjugate point satellites are used to support the wave particle interaction and particle injection experiments P 2D and P-2E. Poloroid film primarily for experiment monitoring adjustment
			Analog				2.3×10^5 Hz				100	100	
			Polaroid Film				30						
P3	Cosmic ray physics laboratory station	High energy particle parameters from Zenith Hemisphere measured by photo-multipliers spark chambers and Nuclear emulsions	Digital	30	continuous	continuous	2.6×10^9	10 (Shuttle only)			100	10	1. Plastic emulsion sheets exposure duration limited by radiation fogging - 7-day exposure assumed average. 2. Digital data rate will be reduced by 50 percent if orientation is random due to earth occultation. 3. If FPE is accommodated on a shuttle free flyer (FF), Monitor function is performed on ground.
			Emulsion	2 sheets/mo	7 days	2/month	2 sheets/mo				100		

Table 5-8

EXPERIMENT DATA REQUIREMENTS (Continued)

FPE	Requirements	Data Acquisition: Measurement Source	Data Acquisition: Output Form (D, A, Film)	Data Acquisition: Data Rate (bps, Hz)	Operation: Duration (Min)	Operation: No. Of Operations Per Day	Operation: Daily Total (Bit kHz, Frame)	Disposition of Data (Approx Percent): Real-Time Transmit (%)	Disposition of Data (Approx Percent): One Orbit Dump (%)	Disposition of Data (Approx Percent): 1 to 7 Days Return (%)	Disposition of Data (Approx Percent): Shuttle Return	Disposition of Data (Approx Percent): On-Orbit Display	Remarks
P-4	Physics and Chemistry laboratory station	Scientific and engineering data	digital	2.4×10^6	30	5	21.6×10^9	100			100	100	30-day cycle
			film								100		
T-2	Fluid management station	Fluid parameters (temp, press, etc)	D	5.78	continuous	continuous	2.5×10^8				100	10	
		Fluids movement	TV	5.8 MHz	30	14	5.8 MHz				100	50	
T-3	EVA	TLM sensors	D	8 (worst case)	180	1/3	8.64×10^7 (worst case)	100 to space-craft			100	60	
		Camera	Film (16 mm)	6 FPS	38	1/3	6,800 frames				100		
		CCTV	A (tape)	3 MHz	180 (worst case)	1/3		100 to space-craft			100	100	
		Voice recorder	tape	4 MHz	180 (worst case)	1/3		100 to space-craft			100		
ES-1	Earth Observation Facility	Earth, including atmosphere	Digital	51.5M	15	4	1.8×10^{11}	1	5	10	100		
			Film				4,000 FPD				100		
C/N-1	Com/nav	Electrical	Digital	1×10^6	60	1	3.6×10^9	10			90	5	
		Optical	Film				30 FPD				100		
		(Not a 5-day candidate - see subgroup sheets Vol II)											

Table 5-8

EXPERIMENT DATA REQUIREMENTS (Continued)

FPE / Requirements		Data Acquisition			Operation			Disposition of Data (Approx Percent)					Remarks
		Measurement Source	Output Form (D, A, Film)	Data Rate (bps, Hz)	Duration (Min)	No. Of Operations Per Day	Daily Total (Bit kHz, Frame)	Real-Time Transmit (%)	One Orbit Dump (%)	1 to 7 Days Return (%)	Shuttle Return	On-Orbit Display	
MS-1	Materials science and manufacturing in space												
		Electrical	Digital	1×10^7	2,880		4.6×10^{12}	10		90			Numbers are FPE totals. See subgroup requirements for subgroup data rates and duration.
		Optical	Film 16 mm		15	2					100		
T-1	Contamination measurements												
		Photometers, crystal gages, mass spectrometers	Digital	3.1	16 hr/day 4 day/mo (worst case)	1 4 day/mo	11.2×10^7 (avg)				100	10	Daily total is average of all experiments and is not based on worst case shown in data rate and duration
		TV Camera	Analog	10 MHz	4 hr/mo			10			100	10	
			Film	1-100 fr per sec	10 sec	8/min					100	0	
T4	Advanced spacecraft systems tests												
		Temperature, calorimeters, radiation detectors, mass spectrometers, press, velocity, time, acceleration, thrust, voltage, current	D	500 (maximum)	100 hr total	variable	40.2×10^9			10	100	10	Exposure experiments operated over 36 months. Passive most of time

Table 5-8

EXPERIMENT DATA REQUIREMENTS (Continued)

FPE / Requirements		Data Acquisition: Measurement Source	Data Acquisition: Output Form (D, A, Film)	Data Acquisition: Data Rate (bps, Hz)	Operation: Duration (Min)	Operation: No. Of Operations Per Day	Operation: Daily Total (Bit kHz, Frame)	Disposition of Data (Approx Percent): Real-Time Transmit (%)	Disposition of Data (Approx Percent): One Orbit Dump (%)	Disposition of Data (Approx Percent): 1 to 7 Days Return (%)	Disposition of Data (Approx Percent): Shuttle Return	Disposition of Data (Approx Percent): On-Orbit Display	Remarks
T4	Advanced Spacecraft Systems Tests (Continued)												
		Sample appearance, manual events	Film		36 mo	variable	8 hr/ year/plus 18 kg (40 lb) total				100		Plus specimens and logs return
T5	Teleoperations												
		TLM sensors	D	4.9	120 (avg)	1/3	3.5×10^7	100 to space-craft			100	70	
		Video	A	8.4 MHz	120 (avg)	1		100 to space-craft			100	100	
	Life Sciences				Dependent on experiment selection								TV and voice must be available near real time on a 24 hour emergency usage basis, otherwise color TV on a 2 hr/day basis for experiments
	Station: (Dedicated life science module) (includes reduced facilities for LS-1 thru LS-7)	Biotrans-ducers, monitoring equipment, data manage-ment require-ment console	Digital	6	Dependent on experiment selection								
		TV, voice	Analog	4 MHz	see remarks								

Table 5-9

ORBITAL OPERATING ENVIRONMENTAL REQUIREMENTS

FPE \ Requirements	Allowable Orbital Temp °C (°F)	Allowable Atmospheric Pressure n/m² (psia)	Atmosphere (Gas Type)	Relative Humidity (%)	Cleanliness (Classification)	Gravity Level (g)	Allowable Radiation Exposure	Remarks
A1 X-Ray Astronomy								
High res telescope	0 ± 1	1.33×10^{4}	None space vacuum	NA	Space vacuum	10^{-4}	10^{-3} rad/hr	
Large area telescope	(32 ± 2)	(2×10^{-8})						
Supplementary experiments								
A2 Advanced Stellar Astronomy								
3 Meter telescope	21 ± 1 max (70 ± 2)	1.33×10^{-4} (2×10^{-8})	Space vacuum	0 Space vacuum	Space vacuum (avoid contaminants)	10^{-4}	0.001 rad/hr to film	
	0.2 for overall							
	0.2 for optics							
	0.1 for instruments							
A3 Advanced Solar Astronomy								
1.5M photoheliograph	18 to 24 (ΔT 2) (64 to 75)	1.33×10^{-5}	Space vacuum	Space vacuum	Space vacuum	10^{-4}	0.001 rad/hr	
XUV spectroheliograph	17 to 21 (ΔT 2) (68 to 70)	(2×10^{-11})		Same		10^{-4}	0.001 rad/hr	
X-ray grazing incidence	17 to 21 (ΔT 2) (63 to 70)					10^{-4}	0.001 rad/hr	
Solar coronagraph	18 to 21 (ΔT 2) (64 to 75)					10^{-3}	NA	
	17 to 21 (ΔT 2) (63 to 70)	1.33×10^{-5} (2×10^{-11})	Space	Space	Space	10^{-4}	0.001 rad/hr	
A4 Intermediate Size UV Telescopes								
0.94M narrow field	26 to 27 (79 to 80)	1.33×10^{-4} (less than 2×10^{-8})	None, space vacuum	Approximately zero	10,000	Less than 10^{-3}	Less than 1 millirad per hour (film)	Max temperature difference 0.3°C (assume across primary mirror)
0.3M wide field	26 to 27 (79 to 80)	1.33×10^{-4} (less than 2×10^{-8})	None, space vacuum	Approximately zero	10,000	Less than 10^{-3}	Less than 1 millirad per hour (film)	Max temperature difference 0.5°C (assume across primary mirror)

Table 5-9

ORBITAL OPERATING ENVIRONMENTAL REQUIREMENTS (Continued)

FPE \ Requirements	Allowable Orbital Temp °C (°F)	Allowable Atmospheric Pressure n/m² (psia)	Atmosphere (Gas Type)	Relative Humidity (%)	Cleanliness (Classification)	Gravity Level (g)	Allowable Radiation Exposure	Remarks
A4 (Continued)								
Station	26 to 27 (79 to 80)	1.33 x 10^{-4} (less than	None, space vacuum	Approximately zero	10,000	Less than 10^{-3}	Less than 1 millirad per hour (film)	Max temperature difference: 0.3°C narrow field telescope; 0.5°C wide field telescope
A5 High Energy Stellar Astronomy	-1 to +1 (30 to 34)	1.33 x 10^{-4} 2 x 10-8)	None, space vacuum	Less than 40	10,000	10^{-4} operating	Less than 1 millirad per hour within energy range of this instrument	Polarimetry and spectrometry experiments are nonoperative in South Atlantic anomaly.
A6 Infrared Astronomy								
Station Telescope	27.6°K ± 1°K (LN_2)	1.33 x 10^{-4} preferred; 0 to 10^9 acceptable	None, space vacuum	Approximately 0%	10,000	10^{-3}	Less than 1 millirad/hr	Do not point aperture at sun
Detectors	2°K (LH_e)	(2 x 10-8) preferred (0-15 psia) acceptable						
P1 Space Physics Research Laboratory All missions	10°C to 32°C (50°F to 90°F) Note 1	Internal equip: 1 x 10^5 (14.7) External equip: 7 x 10-8 (1 x 10-11) to 1 x 10^5 (14.7)	Space environment	0 to 50	10,000 Note 2	Within pointing constraints	Less than 5 rad	NOTES: 1. Temperatures specify limits on equipment internal to S/C. External equipment will allow for operation in a space environment. 2. This does not imply continuous operation at class 100,000 clean room. However, while handling sensors and optics, techniques approaching the clean room level are required.

Table 5-9

ORBITAL OPERATING ENVIRONMENTAL REQUIREMENTS (Continued)

FPE / Requirements	Allowable Orbital Temp °C (°F)	Allowable Atmospheric Pressure n/m² (psia)	Atmosphere (Gas Type)	Relative Humidity (%)	Cleanliness (Classification)	Gravity Level (g)	Allowable Radiation Exposure	Remarks
P2 Plasma Physics and Environmental Perturbation Laboratory	Electronics 0 to 40 (32 to 104) Antennas -30 to 60 (-22 to 140)	0 to 10^5 (0 to 14.7)	Vacuum and O_2/N_2	80	NA	NA	Polaroid	Remperature ranges for sensors and electronics, not antennas. Sensitive to EMI
P3 Cosmic Ray Physics Laboratory	10 to 30 (50 to 86) except for nuclear emulsions 2 to 25 (36 to 77)	10^5 (14.7)	O_2/N_2	80	NA	NA	Shielding required in South Atlantic anomaly. Provided as part of support equipment. See experiment group weight size and support equipment table	
P4 Physics and Chemistry Laboratory	0 to 32 (32 to 90)	0 to 10^5 (0 to 14.7)	Air or nitrogen	50	100,000	10^{-4} max	Film protection required	
ES1 Earth Observation Facility	7 to 27 (45 to 81)	0 to 10^5 (0 to 15)	N_2O_2	30 to 70	100,000	0 to 1	0.9 rad/day	
C/N 1 Communications/Navigation	0 to 40 (32 to 112) exclusive of external equipment	0 to 10^5 (0 to 14.7)	N_2, O_2	40	See remarks	Not critical	No limitation assuming minimal film vault and complete 30-day (max) turnover of onboard film	1. Optical experiments contamination sensitive. Filter air to class 100,000 level; avoid waste dumps during experiment deployment. Locate thrusters (and their centerline) as far from experiments as possible.
MS-1 Materials Science and Manufacturing in Space	-40 to +75 (-40 to +161)	0 to 10^5 (0 to 14.7)	N_2O_2	50	100,000	0 ± 10^{-3}	No requirement	

Table 5-9

ORBITAL OPERATING ENVIRONMENTAL REQUIREMENTS (Continued)

FPE / Requirements	Allowable Orbital Temp °C (°F)	Allowable Atmospheric Pressure n/m² (psia)	Atmosphere (Gas Type)	Relative Humidity (%)	Cleanliness (Classification)	Gravity Level (g)	Allowable Radiation Exposure	Remarks
T-1 Contamination Measurements	10 to 32 (50 to 90) Note 1	Internal equip: 1×10^3 (15) External equip: 7×10^{-8} (1×10^{-11}) to 1×10^5 (15) Note 2	Space environment	0 to 50	100,000 (Exclusive of contamination collection surfaces during exposure) Note 3	Within pointing constraints	Less than 5 rads	Notes: 1. Temperatures specify limits on equipment internal to S/C. External equipment will allow for operation in a space environment. 2. The contaminant cloud composition measurement sensor must be 1.3×10^{-2} n/m². 3. This does not imply a continuously operated class 100,000 clean room. However, while handling contamination samples, techniques approaching the clean room level are required.
T-2 Fluid Measurement	21 (70) nominal	Nominal shirt-sleeve: 1.3×10^{-4} (2×10^{-8})	N/A	N/A	N/A	10^{-3}; 10^{-4}; 10^{-5}; coast	N. A	
T-3 EVA	-3 to 47	26 (3.75) to pressure suit external: 0 to 10^5 (0 to 14.7)	100 percent O_2 to pressure suit external no requirement	40 to 70 (suit)	Not critical	No requirement	Skin 75 rem/30 days Eye 37 rem/30 days Testes 13 rem/30 days Marrow 25 rem/30 days	Film radiation limits: less than 5 rads

Table 5-9

ORBITAL OPERATING ENVIRONMENTAL REQUIREMENTS (Continued)

FPE \ Requirements	Allowable Orbital Temp °C (°F)	Allowable Atmospheric Pressure n/m² (psia)	Atmosphere (Gas Type)	Relative Humidity (%)	Cleanliness (Classification)	Gravity Level (g)	Allowable Radiation Exposure	Remarks
T-4 Advanced Spacecraft System Tests	20 (70) Nominal and space conditions; solar and away-from-sun orientation	Nominal shirtsleeve and 1.3×10^{-4} (2×10^{-8})	Fireproof chamber	N/A	N/A	N/A	N/A	
T-5 Teleoperations	5 to 47 (41 to 120)	No requirement 0 to 10^5 (0 to 14.7)	No requirement N_2/O_2	Not critical 40 to 70	Not critical	No requirement	Not critical	
Life Sciences								
Station: (Dedicated Life Science Module) (Includes reduced facilities for LS-1 through LS-7)	25 ± 1 (76.5 ± 2)	10^5 (15)	21% O_2 79% N_2 0.004% CO_2	50 ±5	100,000 level	Max 10^{-5} 90 percent time 10^{-4} 10 percent time	1 rem/hr	

Table 5-10

ORBIT REQUIREMENTS

FPE / Requirements	Altitude Km (nmi) Acceptable	Altitude Km (nmi) Preferred	Inclination Rad (Deg) Acceptable	Inclination Rad (Deg) Preferred	Maneuvers	Altitude (Inertial/ Velocity Vector (Etc.)	Pointing Accuracy Radians (Deg)	Stability/ Observation Time Rad/Min (Sec/Min)	Remarks
A1 X-ray Astronomy - High RKS Telescope - Large Area Telescope - Supplementary Experiments	370 to 740 (200 to 400)	740 to 930 (400 to 300)	0 to 0.96 (0 to 55)	0	Orient to various points on the celestial sphere slew rate of 5×10^{-6} to 2.6×10^{-3} rad/sec	Stellar inertial	2.9×10^{-4} (60 sec) 2.9×10^{-4} (50 sec + 15 sec) 1.75×10^{-3}	5×10^{-6}/100 (1/100) 5×10^{-6}/100 (1/100) 5×10^{-6}/100 (1/100)	
A2 Advanced Stellar Astronomy 3-Meter Telescope	460 to 670 (250 to 360)	670 to 830 (360 to 450)	0	0.489 to 0.96 (28 to 55)	Point to any spot in celestial sphere rate = 1.75×10^{-3} rad/sec (6 deg/min)	Stellar inertial	5×10^{-6} (1 sec)	5×10^{-9}/4 hr (0.005 sec/4 hr)	
A3 Advanced Solar Astronomy 1.5 M Photoheliograph XUV Spectroheliograph X-ray Grazing Incidence Solar Coronagraph	370 to 740 (200 to 400)	500 (270)	0 to 0.96 (0 to 55)	Sun sync	Solar pointing 5×10^{-5} rad/sec (10 sec/sec) 2.9×10^{-4} rad/sec (60 sec/sec)	Solar inertial	5×10^{-6} (1 sec) 1.2×10^{-5} (2.5 sec) 5×10^{-6} (1) 7.5×10^{-5} (15 sec)	5×10^{-8}/ 2,700 sec (0.017 sec/ 2,700 sec) 5×10^{-7}/ 2,700 sec (0.1 sec/ 2,700 sec) 2.4×10^{-6}/ 2,700 sec (0.5 sec/ 2,700 sec) 5×10^{-6}/ 2,700 sec	
A4 Intermediate Size UV Telescopes 0.94 M Narrow Field	370 to 740 (200 to 400)	370 to 667 (200 to 360)	Any	0.489 to 1.22 (28 to 70)	Acquire and track any target within a celestial hemisphere, maximum slew rate: 1.75×10^{-3} rad/sec (360 arc sec/sec)	Stellar inertial	Instrument: Less within 5×10^{-6} rad (less than 1 sec) support spacecraft: 8.7×10^{-3} rad (30 arc min)	Less than 5×10^{-6} rad/ observation time Pointing hold time: 2,400 to 14,400 sec (40 to 240 min)	

Table 5-10

ORBIT REQUIREMENTS (Continued)

FPE / Requirements	Altitude Km (nmi) Acceptable	Altitude Km (nmi) Preferred	Inclination Rad (Deg) Acceptable	Inclination Rad (Deg) Preferred	Maneuvers	Altitude (Inertial/ Velocity Vector (Etc.)	Pointing Accuracy Radians (Deg)	Stability/ Observation Time Rad/Min (Sec/Min)	Remarks
A4 Intermediate Size UV Telescopes (Continued) 0.3 M Wide Field	370 to 740 (200 to 400)	463 to 667 (250 to 360)	Any	0.489 to 1.22 (28 to 70)	Same as above	Stellar inertial	Same as above	2.4×10^{-6} rad per observation time (0.5 arc sec/ obs) Pointing hold time: 360 to 14,400 sec (6 to 240 min)	
Station	370 to 740 (200 to 400)	463 to 667 (250 to 360)	Any	0.489 to 1.22 (28 to 70)	Acquire and track any target within a celestial hemisphere, maximum slew rate: 1.75×10^{-3} rad/sec (360 arc sec/sec)	Stellar inertial	Instrument: Less than 5×10^{-6} rad (Less than 1 arc sec) support spacecraft: 8.7×10^{-3} rad (30 arc min)	2.4×10^{-6} rad per observation time (0.5 arc sec/ obs) Pointing hold time: 360 to 14,400 sec (6 to 240 min)	
A5 High Energy Stellar Astronomy	370 to 740 (200 to 400)	740 to 930 (400 to 500)	1 to 0 (55 to 9)	0 (0)	Survey the celestial sphere and orient to various points on the celestial sphere, maximum slew rate: 1.7×10^{-3} rad/sec (360 arc sec/sec)	Stellar inertial	5×10^{-6} (1 arc sec)	5×10^{-6} rad (1 arc sec) 0.83 to 24 hr (3,000 to 86,400 sec)	
A6 Infrared Astronomy	460 to 740 (250 to 400)	500 to 560 (270 to 300)	0.436 to 1.22 (25 to 70)	0.873 to 1.05 (50 to 60)	Survey the celestial sphere and orient to various points on the celestial sphere, maximum slew rate of 11.6×10^{-4} (240 arc sec per sec) during earth orbital scan. Maximum slew rate of 17.4×10^{-4} (360 arc sec per sec) for radiometry and spectrometry.	Stellar inertial	5×10^{-6} (1 arc sec)	5×10^{-6} (less than 1 arc sec up to 4 hr)	

Table 5-10

ORBIT REQUIREMENTS (Continued)

FPE / Requirements	Altitude Km (nmi) Acceptable	Altitude Km (nmi) Preferred	Inclination Rad (Deg) Acceptable	Inclination Rad (Deg) Preferred	Maneuvers	Altitude (Inertial/ Velocity Vector (Etc.)	Pointing Accuracy Radians (Deg)	Stability/ Observation Time Rad/Min (Sec/Min)	Remarks
P-1 Space Physics Research Lab	185 (100)	Varies from 185 Km (100 to 370 (200)	1.13 to 1.57 (65 to 90)	Polar	No requirement	Velocity vector and stellar inertial	$\pm 5.8 \times 10^{-4}$ (±2 min)	$\pm 1.05 \times 10^{-2}$ (±0.01/sec) for 1 hr max	
P-2 Plasma Physics and Environmental Perturbation Laboratory	500 (270)	Fixed and variable from 300 to 1,000 (165 to 550)	1 (55)	1 to 1.6 (55 to 90)	Desirable to have variable altitude over 165 to 300 Km. Various orientations with respect to velocity vector. Subsatellite criss-cross of station and balloon wakes.	Velocity vector and magnetic field directions	0.01 (0.5)	0.01 rad/min (0.5 deg/min)	Booms must be supplied with sufficient length to reduce interference by station to an acceptable value in 4 coverage sensors. (12 M booms are recommended as support equipment)
P-3 Cosmic Ray Physics Laboratory	500 (270)	370 (200)	1 (55)	0.5 (28.5)	None	Any in zenith hemisphere	Need knowledge of position only 0.02 (1)	N/A	Data are useful only from particles arriving from the zenith hemisphere. Desire random orientation for flux survey with minimum pointing to earth.
P-4 Physics and Chemistry Laboratory	185 (100)	Any	1 (55)	Any	None	Inertial and velocity vector required depending on individual experiments	±0.02 (1)	N/A	

Table 5-10

ORBIT REQUIREMENTS (Continued)

FPE / Requirements	Altitude Km (nmi) Acceptable	Altitude Km (nmi) Preferred	Inclination Rad (Deg) Acceptable	Inclination Rad (Deg) Preferred	Maneuvers	Altitude (Inertial/ Velocity Vector (Etc.)	Pointing Accuracy Radians (Deg)	Stability/ Observation Time Rad/Min (Sec/Min)	Remarks
ES-1 Earth Observations Station	500 (270)	185 (100)	0.9 (50)	0.6 (90)	None	Primary pointing mode is to Nadir. Some off Nadir pointing required infrequency (50 deg foreward, 40 deg aft 45 deg cross-track)	±0.5 deg of Nadir or of specific target of total observation time (0.05 to 0.4 hr/pass)	0.001 (0.05 deg/sec) Same	
C/N-1 Communications/Navigation Station	185 to 556 (100 to 300)	148 to 740* (80 to 400)	0.95 (55)	Polar	Primary orientation - earth looking track station; some experiments desire track sync satellite	Pointing: Earth Other satellites Horizon Deep space	(0.000175) (0.01)	0.000175 (0.01) 10 minutes per meas.	*2-4 orbits at each of: 148 (80) 296 (160) 494 (240) 592 (320) 740 (400)
MS-1 Material Science and Manufacturing in Space Station	Any altitude with 10^{-4}	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
T-1 Contamination Measurements All Missions	No requirement	No requirement	No requirement	No requirement	No requirement	Solar inertial clear view of sun with minimum occultation by spacecraft	0.87×10^{-2} (±0.5)	($\pm 5.2 \times 10^{-2}$) for several minutes	
T-2 Fluid Management Station	Any altitude to achieve lifetime of 5,246 hr		N/A	N/A	*10^{-3} G for 17 hr 10^{-4} G for 200 hr 10^{-5} G for 475 hr Coast for 4,200 hr	Gravity in direction of flow, counter to flow, and perpendicular to flow	N/A	N/A	*Times required at each g-level are totals and need not be continuous
T-3 EVA	No requirement	No requirement	No requirement	No requirement	Restricted maneuvering of parent spacecraft during EVA. No maneuvering during AMU or MWP launch/dock	No requirement	No requirement	No requirement	

Table 5-10

ORBIT REQUIREMENTS (Continued)

FPE / Requirements	Altitude Km (nmi) Acceptable	Altitude Km (nmi) Preferred	Inclination Rad (Deg) Acceptable	Inclination Rad (Deg) Preferred	Maneuvers	Altitude (Inertial/ Velocity Vector (Etc.)	Pointing Accuracy Radians (Deg)	Stability Observation Time Rad/Min (Sec/Min)	Remarks
T-4 Advanced Spacecraft Systems Tests Station	Any altitude to achieve drag of 10^{-5} g		N/A	N/A	Thrusters may be used for orientation control	Solar and away-from-sun orientation maximized	Solar cell array oriented toward local solar flux to within 1.7×10^{-3} rad (0.1) during calibration	Instrument platen stability of 2.4×10^{-8} rad (0.005 arc sec)	
T-5 Teleoperation	No requirement		No requirement		No maneuvering of parent spacecraft during T/O launch/ dock				
Life Science Station: (Dedicated Life Science Module) (Include Reduced Facilities for LS-1 through LS-7)	250 nmi		0.96 (55)	0	No requirement	No requirement	N/A	N/A	

Altitude - The altitude constraints within which the experiments will perform at an acceptable level of output and the limits within which the output will be optimized.

Inclination - The orbit inclination (with respect to the Earth's equatorial plane) within which the experiments will perform at an acceptable level of output and the limits within which the output will be optimized.

Maneuvers - Orbital maneuvers required for the execution of an FPE experiment.

Attitude - Required orientation of module within an orbit (i.e., inertial, solar, velocity vector, etc.).

Pointing Accuracy - Angular pointing requirements, for the acquisition of a target.

Stability/Observation Time - Accuracy of pointing and duration of accuracy requirement for maintaining a target track during an experiment.

5.4.1.5 Crew Skills and Manpower Requirements

The data in Table 5-11 is a summary of the crew skill and time requirements for the experiments within each FPE. The times listed for each skill are totals for all tasks including setup, operate and shutdown/evaluate.

The EVA time requirements include preparation time and post-EVA activities in addition to the time required outside the spacecraft.

The crew skill requirements indicate a requirement for a particular skill and do not indicate the number of crewmen required.

Crew time per day indicates the time required for each skill during the period of experiment operation. Where the experiment operates continually, the crew time per day shown is a daily average.

5.4.2 Experiment Module Interfaces

The following interface data applicable to free flying modules assumed each will be docked for 7 days at 60 day intervals.

5.4.2.1 Electrical Power

The Space Station shall provide 115 ± 3 vdc through the interface to both attached module and free-flying module loads while docked to the station. The power requirements are as specified in Table 5-12. In addition to the power dissipated in the experiment module, power will be required in the Station for displays and controls and for module pumpdown. These additions are also included in Table 5-12. The daily average value is the power used during a typical operating (attached modules) or checkout (free flying modules) day averaged over a full 24 hours. The 90 day average is the daily average times the number of operational or checkout days per 90 day period.

Pumpdown requirements are based on 2,150 watts per hour at a rate of 4 hours per 1,000 cu ft to be pumped down. For 90 day period, a free-flying module pumpdown of 1.5 times was assumed and 6 times for attached modules.

5.4.2.2 Communications and Data Management

The module to Space Station data management interface consists of a hard line command, data management link while in the free flight mode. The data types to be transmitted across this interface are described in Table 5-13.

5.4.2.3 Environmental Control and Life Support

The experiment module environmental control and life support subsystem interfaces with the Space Station inside the pressurized section of the docking adapter. All connections are operational and accessible when the experiment

Table 5-11

CREW REQUIREMENTS

FPE / Requirements	EVA (hr)	Skill Type	Crew Time (hr per Operating Day)	Crew Time (hr per Mission)	Remarks
A6 Infrared Astronomy	None	Astronomer, Astrophysicist, Astronaut	8.3	2,804	Mission of about 1 year (337 days) to survey complete celestial sphere.
					Attached Module
P1 Space Physics Research Laboratory					
	6 each 7-hr EVA's per mission plus one 4-hr EVA/mo.	Electromechanical Technician	2.9/average	113 hr one time/yr plus 78.7 hr/mo for 1 yr	
	6 each 7 EVA's per mission plus one 4-hr EVA/mo	EVA backup	0.23/average	35 hr one time/yr plus 4 hr/mo for 1 yr	
	None	Physicist	2.77/average	79 hr one time/yr plus 76.7 hr/mo for 1 yr.	
Total	Six 7-hr EVA's per yr plus 4-hr EVA/mo for 2 men		5.90/average	227 hr one time/yr plus 159.4 hr/mo for 1 yr	
P2 Plasma Physics and Environmental Perturbation Laboratory					
Station and 30-Day Shuttle	None Planned	Physicist	10.8	108	Over a 10-day period single shift operated, some rest periods allowable during the approximately 10 hr workdays required.
		Electromechanical Technician	10.8	108	
		Pilot/Navigator	4:0	40	
P3 Cosmic Ray Physics Laboratory	4 - once/year	Electromechanical Technician	10 hr - 4 days	40 hr/mo	It is assumed that the EVA will be required for yearly magnet/dewar exchange. (Decrease in DWAR DIA to 5 ft to pass through airlock would shorten the interval between replacement) If a shuttle/FF mode is used, a 4-day setup, maintenance and reconfiguration period is required for each monthly visit. A longer interval between visits may prove more practical. Monitoring and control is obviously from the ground.
			10 hr - 4 days		
		Physicist	2 hr - 26 days	92 hr/mo	

Table 5-11

CREW REQUIREMENTS (Continued)

FPE \ Requirements	EVA (hr)	Skill Type	Crew Time (hr per Operating Day)	Crew Time (hr per Mission)	Remarks
P4 Physics and Chemistry Laboratory	Not Required	6 Physicists	6 5.0	(Per 90 Days) 448	
		25 Physical Chemists	25 3.5	313	
		9 Thermodynamacist	9 1.0	98	
		12 Electromechanical Technicians	12 17.2	1,538	
ES1 Earth Observations Facility (ES-1A through ES-1F)	0		Station	(Per 90 Days) Station	
		Photo Technician/ Cartographer	12	120	
		Electronic Engineer	2.3	32	
		Electromechanical Technician	16.5	159	
		Optical Technician	10.2	107	
		Oceanographer	5.7	77	Attached Module
		Meteorologist	6.2	80	
		Acronomist	5.9	59	
		Physicist Geologist	4.0	40	
		Geographer	4.6	46	
		Hydrology	2.4	32	
C/N-1 COMM/NAV Station (1 yr)	45	10 Electronic Engineers	1.2	437/yr	Time allocated to a specific skill code may actually be worked by a different crew member under the cognizance of the skill code listed.
		12 Electromechanical Technicians	0.4	138/yr	
		14 Optical Technicians	0.3		Attached Module
		17 Microwave Spec	1.1		
MS-1 Materials Science and Manufacturing In Space	None		7.7	232/30 days	These times represent total crew time for total FPE. See Subgroup crew requirements for skill types and crew times for each Subgroup.
T-1 Contamination Measurements	11.6/30 days (avg)	Electromechanical Technicians	0.99	29.7/30 day	11.6 hr EVA results from 23 hr/ 2 yr plus 10.6 hr/mo
	11.6/30 days (avg)	EVA backup	0.51	15.1/30 day	11.6 hr EVA results from 23 hr/ 2 yr plus 10.6 hr/mo
		Physicist	1.72	51.6/30 day	Higher EVA and crew hr/day and assumes higher rate of experiment operation.

Table 5-11

CREW REQUIREMENTS (Continued)

FPE / Requirements	EVA (hr)	Skill Type	Crew Time (hr per Operating Day)	Crew Time (hr per Mission)	Remarks
A1 X-Ray Astronomy					
High-Res Telescope Large Area Telescope Supplementary Exp	None	Astronomer/ Astrophysicist	3.0	90/30 Days	Free-flying module
A2 Advanced Stellar Astronomy 3-Meter Telescope	None Planned	Astronomer/ Astrophysicist	4.8	144 hr/30 days	The total crew time of 448 hours/ 30 days includes 1 hour for maintenance, and 447 hours for experiment operation. The 447 hours could be performed from a remote location such as the ground. Free Flying Module
A3 Advanced Solar Astronomy 1.5M Photoheliograph	None Planned	Astronomer/ Astrophysicist	0.30 min/orbit 0.333 min/orbit	16 orbit/day	30 min is setup time
XUV Spectroheliograph X-Ray Crazing Incident Solar Coronagraph	None Planned None Planned None Planned	Same Same Same	2.83 min/orbit 3.5 min/orbit Sun Side		Duty cycle based on operating coronagraph for 45 min on sun side of orbit. Free Flying Module
A4 Intermediate Size UV Telescopes					
0.94M Narrow Field	None	Astronomer/ Astrophysicist Source	2.2 hr 4.0 hr		
0.3M Wide Field	None	Astronomer/ Astrophysicist	1.6 hr 7.8 hr		Attached Module
A5 High Energy Stellar Astronomy (7 Experiments)	None	On-Orbit Physicist/ Astronaut	1.9	Continuous 1.9 hr/ day times number of days	Attached Module Time (hr per mission) - function of MSS mission duration plus 28 MH/180 days for maintenance.

Table 5-11

CREW REQUIREMENTS (Continued)

FPE \ Requirements	EVA (hr)	Skill Type	Crew Time (hr per Operating Day)	Crew Time (hr per Mission)	Remarks
T-2 Fluid Management	None	Electromechanical Technician	14	527 hr/30 days	1,209 manhours total
		Thermodynamicist	8	347 hr/30 days	Attached Module
T-3 EVA All Missions	48/30 days (avg)	Electromechanical Technician	16.5/3 days	161/30 days	
	48/30 days (avg)	Electromechanical Technician	16.5/3 days	161/30 days	
	48/30 days (avg)	Electromechanical Technician	16.5/3 days	161/30 days	
T-4 Advanced Spacecraft Systems Tests	14 hr/mo	Electromechanical Technician	21.7	650/30 days	
		Electronic Engineer	0.8	25/30 days	
		Mechanical Engineer	2.3	70/30 days	
		Thermodynamicist	0.7	20/30 days	
		Microbiological Technician	0.8	23/30 days	
		Physical Chemist	0.3	10/30 days	
		Metallurgist	0.1	1/30 days	
T-5 Teleoperation	0	Electromechanical Technician	11.8	135/30 days	
Life Sciences					Attached Module
LS-ST/D Dedicated Life Science Facility	(Experiment Dependent)	Medical Doctor	10	720/90 days	Calculated on the basis of 60-hr week, peak days consist of 14 hr.
		Life Science Technician	26	1440/90 days	

Table 5-12

ELECTRICAL POWER INTERFACES

Item	ISS	GSS
Average Power	4.8 kwe (total of RAM's and integral experiment)	12.1 kwe (total of RAM's and integral experiment)
Load Bus Characteristics	115 ± 3 vdc	115 ± 3 vdc
	2.4 kwe (24 hr avg/RAM)	4.0 kwe (24 hr avg/RAM)
	3.6 kwe (1 hr avg/RAM)	6.0 kwe (1 hr avg/RAM)
	115/200 vac, 400 Hz	115/200 vac, 400 Hz
	0.5 kwe (24 hr avg/RAM)	0.5 kwe (24 hr avg/RAM)
	0.75 kwe (1 hr avg/RAM)	0.75 kwe (1 hr avg/RAM)
	2.8 kwe (5 min peak, total of RAM's and integral experiment)	7.1 kwe (5 min peak, total of RAM's and integral experiment)

module and station hatch doors are open or closed. Connections are made manually except for the repressurization line which will be connected and disconnected automatically. Interface data is summarized in Table 5-14.

5.4.2.4 Guidance, Navigation, and Control

The Experiment/Module pointing and stability interface requirements imposed on the Space Station are identified in Table 5-15. These module requirements are much less stringent than those for the experiments in most cases due to the use of gimbal systems.

5.4.2.5 Crew Skills and Manpower Requirements

The data in Table 5-11 represents the crew times and skills for both the free-flying, attached modules and integral experiments. The free-flying and attached modules are noted in the remarks column.

Table 5-13

COMMUNICATIONS DATA MARGINAL, ONBOARD CHECKOUT INTERFACES

Item	ISS	GSS
Primary Mode	Attached RAM's	Attached RAM's
	Comm with SS (Data Bus)	Comm with SS wideband
	Comm with Ground (via Space Station and DRSS)	Same as ISS
Interruptions	Near full-time wideband capability	Same as ISS
Backup Mode	S-Band to MSFN	Same as ISS
Attitude Constraints (Imposed by Comm)	None	Same as ISS
Voice - Full Duplex (SS to Ground)	3 channels maximum (for experiment)	Same as ISS
Exp TLM to Ground	2 channels	Same as ISS
	12.5 Mbps (real time)	Same as ISS
Exp TLM from FF RAM	N/A	6 channels 10^3 to 10^7 bps
Text/Facimile	1 channel	1 channel
	10 Kbps (max)	10 Kbps (max)
TV B and W or Color (MSS to Ground)	2 channels (max	2 channels (max
TV B and W from FF RAM	N/A	2 channels
Internal comm	-	
Voice	30 channels + 3 per RAM	Same as ISS
CCTV	14 channels	

Table 5-13

COMMUNICATIONS DATA MARGINAL, ONBOARD CHECKOUT INTERFACES (Continued)

Item	ISS	GSS
Data Acquisition/ Storage	10 Mbps Data Bus second and third data bus available for limited time)	Same as ISS
Support to Experiment	Data acquisition	Same as Iss
	Computation	Same as Iss
	Data storage	Same as ISS
	Data Distribution	Same as ISS
	Display and Control	Same as ISS
	Timing	Same as ISS
Onboard Checkout	Attached RAM C/O	Attached and FF RAM
	Controlled from station	Controlled from Station
	Test sequencing	Same as ISS
	Fixed and Portable	Same as ISS
	Control and displays	Same as ISS
	General-purpose stimuli	Same as ISS

Table 5-14

ENVIRONMENTAL CONTROL/LIFE SUPPORT INTERFACES

Item	ISS	GSS
Habitable Areas	Shirtsleeve environment	Same as ISS
Airlock-Pumpdown/ Repressurization	Supports any requirement to access RAM's	Same as ISS
RAM Pumpdown/ Repressurization	Up to 820 cu ft (power limitation determines frequency)	Same as ISS
Pumpdown and Repressurization Flow Rate	820 cu ft in 4.85 hr	Same as ISS
RAM Atmospheric Circulation	136 CFM	Same as ISS
Thermal Load (Atmospheric)	None (Crew Only)	Same as ISS
Atmospheric Pressure	14.7 psia O_2/N_2	Same as ISS
Humidity Control	1.0 lb/day (not crew)	Same as ISS
Water Coolant (RAMs and Integral Experiments)	4.8 kwe	12.1 kwe
Contamination - Experiments	None (except normal atmosphere)	12.1 kwe
Waste Management	None (except for crew)	12.1 kwe

Table 5-15

GUIDANCE, NAVIGATION AND CONTROL INTERFACES

Item	ISS	GSS
G&N Accuracy	±1850 m (±1 nmi)	Same as ISS
Attitude Orientation Preferred	Trimmed Horizontal (All Attitude Capability Exists)	Same as ISS
Attitude Control Pointing Error	±0.25 deg (Pointing Error)	Same as ISS
Fine Pointing	±0.02 deg Attitude Reference	Same as ISS
Attitude Stability Angular Rate Limit	±0.005 deg/sec	Same as ISS
Fine Pointing	±0.001 deg/sec	Same as ISS
Ranging	None	±0.1 percent to 1,000 nmi

Section 6
INFORMATION MANAGEMENT SYSTEM ANALYSIS

The Information Management System (IMS) for the Modular Space Station is similar to the IMS for the 33 ft Space Station. Slight variations result from the following three factors:

A. The availability of the January 15, 1971 edition of Reference Earth Orbital Research and Applications Investigations, commonly referred to as the Blue Book.

B. A later launch date and delayed system buildup. In some cases, this will allow use of advanced technology which would not be available in the earlier time frame.

C. The Modular Space Station buildup concept. The buildup sequence determines the experiment schedule. This, in turn, requires an IMS configuration to support (provide processing, storage, transmission capabilities) the set of active experiments.

This section will first examine the information requirements of the final experiment program, Case 534-G, and secondly review IMS trade studies performed for the 33 ft Space Station to determine the effects of the above three factors.

6.1 EXPERIMENT DATA REQUIREMENTS ANALYSIS

The schedule for the experiment program is shown in Figure 6-1. Digital data outputs derived from analysis of the January 1971 NASA Blue Book have been plotted in Figure 6-2, with the area for analysis shaded. Data rates range between 9.8×10^{10} and 1.1×10^{11} bits per day depending on resolution and operating modes chosen.

Real-time requirements for digital data are shown in Figure 6-3. Real-time rates during the time of interest are 15×10^{9} bits per day. Transmission capacity of a number of different ground station configurations and

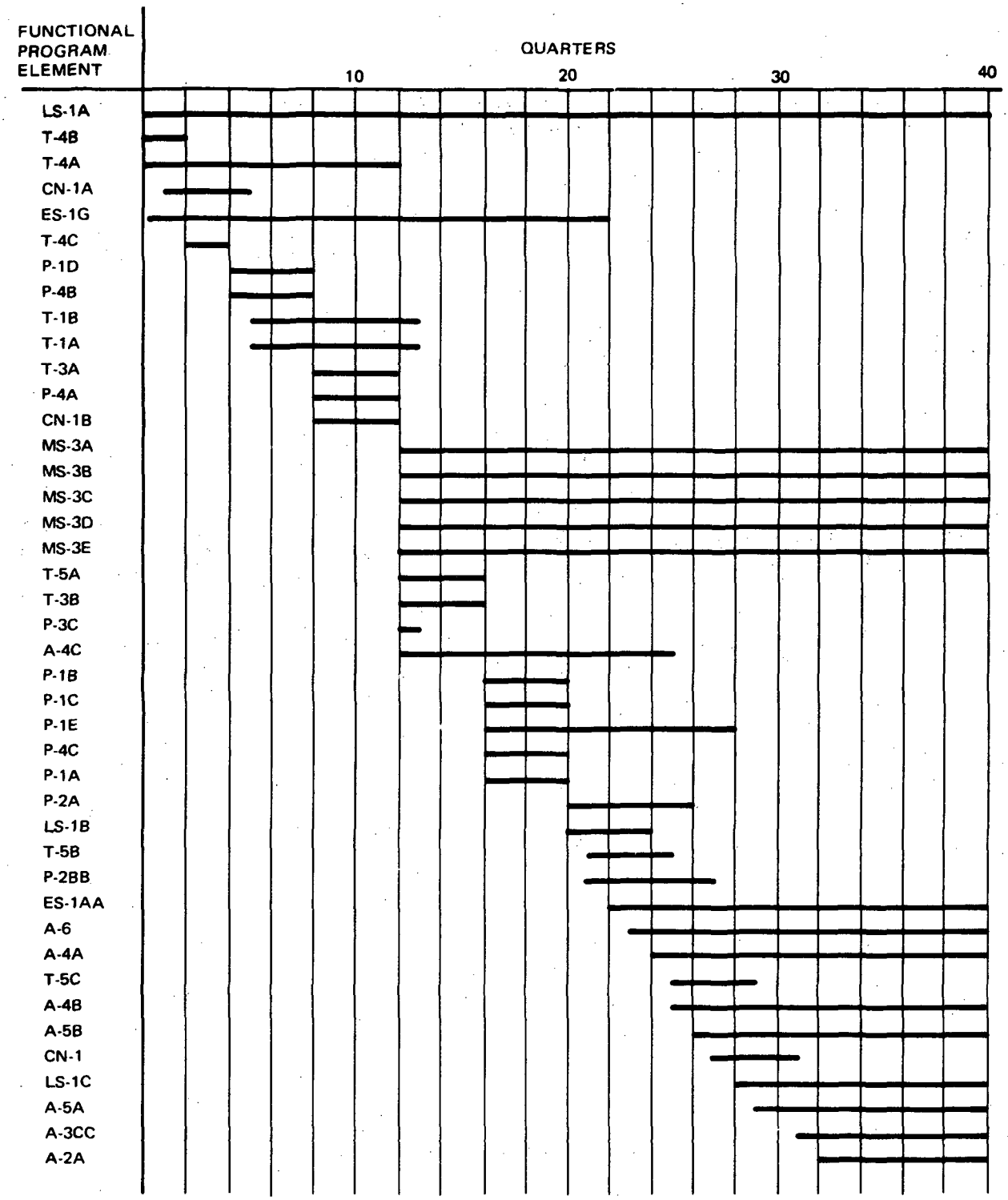


Figure 6-1. Experiment Schedule Case 534-G

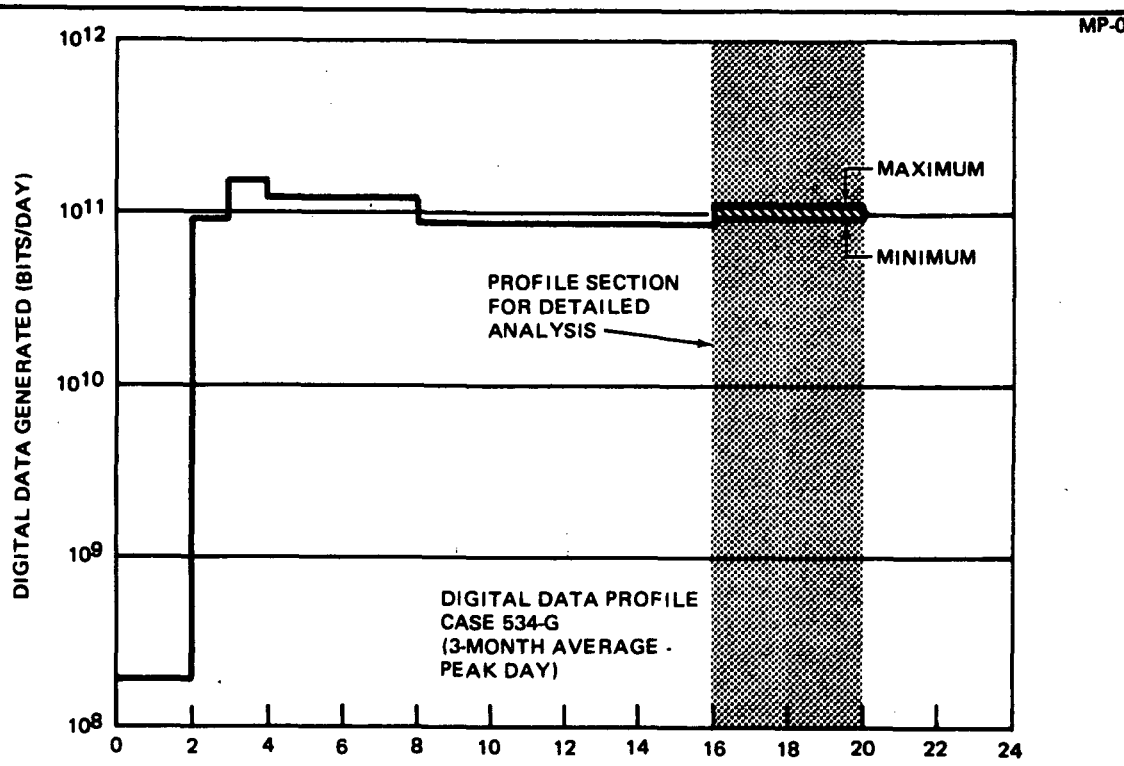


Figure 6-2. Mission Quarters

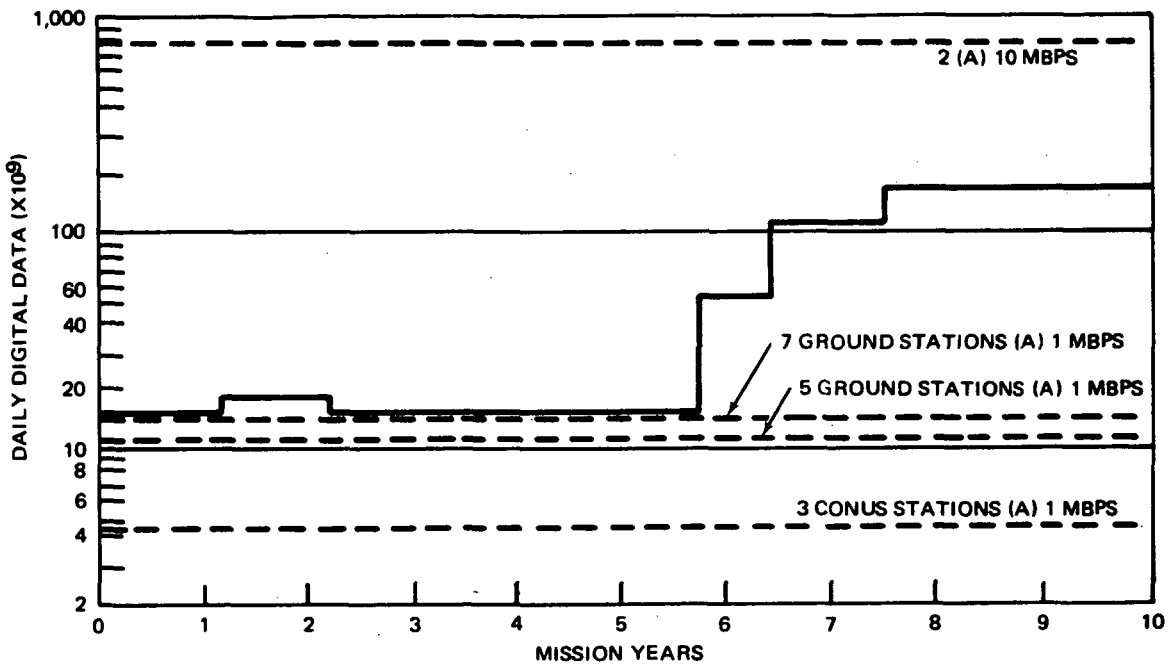


Figure 6-3. Real-Time Digital Transmission Requirements

one data relay satellite configuration is shown as dashed lines on the plot. Capability to meet real-time and near-real-time requirements exists only with the Data Relay Satellite System (DRSS).

