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## MODULAR **space station** PHASE B EXTENSION

### PROGRAM COST AND SCHEDULES

Volume I - Cost And Schedule  
Estimating Process And Results



PREPARED BY:  
PROGRAM BUSINESS MANAGEMENT

JANUARY 1972



Space Division  
North American Rockwell

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MODULAR  
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North American Rockwell

**TECHNICAL REPORT INDEX/ABSTRACT**

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<p><b>ABSTRACT</b></p> <p>COST ESTIMATES AND FUNDING SCHEDULES ARE PRESENTED FOR THE EARTH ORBITAL MODULAR SPACE STATION PROGRAM, FOR A GIVEN CONFIGURATION AND COSTING GROUND RULES. COST METHODOLOGY IS DESCRIBED AND THE COST EVOLUTION FROM A BASELINE CONFIGURATION TO A SELECTED CONFIGURATION IS PRESENTED, EMPHASIZING CASES IN WHICH COST WAS A DESIGN DRIVER. PROGRAMMATIC COST AVOIDANCE TECHNIQUES ARE DISCUSSED. A WORK BREAKDOWN STRUCTURE AND DICTIONARY, ESTIMATED SUBCONTRACTOR COSTS, AND TECHNICAL CHARACTERISTICS DATA ARE PRESENTED.</p>
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## FOREWORD

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

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

ADMINISTRATIVE REPORTS	TECHNICAL REPORTS		STUDY PROGRAMMATIC REPORTS	DOCUMENTATION FOR PHASES C AND D	
				SPECIFICATIONS	PLANNING DATA
<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           EXTENSION PERIOD STUDY PLAN            DRL-62 DRD MA-207T            SD 71-201         </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           QUARTERLY PROGRESS REPORTS            DRL-64 DRD MA-208T            SD 71-213, -235, -576         </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           FINANCIAL MANAGEMENT REPORTS            DRL-63 DRD MF-004         </div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS PRELIMINARY SYSTEM DESIGN            DRL-68 DRD SE-371T            SD 71-217         </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS MASS PROPERTIES            DRL-69 DRD SE-372T            SD 71-218, -219         </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS INTEGRATED GROUND OPERATIONS            DRL-73 DRD SE-376T            SD 71-222         </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS SHUTTLE INTERFACE REQUIREMENTS            DRL-71 DRD SE-374T            SD 71-221         </div> <div style="border: 1px solid black; padding: 5px;">           MSS SAFETY ANALYSIS            DRL-75 DRD SA-032T            SD 71-224         </div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS DRAWINGS            DRL-67 DRD SE-370T            SD 71-216         </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS MOCKUP REVIEW AND EVALUATION            DRL-70 DRD SE-373T            SD 71-220         </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS KSC LAUNCH SITE SUPPORT DEFINITION            DRL-61 DRD AL-005T            SD 71-211         </div> <div style="border: 1px solid black; padding: 5px;">           INFORMATION MANAGEMENT ADVANCED DEVELOPMENT            DRL-72 DRD SE-375T            SD 72-11         </div>	<div style="border: 1px solid black; padding: 5px;">           EXTENSION PERIOD EXECUTIVE SUMMARY            DRL-65 DRD MA-012            SD 71-214         </div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS PRELIMINARY PERFORMANCE SPECIFICATIONS            DRL-66 DRD SE-369T            SD 71-215         </div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS PROGRAM MASTER PLAN            DRL-76 DRD MA-209T            SD 71-225         </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">           MSS PROGRAM COST AND SCHEDULE ESTIMATES            DRL-77 DRD MA-013(REV. A)            SD 71-226         </div> <div style="border: 1px solid black; padding: 5px;">           MSS PROGRAM OPERATIONS PLAN            DRL-74 DRD SE-377T            SD 71-223         </div>

This document consists of two volumes: Volume I - Cost Estimating Process and Cost, Schedule and Funding Summaries, presents cost methodology and describes the evolution of cost beginning with a reference configuration and progressing to a selected configuration. The impacts of various



costs avoidance techniques are discussed. Costs, schedules, and summaries of funding are given. Volume II - Appendices presents the Work Breakdown Structure (WBS) and dictionary, subcontractor and prime contractor costs for WBS items, technical characteristics data, and program funding for the WBS items. Supporting data for the reference configuration and selected configuration are given.



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## 1. INTRODUCTION AND SUMMARY

### 1.1 INTRODUCTION

This report presents cost estimates and schedules for the Space Station Earth Orbital Program which are the outcome of a Phase B study of the modular space station (MSS) sponsored by the Manned Spacecraft Center (MSC) of the National Aeronautics and Space Administration (NASA) and performed by the Space Division of North American Rockwell under Contract NAS9-9953.

This section briefly describes the modular space station and how it is used, and summarizes the costs and funding requirements of the Space Station Earth Orbital Program. A general description of the station, including weights for both the initial operational version and the growth version, is presented. Each system is briefly described; mission flight orbit, assembly and buildup approach, initial station buildup sequence, typical delivery operations sequence, flight mode, and growth station buildup. This description is followed by a summary of the mission sequence plan which emphasizes the scheduling of experiments; crew requirements, logistics requirements, and shuttle support operational requirements which impacts the mission sequence plan are also discussed. Mission support operations and final disposition of the modular space station are briefly described. A cost and funding summary for the various projects of the program is presented, by procurement phases, at the end of Section 1.

Section 2 presents the costing ground rules that explain the dollar indices used, the degree of contractor commitment, the data bases for the estimates, the schedules for go-ahead, IOC, other milestones, and the duration of the program. It also defines the depth to which costs are included in the Work Breakdown Structure (WBS), notes production sequence, weights, cost avoidance, and specific inclusions and exclusions. The program master schedule in Section 2 defines key milestones plus schedule ground rules that affect sequence, start dates, and time duration of the various WBS items.

The overall cost methodology used in this report is presented in Section 3. The sequence of cost buildup is emphasized, as is the relationship among design parameters and data which are comparable to the items being costed. Note is taken of the various comparative base data that are used for flight items and software, and the impact on the estimating process.



The factors for nonflight hardware and programmatic support, the use of computer models in trade studies, and the uniqueness of some of the NASA-furnished costs for experiment projects, are also outlined.

The process of injecting cost into the design process is initiated by the costing of a reference MSS configuration. Section 4 presents the rationale behind the subsystems costs derived for the reference barbell configuration. The reference MSS costs were approved at Engineering Review Board (ERB) Meeting 20 and served as a point of departure for all subsequent cost exercises.

Design evolution resulted in changes from the reference MSS barbell configuration to the cruciform selected MSS configuration. This selected configuration is described in the first part of Section 5. The evolution of costs which are applicable to this configuration are then developed in the actual sequence in which they occurred. First, trade studies were conducted that resulted in the integration of the environmental control life support system (ECLSS), electrical power system (EPS), reaction control system, (RCS). Following that integration, weight changes, subassembly reallocation, and other changes, including update of the comparative cost data, occurred; and finally cost allocation by module was determined. The rationale and effects of all these changes are presented in Section 5. Also, the nonflight hardware and programmatic factors not required for purposes of defining costs at the time of ERB 20 were then defined as described in Section 5. Cargo modules and growth modules were also costed, although not defined to the same depth in the WBS as the initial space station modules by virtue of contractual agreements. Section 5 concludes with a cost summary of the MSS project, and a summary of cost avoidance resulting from trade studies, elimination of redundant equipment, and advances in program management.

Section 6 deals with costs of the Experiment and Experiment Definition Projects and Research and Application Module (RAM) Projects. The experiment capability levels by host spacecraft are defined and the manpower and other constraints are noted in developing an experiment and duration (mission) sequence plan. The impact of this plan on experiment and RAM requirements is noted and the manner in which costs are developed is described.

Finally, in Section 7 the costs of the Space Station Earth Orbital Program are summarized and presented in the Cost Estimate Data Form A. These are at WBS Level 5 on the MSS and at WBS Level 4 for all other projects, of all three procurements phases. Significant cost breakdowns and some funding impacts due to the cost ground rules are cited.



The appendices, which appear in a separate volume, present the detailed work breakdown structure (WBS) and the applicable dictionary, sub-contractor and prime contractor cost breakdowns (Cost Estimate Data Form B), technical characteristics data, (Form C) and program funding (Cost Estimate Data Form D). Supporting cost data for the reference MSS and selected MSS are also included.

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## 1.2 SPACE STATION CONCEPT AND CONFIGURATION

### 1.2.1 INITIAL STATION

The MSS system consists of a cluster of four station modules (SM-1 through SM-4), two special modules (core and power), and a cargo module arranged in a cruciform configuration as shown in Figure 1-1. Each module of the system is capable of being transported to and from orbit internal to the space shuttle for on-orbit assembly.

The initial station system has the capability to support at least six crewmen, has a general purpose laboratory (GPL) capability, and has the ability to accommodate two attached or detached research and application modules (RAM's). The GPL capability includes two airlocks, one earth (NADIR) oriented, and the other zenith oriented.

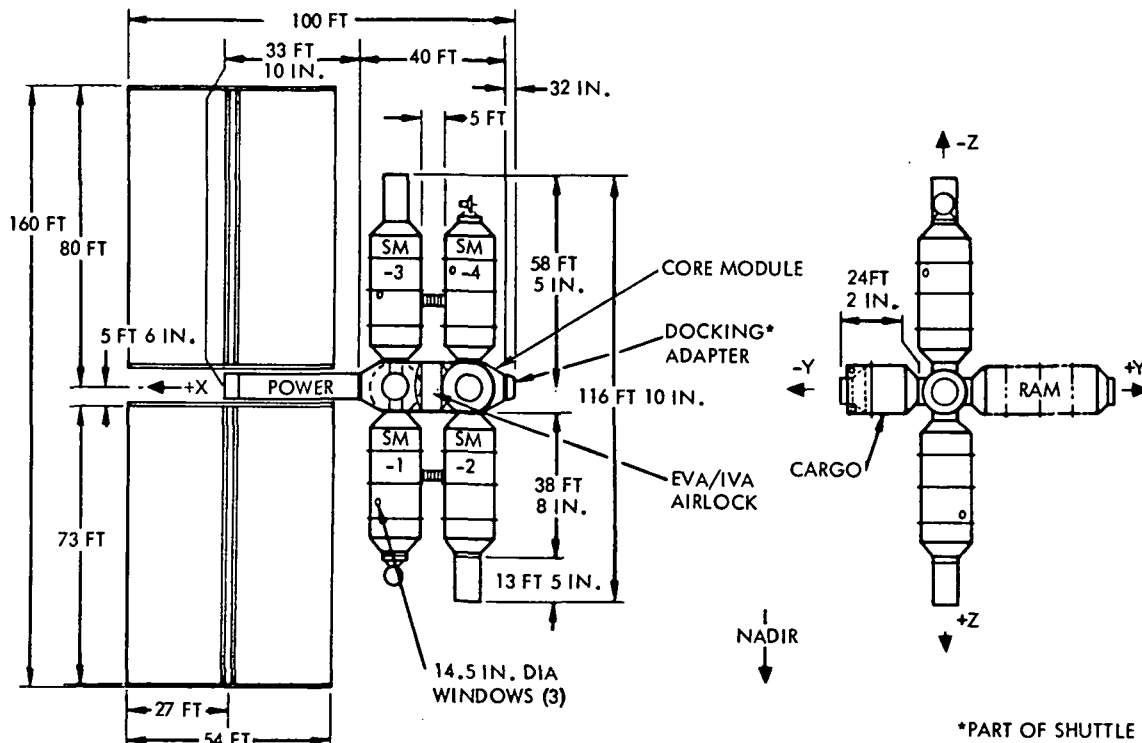


Figure 1-1. Initial Station

### 1. 2. 2 GROWTH STATION

The growth station system has the capability to support 12 men and has as its goal, has the objective of low development costs (Figure 1-2). The two additional station modules utilized for growth have taken maximum advantage of accommodation features developed for the initial station. ECLSS water management and air revitalization accommodation features from Modules 2 and 3 of the initial station have been integrated into Modules 5 and 6, as have the split-level accommodation features from Modules 3 and 4. All other assemblies are similar to initial station assemblies. Also, a short core module is included to provide additional berthing ports required to support RAM's, since the two additional station modules occupy the initial station ports. A 10,000-square-foot solar array package is included to satisfy growth power needs. This package replaces the 7000-square-foot initial station solar array assembly and retains the power-module boom structure.

The weight breakdowns for the initial station, cargo modules, and growth station are given in Table 1-1. The cargo modules and growth station modules were not studied to the same depth as the initial station modules; that is, the cargo and growth modules and subsystems were defined to a conceptual level only and not to the preliminary design level characteristic of the initial station.

### 1. 2. 3 SPACE STATION SUBSYSTEMS

The space station system contains seven functional subsystems. Brief functional descriptions of these subsystems are presented in the subsequent paragraphs.

#### Structural and Mechanical Subsystem

The structural and mechanical subsystem provides the space station pressure enclosure as well as the living and working quarters contained within the structure. It provides for the mounting of associated subsystem hardware and the general purpose laboratory provisions and provides storage facilities. It also provides berthing ports and mechanisms for crew and equipment transfer.

#### Environmental Control Life Support Subsystem

The environmental control life support subsystem (ECLSS) provides essential atmospheric gases, temperature, pressure, and humidity control; food storage and preparation provisions; water and waste management; and personal hygiene facilities and materials for modular space station operation

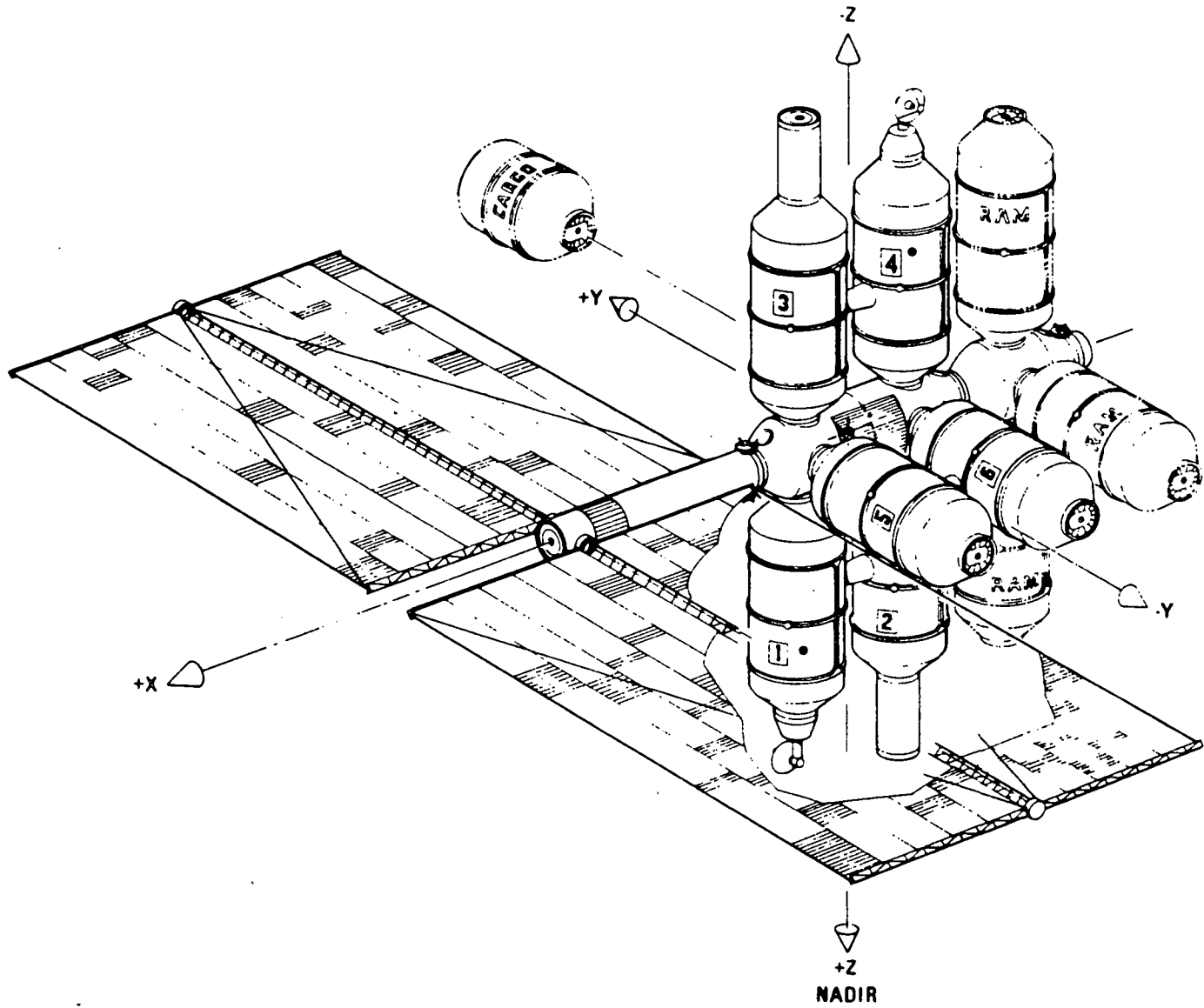


Figure 1-2. Growth Station

Table 1-1. Selected MSS Configuration, Initial and Growth Station Dry Weights

Subsystem/Assembly	Dry Weight (Pounds)			
	Initial Station	Cargo Modules (each)	Growth Modules	Total <sup>(1)</sup>
<b>Structural and Mechanical</b>				
Primary	26,420			
Secondary	17,201			
Environmental shield	4,674			
Berthing	5,190			
General purpose laboratory furnishings	5,555			
Subtotal	<u>59,040</u>	6,260	28,472	93,772
<b>Environmental Control/Life Support</b>				
Gaseous storage	829			
CO <sub>2</sub> management	1,494			
Atmospheric control	3,727			
Thermal control	7,759			
Water management	1,342			
Waste management	328			
Hygiene	506			
Special life support	318			
Subtotal	<u>16,303</u>	4,230	9,545	30,078
<b>Electrical Power</b>				
Primary power generation	7,688 <sup>(2)</sup>			
Secondary power generation	0			
Energy storage	4,966			
Power conditioning	443			
Distribution control and wiring	3,325			
Lighting	794			
Subtotal	<u>17,216</u>	235	9,682	27,132

(1) With one cargo module

(2) Because of lead times necessary to produce cost estimates, anomalies exist in the weights used in costing and those appearing in SD 71-219. None of these are significant and none are noted except the larger power generations assembly used for costing purposes. The rationale for using the larger assembly in the initial station is based upon considerations given in Subsection 5.5.

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Table 1-1. Selected MSS Configuration, Initial and Growth Station Dry Weights (Cont)

Subsystem/Assembly	Dry Weight (Pounds)			
	Initial Station	Cargo Modules (each)	Growth Modules	Total <sup>(1)</sup>
Guidance and Control				
Inertial reference	65			
Optical reference	346			
RCS electronics	75			
Momentum exchange	984			
Subtotal	<u>1,470</u>			1,470
Reaction Control				
Propellant accumulators	176			
Propellant feed controls	190			
Engines	120			
Fluid storage	0			
Propellant conditioning	0			
Subtotal	<u>486</u>		200	686
Information				
Data processing	1,774			
Command/control and monitoring	1,099			
External communications	1,791			
Internal communications	1,429			
Software	160			
Subtotal	<u>6,253</u>	75	1,541	7,869
Crew Habitability				
General/emergency equipment	1,438			
Furnishings	586			
Reaction/exercise/crew care	987			
Food Management	844			
Subtotal	<u>3,855</u>	140	1,041	5,036
<b>TOTAL</b>	<u><u>104,623</u></u>	<u><u>10,940</u></u>	<u><u>50,481</u></u>	<u><u>166,044<sup>(1)</sup></u></u>

(1) With one cargo module

(2) Because of lead times necessary to produce cost estimates, anomalies exist in the weights used in costing and those appearing in SD 71-219. None of these are significant and none are noted except the larger power generations assembly used for costing purposes. The rationale for using the larger assembly in the initial station is based upon considerations given in Subsection 5. 5.

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with a crew of six. The subsystem maintains thermal balance of the MSS as well as emergency reactant storage for the electrical power and reaction control subsystems. In addition, special life support capabilities are provided for emergency conditions.

### Electrical Power Subsystem

The electrical power subsystem (EPS) shall store, generate, regulate, control, and condition electrical power required by the MSS for the full duration of the mission, including backup and emergency contingencies (except for emergency fuel cell reactants which are stored by the ECLSS). In addition, the electrical power subsystem shall be capable of transferring power to docking logistics vehicles and research and applications modules through electrical interfaces, besides power distribution and internal and external lighting, the electrical power subsystem provides the electrical distribution wiring of all subsystem interfaces.

### Guidance and Control Subsystem

The guidance and control subsystem (G&C) determines the actual and desired station state vector, provides stable attitude for the conduct of experiment operations, and provides commands to the reaction control subsystem to maneuver the station to the desired state vector.

### Reaction Control Subsystem

The reaction control subsystem (RCS)(together with the torques supplied by the control moment gyroscopes) provides the forces and moments necessary for attitude control of the space station and those forces required for orbit altitude maintenance.

### Information Subsystem

The MSS information subsystem (ISS) provides the effective acquisition, processing, distribution, and analysis of data. It serves mission planning and operations scheduling, command control, checkout, monitor and alarm, configuration control, inventory control, flight control, data management, support between MSS subsystems, the ground network, docked vehicles (space shuttle, RAM's, and cargo modules), integral experiments and the crew using communications, displays and controls, data processing, software, and special support equipment.



## Crew Habitability Subsystem

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

### 1.2.4 STATION MISSION DESCRIPTION

The MSS system is designed and sized for operation at an altitude of 240 n mi and an inclination of 55 degrees. The basic flight mode is with the X-axis perpendicular to the orbit plane, the Z-axis along the local vertical, and the positive Y-axis opposite to the velocity vector (X-POP, Z-LV, Y-OVV). This mode will be flown at all times except for short periods of inertial flight for solar/stellar viewing, and shuttle approach and berthing/unberthing operations. The system is capable of operating at altitudes between 240 and 270 n mi at an inclination of 55 degrees in either a local vertical hold or inertial hold flight mode.

### Assembly and Buildup Approach

All modules are launched with complete subsystems. This approach results in a design that minimizes the impact on station activation for normal subsystems operations.

With all subsystems installed at launch, with no internal connection breaks and with fluid lines filled, on-orbit assembly operations are reduced primarily to module-to-module interface connections, verification, and checkout. Other startup operations such as subsystem filling, purging, and recheck are eliminated.

The assembly and buildup approach is organized to allow only minimum system activation until permanent manning occurs. Only those subsystems required to maintain the station in a quiescent mode between launches are activated. Some subsystems are deactivated during quiescent operations; for example, the reaction control subsystem, most of the ECLS subsystem (except for atmosphere and thermal control), internal lighting, etc.

A wakeup receiver provides the communications link from ground or shuttle to the station, which has the capability of interrogating subsystem

status, turning quiescent systems on and off, and commanding attitude orientation and control, etc.

### Initial Station Buildup

Figure 1-3 illustrates the buildup sequence of the initial MSS. Preferably, the initial module to be delivered to orbit has a minimum amount of scar equipment over and above that required for normal operations. Trade studies have shown that this objective was best achieved with the initial core module launched first, followed by the power module. These two assembled modules are flown in a gravity gradient mode at minimum (nearly quiescent) power between buildup launches.

A subsequent launch adds the first control/crew module (SM-1). The solar arrays are partially deployed and operated automatically with the now-present ISS. The configuration is now flown oriented about the principal axis and the regenerative segments of the fuel cells are activated. In subsequent sequence, the first laboratory/ECLSS module (SM-2), the second laboratory/ECLSS module (SM-3), and the second control/crew module (SM-4) are added at 30-day launch intervals.

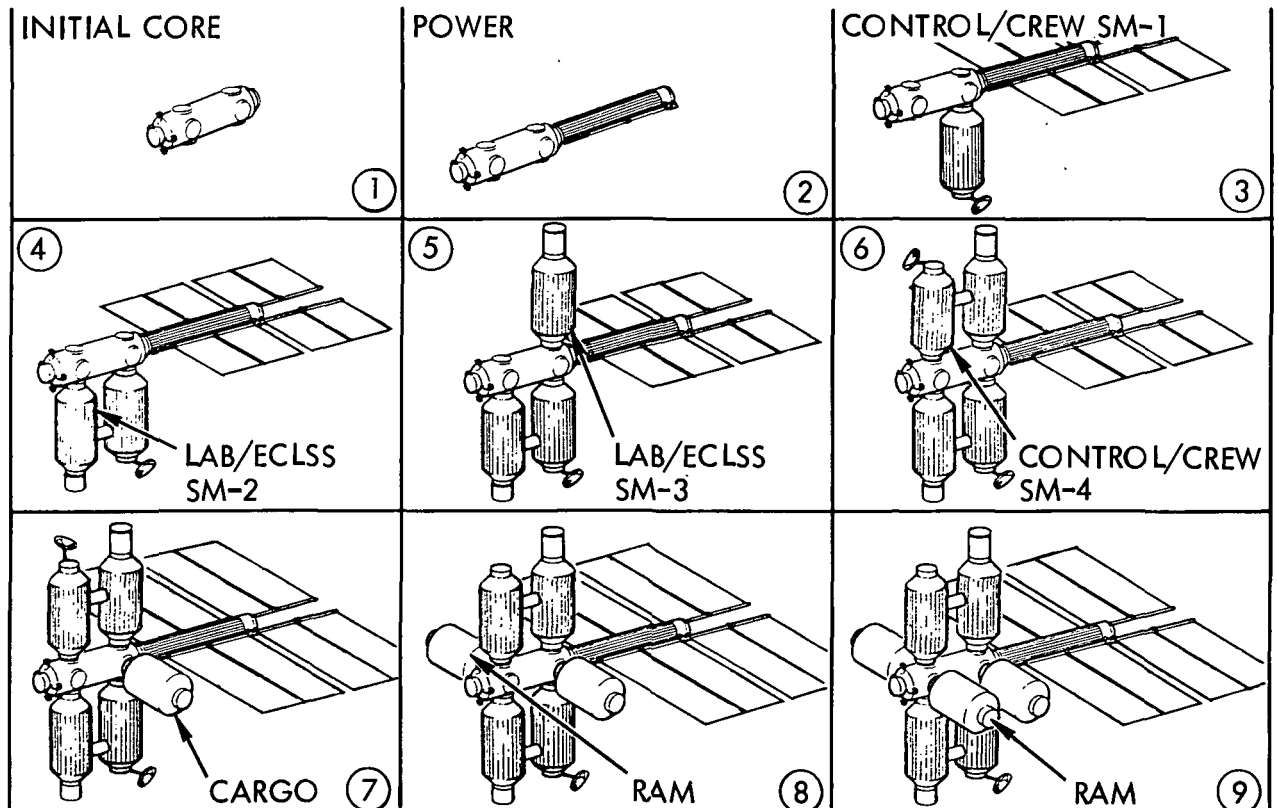


Figure 1-3. Initial Station Buildup Sequence



Although Figure 1-3 indicates the numerical sequence of buildup, there are still station module alternate sequence variations that are viable options. An example, would be putting step ⑤ before step ④. This provides a more balanced configuration, but defers the early flexport assembly between SM-1 and SM-2 shown in step ④. Seven module launches are required to reach the initial operational capability (IOC) of the 6-man space station. Redundant subsystems in complete general purpose laboratories are available at this point to begin the program of experiment operations for a 6-man crew. Provisions are available for the subsequent addition of two RAM's, shown in steps ⑧ and ⑨ of Figure 1-3, during the initial space station operational period.

### Typical Delivery Operations Sequence

The sequence of operations shown in Figure 1-4, is typical for the delivery of almost any station module, but is specifically directed to the first control/crew module since a significant amount of activation and checkout occurs at this stage of station buildup.

As illustrated, the shuttle containing the control/crew module activates the on-orbit core and power module cluster approximately 90 minutes prior to berthing the core and power cluster to the shuttle crew ingress/egress hatch. (An adapter is utilized between the core and shuttle to compensate for the different hatch envelope dimensions.)

Shuttle and station interface connections include caution and warning connections, core module TV hardwire connection, and air circulation ducts for humidity control and CO<sub>2</sub> removal.

As noted, suited crew ingress into the core module is performed for the functions listed prior to initiating the berthing of the control/crew module (SM-1). After berthing, two crewmen will normally work in a shirtsleeve environment to make all module-to-core fluid/gas/electrical connections and verification.

Following the control/crew module hookup and verification with the core module, the activation and checkout of many subsystem assemblies can proceed. The order of activation on Figure 1-4 is as listed: (1) the information system in the control/crew module; (2) the fluid loops in the control/crew module external radiators; (3) deployment of the solar arrays; (4) power transfer from fuel cells to arrays; (5) initiation of regenerative fuel cell energy storage; and (6) startup of the control moment gyros.