Downlink capability requires consideration of the time (expressed in percentage of a 24 hour day) that the link is available as well as the amount of information which may be transferred when it is available. The maximum coverage time for each of the configurations is shown on Figure 6-4 with real-time analog (video) in minutes per day. Clearly, the requirements exceed all but the capability of a data relay satellite for coverage.

In order to identify the nature and distribution of DMS support functions, it is necessary to define in greater detail, some of the operational aspects and data-use functions resolved to an hour-by-hour schedule.

The following sections describe the analytical steps performed to identify the time slice selection; scheduling of experiments during the selected period, the resulting data profiles representing data generated, real-time

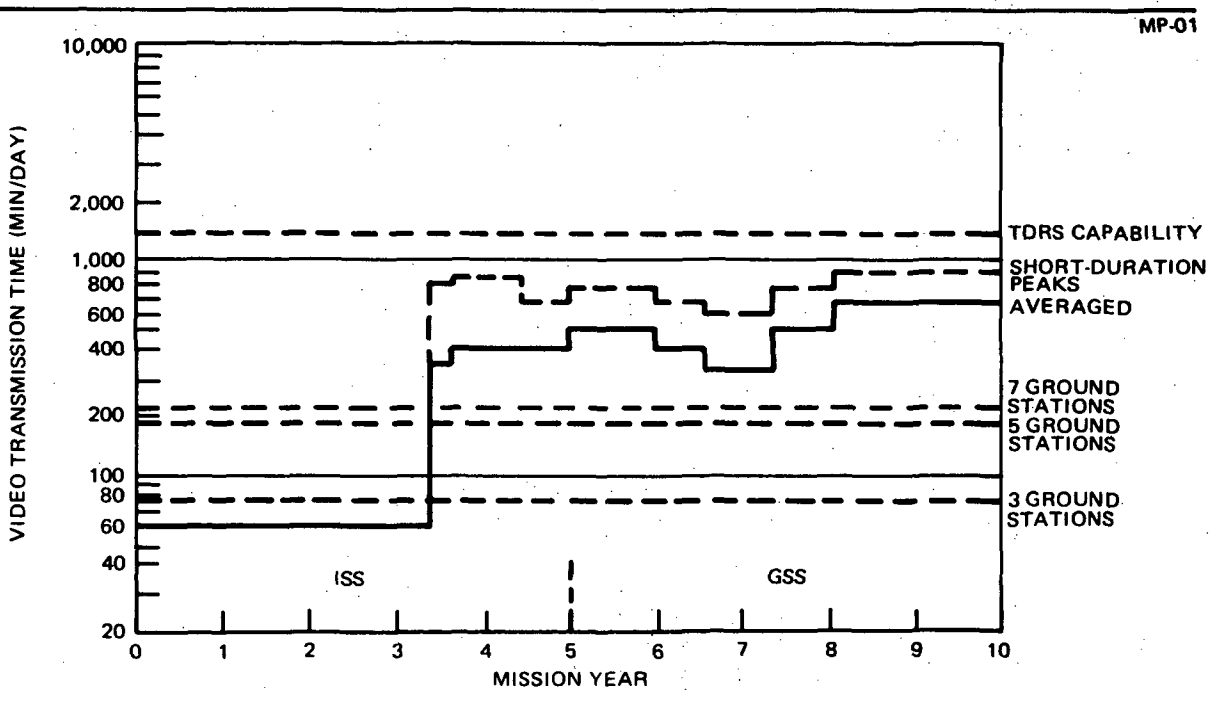


Figure 6-4. Real-Time Analog Transmission Requirements

transmission requirements; and a brief description of the support functions required by each of the experiments operated during the expanded period.

6.1.1 Time Slice Selection

The shaded quarters (16-20) in Schedule 534-G (Figure 6-5) were chosen to be representative of orbital experiment operation during ISS. Thirteen experiments are included in the six-month period chosen, all of which are shown in continual operation during the entire period. The characteristic duty cycle and output data rates and quantities for each of the thirteen experiments is shown in Table 6-1. The duty cycle information shown in the first five columns indicate that instead of continuous operation, as implied by the earlier schedule, some of the experiments are operated only infrequently. Examples are MS-3A-1, which is performed as infrequently as once per month, and P-1A, which is operated only 10 days every other month. Duty cycle data obtained from analysis of crew operations provided the constraints for further scheduling breakdowns explained in the following section.

6.1.2 Weekly Experiment Schedule

The 13 experiments included in the time slice were reviewed and a representative selection (11 of 13) made for operation during one of the 52 weeks. The experiments were arbitrarily chosen but all of the operational constraints developed by Martin Marietta Company were observed. The resulting array of operation cycles is shown in Figure 6-6. Efforts were made to limit operations to six days per week although some operations have been scheduled on the seventh day of the week.

Operation of the experiments results in data being generated as shown in Figure 6-7 illustrating two days of data yield. Data peaks of 50.1 Mbps are caused by the Multispectral Scanner in the Earth Resources experiment package.

Timeliness criteria imposed upon the data system is established by operational responsiveness defined for each experiment. Responsiveness is identified by real-time digital and analog transmission requirements and the requirement for experimenter displays.

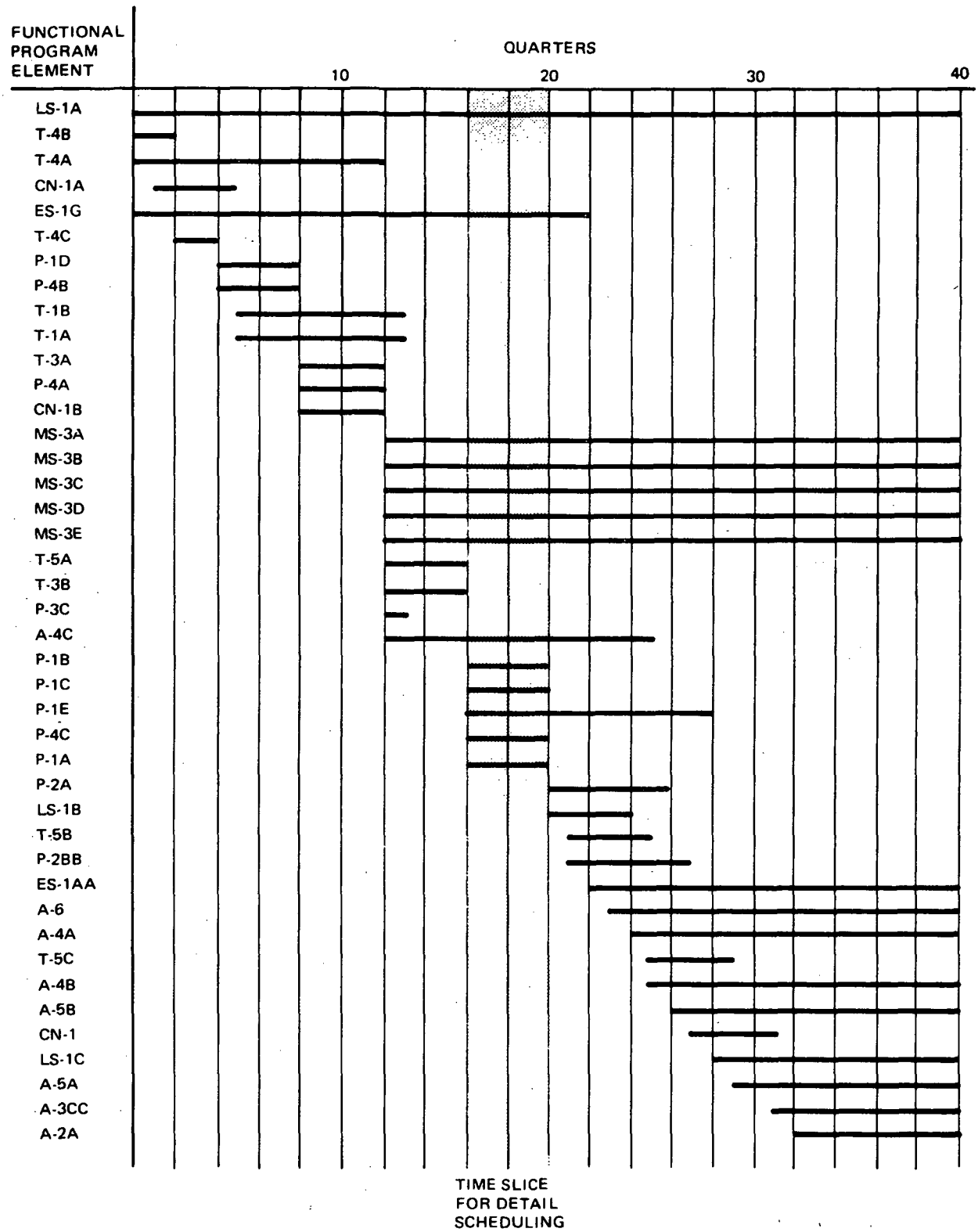
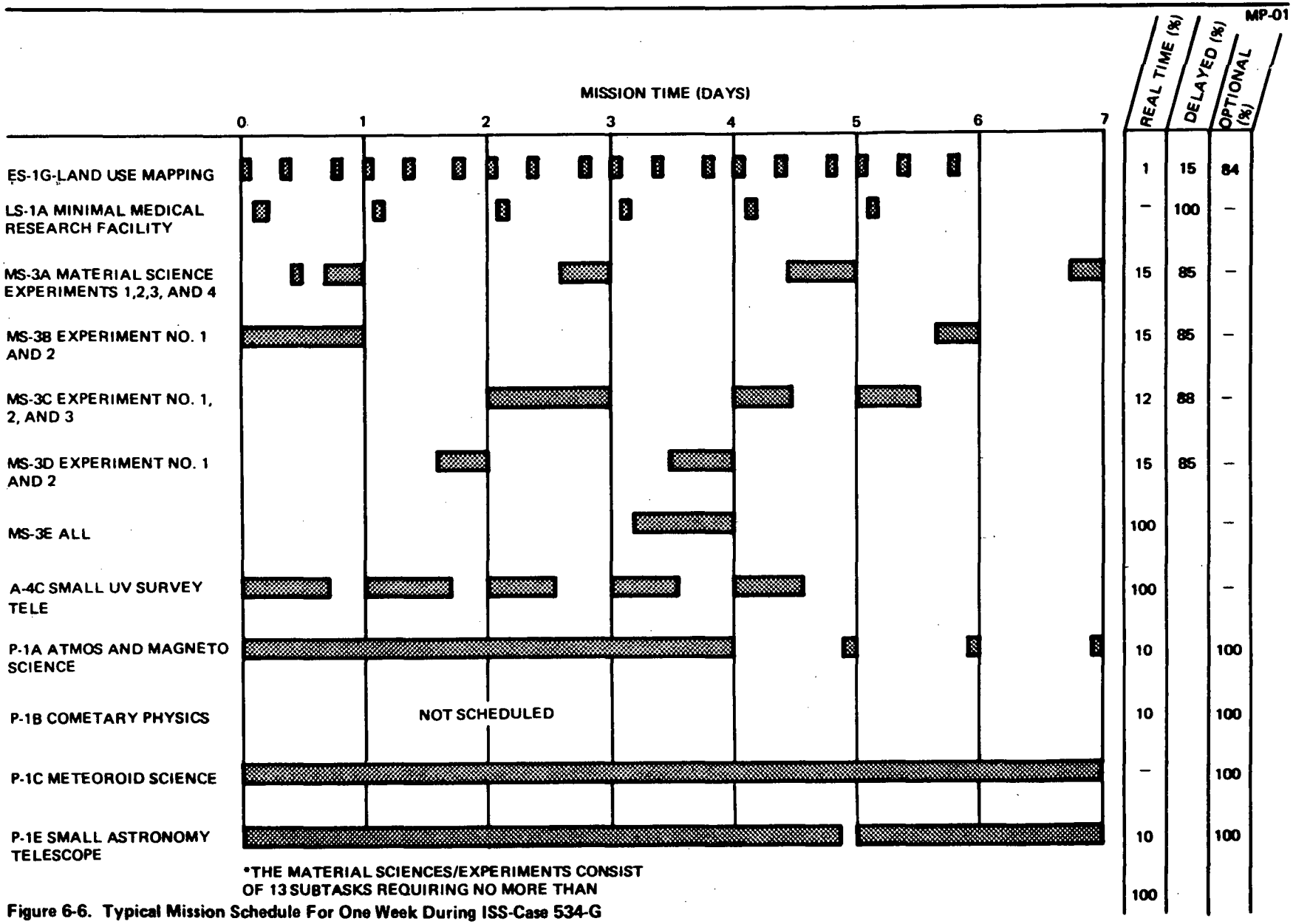


Figure 6-5. Experiment Schedule Case 534-G

Table 6-1

EXPERIMENT OPERATING AND OUTPUT CHARACTERISTICS

Experiment	Schedule	Hours Per Day (Times)	Days Per Week	Weeks Per Quarters	Quarters Per Year	Comments	Data Rate (bps)	Daily Data Quantity (bpd)
ES-1G World Land Use Mapping		1.75 (3)	6	11	4	10-Year duration	50 Mbps	1.35×10^{11}
		45 min Data Cycle				8 Hr/Qtr initial setup, Calibrate, reconfigure	(5-Channels)	
LS-1A Minimal Medical Research Facility		2.00 (1) Avg 4.5 (1) Max	5 1	11	4	Continuous for Station life 2-hr maintain, service, evaluate	12 K 2 K	7×10^{7}
MS-3A-1 (1st Q)		14.0 (1)	1	3	4	10-year duration	10^4	28.8×10^{7}
-2		8.5 (2)		9 Days		Minimum Operation	10^4	1.8×10^{8}
-3		8.5 (2)		12 Days			10^4	4.38×10^{8}
-4		4.0 (2)		12 Days			10^4	2.16×10^{8}
-5		8.0 (2)		12 Days			10^4	4.32×10^{8}
MS-3B-1		9.0 (2)		6 Days		Minimum	10^4	2.16×10^{9}
-2		7.5 (2)		6 Days			10^4	1.1×10^{8}
MS-3C-1		9.0 (2)		6 Days			10^4	2.2×10^{8}
-2		8.5 (2)		6 Days		Minimum	10^2	18×10^{5}
-3		10.0 (2)		6 Days			10^5	21.6×10^{8}
MS-3D-1		8.0 (2)		3 Days			10^2	14.4×10^{5}
-2 (1st Q)		10.0 (2)		3 Days		Minimum	10^5	21.6×10^{8}
MS-3E-		25.0 (1)		6 Days		Minimum	10^4	7.4×10^{8}
A-4C	Operate	1.0 (16)	5	11	4	1 to 2 year duration	500	4.3×10^{7}
	Service	13.0 (1)	1	11	4	Once per week		
P-1A Atmospheric and Magneto-Science								
	Mode 1	24.0 (1)	4 Only				84.8 K continuous	1.3×10^{10}
	Mode 2	3.0 (1)	10 Days		4	Operated every other month	with 31.1 K 1 hr. 3/day	1.62×10^{9}
P-1B Cometary Physics		2.5 (1)				10 times only during 1 year	20 K	7.2×10^{7}
P-1C Meteoroid Science		24.0 (1)	7	12	4	2-year duration 4 hr EVA per 30 days	Neg	3.12×10^{4}
P-1E Small Astronomy Telescope		24.0 (1)	7	12	4	2-year continuous operation; 3 hr twice/ week - service, deploy, etc.	120 K	5.2×10^{9}
P-4C Test Chamber Experiments								
	Operate	24.0	7	9	1 Only		65 K	1.3×10^{9}
	Measure	5.6 (1)	7	9	1 Only			
	Heat Transfer	7.5	20 Times	1 Only				



*THE MATERIAL SCIENCES/EXPERIMENTS CONSIST OF 13 SUBTASKS REQUIRING NO MORE THAN

Figure 6-6. Typical Mission Schedule For One Week During ISS-Case 534-G

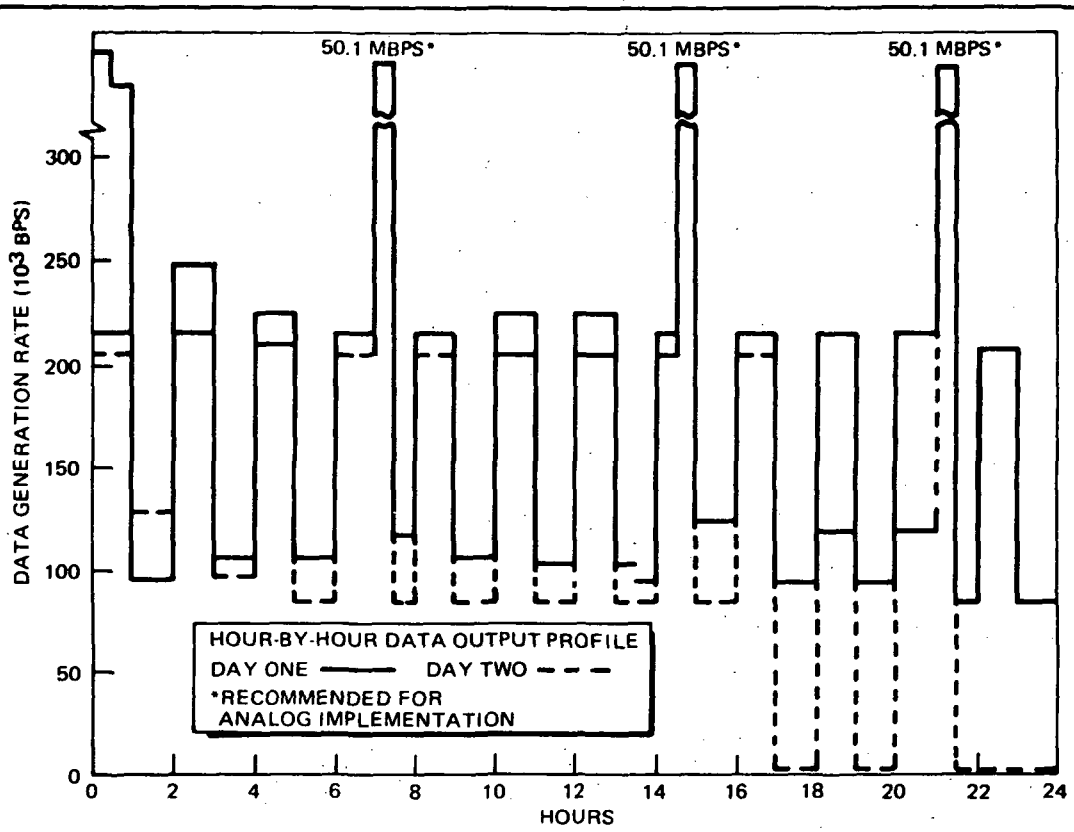


Figure 6-7. Composite Data Generation Profile – Typical Worst Case – Case 534-G

Real-time digital data requirements are shown in profile for one of the reference days in Figure 6-8. Analog data rates and the periods of operation are shown in Figure 6-9.

6.1.3 Real-Time Data Requirements

Digital data transmission requirements are established by the Multispectral scanner in the Earth Survey experiment package. A real-time requirement of one percent has been estimated. If this is interpreted to require transmission to the ground in digital form, a real-time requirement for transmission between 50 Mbps (1 percent of the operating time) and 500 Kbps (1 percent of the peak rate during 100 percent of the operating time) is required. If this real-time requirement is satisfied by transmission of the analog sensor output, the maximum digital transmission requirement is reduced to approximately 25 Kbps (as shown in Figure 6-8) with a 50 percent duty cycle. The off-peak rate varies between 9 and 14 Kbps (also as shown in Figure 6-8).

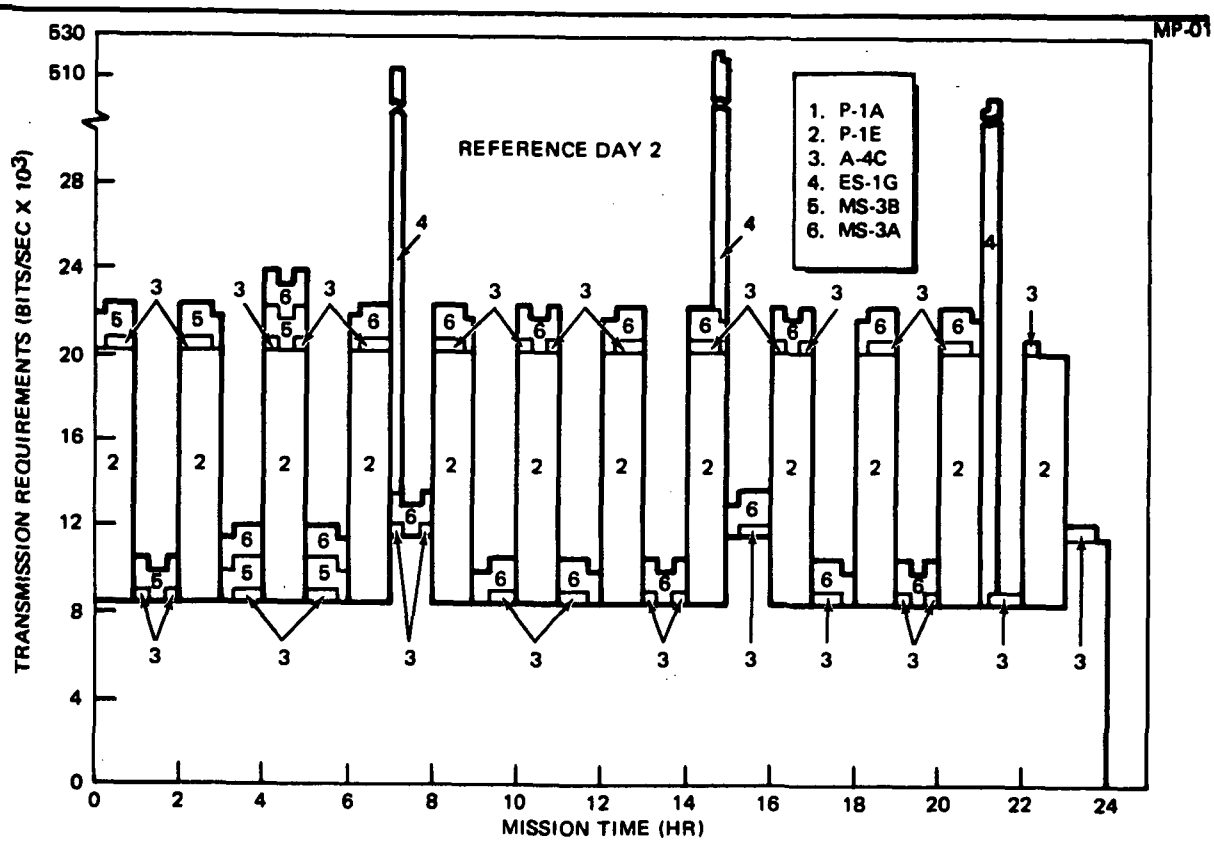


Figure 6-8. Real-Time Data Transmission Requirements

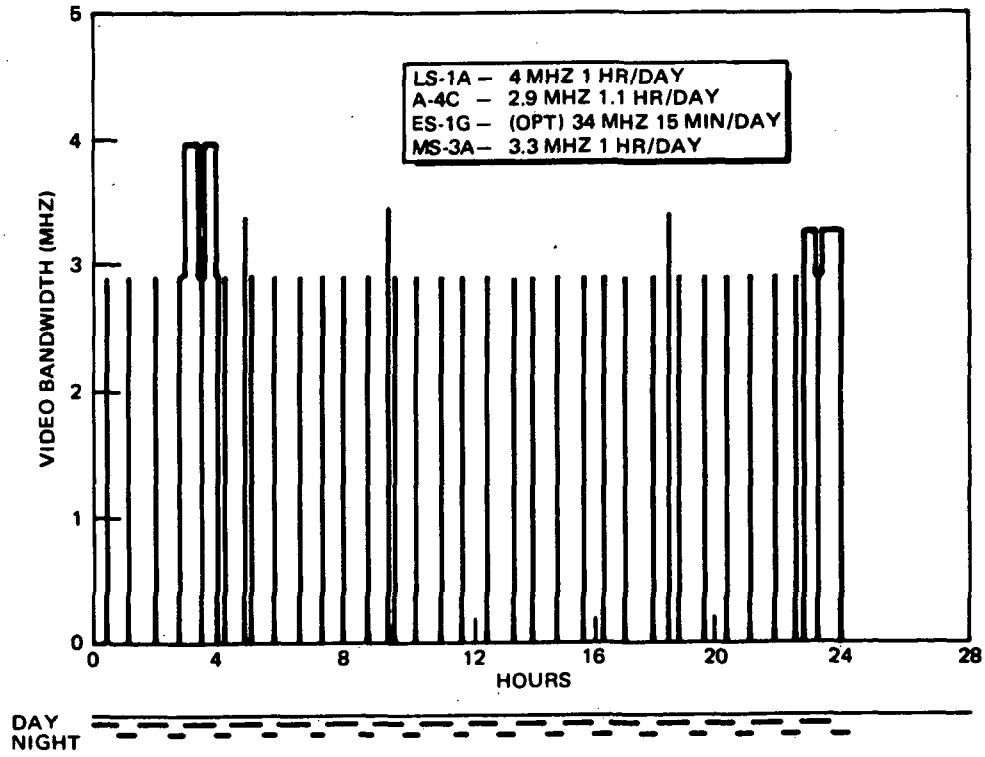


Figure 6-9. Real-Time Video Requirement – Day 1

Real-time analog requirements are well within the bandwidth capability of even the least capable system but, like the digital data, it is the coverage that determines the configuration. Data occurrence is uniformly distributed in time and probably cannot be scheduled to coincide with periods of coverage.

There may be some system flexibility to be found in the real time-lines requirements. If a few minutes delay can be tolerated, buffering would allow some bandwidth reduction and a chance for scheduling.

6.1.4 Data Processing

The onboard data management system will provide all of the onboard interface between man, data and ground. Functions provided will allow visibility and control necessary for operation of the experiments and acquisition of the desired data.

Table 6-2 lists data operations performed by the DMS that have been identified for data functions, control functions, service functions, safety functions, and data analysis functions. Analysis of the processing capability requires both identification of functions to be performed and the input characteristics of the data to be processed. Table 6-3 lists each of the experiments with detailed signal definitions.

6.1.4.1 Data Processing Assumptions

The following system design assumptions were used to establish the processing and buffer requirements:

A. Standard Interval Rate (SIR) of 50 per second was utilized.
B. Device control is always at a multiple of the SIR.
C. Scientific data is buffered at the source to match the standard interval.
D. Digital data rates greater than SIR x 256 are transferred direct to Bulk Memory.
E. All other scientific and monitoring data goes to the Central Processing Unit memory.

Table 6-2

DMS FUNCTIONS

- Data Functions
  - Acquisition
    - Sampling
    - Conditioning
    - Formatting
    - Limit checking
  - Trafficing
    - Data terminal control
    - Data tagging
    - Subsystem control
  - Evaluation
    - Limit checking
    - Computation
    - Display
    - Select data
    - Enhance
    - Correlate
    - Transform
  - Buffer
    - Real-time
- Control Functions
  - Initiation
  - Sequencing
  - Tracking
  - Timing
  - Display
  - Control processing
  - Checkout
  - Evaluation
  - Scheduling
  - Indexing
  - Motion compensation
  - Pointing or locating
- Service Functions
  - Maintenance
  - Data acquisition (correlative information)
  - Monitoring
  - Calibration
  - Store and retrieve
  - Status monitor
  - Buffer
  - Print
  - Acquire or generate ancillary data
  - Telemetry
- Safety Functions
  - Caution and warning
  - Limit testing
  - Sample
  - Alarm
  - Indicate
- Data Analysis
  - Image
    - Data select
    - Display
    - Interpret
    - Compare
    - Compensate
    - Correlate
    - Transform
    - Enhance
    - Filter
  - Spectral
    - Select
    - Display
    - Transform
    - Quantity
    - Compare
  - Temporal
    - Reasonable test
    - Limit check
    - Threshold
    - Trend
    - Count

F. Monitor and scientific data are available on single but separately addressable Remote Data Acquisition Units.

G. All data will be buffered in Auxiliary or Bulk Memory.

The level of concurrent data processing was determined by selecting any experiment that operated five or more days per week and 24 hours per day or the ratio of the hours operate to a 16 hour day. The latter to permit simplified scheduling for a six-man crew. Worst case experiments were selected from the remaining experiments. Data rates and quantities were shown in Table 6-1. Table 6-4 lists the processing requirement parameters assuming a Standard Base sample or control rate of 50 per second with source buffers up to 512 bits.

6.1.4.2 Frequent Data Processing Functions (High Utilization)

Any time a nontrivial function is performed on a set of scientific data words, W operations per second are added (W = repetitive rate x K + number of data words x L). For estimating purposes, the parameters, in addition to those given in Table 4, are listed with the following processing functions (K and L are shown in parenthesis):

A. Data handling, including sampling, data terminal control, data tagging, and real-time buffering (100, 10). The average time each data word remains in memory is assumed to be less than 5 sec.

B. Display a set of variables with binary to decimal conversion and limited formatting (250, 100); manual control processing is assumed to be negligible.

C. Temporal or accomplishing a limited operation on a data string for display or data analysis for the purpose of process or storage control (50, 16).

D. Stabilization support for an experiment platform and additional gyro readings for stability or pointing accuracy, not supplied by the GN&C subsystem, adds 20,000 operations per second and 4,000 words of main memory (ES-1G, Table 6-3).

E. Evaluation support (data enhance, correlate, or transform) is assumed to be similar to a Fourier transformation (150 x number of coefficients 75 + 15 x number of data points). The occurrence must be infrequent and on a limited amount of data.

Table 6-3

SUMMARY OF DATA CHARACTERISTICS

Experiment	Data Type	Sample or Message Size	Sample or Message Frequency	Displays	Controls	Pointing Accuracy/ Rate (deg)	Display (%)
A-4C Small UV Survey Telescope	Video	Image grame 525 TVL 35 mm	30 fps 96 fpd (35 mm)	TV monitor Attitude Attitude rate Focus and alignment Experiment mode and status Instrument mode and status	Subsystem Pointing Video system Focus and Align Mode control Instrument select Camera system		
ES-1G							
Metric Camera	Film	9 x 14 in.	2 fr/min	Status	Instrument mode	1/0.05/sec	
Multispectral Camera	Film	70 mm		Attitude	Pointing/tracking	2/0.05/sec	
Multispectral Scanner	Digital	TBD scan/sec	15 min 3 times/day	Attitude rate	Exposure	1.0/0.05/sec	
Microwave Scanner		1.3 MHz		Camera status	Gimbal control	1.0/0.05/sec	
Microwave Radar	Film (70 mm)	900 cm/Min		Gimbal position	Video control		
Multispectral Radiometer	Digital	9 bit/word, 2,700 bps	3 ch each with 100 words/sec	Location		0.5/0.3	
Scatterometer	Digital	3 ch 10 bit words	1,000 words/sec/ch	Video		2.5/0.05	
Multispectral Spectrometer		5 ch, 10 bit words	680 sps 27.2Kbps 4 sps 40.0Kbps	Camera system			
Polarimeter		10 ch, 10 bit word	16 sps			0.5/0.2	
Stellar Regerence Camera	70 mm	4 Cameras	2 fr/min				
Engineering Data	Digital	120 ch at 8 bit code	20 ch 16 B/S 83 ch 0.8 sps 1862 33 ch 40 sps bps				
LS-1A Minimal Life Support	Digital	3 ch at 10 bit/word or 10 ch at 10 bit/ word, or 40 ch at 10 bit/word	400 words/sec ch 40 words/sec ch 10 words/sec	Waveform Mode indication	Function control Data callup Mode control Video camera	N/A	100
	Video (Color)	Analog video frame	30 fps	Monitor			
MS-3	Video	High Resolution analog	1 to 4 fps	Monitor Temperature (14)			
A-1 Crystal Growth, Solution	Digital	19 ch 10 bit/word Various-physical electrical, optical, and x-ray analyses	1 word/sec/ch 10^4 100 sk bps	Press. (5)			

Table 6-3

SUMMARY OF DATA CHARACTERISTICS (Continued)

Experiment	Data Type	Sample or Message Size	Sample or Message Frequency	Displays*	Controls*	Pointing Accuracy/Rate (deg)*	Display (%)*
MS-3E	Digital	44 ch 10 bit/word	1 sps				
Super Cooling		10 ch 10 bit/word	10 sps				
		20 ch 10 bit/word	50 sps				
PIA Atmospheric and Margetu Science							
Photometric Cluster	Digital	128 ch 10 bit	64 sps				
Interferometer	Digital	4 ch 10 bit	1000 sps				
Scanner Spectrometer	Digital	1 ch 10 bit	2000 sps				
Euv Spectrometer		32 ch 10 bit/word	40 sps				
Particle Sensor		192 ch 10 11/11	128 sps				
Image Isocon		1 ch (2 frames/ sec 10 min) (800 line 5 bit code)	3 x 10⁶ bits/ frame				
Open Source Mass Spectrometer	2 ch 10 b	2 ch 10 bit/word	20 sps				
Closed Source Mass Spectrometer	2 ch 10	2 ch 10 bit/word	20 sps				
		1 ch 10 11/11	10 sps				
Neutral Gas Temp.		1 ch 10 11/11	50 sps				
Ion Mass Spectrometer		4 ch 10 11/11	20 sps				
Ion Trap		2 ch 10 11/11	50 sps				
Electro Static Probe		2 ch 10 11/11	25 sps				
Electric Field Probe		3 ch 10 11/11	30 sps				
Flux Gate Magnetometer		3 ch 10 11/11	30 sps				
Magnet Search Coil		1 ch 10 11/11	500 sps				
VLF Sensor		90 KHz on tape					
Aluminum Fail Samples							
A-3 Biological Separation	Digital	20 ch 10 bit/word	1 sps				
	Digital	10 ch 10 bit/word	10 sps				
	Digital	10 ch 10 bit/word	100 sps				
	Video	High res 3 ch Video					
	Digital	1 ch 10 bit/word	20 sps				

*Similar to data indicated for Experiments A-4C, LS-1A, and MS-3.

Table 6-3

SUMMARY OF DATA CHARACTERISTICS (Continued)

Experiment	Data Type	Sample or Message Size	Sample or Message Frequency	Displays*	Controls*	Pointing Accuracy/Rate (deg)	Display (%)*
A2 Crystal Growth Melt	Digital	30 ch 10 bit/word	1 sps				
	Digital	40 ch 10 bit/word	30 sps				
	Digital	2 ch 10 bit/word	10 sps				
	Analog	High res video 2 ch					
A-4 Biological Presser	Digital	20 ch 10 bit/word	1 sps				
	Digital	20 ch 10 bit/word	50 sps				
MS-3							
B-1 Crystal Growth Vapor	Digital	23 ch 10 bit/word	1 sps				
		20 ch 10 bit/word	50 sps				
B-2 Free Casting	Digital	60 ch 10 bit/word	1 sps				
		20 ch 10 bit/word	50 sps				
MS-3							
C-1 Metal Matrix Composites	Digital	36 ch 10 bit/word	1 sps				
	Digital	20 ch 10 bit/word	50 sps				
C-3 Preparation Glasses		62 ch 10 bit/word	1 sps				
		10 ch 10 bit/word	10 sps				
		20 ch 10 bit/word	50 sps				
C-2 Controlled Density Materials	Digital	47 ch 10 bit/word	1 sps				
		10 ch 10 bit/word	10 sps				
		20 ch 10 bit/word	50 sps				
MS-3							
D-1 Liquid Dispersions	Digital	27 ch 10 bit/word	1 sps				
		20 ch 10 bit/word	50 sps				
D-2 Glass Processing	Digital	82 ch 10 bit/word	1 sps				
		10 ch 10 bit/word	10 sps				
		20 ch 10 bit/word	50 sps				
P-1B Cometary Physics		1 ch 10 bit/word	2,000 sps				
P-1C Meteoroid		1 ch 8 bit/word	6 sps				
P-1E							
Scan Grate Spectrometer		1 ch 10 bit/word	2,000 sps				
Video Camera		1 ch 10 bit/word	100Kbps for 1 frame/min				
P-4C Test Chamber		10 ch 10 bit/word	1 sps				
		5 ch 10 bit/word	10 sps				
		5 ch 10 bit/word	100 sps				
		3 ch 10 bit/word	2,000 sps				

*Similar to data indicated for Experiments A-4C, LS-1A, and MS-3.

Table 6-4

PROCESSING REQUIREMENT ESTIMATING PARAMETERS

Experiment	Control Cycles/Sec	Wt	Average Cycles/ Second	Peak* Digital Words/Sample
ES-1G	218	1	218	50
LS-1A	41	1	41	50
MS-3A-1	5	0.04	0.2	40
MS-3A-2	42	0.12	5	40
MS-3A-3	52	0.16	9	20
MS-3A-4	52	0.16	9	20
MS-3A-5	52	0.16	9	20
MS-3B-1	52	0.08	5	20
MS-3B-2	52	0.08	5	20
MS-3C-1	1	0.08	0	36
MS-3C-2	12	0.08	1	10
MS-3C-3	62	0.08	5	20
MS-3D-1	52	0.04	2	20
MS-3D-2	63	0.04	3	20
MS-3E	62	0.08	5	20
A-4C	32	1	32	**
P-1A	526	0.5	268	40
P-1B	51	0.03	2	40
P-1C	35	0	0	1
P-1E	101	1	101	40
P-4C	63	1	63	10

*Words of data routed to the CPU memory (assume 10 bits packed 3 or 4 per CPU memory word).

**Majority is video or film.

F. Support and checkout functions include such items as DMS or experiment maintenance, scheduling, inventory management, and operational procedures or tutoral messages to the crew. The operations can usually be delayed resulting to no conflict to short term peaks in actual experiment processing. But a minimum capability of 50,000 operations per second and 10,000 words should be provided during most time periods.

G. Supervisor or subsystem control is assumed to be 20 percent of other data processing.

H. Contingency and growth capability should be included over and above explicit requirements. As with Support and Checkout, at least an average capability of 50,000 operations per second and 10,000 words should be provided.

6.1.5 Data-Processing Requirements Estimates

The estimated processing requirements are shown in Table 6-5 based on an examination of the selected quarters (16-12, Figure 6-5). The operations per second are based on the previous listed processing functions. Image processing support is not included or any other complex evaluation technique requiring a significant amount of processing. The latter can be supported if the occurrence is infrequent and can be accomplished within the excess capability during off-peak periods provided by items other than 1 and 6 in Table 6-5.

6.2 TRADE STUDY REVIEW

An analysis of the Modular Space Station configuration and operational requirements was made to determine their impact on Information Management System Trade study results from the 33-ft Space Station Study. These impacts are summarized in Table 6-6. In most of the trade studies, no significant changes in the conclusions were made. The basic factors producing changes were:

A. Changes in onboard data processing requirements due to the modular buildup process and performance of most RAM's experiment data processing within the RAM's modules.

B. Changes in the Modular Space Station launch date and experiment schedules.

Table 6-5

PROCESSING REQUIREMENTS SUMMARY

	Processing Function	Operations/ Second x 10^3	Main Memory Words x 10^3	Auxiliary or Bulk Words x 10^3 *1
1.	Data Handling (Packed 3:1) *3	118	60	(6.6×10^{10}) *2
2.	Display and Control	10	6	60
3.	Temporal (0.2 per word) *4	115	12	60
4.	Stabilization	20	4	20
5.	Evaluation (1 per minute) *5	18	12	60
6.	Support and Checkout	50	10	2,000
7.	Supervisor	60	14	20
8.	Contingency/ Growth	50	10	1,000
	Totals	441	128	3,220+ (*6)

*1 Words are assumed to be 32 bits of digital data.

*2 Average daily digital accumulation is given in parenthesis.

*3 Three 10-bit experiment words are packed in one CPU word.

*4 A ratio of simple operations to data words.

*5 60 coefficients and 1,200 data points.

*6 Buffer requirement determined by schedule restrictions and down link rates or tape weight restriction for the Shuttle.

Table 6-6

IMPACT OF MODULAR SPACE STATION ON 33-FT-DIA SPACE STATION IMS TRADE STUDIES

Trade Study	Impact	Rationale/Comments
Onboard vs Ground Processing Allocation	No significant change in allocation of onboard and ground processing functions.	Same kinds of functions required, but to a lesser degree during early mission phases.
	Onboard Modular Space Station experiment data processing requirements will be reduced by performing most RAM's data processing in RAM modules.	Later launch will permit use of more capable onboard processing equipment. Increased CPU and memory speed as well as reduced weight, power, and volume will make onboard processing more attr attractive to reduce data stored for for Shuttle return or transmission to earth via RF.
Onboard vs Ground Checkout	Autonomous checkout still preferred due to lower cost and increased importance in assembly of Modular Space Station in orbit.	Two modules (Crew Operations No. 1 and Crew Operations No. 2) will require ancillary checkout equi equipment during factory and prelaunch checkout, since these modules do not have separate computing facilities.
Degree of Centralization or Decentralization	Consolidation of dedicated guidance and navigation and biomedical processors into subsystem and experiment multiprocessor facilities.	Experiment modules will have local processing, thus reducing Modular Space Station processing requirements, easing consolidation.
		Separate guidance and navigation computer requirements deleted from guidelines and constraints.

Table 6-6

IMPACT OF MODULAR SPACE STATION ON 33-FT-DIA SPACE STATION
IMS TRADE STUDIES (Continued)

Trade Study	Impact	Rationale/Comments
Specialized vs General-Purpose Processors	Requirements for dedicated general purpose guidance and navigation and biomedical processors deleted.	See Centralization or Decentralization above. General-purpose processors in reconfigurable multiprocessor configuration still best choice for flexibility, availability, maintainability and other considerations.
Physical vs Radio Frequency Return of Data to Ground	Use of both return methods still required.	Allocation of data return methods is independent of Space Station modularity and depends on Space Shuttle and communications link capabilities, as well as program requirements for quantity and timeliness of data returned.
Centralized vs Decentralized Ground Data Processing	Slower buildup of personnel and facilities required. Allocation of data reduction processing functions to centralized or decentralized computing facilities required further consideration.	Reduced operations during early years and postponement of Space Station launch. Program postponement permits utilization of more capable computing and communications facilities. Best approach depends on these facility advances and relative costs.

Table 6-6

IMPACT OF MODULAR SPACE STATION ON 33-FT-DIA SPACE STATION
IMS TRADE STUDIES (Continued)

Trade Study	Impact	Rationale/Comments
Data Storage Subsystem	Ultra-high density magnetic tape for bulk storage still preferred for storage density and handling convenience.	Location of separate magnetic tape facilities near primary and secondary control stations for tape change accessibility reasons.
	Bubble memory preferred for auxiliary memory.	Significant speed, reliability, weight, power, and volume advantages over magnetic disks potentially achievable.

Consideration of these factors resulted in the consolidation of onboard data-processing equipment into two multiprocessing computing facilities: one dedicated to subsystem support and the other primarily for supporting experiment operations with a capability to perform selected subsystem operations in event that the subsystem computing facility is not operational. Both facilities will be capable of modular buildup to efficiently accommodate the buildup in subsystem and experiment computating requirements during the 10-year life of the program. The modular buildup capability in the experiment data processing facility will permit the accommodation of significant variations in the experiment program as this program becomes better defined.

Postponement of the Modular Space Station launch date and changes in the experiment program schedules will allow the utilization of more capable onboard and ground computing equipment than was considered in the 33-ft Space Station study. Advances in onboard computing system and Modular Space Station to ground communications capabilities will enable a more efficient and more timely experiment program. Advances in ground data processing and ground communications capabilities will enable faster and more thorough data reduction prior to dissemination to users and investigators.

Section 7
LONG-LIFE ASSURANCE AND SAFETY

The long-life assurance and safety analyses conducted on the Modular Space Station are discussed in the following subsections.

7.1 LONG-LIFE ASSURANCE STUDIES

The long-life assurance tasks have been conducted in close support of the design studies to determine preferred configuration for a Modular Space Station and to develop top-level program and project goals and requirements. These were developed from estimates and data resulting from the other study tasks and provided reliability predictions, failure modes and effects analysis, a critical items list, redundancy requirements, maintainability and maintenance requirements and life requirements.

The long-life assurance studies have taken full advantage of the previous studies for a 10 M Space Station. Some of the estimates have been developed by extrapolation from these previous study results. The analytical philosophy and methodology are the same and are not repeated here.

The following performance estimates summarize the analytical findings and performance estimates which are described in the sections entitled Reliability and Maintainability.

Availability for manning at 90 days (probability)	0.97
Availability for mission operations (probability) for 120 days	0.96
Design improvements for redundancy and onboard spares weight to achieve availability	ISS 1,633 kg (3,600 lb) GSS 2,041 kg (4,500 lb)

90-day resupply of maintenance spares (scheduled replacement and random failures)	ISS 773 kg (1,550 lb) GSS 1,211 kg (2,670 lb)
Maintenance man-hours per month (MMH/mo.) corrective and preventive	ISS 65 (MMH/mo.) GSS 105 (MMH/mo.)

The following conclusions resulted from evaluation of the long-life study:

A. The modular concept does not materially affect operational availability; however, there is an increase in maintenance man-hours over those for a similarly complex large volume station.