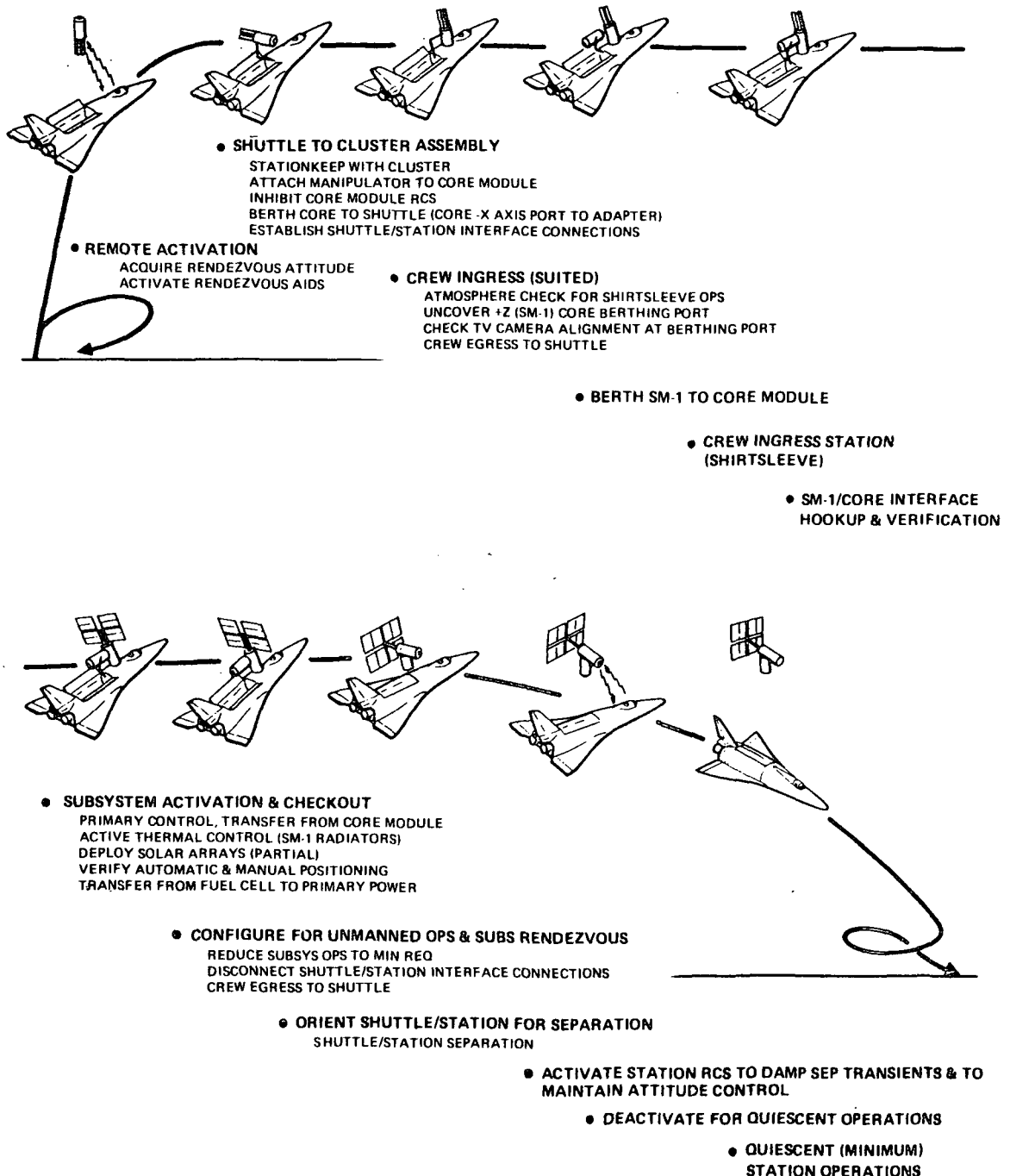


Figure 1-4. Typical Delivery Operations Sequence

After shuttle separation from the station cluster, the station maintains an orientation which minimizes RCS propellant expenditure. All major activated systems remain activated at this point in the buildup sequence. Some minor functions associated with manned operations are deactivated when the buildup crew leaves.

### Flight Mode

The modular space station is capable of maintaining a local vertical hold and an inertial hold flight mode. This provides the basic stable platform mode for earth viewing and solar/stellar viewing instruments, respectively.

The reference flight mode orientation is illustrated on Figure 1-5. The X-axis is perpendicular to the orbit plane (toward the south), the Z-axis is along the local vertical (down) and the positive Y-axis is opposite the velocity vector. The flight mode acronym therefore is X-POP, Z-LV, Y-OVV. This mode will be flown at all times except for the short periods of inertial flight for solar/stellar viewing and shuttle approach and berthing/unberthing operations.

The X-POP flight mode is selected based on minimizing solar array shadowing by the station modules, best in-plane ground viewing, best orientation for combined orbit makeup, and control moment gyro desaturation.

### Growth Station Buildup

Growth station capability is achieved by the addition of two station modules with crew quarters and life support, and by the addition of a short growth core module with added fuel cell and electrolysis equipment. The solar array is replaced with a 10,000-square-foot array. The growth station buildup sequence is shown in Figure 1-6, with steps numbered sequentially to those in Figure 1-3. Crew buildup to the 12-man level is completed following step (14).

### Mission Sequence Plan

The mission sequence plan provides the time phasing of the program elements with emphasis on the scheduling of experiments. The final mission sequence plan is described in detail in the MSS Preliminary System Design, SD 71-217, Volume II, and presents the experiment time phasing, accommodation mode, crew requirements, and logistics requirements. The resultant total orbital program, including initial and growth station buildup, and the conduct of one cycle of Blue Book (Reference 3) experiments covers a time span of approximately 16 years.

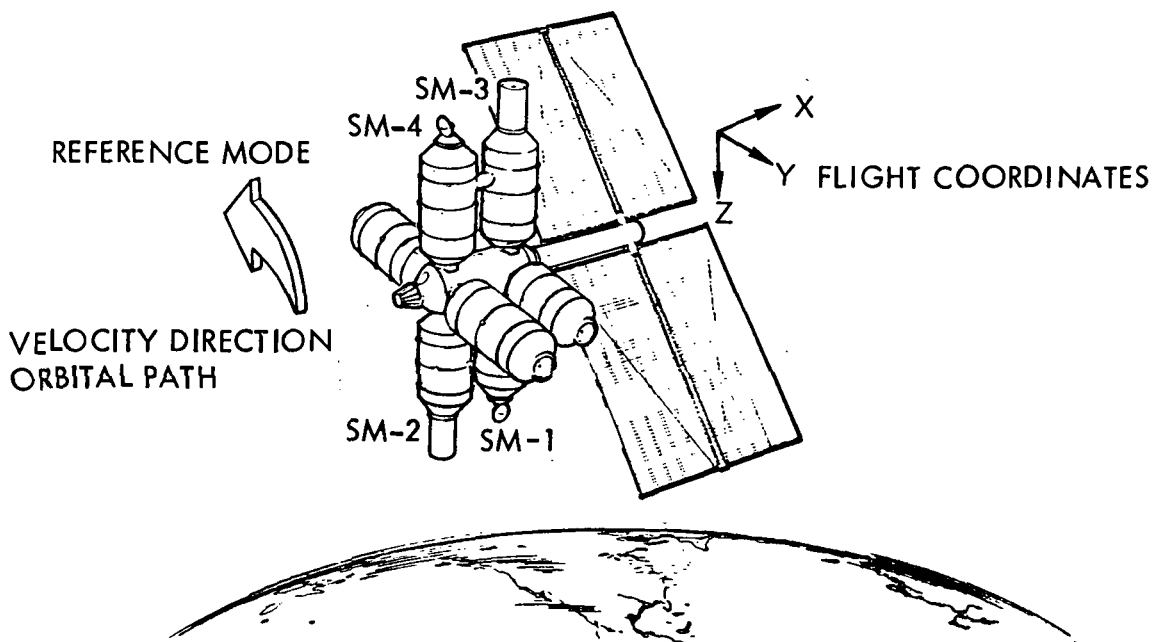


Figure 1-5. Reference MSS Flight Mode

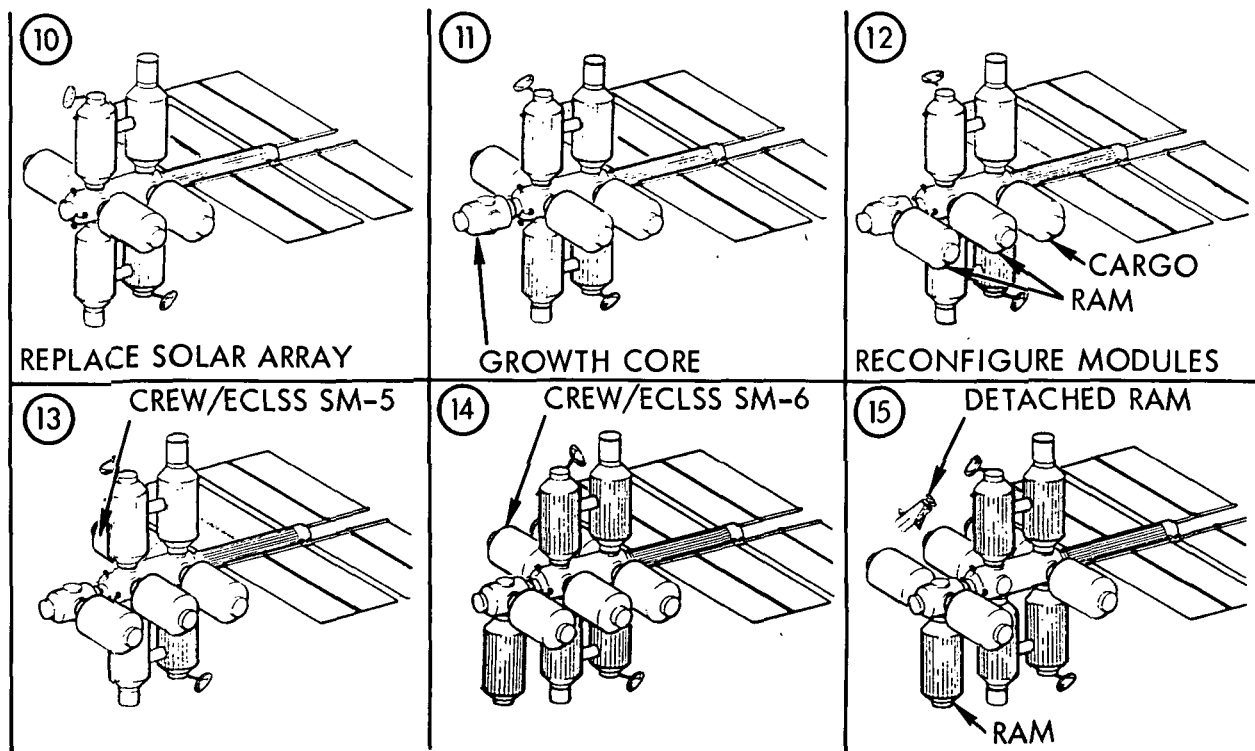
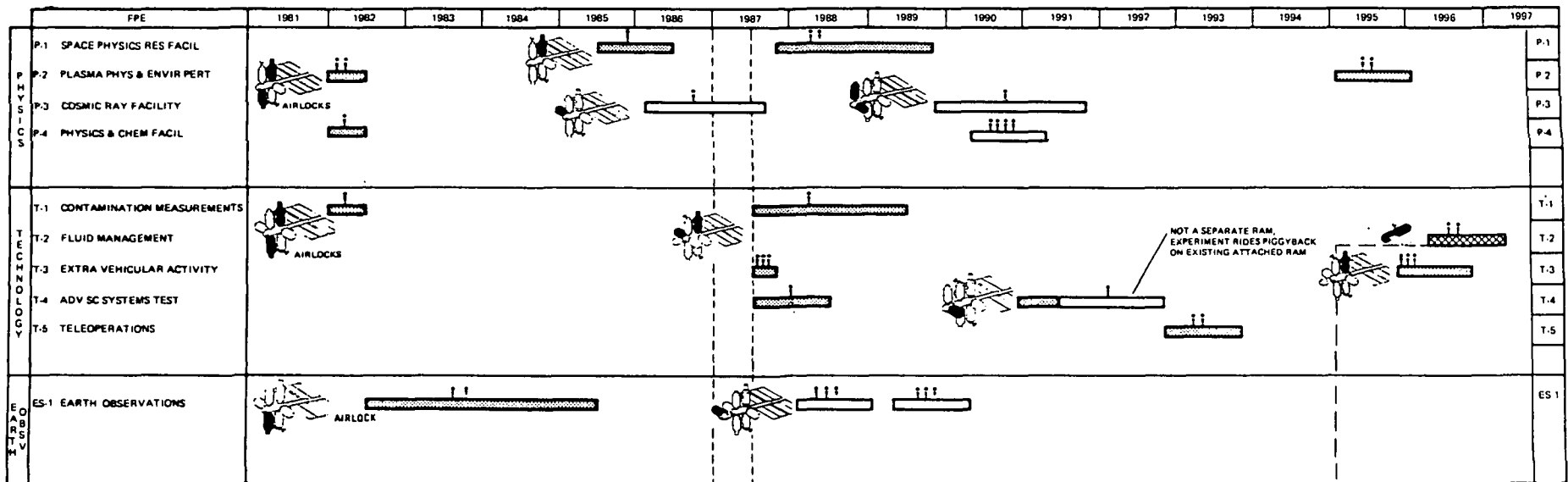
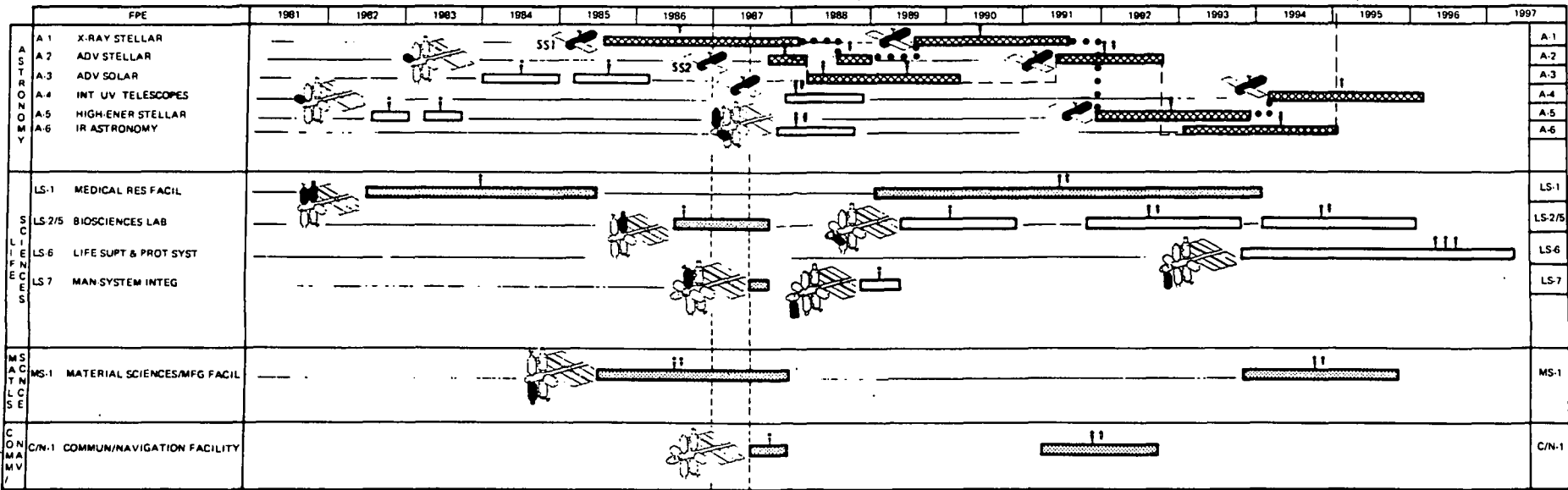


Figure 1-6. Growth MSS Buildup Sequence



☿ = 1 EQUIVALENT MAN PER DAY



..... SEQUENCE OF USAGE, SUPPORT SECTION 1  
 ——— SEQUENCE OF USAGE, SUPPORT SECTION 2

Figure 1-7. Mission Sequence Plan - Experiment Schedule, Accommodation Mode (Host Spacecraft) and Crew Requirements

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The mission sequence plan and the associated experiment scheduling is intended to be representative of the operations of the modular space station. It is not intended to represent the experiment program which must be scheduled since the space station has the inherent capability and flexibility to accommodate alternate programs: e. g., one which emphasizes socio-economic benefits or one which emphasizes advancements in scientific knowledge. The mission sequence plan is intended to emphasize certain fundamental characteristics. For example, by defining an initial level of experiment activity (Level II), the majority of the functional program elements (FPE)\* can be accommodated early in the space station program while deferring some of the experiment equipment development costs until after the space station development peak annual funding. The Blue Book level of activity (Level III) is then deferred until the growth space station which provides a "facility capability" for accommodating the FPE's, as defined by the Blue Book. In this respect, the mission sequence plan illustrates the capability of the selected design concept to accommodate the Blue Book in a balanced program wherein all disciplines are represented throughout the program. The mission sequence plan is summarized by FPE in Figure 1-7, and further information is given in Section 6.

### Crew Requirements

The basic crew requirements are divided into those requirements associated with station operations, experiment support operations, and experiment operations. The crew requirements for station operations and experiment support operations for the initial space station are on the order of 25 man-hours per day. These operations include the routine daily operations of the space station, routine and periodic maintenance, house-keeping, monitor and control of detached RAM's, etc. The experiment operations are those operations associated with the daily conduct of the space station experiments. Based on 25 man-hours per day for station operations and experiment support operations and a 10 hour work day, approximately 35 man-hours per day are available for experiment operations for the initial space station. The corresponding crew time distribution for the growth space station is approximately 30 man-hours per day required for station operations and experiment support operations leaving 90 man-hours per day for experiment operations.

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\* A functional program element (FPE) consists of a group of research and applications investigations ("experiment") related by common objectives and/or by common requirements.

## Logistics Requirements

Approximately 1900 pounds of cargo per month are required for basic operations of the initial space station whereas 3600 pounds per month are required for the growth space station. Based on the experiment scheduling in the mission sequence plan, approximately 1000 pounds of cargo per month are required for operations of the initial space station experiments and 1800 pounds per month for the growth space station experiments.

## Shuttle Support Operational Requirements

The resultant shuttle requirements for support of the space station are summarized in Figure 1-8 in terms of the missions required for the delivery of station modules, crew and/or cargo, RAM's, and RAM support sections. Six shuttle missions are required for delivery of the initial space station modules and an additional four shuttle missions are required for buildup to the growth space station, including one launch for replacement of the solar array. A total of 74 shuttle missions are required for the delivery of crew and cargo. The shuttle launch frequency for delivery of crew and cargo is dictated primarily by considerations of crew rotation since these missions occur at a frequency that permits the concurrent delivery of the cargo necessary for the support of the station and experiment operations. The logistics capability for crew and cargo delivery is based on a cargo module capacity of approximately 11,880 pounds per flight for shuttle missions which concurrently deliver up to six crewmen. As previously noted, the cargo requirements are approximately 2900 pounds per month for the initial space station and 5400 pounds for the growth space station.

In addition to the shuttle missions required for the delivery of the station modules and for crew and cargo delivery, additional shuttle missions are required for the delivery and return of RAM's and the support sections necessary for the operation of detached RAM's. For the experiment program (mission sequence plan) previously identified, only two support sections are required to support detached RAM operations. A third support section is provided for backup. RAM's and support sections are periodically returned to earth for refurbishment and redelivered to orbit for further utilization.

The resultant total shuttle support requirement is 134 flights: 35 flights for the initial space station, and 99 flights for the growth space station including the four shuttle launches for delivery of the station modules necessary for buildup to the growth space station. The resultant launch frequency is approximately one every eight weeks for the initial space station and one every six weeks for the growth space station.

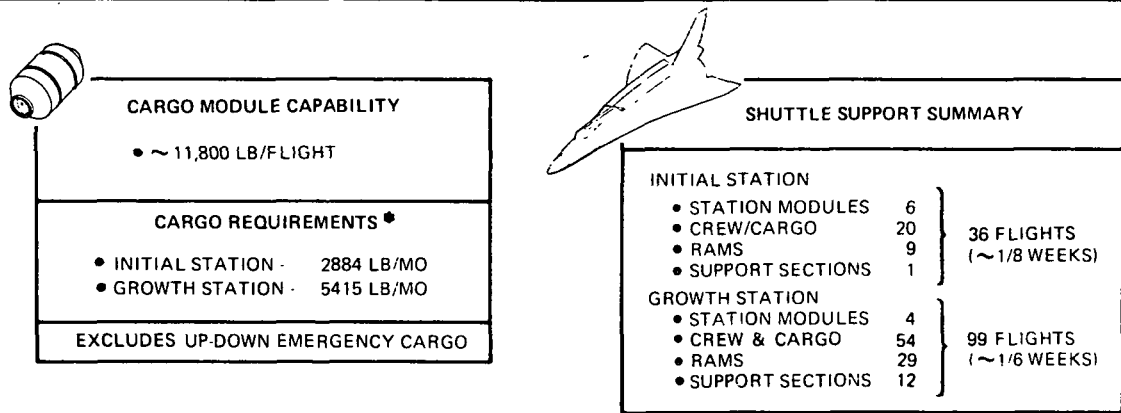
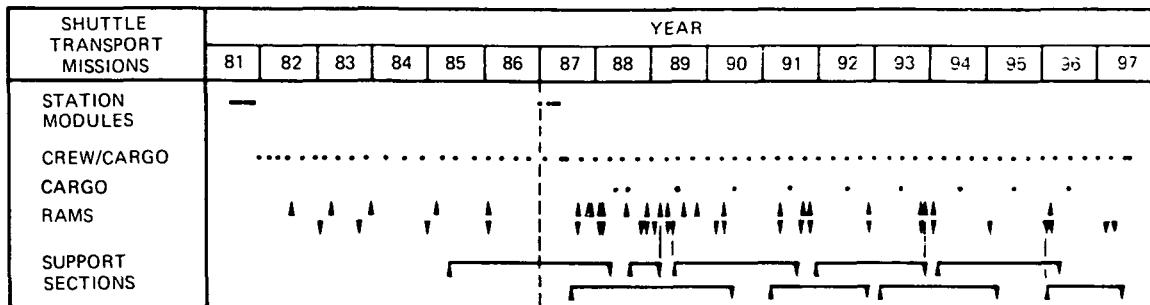


Figure 1-8. Shuttle Support Requirements

Modular Space Station Disposition

Station disposition will be accomplished by the sequenced return of each module to earth. Experiment modules will be returned first, followed by disassembly of the growth space station in the reverse sequence used for buildup. The major exception to this sequence is that a cargo module (for gaseous propellants) will remain attached to the core module until all station modules and the power module are returned. Thus, the final return sequence will be: station modules, power module, cargo module, and core module.

Mission Support

Mission support operations are conducted throughout the space station program. During early and unmanned program phases, actual operational control is provided by the mission operations support system. During most manned phases, mission support activities consist of long-range planning and executive management of program operations. Mission support operations include mission management, ground tracking, communication, and crew training and conditioning.



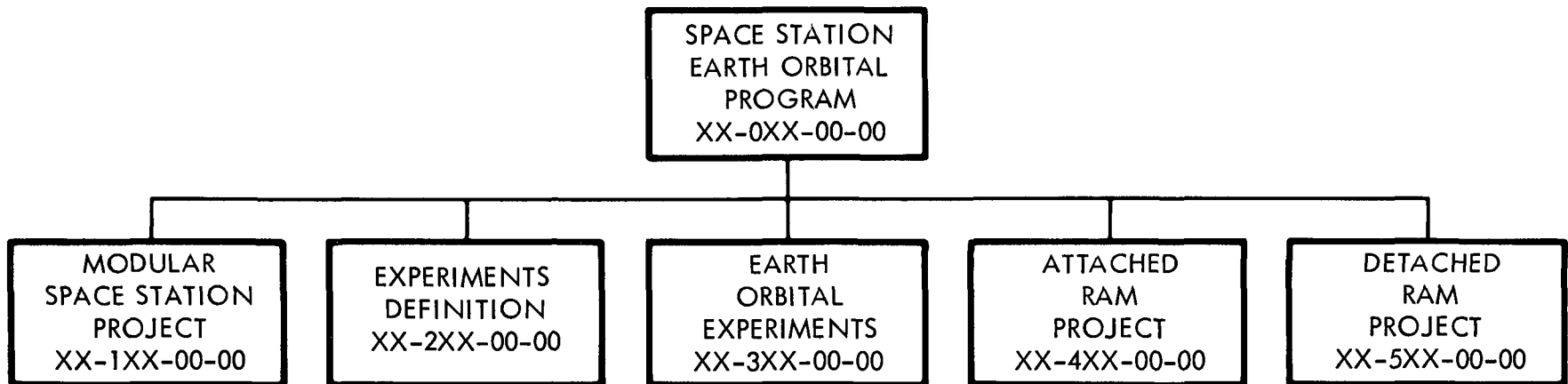
### 1.3 COST AND FUNDING SUMMARY

The summary of the Space Station Earth Orbital Program costs is given in Figure 1-9 by project and procurement phase. These costs are consistent with the ground rules in Section 2, and amount to about \$5,550 million in 1972 dollar value.

Because of manpower and other constraints, the 16-year time span to complete one cycle of Blue Book experiments exceeds the period covered by the MSC guideline. This guideline specifies that "cost spreads are to be indicated through a period of 5 years after the growth space station is achieved." In interpreting this guideline, all work-in-process costs were excluded from those experiments, and their carrier (hosts) RAM's, that are not operational by July 1, 1992. For all experiments which are to be operational by then, operational costs after that date have been cut off. The exclusions are shown by dashed diagonal lines intersecting the bars in the schedule shown in Figure 1-10. The lower intersection of each bar represents the initial cutback in effort associated with experiments not operational by 1992; the upper intersection represents the last activity costed. In the case of experiments definition, all activity ceases well before 1992 because it is completed one year after the initiation of all experiments that are operational by 1992. In the case of all other projects, the last activities costed are the operation cost of experiments in progress in 1992, these costs are terminated at that time. A more detailed example of exclusions is shown by broken lines on the MSS Detail Master Schedule (Sheet 2) in Section 2; all items to the right of the broken lines are excluded. The exclusions, associated with at least one full cycle of Blue Book experiments, amount to \$985.2 million in 1972 dollar value and are broken down as follows:

DDT&E	\$373.0 million
Production	40.9 million
Operations	571.3 million

The program annual funding by procurement phase and the cumulative funding are shown in Figure 1-11. The peak annual funding is anticipated in GFY 1979 in the amount of approximately \$727 million. The cumulative funding is about 64 percent expended at the 50 percent point of the time period shown.



COST SUMMARY (\$ MILLION, 1972 VALUE):

PROJECT	NON-RECURRING	RECURRING		TOTAL
	DDT&E	PRODUCTION	OPERATIONS	
MODULAR SPACE STATION	\$1,593.9	\$418.0	\$361.2	\$2,373.1
EXPERIMENT DEFINITION	114.6			114.6
EARTH ORBITAL EXPERIMENTS	1,863.5	176.3	561.9	2,601.7
ATTACHED RAM	158.4	49.9	0.4	208.7
DETACHED RAM	123.3	64.7	60.9	248.9
<b>TOTAL, SSEO PROGRAM</b>	<b>\$3,853.7</b>	<b>\$708.9</b>	<b>\$984.4</b>	<b>\$5,547.0</b>

Figure 1-9. Summary of Program and Project Costs By Program Phase

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Space Division  
North American Rockwell

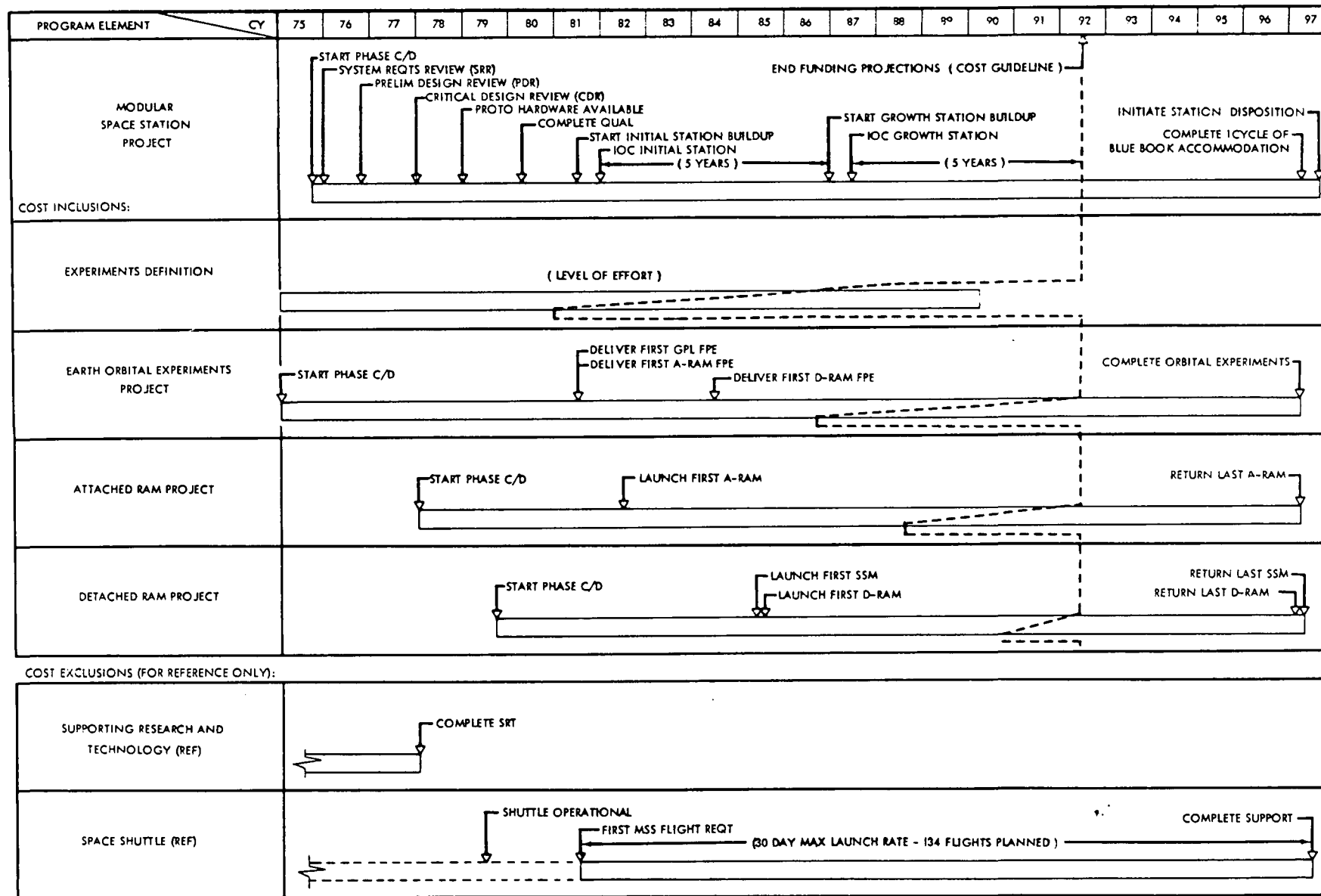


Figure 1-10. Program Summary Phasing Schedule

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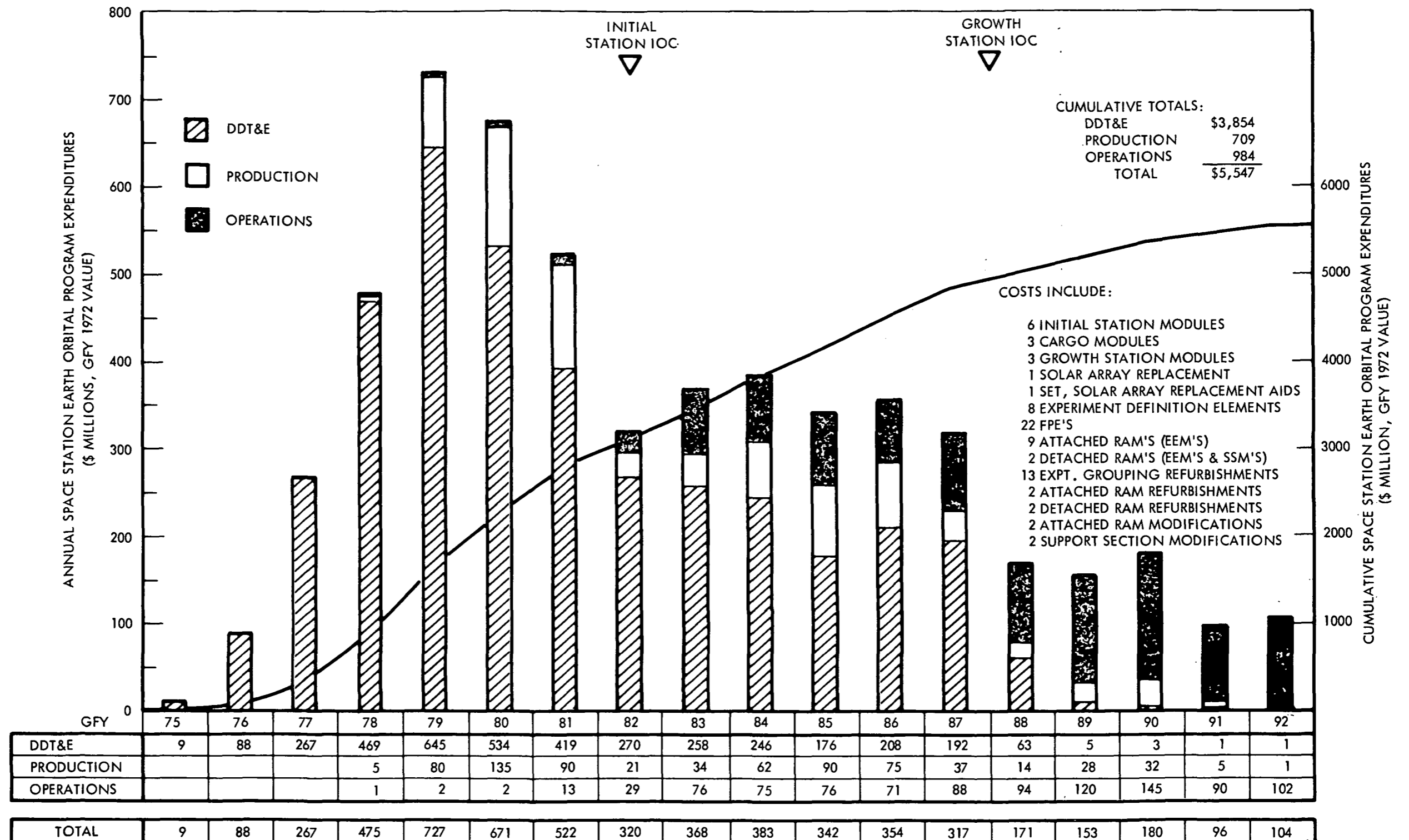


Figure 1-11. Space Station Earth Orbital Program Funding Summary, By Procurement Phase



Figure 1-12 provides the Space Station Earth Orbital Program annual funding by project (WBS Level 3) and again the cumulative funding as commented on for Figure 1-11.

The Modular Space Station (MSS) Project (WBS Level 3) annual funding by procurement phase and the cumulative funding are shown in Figure 1-13. Peak annual funding of \$580 million is anticipated in GFY 1979 with approximately 77 percent of all funds expended at mid-point of the total time spread. Manpower loading of the MSS project is closely related to this funding schedule and is presented in DRL 76, Modular Space Station Program Master Plan, SD 71-225.

The Experiments Definition Project and Earth Orbital Experiments Project (WBS Level 3) costs have been combined for charting purposes and Figure 1-14 shows annual funding by procurement phase and cumulative funding for all phases combined. Peak annual funding of \$267 million is anticipated in GFY 1983 with approximately 52 percent of all funds expended at the mid-point of the total time spread. Figure 1-15 provides annual funding by host (carrier) spacecraft which is either an MSS general purpose laboratory (GPL), an attached research and application module (RAM), or a detached RAM.

The attached RAM project and detached RAM project (WBS Level 3) costs have been combined and Figure 1-16 shows annual funding by procurement phase and cumulative funding for all phases. Peak annual funding of \$67 million is anticipated in GFY 1981 with approximately 39 percent of all funds expended at mid-point of the total time spread. Figure 1-17 shows the annual funding by host (carrier) spacecraft which is either an attached or detached RAM.

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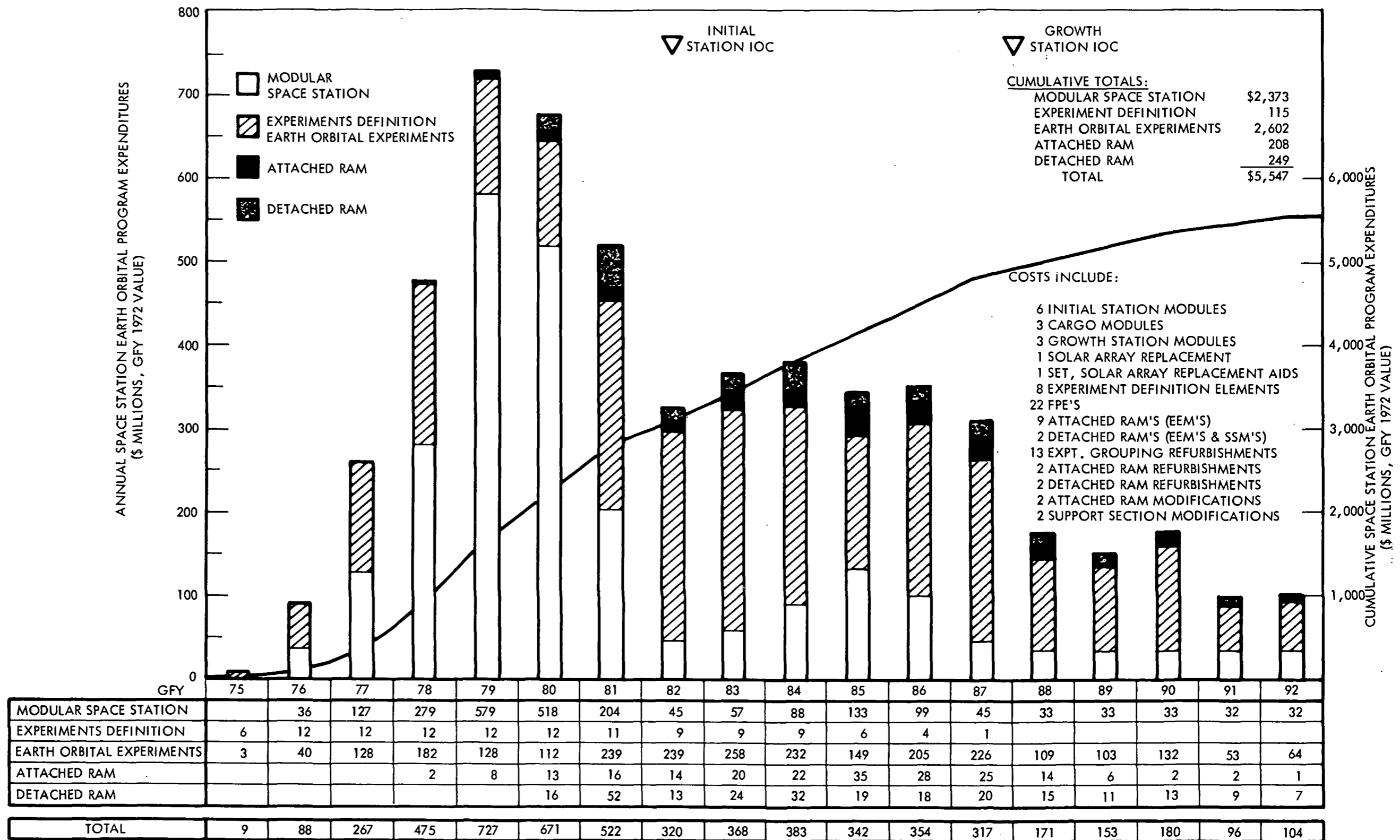


Figure 1-12. Space Station Earth Orbital Program Funding Summary, By Project

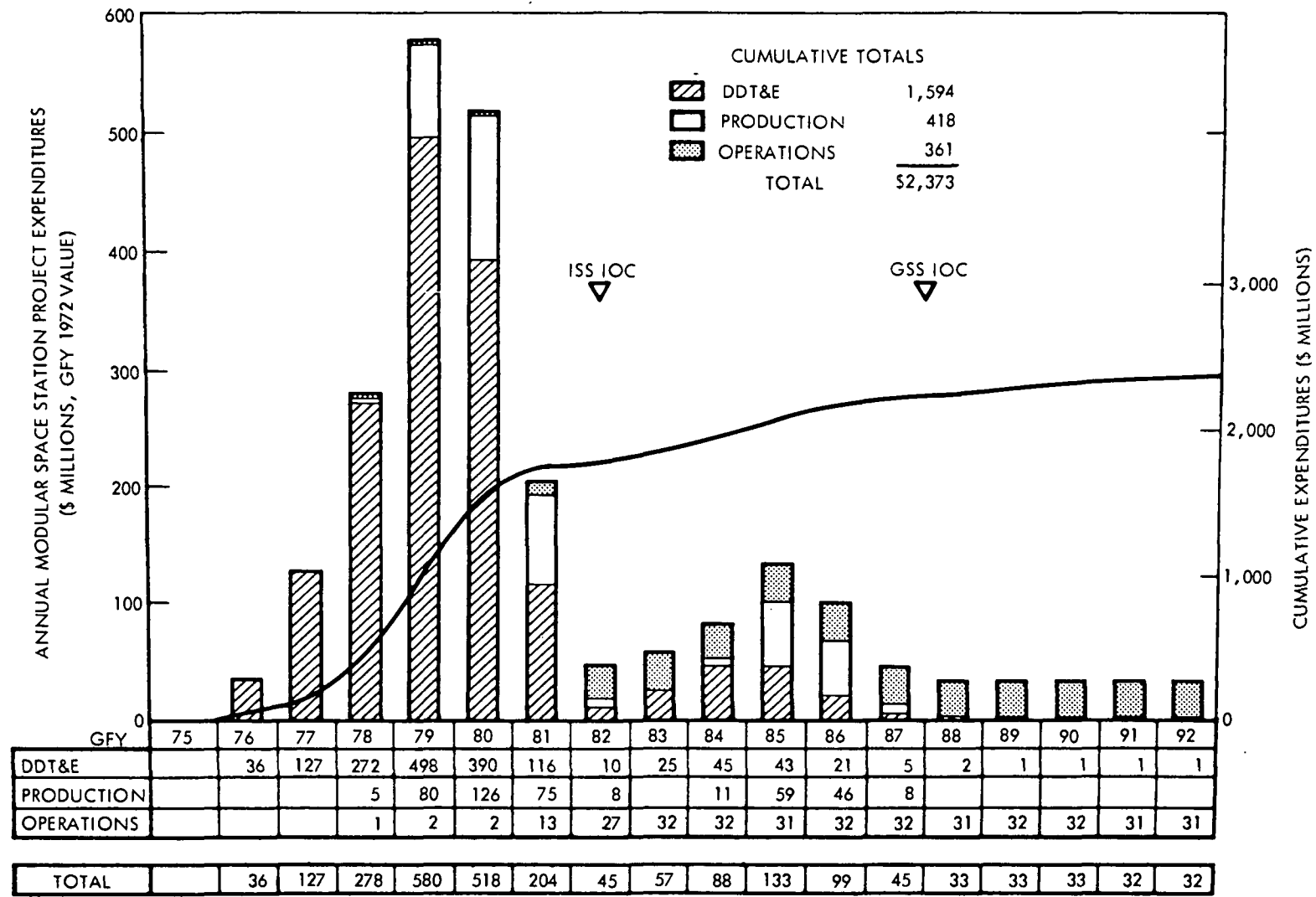


Figure 1-13. Modular Space Station Project Funding Summary, By Procurement Phase

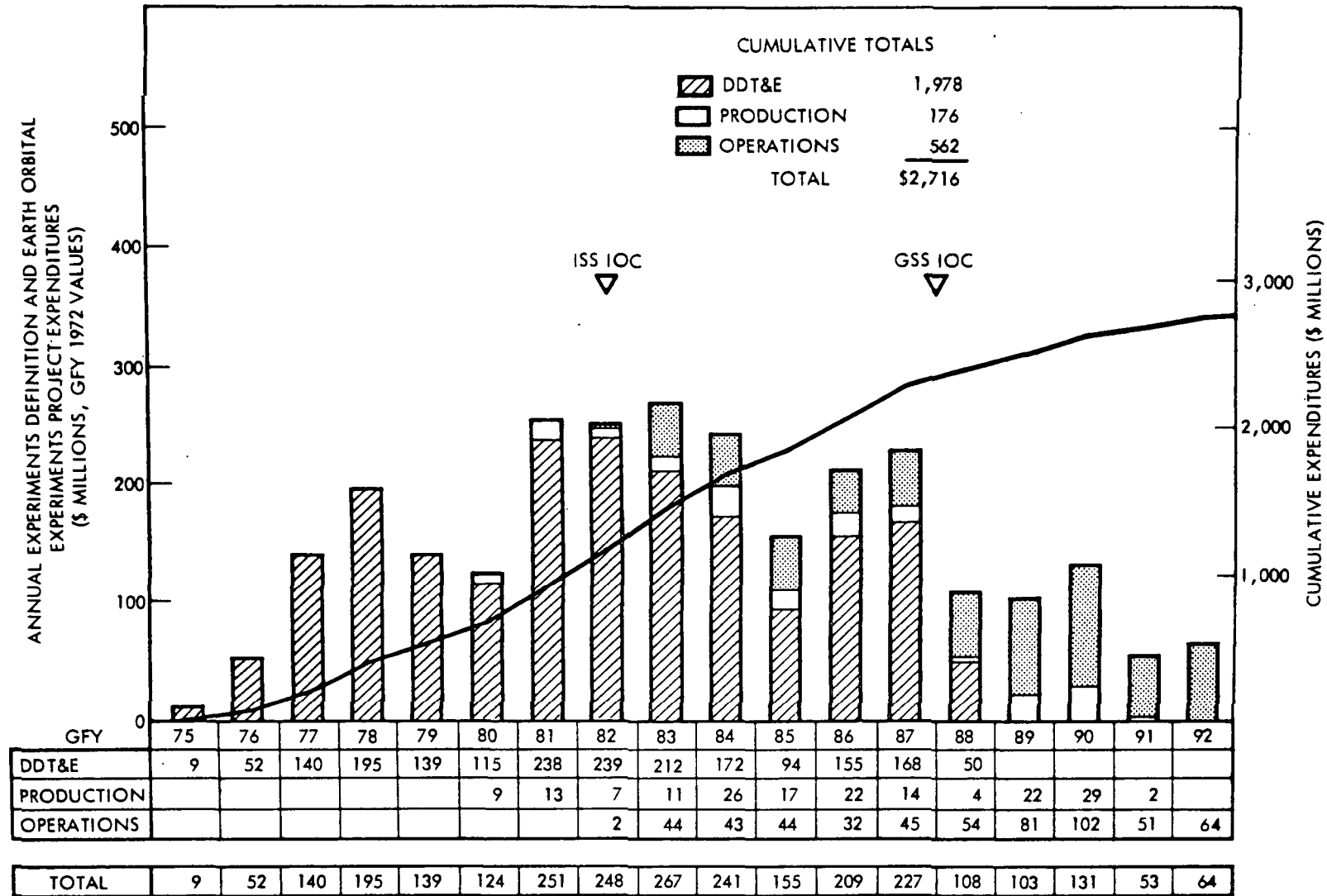


Figure 1-14. Experiments Definition and Earth Orbital Experiments Project Funding Summary, By Procurement Phase

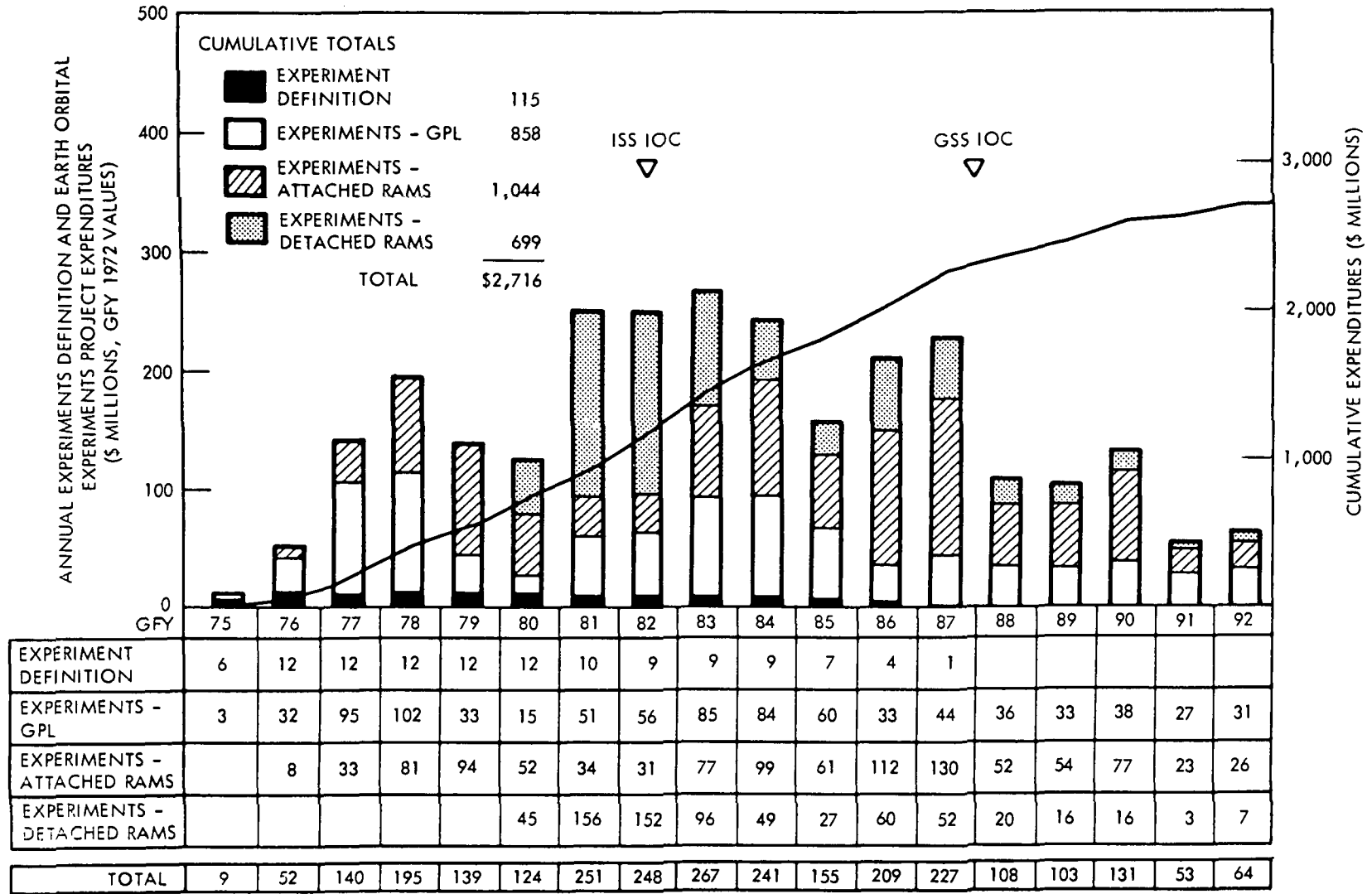


Figure 1-15. Experiments Definition and Earth Orbital Experiments Project Funding Summary, By Host (Carrier) Spacecraft

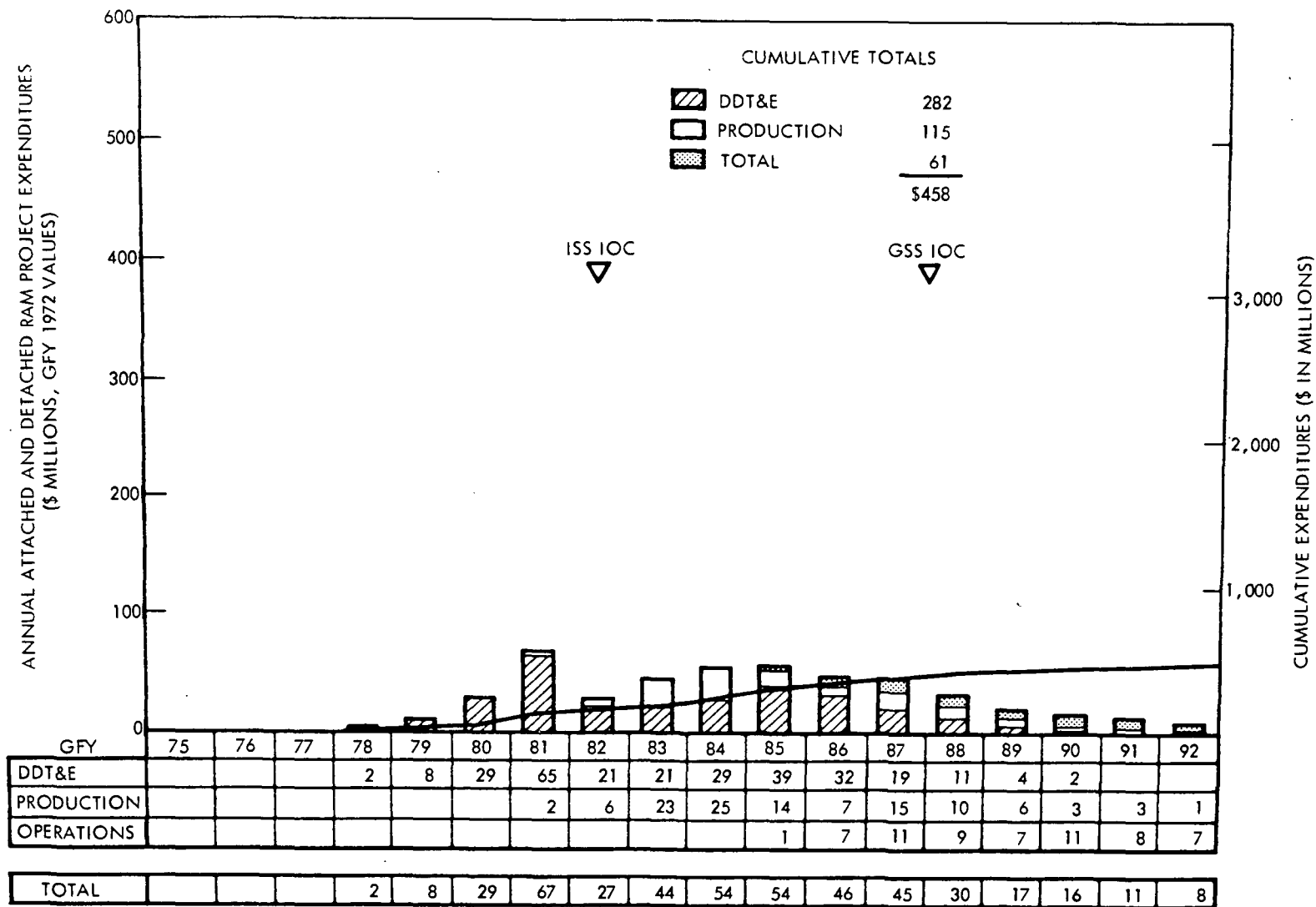


Figure 1-16. Attached and Detached RAM Project Funding Summary, By Procurement Phase

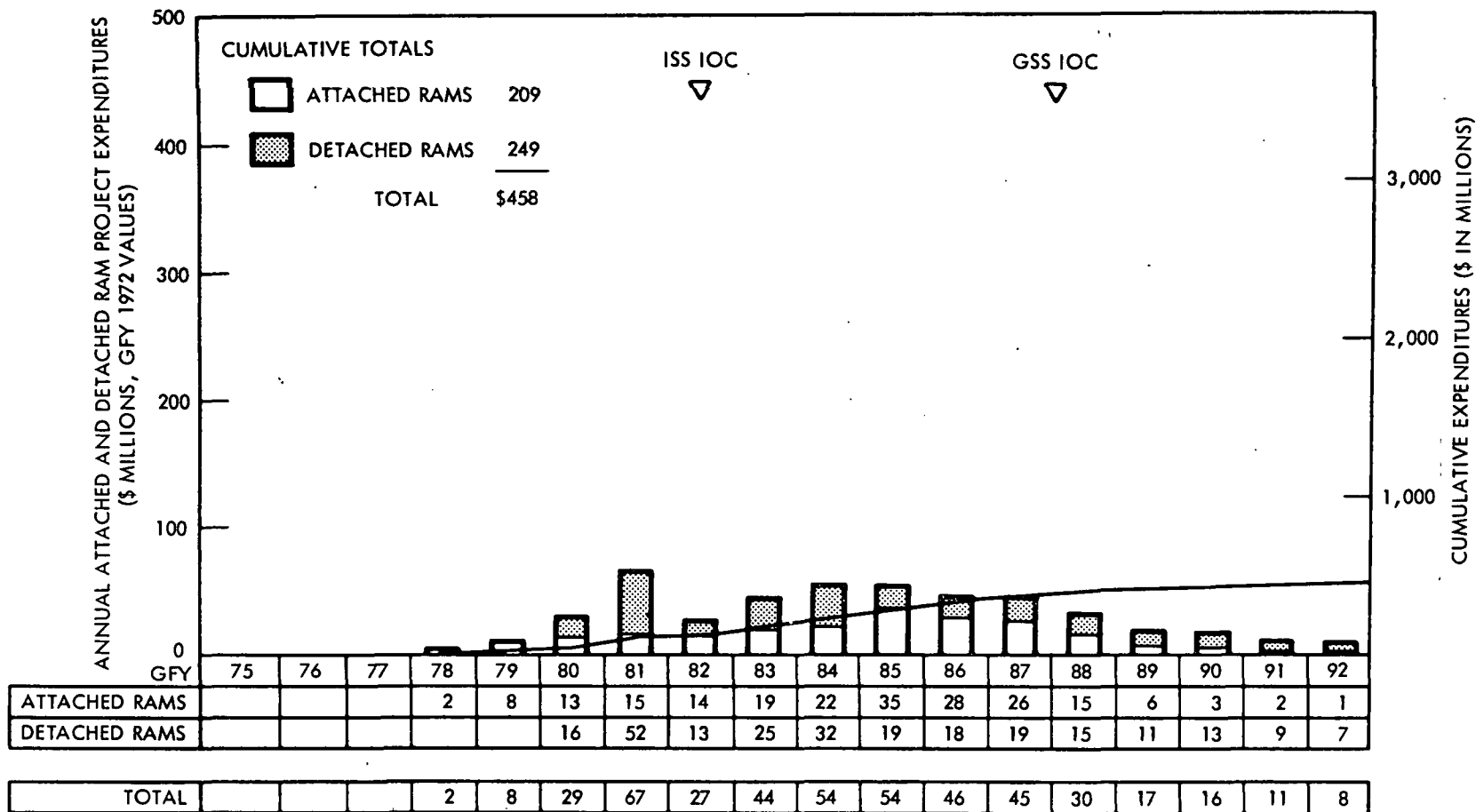


Figure 1-17. Attached and Detached RAM Project Funding Summary, By Host (Carrier) Spacecraft

## 2. COST GROUND RULES AND PROGRAM MASTER SCHEDULE

### 2.1 INTRODUCTION

The cost estimates in this report are based on an orderly, deliberately phased procurement resulting in an economical evolution of effort to realize program goals. The program covers a period from Phase C start in CFY 1976 (October 1975) through 5 years (July 1, 1992) of operation after the growth space station has been achieved. Costs of on-going experiment operations are truncated on July 1, 1992, and all in-process costs for experiments and RAM's which are not operational by that time are omitted. To provide a favorable funding profile, development and production of growth station modules, RAM's, and experiment equipment are delayed in the schedule until required by the mission sequence plan.

The cost ground rules and identification of items in the Work Break-down Structure are enumerated. In addition, along with key milestones a program master schedule consistent with the above funding philosophy is described.

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## 2.2 COST GROUND RULES AND ASSUMPTIONS

The major criteria and assumptions relative to cost, WBS reporting levels, and funding are listed as follows:

1. Cost and funding projections are defined in U.S. dollars at a CFY 1972 value.
2. Costs are for budgetary and planning purposes only and do not reflect a firm commitment on the part of North American Rockwell.
3. All elements of costs through the prime contractor general and administrative (G&A) level are included. No prime contractor fee is included.
4. Costs are based upon NASA experiment cost estimating reports, North American Rockwell, Space Division (NR-SD) historical cost estimating relationships, budgetary and planning quotes by subcontractors, subcontractor studies and catalogue prices.
5. Phase C/D go-ahead is assumed to be October 1, 1975. The space shuttle is assumed to precede the space station. Advancements in the state-of-the-art through 1975, accruing from shuttle developments and supporting technology development such as the space station prototype (SSP) of the environmental control life support subsystem (ECLSS), are applied in estimating subsystem costs.
6. As shown in the detail master program schedule, initial station launch is assumed to occur on July 1, 1981. Buildup to initial operational capability (IOC), as described in Section 1, is achieved on January 1, 1982. This schedule, the timing of the experiment launches, and the consequent funding assume a fully reusable shuttle booster that is capable of a new launch every 30 days.
7. Due to the costs guidelines (Reference 1) that spares costs be identified as operations costs, the schedule summary in Figure 2-1 shows operations beginning January 1, 1978. Operations include experiment operation on the initial space station, growth space station buildup which is completed July 1, 1987, plus 5 years of experiment operation on the growth station.