B. Sequential buildup in space represents an appreciable amount of work and the periods of unmanned operation materially increase the risk of loss prior to permanent manning over that for a station manned on the next available launch.

C. Packaging of subsystems to provide look-alike installations of common items desired for maintenance efficiency is more difficult than with the 10-m-dia, 4-level type station.

D. On-orbit maintenance greatly influences interior arrangements and subsystem design.

E. The possibility of returning any Space Station module to Earth for major maintenance is not precluded by the configuration.

F. The designs presented provide the required access for subsystem and pressure shell maintenance.

G. No scheduled EVA maintenance is necessary. EVA repair will be required for a limited number of items where it is impractical to design for pressurized access.

H. The maintenance work load for corrective and preventive maintenance will require less than 5 percent of crew duty time.

I. Equipment reliability and wearout reduction techniques already available for space hardware will reduce equipment repair frequency to a reasonable level.

J. The fault isolation capability of the onboard checkout system will minimize the incidents of incorrect diagnosis (removal of wrong component) and minimizes crew skill requirements.

The conclusions from the earlier study of a 10-M Space Station are still valid. They are:

A. Long-life designs will result from pursuit of good design practices following the characteristic reliability and maintainability concepts. No new technology is required.

B. The limited-life items and mission-critical items identified are amenable to contractor specification and control.

C. Initial spares and resupply requirements are not excessive and can be readily managed. Cost-effective measures must be employed to control ground stocks as well as procurement and repair activities to maximize availability and minimize costs over the 10-year mission period.

D. Maintenance will not cause an inordinate drain on astronaut time. It is expected that no repair task will require a crew response time so short as to precipitate crew error.

The detailed analyses follows, divided into reliability and maintainability.

7.1.1 Reliability

The reliability analyses have been directed at design support for the several trade studies and special emphasis tasks. They have covered only implicit portions of subsystems required to accomplish explicit operations essential to the Modular Space Station mission, such as solar panel deployment and initial battery power prior to full battery complement. There has been no general update of subsystem reliability (availability) predictions. Instead the detailed analyses for the 10-m station have been evaluated and comparisons drawn to derive estimates for the expected Modular Space Station subsystems. These are represented in the following paragraphs. The study reliability analyses are discussed under the subheading of buildup, critical subsystems, availability predictions, and spares/redundancy.

The Modular Space Station availability is a measure of the capability to withstand the imposed environments from initial launch (T = 0) until required for specific experiments and then to function properly during the experiment time to assure collection of the required experiment data. This is illustrated

by the simple model, Figure 7-1: Blocks 2.0, 4.0, 5.0, 7.0 and 8.0 are related to buildup. Blocks 10.0 and 11.0 and subs are related to on-orbit operations. Each of the blocks assume both a successful operation function and a repair of malfunction function. The launch operations blocks (1.0, 3.0, 6.0, and 9.0) are inserted only for continuity. No predictions of Shuttle launch probabilities were developed. The subject, Buildup, is discussed only from the qualitative point of view. All quantitative estimates for reliability and availability are discussed under the availability subsection.

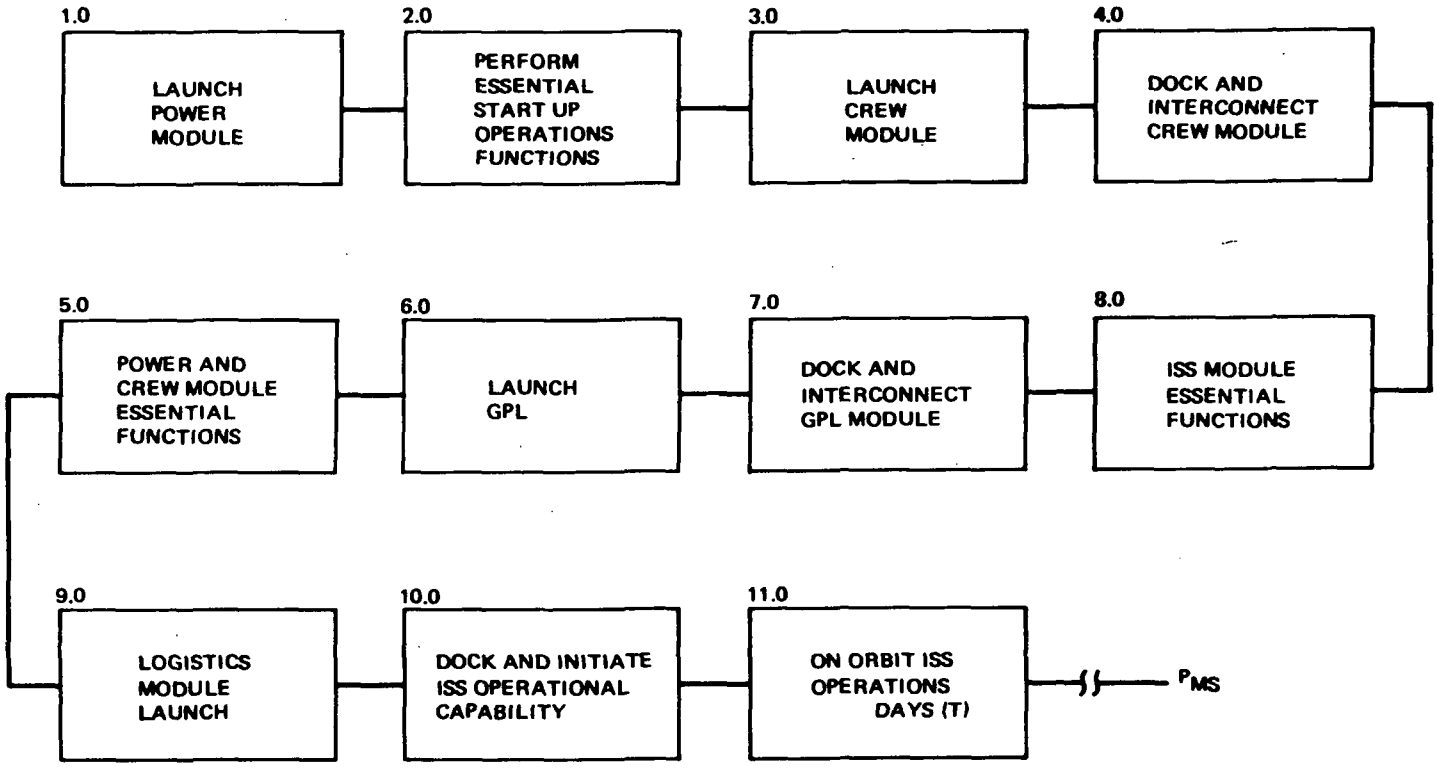
The Failure Modes Effects and Criticality Analysis (FMECA) conducted to the major module and component level for the 10-m Space Station was reviewed and updated to reflect the subsystem changes applicable to the Modular Space Station. This FMECA was issued as an internal document for record purposes. The FMECA has been distributed to the NASA MSFC S&E qualification office and to other interested personnel in that form and is not included in this report.

7.1.1.1 Buildup

The Modular Space Station is built up to manning status by a series of module launches and assembly in orbit. The scheduled time from initial launch to manning is 90 days. Each module has certain dedicated subsystems equipment. Some equipment is distributed so that the components in one module can provide a backup for other modules. For example, all of the solar panels for generating electrical power are on the first module (Power/Subsystems Module). During operations, the battery complement is distributed with two batteries in each module, providing a high level of redundancy.

In order to meet the specified module design to mass of 9,072 kg (20,000 lb), studies were made to determine which equipment could satisfactorily be left out of the module until after buildup. These items would have priority for the initial logistics flight.

The reliability analysis for the buildup time period was directed at the identification of equipment that must be used, and for how long, to assure Space Station life until manning. Subsystem requirements for the Power



NOTES:

1. FUNCTIONS 1.0, 3.0, 6.0, 9.0 REFER TO SHUTTLE FLIGHT AND PAYLOAD HANDLING OPERATIONS
2. FUNCTIONS 2.0, 4.0, 5.0, 7.0, 8.0, 10.0, 11.0 REFER TO MODULE EQUIPMENT FUNCTIONAL OPERATION

Figure 7-1. Modular Space Station System Reliability/Availability Model

Module during its initial orbit operation are shown in Table 7-1. The Module 2 Launch column indicates subsystem status, desired for a normal buildup event. A parallel study was directed at the definition of the sequence of events leading to buildup. This scheduled equipment functions with regard to facility considerations and the length of time required. For example, the reliability analysis identified that power requirements for communications, thermal control, etc., necessitated the early deployment of solar panels and identified equipment items required to extend and activate the solar panels and maintain power generation. These analyses to identify required functions became the basis for the initial 30-day power module availability estimates. The sequence of events analysis identified the time required for each event and preferred sequence from Shuttle lift-off through module verification and orbiter return to assure that the events did not require an inordinate orbiter stay time. These analyses provided a check and balance on equipment in use and provided the basis for some on-time estimates.

The Buildup operations events analysis, Table 7-2, lists buildup events/functions; required equipment or subsystems, and failure mode; and the preferred failure correction method. Each event has been given a corrective method code to permit rapid assessment of which events are of greatest concern. Events that were common from module to module were not identified in the narrative analysis for subsequent modules and risk values for the first module were simply added in the second module risk analysis to obtain availability estimates for initial operation. Many of the functions were found to require man to correct failures or resort to module return. Manned intervention is limited to correction of failures where his superior analytical capability and ability to scavenge a repair part from a less critical subsystem can be utilized to support initial start-up operations. Spares are assumed not available for just launched modules, however, they would be carried up on the next launch to repair failures identified on modules already in orbit.

A specific area of interest was the intermodule connections required during buildup. The connections are shown schematically in Figure 7-2. A typical list indicating the module-to-module connections is given in Table 7-3.

Table 7-1

POWER MODULE SYSTEM STATUS

Major Systems	Status at Separation	Dormant Monitor	Module 2 Launch
Attitude Control	On	Yes	√√
RF Communications	On	Yes	√√√
Thermal Control	On	Yes	√√
Lighting	Off	No	√
High-Thrust Propulsion	On	Yes	√√
DMS Computation	On	Yes	√√√
DMS Data Acquisition	On	Yes	√√
DMS Display and Control	Off	No	√
Power Solar Array	Deployed	No	√√√
Power Orientation	On	Yes	√√
Power Regulation	On	Yes	√
Power Conditioning	On	Yes	√

√√√ Highly Desirable √√ Desirable √ Not Required

Table 7-2

BUILDUP OPERATIONS EVENTS ANALYSIS - ISS POWER MODULE

Item No.	Buildup Event/Function	Required Equipment or Subsystem and Failure Mode	Failure Correction Method	Code*
2-1	Electrical power from batteries	Batteries are connected to essential bus at launch Batteries are connected in series -112V (4 at 28V each) and connect through a voltage regulator	Failure is indicated by failure of communication data link (2-2) after data management and communications are turned on (2-3)	B
2-2	Verify electrical power available	Initial actuation from Shuttle turns on OCS data collection for essential subsystems, command and control and communications link	Failure is indicated by failure of communications link. Any loss of commun. will require manning to assure power on bus and command and control available	M
2-3	Turn on subsystems	Following subsystems required: Communications GN&C - Gyros and Horizon sensors (may be on at launch) EC/LS - Thermal control. Note: Guidance and control is provided by Shuttle orbiter until final test prior to separation	Any failure below a minimum level required for antenna deployment will require manning to repair subsystem	M

*Code: B = Backup equipment (redundancy); M = Crewman Assist; R = Possible module return

Table 7-2

BUILDUP OPERATIONS EVENTS ANALYSIS - ISS POWER MODULE (Continued)

Item No.	Buildup Event/Function	Required Equipment or Subsystem and Failure Mode	Failure Correction Method	Code*
2-4	Deploy solar masts	Motor drive mechanism rotates supports into 180 deg orientation (mast drive rotates one-support 180 deg). Inboard and outboard support assemblies must lock to form rigid beam	Inboard and outboard support assemblies are separate. It may be possible to provide a temporary interconnect to assure synchronized rotation. However, bound arrays also provide beam strength that will transfer loads and provide interconnect for quadrant orientation. Failure necessitates man assist. Failure in rotation mode will prevent restowing and return of module. Man must proceed to mast drive area and repair mechanical failures	B M
		Each strip (20 to 28 strips per array) is bound in a foam covered package held with two explosive nuts. All (40 to 56) nuts must blow on command to permit array extension	Design ordnance system to permit repeated applications of power to explosive nuts during the time that crews are preparing for EVA. Provide sensors on support extension system to show lack of travel indicating Failure of one or more bolts to release.	B

*Code: B = Backup equipment (redundancy); M = Crewman Assist; R = Possible module return

Table 7-2

BUILDUP OPERATIONS EVENTS ANALYSIS - ISS POWER MODULE (Continued)

Item No.	Buildup Event/Function	Required Equipment or Subsystem and Failure Mode	Failure Correction Method	Code*
2-4	Deploy solar masts (Cont'd)		System should have frangible nuts on each end of bolt (redundancy). Failure of any one bolt will necessitate EVA to cut bolt (between nuts) and release panel	M
2-5	Extend solar panels	The panels are extended by means of an articulated truss mast (astromast). Extension draws out two guide cables for each strip and the diagonal guy wire. These have take up motors to tension the system and help take acceleration loads	Jambed strip guide wires or a jambed diagonal cable will prevent extension (and later retraction for repair). Individual strips are attached to outboard supports by a separate motor-driven pull-out reel. Therefore, a single jambed strip guide wire or tension spring would cause that strip to jamb and the remaining strips could extend. If a strip does not extend, this will necessitate EVA repair of the failed drive mechanism	M

*Code: B = Backup equipment (redundancy); M = Crewman Assist; R = Possible module return

Table 7-2

BUILDUP OPERATIONS EVENTS ANALYSIS - ISS POWER MODULE (Continued)

Item No.	Buildup Event/Function	Required Equipment or Subsystem and Failure Mode	Failure Correction Method	Code*
2-6	Orient Solar Panels (GB-20)	Sun sensors located on each panel provide the information for optimum panel orientation for power output. Orientation requires two drive mechanisms in the orientation drive and power transfer turret. Rotational drive utilizes a harmonic drive coupling with a DC brush-type drive motor. A similar motor drives the gimballing mechanism. Check for solar array power output.	Sun sensors will be installed redundantly to permit delay in repair until both sensors on either array fail. Replacement requires EVA travel. Optimum positioning should not be required during buildup due to low electrical load. However, positioning should provide at least 50 percent power. Orientation drive motors, gear drives, bearings, and pressure seals are all accessible and replaceable from within the power drive turret on the end of the tunnel.	M
2-7	Connect solar panels to batteries	Either solar array or both can be connected to either or both of the battery systems through the battery chargers. Proper connection requires closing at least three bus switches, current flow through the source bus, and	Redundant solar power sources to the source bus and redundant battery (CBR's) banks provide high tolerance to failure without necessitating shutdown. All units listed are replaceable as components	B

*Code: B = Backup equipment (redundancy); M = Crewman Assist; R = Possible module return

Table 7-2

BUILDUP OPERATIONS EVENTS ANALYSIS - ISS POWER MODULE (Continued)

Item No.	Buildup Event/Function	Required Equipment or Subsystem and Failure Mode	Failure Correction Method	Code*
2-7	Connect solar panels to batteries (Cont'd)	operation of four battery chargers, each connected in the circuit by two switches. Batteries are charged in parallel and output is in series through the buck regulator. Proper operation requires all chargers to function in order to recharge batteries	(switches, source bus regulators, chargers, and battery modules.) The batteries may be repaired by replacing individual four cell 2.8V modules which indicate an open, short, or high resistance characteristic. Battery life (scheduled replacement) is two years. Battery chargers and voltage regulators will have solid-state devices permitting plug-in replacement of separate functions	M
2-8	Provide thermal control	Thermal heating of radiators is necessary to prevent freezing of freon or H_2O. Also, electronic equipment requires cooling for reliable operation. Requires H_2O pump, heat exchanger, cold plates, freon pump, and thermal radiator loop.	Each pump system (H_2O and freon) is redundant. If the H_2O freezes in the interface heat exchanger, the freon loop can be warmed by bypassing the radiator or solar heating the outlet end to thaw the IFHX. If this fails, the	B

*Code: B = Backup equipment (redundancy); M = Crewman Assist; R = Possible module return

Table 7-2

BUILDUP OPERATIONS EVENTS ANALYSIS - ISS POWER MODULE (Continued)

Item No.	Buildup Event/Function	Required Equipment or Subsystem and Failure Mode	Failure Correction Method	Code*
2.8	Provide thermal control (Cont'd)	Monitor temps in H_2O and freon loops	IFHX may crack and have to be replaced or at least thawed with external heat	
2.9	Turn on data management/OCS	Computer software should be designed to monitor critical parameters to determine switchover requirements	Data furnished to ground will permit minimum switchover capability. No repair capability unless resort to scavenging from less critical equipment	M
2.10	Separate and initiate Power Module Autonomous operation	All subsystems except life support and crew systems must function until next rendezvous (or until selected time to manning). Shuttle maintains loiter until ground gives okay for 30-day operation. Retract (close) meteoroid doors on end docking port	Power Module could be redocked for emergency intervention if necessary. If no failure is indicated within two hours, orbiter may deorbit. Estimate indicates orbiter lands at approx 24 hr after launch	M
4.0	Dock and interconnect Crew Module			
4.1	Command docking doors on Power Module and docking mechanism to extend. Same for Crew Module	Meteoroid door actuators on Power and Crew Modules. Docking ring shock struts must extend	No repair on Power Module - Go to alternate docking port. If failure occurs on Crew Module,	R

*Code: B = Backup equipment (redundancy); M = Crewman Assist; R = Possible module return

Table 7-2

BUILDUP OPERATIONS EVENTS ANALYSIS - ISS POWER MODULE (Continued)

Item No.	Buildup Event/Function	Required Equipment or Subsystem and Failure Mode	Failure Correction Method	Code*
4.1	Command docking doors on Power Module and docking mechanism to extend. Same for Crew Module (Cont'd)		preventing dock, return module.	
4.2	Lock modules together	Docking rings must be oriented, latching links must engage, hook actuator must rotate to engage all hooks (12 on each module) and seals must inflate prior to manning	If locks or seals will not actuate on Power Module, separate and dock to another port. If crew module docking capability is damaged, return module.	R M
4.3	Man module to check security of docking and to mate intermediate connectors	Proceed into crew module for initial inspection. Interconnect power connectors to obtain power and thermal control and EC/LS first.	Adjust outputs as required and repair malfunctions by scavenging from less critical subsystem as available.	M
4.4	Turn on subsystems	Electrical power, thermal control, EC/LS, and data mgmt. system are primary requirements for leaving crew module on orbit.	Repair malfunctions by adjustment or scavenging from less critical subsystem as available.	M

*Code: B - Backup equipment (redundancy); M = Crewman Assist; R = Possible module return

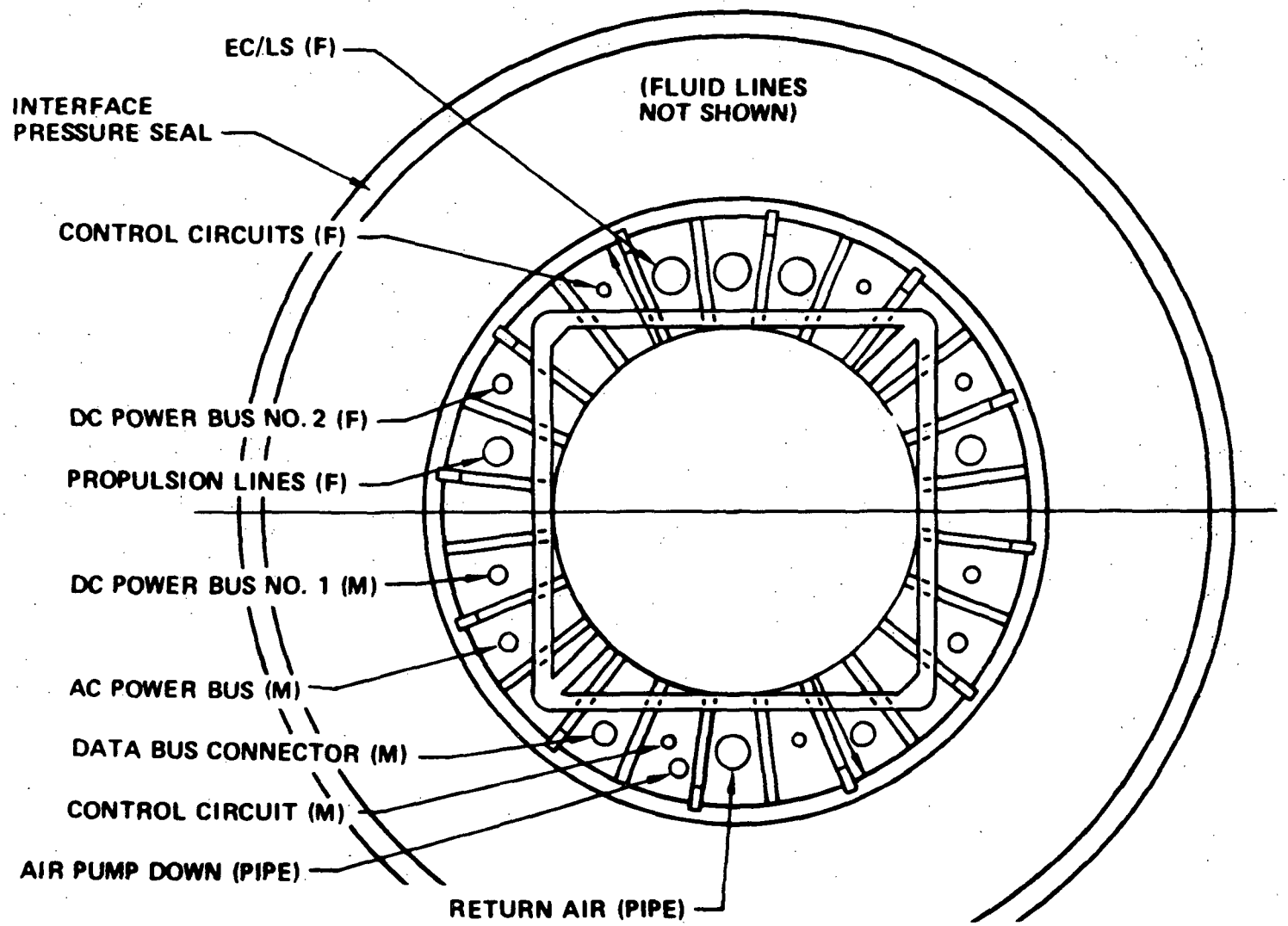


Figure 7-2. Interface Connections

Table 7-3

MODULE-TO-MODULE INTERFACES

Crew/Operations Module	Power Module	GPL	Logistics Module
1/2 in. O_2	X	X	X
1/2 in. N_2	X	X	X
3 in. vacuum	X	X	
2 in. air accumulator	X	X	
2 in. airlock repressurization	X	X	
6 in. air	X	X	X
3/4 in. coolant H_2O	X	X	
3/4 in. heating H_2O	X	X	
1/2 in. urine		X	
1/2 in. condensate H_2O		X	
1/2 in. potable H_2O		X	
1/2 in. wash H_2O		X	
3/8 in. GN_2	X		X
3/8 in. N_2H_4	X		X
1/2 in. N_2H_4	X		
1/4 in. CO_2(2)	X	X	
Caution and warning (2)	X	X	X
Thruster control (2)	X	X	
Data bus (2)	X	X	
115 vdc (4)	X	X	X
115 vac (2)	X	X	

Table 7-4 indicates the types of connections under consideration for each line type, along with safety backups envisioned. Some of the backups are illustrated in Figures 7-3 through 7-5. A mock-up of the interface area with docking ring was prepared to evaluate access (Figure 7-6). The time estimates for interconnect are shown in time-line format in Table 7-5. These same estimates are allocated to subsystems in Table 7-6.

The detail time estimates showing space correction factors used in preparing these two tables are shown in Table 7-7.

The intermodule connections were elected to be accomplished manually rather than as a function of the docking operation because of the consequences of a high force applied to a slightly mismated connector. After module docking by the orbiter, power and control must be applied to both the orbiting and docking module to energize the strut retracting motion to lock the modules and seal the mating face. Docking completion information is furnished to the mating crew aboard the orbiter before the crew enters the docking module. Upon receipt of docking verification and verification of no hazard in either module, the two crew members enter the module and proceed to visually verify the module condition, visually observe the interface volume, equalize pressure across the dome, open the first access door and then carry out the interconnect tasks. Module safety verification and access to the interface area, Mechanical Task No. 1 in Table 7-5, was not included in the time-line.

Establishing electrical power to the arriving module is of first importance. The task analysis indicates that the two men could be utilized to handle electrical and mechanical tasks to minimize hookup time. With this concept of work allocation, it should be possible to accomplish the module interconnection and start-up in less than five hours elapsed time. The time required is of interest from the consideration of initiating equipment function within time constraints (thermal control) and for minimizing the on-orbit stay time for the orbiter (5-day max). Therefore, the design of module mating interconnects and constraints on accomplishing the connection and verification should be accorded special attention during design development in Phases C and D.

Table 7-4

INTERFACE CONNECTOR TYPES

Line Type	Connection	Safety Backup
Fuel (N_2H_4)	Conoseal/flange	Evacuated outer sleeve*
High pressure, (3500 psi, N_2)	Conoseal/flange	Pressure bag*
Medium pressure (300 psi; air)	Quick disconnect	Pressure bag*
Low pressure (15 psi; N_2, O_2, CO_2)	Quick disconnect	-*
Ambient air and vacuum	O-Ring/flange	-*
Fluid (H_2O)	Quick disconnect	Condensation bag*
Electrical (Hardwire signals)	36-pin standard plug	-
Electrical (power)	8-pin standard plug	Nonarcing connector
Electrical (data bus)	Coaxial cable	-

*Gas and fluid lines can have electrical interlocks installed so that in the event of accidental demating, shutoff valves automatically close

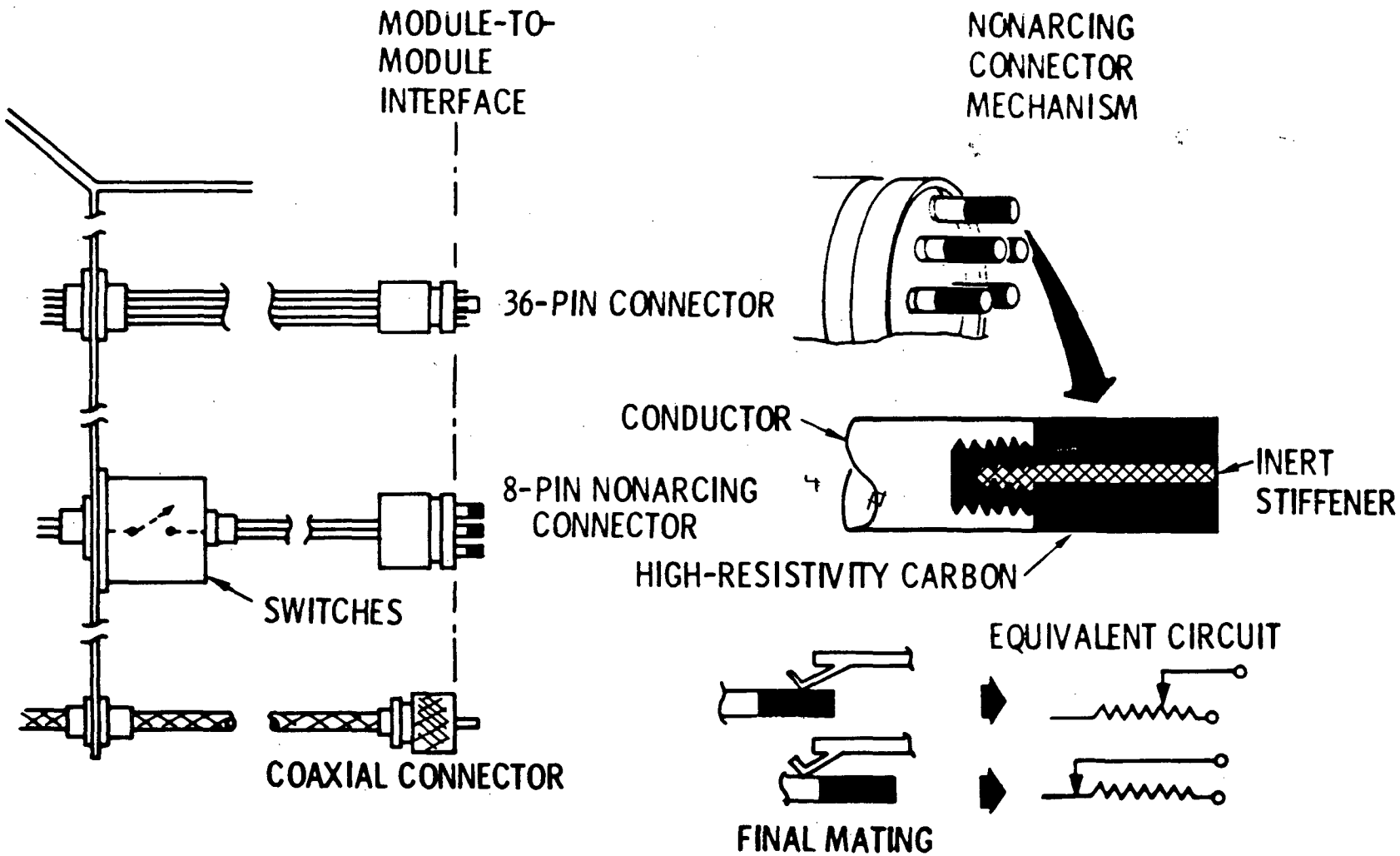


Figure 7-3. Electrical Interface Connection Concepts

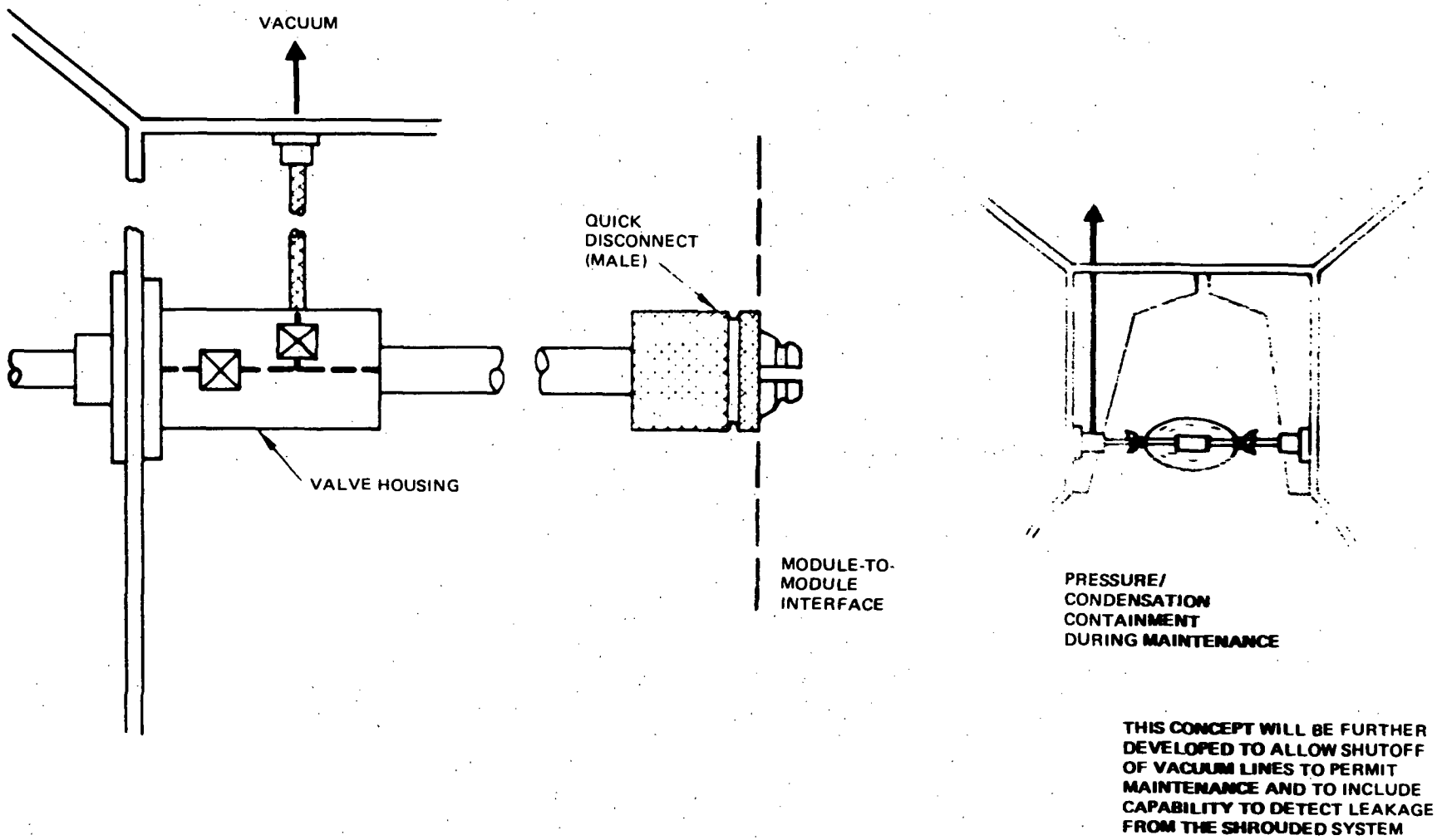


Figure 7-4. Low-Pressure/Fluid-Interface Connection Concept

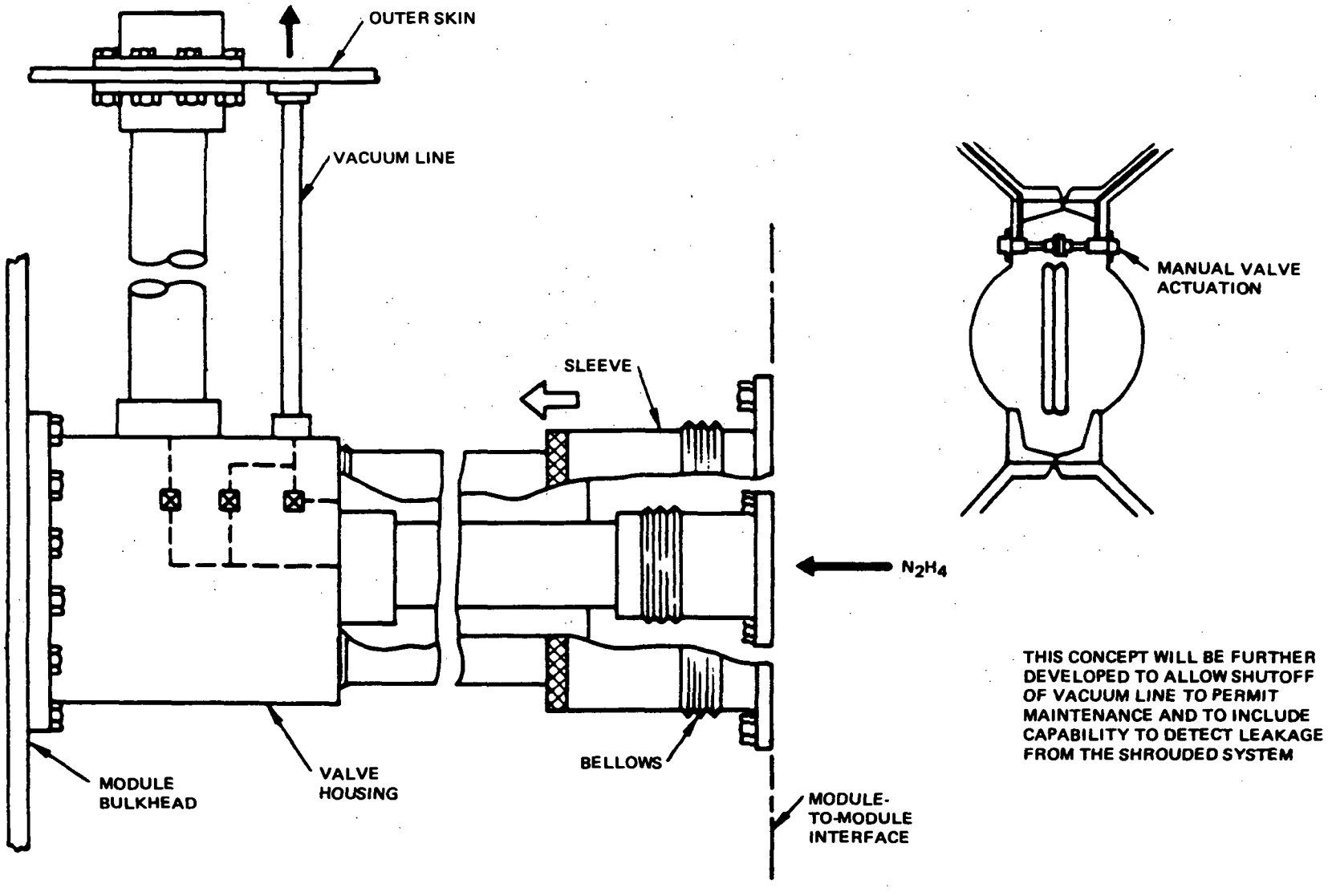


Figure 7-5. N_2H_4 Interface Connection Concept

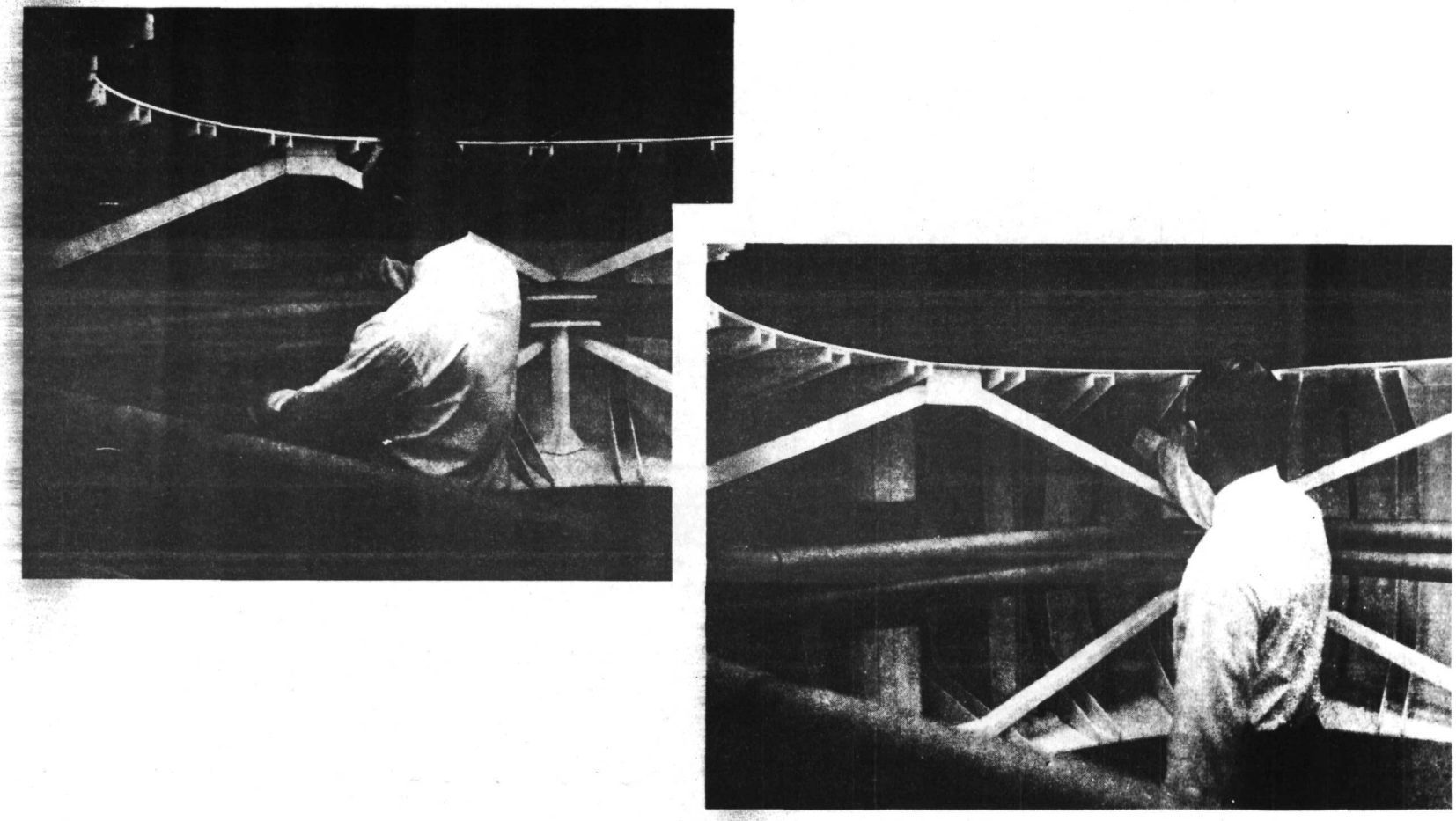


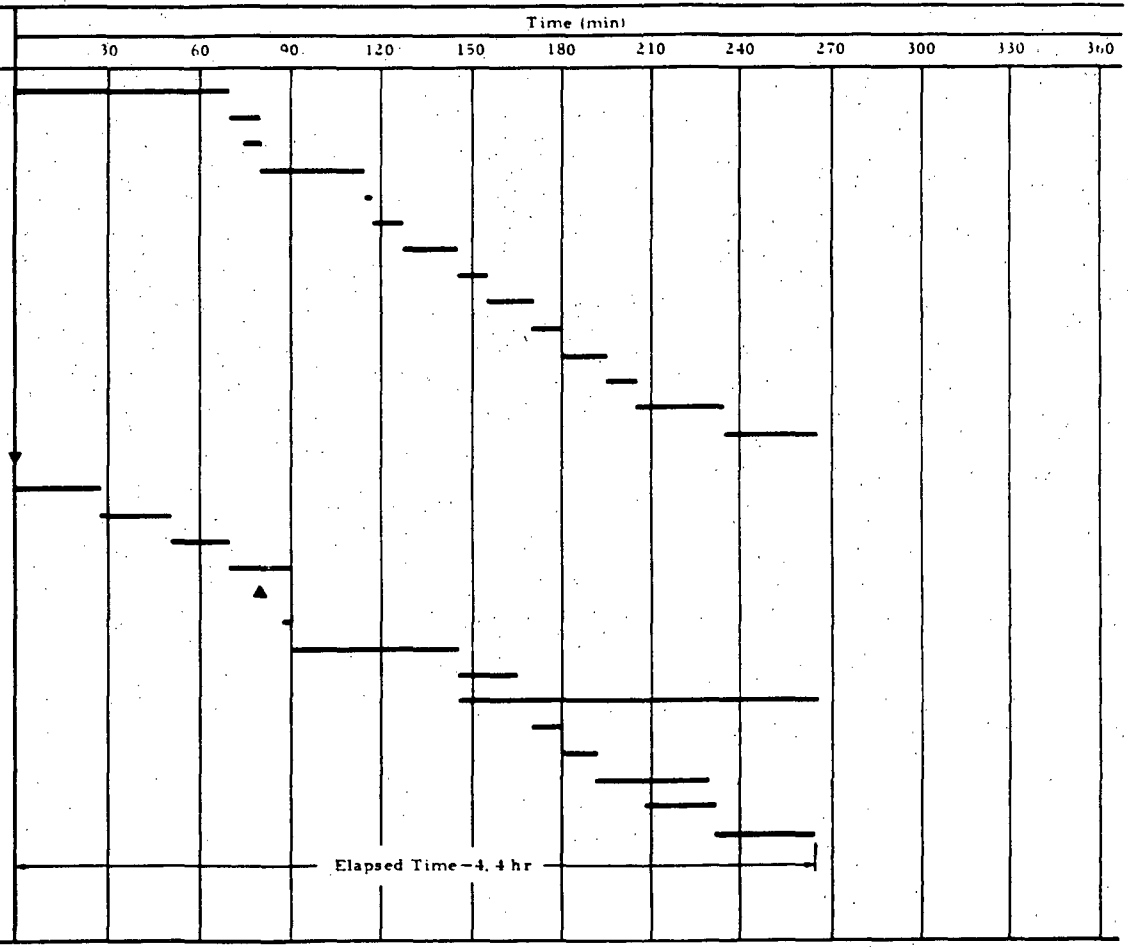
Figure 7-6. Interface Connections

Table 7-5

MODULE INTERCONNECT TIME LINE (CREW)

FUNCTION: Module Interconnect – Crew to Power LOCATION: TIME LINE SHEET:

Spec	Task Sequence	Function and Corresponding Tasks (If Applicable)	
Electrical	1	Connect dc power bus	(4)
	2	Test dc power	
	3	Turn on thermal control, verify	
	4	Connect control circuits (C and W)	(2)
	5	Remove helmet and gloves	
	6	Verify caution and warning	
	7	Connect data bus	(2)
	8	Verify data bus	
	9	Connect control circuits – propulsion	(2)
	10	Verify control – propulsion	
	11	Connect ac power bus	(2)
	12	Verify ac power	
	13	Verify electronic subsystems	
	14	Prepare modules for unmanned operation	
Mechanical	1	Verify safety, open hatch to mate area	
	2	Connect O_2, N_2 lines	(2)
	3	Connect conditioned air	
	4	Connect contaminated air	
	5	Turn on A/C and verify system condition	
	6	Open module hatch	
	7	Remove helmet and gloves	
	8	Connect propulsion lines (N_2H_4)	(2)
	9	Connect GN_2, CO_2 lines	(2)
	10*	Verify no leakage – propulsion	
	11	Verify control – propulsion	
	12	Connect remaining fluid lines	(2)
	13	Verify no fluid leakage	
	14	Verify mechanical subsystems	
	15	Prepare modules for unmanned operation	
Buildup		Crew to Power Module	



*Two hour no leak verification desirable prior to orbiter disconnect or deorbit

Table 7-6

MODULE INTERCONNECT TIME

Subsystem	Crew Operations No	Crew Operations Time	GPL No	GPL Time	Logistics Module No	Logistics Module Time
Electrical Power (min)	6	105	6	105	4	55
EC/LS (min)	6	82	10	106	3	23
Propulsion (min)	4	72	1	9	2	48
Data Management (min)	2	28	2	28	-	--
Command Control (min)	4	70	4	70	2	25
Verification-Fluid Connectors (min)		120		120		120*
Total Man (min)		487		438		271
Elapsed Time (See Time-line) (hr)		4.4		4.4		2.0
Demate - Elapsed Time (hr)		2.7		2.7		1.8

*Verification concurrent with crew and cargo transfer operations

Table 7-7

DETAIL ESTIMATES - INTERFACE CONNECTIONS TIME (min)

Connection (See Table 7-3)	Number Required	Unstow, Mate, Torque, Secure	Correct* for Space Environment	Total Hookup Time	Test and Checkout	Total (Connection)
Electrical						
DC Power Bus	4	5	3.5	70	10	80
AC Power Bus	2	5	1.5	15	10	25
Data Bus	2	6	1.5	18	10	28
Control Circuits	2	5	3.5	35	10	45
Control Circuits	2	5	1.5	15	10	25
Mechanical						
EC/LS-O_2, N_2	2	4	3.5	28	20	90
Air Ducts	2	6	3.5	42		
Fluid (H_2O, Urine, etc.)	2	4	1.5	12	**	12
Fluid (H_2O, Urine, etc.) (GPL only)	4	4	1.5	24	**	24
Propulsion, N_2H_4	2	18	1.5	54	**120	174
Propulsion, CO_2, GN_2	2	4	1.5	12	**	12

*Correction factors used are 3.5 (avg) for work in space suit, 1.5 (avg) for 0 g shirtsleeve environment
**120 min leak monitoring adequate for all fluid systems.