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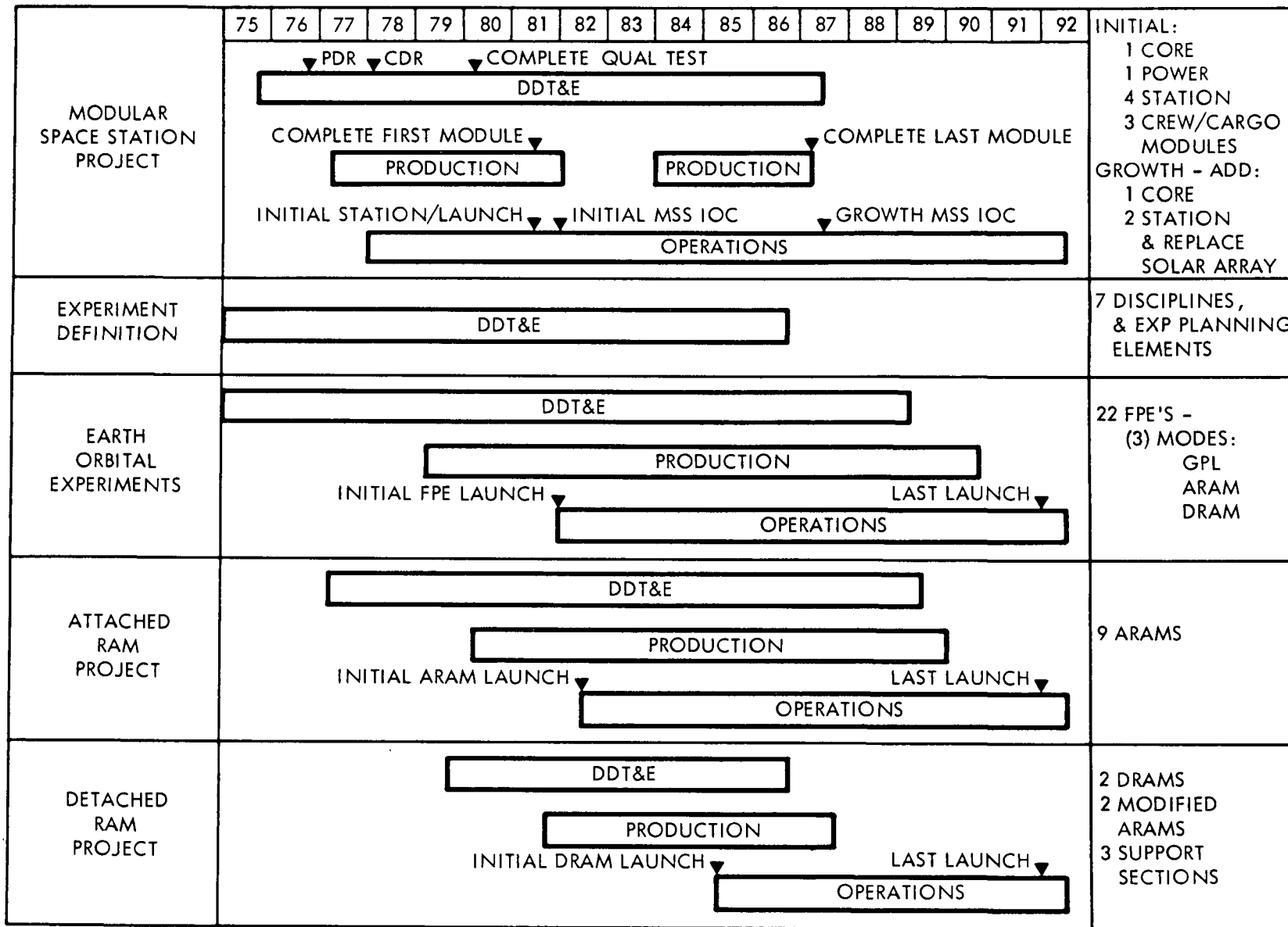


Figure 2-1. Schedule Summary - Earth Orbital Space Station Program

8. Operation for 5 years (through July 1, 1992) after achievement of growth IOC, growth station is an arbitrary cutoff point (Reference 1). Even though the capability is present, not all of the NASA 1971 "Blue Book" (Reference 2) experiments are performed by 1992, due to station manpower limitations. For purposes of cost and funding estimates in the present report, all costs to work-in-process (DDT&E, production and operations) associated with experiments and their carrier (host) RAM's are excluded for those experiments which are not operational by July 1, 1992. For those which are operational by then, all costs incurred through July 1, 1992 are included.
9. The Space Station Earth Orbital Program has been defined in terms of five program elements. These are:
  - a. Modular Space Station Project
  - b. Experiments Definition Project
  - c. Earth Orbital Experiments Project
  - d. Attached RAM Project
  - e. Detached RAM Project

The Work Breakdown Structure applicable to these projects, developed jointly by NR-SD and NASA-MSD on the present contract, is shown in Figure 2-2. The costs reported herein are the "contractor only WBS" items, including those at Levels 2 and 3 already cited, plus further breakdowns. In the MSS project, the cost breakdown includes Level 4 (systems) flight hardware and Level 5 subsystems, plus Level 4 nonflight hardware and programmatic functions and services. The experiments definition project costs are defined to Level 4 scientific disciplines. Earth orbital experiments costs are reported down to Level 4 aggregates of experiments by host (carrier) spacecraft. Each RAM project cost is shown to an aggregate of RAM modules, each of which would be a Level 4 item. The WBS index in Appendix A defines all the cost elements reported herein. Figure 2-2 is an abbreviated version (less definition of MSS subsystems) of the WBS identification number of the WBS index. In the present report, costs are identified only for those items for which a WBS ID number applies; these costs are reported in Section 7 on Cost Estimate Data Form A.

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NAS 9-9953  
MODULAR SPACE STATION  
WORK BREAKDOWN STRUCTURE

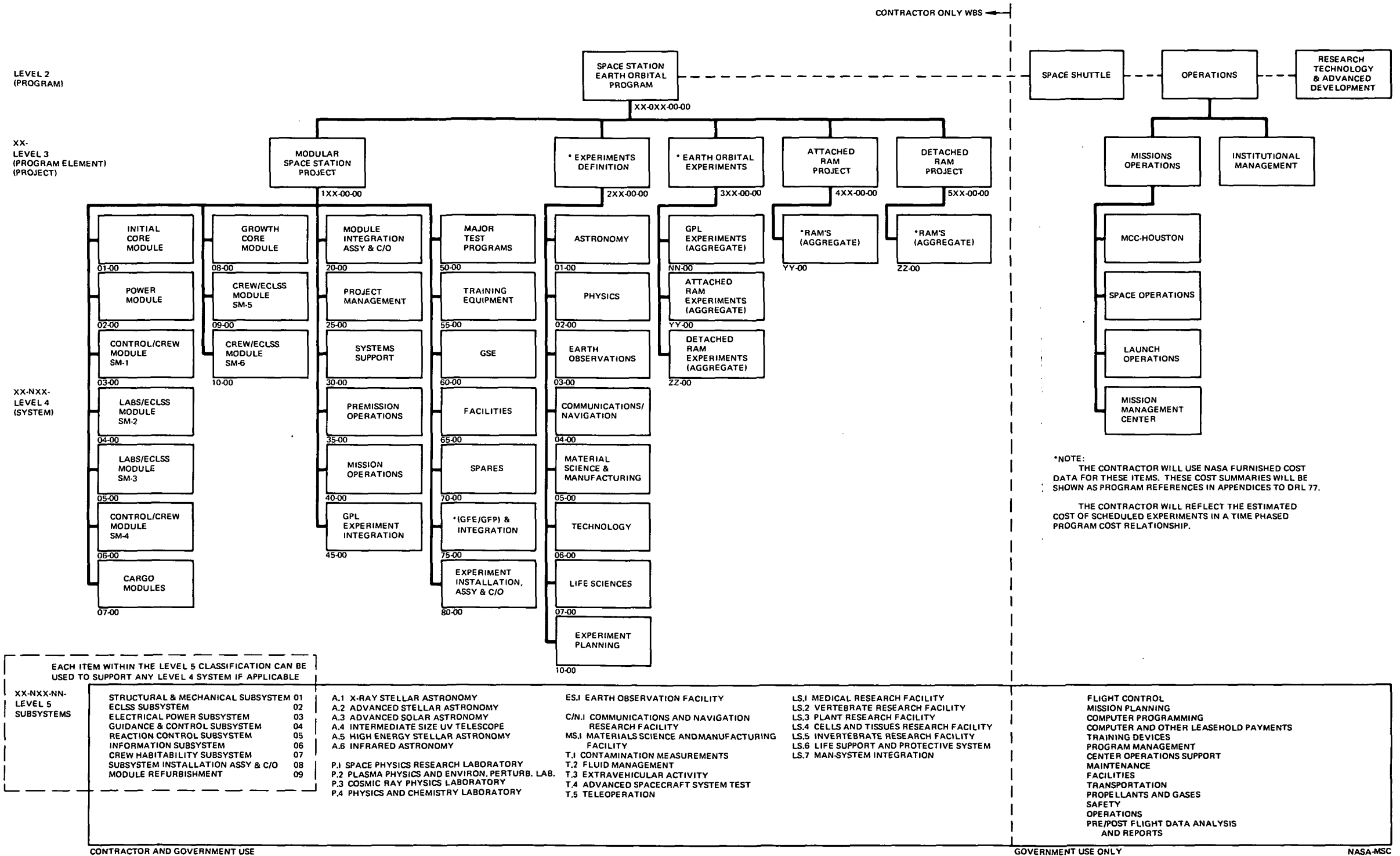


Figure 2-2. Program Summary Work Breakdown Structure and Identification Numbers of Reported Items



10. The subdivision of work cost items included in the various procurement phases is as follows:
  - a. Nonrecurring costs include design and development, initial tooling and special test equipment, project management, systems support, premission operations, experiment integration into the host (carrier) spacecraft, major test programs (major test hardware plus test operations), ground support equipment, and facilities. Because of the difficulty in defining the respective manpower assignments for premission and mission operations in the DDT&E, production and operation phases, the premission operations costs were arbitrarily ground-ruled to be wholly in the nonrecurring phase, with none in the production and operation phases. MSS items not shown in the work breakdown structure (WBS) at Level 4, such as tooling and special test equipment, are included within the Level 5 items under the modules. All experiments definition costs are assumed to be nonrecurring.
  - b. Recurring production costs include subsystem flight hardware; subsystem installation, assembly, and checkout; acceptance tests; sustaining tooling and special test equipment; module integrated assembly and checkout; systems support, project management, experiments installation in the host spacecraft, assembly, and checkout. As in the non-recurring case, items not shown at Level 4 in the WBS are included within the Level 5 items under the modules.
  - c. Operation costs include cargo module refurbishment, project management, systems support, mission operations, spares, experiment operations including principal investigator efforts, experiment refurbishment, and RAM refurbishment. Mission operations were ground ruled to be entirely in the operations phase for reasons outlined in step 9a.
11. Level 5 WBS items entitled Training Equipment and Government-furnished equipment/Government-furnished property (GFE/GFP) and Integration have been provided for planning purposes, but no costs are identified. Omission of training equipment costs arises from the present plan which does not intend any contractor-furnished flight hardware for training purposes. No Government-provided equipment was identified at the time the cost estimates in this DRL were prepared. Hence the costs of GFE/GFP equipment and the integration of such items into the space station project are excluded.



12. The final costs and schedules are based upon the selected configuration described in control drawing V030-942001, dated November 1971.
13. The costs of the space station project include the following sets of hardware:
  - a. Initial space station modules
    - 1 Core module
    - 1 Power module and solar array
    - 2 Control/crew station modules (SM-1 and SM-4)
    - 2 Labs/ECLSS station modules (SM-2 and SM-3)
    - 3 Cargo modules
  - b. Replacement hardware\*
    - 1 Solar array
    - 1 Set, solar array replacement aids
  - c. Growth station modules
    - 1 Growth core module
    - 2 Crew/ECLSS station modules (SM-5 and SM-6)

The major test hardware is defined in terms of mass simulation, prototype, and flight types of hardware in Section 5. A key feature of the test plan, described in SD 71-222, Modular Space Station Integrated Ground Operations, is that no new major test hardware or integrated testing is required for modules of the growth station. This design approach has a significant cost savings impact on major test programs (WBS No. xx-1xx-50-00).

For purposes of allocating nonrecurring costs, a plan for sequential development of each of the subsystems by module has been formulated, the sequence for each subsystem being generally unique. The bulk of design and development costs is assigned to

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\*Costed in initial station WBS because it does not constitute a full module, although used on the growth station. See Cost Estimate Data Form A in Section 7.

the first module in which the subsystem appears, with learning applied to subsequent modules. These applicable sequences are given in Section 5.

14. The production sequence assumes serial uninterrupted production of all subsystems for the initial station, including three cargo modules required for station support. For growth station items, it is assumed that the line will be shut down and reopened at a point consistent with the lead time necessary to meet launch dates for the growth station. This interruption allows some of the MSS funding to be postponed and allows the incorporation of lessons learned in initial station operation into the growth station.
15. Weight of subsystems is an important parameter for estimating costs. The weights used in the present report are preliminary design weights as of October 1, 1971. More detailed weights are presented in SD 71-219, MSS Mass Properties.
16. Two types of cost avoidance are treated in this report. The first type results from engineering design ingenuity with special attention to situations in which high-cost items can be eliminated entirely or replaced by lower-cost items. The second type consists of programmatic cost avoidance, using Apollo experience as a base, due to advances in programmatic techniques and procurement policies. The first type cost avoidance is displayed in the Section 5 discussion of trade studies. The second type is discussed under programmatic changes in Section 5.
17. Module refurbishment on the MSS is planned on cargo modules only.
18. Ground support equipment, tooling, and special test equipment estimates assume no existing inventory. The estimates for ground support equipment do assume, however, that a universal test equipment (UTE) complex will be available by space station Phase C/D go-ahead and the on-board checkout (OBCO) will be more extensively used than on past programs.
19. Facility costs recognize the usage of existing facilities and modifications thereto, plus new facilities as applicable. The reported figures include only facility contracts by NASA to prime and subcontractors. Facilities financed by the contractors themselves are excluded, as are NASA-operated facilities.



20. No modifications to the ground network and synchronous satellite communications systems available to users in general at MSS Phase C go-ahead or development of new facilities, are anticipated, either for the basic system or ground support facilities. No increases in operational costs are anticipated as a result of the Space Station Earth Orbital (SSEO) Program. Hence no costs relative to the basic ground network and synchronous satellite communications systems are included.
  
21. Multi-FPE experiment equipment carried in the general purpose laboratory (GPL) of the MSS is included in the GPL furnishing assembly of the structural and mechanical subsystem. All other experiment equipment costs are grouped into categories which correspond to the initial host (carrier) spacecraft in which the grouping is used. Experiment equipment which is added to the original grouping to achieve a higher capability level is costed against a grouping corresponding to the carrier spacecraft in which the additional equipment is first used. Installation, assembly, and checkout of experiment equipment into a spacecraft is costed against the carrier spacecraft. Experiment equipment refurbishment costs are charged against the grouping corresponding to the carrier spacecraft in which the experiment will be used after refurbishment. These ground rules are especially significant in cases in which experiment usage begins in the MSS and ends in a RAM, or goes from one type of RAM to another, since the incremental costs associated with the experiments are then allocated to a different WBS item than the initial experiment costs.
  
22. Costs excluded from the present report which have not been mentioned previously are:
  - a. Space shuttle hardware (including the docking adapter shown in Figure 1-1) and operations costs
  - b. NASA operations and institutional management costs
  - c. Shuttle sortie module costs, if any
  - d. Supporting research, technology, and advanced development
  - e. Consumables—including cryogenics, foods, clothing, personal gear, medical and dental supplies, and EVA equipment
  - f. Allowances for growth in the preliminary design weight



23. With the exception of the earth orbital experiment costs, furnished by NASA (Reference 3), all cost data were developed by NR. Specific items of common experiment equipment which were made part of the GPL were subtracted from the experiment costs of Reference 4 and included as MSS project costs, after eliminating redundancies.
24. The sequence and timing of the experiments are based on the Mission Sequence Plan summarized in Section 1 and presented in detail in SD 71-223, with availability for installation into host (carrier) spacecraft as outlined in Subsection 2.3.
25. The production sequence and funding period assumed for the RAM's is largely dependent on the launch dates specified by the Mission Sequence Plan. The subsystem installation, assembly, and check-out is scheduled for completion by launch date, with completion of production of subsystems, except for primary structure, 6 months before launch. Primary structures of RAM's are produced serially with starts at 2-month intervals beginning January 1, 1981, thereby completing all RAM's primary structures by 9 months (6/95) prior to the last launch (3/96) of at least one cycle of each of the Blue Book experiments.

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## 2.3 PROGRAM MASTER SCHEDULE AND KEY MILESTONES

A summary of all program elements supporting the NASA Space Station Earth Orbital Program and the time-phased relationship and interaction among the elements has been presented in Figure 1-10. A detailed schedule covering all program elements is contained in Figure 2-3, sheets 1 and 2. The Modular Space Station Project schedule is presented on sheet 1, and the experiments and RAM projects are presented on sheet 2.

### 2.3.1 APPROACH

The approach to preparation of the Space Station Earth Orbital (SSEO) program master schedule includes the following:

1. Establishment of ground rules and assumptions for all project elements
2. Consideration of schedule data from the NASA Apollo, Skylab and space shuttle programs, NASA cost and schedule studies, and schedule data generated during the Solar-Powered Space Station Program Phase B definition study
3. Application of schedule data from the contractor's hardware programs
4. Extraction of applicable data from technical analyses conducted during the modular space station Phase B definition study
5. Preparation of a preliminary hardware tree reflecting the MSS design to ensure that all systems, subsystems, and components are considered for development analysis
6. Preparation of a program WBS identifying the hardware, software, services, and tasks that must be considered in preparing a master schedule
7. Determination of the number and purpose of prototypes, mockups, test articles, and flight hardware
8. Preparation of a list of key program milestones arranged in chronological order

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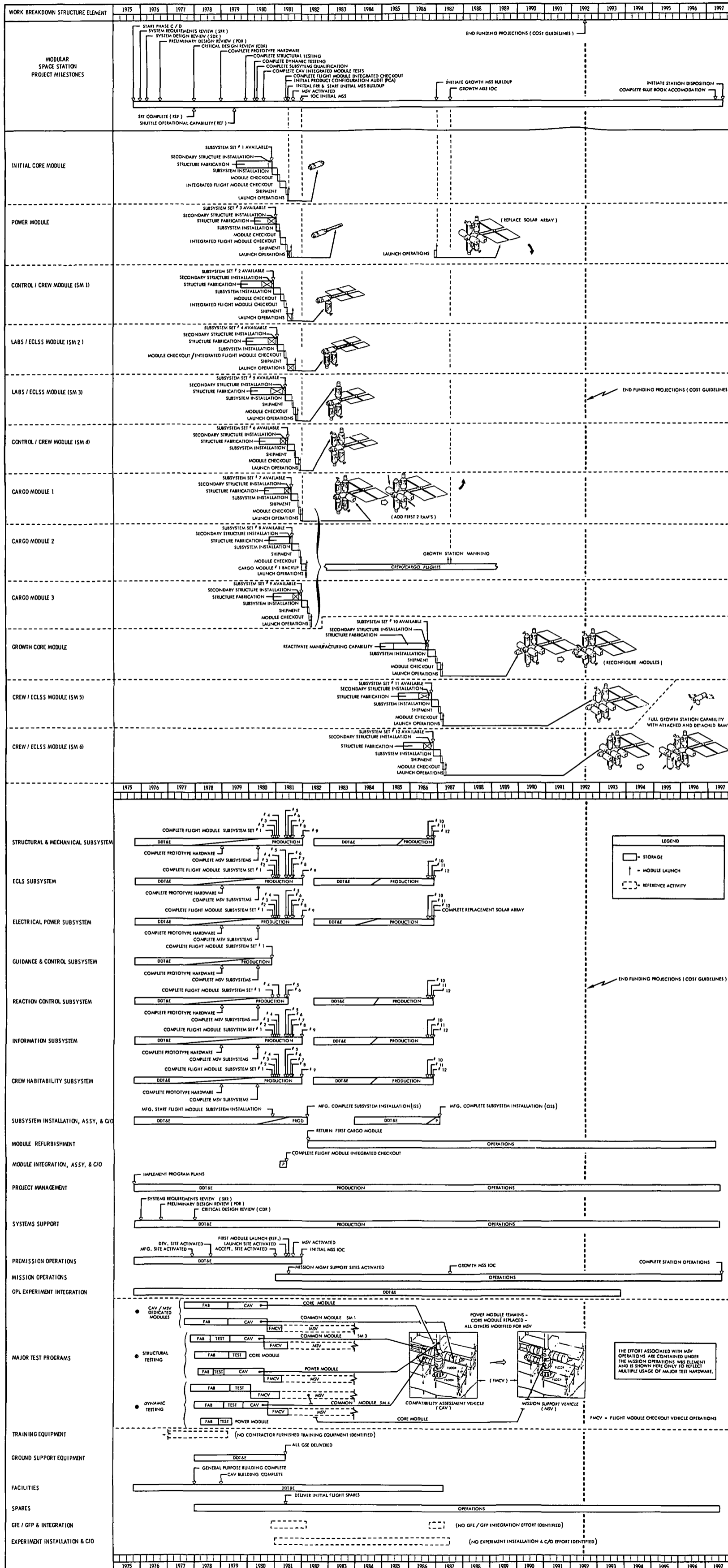


Figure 2-3. MSS Program Master Schedule (Sheet 1 of 2)

2-17, 2-18

SD 71-226-1

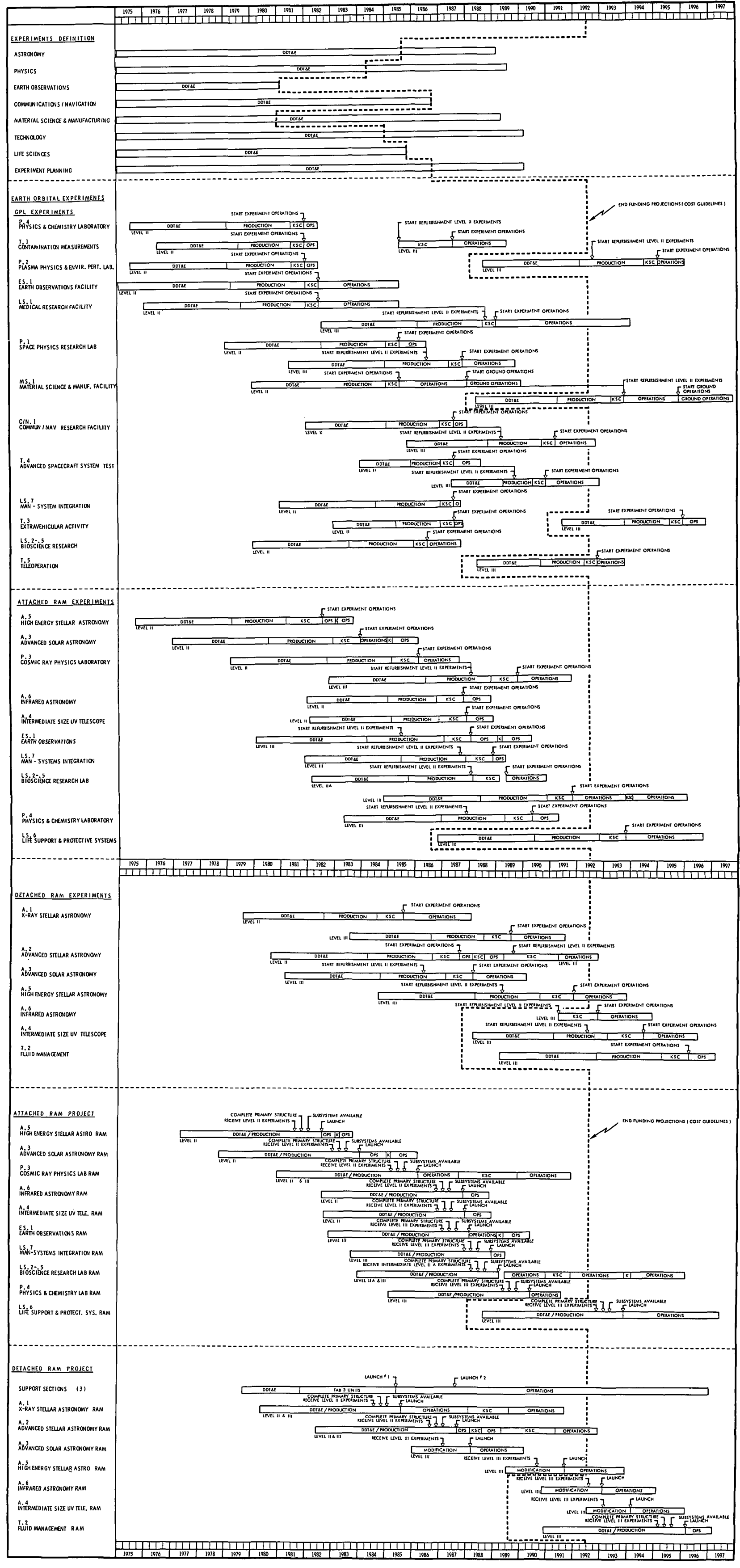


Figure 2-3. MSS Program Master Schedule (Sheet 2 of 2)

9. Analyses of the previous information and translation of the systems and subsystems requirements into development requirements
10. Construction of the master schedule through an iterative process that takes into account all of the preceding factors

### 2.3.2 GROUND RULES AND ASSUMPTIONS

The following ground rules and assumptions were established to provide a common baseline and frame of reference for preparation of the SSEO program master schedule:

1. An integrated schedule is required for all SSEO program effort from the initiation of Phase C through completion of mission requirements.
2. The MSS Phase B study has defined the MSS configuration and established requirements for its development.
3. Phase C and Phase D for the MSS project will be continuous and cover the span from October 1975 through completion of support for the experiment program.
4. All module launches will be made from the Kennedy Space Center via the space shuttle, at a frequency no greater than once every 30 days. Launches will support the mission sequence plan provided in SD 71-217, MSS Preliminary System Design, Volume II, Operations and Crew Analysis.
5. Air transportation will be utilized for shipment of modules from the manufacturing site to KSC.
6. Existing contractor and Government facilities will be utilized; requirements for modified or additional facilities and related equipment will be kept to the minimum.
7. The first four MSS modules will require concurrent, integrated checkout and acceptance prior to shipment and launch of the first module.
8. Capability for complete module acceptance testing will be provided at KSC at the earliest practicable time, by incremental buildup of the MSV from development hardware. KSC systems verification capability will be initiated prior to the arrival of the first flight module from the acceptance site.

9. One set of major assembly tools for special modules (core and power) and one set for "common" (station and cargo) modules will be available.
10. Manufacturing time spans will be based on a one-shift, 5-day work-week, with spot overtime as required.
11. Primary structure fabrication is to be continuous and uninterrupted for all initial MSS modules including the three cargo modules required for support of the initial station; growth module fabrication will be deferred until the in-work need date. Subsystem procurement and/or fabrication will be initiated only as required to support the launch requirements.
12. The program master schedule will define an orderly, economical evolution of events leading to the realization of overall program objectives. The phasing of the program will not be considered as fixed, except for the initiation of Phase C on the MSS project and meeting the operational capability dates.

In addition, the following ground rules and assumptions were generated to provide a frame of reference for preparation of schedule data for the experiments and RAM projects:

1. The experiments definition project will have been initiated by CY 1975 to support development and production lead times for early FPE's.
2. Each experiment definition discipline activity will complete one year after initiation of design of the last FPE in that category.
3. Development and production lead times for earth orbital experiments will be based on NASA MSC-provided data contained in the program development advanced studies report, ASR-PD-MP-71-1, Cost Data for Preliminary Edition of Reference Earth Orbital Research and Applications Investigations (Blue Book), January 15, 1971 Edition, dated April 1, 1971.
4. Experiments planned for delivery to the space station via cargo modules (i. e., GPL experiments) will be available 6 months prior to launch, and experiments planned for installation into attached and/or detached RAM's will be available at the RAM/experiment integration site one year prior to launch.



5. Experiment operation schedules will be based on the mission sequence plan provided in SD 71-217-2, MSS Preliminary System Design, Volume II, Operations and Crew Analysis.
6. Experiment accommodation modes and capability levels are defined and identified in SD 71-217-3, Modular Space Station Preliminary System Design Report, Volume III, Experiment Analysis. Level I (shuttle sortie missions) experiment capability will not be considered in preparation of the program master schedule.
7. RAM development and production lead times will be based on an analysis of experiment module data presented in SD 70-154, Solar-Powered Space Station Program Cost and Schedules.
8. Three support section modules will be developed and produced for the detached RAM project. Two will be used for operations support and one will be maintained as a spare.

### 2.3.3 SCHEDULE HIGHLIGHTS

Figure 2-3 shows an integrated set of activities that depict the evolution of the SSEO program through the phases of design, development, delivery, and launch; achievement of the 1982 10C at the 6-man level; achievement of the 1987 10C for the 12-man growth station; and operations through accommodations of one cycle of Blue Book experiments.

Each element of the program WBS has been scheduled to a depth commensurate with the level of technical definition attained during this phase of the project. As shown, MSS project Phase C/D effort is initiated on October 1, 1975. At this time, planning baselines are verified, work is authorized, and the Phase C/D program plans are implemented as soon as possible. Three months later, on January 1, 1976, the system requirements reviews (SRR) are held to review the initial MSS system specification package and establish an initial system requirements baseline (SRB). Three months later, on April 1, 1976, a systems design review (SDR) is held to establish the project requirements baseline (PRB) based on initial (partial) contract end item (CEI) development (Part I) and GFP and GFE performance and interface (P&I) specifications. Long-lead subsystem development procurement specifications are released at this time.