As shown in Table 7-3, a lesser number of connectors are utilized by the logistics module. This is of concern in minimizing connect and disconnect times. Table 7-8 shows a time-line for interconnecting the Logistics Module to a manned Space Station Crew Module. This indicates a minimum of two hours from the time when a safe interface condition is established and crew or cargo transfer can be commenced.

Table 7-6 also shows demating times for the modules. These times assume two men, shirtsleeve environments, and a minimum subsystem shutdown and safing time.

7.1.1.2 Critical Subsystems

The design conceptual approach for the Modular Space Station, as it was for the 10-m station, has been to optimize the subsystems for manned maintenance. This tends to result in a simplex system with redundancies and back-up functional capability only as required to ensure adequate time for maintenance. In some instances, redundancies will be provided for equipment requiring EVA for repair in order to reduce the risk to a very low value or to achieve a design that will permit postponement of maintenance and some consolidation of tasks during a required EVA excursion.

The length of time prior to manning the Modular Station and the requirement to design for unmanned operation in a semidormant holding state creates new problems for the subsystems. These tend to be compounded by the plan to delay installation of equipment in order to hold module launch weight below the 9,072 kg limit. This equipment (batteries, CMG's, etc) would be supplied with the first manning flight.

Subsystem conceptual studies have progressed along with the configuration studies. This schedule has not permitted reliability analyses to progress to the level of detail that was possible in the 10-m Space Station studies. Therefore, evaluations were conducted to determine which subsystems or equipment were critical to the program decisions and these were accorded the prime effort.

Most of the subsystems were determined to be merely different sized projections of the 10-m station subsystem technology. No new analyses were conducted for these subsystems. Reliability allocations and spares weight allocations were developed by evaluation and interpolation of previous data. The only subsystem considered to be critical to the extent of requiring special analysis was the electrical power subsystem.

The electrical power subsystem is considered critical because of the dependence of the other subsystems. During the unmanned time period, the plan is to operate all modules on a single battery. The solar panels must be erected from the stowed position through a complex series of events; boom rotation, ordnance actuated release, mast extension, and multiple solar panel deployment. The solar power is delivered at 115 v dc which can be converted directly to 115 vac, but charges the four 28-v batteries in parallel. The batteries act in series to supply 115 vdc and 115 vac power during the dark period.

If electrical power is lost for a period of only three or four hours, the thermal control system will become frozen due to loss of both the heat sources and coolant pump power. This condition resulted in a special electrical power analysis for the premanning time period. This is reported in the availability predictions subsection. Thermal conditioning availability as well as other subsystem estimates were developed from interpolation of the previous 10-m Space Station estimates. These are also shown in the following text.

7.1.1.3 Availability Predictions

System availability to conduct experiments is considered as the performance parameter relating to long-life assurance. Availability is expressed as a probability. Availability for an average 120-day time period has been estimated for the purpose of evaluating competitive designs. Availability for manning has been estimated for the buildup time period.

Availability for the actual mission can be measured as a percent of planned experimental data return. During the design development phase, design

Table 7-8

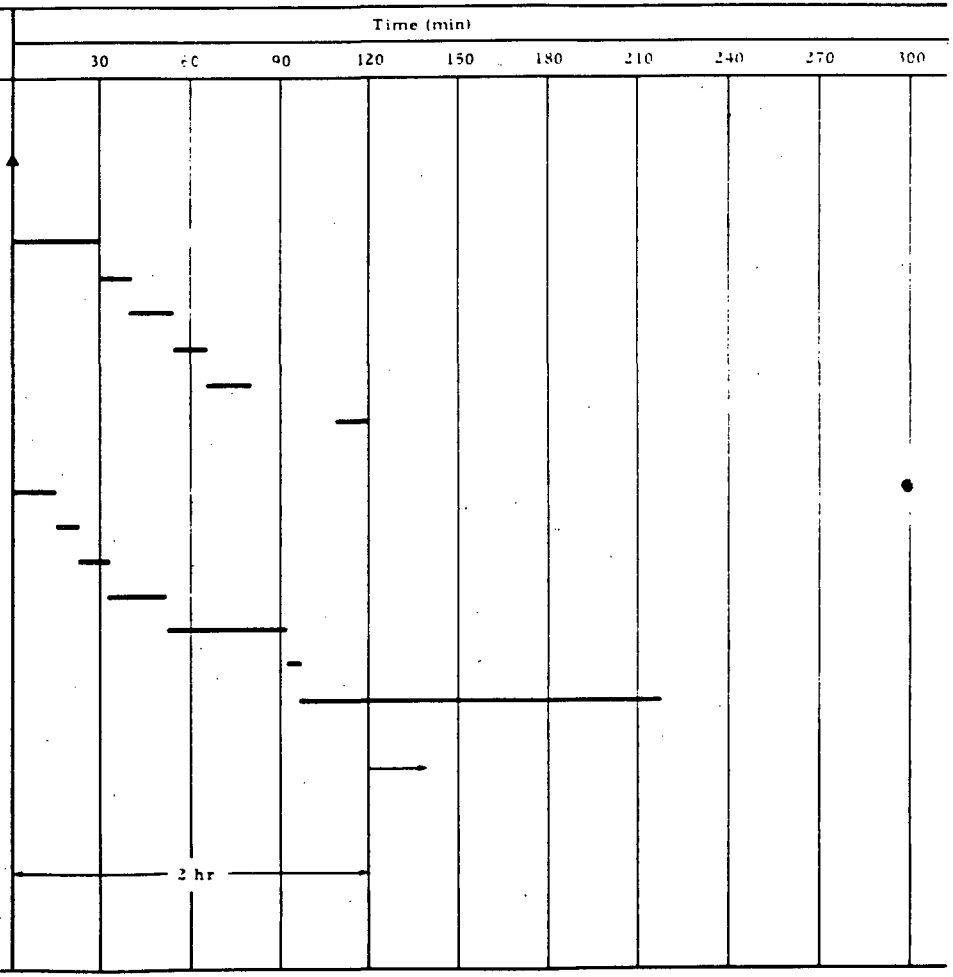
LOGISTICS MODULE INTERCONNECT TIME LINE

FUNCTION: Module Interconnect – Logistics Module to Crew Module

LOCATION:

TIME LINE SHEET:

Spec	Task Sequence	Function and Corresponding Tasks (If Applicable)	
		Dock Logistics Module to Crew Module and verify Space Station is safe. Equalize pressure across Logistics Module door. Open door to interface area. Open door to Crew Module. (Includes time to procure tool kit and kit of attaching parts stored in Logistics Module.)	
Electrical	1	Connect dc power bus	(4)
	2	Test dc power	
	3	Connect control circuits (C and W)	(2)
	4	Verify caution and warning	
	5	Connect fuel controls	(2)
	6	Verify fuel controls	
Mechanical	1	Connect O_2, N_2 lines	(2)
	2	Connect conditioned air	(1)
	3	Connect contaminated air	(1)
	4	Verify A/C system condition	
	5	Connect propulsion – N_2H_4 – transfer	(1)
	6	Connect GN_2 transfer	(1)
	7	Verify no leakage – propulsion	
		Proceed with normal logistics transfer operations	
		Normal mating time – Logistics Module to Crew Module	



decisions and, later, operations and logistics planning must be guided by the results of system predictions. Predictions are usually developed by simulation, using a model that properly represents the equipment utilized, the functional redundancies, required event sequences, and failure rates and operating times for each Space Station item of equipment required for each successive incremental time period to support on-orbit operations and experiments. The simulation model permits determination of system states (operational or failed) and when a failed state is indicated, the simulation also indicates when the item is again operational as a function of repair capability.

For the purpose of this discussion, the availability can be represented by the expression

$$A_{s_j} = \prod_{i=1}^{N} R_i + \left[(1-R)_i \times P_{s_i} \times P_{m_i}\right]$$

where

A_{s_j} = Probability that the Space Station subsystems required to accomplish experiment functions are available over some time period, T_j

R_i = Probability that the i^{th} part required to accommodate the experiment functions over the time period T_j ($R_i = e^{-N\lambda_i T_j}$

P_{s_i} = Probability that sufficient spares are in stock to correct all failures that occur to the i^{th} part during the time period T_j.

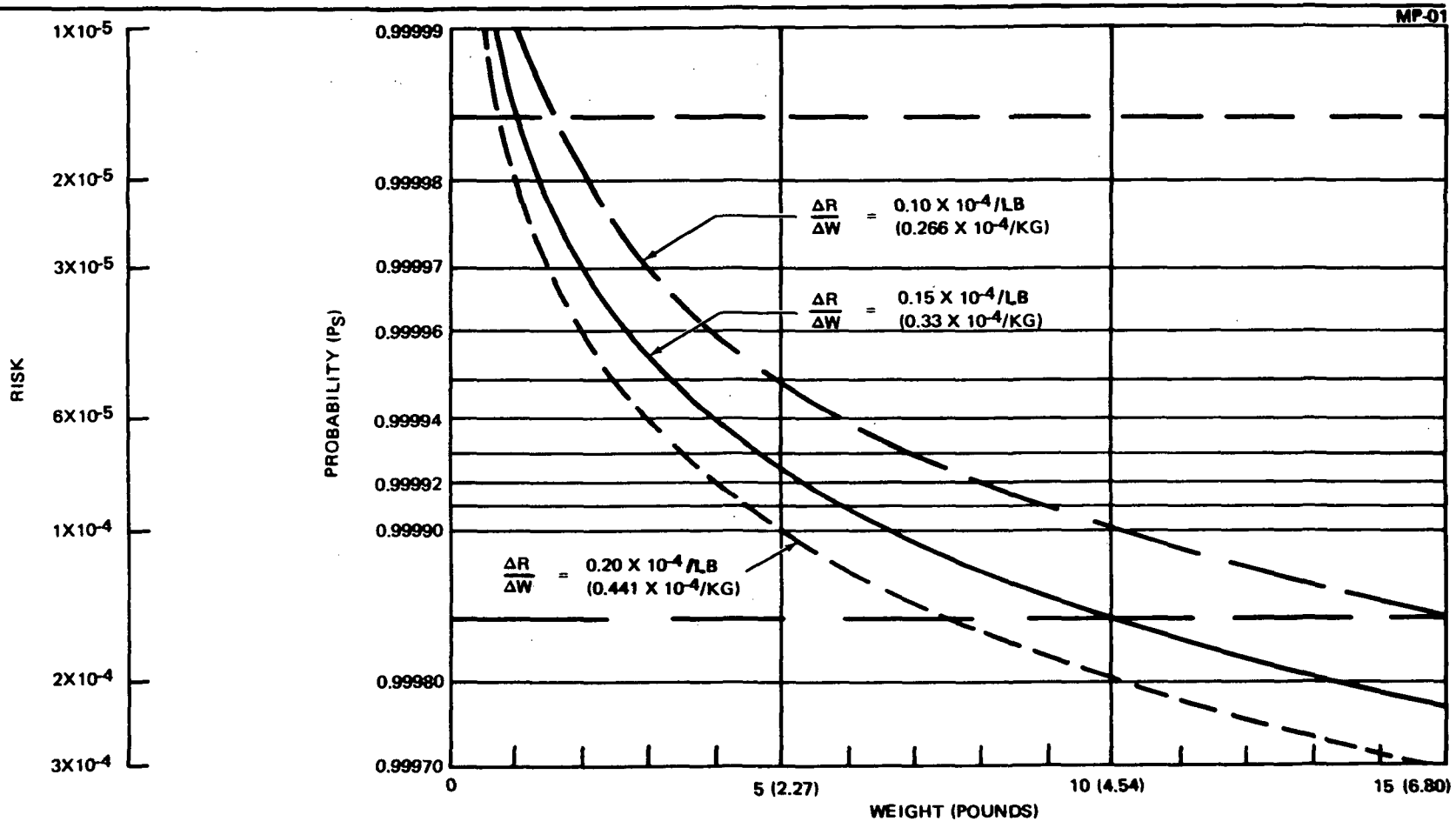
P_{m_i} = Probability that the failures that occur to the i^{th} part can be repaired prior to the loss of any experiment results during the time period T_j

This indicates that the system availability is the product of the availability of each of the individual components. The Phase B study level of subsystem definition does not permit analysis to this level of detail and estimates are made, based on expectations of repair capability, subsystem spares, and

failure rates at the major component level of definition. Computer optimization of most of the subsystems were conducted during the previous 10-m Space Station study. The computer program selects spares, ranked in accordance with the individual item's reliability contribution (ΔR) with respect to its weight (Δw). The actual $\Delta R/\Delta w$ ranking value for the kth item of the ith part is equal to the probability of exactly K failures divided by the weight of the repair part. The spares cut-off criterion used was 0.33×10^{-4} Reliability Improvement per kg ($\Delta R/\Delta w = 0.15 \times 10^{-4}$ reliability improvement per pound). Availability estimates for the Modular Space Station were interpolated from these data, assuming a lesser resupply interval (from 90 to 45 to 30 days), a lesser self-sufficiency time period (120 days), and some differences in subsystem equipment.

Two figures have been included to indicate the general magnitude of values of P_s and P_m that might be expected and to aid in discussions of means of improvement. Figure 7-7 shows probability of individual spare part selection as a function of part weight, and $\Delta R/\Delta w = 0.33 \times 10^{-4}$ represents the minimum probability value (P_s) applicable to the 10-m Space Station when this cut-off criterion was applied. Where cost of spares to orbit is less, as with the planned Shuttle operations, the cut-off criterion will likely be reduced to 0.266×10^{-4}/kg or less. This provides a higher P_{s_i} value for the same ith part spare weight.

Figure 7-8 shows a plot of anticipated repair time distribution for three part classes in the Space Station. This graph has time in hours as the ordinate and probability (%) as the abscissa. This graph can be used to describe a method to calculate P_m. The electrical and electronic line indicates that 50 percent of these types of equipment repairs can be accomplished in 1.2 hrs or less and only 10 percent will require over 2.8 hr (90th percentile). This represents a distributed time line. If an available time for repair of 8 hrs is chosen, this indicates that there is an 0.998 probability that any of these types of failures can be corrected in less than the 8-hr time period (T_A). Actually, P_m is obtained for individual items by evaluating its own repair time distribution against its own critical T_A. If the P_m is too low due to some repair restraint, one possible solution is to improve maintenance



$\frac{\Delta R}{\Delta W}$ = RELIABILITY IMPROVEMENT PER POUND (KG) – VALUES SHOWN ARE LOWER LIMIT (CUT OFF CRITERIA)

ΔR_i = EXPLICIT RISK OF FAILURE OF i^{TH} PART THAT WOULD BE PROVIDED FOR BY THE ADDITION OF A SPARE i^{TH} PART WHERE

$\Delta R_i = \frac{e^{-e} e^{X}}{X!}$ = PROBABILITY OF EXACTLY X FAILURES

WHEN e RISK OF FAILURE = ($N\lambda t$ OR $t/MTBF$)

Figure 7-7. Probability of Sufficient Spare Parts at "Cut-Off" as a Function of Part Weight

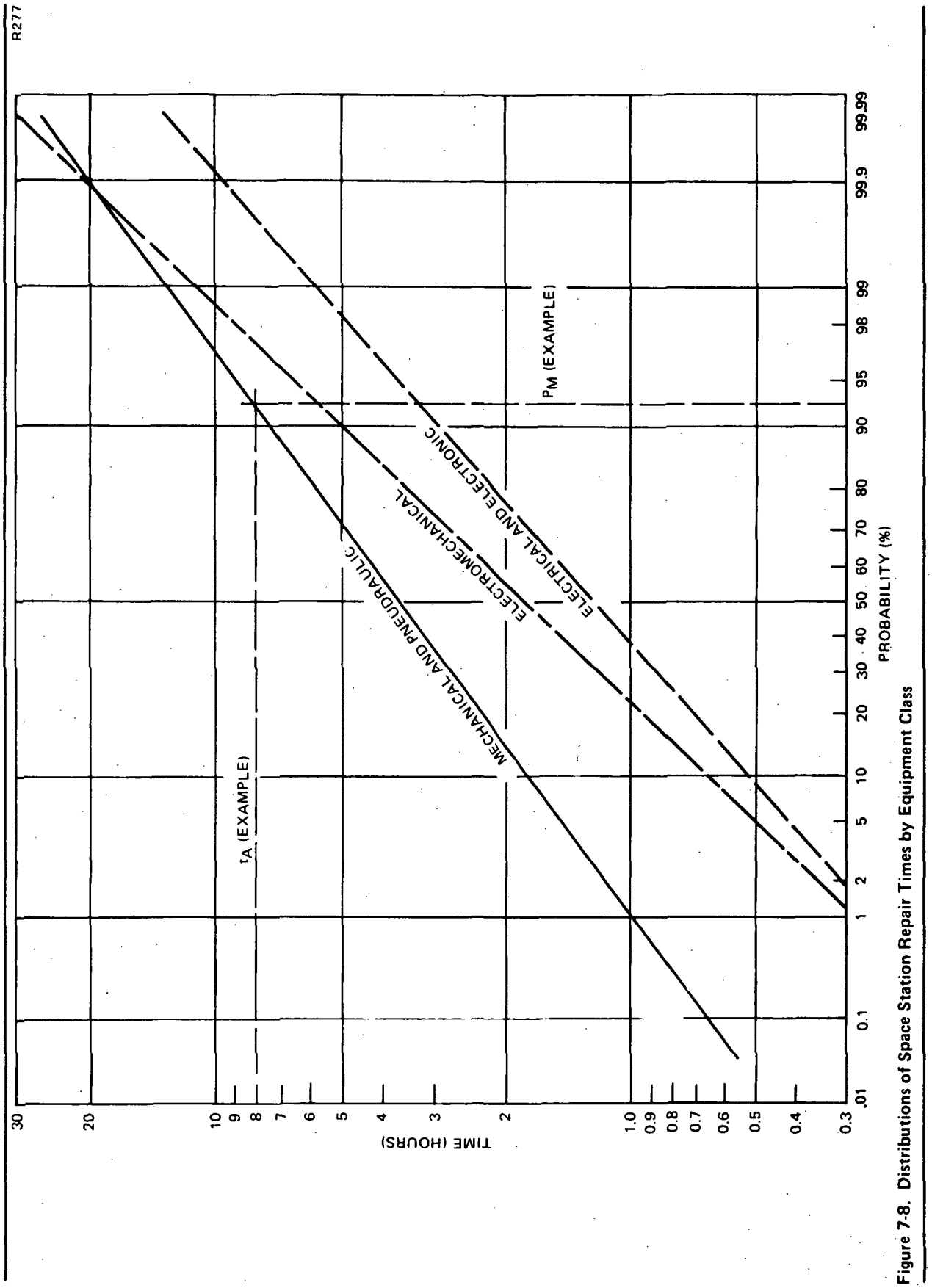


Figure 7-8. Distributions of Space Station Repair Times by Equipment Class

capability; another is to provide a standby mode such as a switchable redundant unit to take over while the failed unit is under repair. During the Phase C and D design, individual decisions are made as an integral part of the analyses to determine spares level and redundancies to optimize availability and experiment time as a function of cost and crew time, which are also related to spares level and repair time.

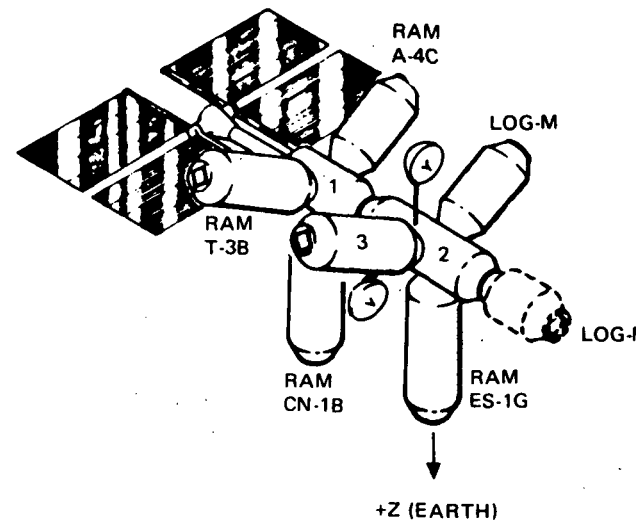
Premanning Availability

The initial buildup time period prior to manning is critical for system survival. The Space Station buildup sequence and an outline of Baseline Space Station characteristics which provide an overview of subsystem distribution across modules are illustrated in Figure 7-9.

Availability for manning is a function of equipment performance with regard to critical requirements. In making availability estimates, it was necessary to estimate the portions of subsystems required, the capability to provide redundancy, and subsystem failure tolerance. The areas of concern are primarily related to the electrical power conceptual approach and thermal control criticality discussed previously, data collection on selected parameters of individual equipment performance, switchover control capability, sufficient heat rejection to keep the thermal loop above freezing, attitude control sufficient to prevent tumbling that would damage solar panels or prevent docking of subsequent modules, and communications loops to permit the ground to monitor critical performance and provide backup command and control.

The graph of probability vs time (Figure 7-10) represents the estimated probability of success during the buildup time period. The breakdown by subsystems is shown in Table 7-9. The initial rapid decrease in probability shown in the graph is associated with solar panel deployment risks of failure and the initial start-up of required subsystems. The ordinate is labeled "probability of manning on schedule." The risk of failure to man the station includes risk of total loss and risk of early module return as a result of failures of a magnitude that cannot be repaired on orbit. The Space Station estimate of 0.929 probability of survival to manning without maintenance was considered unacceptable and recommendations were made to utilize the assembly crew at

MODULE/ SEQUENCE	PRIMARY FUNCTION
1	POWER/SUBSYSTEMS
2	CREW/OPERATIONS
3	GPL



BASELINE SPACE STATION CHARACTERISTICS

	ISS		
BUILDUP SEQUENCE	1	2	3
PRIMARY FUNCTION(S)	POWER/ SUBSYSTEMS	CREW/ OPERATIONS	GPL
FEATURES			
END DOCKING PORTS	2**	2	2
SIDE DOCKING PORTS	3	3	--
EC/LS SYSTEM (MAN SIZE)	--	6	6
DISPLAY AND CONTROLS		PRIMARY	SECONDARY
PROPULSION	HI AND LOW	HI AND LOW	--
CMG'S	4 + 1 SPARE INSTALLED	--	--
HIGH GAIN ANTENNA	--	3	--
BATTERY SETS	2	2	2
GPL	--	--	INITIAL FACILITY***
LAB	--	--	BIO-MED
CREW QUARTERS (MAN SIZE)	--	6	--

Figure 7-9. Initial Space Station (ISS)

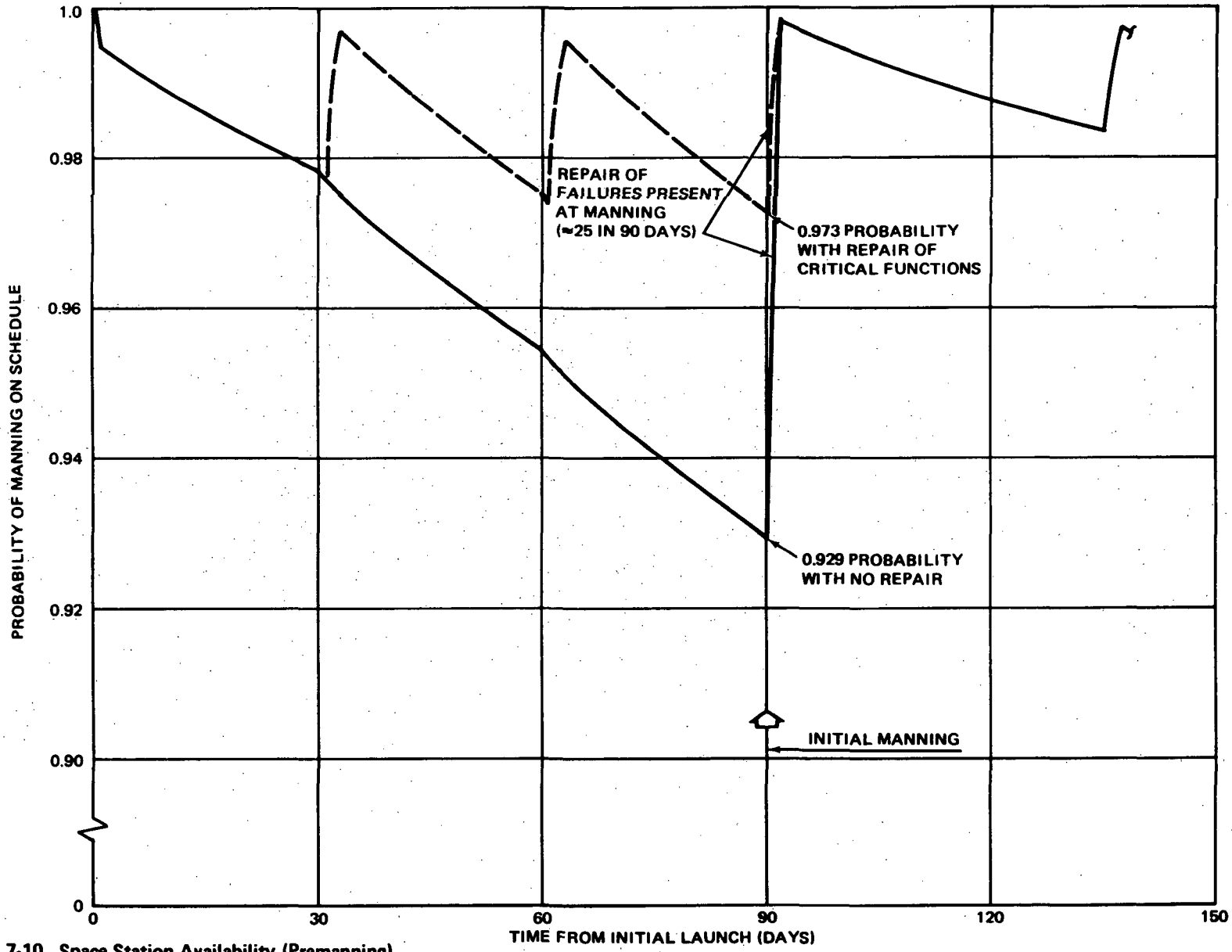


Figure 7-10. Space Station Availability (Premanning)

Table 7-9

PREMANNING AVAILABILITY

	Probability Allocation	
	No Maintenance	With Repair
Electrical Power	0.9622	0.9860
EC/LS	0.9825	0.9915
GNC	0.9983	0.9990
Data Management	0.9959	0.9985
Onboard Checkout	0.9968	0.9980
Propulsion	0.9940	0.9980
Communications	0.9983	0.9990
Structure/Mechanical	0.9997	0.9997
Crew Habitability	--	--
Experiments	--	--
Total probability	0.929	0.97

each buildup step to repair critical failures. This was accepted as the baseline buildup concept. The stepped dotted line represents the improvement in probability provided by emergency manning and repair of failures at each subsequent module delivery flight. This improvement requires rather extensive knowledge of what function is deteriorated prior to next launch in order to transport required tools and spares.

The basic spares inventory will not be available until the initial manning logistics flight. The availability of subsystem performance data will permit the planning of emergency repairs for redundant component failures. This would be expected to reduce the risk by over 40 percent and increase the probability to 0.973. There is only a small risk of loss of capability to locate the Space Station and dock with it, considering the backup provisions of ground tracking capability and orbiter maneuverability. The greatest portion of the risk represents failures that would necessitate module return, such as thermal control freeze-up, damage to solar panels due to attitude control anomalies, and like items.

The work sheets used to summarize the buildup availability estimates are supplied as Table 7-10. These estimates are for individual modules. The module sheet contains columns for the estimated expectation of failure (ϵ_T) for 30 days of operation for critical function equipment for each subsystem and the resulting probability of no failure (R_T). Critical function equipment is that minimal portion of the subsystem assumed to be required for the first 90-day operations.

The sum of the expected failure column provides the basis for the 30-day unmanned availability estimate. A portion of the risk is factored to obtain a special measure of start-up risk and probability. The product of the start-up availability and the 30-day availability provides the estimated availability for the first month for that module.

One of the potential operational conditions considered was the effect if the Shuttle system missed a scheduled launch during buildup. The 30-day minimum launch frequency concept was assumed to prevail. The probability of

Table 7-10

RELIABILITY ESTIMATES (PREMANNING)

Crew Module Mission Period (T): 30 days, Unmanned			
Subsystem	ϵ_T*	R_T*	
Electrical Power	0.00001'	0.99999	
EC/LS	0.00250'	0.99750	
G & NC	0.00010'	0.99990	
Data Management	0.00100'	0.99900	
On board Checkout	0.00010'	0.99990	
Propulsion	0.00100'	0.99900	
Communications	0.00010'	0.99990	
Structure and Docking	0.00017	0.99983	
Crew Habitability	Neg	-	
Experiments	N/A	-	
Intermodule Connections	0.00100	0.99900	
	(0.00598		
	(0.001801)	0.9982	Start up
	(0.00498)	0.99502	30 days unmanned
		0.99323	First 30 days

Start-up $= \frac{0.004810}{6} + 0.001801$

*N/A - Indicates no equipment applicable to this subsystem in this module

Table 7-10

RELIABILITY ESTIMATES (PREMANNING) (Continued)

GPL Module Mission Period (T): 30 Days Unmanned

Subsystem	ϵ_T*	R_T*	
Electrical Power	0.00001'	0.99999'	
EC/LS	0.00250'	0.99750'	
G & NC	N/A	-	
Data Management	0.00010'	0.99990'	
On board Checkout	0		
Propulsion	N/A	-	
Communications	0		
Structure and Docking	N/A	-	
Crew Habitability	Neg		
Experiments	0		
Assembly	0.00100	0.999	
	(0.001435)	0.998565	Start-up
	(0.002610)	0.997400	30 days unmanned
		0.99597	First 30 days

Start-up $= \frac{0.002610}{6} + 0.0010000 = 0.001435$

*N/A - Indicates no equipment applicable to this subsystem in this module

Space Station availability for manning is materially reduced by increased time to manning. The worst case is represented by a missed Logistics Module flight with the initial manning crew after all modules are assembled in space. Figure 7-11 illustrates the relative effects of three delay cases; delay of 30 days between modules, delay after the Initial Space Station complement is on-orbit, and a 45-day delay in the second logistics flight.

The electrical power subsystem for initial startup and operation accounts for 52.4 percent of the initial 90-day risk and the EC/LS subsystem accounts for 22 percent of the buildup risk. The remaining risk is distributed over the other subsystems.

The EC/LS subsystem risk is related to the thermal control system only, wherein the water and Freon loops in each separate module must remain functional. There are redundant water and Freon pumps in each module. There are no intermodule connections to permit utilizing the pumps in one module to provide additional redundancy for the pumps in another module. The plumbing is planned to accommodate maintenance and repair of failures and has redundant paths to maintain water circulation through the radiators.

The electrical subsystem risk during buildup is related to the series functions of mast extension and solar panel extension and then the repeated cycles of solar power and battery power. The power source consists of two solar arrays, their orientation system and the energy storage batteries. The batteries and the distribution system are schematically portrayed in Figure 7-12. The major weight saving available by postponing the installation of the second set of batteries in the power module and all batteries in other modules makes this an attractive change. (Reduces weight by 689 kg mass in the power module and 1378 kg mass in other modules). This configuration was accepted as standard. The resulting power module battery and battery charging arrangement is shown in Figure 7-13.

The 90-day buildup availability estimate for the electrical power system without maintenance is 0.96. (See Figure 7-14). This estimate utilized data from solar panel failure rate estimates from earlier studies on the

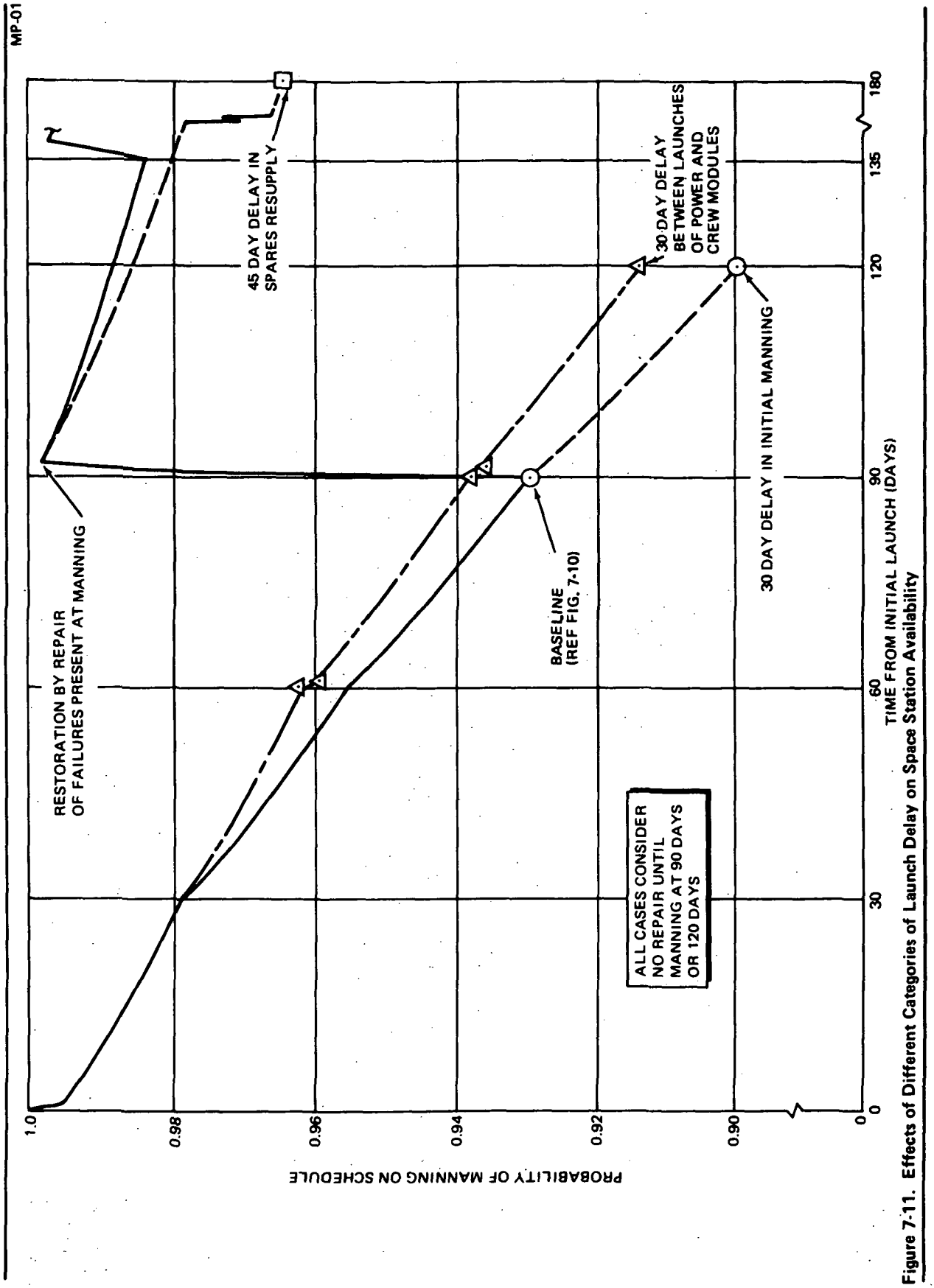


Figure 7-11. Effects of Different Categories of Launch Delay on Space Station Availability

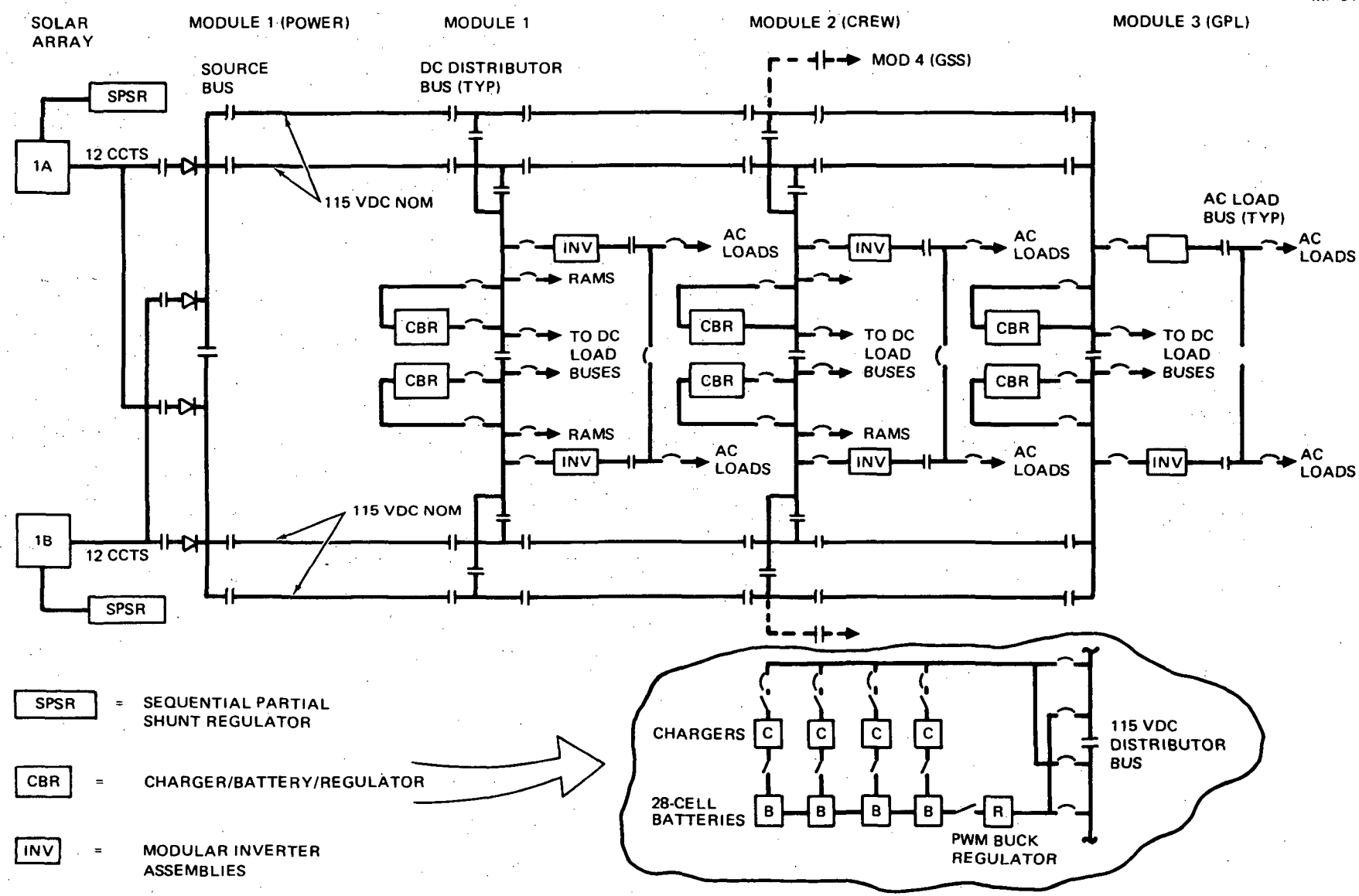


Figure 7-12. IC/ISS Baseline EPS

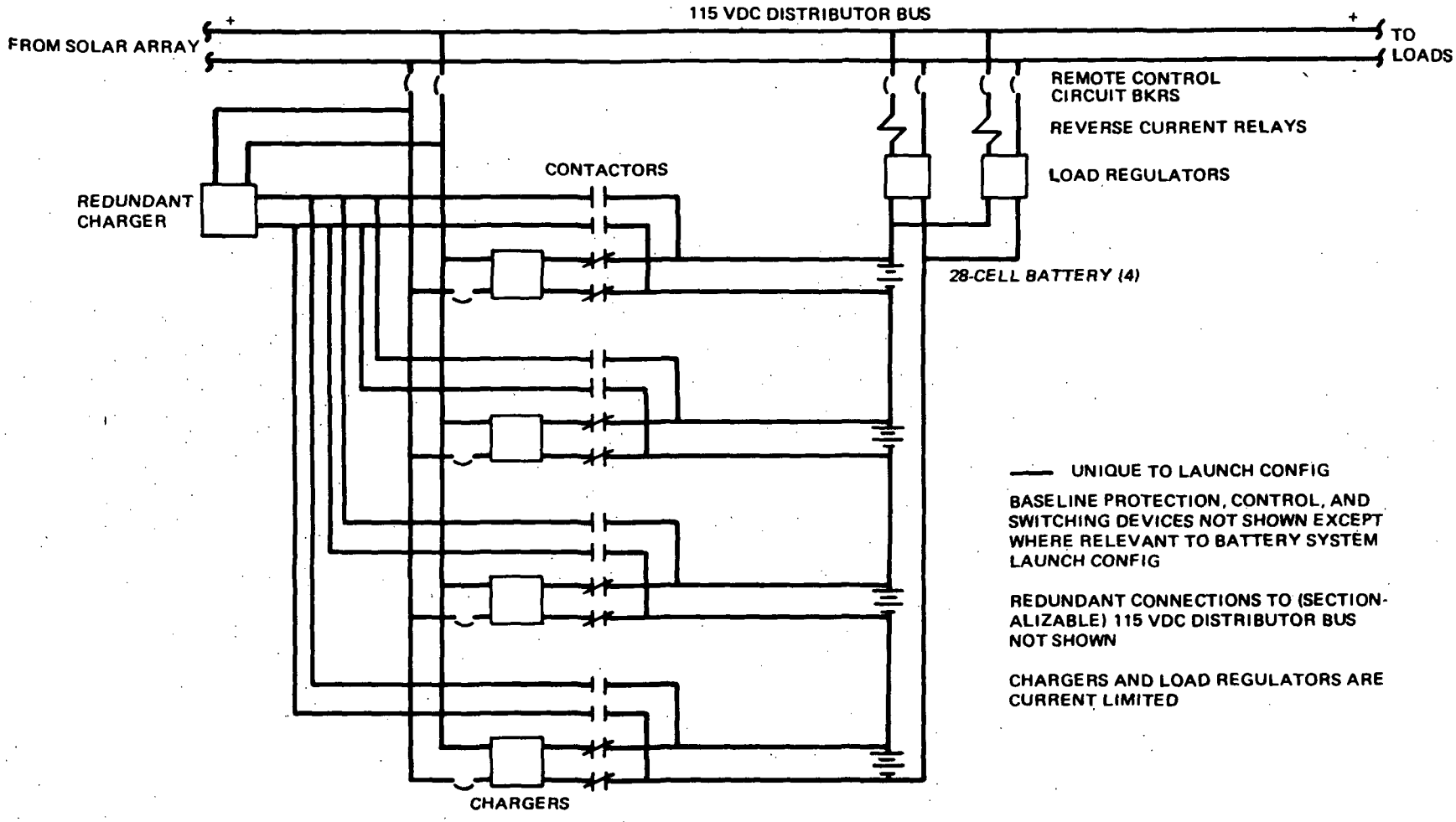


Figure 7-13. Module 1 Battery System Launch Configuration

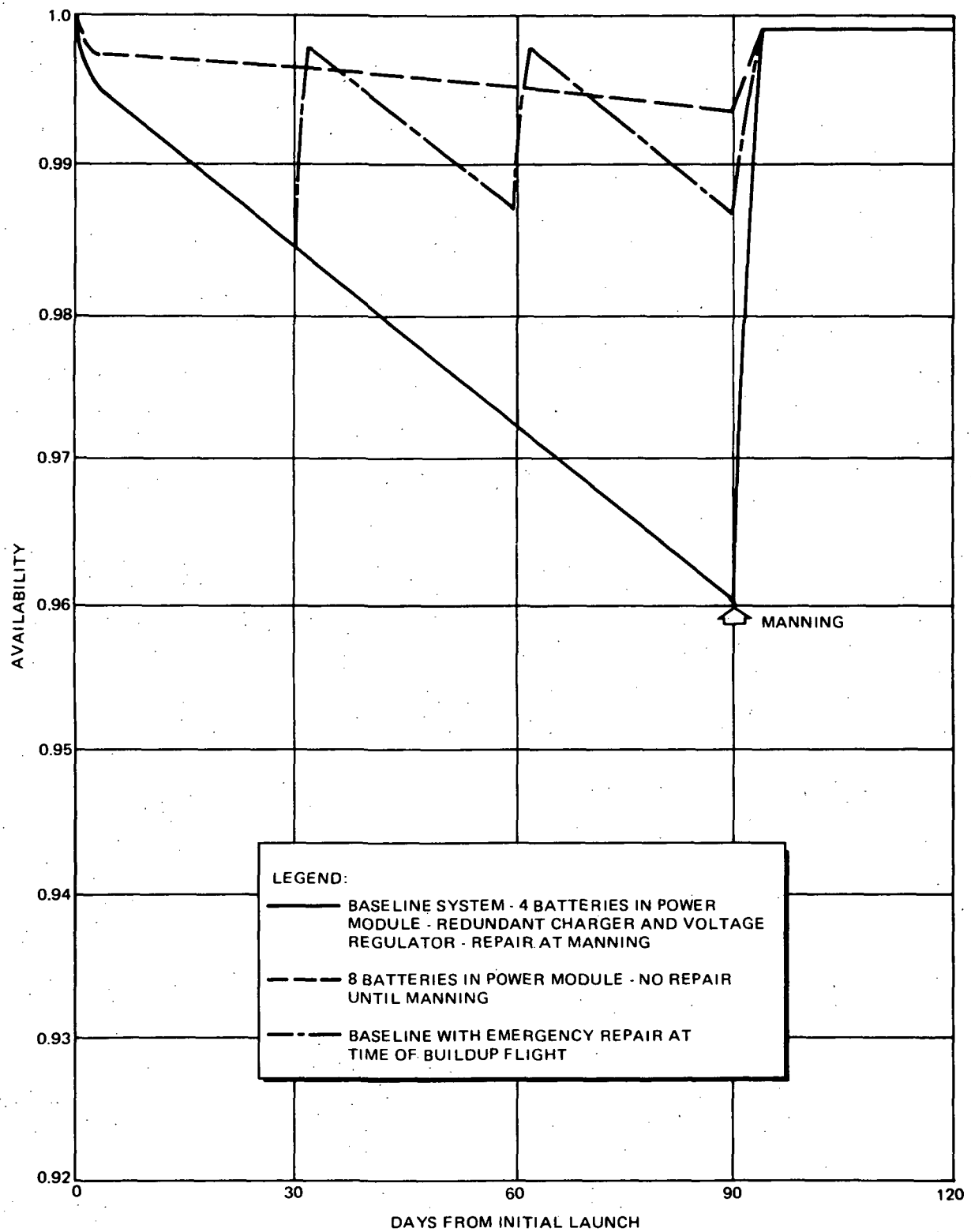


Figure 7-14. Electrical Power Availability Versus Time in Space

10-m station, analysis of the single battery arrangement, and an MDAC estimate for the solar panel erection and deployment method shown in the Lockheed Space Station Solar Array Technology Evaluation Program Mid-Term Report. The low buildup availability estimate prompted a recommendation for utilizing a repair crew to repair existing failures at the time of subsequent buildup flights. This plan for using maintenance crews was accepted as a means to enhance buildup availability, reduce the risk of module return and increase the overall probability of program success.

Operational Availability

The system availability in the manned state was extrapolated from the 10-m Space Station data. A judgment factor was applied to the previously determined subsystem spares weights and the probable cutoff availability value if the modular subsystems were analyzed to the same ground rules. The spares stock level was based on a 120-day supply. The subsystem allocations of reliability and spares weight and the system estimate are shown in Table 7-11. These values formed the basis for the CEI specification (CP02929) requirements. It would be expected that the envisioned design, which would provide cost-effective LRU levels as a function of component features and onboard checkout requirements, long-life design of mechanisms, functional backups to reduce maintenance time criticality, and access to all replaceable components would ensure this level of availability performance.