After the SDR, engineering begins preliminary design, and manufacturing initiates fabrication of required soft mockups. On October 1, 1976, preliminary design reviews (PDR) are conducted to confirm technical requirements and the contractor's engineering approach. The system specifications

are updated and the CEI and computer program contract end item (CPCEI) development (Part I) specifications are formally approved by the NASA, thus establishing the design requirements baseline (DRB). Long-lead procurement requirements are identified and critical procurement is initiated as required.

Detail design and subsystem development is initiated subsequent to PDR, preliminary make-or-buy requirements are determined, supplier surveys are conducted, and remaining long-lead time materials and development procurement specifications are released. The release of structural detail drawings and detailed subsystem drawings occurs as necessary to support the subsystems development and module structure fabrication effort.

On January 1, 1978, a critical design review (CDR) is held to conduct a technical review of the detail design and CEI product (Part II) specifications. At this time, approximately 90 percent of the detail, assembly, and installation drawings are ready for release. The specific design is accepted and released for production, and the drawing configuration baseline (DCB) is established.

During the period from CDR to August 1, 1980, prototype subsystems are acquired, development and qualification test programs are completed, flight module primary structure fabrication has been initiated, and the initial flight subsystems have undergone compatibility assessment and are ready for installation in the flight modules.

On October 1, 1980, subsystems installation begins in the first (initial core) module. The next three flight modules are also begun in series, the four modules receive individual acceptance tests, and the required integrated checkout of all four modules is accomplished during May 1981. The four modules are shipped to KSC on June 1, 1981, initiating prelaunch operations.

Following prelaunch activities in the mission support operations building (MSOB), the core module is installed in the shuttle orbiter at the vehicle assembly building (VAB) and launched to orbit on July 1, 1981. All remaining initial station modules are launched at 30-day intervals, achieving IOC on January 1, 1982, with the launch of the first cargo module and a crew of six.

In parallel with the foregoing operations, buildup of the MSV at KSC has been initiated in February 1981, and completed on September 1, 1981, allowing module SM-3 and all subsequent modules to receive final acceptance test at KSC.



Growth station module production, checkout, and prelaunch operations are shown, leading to the launch of the growth solar array package on January 1, 1987, and the achievement of growth station IOC on July 1, 1987, with a crew of 12 on board. Growth station operations are completed, the last operational crew complement is returned to earth, and station disposition is initiated on July 31, 1997.

Not shown on the MSS program master schedule are the logistic support launches (crew and cargo) planned during the life of the initial station and following the achievement of the growth station IOC.

#### 2.3.4 PROGRAM SCHEDULE BASELINE

The SSEO program master schedule, Figure 2-3, provides the framework for development and preparation of detail schedules for all Phase C/D project activities at the functional and work package levels. It will be maintained and controlled at all times to ensure that only the latest planning data are utilized by all program activities. A chronological summary of key program milestones follows:

- Modular Space Station Project Phase C/D start 10-1-75
- System requirements review (SRR) 1-1-76
- System design review (SDR) 4-1-76
- Preliminary design review (PDR) 10-1-76
- Critical design review (CDR) 1-1-78
- Prototype hardware delivery 1-1-79
- Complete qualification 5-1-80
- Complete flight module integrated checkout (first 4 modules) 6-1-81
- Start initial MSS buildup (launch initial core module) 7-1-81
- Launch initial power module 8-1-81
- Launch SM-1 9-1-81
- Launch SM-2 10-1-81
- Launch SM-3 11-1-81
- Launch SM-4 12-1-81
- Launch first cargo module (IOC initial station) 1-1-82



- Launch first attached RAM 8-1-82
- Launch first support section module 6-1-85
- Launch first detached RAM 8-1-85
- Start growth MSS buildup (launch growth solar array package) 1-1-87
- Launch growth core module 3-1-87
- Launch SM-5 4-1-87
- Launch SM-6 5-1-87
- IOC growth station 7-1-87
- Launch second support section module 8-1-87
- Launch last attached RAM 2-1-94
- Launch last detached RAM 3-1-96
- End of baseline program (initiate station disposition) 7-31-97



### 3. OVERALL COST METHODOLOGY

#### 3.1 INTRODUCTION

The costing process used in the present report applies parametric techniques to the identification of cost elements of the work breakdown structure. The basic building block in generating nonrecurring DDT&E costs for the MSS is the design and development (D&D) effort associated with subsystem elements in the modules. Production costs are built up from the recurring theoretical first unit (TFU) fabrication, including installation, assembly and checkout acceptance testing cost for subsystem elements. These building blocks are based on historical cost estimating relationships, budgetary and planning estimates by subcontractors, subcontractor studies, and catalogue prices; they exclude tooling and special test equipment costs.

In addition to the building block costs, nonflight hardware and programmatic support efforts are needed to complete the DDT&E and production costs. These are derived from historical program experience as adjusted by program management to reflect more advanced programmatic techniques and procurement policies.

Operations costs are based upon the building blocks for spares, refurbishment, and modification efforts, and head count estimates for on-site and in-plant operational support.

Trade studies used in optimizing the subsystem design utilizes the D&D and TFU costs plus logistics costs of operation to determine whether higher D&D and TFU costs are warranted in order to reduce operational costs. In addition to the MSS project, the research and application module (RAM) projects were costed on a building block approach, but at a grosser level of parametric definition.

Experiment costs were extracted from NASA-provided data which included the sum of D&D and TFU plus operational costs rather than using the building block approach.

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### 3.2 ELEMENTS IN THE ESTIMATING PROCESS

Costs for the MSS project are illustrated in a three-dimensional format in Figure 3-1. Along the horizontal axis into the page are shown the basic D&D and TFU building blocks for each of the subsystems of the flight hardware. By agreement with NASA, tooling and special test equipment are also included in the DDT&E subsystem WBS elements for comparability with estimates from other contractors. Production TFU building blocks are adjusted for quantity wherever appropriate. Subsystem installation, assembly, and checkout costs extracted from the basic TFU costs, in production, and refurbishment costs in operations are, by agreement with NASA, included in the module costs at Level 5. Allocation of costs by module for both DDT&E and other procurement phases are based upon development sequences in Section 5. All of the cost elements described are included in Cost Estimate Data Forms A, B, and D in Section 5.

Shown along the horizontal axis to the right are nonflight hardware and programmatic support WBS Level 4 items. Each of these is enumerated as a line item in Cost Estimate Data Forms A, B and D.

Along the vertical axis are the elements of cost which make up the flight hardware, nonflight hardware, and programmatic support effort and which have been traditionally accumulated by contractor cost accounting systems. Cost Estimate Data Form B has been established by NASA to report these elements, which consist of the following:

1. Engineering labor hours and dollars
2. Manufacturing labor hours and dollars
3. Major subcontractor
4. Minor subcontractor
5. Other material
6. Other direct costs
7. Interdivisional work authorization (IDWA)
8. Total direct costs
9. Engineering burden
10. Manufacturing burden
11. Material procurement costs (MPC)
12. G&A
13. Total indirect costs
14. Total costs



The enumeration of each of these elements has, by mutual agreement with NASA, been determined to be of little use at this stage of the program. Accordingly, the elements on Form B, presented in Appendix B, have been limited to the following as shown in Figure 3-1:

1. Subcontractor costs (including fee, plus MPC and G&A costs).
2. In-house prime contractor costs (excluding fee and including IDWA)
3. Total costs

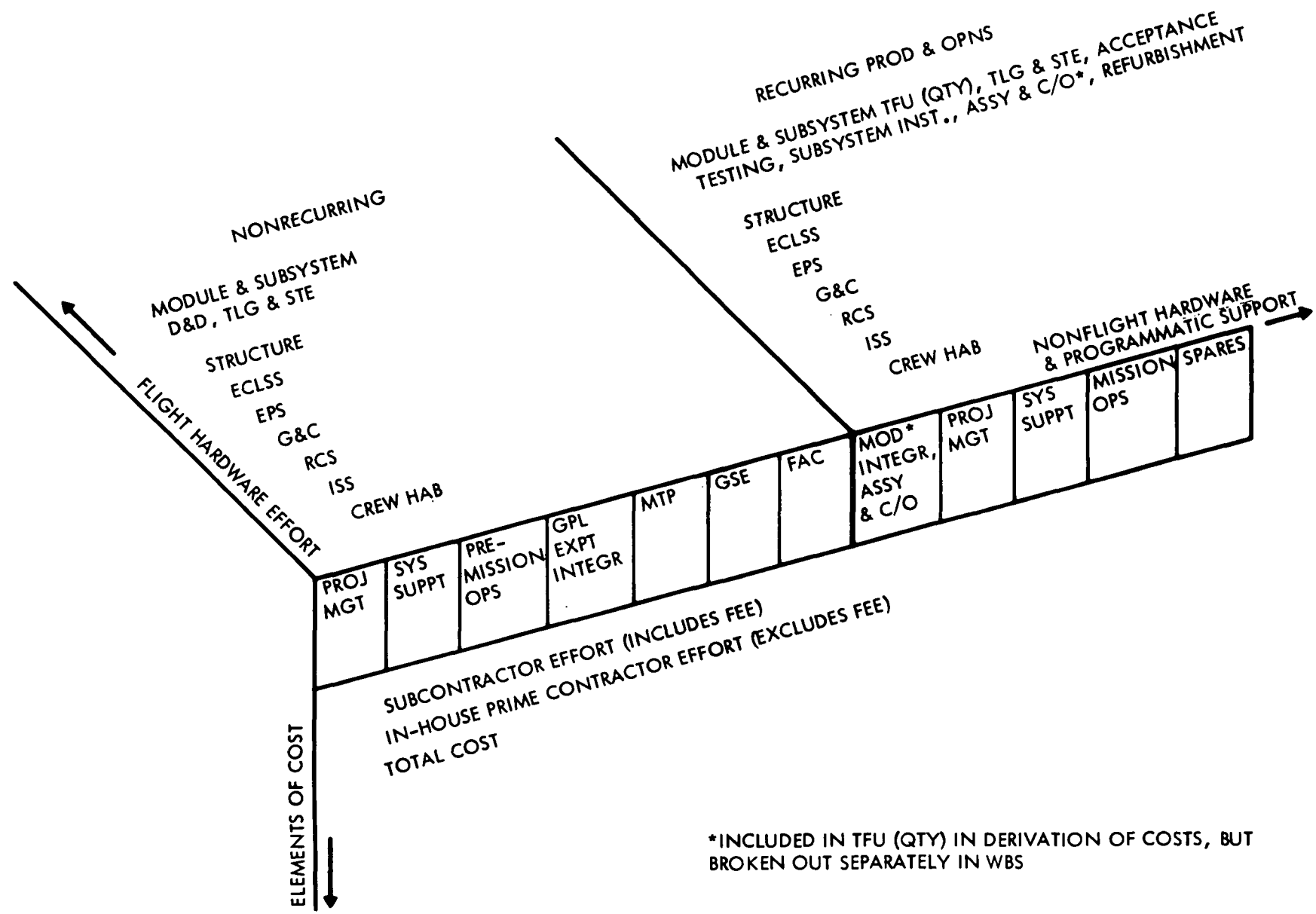


Figure 3-1. Cost Items of MSS Project

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### 3.3 ESTIMATES OF D&D AND TFU COSTS FROM TYPICAL COMPARATIVE D&D AND TFU DATA

The basic building blocks for estimating costs associated with flight hardware are the design and development (D&D) and theoretical first unit (TFU) costs. These costs are derived parametrically by comparing the item to be costed with a like item for which source data were available. The comparison is made in terms of some meaningful physical parameter, usually weight, and in terms of technical complexity and know-how. Each of these parameters is discussed in the subsequent paragraphs.

The typical source data for MSS project building block costs come in several varieties. They consist of historical cost estimating relationships (CER's) from the NR parametric cost data bank, and subcontractor budgetary and planning estimates and studies. In the present report, the source data are referred to as "comparative data," and their cost is plotted as a point on a log-log graph as shown in Figure 3-2. One such plot is used for D&D costs and another for TFU costs.

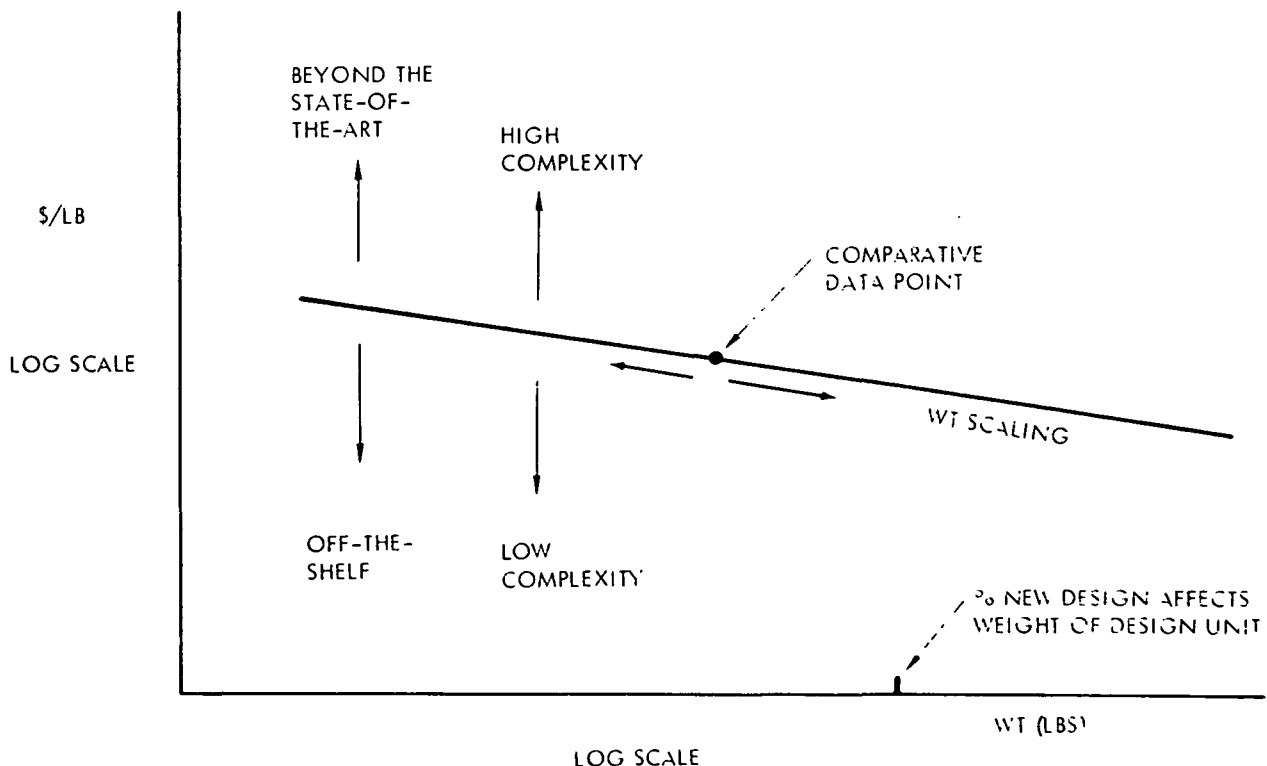


Figure 3-2. Typical Cost Parameters



Experience shows that cost is sensitive to weight for most subsystems; that is, the amount of labor expended per unit weight for a given technical complexity and know-how level decreases exponentially as the weight increases. This behavior is manifested by the negative slope in Figure 3-2. The value of the slope depends upon the subsystem and also varies between D&D and TFU in some cases, depending primarily upon the number of repetitive usages of various design units of the subsystem. When converted to a plot of total dollars on the ordinate versus weight on the abscissa for the subsystem, the behavior is always one of increasing cost with increasing weight.

One notable exception to the cost sensitivity to weight just described is for electronics assemblies in which microminiaturization, for example, makes weight scaling impractical. Accordingly, many of the assemblies in the information subsystem are costed without weight scaling.

Weight scaling of cost is accomplished by moving along the line through the comparative data point until the abscissa location corresponding to the weight of the item to be costed is reached. This weight is largely a function of the new design weight estimated by the responsible subsystem engineer in the D&D case, and of the total weight in the TFU case.

Complexity is a parameter which is defined as a measure of the intrinsic physical or functional features which specifies the effort needed to design and develop an item, keeping weight and know-how constant. If the item to be costed is more complex than the comparative data item, the factor is greater than unity and the cost is increased; if simpler, a factor less than one applies, thus decreasing the cost. The complexity factor is determined by consultation with the responsible subsystem engineers. Usually, the same complexity factor is assumed to apply to both the D&D and TFU costs.

The know-how factor is a ratio derived from relative ranking levels between the item to be costed and the comparative data item. This ranking level is defined in Table 3-1, and is based on a composite of state-of-the-art, production experience, specification status, and knowledge as to operating program characteristics. The effect of the ranking is represented in Figure 3-2, as ranging between off-the-shelf and substantially beyond the state-of-the-art. The ranking is determined by interviewing the responsible subsystem engineers. Ranking for the item of interest is estimated at the inception of Phase C of the MSS, including all relevant technological fall-out from other programs, and applicable to the capabilities of North American Rockwell and its team of subcontractors. This ranking is compared with an estimated ranking of the comparative data item at its program inception to obtain a factor while maintaining weight and complexity constant. This factor is subject to the judgment of the estimator, particularly at the extremes of

Table 3-1. Subsystem Know-How Status\*

Know-How Ranking	State-of-the-Art	Production Experience	Specification Status	Operating Program Characteristics
1	The item will require no modification.	The item has been produced in production quantities.	The specification is for the item as produced.	The OPC have been defined and are met by the item.
2	The item will involve a minor modification of commercial or standard aerospace issue item.	The item has been produced in limited quantity.	A specification for the item has been prepared but is under review or revision.	The OPC have been substantially defined, but are under review or revision.
3	The item is within the state of the art but no commercial counterpart exists.	A prototype of the item has been produced.	A specification for the item has not been completed, but a specification on a similar item is available.	The general outline of OPC has been formulated, but many specific details are lacking.
4	The item is slightly beyond the current state of the art. Some development work is required.	Experimental laboratory fabrication of a similar item is in process.	Work on a specification is in an early stage and only general requirements are identified.	The general outline of OPC under which the item will be used has been only tentatively defined and many specific details are lacking.
5	The item is substantially beyond the current state of the art. Major development work is required.	No production of any kind has been started.	No work on a specification has started.	None of the OPC for using the item has been formulated.

\*Adapted from AFSCM 173-1



the ranking levels. This factor is applied to design and development only, based on the rationale that the know-how sufficient to produce the item will have been developed during the design phase. In subsystems in which commonality exists, the effort associated with the "% New Design" portion of the subsystem is at a given know-how level and the subsequent usage of the same item in a design is at a level tending towards off-the-shelf ranking.

The original input format by engineering personnel is described in Figure 1-12 of SD 71-217-4, Modular Space Station Preliminary System Design, Trades and Analyses. Because of the judgmental process involved, the necessity to convert the engineering inputs to meaningful cost values and the need to insure that the parameters were being interpreted properly by both the engineer and parametric cost estimator, the interviewing process was very important and useful.



### 3.4 DERIVATION OF D&D AND TFU COSTS FROM COMMERCIALY AVAILABLE EQUIPMENT

An atypical subsystem insofar as cost estimating is the information subsystem in which many of the comparative items used in estimating costs were catalog items produced in quantity for the commercial market. In such cases, the procedure was first to establish a relationship between fabrication and assembly costs assuming mass production on the one hand, and TFU costs of a space-qualified product on the other. Then D&D costs were derived using ratios between D&D and TFU derived from historical data and estimates of the relative know-hows between the items.

Another major difference between information subsystem and the other subsystems was the absence of weight scaling in many of the estimates. In the information subsystem, the components often are off-the-shelf items of minute weight and the new design effort is primarily one of combining these components properly, so that weight frequently is not a good index of effort.

Discussing first the relationship between the catalogue price (CP) and TFU costs, it was assumed that the commercial item employed relatively hard tooling and that the learning curve had flattened off. If produced as a space-qualified item, on the other hand, it would have softer tooling and a greater variety of production work tasks leading to a steeper learning curve. Learning curves for both the labor and material elements of cost were assumed under both conditions, and the proportion of labor and material costs to the total were estimated. A TFU/CP ratio was derived by assuming a crossover or meeting point of the unit cost curves as a function of quantity. This point was assumed to occur between the 100th and 200th production item, and resulted in TFU/CP ratios of about 7.5 and 9.5, respectively. A check of this against personal experience with factory-assembled versus home-made electronic kits resulted in the choice of a value of 8.0 for estimating purposes.

This ratio was applied to the catalogue price to arrive at a TFU cost for a space-qualified item of equivalent complexity and know-how. To obtain TFU costs for the item of interest, a complexity factor is applied. This factor is unity if an item equivalent to the catalogue item is used but may vary considerably from unity for differing combinations of electronic components compared with the catalogue item. As mentioned previously, weight is not used as a parameter if the components are so small as to preclude meaningful scaling in this manner.



The D&D costs are derived from ratios of D&D to TFU experienced for various manned and unmanned weapon subsystems and projections of various manned and unmanned space subsystems, plotted as a function of estimated know-how. The D&D/TFU ratio derived from this plot is multiplied by the TFU costs derived above to arrive at an equivalent D&D cost for the catalogue item. Most catalogue items are assumed to be a minor modification of a previous item, and are rated at a know-how level of 2. To arrive at a D&D cost for the item of interest, a know-how factor is derived by using the plot and ratioing it against the know-how factor of the catalogue item. A complexity factor is also applied as it was for production costs.

### 3.5 DERIVATION OF SOFTWARE COSTS

The costs of software for the information subsystem consist of programming costs and computer running time costs.

The programming costs are generated in a series of steps as follows:

1. The number of words is defined by usage; that is, for use on the station, for information subsystem hardware development, and for validation and test of the operating programs. It is also defined by type of program; supervisory, subsystems application, and subsystems data base. The numbers for each usage are added to obtain a total by type of program.
2. The number of words in each type of program is broken down into words which must be written before IOC and those which can be scheduled for after IOC if desired. Each of these is further broken down into original or "new" words and "repeat" words that represent modifications of the originals.
3. The number of instructions is defined in terms of "new" and "repeat" instructions by the type of program based on a different ratio of instructions to words for each type of program.
4. A cost per instruction is derived for both the "new" and "repeat" types, based on assumed labor rates and speed of writing instructions.
5. A breakdown of subcontractor and prime contractor effort is assumed, with appropriate factors for prime contractor efforts added to costs as delivered by the subcontractor.

The computer running time costs are based upon the GE regression formula (Reference 4) using the method developed by the System Development Corporation. The parameters used in this formula are the number of machine words, the programming complexity, and the logarithm (base 10) of the number of words in the data base. As in the programming costs, a breakdown of subcontractor and prime contractor effort was assumed and appropriate factors applied.

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### 3.6 PRIME CONTRACTOR AND SUBCONTRACTOR ELEMENTS OF COST

These costs are represented along the vertical axis of Figure 3-1. The prime contractor engineering and manufacturing effort in support of subcontractor work is based upon the Apollo CSM 1968 Cost Study (Reference 5), in the case of the reference modular space station described in Section 4. As the Apollo CSM 1971 Cost Study (Reference 6) became available, it was used for the selected configuration of Section 5. In both cases, the historical experience is adjusted to reflect programmatic cost avoidance due to advances in programmatic management techniques and procurement policies. The amount of cost avoidance is based upon studies first reported for the 1970 design (Reference 6) under the current Phase B space station contract.

In arriving at the subcontractor and prime contractor D&D and TFU costs, the historical data were broken down into subcontractor, interdivisional work authorization (IDWA), and prime contractor efforts by D&D and TFU, respectively. It should be noted that the subcontractor cost element herein includes associated material procurement costs (MPC) and G&A costs of the prime as well as major and minor subcontractor costs per se. The IDWA effort was further broken down into a portion paralleling that of subcontractors and a portion paralleling that of the prime contractor. The total cost avoidance estimates of Reference 7 were assumed to apply to the modular space station as well, and divided into subcontractor and prime contractor portions. These portions were then deducted from the corresponding portions of the historical data to arrive at a cost breakdown after cost avoidance. For the reference configuration, the percentages of prime versus subcontractor effort were the same for all subsystems except structure due to the fact that the costs in Reference 5 are generated from the top down to the cost elements, based on overall program costs. Also, TFU costs were adjusted downward to reflect greater accessibility and modularity on the space station. The subsequent cost study (Reference 6), on the other hand, is built from the bottom up, so that there is considerable variation among the subsystems.

The breakdown thus derived were used in one of two ways. Either they were employed to build up total costs for assemblies whose cost input initially consisted of costs at the subcontractor level, or were used to obtain a breakdown of costs initially input at the total cost level and expected to be subcontracted on MSS. Cost inputs from subcontractor inputs were assumed to contain cost avoidance as were those of References 5 through 7.

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### 3.7 FACTORS FOR NONFLIGHT HARDWARE AND PROGRAMMATIC SUPPORT

Having generated the D&D and TFU costs through the subcontractor and prime contractor levels, the next step is to generate the nonflight and programmatic support costs, plotted along the horizontal axis in Figure 3-1. These costs were not used in the trade studies of Section 4 for evolving hardware design features (see DRL 68, Volume VI); they are percentages of the D&D and TFU costs and do not affect the choice of subsystem configuration. They are significant, however, in estimating total costs in the selected configuration (Section 5). The major test hardware portion of the Major Test Programs is derived by defining a set of test hardware in terms of equivalent TFU articles. All other items, making up the programmatic support, are based on adjusted historical data, expressed as a percentage of a relevant chosen cost base.

In order to generate these factors, the costs for each of the WBS items in the Apollo CSM 1971 Cost Study (Reference 6) were converted to the WBS items of the MSS. The cost avoidance items of Reference 7 (Subsection 3.6) were also broken down by MSS WBS item. The cost savings in comparison with the historical data, as is explained in more detail in Reference 7, stem mainly from:

1. Reduced quantities of major test hardware due to the more benign environment during launch, and to the possession of much more technical know-how than was available in the early sixties. An additional fallout of this reduction is the reduction of test operations and site support efforts.
2. Phased procurement with a schedule offering an orderly economical evolution of events. This planning would lead to a better balance of sequential and concurrent operations, thereby resulting in significant engineering and manufacturing savings due to reductions in the number of parts designed, built, and tested.
3. New engineering and management tools, such as automated engineering release and manufacturing data retrieval systems, automatic drafting machines, and others.



To these reductions in costs were added certain reductions which were, in the judgement of the program management, pertinent to the MSS project but not included in the above avoidance items. The additional reductions consist primarily of: (1) documentation and program control efforts in program management due to a better knowledge and hence a need for fewer requirements and planning documents; (2) less system support efforts for configuration management, and far fewer trajectory analyses which more than offset slightly increased efforts in integration analysis; (3) fewer over-haul, repair, and maintenance activities on major test hardware items due to better knowledge of test requirements; and (4) drastically reduced ground support equipment (GSE) needs due to the availability of universal test equipment (UTE) underdevelopment by the NASA and maximum use of on-board checkout (OBCO) equipment, plus a lack of common use items.

More details in regard to the nonflight hardware and programmatic support costs are given in Section 5.

### 3.8 TRADE STUDY LOGISTICS COSTS

The D&D and TFU costs previously described were used to evaluate various subsystem concepts in trade studies in which cost was considered significant in the choice among concepts. It was also necessary to add logistics costs, however, in order to arrive at a true picture of total costs. That is, options with low development and production costs were often so costly to operate over the period defined by the MSC study guidelines that they proved to be noncompetitive from a cost standpoint.

The operation costs were limited to logistics costs of supply. The cost impact of the resupply was determined through a computer program that superimposed the resupply requirements for each of the nine concepts on a selected constant experiment program logistics profile. The computer output was a tab run and cathode ray tube (CRT) plots that gave a required shuttle flight schedule to support each concept. Logistics costs to support each concept were established from these data.

Section 5 summarizes the results of trade studies in which cost was a significant factor, and SD 71-217-6, Modular Space Station Preliminary System Design, Volume VI, Trades and Analysis, describes the study logic and concepts in detail.

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### 3.9 EXPERIMENT PROJECT COSTS

Experiment projects include the Experiments Definition Project and the Earth Orbital Experiments Project. In the definition project, the costs were based on an arbitrary choice of a constant annual expenditure level per scientific discipline. This level was assumed over a time period slightly preceding the MSS Phase C start and terminating, in the case of each scientific discipline, one year prior to the initiation of design of the last experiment equipment grouping to meet the full NASA Blue Book requirements, as defined by the Mission Sequence Plan (MSP) in SD 71-217-2, MSS Preliminary System Design, Volume II, Operations and Crew Analysis.

The costs of the Earth Orbital Experiments Project were derived from NASA provided data in Cost Data for Preliminary Edition (January 15, 1971) of Reference Earth Orbital Research and Application Investigations (Blue Book), MSFC Program Development Advanced Studies Report, ASR-PD-MP-71-1, April 1, 1971. These data included combined D&D and TFU costs for equipment lists which did not correspond to the combination of multiexperiment servicing equipment housed in the MSS in the present design and the experiment-unique equipment in each of the host spacecraft, and operational costs which did not correspond to the MSP in operational duration or sequence. It was therefore necessary to redefine the ASR-PD-MP-71-1 data in terms of the planned equipment groupings, to break down the combined D&D and TFU costs into their constituents for reporting in cost Form A, and to make operational costs compatible with the MSP.

More details regarding this effort are given in Section 6.

## 4. REFERENCE SUBSYSTEM COSTS

### 4.1 INTRODUCTION

The evolution of costs in the MSS project represents a deliberate effort to incorporate cost considerations into the design process. The starting point for introduction of costs is the definition of a reference set of hardware.

In order to assess the impact of subsystem design changes, which are to be defined in terms of changes at the assembly and subassembly levels (WBS Levels 6 and 7), the D&D and theoretical first unit (TFU) costs were derived at these WBS levels for the reference configuration. Nonflight hardware and programmatic support efforts were not included in the costs since they were not expected to affect the outcome of the design trade studies.

The reference configuration and the methodology employed in deriving the D&D and TFU cost factors are described in the following paragraphs.

### 4.2 REFERENCE CONFIGURATION FOR COSTING

The MSS Phase B contract began with a barbell configuration which emanated from the configuration syntheses and analyses of the Phase A contract. The reference configuration for costing included all hardware elements of the six-man initial space station that had been defined through Engineering Review Board (ERB) Meeting 20 and the action items arising from that meeting. It is a barbell configuration consisting of two core modules 31 feet in length with four side-berthing ports, two crew quarter modules 28 feet long, two control center modules 28 feet long, and one power module 42 feet long plus an 8000-square-foot solar array. All modules are 14 feet in outside diameter except for the cores, which are 12 feet. Figure 4-1 shows this configuration, illustrating the capacity to accommodate RAM's and cargo modules which were not costed.

Noteworthy features of this configuration include dual egress in a shirtsleeve environment from all crew and control center modules, external radiators on all modules except the core, and an IVA/EVA airlock in Core Module 1.

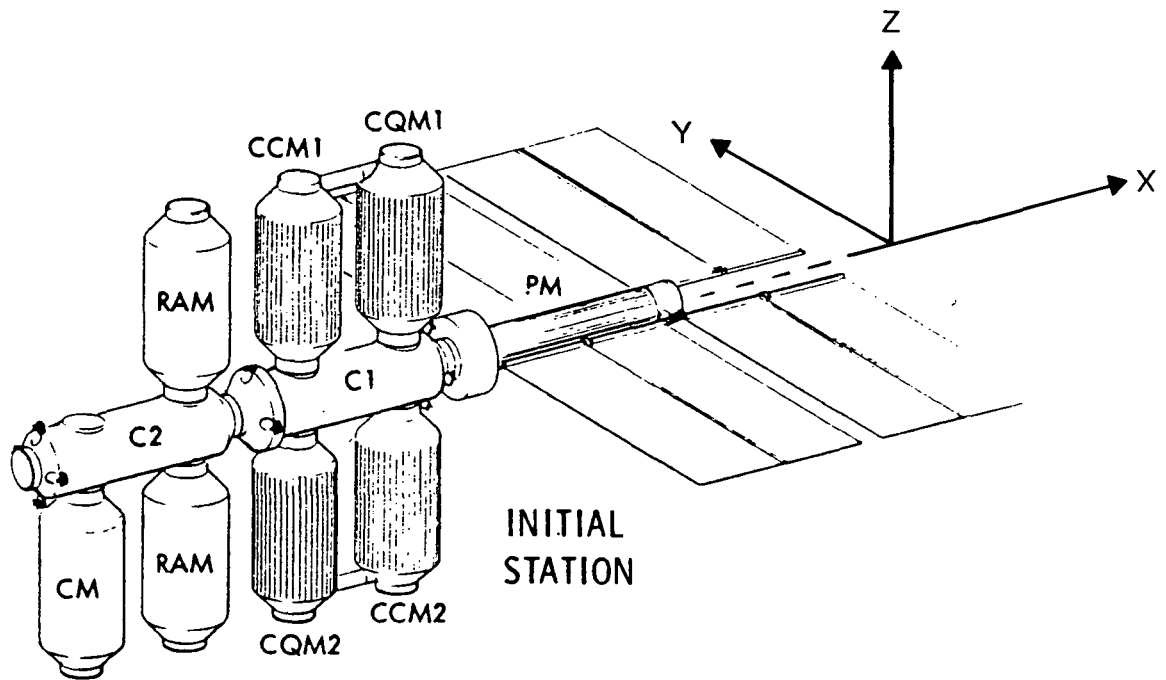


Figure 4-1. Reference MSS Configuration

In addition, certain features of each of the subsystems are worth observing for cost perspective. These features are summarized in Table 4-1. The dry weight for each of the subsystems is summarized in Table 4-2.

Table 4-1. Subsystem Characteristics Relative to Cost

Subsystem	Characteristics and Assemblies
Structures	Skin stringer aluminum cylinders with Cassinian curve end bulkheads; high-performance mylar insulation; universal docking ports with stand-up egress/ingress. It also includes internal primary and secondary structure and crew furnishings
Environmental/thermal control and life support	Includes atmospheric storage; atmospheric and thermal control; CO <sub>2</sub> , water, food, and waste management; hygiene; special life support; and crew provisions. CO <sub>2</sub> removal by electrochemical H <sub>2</sub> depolarizer; O <sub>2</sub> supply by water electrolysis; N <sub>2</sub> cryogenic storage; cryogenic storage of H <sub>2</sub> for sabatier operations; cryogenic storage of N <sub>2</sub> and O <sub>2</sub> repressurization
Electrical power	Solar array for primary power generation, open-loop fuel cells for emergency secondary power generation, and 100 ampere-hour NiCd batteries. Also includes power conditioning, distribution control, and lighting
Guidance and control	Strapdown inertial reference using ISS developed preprocessors; optical reference consists of horizon tracker, star tracker, sextant/telescope, and calibration links; torques include new control moment gyros (CMG's) and RCS electronics; new preprocessor used in CMG assembly
Reaction control	Cryogenic H <sub>2</sub> and O <sub>2</sub> storage, plus propellant thermal conditioning, feed control, accumulators, engine quads. Also significant cargo cryogenic storage
Information	Data processing, display/control, and communications assemblies

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Table 4-2. Reference Configuration Dry Weight Summary\*

Subsystem	Weight (lb)
Structure (w/o manipulator)	47,250
Environment/thermal control and life support**	12,677
Electrical power	23,090
Guidance and control	1,830
Reaction control	3,230
Information	5,590
Total	93,667
<p>* 2 core modules, 2 crew quarter modules, 2 control center modules, 1 power module, and 1 solar array</p> <p>**Excludes potable life support system (PLSS) and pressure garment assembly (PGA), both Government-furnished equipment (GFE) items</p>	



#### 4.3 COSTING PROCESS, REFERENCE MSS

Once the reference configuration had been determined, the costs of the various subsystem assemblies and subassemblies were estimated precedent to trade studies leading to the selection of a final configuration. Since nonflight hardware and programmatic support efforts were not expected to impact the trade study results, they were not included in the estimates.

The methodology followed was that described in Section 3. For all subsystems except the structure, the costs were calculated at the total station level; that is, the cost calculation implicitly assumed that the development sequence was included rather than explicitly defining a sequence as in the case of structures. This approach was necessary because allocation of the subsystems by module was undefined. The sequence of development for the structural subsystem subassemblies is defined in Table 4-3. It should be noted that initial development varies by subassembly and by modules. In the case of crew furnishings and general-purpose laboratory furnishings, each module was considered to be a unique modification of the initial design effort and equivalent to the initial effort, respectively, in know-how.

The comparative data used in making the cost estimates, the complexity of the MSS item as a factor of the comparative item complexity, the know-how rating of the MSS item versus the comparative item, and the resulting know-how factor, are presented in subsequent tables. The rationale leading to the choice of the complexity and know-how ratings is also presented. The tables provide traceability of the evolution of costs for the reference MSS subassemblies, which are presented in Appendix E. They are intended to promote an understanding of the costing process. Certain key values in the cost calculations — the comparative data costs and weights of both comparative and MSS weights - have been omitted because the calculations in their entirety are considered proprietary. They are being furnished to NASA under separate cover.

The traceability of the evolution of costs for the structures subsystem is given in Table 4-4, but this should be used in conjunction with Table 4-3, since only the initial design efforts are presented in the interest of brevity. The S-II CER's used for comparative data were generated by the S-II Cost Analysis group in February, 1971.

Table 4-3. Reference MSS Structures Sequence Matrix of Design and Development and Production

Structure	Know-How Rankings <sup>(1)</sup> Assumed						
	Modules						
	Core		Control Center		Crew		Power
	No. 1	No. 2	No. 1	No. 2	No. 1	No. 2	No. 1
Primary Sidewalls	C <sub>T1</sub> (3)	C <sub>T2</sub> (2)	CC <sub>T1</sub> (3)	CC <sub>T2</sub> (2)	CC <sub>T3</sub> (2)	CC <sub>T4</sub> (2)	P <sub>T1</sub> (3)
Bulkheads	C <sub>T1</sub> (3)	C <sub>T2</sub> (2)	CC <sub>T1</sub> (3)	CC <sub>T2</sub> (2)	CC <sub>T3</sub> (2)	CC <sub>T4</sub> (2)	P <sub>T1</sub> (3)
Floors	--	--	CC <sub>T1</sub> (3)	CC <sub>T2</sub> (2)	CC <sub>T3</sub> (2)	CC <sub>T4</sub> (2)	--
Fittings	C <sub>T1</sub> (3)	C <sub>T2</sub> (2)	CC <sub>T1</sub> (3)	CC <sub>T2</sub> (2)	CC <sub>T3</sub> (2)	CC <sub>T4</sub> (2)	P <sub>T1</sub> (3)
Secondary Crew Partitions	C <sub>T1</sub> (2)	C <sub>T2</sub> (1)	CC <sub>T1</sub> (2)	CC <sub>T2</sub> (1)	CC <sub>T3</sub> (1)	CC <sub>T4</sub> (1)	P <sub>T1</sub> (2)
Utility Dist.	C <sub>T1</sub> (2)	C <sub>T2</sub> (1)	CC <sub>T1</sub> (2)	CC <sub>T2</sub> (1)	CC <sub>T3</sub> (1)	CC <sub>T4</sub> (1)	P <sub>T1</sub> (2)
Doors	C <sub>T1</sub> (3)	C <sub>T2</sub> (2)	C <sub>T3</sub> (1)	C <sub>T4</sub> (1)	C <sub>T5</sub> (1)	C <sub>T6</sub> (1)	C <sub>T7</sub> (1)
Airlocks	--	--	CC <sub>T1</sub> (4)	CC <sub>T2</sub> (1)	CC <sub>T3</sub> (1)	CC <sub>T4</sub> (1)	--
Brackets	C <sub>T1</sub> (2)	C <sub>T2</sub> (1)	CC <sub>T1</sub> (2)	CC <sub>T2</sub> (1)	CC <sub>T3</sub> (1)	CC <sub>T4</sub> (1)	P <sub>T1</sub> (2)
Environmental Shield	C <sub>T1</sub> (4)	C <sub>T2</sub> (1)	CC <sub>T1</sub> (4)	CC <sub>T2</sub> (1)	CC <sub>T3</sub> (<1)	CC <sub>T4</sub> (<1)	C <sub>T3</sub> (1)
Docking Passive	C <sub>T1</sub> (4)	C <sub>T2</sub> (2)	C <sub>T3</sub> (2)	C <sub>T4</sub> (1)	C <sub>T5</sub> (1)	C <sub>T6</sub> (1)	C <sub>T7</sub> (1)
Active	--	C <sub>T1</sub> (4)	C <sub>T2</sub> (2)	C <sub>T3</sub> (1)	C <sub>T4</sub> (1)	C <sub>T5</sub> (1)	C <sub>T6</sub> (1)
Crew Furnishings	C <sub>T1</sub> (3)	C <sub>T2</sub> (2)	C <sub>T2</sub> (2)	C <sub>T2</sub> (2)	C <sub>T2</sub> (2)	C <sub>T2</sub> (2)	C <sub>T2</sub> (2)
General Purpose Lab	--	--	CC <sub>T1</sub> (3)	CC <sub>T1</sub> (3)	--	--	--

(1) Know-how ratings are denoted by the numbers within parentheses in each column. See definitions on another sheet.

C<sub>TN</sub> = Nth theoretically (T) derived cost item which is identical to, or a minor modification of, Core Module No. 1

CC<sub>TN</sub> = Nth theoretically (T) derived cost item which is identical to, or a minor modification of, Control Center Module No. 1

P<sub>TN</sub> = Nth theoretically (T) derived cost item which is identical to, or a minor modification of, the Power Module

The costing process for the environmental/thermal control and life support subsystem is traceable in Table 4-5. Many of the costs are based on studies performed by the Hamilton Standard Division of United Aircraft Corporation, as adjusted for know-how ranking. The adjustment reflects increased know-how assumed to accrue from space station prototype (SSP) activity expected before space station Phase C inception. Numerous items of comparative data are at the total CER cost level rather than the subcontract input level, and therefore do not require the application of prime contractor add-on costs to the comparative data inputs.

Table 4-6 shows the comparative data and technical factors influencing the electrical power subsystem costs. This subsystem borrows extensively from existing programs and programs scheduled to be well under way or completed by the inception of Phase C of MSS. This fallout is expected to reduce significantly the costs of fuel cells by utilizing off-the-shelf shuttle fuel cells and Skylab batteries for primary power. In the case of secondary batteries, the Station Technology Advanced Requirements Testing (START) project, for continuing early development testing on MSS subsystems into the 1972-1974 time period, is expected to advance the state-of-the-art from its present level. Prime contractor engineering and manufacturing support was assumed to be less in the case of the solar array than for other subassemblies because of the large size of similar hardware assembled at the subcontractor facilities.

The guidance and control subsystem traceability data are summarized in Table 4-7. This subsystem utilizes much existing state-of-the-art, with development efforts primarily in the CMG and navigation base subassemblies. ISS-developed preprocessors are used wherever possible. Software costs are based on special G&C requirements which are separate from those of the ISS.

The comparative data, complexity, and know-how factors used in the reaction control subsystem are presented in Table 4-8. Most of the subassembly comparative data are from the Apollo command and service modules records. Because of more stringent design requirements, several of the subassemblies are more complex than the comparative items. Not much in the way of shuttle development fallout is expected for this subsystem, and some concepts are not yet pinned down; thus the gauging subassembly required new development and the blower assembly creates a new design problem. In the case of TFU costs, some of the subcontractor cost inputs were adjusted by in-house engineering and manufacturing support costs that had as inputs the total Apollo CSM flight hardware costs and subcontractor costs by engines, tanks, and feed controls of the service modules. The in-house costs were defined by estimating the breakdown of total Apollo RCS costs between the service module and command module portions, and subtracting from the service module portion the total subcontractor costs to

Table 4-4. Traceability of Cost Evolution Reference MSS Structures  
Subsystem (Initial Station)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Module - Core No. 1				
<u>Primary</u>				
Sidewalls	S-II Tanks CER	1.0	3 vs 4, 75%	Core sidewalls are similar to S-II vehicle. Both are pressurized and sustain side loads. Machining and forming will be the same. The state of the art has advanced since 1963, therefore minimal development will be required.
Bulkheads	S-II Tanks CER	0.6	3 vs 4, 75%	Elimination of waffle and common bulkhead problems reduces complexity. Bulkheads smaller and not required to accept extreme temperatures of S-II stage.
Fittings	S-II Tanks CER	1.0	3 vs 4, 75%	Similar effort to LH <sub>2</sub> feedline ports on S-II.
(1) (See footnote at end of table.)				

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Table 4-4. Traceability of Cost Evolution Reference MSS Structures  
Subsystem (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Module - Core No. 1 (continued)				
<u>Secondary</u>				
Crew Partitions	S-II Fairings CER	1.0	2 vs 2, 100%	Similar to S-II fairings. Nothing exotic. Fits into effort of airframe fabrication that has been done for many years.
Utility Distribution	S-II Fairings CER	1.0	2 vs 2, 100%	Same as Crew Partitions.
Doors/Hatches	S-II Tanks CER	1.2	4 vs 4, 100%	Use S-II tank CER. Because of details, complexity factor is increased. Large amount of machining. Development work required.
Brackets	S-II Forward Skirt CER	1.0	2 vs 2, 100%	Effort similar to S-II forward skirt. Rivet and subassembly effort.
<u>Environmental</u>				
Thermal Meteoroid	S-II Insulation CER	2.5	5 vs 4, 125%	HPI-high performance insulation (mylar) significantly more complex than the S-II sprayfoam. Installing the meteoroid barrier hard points and standoffs add more to the complexity. The barrier HPI will require substantial development.
(1) (See footnote at end of table.)				

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**Table 4-4. Traceability of Cost Evolution Reference MSS Structures  
Subsystem (Initial Station) (Cont)**

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Module - Core No. 1 (continued)				
<u>Docking</u> Passive	S-II Tanks CER	1.0	4 vs 4, 100%	The S-II tank CER is used. This is applied to the first unit (290 lb). The next 5 units are considered slight modifications and therefore are rated 2 on the know-how scale.
<u>Crew Furnishings</u>	S-II Forward Skirt	1.2	2 vs 3, 67%	The S-II fairing CER is used as a basis. The complexity is increased due to smaller details and more complex configurations.
Module - Core No. 2 (New Design Effort Only)				
<u>Docking</u> Active	S-II Tanks	1.5	4 vs 4, 100%	Use S-II tank CER. This item is approximately 50% more complex than the passive ring. The CER is applied against the total weight (580 lb) for one ring.
(1) (See footnote at end of table.)				

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Table 4-4. Traceability of Cost Evolution Reference MSS Structures  
Subsystem (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Module - Control Center No. 1 (New Design Effort Only)				
<u>Primary</u>				
Sidewalls	S-II Tanks CER	0.5	3 vs 4, 75%	Complexity 50% of S-II tank. Roll thin sheets. Less welding and machining.
Bulkheads	S-II Tanks CER	0.6	3 vs 4, 75%	For rationale, see Core No. 1 Bulkhead differs from core module configuration.
Floors	S-II Thrust Complex CER	1.0	3 vs 3, 100%	S-II thrust complex CER used due to similarity of load requirements and configuration.
Fittings	S-II Tanks CER	1.0	3 vs 4, 75%	Similar effort to LH <sub>2</sub> feed line ports on S-II. Different configuration from core module.
<u>Secondary</u>				
Crew Partitions	S-II Fairings CER	1.0	2 vs 2, 100%	Did not use Core No. 1 learning, as interface with structure of control center will change.
Utility Dist.	S-II Fairings CER	1.0	2 vs 2, 100%	See Crew Partitions above.
(1) (See footnote at end of table.)				

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Table 4-4. Traceability of Cost Evolution Reference MSS Structures  
Subsystem (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Module - Control Center No. 1 (New Design Effort Only) - (Continued)				
<u>Secondary - Continued</u>				
Airlock	S-II Tanks CER	1.5	4 vs 4, 100%	Use S-II tank CER. This effort is more complex due to details and configuration.
Brackets	S-II Forward Skirt CER	1.0	2 vs 2, 100%	See Core No. 1. New effort to Core No. 1 because of new primary configuration.
<u>Environmental</u>	S-II Insulation CER	2.5	4 vs 4, 100%	See Core No. 1. Requires whole new look because configuration of insulation and meteoroid protection entirely different.
(1) (See footnote at end of table.)				

. Table 4-4. Traceability of Cost Evolution Reference MSS Structures  
Subsystem (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Module - Power No. 1 (New Design Effort)				
<u>Primary</u>				
Sidewalls	S-II Tanks CER	0.5	3 vs 4, 75%	All new effort (new configuration), rationale similar to Core No. 1 - skin/stringer. Roll thin sheets.
Bulkheads	S-II Tanks CER	0.6	3 vs 4, 75%	All new effort (new configuration), rationale similar to Core No. 1 - skin/stringer. Roll thin sheets.
Fittings	S-II Tanks CER	1.0	3 vs 4, 75%	All new effort (new configuration), rationale similar to Core No. 1 - skin/stringer. Roll thin sheets.
<u>Secondary</u>				
Crew Part.	S-II Fairings CER	1.0	2 vs 2, 100%	See Core No. 1. New dimensions.
Utility Dist.	S-II Fairings CER	1.0	2 vs 2, 100%	See Core No. 1. New dimensions.
Brackets	S-II Fwd Skirt CER	1.0	2 vs 2, 100%	See Core No. 1. New interfaces.
General Purpose	S-II Fairings CER	1.2	3 vs 3	All modules unique.
(1) Know-how ranking applies to first design and development item only. See sequence matrix on another page to obtain know-how for subsequent design and development items.				

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Table 4-5. Traceability of Cost Evolution Reference MSS, (ETC/LSS)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
N <sub>2</sub> Conditioning	Apollo ECS Heat Exchanger and Apollo RCS Accum.	1.0	2 vs 2, 100%	Includes a combination of ECS heat exchanger and RCS accumulator comparative cost data.
Pumpdown (Airlock)	HP N <sub>2</sub> Storage Tanks, RCS Apollo Suit Compressor & Pressure Reg.	1.0	2.5 vs 2.5, 100%	
Mounts & Supports (See Below)				
H <sub>2</sub> Depolarizer	UAC/HS B&P	1.0	4 vs 4, 100%	
Sabatier Reactor	UAC/HS B&P	1.0	3 vs 4, 75%	
Electrolysis	UAC/HS B&P	1.0	3.5 vs 4, 85%	
Circulation (Ducts)	S-II Structure	0.5	2.5 vs 2.5, 100%	
Temp., Humidity Control/Fans	UAC/HS B&P	1.0	2.5 vs 3.0, 85%	
Pressure Control	UAC/HS B&P	1.0	3.0 vs 3.5, 85%	
Contaminant Removal Monitor	UAC/HS B&P	1.0	3.5 vs 4.0, 85%	
(1) (See footnote at end of table.)				

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Table 4-5. Traceability of Cost Evolution Reference MSS, (ETC/LSS) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(2)</sup> MSS vs Comparative, Factor	Rationale
Water, Intercooler, Freon Loops:	UAC/HS B&P			
Water Loop		1.0	2.0 vs 2.5, 80% on 1st; <1.0 vs 2.5 on other modules.	Minor modifications to Apollo coldplates and plumbing. Quite familiar with water as working fluid.
Freon Loop		1.0	2.5 vs 3.0, 85%	Same design problem less familiarity with freon as working fluid, externally mounted
Intercooler		1.0	4.0 vs 4.5, 90%	Still less familiarity with freon/water interface and toxicity precautions for internally mounted assemblies.
Radiator Panels and Control Valves	33 ft Station Structure CER Based on S-II	2.0	2 vs 2, 100%	Includes panels, controls, ISS interface, which are more complex than 33 ft Station structure.
Vapor Compression	UAC/HS B&P	1.0	2.5 vs 3, 85%	
Reverse Osmosis	UAC/HS B&P	1.0	2.5 vs 3, 85%	
Water Storage & Purity Monitor	UAC/HS B&P	1.0	2.5 vs 3, 85%	
(1) & (2) (See footnotes at end of table.)				

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Table 4-5. Traceability of Cost Evolution Reference MSS, (ETC/LSS) (Cont,

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How(2) MSS vs Comparative, Factor	Rationale
Waste Management <sup>(3)</sup> (Fecal/Urine Collection, Waste Processor)	UAC/HS AiResearch B&P	1.0	2.5 vs 3, 85%	Based on data for fecal/urinal collection <sup>(3)</sup> .
Shower	UAC/HS B&P	1.0	2.5 vs 3, 85%	
Sink	33 ft Station AiResearch B&P	1.0	100%	
Freezer/ Refrigerator	SM Structure CER	1.0	100%	
Ovens (Resistance/ Microwave)	SM Structure CER	1.0	100%	
Reconstitution Unit	Whirlpool Co. B&P	1.0	3 vs 3, 100%	
IVA/EVA Provisions	Apollo CER's	1.0	1.5 vs 1.5, 100%	Used a combination of AiResearch ECU data and structure.
Fire Control	Apollo RCS Plumbing CER	0.5	100%	Assembly consists of fire extinguishers. CO <sub>2</sub> bottles, plumbing and distribution, detectors, etc.
(1), (2), & (3) (See footnotes at end of table.)				

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Table 4-5. Traceability of Cost Evolution Reference MSS, (ETC/LSS)(Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(2)</sup> MSS vs Comparative, Factor	Rationale
Crew Equipment	33 ft Station Structure CER	0.5	100%	
Lower Body Negative Pressure	33 ft Station EPS CER	1.0	100%	
Mass Measure	33 ft Station EPS CER	1.0	100%	
Physiological Console	33 ft Station Displays/ Controls, EL 228 CER (GE)	1.0	1.5 vs 3, 100%	Know-how assumes very slight modification of ISS consoles.
Ergometer	NA			Estimated recurring costs without using specific comparative data. Estimated non-recurring as a ratio of recurring.
Examination Table	33 ft Station Structure CER	0.5	100%	
Surgical Inst./ Sterilizer	33 ft Station Structure CER	1.0	100%	
X-Ray	33 ft Station Structure CER	1.0	100%	
(1) & (2) (See footnotes at end of table.)				

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Table 4-5. Traceability of Cost Evolution Reference MSS, (ETC/LSS) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How (2) MSS vs Comparative, Factor	Rationale
Repair Tools		1.0	100%	
Mounts & Supports	S-II Structure CER	0.5	2 vs 2, 100%	
<p>(1) Comparative data "UAC/HS" refers to ECLSS definition study for 33 ft Station made by Hamilton Standard Division of United Aircraft Corporation. Data is documented in Volume IV, (SVHSER 5611) Cost and Plans, dated 6-11-70. Validity considered good at subsystem level on basis of rough checks against Apollo CER's.</p> <p>(2) Higher ranking of 0.5 for all subassemblies based on UAC/HS data except for N<sub>2</sub> conditioning, H<sub>2</sub> depolarizer, and Sabatier reactor. This ranking benefit reflects advances in know-how expected from Space Station prototype (SSP) activity expected prior to phase C inception, which is not reflected in comparative data. Where rankings are not noted, it indicates that MSS know-how has been assumed to be equivalent to the comparative know-how without actually determining the ranking.</p> <p>(3) Total costs of fecal and urinal units based on UAC/HS data. Split based on AiResearch B&amp;F on 33 ft Station. Waste processor estimated to cost halfway inbetween, based on discussions with Engineering.</p>				

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Table 4-6. Traceability of Cost Evolution Reference MSS, EPS

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Solar Array	GE EL-405 Data 33 ft Station	1.0	3 vs 4, 75%	The non-recurring and recurring cost is based on GE data as used in DRL 5 estimate, but scaled to the current area (equivalent to wt or power adjustment) on an 85% cost reduction curve was 10,000 sq ft (90 kw) on 33 ft Station, is 8000 sq ft (72 kw) on MSS. Accordion fold-out type assumed to be equally complex to GE roll-out design. Know-how assumed greater because large fold-outs are already within state-of-the-art, rollup is new.
Power Transfer/ Orientation	Apollo EPS	1.0	3 vs 4, 75%	The Apollo EPS represents a mix of tasks similar to the MSS power transfer and orientation. The power transfer is electrical transfer to the conditioning areas. The orientation system is a combination of motors, gears and bearings. The MSS effort is within the state-of-the-art and will require no major development program.
Primary Generation Support Structure	SII Structure	1.0	2 vs 4, 50%	The structure requirements are basically a support boom on which the solar array deployment mechanism is attached. It must have sufficient rigidity to support the transfer operation of the array. Equipment equivalent to a minor modification of SII structure can be used.

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Table 4-6. Traceability of Cost Evolution Reference MSS, EPS (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Primary Battery	Apollo EPS CER	1.0	<1 vs 4, 10%	Packaging Skylab batteries. For lack of non-recurring data on Skylab, we are using Apollo data. Batteries on Skylab more complex than Apollo due to longer life, higher power, more frequent recharging, but CER contains other more complex components. Overall judged to be 100% of Apollo CER. Know-how much higher than Apollo due to existing equipment. Recurring costs based on current price of \$7,500 delivered by subcontractor.
Secondary Battery	NASA Big Meadows Workshop Data + 45% Growth	1.0	3 vs 3, 100%	Assume development performed during START program. Design effort based on Apollo Eagle-Picher battery, plus 45% growth. This is equivalent to higher complexity over existing batteries. Higher amp-hour, more complex charge-discharge system, including temperature control, longer life.

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Table 4-6. Traceability of Cost Evolution Reference MSS, EPS (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Fuel Cells	Shuttle Fuel Cells	1.0	<1 vs 4, 10%	Will use components identical to those on Shuttle. Only very simple integration problems are unique to MSS. Shuttle needs development oriented to higher power, longer lifetime, re-start capability, lower volume, lower fuel consumption, and lighter wt/kw than Apollo. Hence, some development work is required on Shuttle.
Plumbing	Apollo RCS Feed Control (Same as in RCS Subsystem comparative data)	1.0	3 vs 4 for 1st unit, 75%  <1 vs 3 for 3 remaining units, 10%	This represents only tubing and valving hardware. As the interface components between the bussing and the four units are identical, the weight of one unit has been used for initial design cost, with packaging effort only on the others. Apollo required extensive development of valves, regulators, etc., which will not be required here.
Mounts for Assemblies Other than Power Generation	33 ft Station Structure (derived from SII Structure)	0.75	2+ vs 4, 66.7%	Bracketry, vibration mounts, etc., simpler than 33 ft Station overall structure and know-how level higher. Know-how between 2 and 3 to allow for some original design work as well as for the equivalent of minor mods to existing designs.

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Table 4-6. Traceability of Cost Evolution Reference MSS, EPS (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Power Conditioning/ Dist.  Chargers Controls Solar Inverter Battery-Fuel Cell Inverters (1) Secondary Bus Feeders Contactors Bus Structure Wiring	Items from Apollo EPS	Relative component complexity factors: 10 20 10 10 10 3 5 2 1 } Overall Factor 0.8	Overall: 2.5 vs 4, 62.5%  Component know-how: 3 3 3 2 2 2 2	This equipment is lumped together for lack of component CER data. Overall complexity assumed less than Apollo because of greater room in which to package components. After deriving overall subassembly costs, costs by components is derived by estimating relative complexities and weights of the components. Overall know-how about 2.5 on MSS, with variation among components estimated as shown.
Lighting Fixtures	Apollo EPS	1.5	3 vs 4, 75%	Assume development required to improve the Skylab lights from 25 Lumens to 40 Lumens. This could require significant redesign, but saves 10-100 times in wattage requirements
(1) Assumed to be a modification of the solar array inverter, which is considered a new design.				