7.1.1.4 Spares and Redundancy

The spares analysis for the Modular Space Station has been based on component lists prepared for the weight, volume, and power studies (Program P1-268) and extrapolation from the 10-m station data. The data for the 10-m Space Station was prepared by subsystem spares optimization aided by computer analysis.

Estimates have been prepared for spares and redundancy to provide the desired system availability (Table 7-11). An example of the computer analysis results for the structures subsystem, including the ranked order of spares and the cumulative weight is shown in Table 7-12. The last item listed is the final item meeting the $\Delta R/\Delta w$ cutoff criterion.

Table 7-11

AVAILABILITY ALLOCATION - ISS

Subsystem	Availability	Initial Spares Weight (120 Day) (kg)(lb)	
Electrical Power	0.996	363	(800)
EC/LS	0.997	490	(1,080)
GNC	0.996	249	(550)
Data Management and Onboard Checkout	0.993	204	(450)
Propulsion	0.996	159	(350)
Communications	0.995	145	(320)
Structure/Mechanical	0.996	45	(100)
Crew Habitability	0.993	68	(150)
Experiment Support	0.997	91	(200)
Totals	0.96	1,814	(4,000)

*Initial spares weight includes some early time replacement item stocks, sustained spares weight is 1,633 Kg (3,600 lb)

Table 7-12

EXAMPLE OF RELIABILITY OPTIMIZATION ANALYSIS

No. of Spare Parts	Part Title	Cumulative Weight (Kg)
1	Dock port door seal	0.227
1	Hydraulic lines/strut leak	0.680
1	Airlock door seal	0.816
1	Viewport seal	0.907
1	Airlock door view seal	0.998
2	Dock port, door seal	1.225
1	Hydraulic lines	2.132
2	Hydraulic lines/strut leak	2.586
1	Docking structure kit	3.720
1	Meteoroid/hole patch kit	3.992
1	Docking strut	6.260
2	Airlock door seal	6.396
1	Dock lock	11.204
1	Dock lock actuator	16.012
3	Dock port door seal	16,239
1	Viewport glass	18.960
1	Dock port door tors asm.	22.589
1	Viewport glass	31.661
2	Viewport seal	31.752
3	Hydraulic lines/strut leak	32.206
1	Viewport glass airlock	34.927
1	Dock port door lock	45.360 (100 lb)

Maintenance Concept

The maintenance concept for the Space Station and experiment modules calls for fault isolation to the component level and component replacement to correct failures or wearout. On-line maintenance will be used wherever possible to reduce downtime. Subsystems will be designed to be tolerant of any required downtime for maintenance without detracting from experiment support capability. Redundant capability will be provided where necessary to assure adequate maintenance reaction time and will be used as a means to reduce requirements for EVA maintenance excursions.

The system is designed so that no planned maintenance requires EVA travel. There are some equipment items that must be installed on the outer surfaces which have some risk of failure and EVA has been found to be the most cost effective method for repair of these items. EVA maintenance is discussed in more detail in a later subsection.

Maintainable items are designed to be replaced and adjusted with a minimum complement of common space qualified tools. These will have the form and dimensions of standard mechanics tools (e. g. , box end wrenches, spin tights, tubing wrenches, Allen wrenches, socket wrenches with extension handles) and will be designed to lighten, provide tethers, and to minimize risk of shorting.

Requirement for Spares and Redundancy

The availability estimates have been based on the assumptions that an adequate stock of spare parts would be available and that those spares relating to functions with an unreasonably short allowable downtime would be installed redundantly to permit rapid function replacement and thus allow more relaxed maintenance. The redundancy may be active or switchable, depending on individual considerations.

The concept of system optimization followed is to establish a basic capability to perform the required function with no provisions for failure tolerance. This is called a simplex system. It has a set cost, weight, and availability. The design improvements that can be incorporated to reduce the consequence

of individual failures and improve availability are then identified and ranked in order of effectiveness; in this case, availability improvement with respect to weight.

The subsystems are currently described with some redundant elements, primarily redundant tankage, pumps, and thrusters, which are characteristic for the type of subsystem design expected to result from the final optimization. The availability and spares analyses take these into consideration. The computations are made to represent a simplex system and the redundancy concept is fulfilled before added items are considered as installed or stocked spares. The relationship between availability and weight of spares is illustrated in Figure 7-15. The increase in weight and availability represents the incrimental addition of spare items based on their effectiveness. The cutoff point at 1633 kg (3,600 lb) and 0.96 availability represents the system status when the individual items have been selected to a cutoff value of 0.33×10^{-4} reliability improvement per kg.

The initial estimates for subsystem spares (installed or stocked) allocated to subsystems are shown in Table 7-11.

Definition of Spares

An estimate of the number of replaceable components (line-replaceable units or LRU's) was developed from the computer list, P1-268. This estimate, broken down by subsystem, is shown in Table 7-13. The components are selected at a level representing the capability to detect, fault-isolate, and retest with the onboard checkout system. The number includes the estimated number of gauges, circuit breakers, and switches that will be installed in locations permitting individual item replacement.

A better identification of some of the replaceable components and the number installed, are shown in the potential limited-life item list (Table 7-14). This

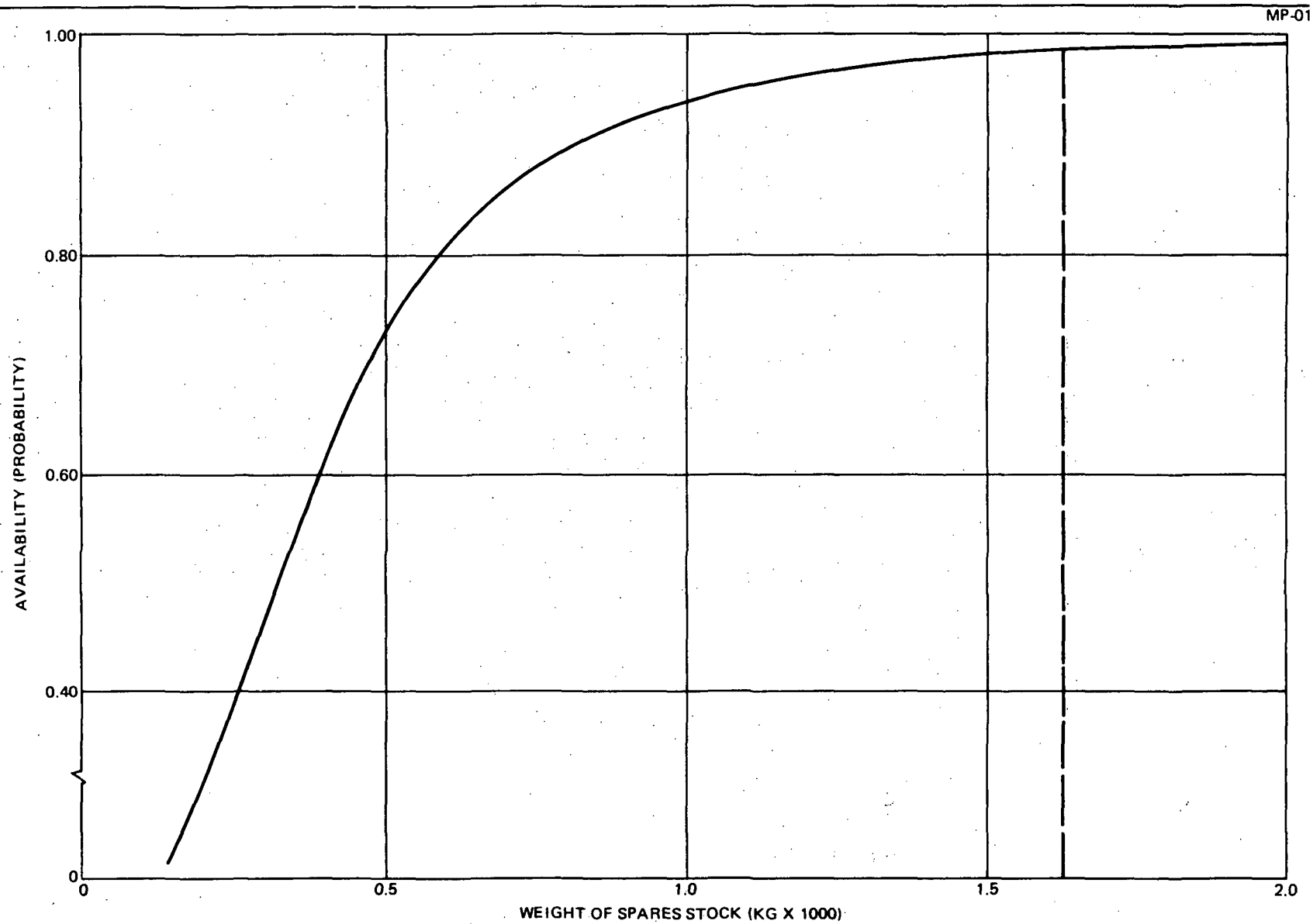


Figure 7-15. Availability Growth with Addition of Spares (120 Days)

Table 7-13

ESTIMATE - PLANNED REPLACEABLE UNITS (LRU'S)

Subsystem	Totals	
	ISS	GSS
Electrical Power	949	1,683
EC/LS	810	1,200
G/N&C	67	103
Data Management and OCS	270	450
Propulsion	341	588
Communications	96	(120)
Structure and Docking	400	730
Crew Habitability	70	140
Lighting	450	734
Experiments	---	---
Totals	3,453	5,748

Table 7-14

POTENTIAL LIMITED LIFE ITEMS (ISS)

Subsystem/Item	*Quantity*	Generic *Life*	Operating Time (10 Yr)	Use 10 Yr	Use 90 Days	Weight Each (lb)	Weight 90 Days (lb)
EL/LS							
Tri-bed cartridge	2	45 Days	3,650 Days	162	4.0	30.0	120.0
Cat oxidizer cartridge	2	180 Days	3,650 Days	40	1.0	5.0	5.0
Water transfer disks	2	180 Days	3,650 Days	40	1.0	9.6	9.6
Bacteria filters - laboratory	2	180 Days	3,650 Days	40	1.0	1.3	1.3
Charcoal filters	1	20 Days	3,650 Days	182	4.55	2.0	9.1
Urine pretreatment	1	180 Days	3,650 Days	20	0.5	50.0	25.0
Bacteria filters	2	20 Days	3,650 Days	365	9.0	3.0	27.0
Bacteria filters	2	20 Days	3,650 Days	365	9.0	1.0	9.0
Reverse osmosis cart. - B10	1	180 Days	3,650 Days	20	0.5	37.0	18.5
Filters	4	1 each 15 Days	3,650 Days	243	6.0	15.0	90.0
Fans	20	50,000 hours	87,600 hours	35	0.9	6.0	5.4
Pumps	8	20,000 hours	17,520 hours	7	0.2	2.0	0.4
Valves	80	150,000 cycles	18 cycles/ month	0.1	-	1.4	-

Table 7-14

POTENTIAL LIMITED LIFE ITEMS (ISS (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 Yr)	Use 10 Yr	Use 90 Days	Weight Each (lb)	Weight 90 Days (lb)
Regulators	4	40,000 Hr	87,600 Hr	8.75	0.22	1.7	0.4
Compressors	4	20,000 Hr	87,600 Hr	17.5	0.44	20.0	8.8
Motors	8	20,000 Hr	17,520 Hr	7	0.2	3.0	0.6
Pressure switches	4	30,000 Hr	87,600 Hr	11.8	0.29	0.4	0.1
O_2 tanks	3	Considered in Logistics		-	3	-	-
N_2 tanks	5	Considered in Logistics		-	1	-	-
Solar collectors	2	35,000 Hr	53,436 Hr	0.05	-	-	-
Radiators-thermal cont.	3		87,600 Hr	0.05	-	-	-
	(160)			(1564.25)		(330.2) (149.8 kg)	
Electrical Power							
Batteries	2.4	2.5 Yr	10 Yr	96	2.4	380.0	912.0
Circuit breakers	250	35,000 Cycles	50 Cycles/ Month	4	0.01	0.1	-

Table 7-14

POTENTIAL LIMITED LIFE ITEMS (ISS) (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 Yr)	Use 10 Yr	Use 90 Days	Weight Each (lb)	Weight 90 Days (lb)
Gears	6	20,000 Hr	8,760 Hr	2.6	0.07	20.0	1.4
Motor drives	3	20,000 Hr	8,760 Hr	1.3	0.04	10.0	0.4
Bearings	6	100,000 Cycles	16 Cycles/ Day	3.0	0.08	16.0	1.3
Sun sensors	2	35,000 Hr	53,436 Hr	0.05	-	0.7	-
Switches	300	300,000 Cycles	30 Cycles/ Month	3	0.07	0.1	-
Solar panel	2	-	53,436 Hr	(4.0)	-	120.0	-
Shunt regulator	2	40,000 Hr	53,436 Hr	2.5	0.06	173.0	10.2
	(595)			(109.46)			(925.3) (419.7 kg)
GNC							
Control moment gyros (bearings)	4/5	17,500 Hr	87,600 Hr	20	0.5	4.0	2.0
Star trackers	2	17,500 Hr	17,520 Hr	2	0.05	120/3	6.0
Horizon sensors	4	17,500 Hr	87,600 Hr	20	0.5	20/2	10.0

Table 7-14

POTENTIAL LIMITED LIFE ITEMS (ISS) (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 Yr)	Use 10 Yr	Use 90 Days	Weight Each (lb)	Weight 90 Days (lb)
Attitude gyros	6	50,000 Hr	87,600 Hr	10	0.25	17.3	4.3
	(16)			(52)			(22.3) (10.1 Kg)
Propulsion							
High thrusters	40	20/Hr	1 Hr/30 Days	6	0.15	10.0	1.5
Low thrusters	32	20,000 Hr	8,760 Hr	16	0.4	10.0	4.0
Regulators-High	2	40,000 Hr	87,600 Hr	4	0.1	1.6	0.2
Valves - High	30	150,000 Cycles	240 Cycles	-	-	1.2	-
Filters - High	3	45,000 Hr	87,600 Hr	6	0.15	0.4	0.1
Regulators - Resistojet	4	40,000 Hr	87,600 Hr	9	0.22	1.6	0.4
Valves - Resistojet	20	150,000 Cycles	36,500 Cy cles	4.8	0.12	1.2	0.1
Filters - Resistojet	18	45,000 Hr	8,760 Hr	3.5	0.09	0.4	0.1
Pumps - Resistojet	4	20,000 Hr	17,520 Hr	3.5	0.09	10.0	0.9 (7.3) (3.3 kg)

Table 7-14

POTENTIAL LIMITED LIFE ITEMS (ISS) (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 Yr)	Use 10 Yr	Use 90 Days	Weight Each (lb)	Weight 90 Days (lb)
Data Management							
Recorders	9	17,000 Hr	8,760 Hr	4	0.1	30.0	3.0
Keyboard and Display		17,000 Hr	21,900 Hr	5	0.12	23.0	2.8
Printers	1	17,000 Hr	4,380 Hr	0.25	-	14.0	-
Aux memory units	4	25,000 Hr	29,200 Hr	4	0.1	30.0	3.0
Cathode ray tubes	10	17,000 Hr	8,760 Hr	5	0.12	25.0	3.0
Traveling wave tubes	4	17,000 Hr	8,760 Hr	2	0.05	4.0	0.2
Potentiometers	60	50,000 Cycles	500 Cycles	0.7	0.02	0.2	-
Film tape transport	2	10,000 Hr	29,200 Hr	5.8	0.14	40.0	5.6
	(94)			(26.8)			(17.6 lb) (8.0 Kg)
OCS							
Transducers/ sensors	800	350,000 Cycles	7,300 Cycles	17	0.5	0.05	-

Table 7-14

POTENTIAL LIMITED LIFE ITEMS (ISS) (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 Yr)	Use 10 Yr	Use 90 Days	Weight Each (lb)	Weight 90 Days (lb)
OCS							
Transducers/ sensors	800 (800)	350,000 Cycles	7,300 Cycles	17 (17)	0.5	0.05	-
Totals	(1,818)			(1822.31)	(45.6)		(1302.7 lb) (590.9 Kg)

table shows the number installed, the generic life estimate, the operating time and weight of each. These values permit the calculation of weight per 90-day interval (8th column). The total weight per 90-day interval was the basis for the scheduled replacement item weight used in Table 7-15.

The same P1-268 computerized data used to estimate the number of LRU's was used to estimate the weight of LRU's, as distinguished from system weight. The estimated weight of LRU's by subsystem for the ISS is shown in Table 7-16. A total weight of LRU's by item count and individual item weight was not possible at this level of system definition. However, the LRU's listed in Table 7-13 approximate 7,394 kg (16,300 lbs). The weight estimate in Table 7-16 was obtained by subtracting weight elements identified as wiring, plumbing, structure, partitions, solar panels, and fluids from subsystem weights. Weights for such items as instrument panel structure, equipment supports, console structures and some ducting and plumbing were not separately identified and may be included in addition to the actual LRU's. This weight would indicate an average LRU weight of 3.6 kg (8 lb). An average spare part weight of 2.7 kg (6 lb) was used in computing resupply weights for random failures, based on some of the data developed in the 10-m Space Station subsystem optimization analysis. These weights do not include packaging.

Table 7-15
SPARES WEIGHTS

Onboard Stock - 120 Day Self-Sufficiency

ISS (kg)	1814 Initial (4, 000 lb)	1633 Sustained (3, 600 lb)
GSS (kg)		2041 Sustained (4, 500 lb)

Resupply Weights Per 90 Day Interval

	Scheduled Replacement*		Random Failures		Total/90 days
ISS (first 5 years) (kg)	594 (1, 310 lb)	+	109 (240 lb)	=	703 (1, 550 lb)
GSS (after 5 years) (kg)	1034 (2, 280 lb)	+	177 (127 lb)	=	1211 (2, 670 lb)

*Includes batteries; does not include O_2, N_2 tanks, food, etc.)

Table 7-16

ESTIMATE–PLANNED REPLACEABLE UNITS (LRU'S)

Subsystem	Totals ISS (No. of LRU's)	Weight* Kg	(Lbs)
Electrical Power	949	4,813	10,610
EC/LS	810	2,402	5,296
G/N&C	67	998	2,200
Data Management/Onboard Checkout	270	2,145	4,729
Propulsion	341	698	1,539
Communications	96	481	1,060
Structure and Docking	400	569	1,915
Crew Habitability	(70)	238	524
Lighting	450	293	647
Experiments	-	-	-
Totals	3,453	12,937	28,520

*This weight includes such items as instrument panels, equipment supports, console structures, and some ducting and plumbing not usually subject to replacement in flight vehicle systems.

Packaging weight allowances were added for the logistics resupply weight analyses.

7.1.2 Maintainability

The maintainability support of design and operations study efforts has been directed at the analyses necessary to understand potential maintenance requirements, determine the impact of the required maintenance on time or configuration considerations, and contribute to the resolution of preferences among conceptual approaches. The analyses have provided an understanding of maintenance requirements leading to maintenance and manpower estimates. Separate estimates were prepared for EVA activities for the Space Station and planned experiments. Trade studies were conducted to determine the cost-effectiveness of ease of sidewall access and to arrive at a decision with regard to on-orbit vs module return for refurbishment. These facets of the study are all reported in this section.

From the maintainability standpoint, it can be stated that the expected subsystem performance does not create an inordinate amount of maintenance. The equipment can be made adequately accessible to permit repair at the effective level for saving weight of spares and crew time. The EVA maintenance requirements for the Space Station are minimal for repair of failures. The EVA maintenance for experiments is inherent in the type of experiments planned and the design concepts prompted by the equipment or the shuttle weight limitations. The experiments also require some EVA for operations functions and adjustments.

7.1.2.1 Maintenance Requirements

The total in-orbit maintenance requirements are related to man intervention during buildup, repair of critical subsystem failures during buildup, repair of random failures, and scheduled maintenance. These are discussed separately.

Buildup

The buildup time period permits a minimum of maintenance. A two man buildup crew mans each module on-orbit to do final checkout and to establish an optimum performance status in consideration of the equipment status. Spares are transported onboard subsequent orbiters to repair failures of modules already in orbit as a product of monitoring equipment operation and identification of failed items. Manned intervention of just orbited modules is limited to corrections of low performance by making equipment setting adjustments or to interchange of like items from less critical subsystems by some limited scavenging. The orbiting three-module Space Station will have numerous failures onboard at final manning at 90 days (estimated 25 failures in operating equipment). This is depicted in Figure 7-10. Repair of critical functions is of primary importance to the manning crew and these tasks must be integrated with the planned buildup work to install batteries, CMG's, tanks, etc. The initial on-orbit spares stock inventory will assure a high availability as a product of the provisioning policy for long-term unsupported operations (120 days).

Repair of Random Failures

The maintenance work load is expected to be almost evenly divided between corrective maintenance and preventive maintenance. The failure prediction estimates indicate an average of 13 failures per month for the ISS configuration. The average monthly failures for each subsystem are shown in Table 7-17. The EC/LS subsystem accounts for the largest portion of the failures. This is partially due to the large number of components that must be on at all times and partially to the electromechanical nature of the components. Fans and thermal control pumping equipment are expected to provide the greatest number of maintenance actions in this subsystem. One of the major failure contributors is the temperature or pressure sensing transducer. The high number of these in the environmental control, data management and propulsion subsystems account for a high percentage of the failures. The repair time estimates have been based on values considered to be representative of the level of access and type of fault isolation and retest capability available in the Space Station.

Table 7-17

REPAIR ACTIONS AND REPAIR TIME ESTIMATES

Subsystem	Repairs/120 Days			Maintenance Man-Hours/120 Days		
	Power*	Crew Operations*	GPL	Power*	Crew Operations*	GPL
Electrical Power	3.0	2.0	2.0	6.10	2.80	2.80
EC/LS	6.0	8.5	8.5	24.00	31.45	31.45
G&NC	1.7	0.1	N/A	3.06	0.18	--
Data Management	1.0	4.8	4.8	1.20	5.76	5.76
Onboard Checkout	0.3	1.0	0.5	0.36	1.20	0.60
Propulsion	0.44	0.6	N/A	2.01	2.93	--
Communications	2.2	0.1	0.1	2.64	0.12	0.12
Structure and Docking	0.07	0.035	0.035	0.45	0.16	0.04
Crew Habitability	Neg.	4.0	0.05	--	10.00	0.13
Experiments	N/A	N/A	TBD	--	--	--
Total: 120 Days	14.71	21.24	16.0	39.92	54.60	40.90
Total: 30 Days	13.0 Repairs/Mo (Avg)			35 Maintenance Man-Hours/Mo (Avg)		

*Approximately duplicated for GSS (22 Fail/Mo; 60 Maintenance Man-Hours/Mo Avg)

The representative values for internal maintenance are shown in Table 7-18. These times are the basis for the plotted distributed repair times shown in Figure 7-8. These are generally 20 percent higher than the values used in the 10-M Space Station to reflect the expected reduction in accessibility resulting from the peripheral arrangement and more compact packaging expected for much of the equipment. These times include the effect of zero g, which tends to increase the space time over terrestrial time, but do not include environmental effects. Any repair tasks in the solar panel rotation compartment or the normally unpressurized propulsion tanks storage area must be further corrected for travel time through the bulkhead to the work area to obtain downtime estimates, when repressurization time and air condition verification times are better understood. All EVA tasks are corrected upward to account for pressure suit constraints. EVA overall tasks have generally been estimated at 3.5 times the estimated terrestrial task time values as was documented for the 10-M Space Station study.

Average task times by subsystems were based on the averages from the 10-M Space Station study. These were used with the subsystem failure estimates to estimate the subsystem repair man-hours shown in Table 7-17. The table values were based on 120-day estimates because this time period was selected to estimate failures for spares stocks and spares usage calculations. Table 7-17 shows failure and repair time estimates by module for the ISS and then a system total failures per month and maintenance man-hours/mo. An average monthly corrective maintenance work load of 13 repairs and 35 man-hours is estimated for ISS with an average of 22 failures and 60 man-hours per month for the GSS configuration for Space Station subsystems.

The Space Station corrective and preventive maintenance work load is shown separately by module and by subsystem in Figure 7-16. This includes EVA time. The subject of EVA corrective maintenance tasks has been discussed in another subsection.

Table 7-18

REPAIR TIMES—SHIRTSLEEVE

Task Type	10-M Median/90 Percent (hr)	Modular Median/90 Percent (hr)
Electrical and Electronic	1.0/2.5	1.2/2.8
Electromechanical	1.5/4.0	1.8/4.8
Mechanical and Pneudraulic	3.0/6.0	3.6/7.2

Preventive Maintenance

Preventive maintenance includes all scheduled replacement of hardware items such as those listed in the potential limited-life item list, and their adjustment and verification after exchange. It does not include housekeeping tasks which have been included in the crew work-rest cycle studies nor the logistics time to transfer crew supplies and arriving fluids and spares from the Logistics Module to the Space Station. Preventive maintenance man-hours per month estimates are apportioned to subsystems as shown in Table 7-19. The estimate for potential limited-life items is only 30 maintenance man-hours/mo as shown in Table 7-20. The maintenance man-hours/task is shown in the column labeled maintenance time (H).

The total preventive and corrective maintenance work load is estimated as 65 man-hours per month for ISS and 105 man-hours per month for GSS. For the ISS with its 3,453 LRU's, this represents the replacement of 13 random failure items and 15 scheduled replacement items on the average per month. The shaded portion of the bars in Figure 7-16 show how the maintenance man-hours are distributed among modules and subsystems. The preventive maintenance portion may have the tasks scheduled for crew convenience, while corrective maintenance urgency depends upon the category of equipment involved in the individual failure case.

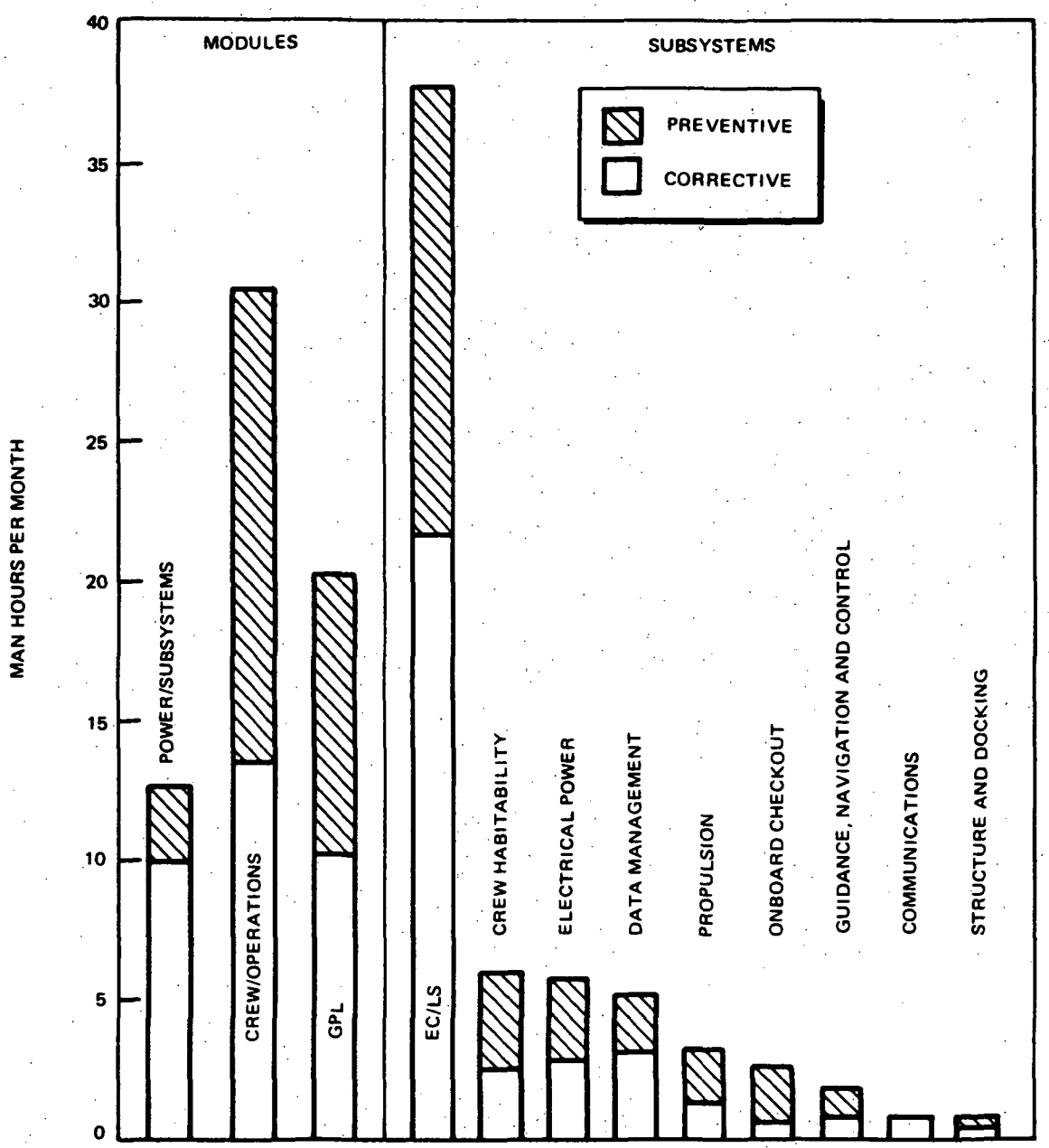


Figure 7-16. Maintenance Workload (ISS)

Table 7-19

PREVENTIVE MAINTENANCE (SCHEDULED)

Subsystem	10-/m Est (Ref)	ISS	GSS
	Maintenance man-hours/mo		
Electrical Power	5	3	6
EC/LS	20	16	24
Guidance/Navigation and Control	2	1	2
Data Management	2	2	2
Onboard Checkout	2	2	2
Propulsion	3	2	3
Communications	0	0	0
Structure and Docking	1	0.5	1
Crew Habitability	5	3.5	5
Experiments	-	-	-
Totals	40	30	45

Table 7-21 shows the estimated division of crew on-duty times (daily averages in minutes) for Space Station tasks and the remainder available for experiments. For the ISS, this calculates out as 21.9 percent of available crew time for Space Station tasks, with 3.6 percent for subsystem maintenance. A design objective of 5 percent or less of crew available time for maintenance was established in the CEI specification. It is believed that this amount of time is reasonable. The predictions indicate that this value is achievable with careful design attention to assure low failure rates and ease of maintenance.

Table 7-20
Preventive Maintenance-Limited-Life Items

Subsystem/Item	Quantity	Generic Life	Operating Time (10 yr)	10 Yr	90 Day	Maintenance Time (Hr)	Maintenance 90 Day	Maintenance 30 Day
EC/LS								
Tri-bed cartridge	2	45 Day	3,650 Day	162	4.0	1.2	4.80	
Cat oxidizer cartridge	2	180 Day	3,650 Day	40	1.0	1.2	1.20	
Water transfer disks	2	180 Day	3,650 Day	40	1.0	0.5	0.50	
Bacteria filters laboratory	2	180 Day	3,650 Day	40	1.0	0.5	0.50	
Charcoal filters	1	20 Day	3,650 Day	182	4.55	0.5	2.28	
Urine pretreatment	1	180 Day	3,650 Day	20	0.5	1.2	0.60	
Bacteria filters	2	20 Day	3,650 Day	365	9.0	1.2	10.80	
Bacteria filters	2	20 Day	3,650 Day	365	9.0	0.5	4.50	
Reverse osmosis cart. -bio	1	180 Day	3,650 Day	20	0.5	2.5	1.25	
Filters	4	1 ea. 15 Day	3,650 Day	243	6.0	0.5	3.00	
Fans	20	50,000 Hr	87,600 Hr	35	0.9	2.5	2.25	
Pumps	8	20,000 Hr	17,520 Hr	7	0.2	2.5	0.50	
Valves	80	150,000 Cycle	18 Cycle/ Mo	0.1	—	3.5	—	

Table 7-20
Preventive Maintenance-Limited-Life Items (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 yr)	10 Yr	90 Day	Maintenance Time (Hr)	Maintenance 90 Day	Maintenance 30 Day
Regulators	4	40,000 Hr	87,600 Hr	8.75	0.22	3.5	0.77	
Compressors	4	20,000 Hr	87,600 Hr	17.5	0.44	4.5*	1.98	
Motors	8	20,000 Hr	17,520 Hr	7	0.2	2.5	0.50	
Pressure switches	4	30,000 Hr	87,600 Hr	11.8	0.29	1.8	0.52	
O_2 tanks	3	Considered in Logistics			—	—		
N_2 tanks	5	Considered in Logistics			—	—		
Solar collectors	2	35,000 Hr	53,436 Hr	0.05	—	—		
Radiators - thermal control	3		87,600 Hr	0.05 (1564.25)			(35.95)	(11.98)
Electric Power								
Batteries	24	2.5 Yr	10 Yr	96	2.4	3.0*	7.20	
Circuit breakers	250	35,000 Cycle	5 Cycle/ Mo	4	0.01	0.6	0.01	
Gears	6	20,000 Hr	8760 Hr	2.6	0.07	6.0*	0.42	
Motor drives	3	20,000 Hr	8760 Hr	1.3	0.04	6.0*	0.24	
Bearings	6	100,000 Cycle	16 Cycle/ Day	3.0	0.08	6.0*	0.48	

*2 man tasks (man hours)

Table 7-20
Preventive Maintenance-Limited-Life Items (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 yr)	10 Yr	90 Day	Maintenance Time (Hr)	Maintenance 90 Day	Maintenance 30 Day
Sun sensors	2	35,000 Hr	53436 Hr	0.05	—	5.0*	—	
Switches	300	300,000 Cycle	30 Cycle/ Mo	3	0.07	0.6	0.42	
Solar panel	2	—	53436 Hr	(4.0)		12.0*	—	
Shunt regulator	2	40,000 Hr	53436 Hr	2.5 (109.45)	0.06	6.0*	0.36 (9-13)	(3.04)
GNC								
Control moment gyros	4/5	17,500 Hr	87,600 Hr	20	0.5	4.0	2.00	
Star trackers	2	17,500 Hr	17,520 Hr	2	0.05	6.0*	0.30	
Horizon sensors	4	17,500 Hr	87,600 Hr	20	0.5	6.0*	3.00	
Attitude gyros	6	50,000 Hr	87,600 Hr	10 (52)	0.25	4.0	1.00 (6.30)	(2.10)
Propulsion								
High thrusters	40	20 Hr	1 Hr/30 Day	16	0.15	6.0*	0.90	
Low thrusters	32	20,000 Hr	8760 Hr	16	0.4	6.0*	2.40	
Regulators - high	2	40,000 Hr	87,600 Hr	4	0.1	6.0*	0.60	

*2 man tasks (man hours)

Table 7-20
Preventive Maintenance-Limited-Life Items (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 Yr)	10 Yr	90 Day	Maintenance Time (Hr)	Maintenance 90 Day	Maintenance 30 Day
Valves - high	30	150,000 Cycle	240 Cycle	—	—	6.0*	—	
Filters - high	3	45,000 Hr	87,600 Hr	6	0.15	3.0*	0.45	
Regulators - resistojet	4	40,000 Hr	87,600 Hr	9	0.22	6.0*	1.32	
Valves - resistojet	20	150,000 Cycle	36,500 Cycle	4.8	0.12	6.0*	0.72	
Filters - resistojet	18	45,000 Hr	8760 Hr	3.5	0.09	3.0*	0.27	
Pumps - resistojet	4	20,000 Hr	17,520 Hr	3.5 (52.8)	0.09	6.0*	0.54 (7.20)	(2.40)
Data Management								
Recorders	9	17,000 Hr	8760 Hr	4	0.1	1.8	0.18	
Keyboard and display	4	17,000 Hr	21900 Hr	5	0.12	1.5	0.18	
Printers	1	17,000 Hr	4380 Hr	0.25	—	1.5	—	
Aux. memory units	4	25,000 Hr	29,200 Hr	4	0.1	2.0	0.20	
Cathode ray tubes	10	17,000 Hr	8760 Hr	5	0.12	2.0	0.24	

*2 man tasks (man hours)

Table 7-20
Preventive Maintenance-Limited-Life Items (Continued)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 Yr)	10 Yr	90 Day	Maintenance Time (Hr)	Maintenance 90 Day	Maintenance 30 Day
Traveling wave tubes	4	17,000 Hr	8760 Hr	2	0.05	2.0	0.10	
Potentiometers	60	50,000 Cycle	600 Cycle	0.7	0.02	2.5	0.05	
Film tape transport	2	10,000 Hr	29,200 Hr	5.8 (26.8)	0.14	3.0	0.42 (1.37)	
OCS								
Transducers/ sensors	800	350,000 Cycle	730 Cycle	2 (2)	0.05	2.0	0.10	
Totals/90 days				(1822.31)	45.6 actions		(60.05)	
Totals/30 days - Estimate					13.5 actions/mo.			(20.02 MH)
- Use (factored estimate)					15.0			30

*2-man tasks (man hours)

Table 7-21

CREW OPERATIONS TIME REQUIREMENTS SUMMARY

(Daily Averages in Minutes)

	ISS	GSS
Mission Planning and Control	345	665
Housekeeping and Logistics	145	250
Subsystem Operations	167	261
Subsystem Maintenance	130	210
	787 (1.3)	1,386 (2.3 men)
Available for Experiments	2,813 (4.7)	5,814 (9.7 men)
Total	3,600	7,200

7.1.2.2 Configuration Impact

One of the considerations used to evaluate module arrangement studies was the traffic generated by maintenance activities. The study results for the final configuration selected for the ISS is discussed here.

The maintenance steps that contribute to maintenance movement are shown in Figure 7-17. The Space Station spares and tools are located beneath the floor in the Crew Operations Module. The experiment spares and any special tools for experiment equipment will be stored in the GPL. The scheduled replacement items will be brought up in the Logistics Module and will be exchanged from that location on an as required basis. The maintenance movement study reported here relates only to the Space Station maintenance tasks.

The total Space Station logistics load for a 90-day resupply mission is shown in Table 7-22. Item 1 for the most part is replacement for random failures and would be transferred to storage in exchange for failed components. Items 2 and 5 are the most frequently replaced items listed in the potential limited life item list. Travel, in addition to that discussed here, will be required to transfer logistics items 4, 6, 7, 8, 9 and 10. The Logistics Module arrangement is shown: the logistics loads and handling methods are discussed in detail in Subsection 4.2.4 of this document.

Movement to conduct maintenance was estimated for task accomplishment in each module and for exchange of spare parts between the arriving Logistics Module and the spares storage space in the Crew Module. These events are shown in Figure 7-18. Figure 7-19 illustrates maintenance activities and traverses required. The legend used is as follows:

Maintenance actions required in the manned module per month (corrective and preventive).

3.9 Travel movement within a compartment to travel to the scene of the maintenance activity or to obtain spare parts and tools to conduct the activity. This represents the case that the crew will generally initiate travel from within the Crew Module (70 percent of stay time will be in Crew Module, Table 7-23).

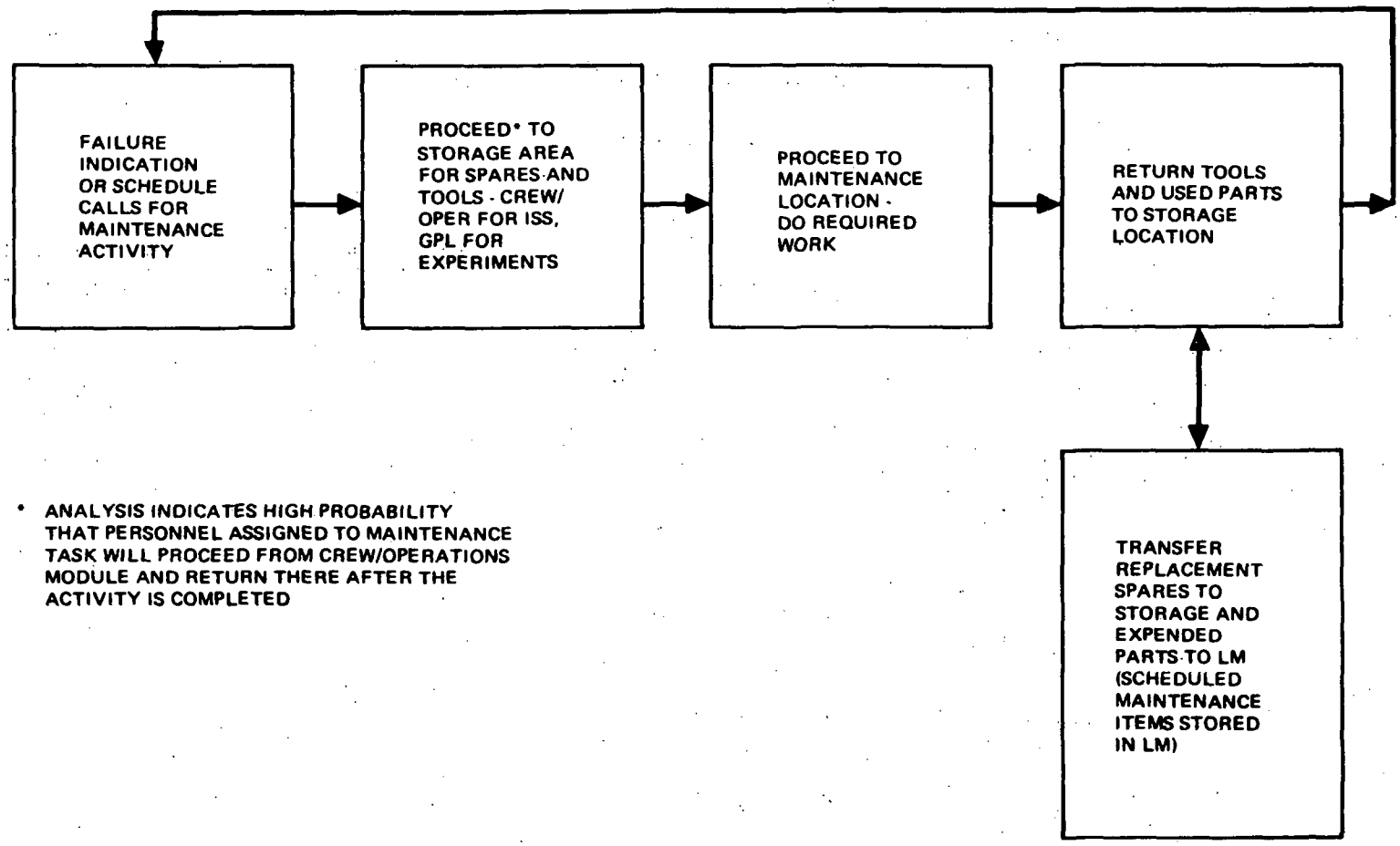


Figure 7-17. Maintenance Movement Causes

Table 7-22

90 DAY SPACE STATION RESUPPLY

Category or Item	Total Requirements (lb - mass)	Storage Requirements Vol Ft^3	Module Storage Location	Transfer By*		
		6-Man/3 Module Configuration				
Spares	363	18	Log/Crew	(P)	Crew	Exchange
Batteries	980	3	Log/Pwr, Crew, GPL	(P)	Crew + TS	Exchange
N_2H_4, GN_2, O_2	24, 3, 2327	2, 10, 34	Log	(P)	Auto	Source
Food	1, 711	54	Log/Crew	(P)	Crew	Replenish
ECLS Consumables	418	24	Log/Crew	(P)	Crew	Replenish
Trash Containers	75	105	Log/Crew	(P)	Crew + TS	Exchange
Crew personal/ consumable	450	45	Crew	(P)	Crew	Exchange Replenish
Film, tape	275	11	GPL/Crew	(P)	Crew	Exchange Replenish
GPL GPL	400	10	GPL	(P)	Crew	Exchange
EVA/IVA suits	275	30	Crew, GPL		Crew	Exchange Replenish

*P = Periodic
TS = Transfer System

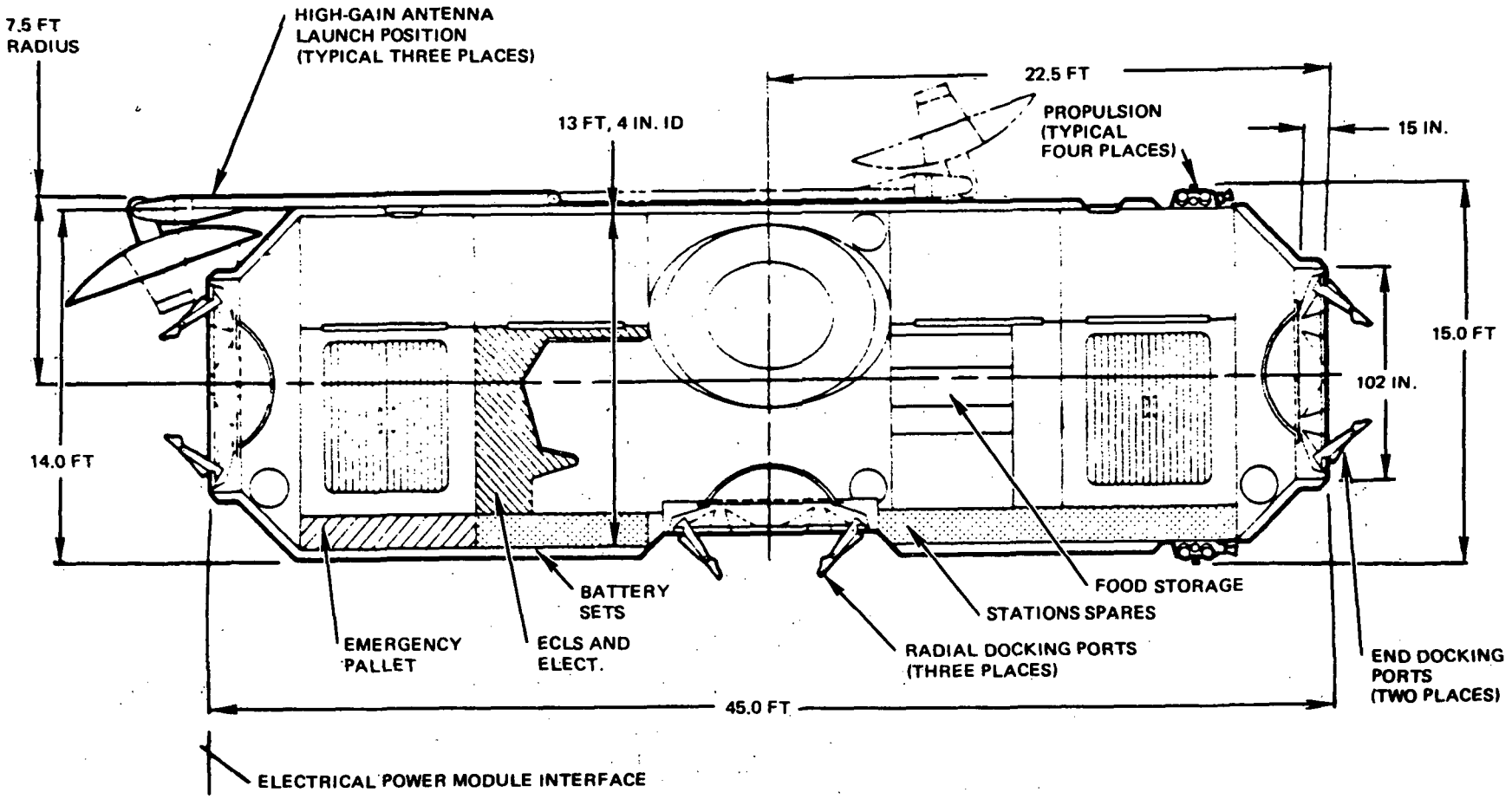


Figure 7-18. Crew/Operations Module (Inboard Profile)

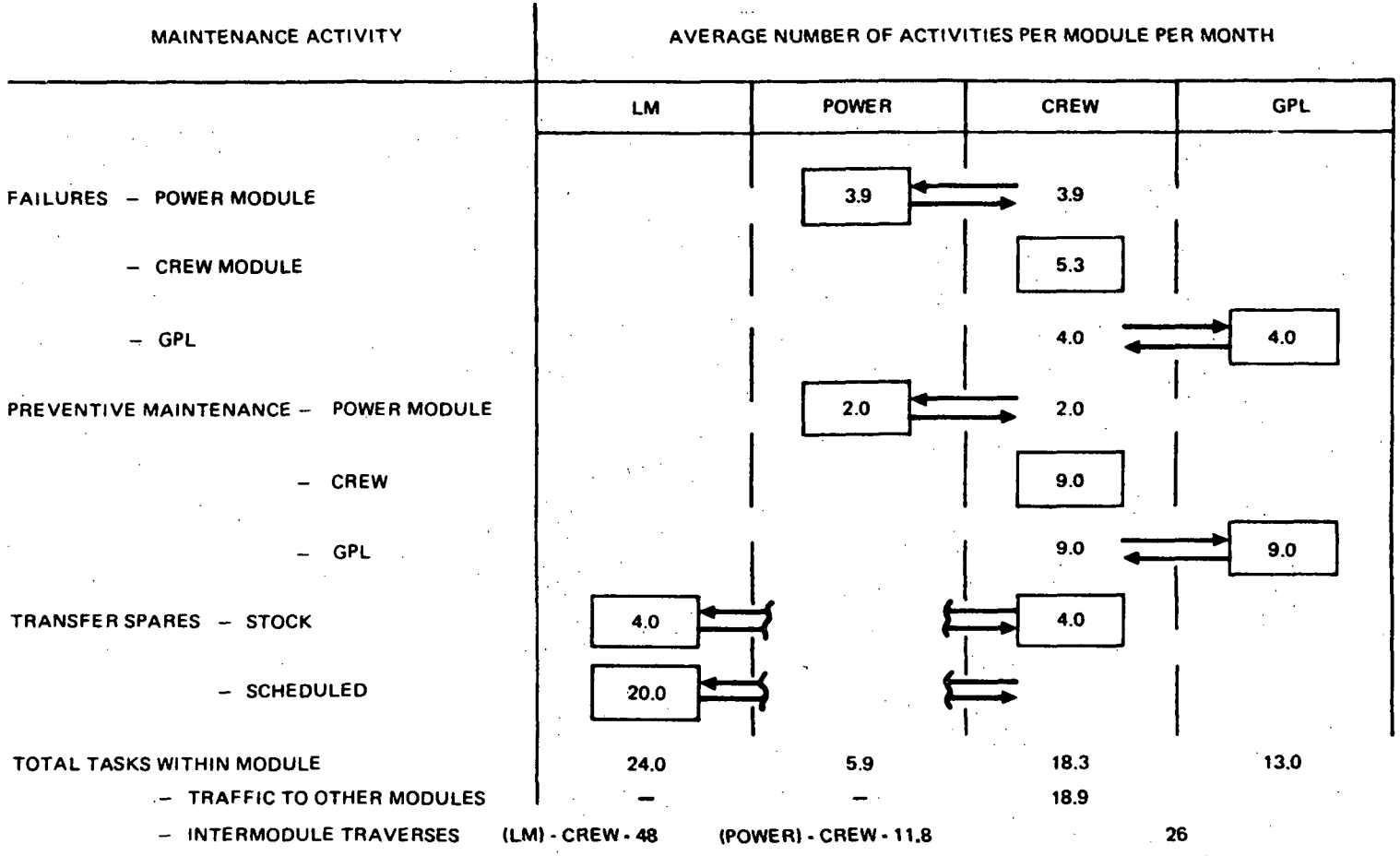


Figure 7-19. Movement Within and Through Modules to Conduct Maintenance

Table 7-23

CREW TIME IN EACH MODULE

Module	First 5 yr	Second 5 yr	10-yr Avg (%)
Crew/Operations	706	706	70
GPL	151	81	12
Power	7	7	1
Log Module	4	4	
Attached RAM's	140	210	17
Totals	1,008	1,008	100

Represents the trips through the intermodule hatches to transport spares and gain access to maintenance areas. The total traverses at the bottom of the page show the number of actual trips either way through the doorway. For example, the average of 26 traverses per month between the Crew and GPL Modules represents the trips required to gain entry to the GPL to carry out a maintenance task and then return failed parts for storage in the Crew Module. If the corrective maintenance procedures were written to require failures to be investigated and verified prior to obtaining the spares and tools, this would double the traverses to correct failures.