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Table 4-7. Traceability of Cost Evolution Reference MSS (G and C)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How (1) MSS vs Comparative, Factor	Rationale
Horizon Tracker Electronics Optics/Electronics	Quantic Ind. B&P	1.0	2 vs 2, 100%	Horizon Tracker--The selected unit has been developed and is being qualified for an unmanned AF program. It is expected that some delta qualification and some minor redesign will be required to incorporate on-board checkout (OBCO) and maintenance. The optics unit will require repackaging.
Star Tracker Optics/Electronics	Quantic Ind. B&P Cost on Horizon Tracker	0.9	2 vs 2, 100%	Star Tracker--The selected unit is believed to be under space qualification by the AF. Some delta qualification and repackaging will be required.
Sextant/ Telescope	Kollsman (Apollo) AC Electronics	1.0	<1 vs 3, 20%	Sextant/Telescope--The Apollo sextant/telescope modified to permit in-flight maintenance. Previous discussions with Kollsman indicate that is feasible and is a design problem and not a development problem. Estimated that only 20% of the Apollo design effort will be required.
Preprocessors (all except CMG)	ISS Preprocessor	1.0	<<1 vs <1, 16.7% for each of three items	Identical components and system specification to ISS Preprocessor--integration problem only, with learning from ISS.
(1) (See footnote at end of table.)				

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Table 4-7. Traceability of Cost Evolution Reference MSS (G and C) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
Navigation Base	(Optical) AC Electronics	1.0	4 vs 4, 100%	Navigation Base--Similar to the Apollo navigation base--no more complex, but a unique design will be required.
Alignment Links	Kollsman (Apollo)	1.0	1 vs 3, 10%	Alignment Links--Currently available hardware is suitable. Simple mounting problems only.
Strapdown Inertial Measurement Unit (IMU)	AC Electronics	1.0	2 vs 3, 67%	Strapdown IMU--Will use gyros currently being developed under NASA contract. Assume gyros and accelerometer are available with only minor development and redesign required. Should be able to use a derivative of Shuttle equipment.
Control Moment Gyro	GE EL 513 (CMG 1 Data, 33 ft Station 'A')	1.0	3.5 vs 3.5, 100%	Control Moment Gyros--Development required with minor technology advancement--primarily a design effort. GE has estimated cost and provided a preliminary development program.
CMG Preprocessor	ISS Preprocessor	1.0	2 vs 2, 100%	Assume a new configuration equivalent to CDC 469, which in turn is considered a minor modification of predecessor designs.
(1) (See footnote at end of table.)				

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Table 4-7. Traceability of Cost Evolution Reference MSS (G and C) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
Jet Driver Unit	M-H (Apollo RCS)	1.0		RCS Driver Electronics--This unit is similar to the jet driver electronics for Apollo. A new design is required, but present technology is adequate.
Software	GE IMS for 33 ft Station	Eng Derived Value		Derived by mathematical formula.
Mounts and Supports (Mod Base)	S-II Structure CER	0.5	2 vs 2, 100%	Exception is the optical reference with a 200% complexity.
<p>(1) Where factors and rankings are not noted, MSS know-how has been assumed to be equivalent to the comparative know-how without actually determining the ranking.</p>				

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Table 4-8. Traceability of Cost Evolution Reference MSS (RCS)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Onboard Tanks	Beech Cryo Tank (Apollo)	0.85	2 vs 4, 50%	The onboard tanks will be the same as the cargo module tanks except without a metal diaphragm and without the outside shell to form the dewar. It is estimated that this tank will require 85% of the effort required for the dewar tank, both in development and manufacturing. This does not include gauging which is considered separately.
Gauging	Simmonds Propellant Utilization Gauging (PUG) (Apollo)	1.0	4 vs 3, 125%	Specific mechanism for gauging not defined, assume complexity equal to Apollo PUG, but reflect uncertainty in concept by showing less know-how than estimated for Apollo.
Heat Exchanger	Service Propulsion Subsystem HX (Apollo)	1.5	2 vs 2, 100%	It is assumed that a single heat exchanger can be developed for both O <sub>2</sub> , H <sub>2</sub> , and N <sub>2</sub> . A single heat exchanger design would have the same complexity as the SPS heat exchanger. The 150% complexity is to account for the development of a single heat exchanger to meet a wide range of requirements and the associated controls.
Blower	ECS Blower (Apollo)	1.7	3 vs 2, 150%	Same as HX, plus the added requirement of designing the components to operate at much colder temperatures.

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Table 4-8. Traceability of Cost Evolution Reference MSS (RCS) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Feed Control (Lines, Valves, Regulators)	Feed Control (Apollo RCS)	1.1	1 vs 1, 100% (Lines)  2 vs 2, 100% (Other)	The additional complexity is to account for the addition of insulation required on some of the lines.  Many of these valves must operate over a wide range of temperature. These regulators must meter the gas flow as a function of both pressure and temperature (Apollo valves metered pressure only).
Accumulators	SPS and RCS He Bottles (Apollo)	1.0	2 vs 2, 100%	The complexity is the same if the accumulators contain O <sub>2</sub> , H <sub>2</sub> at low pressure only (~100 psia). If they also are used at high pressure with O <sub>2</sub> , H <sub>2</sub> (buildup) there may be a materials compatibility problem which must be considered.
Engines (Cryo)	Service Module (SM) RCS engine w/o heater	1.0	3 vs 3, 100%	The O <sub>2</sub> /H <sub>2</sub> engines will require an ignition source which was not necessary with the Apollo engines. They are less complex, however, in the response times required, and lower thruster temperatures (a degraded ISP will be used to alleviate this problem). The detonation problems encountered in the development of the SM RCS engines are not anticipated.
Engine Housing	SM Structure	1.0	4 vs 4, 100%	Similar to Service Module engine housing. Some development allowed for in addition to new design.

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Table 4-8. Traceability of Cost Evolution Reference MSS (RCS) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Mounts and Supports	S-II Structure CER	0.5	2 vs 2, 100%	



obtain a total in-house portion. This portion was then allocated by weight to the engines, tankage, and feed control, respectively, to obtain in-house cost factors. These factors were applied to the subcontractor costs derived for the MSS RCS subassemblies.

The traceability data for the information subsystem are shown in Table 4-9. In many cases, the data used by the subsystem engineer for comparative purposes in defining complexity and know-how ratings represent commercially available equipment. Unlike other subsystems, weight was not used as a parameter in many subassemblies, especially for data processing and display/control items. Some items include one complexity factor to represent the use of off-the-shelf units of the comparative data item and another complexity factor representing the effort necessary to tie these items together, expressed as a factor of the effort necessary to design or produce the comparative item. As might be expected from the use of commercial items for comparative data, many of the complexity factors considerably exceed unity. Also, unlike other subsystems, a plot of know-how factors; factor for other subsystems are selected judgmentally by the estimator without the use of plots.

The software costs of the ISS were all assumed to be nonrecurring, using formulae as described in Section 3. The costs of programming assume major reductions in the cost per instruction from previous experience. These reductions are contingent upon the development of a simpler procedural language (then FORTRAN) called HAL. It is assumed that this language will be fully developed by the start of Phase C of the MSS project. The number of required boards by type of program for the MSS were estimated to be as follows:

Supervisory Program	772,000
Application Program	970,000
Data Base Program	<u>11,959,000</u>
Total	13,701,000

Table 4-9. Traceability of Cost Evolution Reference MSS (ISS)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How(1) MSS vs Comparative, Factor	Rationale
Data Processing				
Data Bus Control Unit	Shuttle CPU/MSU CER	1.1	3 vs 4, 75%	Bit rate 10 times that of Shuttle, same reliability during operation, but life is 3 years in quiescent environment vs 10 days hard environment for Shuttle. Not so many acceleration and deceleration cycles as Shuttle.
RACU	Shuttle ACT Unit	1.5	3 vs 4, 75%	Ten times the Shuttle bit rate, with life-time requirements as in data bus above. Larger number of inputs per unit and more central location than Shuttle. Asynchronous rather than synchronous, i.e., must be addressed individually. Need to look at specific experiments. Creates need for data transfer as well as monitoring function. Station environment more benign than Shuttle and doesn't need digital-to-analogue conversion. Station RACU's will need memory, Shuttle's don't. Same compactness (density).
Central Timing Unit	Shuttle CPU/MSU	1.0	<1 vs 3, 8.33%	Similar to Shuttle clock. Change diode mix, counter, and mounting.
Central (2) Processor, I/O Unit	IBM Model 6, System 3, Medium Size, 'Catalog' Price	2.0 New, 1.0 for Unchanged Units	2 vs 2, 100%	Using comparative system hardware units. Making 4 units 'play' together is more complex than designing each one. Combining them is new design effort.

(1) (See footnote at end of table.)

(2) Utilizes comparative system hardware units.

Table 4-9. Traceability of Cost Evolution Reference MSS (ISS) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
Data Processing - Continued				
Central Processor, Arithmetic Unit <sup>(2)</sup>	IBM Model 6, System 3, Med. Size, 'Catalog' Price	2.0 New, 1.0 for Unchanged Units	2 vs 2, 100%	Similar rationale to I/O unit. Making 4 units 'play' together is more complex than designing each one. Combining them is new design effort.
Central <sup>(2)</sup> Processor, Operating Memory	CDC 469 Preproc. + Extended Memory, Catalog Price	1.0 New, 1.0 for Unchanged Units	2 vs 2, 100%	Interface problems not more severe than CDC 469 design. Just tie together. Must redesign logic registers and decoders to handle 32 bit word instead of 16. Plated wires, like CDC 469. Combining them is new design effort.
Central <sup>(2)</sup> Processor, Mass Memory	CDC 469 preproc. + Extended Memory, Catalog Price	1.0 New, 1.0 for Unchanged Units	2 vs 2, 100%	Plated wires, like CDC 469. Must design logic card, like operating memory. Combining them is new design effort.
Central <sup>(2)</sup> Processor, Archive Memory	Sykes Datatronics Compu/Corder 100, Catalog Price	2.0 New, 1.0 for Unchanged Units	3 vs 2, 200%	4 of these replace about 100,000 cassettes. More bits, more tape width and length in cartridge vs cassette. Combining is new effort.
Local Processor	CDC 469 and Extended Memory Catalog Price	1.0	<1 vs 2, 25%	Off-the-shelf, brackets, and mounts only.
Terminal Unit	Systems IV-70, Catalog Price	1.5	2 vs 2, 100%	Must add RACU capability and interface with data bus. Has 4-phase keyboard and a display with local memory.

(1) (See footnote at end of table.)

(2) Utilizes comparative system hardware units.

Table 4-9. Traceability of Cost Evolution Reference MSS (ISS) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
Data Processing - Continued				
Preprocessor	CDC 469 Computer only, Catalog Price	1.0	1 vs 2, 50%	Off-the-shelf with brackets, cold plates, etc., added.
Display/Control				
Command Console	List of Components at Catalog Prices	1.0	3 vs 2, 200%	Problem is to make all components work together--console, panel displays, CRT, microfilm display, monitor alarm lights, hand control unit, central timing display.
Terminal Unit	Systems IV-70, Catalog Price	1.5	2 vs 2, 100%	Portable unit. Generally similar to above terminal unit in complexity, K-H, new design.
Microfilm Projector	Microscan System Model 1000, Catalog Price	1.0	1 vs 2, 50%	Off-the-shelf, mounting problems only.
Printer	Hewlett-Packard Model 50508, Catalog Price	1.0	1 vs 2, 50%	Mounting problems and cold plates only.
Facsimile Unit	Magnafax, Eng Est Catalog Price	3.0	4 vs 2, 300%	Need resolution for 70 MM negative and produce prints for same resolution use as is.
Wall Clocks	Eng Estimate of Catalog Price	1.0	2 vs 2, 100%	Use as is.
Local Monitor Alarm Units	Eng Estimate of Catalog Price	1.0	1 vs 2, 50%	Mounting problems only.

(1) (See footnote at end of table.)

Table 4-9. Traceability of Cost Evolution Reference MSS (ISS) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How (1) MSS vs Comparative, Factor	Rationale
Communications				
Parabolic Antenna (S-Band)	RCA 35db S-Band Antenna	0.85	3 vs 3, 100%	No foldout requirement, tending to 50% complexity vs RCA foldable design. But 70% growth factor for unforeseen design problems, based on statistics of Apollo experience generated by Shuttle cost analysis group. Overall complexity equivalent to $0.5 \times 1.7 = 0.85$ . No know-how fallout from Shuttle, as there are currently no plans for such an antenna, so know-how is 3.
Semi-Directive Antenna (S-Band)	Apollo Col. Div. IDWA	1.0	1 vs 4, 16.7%	Integration problem only, use unmodified Apollo antenna.
Transponder (S-Band)	GE EOSS Extl. Comm.	1.0	3 vs 3, 100%	Any one of 5 selected frequencies, wider bandwidth than Apollo. Using semi-conductors rather than traveling wave tube.
Modulation Processor	GE EOSS Extl. Comm.	1.0	3 vs 3, 100%	Must assemble and disassemble mixed signals from more sources (5) and to more end pts (5) vs 1 and 1 for Apollo, respectively higher data rate, of higher band width.
Central Switching Unit (CTU)	Transistorized Cross Switch, MTL EST/Catalog Price	10.0	3 vs 1, 400%	Increase in size and logic, overrides, drivers. New design.
Video Recorder	RCA-AH-2, Eng. Est/Catalog Price	1.0	2 vs 2, 100%	Off-the-shelf, packaging problem only.

(1) (See footnote at end of table.)

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Table 4-9. Traceability of Cost Evolution Reference MSS (ISS) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
Communications - Continued				
Audio & Entertainment Recorders	Estimate of Ampex Catalog Recorder	1.0	2 vs 2, 100%	Packaging and integrating problem.
Audio/Video Unit	Rough Cost Estimate	1.0	3 vs 2, 200%	Similar to modern push-button telephone.
TV Camera	Eng. Estimate Catalog Cost	1.0	2 vs 2, 100%	Mounting problem primarily.
TV Monitor	Eng. Estimate Catalog Cost	1.0	1 vs 2, 50%	Mounting problem primarily.
Paging Amplifier	Eng. Estimate Catalog Cost	1.0	1 vs 2, 50%	Mounting problem primarily.
<p>(1) Factors are based on ratios of non-recurring to recurring cost for numerous historical programs and several budgetary and planning estimates. Estimating the know-how for each of the programs and assuming it affects design and development only, a curve of the ratio of non-recurring costs as a function of know-how is generated and is used to quantify the ratio of MSS items to the comparative item.</p>				

(1) (See footnote at end of table.)

#### 4.4 SUMMARY OF REFERENCE MSS COSTS

The costing process and the resulting costs were reviewed in Engineering Review Board (ERB) Meeting 20. The data in Tables 4-3 through 4-9 represent the subassemblies, factors, and rationale approved. An outcome of this meeting of particular interest is the inclusion of a 13-foot high-gain antenna in, and the deletion of an approach radar from, the communications assembly of the information subsystem. The review board also established the costs summarized in Table 4-10, as credible costs for reference purposes.

Table 4-10. Reference MSS D&D and TFU Costs  
 (\$ Millions, GFY 1972 Dollar Value)\*

Subsystem	Design and Development	Theoretical First Unit Production
Structures	\$ 74.8	\$ 23.5
ETC/LSS	184.7	31.0
EPS	82.3	61.8
G&C	57.3	11.4
RCS	73.0	7.2
ISS		
Hardware	73.7	35.3
Software	82.9	--
<b>Total</b>	<b>\$628.7</b>	<b>\$170.2</b>
*Appendix E totals adjusted by inflationary factor of 1.05		

## 5. SELECTED CONFIGURATION COSTS

### 5.1 INTRODUCTION

The barbell configuration used for reference costs was ultimately replaced by the cruciform configuration shown in Figure 5-1 and described in broad terms in Section 1. The modules in the six-man initial station are one core module 40 feet long and 12 feet, 8 inches in outside diameter with eight side-berthing ports; two crew/control station modules and two laboratory/ECS station modules about 39 feet long and about 14 feet in diameter; and one power module about 34 feet long and a little over 7 feet in diameter with a solar array of about a 7000-square-foot area. More information about the modules and airlocks used in this configuration is given later. Cargo modules and the modules of the growth station were not defined in so much detail in keeping with the scope of work under the contract.

The selection of the final configuration was an evolutionary design process incorporating technical and cost considerations. In this section of the report, this evolutionary process is described primarily in terms of its impact on costs. Additionally, certain cost ingredients necessary for application to the WBS are included. The impacts of plans for cost avoidance are also estimated.

For reference purposes, the cruciform configuration selected in the evolutionary design process is presented first, in Subsection 5.2. The changes in costs from the reference configuration of Section 4 to those used for the selected configuration reflect design trade studies, described in Subsection 5.3, and changes in weight and hardware dictated by technical considerations, as described in Subsection 5.4. Cost changes in comparative cost data, along with procedures for that cost allocation by module, are described in Subsection 5.5; tooling and special test equipment (STE) and other flight hardware effort costs are costed and included within specific WBS blocks on the basis of the cost ground rules of Section 2. Nonflight hardware and programmatic costs are derived in Subsection 5.6 to permit the costing of the total project. Cargo modules and growth modules are costed in Subsection 5.7 in a more approximate fashion because technical parameters are not so well defined. A cost summary of the MSS project is given next in Subsection 5.8. Finally, in Subsection 5.9, savings due to cost avoidance techniques are presented. These savings are of two types: (1) cost avoidance by engineering design ingenuity which results in the elimination of redundant equipment and the use of low-cost approaches in place of high-cost approaches, and (2) programmatic cost avoidance which takes advantage of policies of



phased procurement and management techniques made possible by new automation and other management tools and by the advances in space technology and experience which make requirements better understood.

## 5.2 SELECTED CONFIGURATION

### 5.2.1 CONFIGURATION SUMMARY

The barbell configuration used for reference costs are ultimately replaced by the cruciform configuration shown in Figure 5-1 and described in broad terms in Section 1. The cruciform was selected for the preliminary design configuration, with provision for the RAM's and cargo module in the -Y plane. Station modules are in the Y-Z plane. This configuration requires only two special modules, core and power, for the initial station. In comparison with the reference barbell configuration, the cruciform offers reduced impulse requirements which affect propellant usage and gas storage, reduced momentum exchange level which affords reductions in CMG size and number, and increased stiffness. The location of the station modules was selected for buildup and station operation efficiency.

The seven modules that comprise the initial station (core, power, SM-1, SM-2, SM-3, SM-4, and cargo) are described in the following paragraphs.

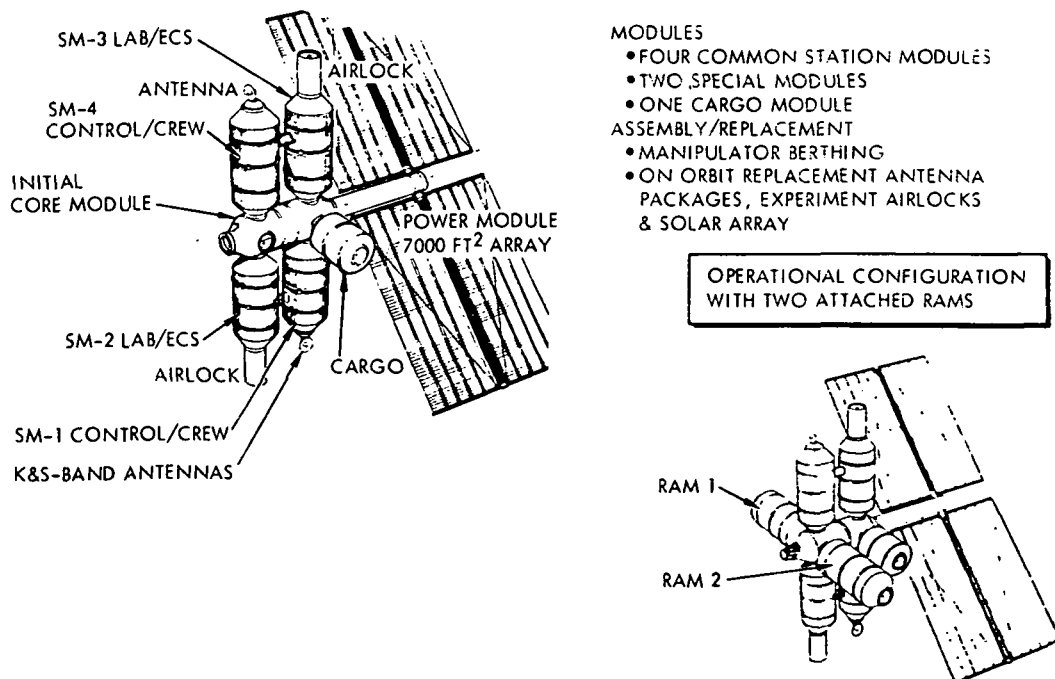


Figure 5-1. Preliminary Design Configuration Initial Station

## Core Module

The core module (Figure 5-2) is 40 feet long between berthing interfaces and has a 12-foot, 8-inch outside diameter. The 15-foot-diameter envelope intersects the edges of the side-berthing ports cluster. Lightweight skin (0.040-inch aluminum) and stringer construction is utilized. The eight side-berthing ports are spaced 20 feet apart, which allows a 5-foot clearance between the station modules. The four side ports are provided with thermal covers. Thermal control of the vertical ports is provided during buildup with special insulation panels.

The installed subsystems are distributed between the  $V_1$  and  $V_2$  volumes separated by the EVA/IVA airlock. The airlock provides an equivalent floor of approximately 5 feet by 7 feet. All of the hatches open outward from the airlock. The EVA hatch (40-inch-diameter clear opening) is located at a 45-degree angle, which provides the maximum clearance between attached modules. The G&C optical reference and CMG's are located adjacent to the RAM berthing ports.

Certain buildup equipment is accommodated such as the antennas, thermal control radiators, RCS propellant, and initial power. All subsystem components are installed with on-orbit shirtsleeve maintenance accommodations including maintenance of the RCS engine assemblies. The utilities

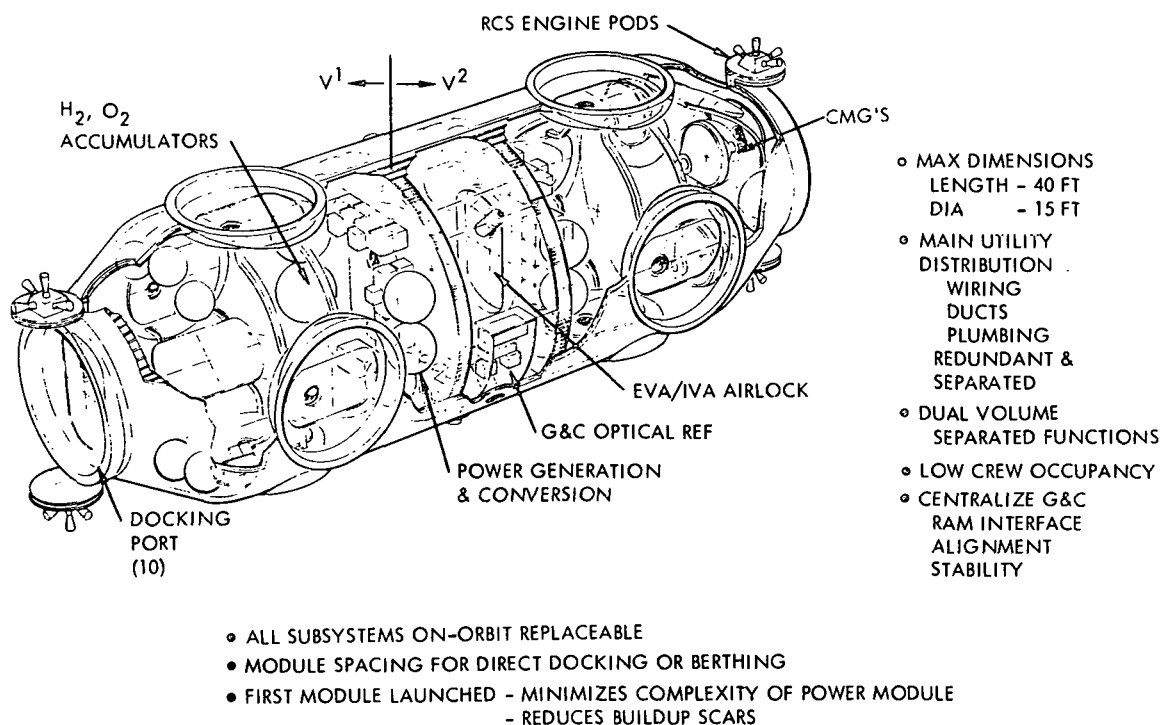


Figure 5-2. Core Module

routing throughout the module from berthing port to berthing port and end to end of the module are redundant and separated for damage containment and safety.

### Power Module

The power module (Figure 5-3) consists of two assemblies, a power boom and a solar array (Figure 5-3). The solar array assembly consists of the arrays and an orientation drive and power transfer mechanism. Shirt-sleeve maintenance of the mechanisms is provided. The solar array assembly is replaceable and utilizes the standard berthing port.

The power boom is 88 inches in outside diameter and 27 feet, 6 inches long. The 88-inch-diameter boom allows the solar array panels to stow within the 15-foot-diameter shuttle payload envelope. The boom is of monocoque construction utilizing 0.145-inch-thick aluminum, which increases its stiffness and consequently increases the natural frequency of the total space station assembly. High-pressure gas storage bottles for repressurization are placed in the boom. Shirtsleeve maintenance and replacement is provided even though the module is normally operated unpressurized.

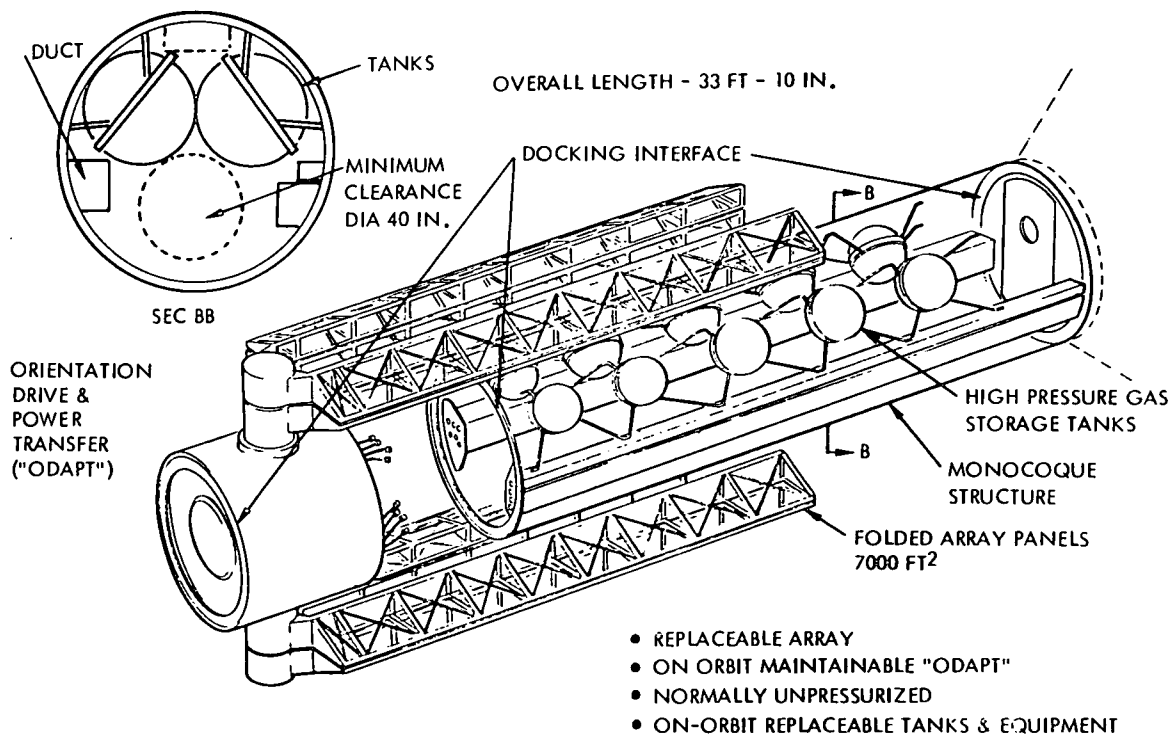


Figure 5-3. Power Module

## Crew/Control Station Modules

The two crew/control modules, SM-1 and SM-4 (Figure 5-4), have common functional allocations and equipment location. Each module performs a similar function in each of the two pressure-isolatable volumes of the station. Where backup functions are provided, they are located in similar areas in the module of the opposite volume.

Both SM-1 and SM-2 contain a commander/executive type stateroom and two crew staterooms in a split-level arrangement. Control centers are located on the upper deck of each module outside the stateroom. The personal hygiene facilities are in similar locations; however, only SM-1 contains a shower. The waste management equipment is located below deck near the personnel hygiene facility to simplify sewage transport and processing.

The area above deck in SM-1 contains the experiment data analysis equipment, including a data analysis control console, a photo-processing laboratory, and an isotonic exercise area. The exercise areas are also equipped to serve as a backup medical facility. The area above deck in SM-4 contains the primary medical and crew care facilities.