For comparison, Table 7-24 shows the spread in module maintenance and traverses per module expected for the various candidate Space Station spares stocking and logistics transfer policies investigated. This shows the high number of traverses required through the crew module if the spares were stocked in the GPL. The baseline policy results in 86 movements per month from within the crew module or across the crew module to conduct maintenance or transport spares. This represents the level of disturbance present as a result of maintenance.

Table 7-24

COMPARISON OF CREW MOVEMENT WITHIN MODULES
TO CONDUCT MAINTENANCE

Events (Figure 7-19)	Baseline-Spares in Crew Module - Scheduled Replacement Items Stored in Logistics Module	Spares in GPL Module - Scheduled Replacement Items Stored in Logistics Module	Spares in GPL Module Scheduled Replacement Items in GPL
Maintenance in Power Module (Activities)	5.9	5.9	5.9
Crew Module (Activities)	14.3	14.3	14.3
GPL (Activities)	13.0	13.0	13.0
Transfer Spares - trips/mo	24.0	24.0	13.0
Intermodule Traverses			
Power - Crew	11.8	11.8	11.8
Crew - GPL	26.0	61.4	131.8
Logistics Module - Crew	48.0	48.0	25.0

7.1.2.3 Accessibility

Testing at KSC will be minimal and can be generally categorized as electrical continuity testing of control circuits and pressure testing of volumes. There will no extended operation of subsystem equipment. Failures or anomalies detected during these tests will be corrected by replacing the same component as planned for on-orbit repair. The provisions for on-orbit repair will provide adequate accessibility for terrestrial repairs. Some special work platforms and crew support provisions may be necessary to permit maintenance if any of the tests are conducted after orbiter mating. All servicing will be limited after receipt at KSC. That servicing required will be scheduled to be accomplished prior to transport to the pad.

Side Wall Accessibility

One of the concerns for Space Station maintenance has always been the consideration of access to sidewalls for inspection and repair of meteoroid penetration damage. There is also some concern for inspection capability for incipient cracks, corrosion or water damage. Water damage can take the form of contribution to corrosion problems or saturation of insulation with the attendant heat leak path to the outer skin. A third concern which is more of a problem on the Modular Space Station than on the 10-M station is maintenance. The 10-M station permitted equipment to be installed in free standing consoles with space between the equipment and the sidewalls or a minimum area blocked at the console attachment plane. The modular concept requires the equipment to be located on the periphery to provide adequate passage around work stations.

A trade study was made to determine the value of sidewall access. The trade values were established as follows:

Volume: $52,966/m^3 ($1,500/cu ft)

Weight: $551/Kg ($250/pound mass)

Crew time: $1,940/man-hour

The requirements for access were identified and the risk was estimated. A maintenance time was estimated representing the time required for access if subsystem equipment had to be replaced or worked around to achieve the inspection or repair. These estimates are shown in Table 7-25. Similar estimates were made of volume required to store loose wire bundles or to provide swivel fittings to transfer liquids and power across the swing-out anchor points and the resulting weights. These are shown in Table 7-26. The average task time for maintenance was considered to be reduced by 10 percent by access which would represent an average saving of 8 man-hours per month or 960 man-hours in 10 years.

The results were as follows:

Cost -	Volume:		$322,563
	Weight:		$484.329
			$806,892
Savings-	Structural Inspection:	364 MMH	706,160
	Maintenance	960 MMH	1,862,400
			2,568,560

Thus, a net savings of $1,761,668 is realized from reduced maintenance time and structural inspection time. This proves the value of designing for ease of access to sidewalls and for two-sided access to subsystem equipment.

7.1.2.4 Return for Refurbishment

One of the key issues assigned for study was module return for refurbishment or replacement. The inherent design features to facilitate assembly on-orbit permit emergency retrieval for major repairs on the ground and for orderly disassembly at the end of the program. This would indicate that return to Earth for major maintenance or refurbishment would be possible with a Shuttle-launched Modular Station, whereas it was not possible with a Saturn-launched station. The planned buildup steps include installation of CMG's, batteries, etc., after manning. This concept also recognizes the need for

Table 7-25

TRADE STUDY - SIDEWALL ACCESS RISK AND MAN-HOURS

Access Requirement	Probability	MMH With Access
Meteoroid	0.03	20 MMH
Water	0.10	54 MMH/m^2 for 2 percent of surface
Structure	0.10	54 MMH/m^2 for 20 percent of surface
Total saving with easy access	= 364 MMH/10 yr	
	= 3.04 MMH/mo	

removal of excess weight and facilitates removal of crew required equipment prior to return of damaged modules when a limited capability is to be retained on orbit.

The list of criteria for on ground maintenance is shown in Table 7-27, which was developed in the options study. A list of criteria requiring further study was also developed during the options study, Table 7-28. Both of these criteria were applied to the Space Station modules and their subsystems to assess potential requirements or events which would necessitate returning a module to earth for refurbishment or replacement. Based on past Space Station analyses, this evaluation was initiated with the assumption that module overhaul

Table 7-26

TRADE STUDY - SIDEWALL ACCESS VOLUME AND WEIGHT

Estimates	Percent not Easily Accessible	Added Volume* to Improve Access
Power Module	65	2.07 M^3
Crew Operations Module	70	2.35
GPL Module	60	1.67
		6.09

Weight at .30 density factor and 561 Kg/m^3 = 879 Kg

*Added volume - Stowage volume for coiled wire bundles, hoses, hinging structure, etc. to permit access without disassembly of subsystem

and retrofit should be possible by component replacement more easily, and cheaper than by module return. Changes in mission objectives is an unknown and was not a criterion.

The results of the assessment are summarized in Table 7-29. Of all of the potentials for serious damage to a module identified that would make ground repair more feasible than space repair, only five problems remained as contenders for module return.

Table 7-27

CRITERIA – ON-GROUND MAINTENANCE

Cannot be installed correctly on delivery
Cost for on-orbit repair approximates cost of new launch for module retrieval
Operation verification requires major test/integration/ alignment equipment
Requires repair equipment too large to transport up in orbiter
Maintenance task requires technique not amenable to 0 g or space ambients (i.e., mirror recoating)
Experiment too large to pass through doors

These were fire, solar panel mechanical damage, thermal radiator replacement (mechanical damage or uncontrollable leakage in the thermal conditioning fluid loop), explosion of tank systems, and biological contamination.

The risk of a failure necessitating considerations for possible module return is approximately 13.5 percent in 10 years (1.35 percent/year average). Conceptually, this means that 13 of every 100 Modular Space Station systems launched would be expected to experience a failure necessitating a module return in 10 years or less. In this case, the 13.5 percent risk can best be thought of as the risk of some mission curtailment with an 86.5 percent probability that all modules will have continued to function satisfactorily for the full 10 years when supported by the normal on-orbit maintenance capability.

Table 7-28

CRITERIA – MAINTENANCE LOCATION DETERMINATION REQUIRES FURTHER STUDY

EVA maintenance required
IVA (space-suited) maintenance required – (allowable man-hours of extended effort)
Removal for repair dumps module atmosphere
Major disassembly required to pass component through dock doors
Requires manipulator on-orbit for EVA/IVA handling

The risk, when apportioned in relation to percentage of thermal cooling, electrical distribution complexity, and docking exposure per module, is not evenly divided between modules. The power modules which are always terminal in the arrangements have 47 percent of the risk. The apportionment by module shown in Table 7-30 indicates that 69 percent of the risk is associated with outside modules (power modules and the GPL). The initial Crew Module is terminal only during buildup, however it could be removed for return after relocating the GPL to a power module side dock position during the first five years.

The risk assessment does not provide strong support for the concept of module return for maintenance or repair as a salient feature of the Modular buildup concept. The risk value assumptions should be subjected to program review as more subsystem detail becomes available prior to reaching a program decision. It is not believed that the requirements for reliable hardware can

Table 7-29

RISK OF MODULE RETURN

Criterion or Condition	10-Year Risk	
Cost approximates new launch		(0.0510)
Electrical fire	0.020	
Solar panel structural damage	0.001	
Solar panel excessive deterioration	0.005	
Extremely hard dock - puncture	0.0083	
Thermal system blockage (includes power loss)	0.0135	
Solar panel extension or orientation system not functional - initial	0.0032	
Maintenance task not amenable to 0 g		(0.0700)
Thermal radiator recoating	0.050	
Radiator leaks or excessive gas entrapment	0.020	
Excessive requirement for space-suited maintenance or protective breathing		(0.0141)
Explosion damage - no pressurization	0.0006	
Biological contamination	0.0035	
Space debris puncture	0.010	
Total risk estimate	0.1351	

Table 7-30

MODULE RETURN CONSIDERATIONS

Cost-effectiveness criteria differ for station modules and RAM modules

Return of RAM's for repair or updating frequently cost-effective

Return of Space Station modules rarely cost-effective

Module	Operation Time (yr)	Probability Estimates	
		Probability	Outside/Inside
Power/subsystem	10	0.0447	0.0447/ 0
Crew/operations	10	0.0303	0.0032/0.0271
GPL	10	0.0272*	0.0292/ 0
Crew Operations	5	0.0144	0.0002/0.0142
Power/subsystem	5	0.0185	0.0185/ 0
		0.1351	0.0938/0.0413

*Does not include experiment equipment related events

be reduced to a level that would show greater economy with ground maintenance and still provide an acceptably low level of maintenance work load and high level of safety. It would seem that every interest should be directed at making the Space Station subsystems easy to maintain and adaptable to on-orbit maintenance and possible refurbishment, rather than rely on ground maintenance.

A solar array concept with a standard docking capability and a similar dockable thermal radiator equipped module could alleviate much of the risk of early module return if these steps should later be chosen to increase system availability. The Shuttle does not appear to make module return for refurbishment cost effective, it does provide capability for major cost savings in the area of spares procurement. The capability for failed part repair with a one to three month turn-around capability has the potential for major savings in on-orbit spares procurement costs. The Shuttle also permits salvage of all experiments and controlled return for salvage of the modules at the end of 10 years. Should a major subsystem functional failure occur that might make demating for ground maintenance seem attractive, the same energies and technical expertise required to devise an operation capability without the module could probably devise an equally acceptable subsystem functional replacement amenable to space installation. The low risk of major damage to the extent of requiring ground repair of the Space Station modules would appear to negate this as a justifiable reason for increasing weight or complexity that would reduce the effectiveness from the standard of a clean, efficient, maintainable design with respect to the planned 10-year mission.

7.1.2.5 EVA Maintenance

The Space Station studies have been conducted under the guideline of no planned EVA. The term "planned EVA" has been interpreted to mean there should be no scheduled maintenance for items requiring EVA for access. Every effort has been expended to visualize means to repair items that fail. Certain of these items must be installed on the Space Station exterior to function. The Phase B studies have indicated that certain of these should be considered for EVA repair in case of failure as a cost and weight effectiveness consideration. These items are listed by class in Table 7-31. This list is expanded in Table 7-32.

Table 7-31

MAINTENANCE TASKS - EVA-SPACE STATION

Item	Number (10 Yr)
Thrusters - High and Low	24
Antennas	2
Miscellaneous Lights, Seals, Sensors	1
Inspection of Suspected High Damage	1
Total Excursions - 10 Years	28
Average 16.5 Man-hours/Year EVA	

The stated concerns for astronaut safety in an EVA mode are recognized. The hazards of EVA travel have been recognized. However, the potentials for mission effectiveness are considered to cover all potential courses for solution. Experience in the Gemini program tests and with equipment recovery from the service module in the Apollo 15 flight have indicated the practicality of EVA as a backup means for critical operations. Certainly, a tethered EVA astronaut in a preengineered EVA maintenance situation is in no more jeopardy than this same astronaut in a long ranging tour of the Moon's surface. It is considered that the 1980 Space Station will have benefitted from the experience of follow-on Apollo missions or experiment designs and that EVA maintenance for mission critical equipment will have been accepted for cases where this proves to be the practicable solution.

Table 7-32

EVA RISK ANALYSIS

Item	Failure Mode	Risk (10 yr)	Action and Maintenance Time (EVA)
Solar Panel	Structural damage - space debris or collision	0.01(1)	Return module (inspect - 2 at 1.5 hr)
	Excess deterioration rate - solar cell or soldered connection failures	0.005(1)	Replace panel or return module 2 at 12 hrs (0.120)
Thermal Radiator	Loop leaks	0.010(1)	Return module (inspect - 2 at 1.5 hr)
	Coating deterioration	0.050(1)	Return module (inspect - 2 at 1.5 hr)
Solar Heat Collector	Leaks in collector or plumbing	0.050(1)	Return module (inspect - 2 at 1.5 hr)
Sun Sensors	Failure redundant sensors	0.049	Replace sensors 2 at 2.5 hr (0.25)
Docking Acquisition Lights	Lights fail in docking mode	1.00	Replace light 2 at 1.5 hr (3.00)
High-Gain Antennas	Failure of reflector positioners, positioner control electronics, acquisition comparator and feed, main comparator and feed, multiplexer and switching assembly, Ku band low noise receiver, S-band tracking receiver and selector switches (3 antennas).	1.64	Replace failed component 2 at 3 hr (9.84)
Docking Port	Pressure seals failed	0.004	Use alternate port
	Docking ring damaged (capture lock, etc.)	0.07	Use alternate port
	Meteoroid door - fail to open/clear, fail to close	0.003 0.003	Use alternate port Replace mechanisms 2 at 3 hr (0.02)
Sensors	Failure of retraction mechanism for star tracker, star sensor or horizon sensor	0.35	Replace failed sensor 2 at 5 hr (3.50) and repair retraction mechanism
Thrusters	Failed high thruster (random and wearout)	6.0	Replace thruster unit 2 at 3 hr (36.00)
	Failed low thruster (random and wearout)	18.0	Replace thruster unit 2 at 3 hr (108.00)
Inspection for (1) items above at 10 x Risk = 10 x 0.125 =		1.25	Inspect area of concern 2 at 1.5 (3.75)
		28.494 = 3 times/yr avg	16.5 MH/yr avg 164.48 MH/10 yr

Maintenance estimates for EVA items used in Table 7-32 are as follows:

Thrusters - The propulsion subsystem uses a Resistojet low thruster system to maintain attitude control and a high thruster system to provide correction for docking disturbances. The low thruster system uses CO_2 or H_2O as propellants. The thrust is obtained by heating the propellant in a specially designed nozzle.

The high thruster system uses N_2H_4 (Hydrazine) for fuel.

There are five high thrusters and 4 low thrusters in each of eight propulsion modules mounted on the end Space Station modules.

The high thrusters are assumed to operate during a one-hour time period each 30 days. Only half of the thrusters were considered as operating because of the redundancy provided. Each replaceable thruster consists of the thrustor nozzle, shut-off valve, pressure sensor, temperature sensor and catalyst. The combined failure rate of 20.1×10^{-6} per hour indicates 0.048 random failures in 10 years. The wearout life is assumed to be 20 hours of continuous operation.

The low thrusters are assumed to operate continuously for orbit-keeping and sporadically for attitude control. For this calculation, the thrusters were assumed to operate half time with a failure rate of 1.043 per million hours. The wearout life was assumed to be 17,500 hours with a 50 percent use factor and a 20 percent stress factor. These provided an estimate of two random failures and 16 wearout replacement in 10 years.

The thruster nozzles account for 86 percent of the EVA. Proper programming to utilize existing redundant thruster capability to permit delay of EVA repair until there is a need for multiple replacements is envisioned as a means to reduce EVA travel to the frequency shown.

Antennas - The three high-gain antennas (parabolic) are mechanically erected and then mechanically positioned with respect to the communication link being used. The equipment listed in Table 7-32 is all located on the antenna mast. Redundant units are planned, however, they must be reached by EVA means if a failure occurs.

Sensors - There is an estimated risk of three sensor failures. The sensors are mounted externally, and the design will provide for retraction into a pressurized box for maintenance from inside the module, much the same as for the 10-M station. The risk of EVA and the high time represents the risk of a retraction actuator failure for the failed sensor of a type necessitating EVA and the repair time for this actuation system and sensor.

Misc. Lights, Seals, etc. - Table 7-32 lists the items considered to require EVA for repair. Solar panel replacement, radiator leaks and radiator recoating are considered so extensive that module return should be considered rather than repair. These are designed for such margins of safety that they will provide many years of various degrees of degraded performance before replacement is a necessity. EVA assistance to deployment of solar arrays in case of jamming and inability to retract masts to fit into the Shuttle are included in the excess deterioration risk.

Most of the docking equipment can be repaired in the docking port pressurized area while a module is docked. The redundant seals and the docking ring cannot be replaced without dedocking the module. However, the risk is low and it would be considered more practical to use other docking ports than to make repairs except in the case of multiple docking port damage.

There are 16 to 20 docking acquisition and position lights on each module. These lights have redundant elements and are mounted on brackets to provide extension beyond the meteoroid shield. The risk of failure for each individual light is low (0.02 average in 10 years) and the weight for making each light retractable for repair would be unreasonably high.

Experiments - EVA maintenance estimates for experiment modules were developed by Martin Marietta as gross estimates based on previous 10-M Space Station data, for the type of modules used. The experiments are flown as Free-Flying Modules (FF), Attached Modules (AM), or Dedicated Modules (DM). The amount of EVA maintenance is a function of design. The modules have subsystem chambers, instrument chambers and experiment chambers and equipment mounted on the exterior (thrusters, antennas, etc.). Each type of module has a slightly different configuration, although the different types are often standard for several experiments of a given class. For example, all AM's have the same external equipment, assumed to have the same failure risks during each year of space use.

Table 7-33 shows the estimates of EVA maintenance man-hours per year for each type of module. The experiment module type column lists all experiments that may have EVA maintenance even though some are not planned in Case 534G. The times shown per year represent the estimated time that the crew would be in an EVA mode. All EVA maintenance tasks are accomplished by two men. The maintenance task times for individual subsystems were estimated and total module maintenance estimates are a function of which subsystems are in pressurized or unpressurized compartments. Column 2 identifies which chambers are pressurizeable, permitting shirtsleeve maintenance, and which are not, requiring a space suit.

Table 7-34 shows maintenance estimates for the individual subsystems used to develop these module estimates.

Table 7-35 shows the experiments as scheduled in Case 534G in order to provide yearly estimates of EVA maintenance time. This shows the major impact that results from free-flyer operations.

Table 7-33

EXPERIMENT MODULE MAINTENANCE REQUIREMENTS

Module Type	Pressurizable Chambers	Maintenance Time Per Year - Man-hours*			
		Shirtsleeve	EVA/IVA	Always EVA	Total EVA
FF 1, 4, 5	Subsystem Chamber	26.6	76.8	5.8	82.6
FF-2	None	None	128.8	5.8	134.6
FF-3	Subsystem and Detector Chambers	59.4	12.4	5.8	18.2
AM1-12	All	62.7		2.8	2.8
FF-6	All	65.7		7.4	7.4
DM1, 3	All	62.7		1.2	1.2
DM-2	All	62.7		2.8	2.8
FF7, 8	All	65.7		5.8	5.8

*Excludes pre- and post-EVA activities

Table 7-34

MODULE MAINTENANCE—EXPERIMENTS

Subsystem Baseline

Shirtsleeve or EVA/IVA*
Depending on Pressurization (task hr/yr)

	Total	Subsystem Chamber	Instrument Chamber	Experiment Chamber	Always EVA Task (hr/year)	
Experiments	28.4	0	25.6	2.8	0.8	Only for modules with pressure doors for vacuum viewing
Structures	3.0	1.0	1.0	1.0	0.3	(Primarily for docking parts
Data Management	13.0	10.4	2.6	0	0.3	Free Flyers only (antennas)
G&C	6.4 FF only	6.4	0	0	0	
Attitude Control	3.0 FF only	3.0	0	0	0.6	Free Flyers only (jets)
Thermal Control	4.5	1.5	1.5	1.5	0.3	Inspection
Atmosphere Control	1.3 Only if pressurized	0.65	0.65	N/A	0	
Electrical Power	3.0	2.4	0.3	0.3	1.4	Free Flyers only (for solar arrays)
C&D	6.4 In GPL, none in Free Flyer	N/A	N/A	N/A	0	
OCS	3.0	1.2	1.2	0.6	0	

*Where chambers cannot be pressurized:
total EVA man-hours exclusion or pre- and post-EVA activities = 2 X (task hours for unpressurized chamber + Always EVA task hours)

Table 7-35

EVA MAINTENANCE—EXPERIMENTS MMH/YR

Experiment/ Module	EVA MH/Yr	1	2	3	4	5	6	7	8	9	10
FF1-A1	82.6										
FF2-A2	134.6										
FF3-A2A	18.2									[18.2]	18.2
FF4-A3	82.6										
FF5-A3C, D, E	82.6								20.7	[82.6]	82.6
AM1-CN1A	2.8	[2.1]	0.7								
2-CN1B	2.8			[2.8]							
3-T3B	2.8				[2.8]						
4-A4C	2.8				[1.4]	2.8	2.8	0.7			
5-P2B4	2.8						[1.4]	[2.1]			
6-A6	2.8						0.7	[2.8]	2.8	2.8	2.8
7-A4A	2.8							[2.8]	2.8	2.8	2.8
8-A4B	2.8							[2.1]	2.8	2.8	2.8
9-A5B	2.8							[1.4]	2.8	2.8	2.8
10-CN1	2.8							0.7	[2.1]		
11-	2.8										
12-	2.8										
FF6-A5A	7.4								[3.7]	[7.4]	7.4
DM1-P3, 3A, 3B	1.2										
DM2-ES1C	2.8	[1.4]	[2.8]	[2.8]	[2.8]	[2.8]	[1.4]				
ES1AA	2.8						[1.4]	[2.8]	[2.8]	[2.8]	[2.8]
FF7-T2A	5.8										
FF8-T2B, E	5.8										
EVA Maint Time MH Total per Year		3.5	3.5	5.6	7.0	5.6	7.7	15.4	40.5	122.2	122.2

Notes: 1. Estimates based on MMC Data
2. Experiment Modules shown as [MH] are only Experiments Scheduled in Case 534G.

7.2 SYSTEM SAFETY

The overall objective of the system safety task was to provide an acceptable level of safety for the Modular Space Station Phase B definition. Specific objectives of the Modular Space Station safety program were as follows:

A. Plan and incorporate safety into the configuration, design and operations as early as possible.

B. Develop and implement safety requirements to ensure their incorporation as inherent design features rather than adopt remedial safety measures later.

C. Assess potential hazards and determine methods to eliminate them or reduce them to acceptable levels.

D. Provide documentation of the activity for use in subsequent phases, and for management and NASA visibility.

Table 7-36 depicts the Phase B safety program task flow which was required to accomplish these objectives.

As in previous studies, emphasis was placed on preventive safety to minimize the need for remedial safety. Safety must be designed in and built-in, not added on. The MDAC approach based on extensive experience from the design and manufacture of manned craft (military and commercial aircraft and manned spacecraft) has been to recognize hazards and eliminate, reduce, and control them by good initial design. Safety was incorporated in the earliest concept, configuration, and preliminary design activities as an inherent design parameter.

Although the emphasis was placed on initial design safety (preventive), the requirements for remedial safety measures were also considered. Contingencies are provided for and such remedial safety aspects as on-board warning system, 96-hour emergency supplies, escape routes, and shuttle rescue are included.

Safety analyses were performed to identify the effect of failure of components. Those failures which could result in crew hazards were examined in greater detail by a preliminary hazard analysis and examination of all operations.

Table 7-36

SYSTEM SAFETY TASK FLOW

Review Documentation Results of 10-m study Preliminary layouts Configuration concepts System descriptions Guidelines Participate in Design, operations, and configuration meetings	Perform Studies and Analyses Failure mode and effect analyses Preliminary hazard analyses Contingency/emergency procedures Hazard time exposure Design, operations, and configuration trades Establish initial safety requirements Hazard Identification Eliminate Reduce Control Procedures	Safety recommendations to design, configuration, operations Final safety criteria and requirements Inputs to CEI, program specification, project specification, program development plan Report and support NASA working group meetings, operations design meetings, technical reviews Final documentation

Emergency procedures analyses were prepared for selected hazards to verify that adequate emergency responses were possible.

The approach to achieving an acceptable level of safety for the Modular Space Station has featured retreat-refuge (and recovery) rather than abandonment. Hazards have been minimized throughout design, operations, and configuration. First-level backup provisions permit operation from either the Crew Operations Module or GPL with full recovery possibilities if retreat from either module is required. Lower level alternatives are available by making every module (including RAM's) a safe refuge area for a minimum of 96 hours. If recovery from a contingency is not possible, Shuttle rescue is always available as the final backup.

The ISS configuration, composed of the GPL, Crew Operation Module, Power/ Subsystems Module, Logistics Module, and RAM's, optimizes escape paths and rescue potential to the highest degree. Time-distance to a safe area for any crewman is minimized by providing each module with two escape routes that do not terminate in a common area and providing each module with a minimum of 96 hours life support capability. Size of hatches permits free passage of IVA and EVA suited crewmen, as appropriate.

The risk of meteoroid penetration was minimized by structural wall design (double meteoroid bumper) which provides a no-penetration probability of 0.936, far exceeding the statement of work requirement of 0.90. Means for detection and a repair kit are provided for the crew if a penetration of the pressure shell does occur.

Potential hazards on the Space Station were minimized by equipment location (e.g., location of high-pressure vessels and propellant tanks in normally uninhabited areas, location of Freon loops outside the pressure compartments, and use of isolation chamber for cryogenics). Least safe equipment is located in minimum crew occupancy areas.

The risks associated with any pressure-suited operation have been minimized by (1) designing to preclude the need for EVA and IVA to the maximum practical extent, and (2) making the pressure-suited operation as safe as possible. The latter was accomplished by providing ready access to the suits, requiring use of the buddy system, multiple IVA umbilical connectors located in all compartments, time limitation on each EVA, establishing EVA rescue conditions, and defining requirements for lighting, communications, observation and monitoring.

The design and operation of airlocks were examined because of the critical considerations associated with safety. Safety requirements were established and implemented for location, size (minimum of 2 men), operation of doors from each side, pressure relief within the airlock, atmosphere condition display on each side of doors, etc. An IVA airlock is provided between every adjacent module.

The possible causes of decompression were evaluated to determine the probability of occurrence. Times of decompression for various hole sizes and volumes were determined to assure that the crew has sufficient reaction time to evacuate or stay and repair. Repressurization capability in the event of loss of atmosphere was examined and it is apparent that the station could sustain a significant loss of pressure without approaching emergency conditions.

The previous 10-m (33 ft) Space Station study was used to determine any significant difference in safety aspects when compared to the Modular Space Station, As a result, some areas which did not require consideration in the previous study were found to be of extreme importance. For example, the hazards associated with buildup and activation, with the many interfaces, and the problem of safing a module for return all received significant attention in this study. The comparison also indicated areas of the two studies that were so similar that much of the previous analysis was applicable with minor modification.

7.2.1 Comparison of Modular Space Station with 10-m (33-ft) Diameter Space Station

At the start of the Modular Space Station study, a comparison was made between the previous work accomplished on the 10-m Space Station, (MDC GO634, DRL-13, Volume III) and this smaller diameter/multimodule Space Station. The purpose was to indicate areas of significant differences in important safety aspects so that emphasis could be placed where needed. Table 7-37 shows that each has some inherent safety advantages on an item by item comparison.

One thing that is very evident is the differences in space assembly operations. Because of the unique problems associated with buildup in space, activation, and many interfaces, special emphasis was placed on these areas not only by safety analysts but by other elements of the study team such as Operations, design, crew systems, maintainability, and reliability.

All modules that dock to the Modular Space Station are required to meet the established cluster safety criteria so that safety of the cluster is not compromised. The logistics modules and experiment modules (RAM's) have the usual manned spacecraft potential hazards associated with day-to-day operation of the station. The unique potential hazards of particular experiments (reference NHB 7150.1) were examined and appropriate precautionary measures incorporated. Details of experiment safety can be found in MDC G0634, DRL-13, Volume III. The Logistics Module is considered a part of the baseline configuration (at least one Logistics Module is always attached to the cluster) and thus received the same detail attention as the other modules.

The Modular Space Station safety study resulted in the following conclusions:

A. An acceptable level of safety can be achieved with no compromise of operational objectives. The MDAC ISS and GSS configurations satisfy all program safety requirements.

B. Safety is an inherent design parameter and strongly influenced initial concept, configuration, and design selections.

C. Safety is an integrated consideration covering all program aspects, such as hardware, operations, and procedures.

Table 7-37

SAFETY ASPECTS: MODULAR SPACE STATION VS 10-M-DIA SPACE STATION

Characteristic	Modular	10-m Station
Dual access routes	All Space Station modules have shirtsleeve dual access capability	Provided for all decks and tunnel
	Logistics modules and RAM's have dual access routes	Not provided for RAM's or CCM's
Ordnance devices	Very limited use	Extensive use
Damage containment and control	Local action emphasized	Larger portion of vehicle required for isolation
	Facilitates isolation and control	Central command and control facilitated
	Central control more difficult	
	More options available for repair of major damage	
Space assembly operations	Many interfaces, interconnections	Smaller number of interfaces
	One-of-a-kind docking and mating	No assembly other than routine docking
	Incremental checkout and test	Full systems checkout
Rescue	Not dependent on one rescue vehicle	CCM only rescue
	Orbiter alone may suffice	Crew must have access to CCM for rescue (Orbiter could not dock directly to Space Station)

Table 7-37

SAFETY ASPECTS: MODULAR SPACE STATION VS 10-M-DIA SPACE STATION (Continued)

Characteristic	Modular	10-m Station
Retreat/Refuge	Many refuge areas (12 to 15). Each module can serve as emergency retreat area	Refuge areas limited to 4 (tunnel, 2 main compartments, CCM)
Docking/Redocking	Neuter hardware permits all possible module arrangements	Male/female did not permit docking RAM to RAM, CCM to CCM, or CCM to RAM
	Dedocking of orbiter/space station modules critical to buildup or activation	Dedocking of orbiter not critical to Space Station activation
Activation/initial manning	Hard dock by orbiter	Hard dock by orbiter
	Special activation or assembly crew	Space Station launched to support 12 men
	Two-man buildup team	12-man initial crew
	Pressure suits not required for initial activities	Initial crew provides activation
		Two man premanning/inspection crew
		Pressure suits required for initial activities
Module return	All modules can be returned Modules must be safed for return.	Possible only for RAM's and CCM

7.2.2 Decompression

A potentially catastrophic event which is always of concern in the environment of space is loss of atmosphere. Decompression can range from an explosive decompression to a relatively slow leak rate. Explosive decompression could result from a massive rupture of the pressure shell (critical crack length is 25.4 cm (10 in.), blowout of a large view port, or failure of a hatch.

The likelihood of occurrence of these events is extremely rare because of the safety factors, design which precludes inadvertant operation of a hatch, and other fail-safe features of design. Details of the pressure shell structure, view ports, and hatches can be found in SE-04 (Section 4).

Loss of atmosphere from smaller holes (at a critical but not catastrophic rate) is far more probable. Typical causes could be a module relief valve failed in open position, leakage at view port or hatch, or meteoroid penetration. (See hazard analysis, Table 7-42, for loss of compartment pressure causes and implemented controls.) Table 7-38 provides estimates of probabilities for accidental loss of atmosphere of a module.

Significant factors affecting the degree of safety in the event accidental decompression does occur are crew time required to evacuate a module, equivalent hole size, time of useful consciousness, time of unimpaired response, and pressurized volume. Figures 7-20 and 7-21 are plots of the effects of these factors.

The volume of the various ISS modules is shown below:

Module	Volume—cu m(cu ft)
GPL	156 (5,500)
Crew Operations	156 (5,500)
Power/Subsystems	107 (3,780)
Log Module	74 (2,600)

Table 7-38

REASONS FOR DECOMPRESSION OF A MODULE

	Probability
Loss of seal at pressure hatch	0.0005
Loss of viewport	0.0010
Dump/relief valves open	0.0016
Docking collision	0.0003
Space debris collision	0.0005
Meteroid puncture	0.0010
Overpressurization/rupture of pressure shell (explosion)	0.0006
Structural failure of pressure shell	0.0002
Corrosion of shell	0.0005
Internal puncture	0.0010

7.2.1 Safety Influence on Space Station Definition

The influence of system safety on the Modular Space Station operations, configuration, and subsystem definition is discussed in the following section. Only the more significant features are included or those that differ significantly from the previous study on the 10-m Space Station. No attempt was made to cover all considerations in this report. Consistent with the objectives of retreat or refuge rather than abandonment, the basic considerations are to (1) take all practicable preliminary measures to prevent the occurrence of a catastrophic or critical event, (2) minimize and localize damage if it occurs, and (3) provide recovery and survival capability after it occurs.

Figure 7-20 compares the time of pressure decay from 101 KN/m^2 (14.7 psia) to 59.3 KN/m^2 (8.6 psia). While this final pressure (equivalent to 94 mm Hg PO_2) is too low for sustained crew operations without acclimatization, it is a reasonable lower value for the purpose of this analysis. The crewmen would experience very little impairment at this pressure as they moved out of the module. Any symptoms of hypoxia can be alleviated by donning an emergency oxygen mask which is readily accessible in each module. Decompression sickness, the bends, would be no problem since a drop to approximately 360 mm Hg total pressure from 760 mm Hg can usually be tolerated safely. Susceptibility to bends varies somewhat with the individual. The curves in Figure 7-20 show the reaction times for the various volumes of the modules. No makeup from on-board atmosphere supplies has been assumed for the decay rate.

The top curve of Figure 7-20 (for a volume of 490 cu m) is equivalent to the ISS configuration composed of the four modules listed above. This is a conservative number for the volume since RAM's also will contain atmosphere referenced to the baseline modules. Note that a hole as large as 15 cm (6 in.) (equal to complete loss of viewing port) still would provide two minutes of reaction time. The estimated times for crewmen to move the entire length of the different modules is shown below:

Module	Translation Time (sec)
GPL	23
Crew Operations	23
Log Module	11
Power/Subsystems	15

These must be considered worst-case escape times since they assume the crewman must move to the opposite end of the module. The times represent movement at 0.6 m/sec (2'/sec) which could easily be accelerated under emergency all-out conditions. These values are indicated by circles on the different curves in Figure 7-20. Closure of the appropriate hatch can be accomplished rapidly; an estimate of 30 sec or less is a conservative assumption. Addition of this time to the movement times still provides a worst-case 2 to 1 safety factor. For holes in the equivalent size range of 2 in. or less, so much time

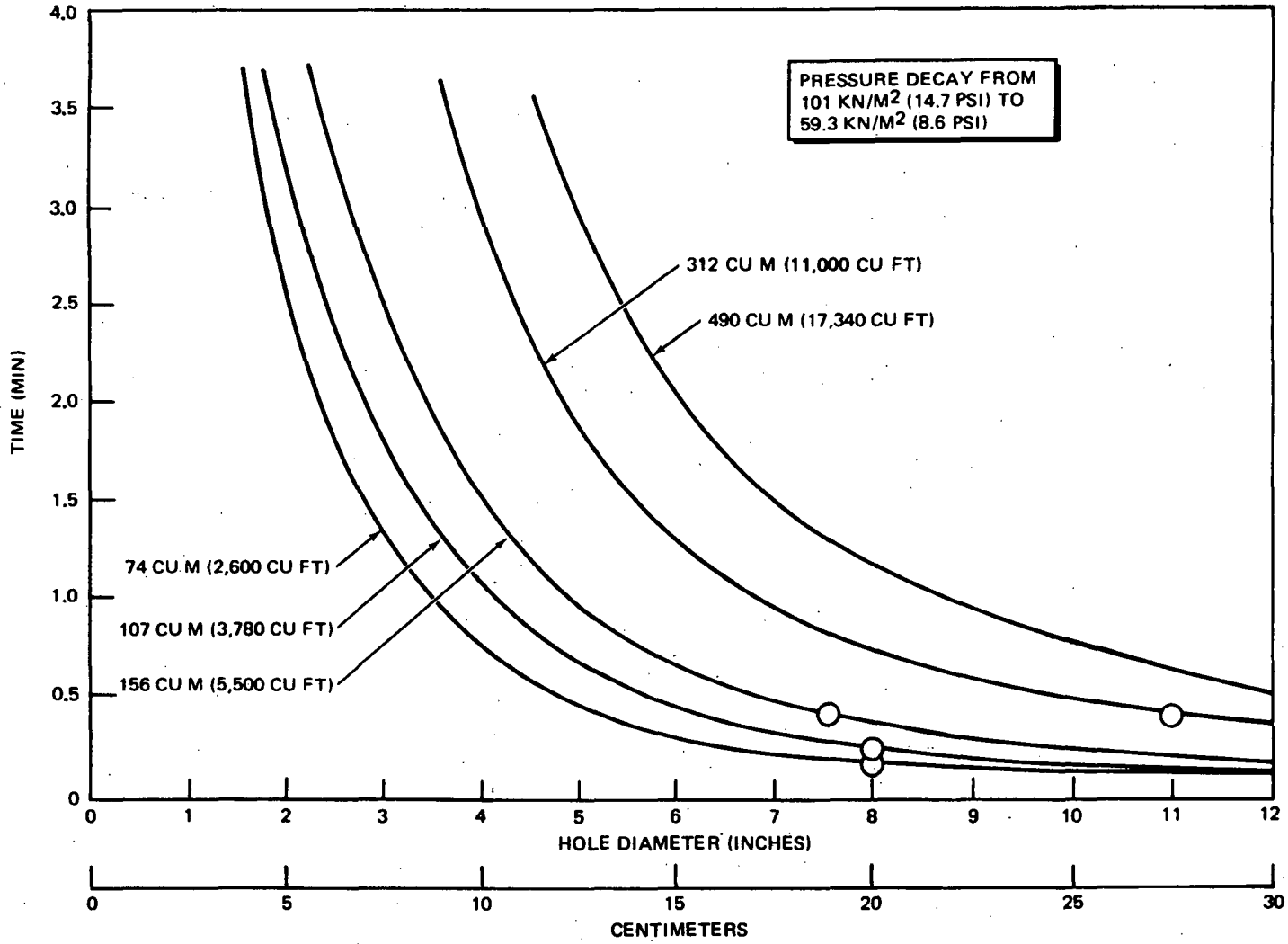


Figure 7-20. Crew Reaction Time for Wall Hole

is available for repair that evacuation of the module might not be required. Time needed for repair is a function of the location of hole and wall accessibility.

Figure 7-21 shows the effects of pressure loss for the ISS. Points are indicated to illustrate the effects of loss of atmosphere equivalent to the volume of the various modules. For example, loss of atmosphere equivalent to the 156 cu m of the GPL (without any makeup) would bring the total pressure of the ISS down to only 70 KN/m^2 (10.2 psia). This total pressure (ppo_2 equals 110 mm Hg) presents no particular hazard to the crew. The crew would have the option of (1) repressurizing with N_2 and O_2 to restore the atmosphere to the normal 760 mm Hg level, (2) using O_2 to slightly enrich the atmosphere (from 21 to 25 percent O_2 increases the fire hazard very slightly), or (3) keeping the atmosphere as is and retain onboard repressurization N_2O_2 for any emergency. Repressurization supplies are onboard to provide 262 cu m (9,300 cu ft) at 760 mm Hg. This is in addition to the onboard supply for normal makeup. It is apparent that the station could sustain substantial loss of atmosphere without approaching emergency conditions.

7.2.1.3 Buildup, Activation, and Docking

The buildup and activation of the Modular Space Station present new problems in operations, see Table 7-2. For the first time in manned space flight, a complete integrated space system will be launched in discrete parts and assembled in earth orbit. Unique safety problems are present in these operations which were not previously encountered in Space Station studies. In addition to the problem of assembly, the Space Station launch constraint of no more than one launch every 30 days requires that the Space Station operate in an unmanned mode until the orbiting configuration is completed and manned for sustained operation, with full functional capability and safety backups. During buildup, two assembly crewmen will accompany each of the Space Station modules to orbit as passengers in the Space Shuttle.

The first Space Station module launched is the Power/Subsystems Module which is equipped with one set of batteries to supply the required electrical power until solar array deployment and checkout. The Power/Subsystems Module also provides its own atmosphere from oxygen and nitrogen storage

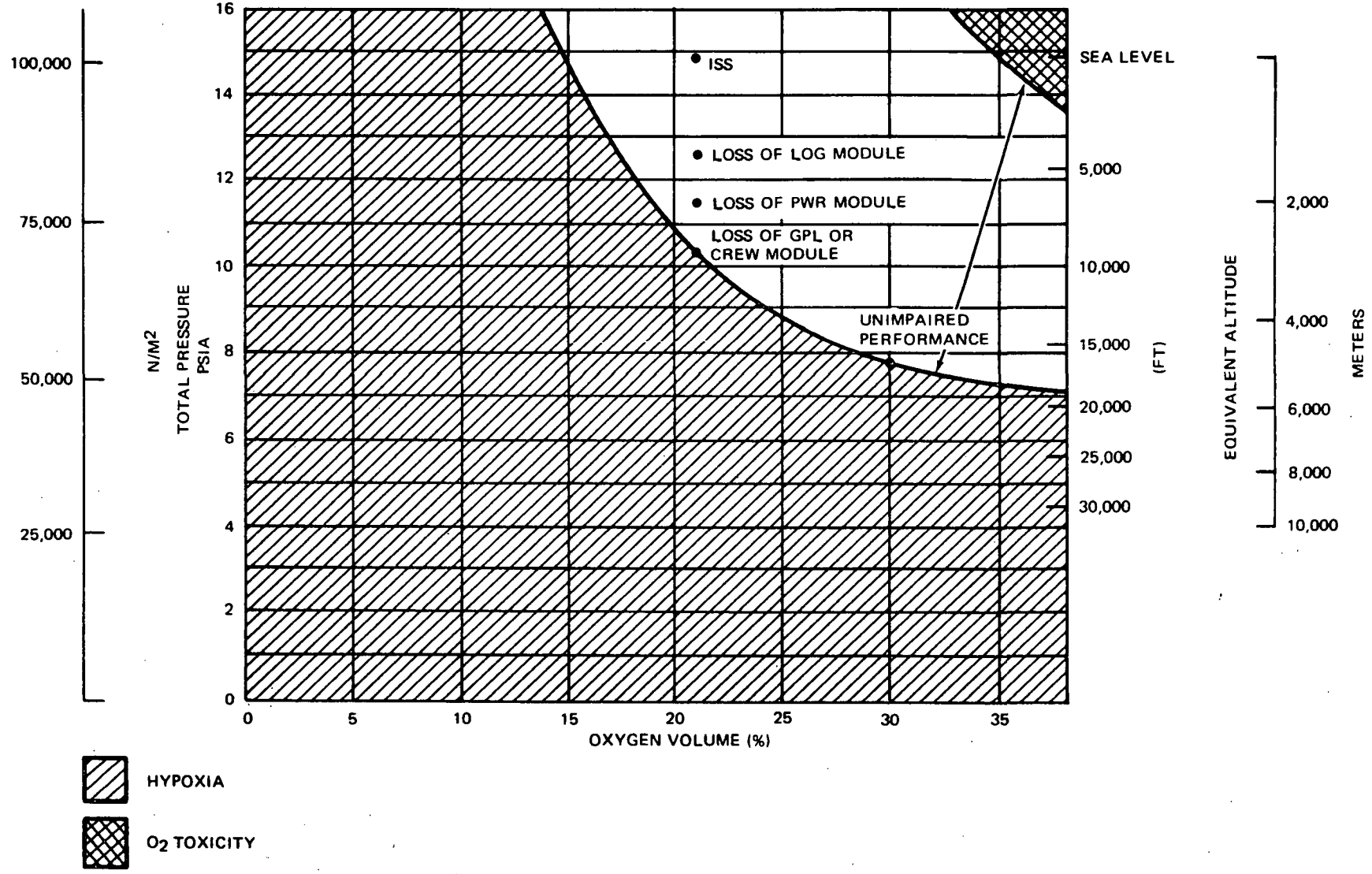


Figure 7-21. Oxygen-Pressure Effects

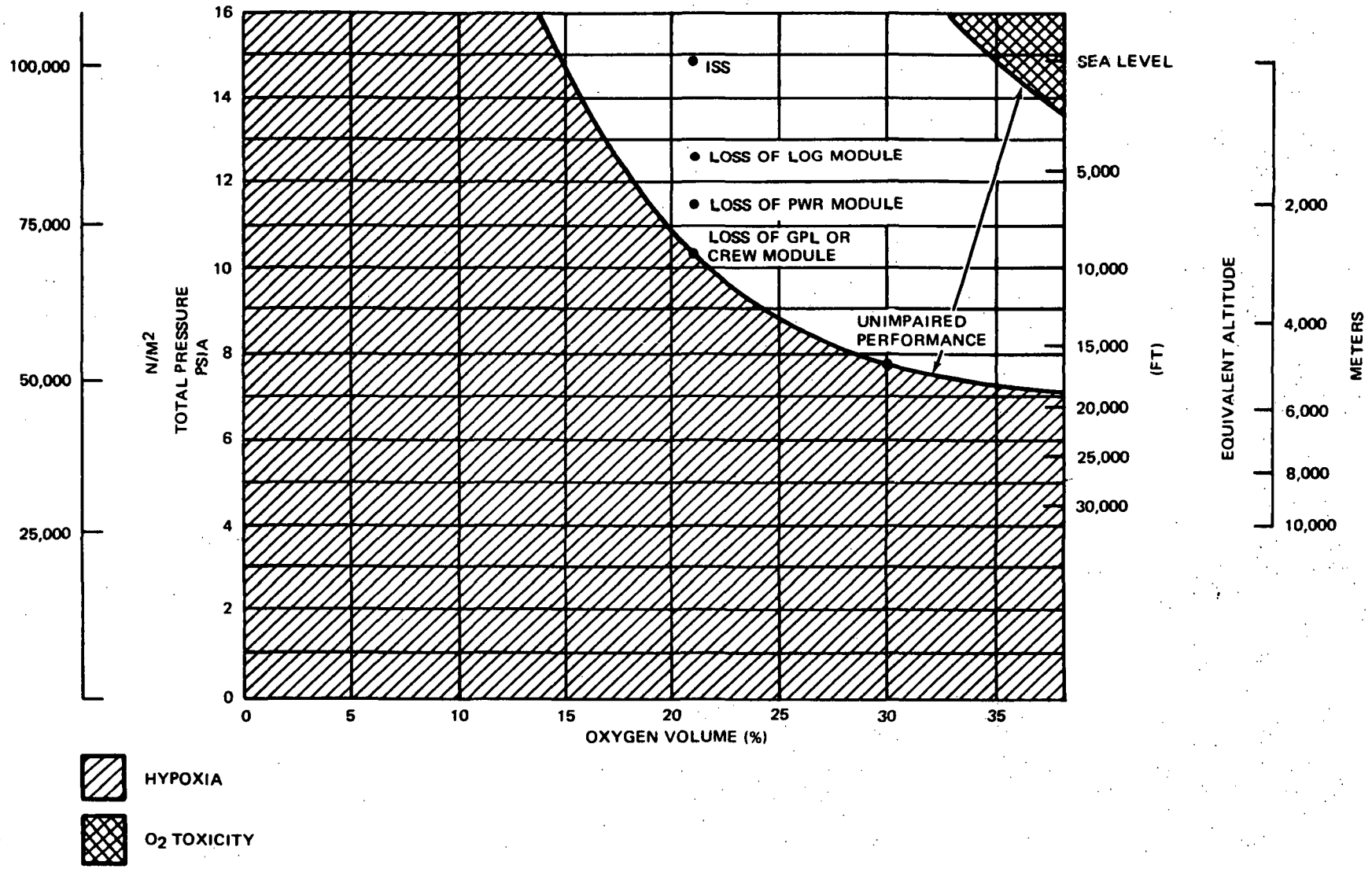


Figure 7-21. Oxygen-Pressure Effects

The second flight of the Space Station mission is delivery of the Crew Operations module and the mating of this module to the Power/Subsystems Module. Once the Crew Operations Module is delivered to orbit and docked to the longitudinal docking port of the Power Subsystems Module, 36 interfaces are mated between the two modules. These module-to-module interfaces are mated by the two assembly crewmen who accompany the Crew Operations Module to orbit.

This second flight of the buildup operations requires the first direct docking operations of one module to another, utilizing the Space Shuttle systems. The technique for direct docking utilizes manual control by a Space Shuttle crewman located at the docking station in the Space Shuttle airlock. With the defined Shuttle orbiter capabilities and docking aids, a simulation was conducted during the Phase B study to assess the acceptability of the manual mode. The results verified that direct docking mode is acceptable, and controlling final contact errors to an acceptable value presents no serious difficulty or hazard.

Although not directly related to buildup operations, concern also existed over a possible side collision resulting from the various configurations of the Space Station, while attempting to dock modules of various lengths to the Space Station radial ports. The simulation included investigation of this problem, and the results established that clearance was more than adequate for the Space Shuttle. However, to ensure collision avoidance, a lighting system for the Space Station, similar to the running lights on a boat, was developed to provide a positive cue to the Shuttle, should the Shuttle inadvertently maneuver to a position where collision is possible. Additional details on docking are found in Section 4.

Following docking, the Space Station attitude control system is deactivated and the assembly crew transfers to the Shuttle airlock and enters the crew transfer tunnel. After the two assembly crewmen arrive at the entry hatch into the Crew Operations Module, they activate the module lighting and intercom systems and perform checks to establish that the module is safe to enter, as they did before for the Power Module.

The Crew Operations Module contains an atmosphere control system and sufficient oxygen and nitrogen for 12 man-days of habitation; however, this will be kept in reserve, and the module(s) will be supported by the Space Shuttle ECS.

After verifying life-critical parameters, the crewmen equalize pressure across the hatch, enter the module, and perform a visual check of the equipment and environment. The crewmen then transfer to the hatch at the Crew Operations Module - Power/Subsystems Module interface. They equalize pressure in this natural airlock between the modules, and then enter the airlock. In this position, the crew will perform visual checks of the Power/Subsystems Module and verify that the status of the module is still safe.

Following visual inspection, the two assembly crewmen return to the Crew Operations Module to begin mating the interface connectors. All electrical connectors are standard except the power plugs which incorporate a nonarcing feature in case of accidental demating. The power plug automatically eliminates arcing during mating and demating, Figure 7-3. While the first assembly crewman (an electrical technician) is completing the power interface, the second assembly crewman (an electromechanical technician) mates the oxygen, nitrogen, and air ducting interfaces. The fluid interfaces connected by the second crewman employ quick disconnects with interlocks to shutoff valves for emergencies, Figure 7-4. To detect leakage at these interfaces, the joints are encased in transparent bags, which by condensation or swelling will signify leakage.

Because N_2H_4 is considered a hazardous fluid, it is transferred inside a line contained in an evacuated sleeve which is vented overboard, Figure 7-5. The sleeve can be retracted for ease of connection of the inner line. On completion of the interface mating, the crew returns to the Crew Operations Module and secures the hatch, isolating the interface volume from both modules. By proper valve manipulation, these lines are evacuated, and then the propellant lines are filled by remote command from the source tanks in the Power/Subsystems Module and verification of no leaks is made.

The assembly crew performs a total of 10 hours of subsystems tests on primary, redundant, and backup systems to establish the operational readiness of the two modules. Once the operational readiness of the modules has been established, the crew prepares the module systems for unmanned operations and then transfers to the payload tunnel area and secures the Crew Operations module hatch. Following this, the crew disconnects the umbilicals to the Shuttle and then enters the Space Shuttle airlock. The tunnel then is depressurized and the Shuttle orients the modules to their separation attitude. Once the attitude is attained, the Shuttle separates from the modules, activates the Space Station propulsion system, and commands the closure of the hatch cover over the exposed hatch. For one orbit (or more), the Shuttle station keeps with the modules, and at the proper time returns to the earth, completing the second phase of the buildup operations.

The third and final flight of the buildup operations is the delivery and mating of the GPL to the Crew Operations module. Similar activities are performed for this module (see Section 4).

Safety features of the buildup, docking and interfaces are as follows:

A. Buildup
   1. No EVA required.
   2. Minimum activation crew.
   3. Verification of life-critical functions prior to entry.
   4. No manning until all life-critical functions are fully operational.
   5. Orbiter attached while buildup crew in Space Station module.
   6. Caution and warning system active.
   7. Remote activation of pressure lines.

B. Docking
   1. Direct single movement of modules.
   2. Simple manual control.
   3. Fail-safe docking aids.
   4. Windows in all docking ports for visual viewing.

5. Space Station high-thrust system available for assistance if required.
6. Fully redundant docking mechanisms.
7. All docking ports common and neuter.
8. Manual latch/unlatch of docking hooks possible as backup mode.
9. Collision corridor warning lights provide backup to primary docking aids.

C. Interface
1. Hydrazine connectors and lines vented overboard.
2. Electrical lines separated from flammable fluids.
3. Hydrazine lines separated from oxidizer line.
4. Shutoff controls on both sides of interfaces.
5. Redundant lines separated.
6. Fluid lines purged overboard prior to mating and disconnecting.
7. Shirtsleeve access.

7.2.1.4 Dual Egress

The previous Space Station studies performed on a 10-m Space Station resulted in a 3-m center tunnel extending the length of the entire station. The tunnel provided structural efficiency, a main traffic artery for crew and cargo, and was used for through passage for conduit, piping and ducting. Hatches were provided between the tunnel and each compartment and in addition separate hatches were provided between compartments. The 10-m station thus inherently (or with little if any penalty) satisfied the requirement for dual egress/ingress between pressurized compartments.

With the change of the program to a 4.3-m modular station, need for the tunnel is no longer obvious and a new evaluation of the requirement for dual escape routes was made. The guideline established by NASA for escape routes was as follows:

"Personnel escape routes shall be provided in all hazardous situations. A design goal shall be to provide alternate escape routes that do not terminate into a common module area."

A hazardous situation requiring escape routes is defined as one in which environment, personnel error, design characteristics, procedural deficiencies or equipment malfunction will cause death or personnel injury or which requires immediate corrective action for personnel survival.

Escape to a safe refuge area is sufficient, i.e., retreat and recovery is the design objective, not abandonment (retreat to a life boat or CCM is not required). A safe module area is one that provides life support (survival) for a minimum of 96 hours (See Table 7-39 for estimated Shuttle maximum response time.) An active EC/LS system is not required in a closed module to provide life survival capability for 96 hours. However, a small oxygen supply and CO_2 removal to supplement the enclosed atmosphere is required. Details on 96-hour emergency provisions are given in Subsection 7.2.1.5. The 96-hour emergency life support provisions are available in every module of the Space Station.

7.2.1.4.1 Methods

Various techniques can be used to provide dual egress from one module to other safe module areas. These include EVA, rearrangement of the modules, and addition of tunnels or chutes either external or internal, and use of emergency refuge areas. Of these techniques, EVA has the obvious disadvantages of not providing a fast response time by the crew. However, for events which result in a crewman becoming isolated in a module with survival capability so that the emergency is not time critical, EVA can be an acceptable secondary means of crew transfer. For EVA to be considered a safe primary means of escape would require crewmen to wear pressure suits at all times which is completely unacceptable. Other considerations are that while the crewman is occupied for 5 minutes or more donning his suit, he is not available to take corrective action which might control the event, and if he does have to evacuate the module immediately after donning the suit without prebreathing, he will be subjected to the bends. Approximately three hours of prebreathing is normally required. Sections 7.2.1.8 and 7.2.1.10 provide additional detail on locations and use of pressure suits and availability of airlocks.

Table 7-39
SHUTTLE RESCUE CAPABILITY
(Worst-Case)

	Low and Medium Launch Rate (50/YR) (hr)	High Launch Rate (75/yr) (hr)
Launch Preparation	24	56
Ground Hold for Window	15	15
Rendezvous	16	16
Rescue Operations	3	3
Total	58	90

Note: Four orbiters and three boosters available. Worst-case phasing. Maximum ground hold for launch opportunity. Vehicle maintained at T-24 hr status for low- and medium-rate case.

Rearrangement of modules may be possible in some cases. Limitations of this technique include such restrictions as availability of alternate docking ports, lack of pass-through capability for RAM modules, docking clearance, and possible compromise of optimum traffic flow. Tunnels have the following advantages and disadvantages:

Interior:

Advantages:

A. No EVA required for installation, repair or removal.
B. Does not interfere with movement of module (docking-dedocking).
C. Easily pressurized.
D. Does not require meteoroid protection.
E. Does not require leak-proof structure.

Disadvantages:

A. Uses 3 or 4 percent of module free volume. Tunnel is single-purpose.
B. No utility other than as passageway.
C. Restricts equipment location and layout.
D. Restricts normal traffic flow
E. Adds weight (tunnel and hatches).
F. Complicates docking interface.

Exterior:

Advantages:

A. Out of way of normal activities.
B. Does not reduce useful available volume.
C. Does not interfere with interior equipment arrangement and layout.
D. Tunnel can be deployed when and if required rather than installed as permanent interior installation.

Disadvantages:

A. Requires EVA and special deployment and retraction equipment.
B. Restricts movement of module.
C. Requires side hatch.
D. Requires special pressurization system or relatively leak-proof structure.
E. Heavier tunnel required than internal (meteoroid protection, space environment, full pressure capability).

7.2.1.4.2 Implementation

Dual egress has been provided for each of the ISS modules with a minimum compromise of design and operations as follows:

Crew Operations Module: The Crew Operations Module is always docked to the Power/Subsystems, GPL, Log Module, and a RAM. Each of these provides a safe refuge, the GPL for an indefinite time, the others for a minimum of 96 hours. Four different routes are thus available from the Crew Operations Module.

Power/Subsystems Module: Three RAMS and the Crew Operations Module are docked to the Power/Subsystems Module. In addition to these four routes, another is available through the solar array tunnel. The latter would be used only if all the other routes were blocked.

GPL: The GPL is radially docked to the Crew Operations Module. It is divided into two compartments: the laboratory portion of the module has dual egress either into the test and isolation facility refuge (which is also an EVA airlock) or back into the crew module.

Logistics Module: The Logistics Module is always either radially docked to the Crew Operations Module or end-docked to this module. The end of the Logistics Module which is always away from the Space Station contains the primary EVA airlock. Thus, the two routes out of the Logistics Module are into the Crew Module or refuge into the airlock.

RAM's: RAM's are radially docked to either the Power Module or to the Crew Module. Each RAM is required to have an EVA airlock. The two exits out of a RAM are back into the Power or Crew Module and into the EVA airlock.

Thus, at least two alternate shirtsleeve routes are provided from every normally habited compartment. Each route terminates in a different safe area.

7.2.1.5 Long-Term Refuge

One of the most significant configuration drivers for safety was the following requirement from NASA for two separate volumes in the Modular Space Station:

"The Space Station shall be divided into at least two pressurized habitable volumes so that any damaged module can be isolated as required. Accessible modules will be equipped and provisioned so that the crew can safely continue a degraded mission and take corrective action to either repair or replace the damaged module."

This requirement for providing recovery capability until emergencies are overcome or emergency survival until rescued influenced Space Station configuration in many areas. Since the start of the study, the duality concept has been

implemented for life-essential and control facilities. The two primary separate habitable volumes at the ISS level are the Crew Operations Module and the GPL. Each is equipped and provisioned so that the six-man crew can remain in either for an indefinite period in the event the other module becomes uninhabitable. Independent control centers are provided in each module. The primary control center is located in the Crew Operations Module and the secondary in the GPL. Each center is capable of providing all essential Space Station command and control functions including fault isolation and detection, caution and warning, and monitoring and control of Space Station subsystems.

The life support functions are provided for these modules as follows:

A. Normal Operations

1. Hygiene facilities, two complete units, are located in the Crew Operations Module; the Water Management Subsystem equipment for the ISS are located in the open sectors adjacent to these facilities.
2. Complete hygiene facilities are not provided in the GPL; hence, a Water Management Subsystem is not required there. Potable water for drinking and experiment use and a hand wash unit are provided in the GPL.

B. Contingency Consumables

A contingency supply of consumables to continue normal operations for 30 days beyond the next scheduled resupply appointment is located as follows:

1. Atmospheric supply—180 man-days of gaseous oxygen stored in two separate tanks, located in the Power/Subsystem Module.
2. Food—180 man-days of freeze-dried food is located in the GPL.
3. Water—180 man-days of potable water is stored in the GPL. This quantity is purely arbitrary as contingency water is not required for extension of normal operations (with water-recovery subsystem functioning) as the closed-loop water system is not dependent on the water in the food supply for metabolic balance. A 30-day supply was selected solely for a degraded mission mode (See below.)

C. Degraded Mission Mode

A degraded mission mode normally results from a major system failure and may continue for an indefinite period, i.e., until repairs are made or until some other course of action is taken, such as commitment for module return. In this mode of degraded operations, crew facilities and provisions need not be of the same standard as during normal operations. The most obvious degraded mode wherein requirements for supplementary crew provisions are derived is when one of the dual independent compartments is uninhabitable. In this event, of course, the primary crew effort will be to restore habitability to that compartment.

In a degraded mode in which the GPL module (one of the two dual compartments) is uninhabitable, no additional crew provisions are required to continue the mission until repairs are made. However, if the crew is isolated in the GPL (Crew Operations Module uninhabitable), the following supplementary crew provisions are provided in the GPL.

1. Atmospheric supply and control is accomplished with a fully independent EC/LS system located in the GPL. Accessibility to the normal atmosphere stores in the Logistics Module and the Power/Subsystems Module are provided through the redundant interface connections and lines.
2. Water is initially provided from the accumulator in the Crew Operations Module through the potable water supply line into the GPL. Depending on the level in the accumulator, up to 12 man-days of potable water may be available. As mentioned previously, the 30-day contingency water is located in the GPL and would next be used should repairs to restore habitability to the other compartment not be completed. A 30-day supply was selected simply to be commensurate with the food supply.
3. Food immediately available to a GPL isolated crew is of the freeze-dried type which is reconstituted with water. The necessary utensils and supplemental containers are part of this contingency supply. Since the primary effort of the flight crew will be to

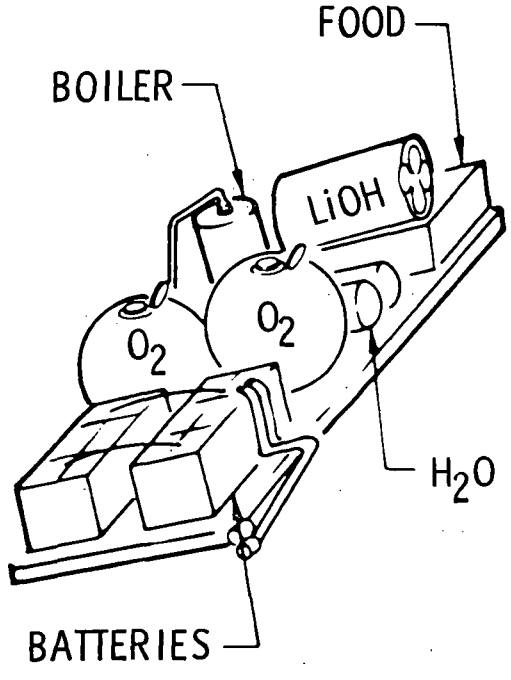
restore habitability to the other compartment and hence make the normal food supply and preparation facilities available to them, the contingency food would not normally be used for any appreciable duration. The sole exception would be the case when the onboard flight crew cannot effect sufficient repairs to permit even intermittent occupation of the other compartment. Of course, fresh food may be obtained by IVA or EVA from the Logistics or Crew Operations Modules.

4. Hygiene facilities for collection of body wastes will be accomplished with the use of Apollo-type (or further improved) collectors. An arbitrary quantity sufficient for 30 days will be stored in the GPL. However, as with the discussion of the food supply, normal anticipation is for the rapid restoration of habitable conditions in the Crew Operations Module and availability of normal hygiene facilities. Thus, use of the degraded-mode waste collection bags could be expected to be of short duration.
5. Sleep restraints are stored in the GPL.

D. Emergency Mode

This mode of operation occurs if normal and even contingency provisions cannot be relied on to safely continue operations. It may range from a situation in which one or more crewmen are isolated in a module to a situation where the safety of the entire crew is severely jeopardized by a catastrophic incident resulting in failure of both (redundant) life support systems, e.g., a complete power failure. Use is made of a 96-hour pallet containing critical supplies of oxygen, lithium hydroxide for CO_2 control, a water boiler for thermal control, food, water, waste collection bags, and a battery power supply. Analyses have shown that a pallet sized for three men for 96 hours (about 160 Kg or 350 lb) best satisfies emergency requirements (Figure 7-22). Location of three-man pallets would be as follows:

1. Two three-man pallets in the GPL under the floor.
2. One pallet required initially in the Power/Subsystems Module, but can be optionally removed when a RAM is attached.
3. One pallet in each attached RAM.
4. One pallet for the Logistics Modules.



3-MAN PALLET

PROVISION	REQUIREMENT	WEIGHT KG (LB)
OXYGEN	METABOLIC O_2	23.6 (52)
WATER	CREW INTAKE + COOLING	64.5 (142)
FOOD	2700 KCAL DIET	14 (30)
LiOH	MAINTAIN 7.6 mmHg PCO_2	19 (42)
BATTERIES	960 WATT-HR	23 (50)
WATER BOILER	1600 BTU/HR COOLING	3.2 (7)
MISC SUPPLIES		2.3 (5)
PALLET/PACKAGING		11.4 (25)
	TOTAL	161 (353)

Figure 7-22. 96-Hour Emergency Provisions

Contingencies and actions leading to these modes of operation are shown in Figure 7-23 and Table 7-40. Table 7-41 summarizes the foregoing discussion and indicates the order of precedence for refuge or retreat action by the crew.

7.2.1.6 Meteoroid Protection

The Meteoroid Protection assembly shall assure the probability of 0.90 of no puncture in 10 years of operations and a 0.99 probability of no unrepairable damage in one year of operation. Module size and number of modules, including the Logistics Module, and the time on-orbit were considered in the design of the Meteoroid Protection assembly.

The final structure concept (Figure 7-24) is the result of the integrated design requirements for cabin pressure, meteoroid protection, thermal protection, radiation protection, launch load survival, damage resistance, and long life. The meteoroid protection outside the pressure shell is a double bumper of 0.045 cm (0.016 in.) and 0.025 cm (0.010 in.) aluminum separated by radiator frames. The double bumper protects the high-performance insulation as well as protects the pressure vessel. The remaining meteoroid protection is the pressure vessel, which in combination with double bumper, provides the 0.9 probability of no puncture in 10 years. Integrating the module size, number of modules, and time on orbit of the Space Station and Logistics Modules, an 0.125 cm (0.049-in.) wall is the minimum thickness required to meet the specified environment. The launch loads are resisted by the integrally stiffened pressure shell which has circumferential ring frames and widely spaced longitudinal stringers.

For the modules to provide life in excess of 10 years, the pressure vessel design must possess inherent damage resistance. The design selected for the long-life consideration of the Modular Space Station is an 0.152 cm (0.060-in.) pressure shell thickness with integral 2.54 by 0.18 cm (1 by 0.071 in.) ring frames, 20.3 cm (8 in.) on center. The 0.152 cm wall, with an operating stress of 138 MN/m^2 (20,000 psi), will provide good resistance to damage from stress

corrosion and impact and the ring frames will resist damage due to cuts or tears. This design can sustain a crack or tear up to 25.4 cm (10 in.) in length 5. cm (2 in.) in excess of the ring spacing) without the threat of sudden decompression. Sizing for the long-life consideration results in an effective pressure factor approximately 3 and a meteoroid no-puncture probability of 0.936 in 10 years.

A. Detection and Location of Meteoroid Damage

Although the probability of meteoroid penetration is estimated to be quite low, provisions for detection and location in the event a penetration does occur are extremely important. Several techniques have been recommended and are under investigation.

Leak detection sensors are required at strategic locations throughout the modules to alert the crew of a hazardous condition. Sensor outputs are relayed to the Warning and Alarm System.

B. Meteoroid Damage Repair

Repair techniques are provided for damage to the main wall as follows:

1. Dimple -- Detected by acoustic wall sensor. May yield significant signature. Crew should routinely examine wall for stress cracks and watch for progressive failure.
2. Spall -- Detected by acoustic wall sensor. May yield characteristic signature. Crew should routinely examine spall area for cracks and apply sealer and patch, as required. Damage should be routinely monitored for progressive failure.
3. Leaks (very small hole or perforation/seal defect) -- Detected by an acoustic wall sensor or perhaps a gas controller indication. Crew should examine slow leaks with a portable leak detector and apply sealing compound as required. Larger holes would be repaired with a flat or blister patch, as needed. A critical leak or large perforation could be sensed by a gas controller which stimulates the alarm system. The crew would abandon the compartment. Later, the operations crew would enter the area in protective garments and repair the damage if possible; if not, the area would be sealed-off from further use.

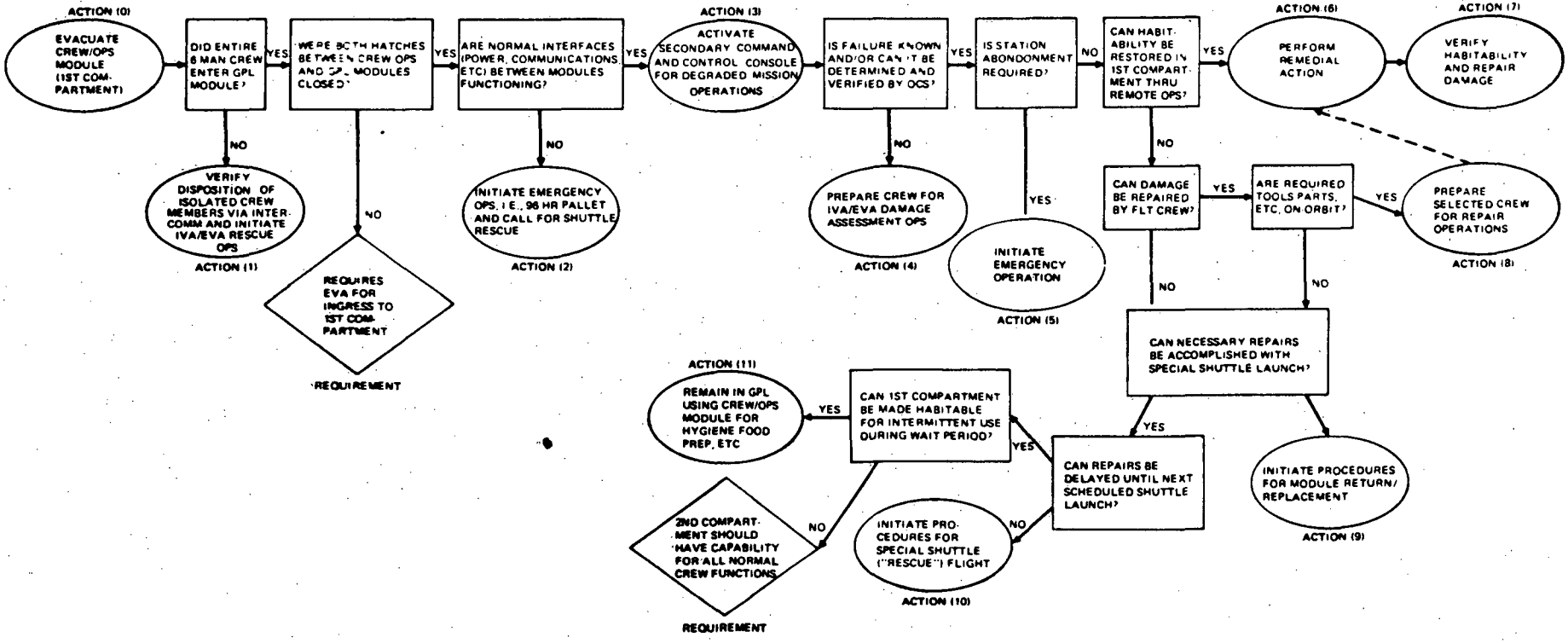


Figure 7-23. Contingency Analysis – Space Station Operations with One Compartment Uninhabitable

Table 7-40

LIST OF TYPICAL CONDITIONS RESULTING IN A REQUIRED ACTION

Action	Condition
0	Fire, rapid drop in total pressure, an apparent meteoroid penetration, structural damage from docking operations, atmospheric contamination.
1	Head Count $\neq$ 6
2	Interfaces are damaged in the accident (e.g., no power bus voltage)
3	Any time primary command and control station is inoperative
4	Gross damage from fire, collision, etc.
5	Any apparent catastrophic event resulting in unsafe habitation conditions
6	Repressurization, isolation of damage, etc.
7	Unscheduled maintenance/repair
8	IVA/EVA maintenance/repair
9	Major structural damage unrepairable in orbit
10	Repairs required to ensure crew safety
11	Continue operations in degraded mode until full habitability restored.

Table 7-41

REFUGE/RETREAT PRECEDENCE

First Order -	To Crew Operations Module or GPL
	Each fully equipped to operate with little if any degradation
	No special Shuttle flight likely
Second Order -	To Power/Subsystems Module or Log Module
	96-hour life support
	Airlock available
	Shuttle flight probably required
	Docking port available
Third Order -	To attached RAM's
	96 hour life support
	Requires EVA transfer or Shuttle rescue
	Airlock available

7.2.1.7 Onboard Checkout System

The most important function of the OCS, from a safety standpoint, is to monitor life- and mission-critical parameters continuously, and to provide distinguishable caution and warning indications for conditions requiring crew attention. Warning parameters are those which, if out-of-tolerance, could present an immediate threat to crew life. Caution parameters are those which, if out-of-tolerance, could result in major degradation of ISS performance unless specific crew action is taken. The status of noncritical parameters is determined as part of normal checkout and other operational activities, and does not require an interface with the OCS caution and warning system.

For reliability and simplicity, elements of the caution and warning system associated with warning parameters are hardwired and implemented completely separate from other OCS/DMS equipment and checkout sensors. All warning information, however, is made available to the data management subsystem. Detection of out-of-tolerance conditions activates both visual and audible

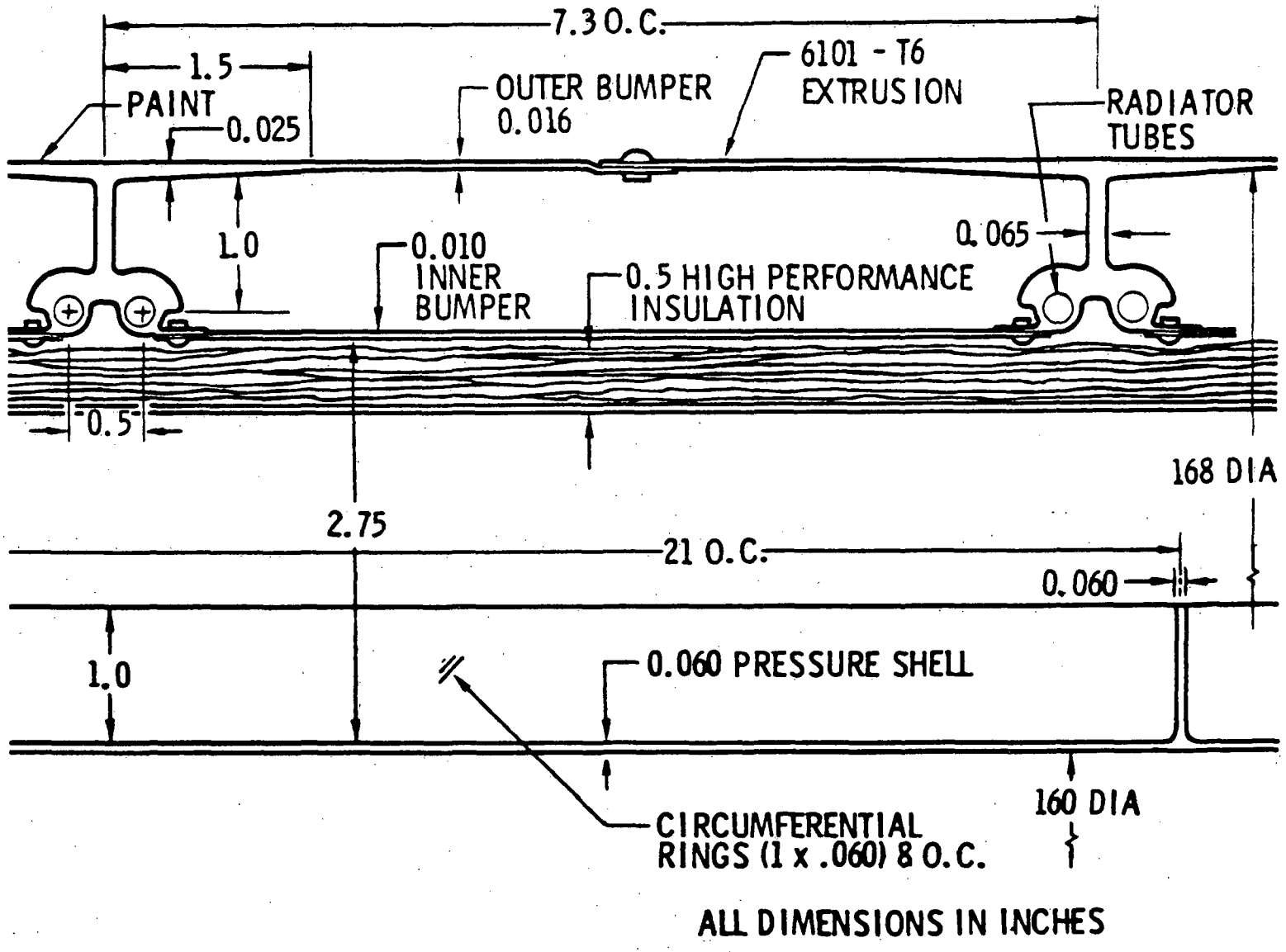


Figure 7-24. Typical Wall Configuration

alarms in each ISS habitable compartment as required by safety guidelines. Overall caution and warning status is provided at both the primary and secondary ISS control centers.

In addition to generating alarms, certain types of failure may require immediate corrective action which cannot wait for crew intervention. For these cases, an automatic command capability is provided for initiating corrective action. Whether critical corrective action is automatically taken by the caution/warning system or by the subsystem itself, appropriate indications are provided at the ISS control centers.

A capability is also provided, consistent with safety guidelines, for changing stored critical parameter limits and for inhibiting the alarm of individual functions to accommodate changing operational conditions. Limits for warning parameters, however, may only be changed manually. Caution parameter limits, on the other hand, may be changed by remote control.

Unique safety features of warning contingencies include the following: (1) redundant sensors, lamps, and wiring exists for warning parameters; (2) audible and visual alarms override other forms of communications; (3) separate power bus; (4) audible or visual indication of type and location of hazard to Space Station crewmen; and (5) dedicated displays.

About 275 subsystem functions are monitored by the caution and warning system with about one-sixth of these falling in the warning category. It is estimated that less than 15 warning parameters from each attached RAM will interface with the ISS caution and warning system. In addition, a capability for accommodating up to 10 caution or experiment-alert functions is provided for ISS experiments.

The subsystem warning parameters are: O_2 storage, N_2 storage, dump and relief valve, contamination monitor, coolant H_2O circulation, radiator control, radiator recirculation, propellant, compartment pressure, partial O_2 and fire.

7.2.1.8 EVA/IVA Safety

The modular Space Station design and experiment program precludes EVA to the maximum extent possible. Safety personnel have continuously evaluated subsystem configurations to minimize any scheduled or unscheduled EVA, subsection 7.1.2.2.5.

Pressure suit assemblies (PSA's) and associated support equipment are required for planned and emergency IVA and EVA operations. Operations personnel will perform all anticipated EVA and IVA. They will require individually fitted suits and backpacks (portable life support systems) to ensure the mobility and dexterity required of these operations. Additionally, four grossly fitted suits are provided for research personnel in case of double failure or an unusually hazardous condition. The EVA suits and backpacks and IVA suits and umbilicals are stored in readily accessible areas for ready access from all points in the station. For ISS, there will be a total of eight pressure suits onboard at all times. This provides a suit for each crewman plus two spares. Two individually-fitted EVA/IVA suits will be located in the Log Module adjacent to the EVA airlock at the primary suit station. Two other EVA/IVA suits will be located in the GPL near the test and isolation chamber which serves as the secondary EVA airlock. The four grossly fitted suits will be located as follows: two in Crew Operations Module, two in Power/Subsystems Module.

This suit placement provides ready accessibility, facilitates any normal EVA, and minimizes the risk of loss of suits because of loss of any one module. IVA umbilical outlets are directly connected to the Space Station EC/LS and are located in every pressurizable compartment. They would be used primarily when inspection or repair of an unpressurized or contaminated module is required. Additionally, IVA suits provide protection against hazards in a pressurized area. For EVA, the following components are added to the basic IVA suit -- sun visor, thermal-meteoroid garment, and PLSS thermal-meteoroid cover.

Prior to EVA operations, denitrogenation is required to accommodate the lower pressure of the PSA, i.e., 101 to 25.5 KN/m^2 (14.7 to 3.7 psi). This is accomplished by breathing 100 percent oxygen for approximately three to

four hours. Oxygen is available from the IVA umbilical sources and may be consumed while resting, reading, or performing most duties at a work station.

Pressure-suited operations will be conducted using the buddy system; that is a backup man will always be suited and fully operational either accompanying the prime crewman within visual range or within constant communication link with the other crewmen. The purpose of the buddy crewman is to (1) provide warning of any approaching contingency; (2) observe whether the other crewman requires retrieval or rescue (may be upon signal from the other crewman or a condition unknown to the other crewman); and (3) provide assistance in the event of an emergency.

Because of the critical conditions associated with EVA, emergency operations must be considered. MDAC, has defined EVA rescue as the mandatory retrieval of an incapacitated crewman who cannot return to the Space Station or a safe pressurized area under his own power. If this contingency should arise, the buddy crewman will proceed immediately to the incapacitated crewman, assess the situation, and provide assistance to him under any of the following conditions:

A. At request of the EVA crewman.
B. When the crewman will not reenter the Space Station within a reasonable period after command.
C. When communications contact is lost and visual contact does not confirm acceptable status.
D. When an out-of-limit physiological condition is indicated.
E. When RF-monitored data and communications are lost.

The assistance provided will depend on the specific situation. For example, local assistance such as untangling a tether, providing needed equipment or providing verbal guidance may be all that is required. In other cases, physical assistance may be required using manual locomotion (harness, shorter tether, push-pull, or maneuvering unit, transport aid).

Safety criteria for EVA and IVA were developed to ensure maximum safety of the EVA and IVA crewmen. Some of the most significant are listed below:

A. Planned EVA will be restricted to a maximum of three hours.
B. All EVA and IVA will be conducted using the buddy system.
C. EVA will be conducted in a tethered mode.
D. Radiation detectors will be worn when performing EVA.
E. Emergency lighting will be provided to assist in rescue operations if EVA is required during dark part of an orbit.
F. EVA and IVA airlocks are sized for two suited crewmen to enable both crewmen to ingress and egress rapidly in an emergency.
G. Continuous communications will be maintained by Space Station crewmen with EVA and IVA crewmen and with each other.
H. Space Station will continuously monitor PLSS integrity.
I. Normal docking and movement of Logistics Modules and RAM's will not be performed during EVA.
J. Attitude and rate corrections will not be performed during EVA.
K. The EVA pressure suit will be space-hardened for radiation and micrometeoroids.
L. Handholds and guard rails will be provided to assist in scheduled EVA activities.
M. The EVA suit loop (PLSS) will not be dependent on Space Station EC/LS.
N. No hazardous laser or RF radiation will be permitted during EVA.

7.2.1.9 Safing Modules for Return

Analysis of conditions which would result in an unscheduled return of a Space Station module shows the total 10 year risk to be 0.1351, Table 7-29. The corresponding risk of module return for ISS configuration is shown below:

Module	5—Year Risk
Power/Subsystems	0.0229
Crew Operations	0.0152
GPL	0.0136
Total	0.0517

Although this risk is not substantial, it is nevertheless finite and thus is a necessary aspect of planning for contingency operations. There are significant safety considerations associated with the return of modules and the most important are presented below. Note that the returning module is made as inert as possible; i.e., ignition sources, flammables, toxics, explosive sources, and other potentially hazardous equipment are removed.

A. Weight--Modules to be returned must not exceed the return payload limit of 9.072 kg (20,000 lb). Off-loading must be accomplished to bring the particular module weight down below this limit.

B. Module Pressure--Maintain 101 KN/m^2 (14.7 psia) plus a safety margin in module through return flight. If this full pressure (101 KN/m^2 plus safety margin) cannot be maintained, then the module must be completely depressurized and sufficient venting provided to ensure that no negative pressure differential will occur across the module pressure shell, e.g., open docking ports.

C. Configuration--Tiedown/secure all lines, drawers, cabinets. Remove all loose items. Lock docking port and window covers in either closed or open position.

Retract and lock all deployed antennas, arrays, booms, etc. Remove cryogenic tanks. Transfer consumables. Transfer hydrazine into other module tanks, expel residual through thrusters, purge lines.

Remove batteries.
Transfer O_2 and N_2 to other modules, purge O_2 lines.
Relieve all pressure bottles.

7.2.1.10 Airlocks

The primary function of an airlock is to provide a safe means of egress or ingress between adjacent volumes which are at different pressure levels. A secondary use of the airlocks on the Modular Space Station is to provide temporary refuge for pressure suit donning in event pressure suit retreat is required from the GPL, Logistics Module or RAM's. Figure 7-25 illustrates the location of the airlocks. All, with the exception of the scientific airlock which is not intended to provide manned passage, are sized to accommodate

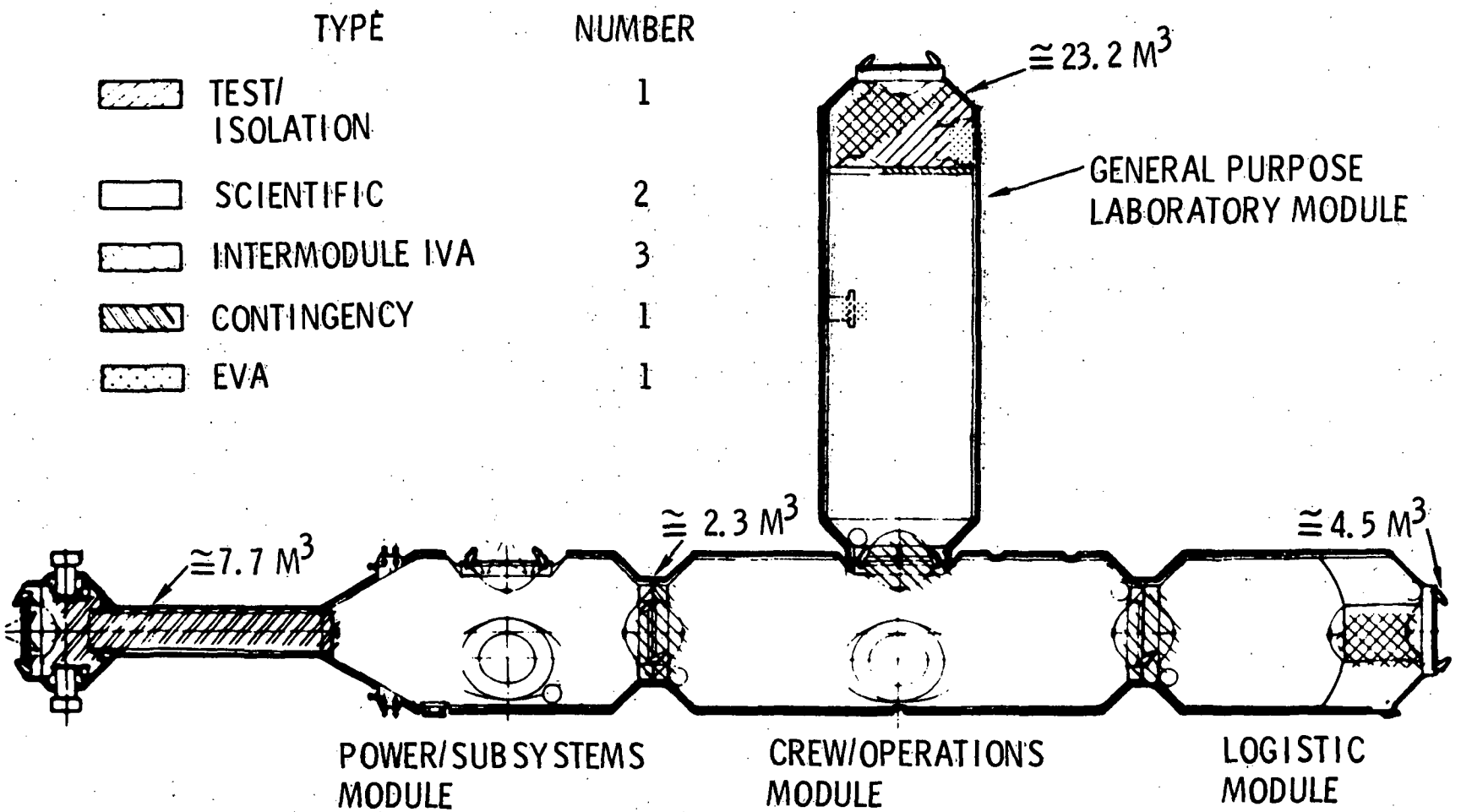


Figure 7-25. Space Station Airlocks

two pressure suited crewmen. The smallest of these, the IVA airlock, is shown in Figure 7-26 with two pressure suited crewmen inside.

The airlock at the end of the Logistics Module has been designated as the primary EVA airlock. This airlock contains approximately 4.5 cu m (160 cu ft) and can be pumped down in less than one hour. For normal operation, the Space Station EC/LS subsystem provides atmosphere pumpdown to evacuate the airlock. Pumpdown time as a function of volume is shown in Figure 7-27. If rapid operation is required for emergencies, the airlock can be dumped to space in matter of seconds. A small panel is located within the airlock and operates in conjunction with the pressurizing and evacuation controls to inform crewman when hatches may be opened.

The test and isolation chamber at the end of the GPL is the secondary EVA airlock. The volume of this chamber, 23.2 cu m (820 cu ft), is such that the three to four hours required for pumpdown present some problem for reasonable crew transfer times.

The solar array tunnel is also available for EVA airlock and because of its relatively small volume would be convenient for EV activities around the solar array and thrusters mounted on the Power/Subsystem Module.

All airlocks can be repressurized from the atmosphere accumulators or O_2 and N_2 stores or by equalizing pressure from the module into the airlock. All airlocks can also be rapidly dumped to space if required.

Other significant safety considerations for airlocks are listed below.

A. Hatch doors will allow rapid ingress and egress, will be operable from each side, and have a positive closure indication visible from each side.

B. Airlock mechanisms will be inoperable if pressures on each side are not equalized; however, manual override capability will exist within specified tolerances.

C. Compartment pressures will be indicated on each side of an airlock.

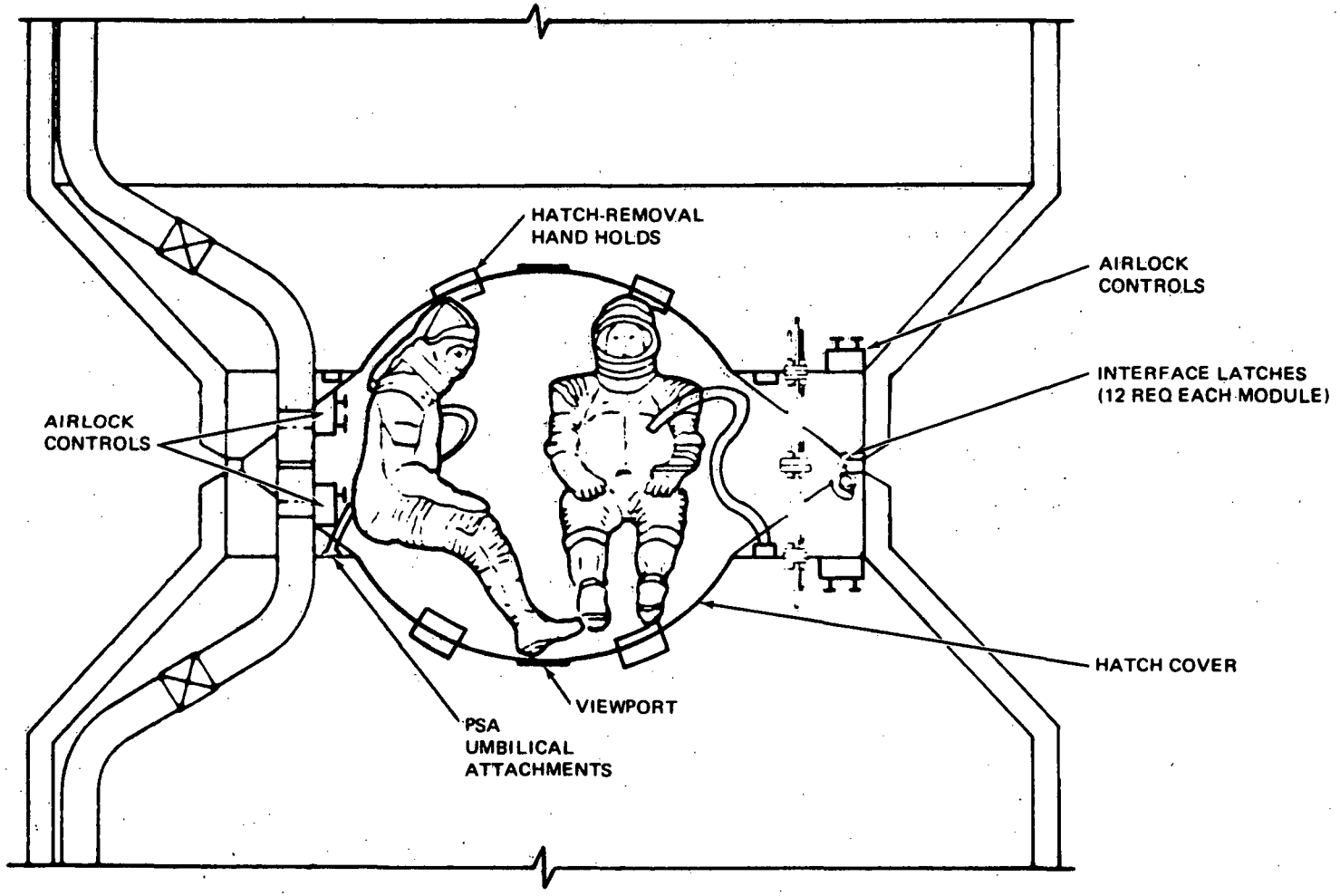


Figure 7-26. IVA Airlock

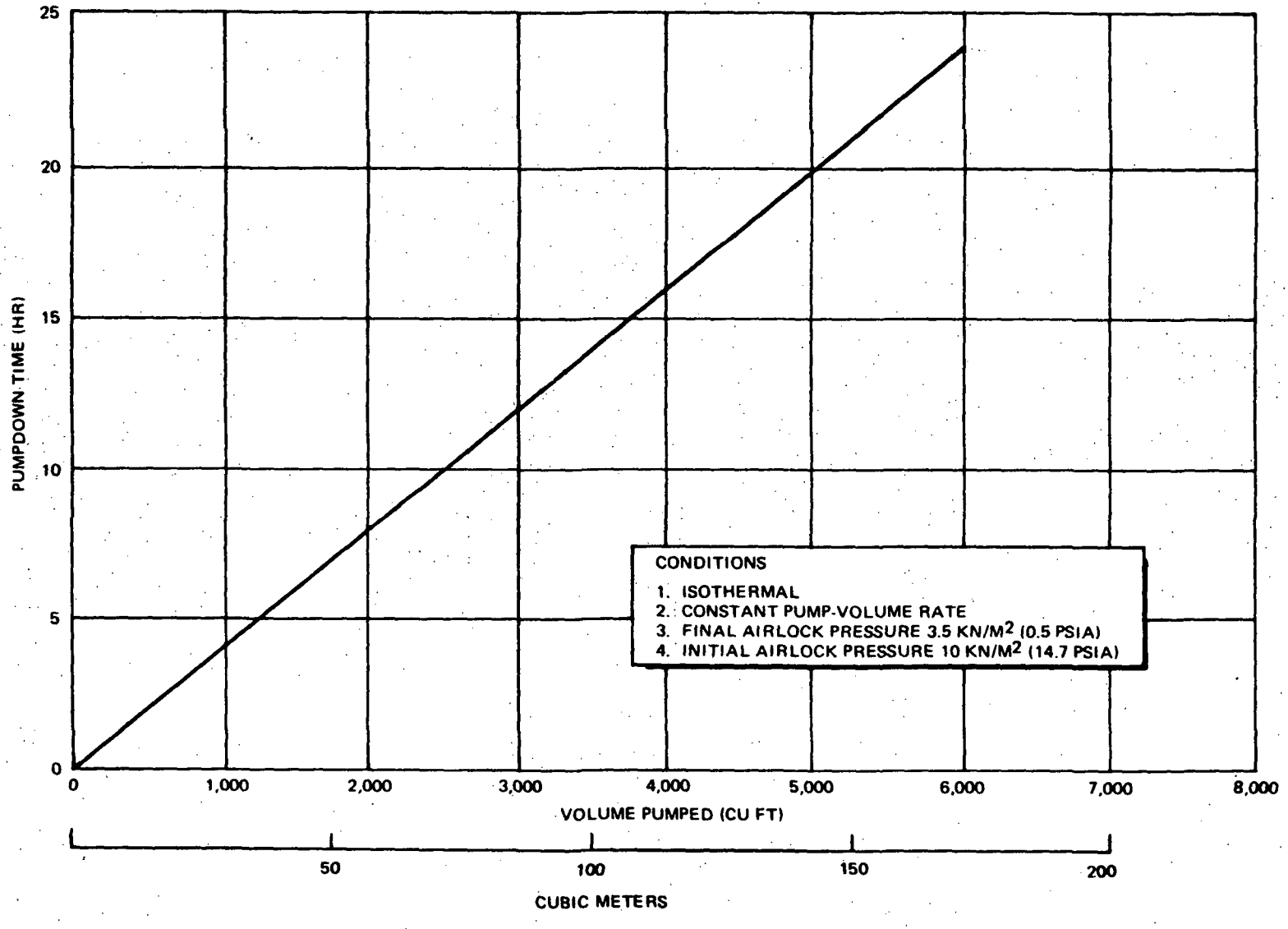


Figure 7-27. Pumpdown Time/Volume Relationship for Airlocks

D. Windows and lights will be provided to allow complete observer coverage of airlock interior conditions.

E. Emergency control of pressurization and depressurization will be provided inside the airlock and outside.

F. Pressure relief valves or other safeguards will be provided to protect the chamber from structural damage in the event of over-pressurization.

7.2.1.11 Logistics Module

The Logistics Module is unique in that it serves not only as the cargo transport vehicle but as a permanent part of the Space Station. Logistics modules are rotated by the orbiter and at least one Logistics Module is always attached to the station. Thus, the Logistics Module must satisfy not only the long-term safety requirements of the Space Station but also the in-transit requirements of the shuttle.

The fundamental approach was to make the Logistics Module as inert as possible. By having the absolute minimum of active systems, the risk of accident or failure which could effect safety of the crew (either Space Station or orbiter) is minimized. For example, the Logistics Module, while attached to the Station, is completely dependent on the core modules for a conditioned atmosphere. Accordingly the Logistics Module need have only a few valves, lines, a fan, and ducts. Thermal control is also provided by the interchange of air from the core modules. Similar simplification is provided for other subsystems. The Logistics Module thus is made operationally simple and can be considered a "dumb pantry."

The function performed as a cargo transport vehicle and on-orbit pantry or storage does introduce some potentially hazardous equipment, which is controlled as follows. Gaseous N_2 and hydrazine are stored in an unpressurized compartment; hydrazine transfer lines are outside the pressurized shell. Gaseous O_2, which is stored inside, is located the length of the module away from the station. Any experiment hazardous equipment or supplies, such as cryogenics will be immediately off-loaded from the Logistics Module upon arrival and taken to a special control area, such as test and isolation chamber.

The Logistics Module will normally be isolated from the core modules by closure of a hatch. Pressure and required air movement will be controlled through the air ducts. Time studies indicate that only 15 to 20 min/day will be spent in the Logistics Module by the crew. The hatches will be open only when crewmen are inside. Monitoring of critical measurements is performed in the Logistics Module using standard Space Station local monitor and display units which process and display all data which generate warning audio and visual alarms. In addition to local display, the warning signals are also transferred via hard wire to the Space Station control center.

During ground checkout, launch and up to docking with the Space Station, system status of the Logistics Module is provided to the payload support system of the orbiter. Critical measurements are monitored such as pressures and temperatures for O_2 and N_2 tanks, $N_2 H_4$, experiment cryogenic tanks, and compartment atmosphere condition. Warning parameters are hard-wired to the shuttle payload support console.

The Logistics Module has a third function which is required only in an emergency condition. It can be used as a temporary refuge area and as an emergency rescue vehicle. Emergency Life Support provisions are located onboard to provide a three-man, 96-hour metabolic O_2 supply, humidity and CO_2 control, cooling, emergency food, waste management and medical supplies. For rescue use, the Logistics Module is outfitted with restraints and essential services for return of the six-man crew. Two three-man 96-hour life support pallets are required during this rescue mode.

The significant safety features of the Logistics Module are summarized below:

A. Minimum active systems.
B. Propellants in unpressurized area.
C. Pass-through capability for direct Shuttle transfer (EVA airlock).
D. Minimum crew occupancy (0.3%).
E. Space Station Logistics Module hatch to be closed during normal operations.
F. 96-hour emergency life support capability.

G. Pressure bottles located the length of module from Space Station.

H. Caution and warning provisions.

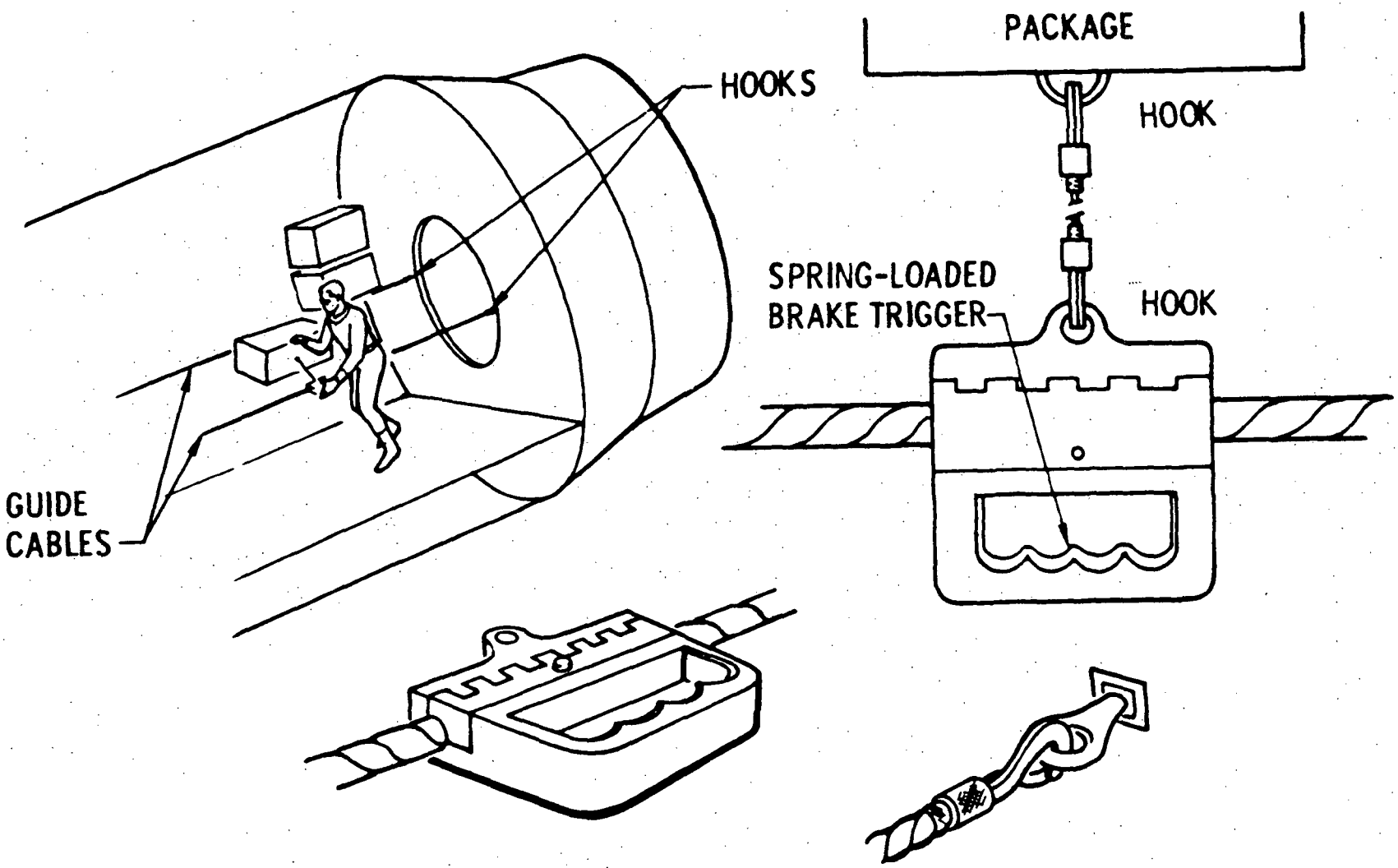
7.2.1.12 Cargo Handling/Movement

Cargo transfer operations are similar to those developed for the 10-m station with some exceptions. Selected liquids and gases are transferred by a transfer system controlled from the Space Station command control console to the subsystem using point (RCS, RAM, GPL, etc.) throughout the station. The fluid or gas is pumped or gas pressure fed to effect transfer. All cryogenics are transferred by the crew from the Logistics Module to the GPL or RAM. Small quantities of special fluids or gases required for experiment operations will be transferred the same as solid cargo. Solid cargo transfer will primarily be accomplished by the crew hand-controlling and translating each item on an as-needed basis or scheduled periodically. The majority of solid cargo items can be safely handled and transferred by the crew from the LM to the Power, Crew, or GPL modules without the aid of a cargo-handling system.

However, the characteristics of a few items exceed the capability of a crewman to safely control and constrain the movement of the item without the assistance of a mechanical aid or cargo handling device. These characteristics include size or shape, moment of inertia, and safety precaution (e.g., transfer of high pressure gas tanks at 20 MK/m^2 [3,000 psig]). Since the usage rate of the transfer system is periodic rather than routine with each resupply flight, a simple safe system that can be easily installed and removed for onboard storage is desired rather than a more sophisticated and permanent system throughout the station.

A proposed dual cable cargo moving system is depicted in Figures 7-28 and 7-29. The system features include the following:

A. Two cables (e.g., of nylon) attached to attachment fixtures located in the aisle ways of each station module and the Logistics Module. Separate cables are attached on each side of the aisle to provide directional control of the cargo transfer.



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Figure 7-28. Cargo Handling System Components

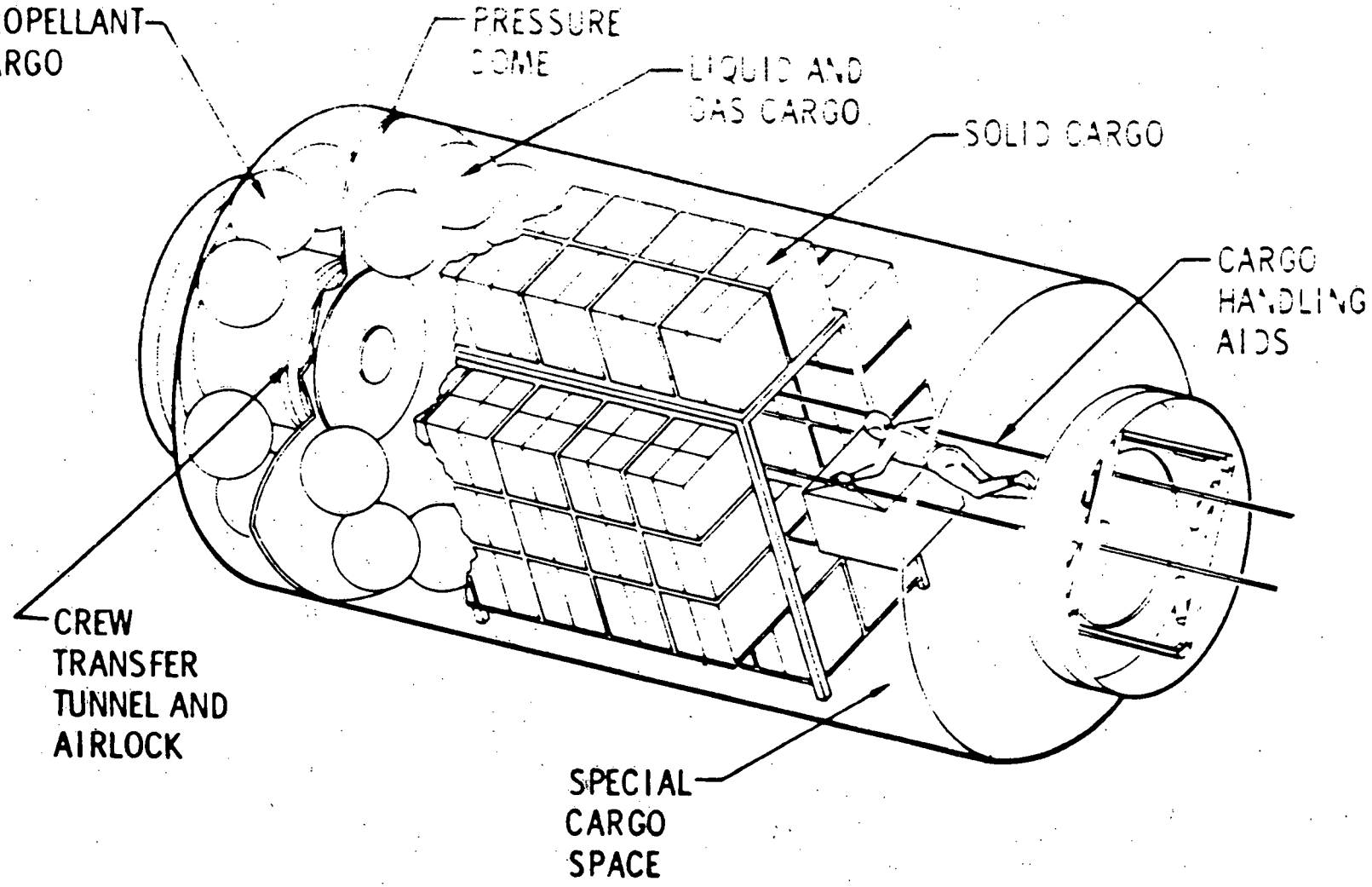


Figure 7-29. Logistics Module

B. No fittings required on the cable.
C. Removable cable trackers easily and quickly installed by a crew member.
D. A deadman brake provided on the tracks for safety.
E. Corners conveniently traversed.
F. System easily adaptable to cargo container design.
G. No maintenance required.
H. Minimum storage on station required.
I. Minimum crew time for installation or removal.

To operate the system, the crew attach the cable runs from the Logistics Module to the equipment location aisle zone in the station module where the equipment or item is to be transferred. The crew then proceed to the storage rack of the Logistics Module and attach one cable tracker to the cable. The tracker is clamped and locked onto the cable and is normally spring-loaded to the brake and the tracker is free to slide along the cable. Releasing the trigger automatically engages the tracker brake.

With one tracker installed, the crew then attach an adjustable cargo constraint cable. One end anchors to the tracker and the other end attaches to the cargo packaging fitting. The cargo item is pulled into the aisleway sufficient to allow installation of the second tracker and guide cables are then adjusted to the proper tension to constrain the cargo. The cargo is now ready to be translated along the cable run by the crew.

Each crewman releases the tracker brake and the crewmen provide the force to translate the item. The crew performs the reverse procedure to remove and install the item at its destination point. The system provides a safe, very simple, easy to operate and store, minimum maintenance and low cost method.

7.2.1.13 Configuration, Equipment Location

Safety considerations have had a strong influence in determining the equipment location and arrangement of modules. The object of course is to minimize the crew exposure to potential hazards. Not only must least-safe equipment be identified but crew occupancy times for each habited module must be

determined. This latter analysis, hazard time exposure, is commonly safety studies, but is considered by MDAC to be an essential part of any thorough safety study.

The objective was to arrange the station so that the crew spends most of their time in the safest area. Crew time lines were examined in detail to account for all of the crew's time-off duty times including rest, sleep, recreation. On duty times included experiment operation, housekeeping/logistics, maintenance, subsystem operation, and mission planning. Figures 7-30 and 7-31 show the results of the analysis (note the 10-year average). It is significant that the crew spends over 80 percent of its time in the Crew Operations Module and the GPL. The time shown for the RAM's is the total for 17 different RAM's and the average time spent in any one is very small.

The crew occupancy times indicate that: (1) Crew Operations Module should be made the safest (maximum freedom from potential hazards); and (2) the least-safe equipment should be put in the Power/Subsystems Module and Logistics Module.

These results had the following effects on configuration, equipment location, and operations.

A. All high-pressure vessels are located in the Power/Subsystems Module and the Logistics Module.
B. Propellant tanks are located in unpressurized compartments in the Power/Subsystems Module and Logistics Module.
C. Any potentially hazardous test will be conducted in the isolation chamber behind a pressure bulkhead. Cryogens for experiments are stored in this chamber. The entire control and operation of any test will be conducted by a crewman outside the chamber. Entry is made only to set up and calibrate tests.

Control of other potentially hazardous materials is accomplished in a similar manner; some examples of control are cited below.

A. Water only in EC/LS inside loops. Freon lines are outside habited volumes to preclude the possibility of a hazard from freon leak.

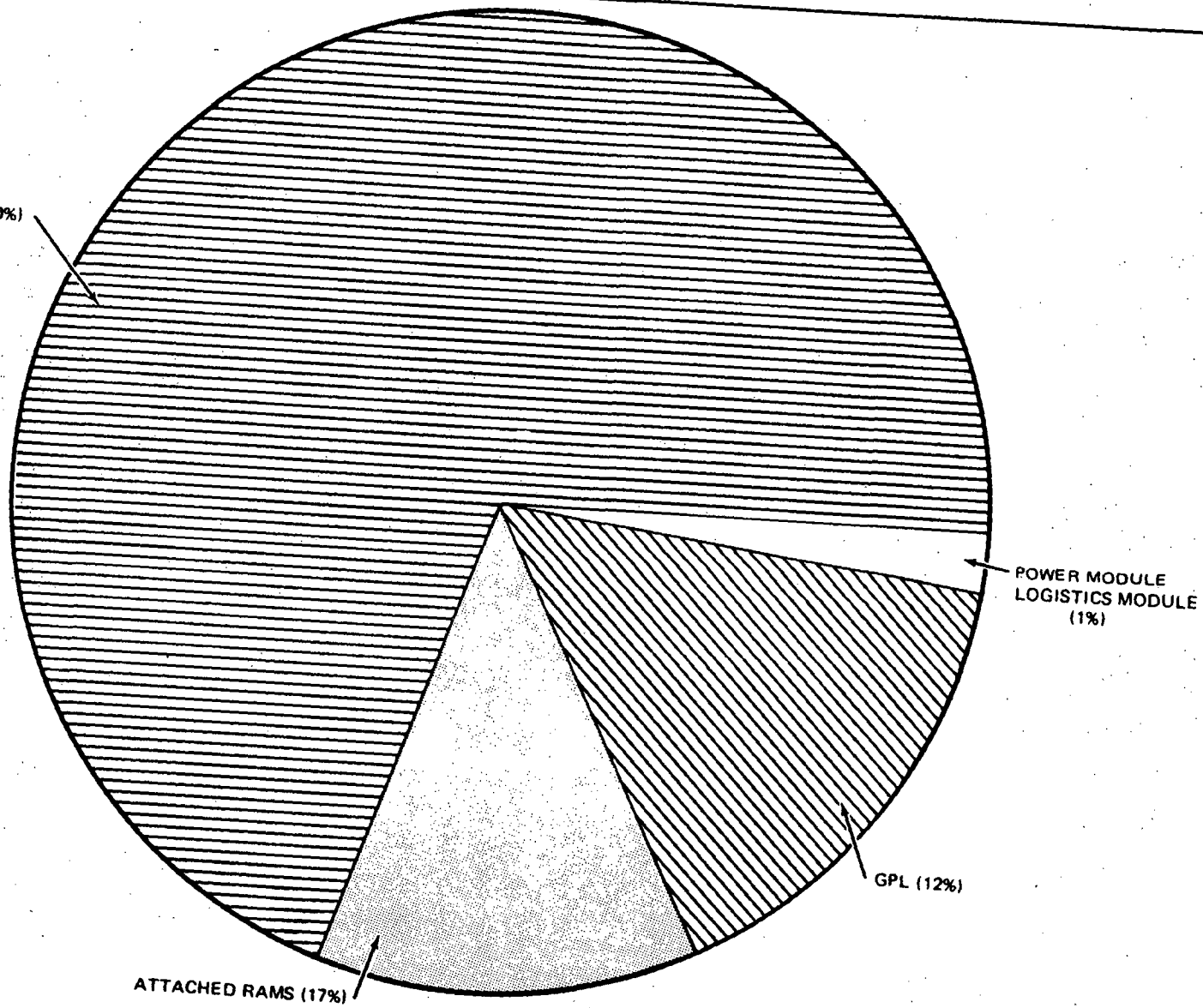


Figure 7-30. Module Occupancy

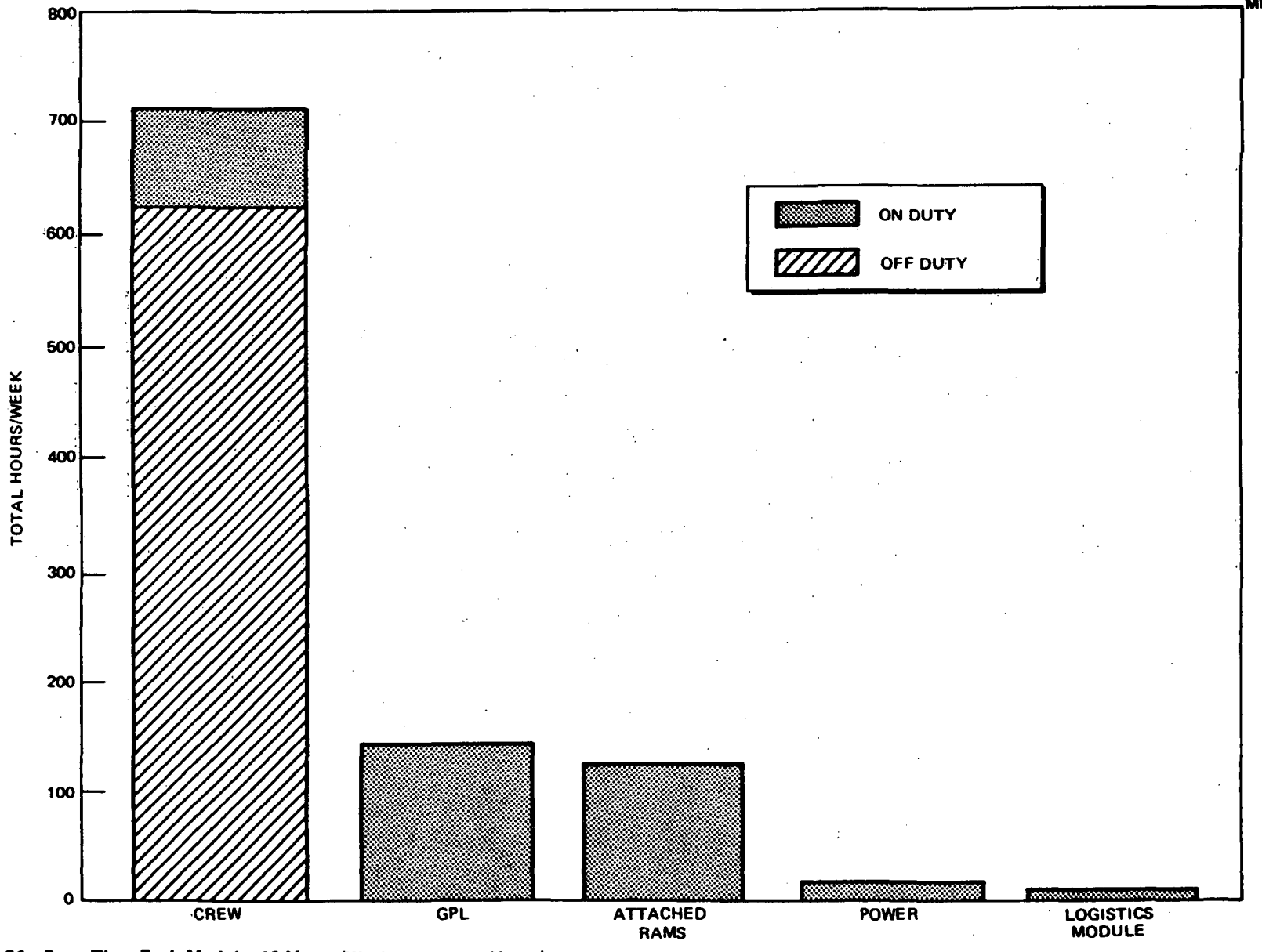


Figure 7-31. Crew Time Each Module 10 Year (Weekly Average, Hours)

B. No flammable fluids stored in habited areas. Hydrazine lines are on the exterior of the pressurized volumes (a connection does go through the module interface, but is completely vented to space, see Figure 7-32).

C. No hydrogen is permitted onboard.

7.2.2 Safety Analyses Results

The following analyses were performed and recommendations made to operations and design personnel in support of Space Station safety:

A. Failure Modes and Effects and Criticality Analyses.

B. Preliminary and Operations Hazards Analyses.

C. Design and Configuration Trade Studies.

D. Emergency Procedure Analyses.

E. Hazard Time Exposure Analyses.

F. Contingency Analysis.

Preliminary failure modes effects and criticality analyses were prepared for all Space Station subsystems to identify the effects of potential component failures on the Space Station. Component failure modes which could result in a crew hazard, designated a, b, or c in Safety Program Directive No. A, were segregated and examined in greater detail as part of the preliminary hazard analyses. Generally, these can be categorized as follows:

Catastrophic -- No recovery is possible or an immediate crew hazard exists (i.e., pressure vessel rupture or premature activation of explosive devices).

Critical -- Immediate crew action required (i.e., automatic switchover to a redundant unit in the case of life support of electrical power component failures).

Marginal -- Curtailment of capability to go EVA, detect fires, detect CO_2 buildup, etc.

This FMECA was issued as an internal document for record purposes and is not included in this report. It was distributed to MSFC S&E Qualification Office and to other interested personnel in that form.

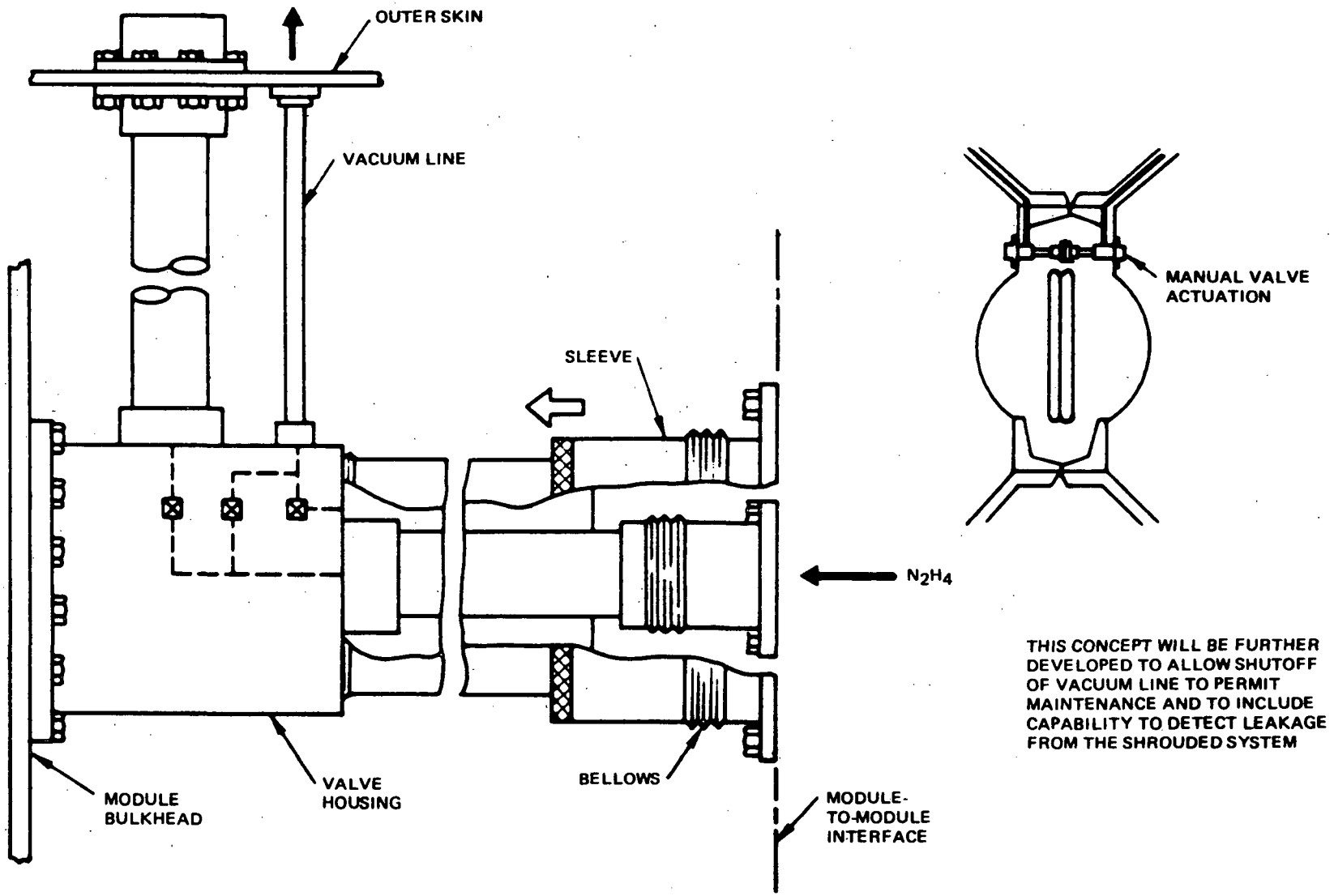


Figure 7-32. N_2H_4 Interface Connection Concept

Completion of preliminary hazards analyses and operations hazard analyses led directly to many design recommendations and requirements for operational procedures. The most important of these are summarized in Tables 7-42 through 7-46. Preliminary hazards analyses were completed for the following hazards: loss of module pressure; loss of O_2; fire and smoke, contamination, radiation, toxicity, buildup/activation, EVA/IVA, and explosion.

Emergency procedures analyses were prepared for those hazards identified in the PHA. An attempt was made to sequentially select the options available to the Space Station crewmen if a hazard should occur. Table 7-46 shows this emergency procedure analysis for on-orbit operation. Contingency analysis, subsection 7.2.1.5, was performed for Space Station operations with one compartment uninhabitable.

Table 7-42

HAZARD ANALYSIS - LOSS OF MODULE PRESSURE

Failure Event	How Occurring	Controls Implemented
Dump and relief valves fail open or inadvertently open. Airlock equalization valves or air ducts inadvertently opened	Human error. Seat contaminated or deteriorated. Galling or solenoid failure	Provide capping or fail-safe design for valves which can open to space environment. Manual closure possible Provide for replacement of embrittled seals Provide for contingency procedure in the event valves fail open (e. g., use masks, move to other compartment, close hatch)
Rupture of pressure shell	Overpressure from explosion of high pressure of propellant tanks Overpressure from broken O_2 or N_2 line, pressure control valves failed in open position	Locate pressure tanks in module isolated from habited modules Locate propellant tanks in unpressurized areas. Provide blow-out panels Provide redundant relief devices. Backup sensing/control alarm system Manual override Size relief valves to handle condition Pressure shell safety factor of 2 to 1
Docking collision causing pressure shell or hatch damage	Thrustor failure. Pilot error Space Station orientation disturbance	Fail-safe thrustor design. Independent braking thrustors. Redundant docking aids. Automatic shutoff of propellant flow to thrustor if duration exceeded.

Table 7-42

PRELIMINARY HAZARD ANALYSIS - LOSS OF MODULE PRESSURE (Continued)

Failure Event	How Occurring	Controls Implemented
		Docking safety officer
		Contingency (back-off) procedures
		Inhibit Space Station thrustors
Viewport seals, EVA hatches, docking ports, etc., fail	Seals degrade and embrittle. Rupture of viewport	Redundant seals
		Provide for scheduled replacement
		Provide contingency procedure for closing off compartments in event of severe leaks
		Monitor total pressure and provide audible or visual alarm if pressure deviates from certain limits
		Provide sensors to detect leakage of pressure through leak and pressure shell
		Use large safety factor
Meteoroid puncture, space debris puncture, internal puncture	Cargo-handling accident. Fragments from explosion	Provide detectors to locate puncture
		Provide patch kit
		Contingency procedure which enables crew to egress rapidly from compartment in event of large hole and rapid venting to space
		Provide shielding for pressure vessels
		Cargo-handling aids

Table 7-43

PRELIMINARY HAZARD ANALYSES - EXPLOSION

Failure Events	How Occurring	Controls Implemented
Rupture or burst of following components located in Space Station, Logistics Module, or RAM Propellant tanks O_2, N_2 gas Pressurant lines Pressure regulators Emergency O_2 tanks Freon accumulator Portable life support system Pumpdown accumulator CO_2 accumulator Gyro tanks	Relief valves fail to open Ding in tanks creates high stress point Human error – Crewmen hits tank with tool Damage by cargo movement Meteoroid puncture Poor weld joint Metal or weld fatigue Break in lines Propellant tank heater fails on	High burst-to-operating pressure safety factor Redundant relief devices Subject components to (1) special handling and shipping controls; (2) double inspection; (3) labeling; (4) tight test controls Shield pressure vessels to avoid chain reaction if one bursts Design anti-shrapnel pressure vessels Locate in unpressurized compartment. Design blowout panel in pressure shell Isolate behind pressure bulkheads
Premature activation of ordnance devices	RF energy present from RF filter failure	Fail-safe filter design Minimum use of ordnance
Batteries or blackboxes rupture	Internal short results in overheating	Provide double stainless steel cases for battery and relief devices for blackboxes

Table 7-43

PRELIMINARY HAZARD ANALYSES - EXPLOSION (Continued)

Failure Events	How Occurring	Controls Implemented
Thrustors explode	Thrust chamber overheats in presence of explosive mixture	Monitor thrustor temperature
Combustible gases or powders in presence of ignition source	Static charge buildup	Provide venting and purging for gases to preclude buildup
	Electrical short	
	Gas leakage	Provide means to constantly ground crewmen
		Ensure that all hazardous experiments are conducted in controlled areas
		Provide for monitoring of gases
		Provide protection against any ignition sources

Table 7-44

PRELIMINARY HAZARDS ANALYSES- FIRE, SMOKE, TOXICITY

Failure Event	How Occurring	Controls Implemented
Battery fluid or gas leakage	Overheating or internal shorting could cause outgassing and leakage of KOH	Provide sensors in vicinity of batteries Contingency procedure to get rid of KOH if leakage occurs
Electrical initiation	Power distribution wires short	Protect with circuit breakers or fuses
	Electronic equipment boxes explodes or outgases	Design boxes to prevent overpressure
		Use fire and smoke detectors near potential fire sources
		Provide automatic or readily accessible fire extinguishers
		Provide contingency procedure for fire or toxicity
Static electricity	Metal tools, etc. in contact with equipment	Arc proof tools or coated tools. Ground all equipment that can arc
	Charge buildup in clothing	Procedure ground crewmen before metal contact
	Inadequate grounding of equipment	
Combustible material and ignition source present together	Hydrazine line or connection leakage into a pressurized area	Locate all hydrazine lines outside of pressurized areas

Table 7-44

PRELIMINARY HAZARDS ANALYSES- FIRE, SMOKE, TOXICITY
(Continued)

Failure Event	How Occurring	Controls Implemented
		Provide shutoff capability and the capability to purge area
		Vent all connections overboard
		Provide sensors to detect pressure of fuels
		Isolate propellant lines from any ignition source
		Provide fire detection sensors and a fire suppressant system
		Minimum use and rigid control of combustible materials
Toxic fluid leakage	Piping breaks, piping connector leakage, container rupture, spill	Provide sensors and warning devices
		No toxics in normally habited areas
		Provide shutoff capability and a capability to purge potentially affected areas
		Toxics in special isolation chamber or RAM areas.

Table 7-45

PRELIMINARY HAZARD ANALYSES- CONTAMINATION

Failure Event	How Occurring	Controls Implemented
High toxicity buildup	Materials outgas and removal devices fail or are inadequate	Provide redundant contamination removal capability
	Caution and warning unit fails to indicate buildup	Provide escape procedures and capability
		Provide redundant caution and warning capabilities
		Use strict materials control during design
		Provide temporary (masks, etc.) emergency provisions
Propellant leakage into cabin	Line or connection leakage into cabin	Weld connections
		Provide monitoring and alarm capability and crew escape procedures
Pathogenic	Experiments	Isolate from space station habited areas. Separate or isolatible EC/LS for specimens. Work in safety cabinet or enclosed hooded bench. Maintain lower pressure in work areas
		Follow standard microbiological safety requirements
	Contaminated water	Bacteria filter
		Pasteurization
		Purity test

Table 7-45

PRELIMINARY HAZARD ANALYSES - CONTAMINATION (Continued)

Failure Event	How Occurring	Controls Implemented
CO_2 buildup	Failure of CO_2 removal unit (molecular sieves, valves, controls, etc.) and failure of caution and warning unit	Redundant CO_2 removal units
Trace contaminants (ammonia, methane, CO, H_2S, etc.)	Failure of trace contaminant control unit (Li_2, CO_3, sorbeads, charcoal, fan, catalytic oxidizer) and failure of monitoring and warning unit	Redundant trace contaminant units Redundant monitoring and capability

Table 7-46

EMERGENCY PROCEDURE ANALYSES

Emergency Condition	Reaction Time	Possible Emergency Response
Inadequate Oxygen:		
1. Loss of total pressure in one pressurized module (GPL or Crew)	Minutes to days	Warn crew of emergency Evacuate module Seal it from other modules Don pressure suits, reenter module via IVA airlock Locate source of atmosphere loss Effect necessary repairs and repressurize
2. Loss of total pressure in both GPL and Crew Modules	Minutes to days	Warn crew of emergency condition Evacuate to Logistics Module, Power Module, or RAM Don pressure suits and reenter module via airlock Locate sources of leakage Effect repairs and repressurize
3. Shortage of O_2 in a compartment with normal total pressure	Hours to days	Evacuate module and reference other modules to other EC/LS Don emergency O_2 masks Reenter compartment and repair fault in EC/LS Permit O_2 level to increase to a safe level before reentering module.

Table 7-46

EMERGENCY PROCEDURE ANALYSES (Continued)

Emergency Condition	Reaction Time	Possible Emergency Response
4. Failure open of dump and relief valve	Minutes	Manually close valve
		Repressurize compartment
		When it is impossible to immediately close valve, warn remainder of crew
		Evacuate module
		Seal off module
		Reference other modules to other EC/LS system
		Don pressure suits and reenter via intermodule airlock
		Close and repair dump valve
		Repressurize module
5. Failure of PLSS to supply viable atmosphere to EVA astronaut	Seconds to Minutes	Apprise buddy of emergency situation
		Immediately head to EVA airlock with assistance of other astronaut
		Notify onboard crew to have emergency oxygen ready as soon as airlock opens
		While airlock is repressurizing, buddy plugs into umbilical outlet in airlock
		Administer oxygen to man
		Take man to dispensary when airlock opens

Table 7-46

EMERGENCY PROCEDURE ANALYSES (Continued)

Emergency Condition	Reaction Time	Possible Emergency Response
Astronaut becomes ill or injured during EVA	Seconds to Minutes	The buddy who is always in visual contact assists endangered man and assures he reenters via EVA airlock as soon as possible Man then taken for medical treatment If man's condition is too severe to be treated, then sends him down via Shuttle emergency flight
Contamination:		
1. Compartment contaminated with substance which is filterable by EC/LS	Minutes to days	Warn crew of dangerous situation Evacuate module and seal it from remainder of Space System Don pressure suit and reenter compartment via intermodule airlock Eliminate source of contamination Wait for EC/LS to clear the atmosphere (2 hr)
2. Compartment contaminated with substance which is filterable by EC/LS	Minutes to days	Warn remainder of crew of dangerous condition Evacuate module and seal it from remainder of Space Station Don pressure suits and reenter compartment via intermodule airlock

Table 7-46

EMERGENCY PROCEDURE ANALYSES (Continued)

Emergency Condition	Reaction Time	Possible Emergency Response
		Empty by opening dump valves
		Eliminate source of contamination
		Close dump valves and repressurize
3. Excessive CO_2 in a module	Hours to days	Evacuate module and reference other modules to other EC/LS
		Don O_2 masks and reenter module
		Repair failure in EC/LS system
		Vacate module and wait until CO_2 level is back to tolerable level before reentering
Radiation:		
Abnormal high flux of protons generated from solar flare activity	Minimum of 2 hours from onset to maximum flux	Personnel move to positions in command center for additional shielding
		Operating crew don EVA suits for additional shielding
Collision between Space Station and logistics vehicle, experiment module, or space debris	Minutes to days	See Items 1 and 2 under inadequate oxygen

Table 7-46

EMERGENCY PROCEDURE ANALYSES (Continued)

Emergency Condition	Reaction Time	Possible Emergency Response
Fire:		
1. Small isolated fire suitable for automatic or manual fire suppression	Minutes	Turn off equipment which may contribute to the fire Put out fire by use of a fire suppressant system EC/LS purge compartment
2. Large conflagration which is beyond the scope of fire suppressant devices	Seconds to minutes	Warn remainder of crew Personnel don emergency oxygen masks Turn off equipment which can contribute to the fire Evacuate module and isolate from remainder of Space Station Purge compartment by remotely opening dump valves Repressurize and reenter
Nitrogen or propellant pressure vessel rupture in unpressurized compartment in Power Module	Minutes to hours depending on damage	If pressure integrity of pressurized section of Power Module is maintained, then Don space suits Enter pressurized section and depressurize Open hatch and enter explosion area Effect repairs to provide pressurizable compartment

Table 7-46

EMERGENCY PROCEDURE ANALYSES (Continued)

Emergency Condition	Reaction Time	Possible Emergency Response
		If the pressurized section has been ruptured, then Don space suits Go through IVA airlock and enter damaged area Repair damage to pressure hull Repressurize and complete repairs

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