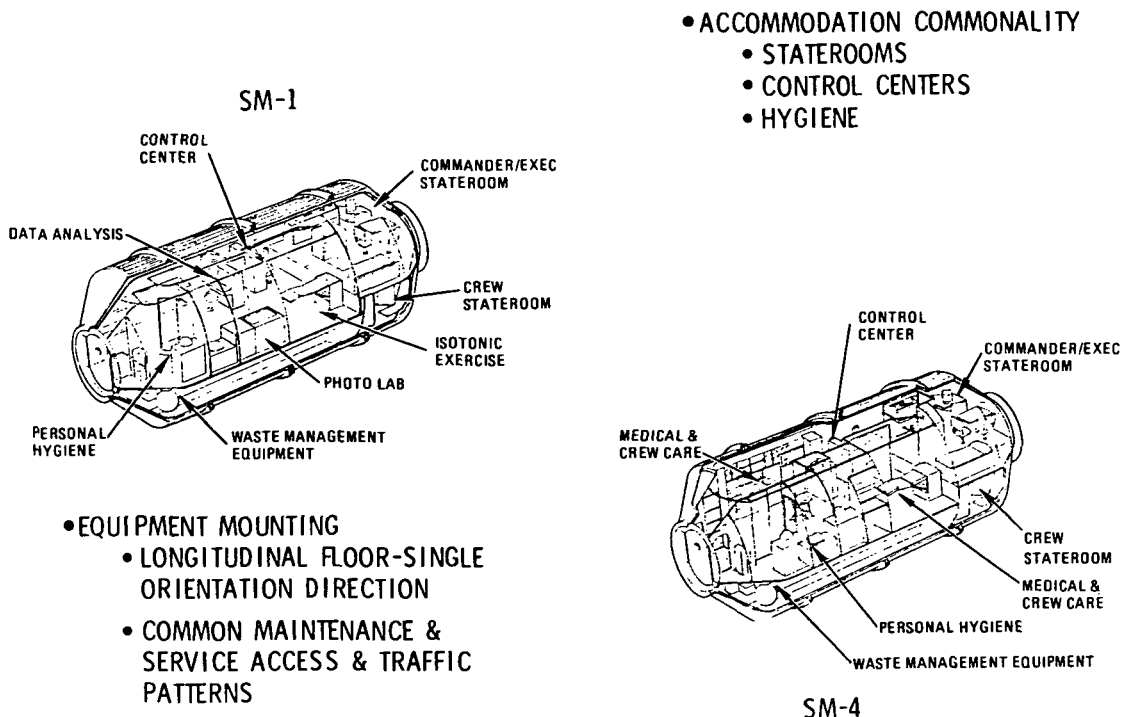


Figure 5-4. Crew/Control Station Modules



Laboratory/ECS Station Modules

The two laboratory/ECS modules, SM-2 and SM-3 (Figure 5-5), are in different isolatable volumes of the station. Where backup functions are provided, they are located in similar areas in the module of the opposite volume.

The lower deck area of SM-2 and SM-3 contain environmental control subsystem assemblies for air revitalization (CO<sub>2</sub> management and atmosphere control). Common installation arrangements provide easy access for maintenance and service. The remaining lower deck area is for storage of station and experiment supplies.

The above-deck area in SM-3 contains the primary galley/dining and recreation areas as well as general-purpose laboratory facilities. The laboratory capability is designed to support both physics and biomedical experiments. The above-deck area in SM-2 contains primarily general-purpose laboratory installations; however, a small backup galley is installed at the inboard end of the module.

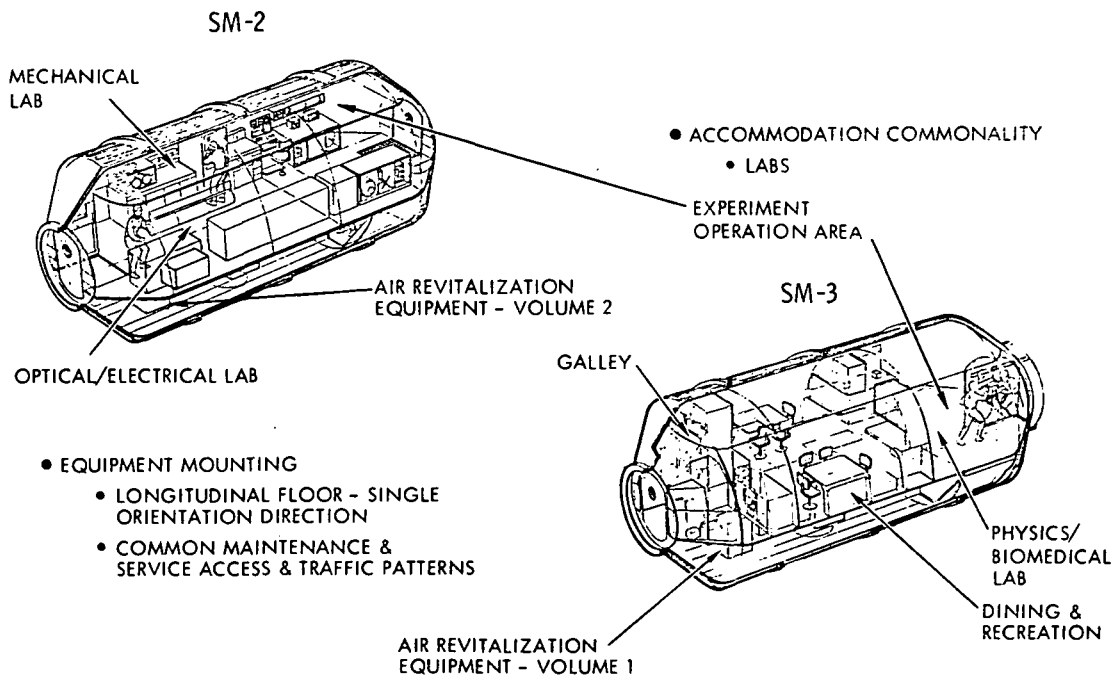


Figure 5-5. Lab/ECS Station Modules

A general-purpose airlock is attached to these laboratory modules. The one on SM-2 points to nadir and the one on SM-3 to zenith. An experiment operations area and airlock loading access space are provided in each module at the airlock end.

### Cargo Module Concept

The cargo module (Figure 5-6) concept utilizes the MSS universal structure except that it is 24 feet in length compared to a station module length of about 39 feet. It is self-sufficient on orbit for six men for 72 hours when in the shuttle cargo bay. Up to 11,800 pounds of cargo can be carried with an up-crew load of six passengers. Passengers would occupy the cargo module only during orbital periods, and transfer to the station would be accomplished through the orbiter. One hundred and twenty cargo containers, located as shown, provide sufficient dry cargo storage capacity to meet resupply and the 120-day storage capacity requirements. Five 48-inch-diameter tanks provide sufficient capacity for all anticipated liquid and gas resupply requirements. Should this requirement ever increase, up to nine tanks can be carried in the annular volume shown.

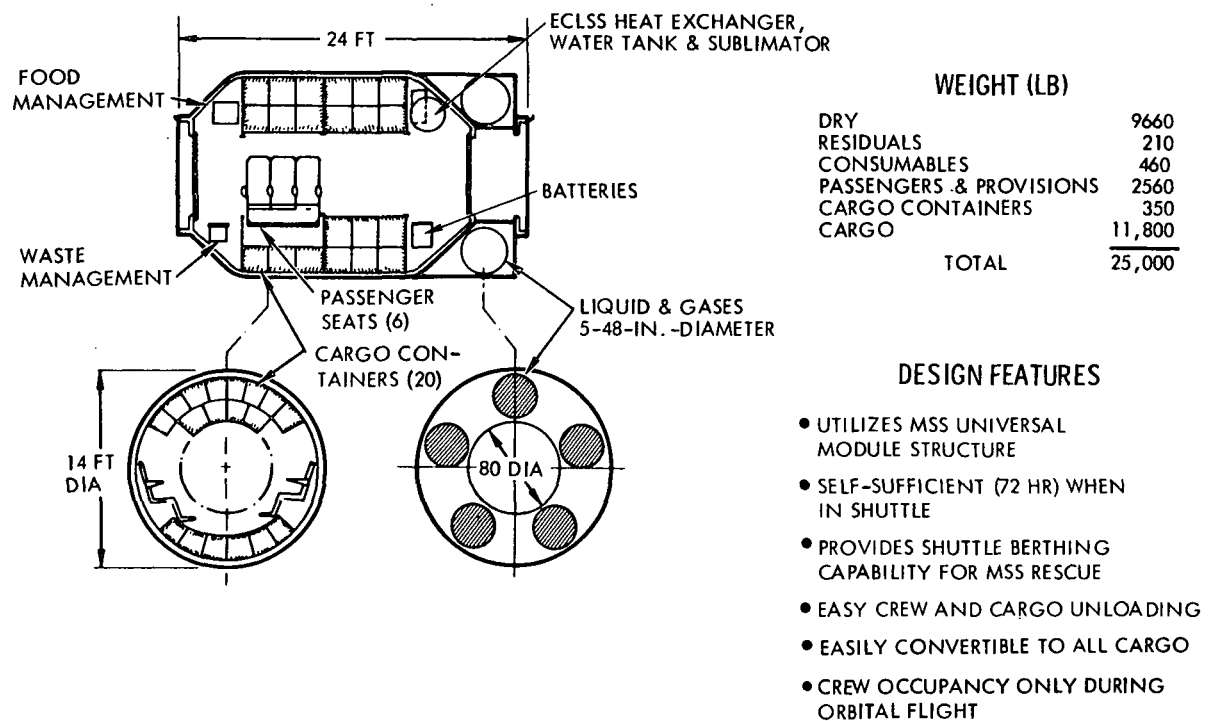


Figure 5-6. Cargo Module Concept

## 5.2.2 EXPERIMENT AIRLOCKS

The experiment airlocks are considered part of the structures and are therefore costed with the primary structure assembly. Operationally, these airlocks are a key portion of the station's experiment accommodations.

Two experiment airlocks (Figure 5-7) are provided as part of the GPL configuration to deploy scientific instruments to the space environment from the station pressurized volume. The nadir-pointed airlock is mounted to the end of Station Module 2 and the zenith-pointed airlock is mounted to the end of Station Module 3. The airlocks are mounted to the station modules with the normal station berthing system that provides mating, sealing, and utilities interfaces. The internal dimensions of the airlock are 80 inches in diameter by 150 inches in length, providing approximately 436 cubic feet of usable volume. The hatch window in the end of the station module is used for viewing the interior of the airlock from the pressurized volume. A standard window is provided in the hinged outer hatch for viewing EVA operations from within the airlock. The hinged outer door utilizes the station berthing system to lock and seal the airlock and is used to support experiment equipment. Both airlocks are pumped down into the station volume by station equipment and pressurized directly from the station atmosphere. Standard subsystem capabilities and deployment devices are provided for the airlocks.

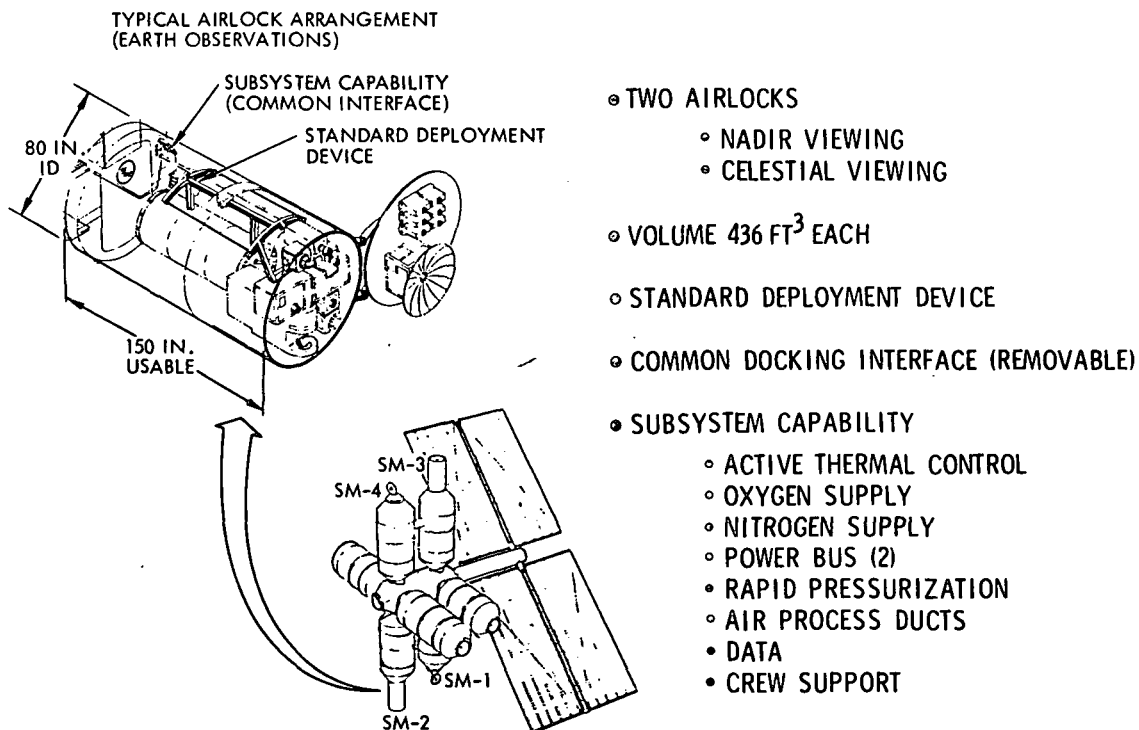


Figure 5-7. Experiment Airlocks

### 5.2.3 SPACE STATION SUBSYSTEMS

The space station system contains seven functional subsystems. Brief descriptions of the subsystems are presented in the following paragraphs.

#### Structural and Mechanical Subsystem

The preliminary design features of the subsystem are shown in Figure 5-8. The station module pressure shell is of monocoque construction utilizing 0.145-inch thick 5052 aluminum alloy. This type of construction and material is cost-effective and insensitive to modifications with long-life characteristics. The three bonded external frames provide the structural payload interface attachment to the shuttle and also provide the manipulator pickup sockets. The external frames provide a clear module interior of 13 feet 8 inches to diameter. An integrated arrangement of radiators, insulation, and pressure shell provides meteoroid and radiation protection and thermal control. Interior arrangement flexibility is provided by utilizing the external ring frames and longitudinal drag longeron. This arrangement will accommodate a longitudinal floor, transverse floors, or no floors.

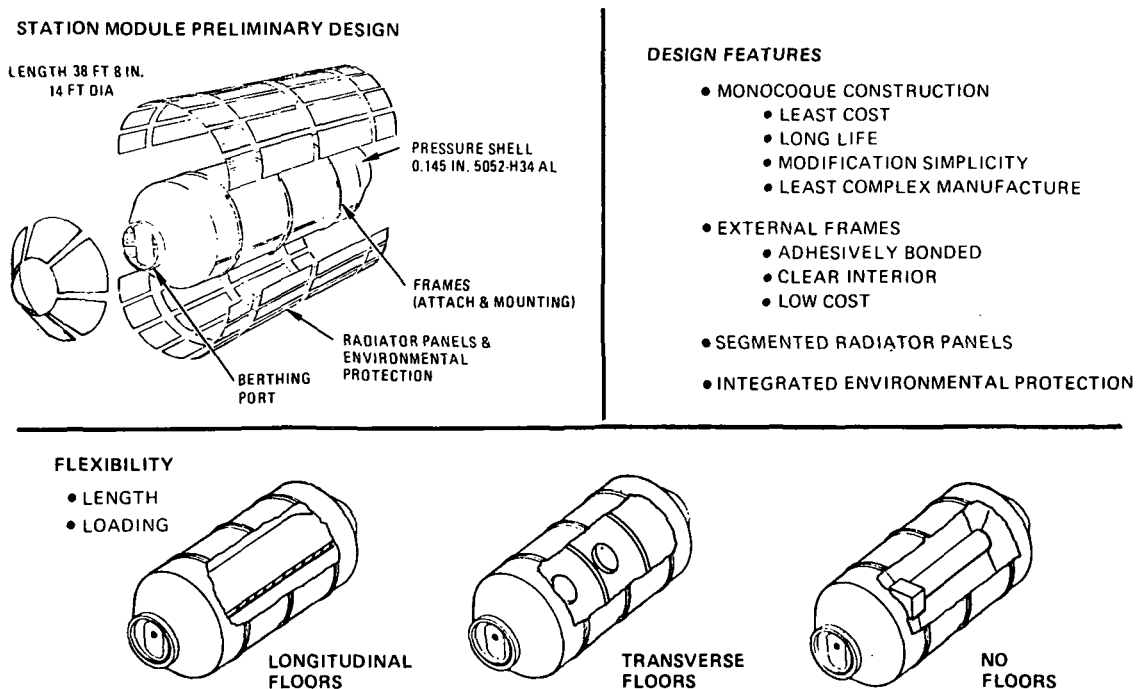


Figure 5-8. Structures Subsystem Design Features

The module has been designed for low-cost monocoque construction (Figure 5-9), using 0.145-inch 5052 aluminum alloy augmented by an 0.030-inch aluminum meteoroid bumper. Three frames are utilized external to the pressure shell, which accommodate the shuttle attach points and manipulator sockets. Kapton-lined insulation is located inside the meteoroid bumper and acts as a secondary bumper.

Environmental Control and Life Support Subsystem

The ECLSS is distributed throughout the modular station (Figure 5-10), with one complete subsystem in each isolatable pressure volume. The repressurization gases are stored in the power boom, with leakage nitrogen, emergency gases (H<sub>2</sub>, O<sub>2</sub>), and other expendables in the cargo module. The ECLSS thermal control radiators are located on the exterior surface of SM-1 through SM-4. Each module has eight panels, a total of 32. The design margins incorporated allow for loss of two panels without impact on station operation.

The dual installation of full ECLSS capability provides mission continuation in the event of a single volume failure, and online redundancy in the event of ECLSS failure. The dual ECLSS separated subsystem results in placement of interrelated subassemblies such as waste management and water management close together, thereby eliminating intermodule connection of

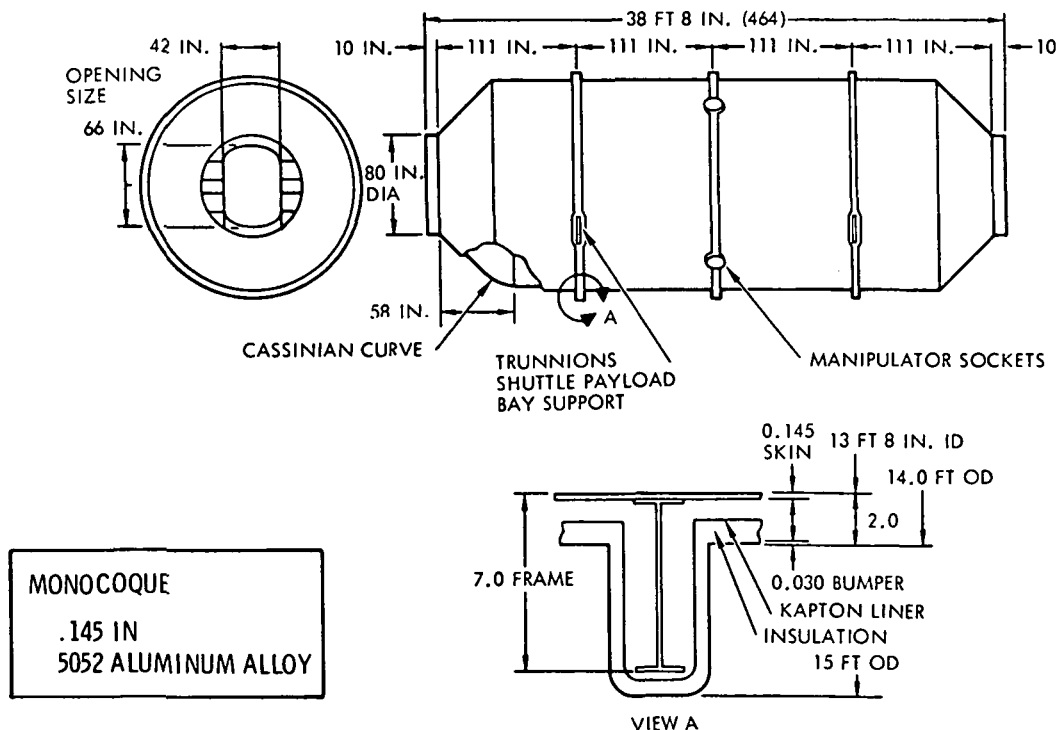


Figure 5-9. Station Module Structural Arrangement

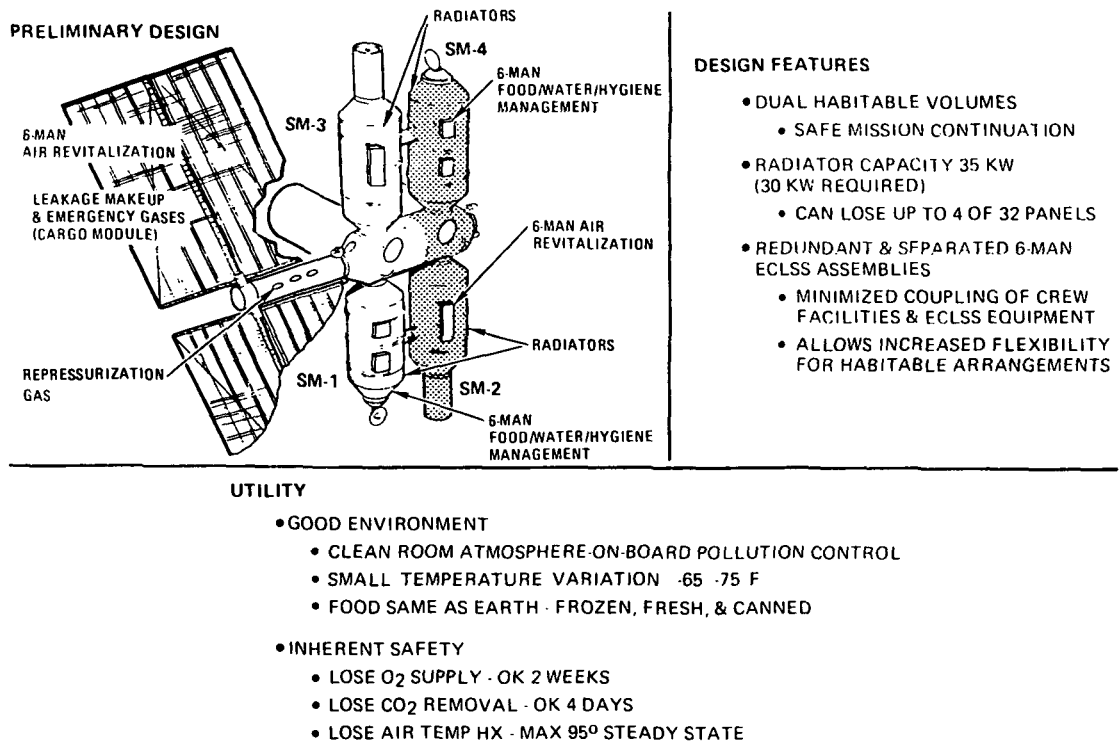


Figure 5-10. ECLSS Subsystem

management of close together, thereby eliminating intermodule connection of urine lines, in addition to reducing greatly the required coupling distance for tubing, ducts, and wiring.

The overall station design provides inherent safety for loss of critical functions such as oxygen supply, CO<sub>2</sub> removal, and atmospheric temperature control. There is sufficient oxygen in the controlled environment to provide metabolic oxygen requirements without oxygen addition for two weeks before reaching fatal oxygen partial pressure levels. The same can be said of CO<sub>2</sub> for a 4-day period at normal generation rates with no removal. Steady-state cabin air temperatures at maximum load have been estimated at a 95 F with the module heat exchanger out after two failures. Each module contains two heat exchangers sized at half the module load; therefore, a single heat exchanger failure would result in a 75 F cabin at maximum heat load.

The selected ECLSS concept (Figure 5-11) for space station application is the regenerative type with reclamation of oxygen from carbon dioxide and water. The individual processes such as Sabatier, electrolysis, and vapor compression are receiving continual development under NASA funding.

The important design features of the oxygen recovery approach are the reduction in logistic resupply and reduction in quantity of gases vented over-board which can contaminate the environment to which experiment program sensors are subjected. The electrolysis is a common process in both ECLSS

and EPS and the advantages of a single hardware development can be achieved. In addition, the two electrolysis installations provide an additional success path for critical functions in both ECLSS and EPS.

A vapor compression water recovery concept was selected for all station water recovery. The vapor compression approach, which utilizes the extraction of energy for condensing on one side of a heat transfer surface to cause boiling on the other side, results in the important design features of both low energy input and low energy output which is heat rejection. The energy input is the form of compressor power which is very small compared to that required to accomplish boiling of waste water. The single concept has only one development whereas dual concepts, which may show a weight advantage, are more complex and costly to develop.

### Electrical Power Subsystem

The EPS design (see Figure 5-12) includes the ability to switch power on the array before it is collected on slip rings. This permits turnoff of power for on-orbit maintenance of turret components and selective switching for power transfer to primary buses and electrolysis units. Switching assists in voltage regulation and helps assure that the converted power is available for station use.

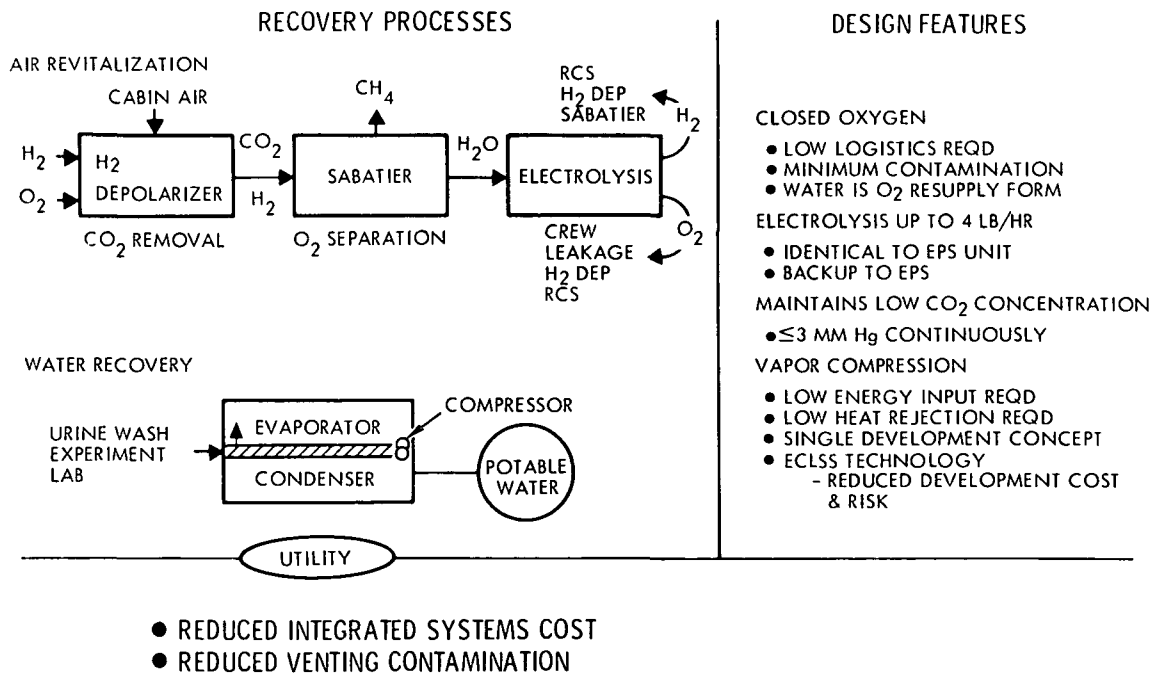


Figure 5-11. ECLSS Concept

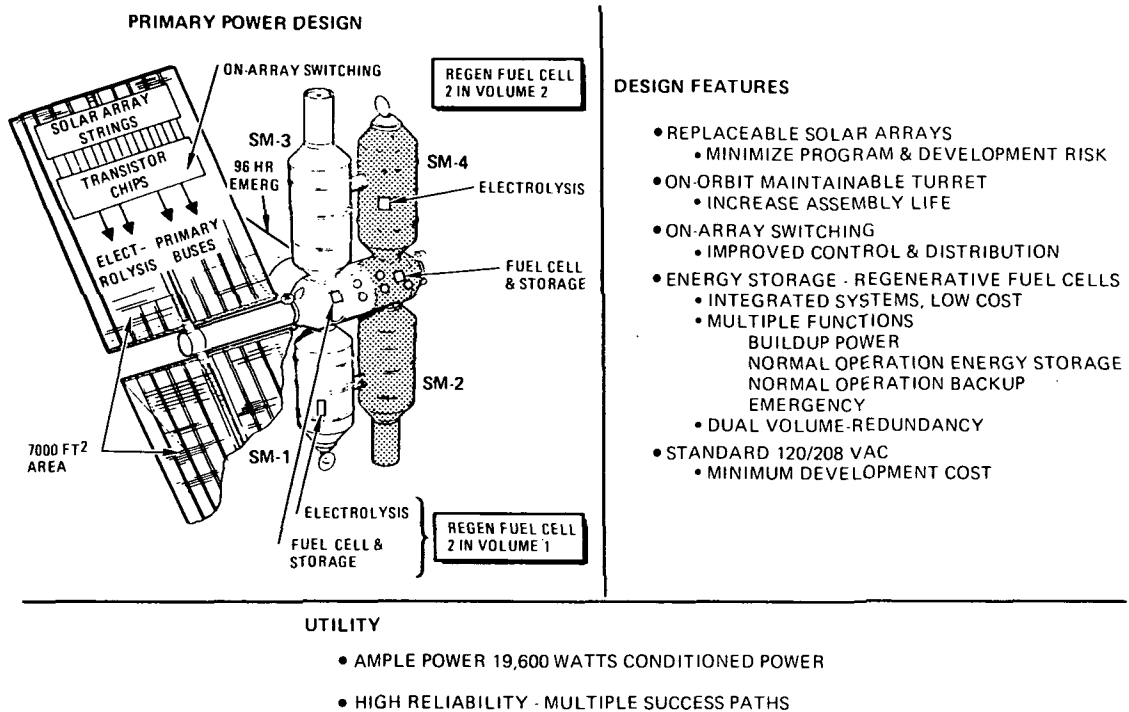


Figure 5-12. Electrical Power Subsystem

A solar array size of 7000 square feet provides for ample electrical power (19,600 watts 24-hour average) over the 5-year life of the initial MSS. The array size includes a 29.3-percent allowance for degradation in the space environment. Replacement is planned at the end of initial MSS life.

A standard 120/208 volt ac distribution provides common power characteristics for experiments and permits the EPS to utilize technology developed by commercial and military aircraft design, leading to lower cost.

Fuel cells and electrolysis are combined in a regenerative energy storage concept to replace large quantities of secondary batteries. The same fuel cells serve multiple purposes to satisfy buildup power and backup and emergency requirements. The fuel cells give the MSS multiple power sources (success paths) to support two isolatable pressure volumes for life support in the event of an emergency.

## Guidance and Control Subsystem

The G&C concept (Figure 5-13) includes a planar array of three double-gimballed control-moment gyros each with an angular momentum of 1100 ft-lb-sec. The gyros are sized for geometric axes, local-level mode operation with a minimum of 12 hours between desaturations. The control-moment gyros are desaturated by firing orbit makeup corrections so that they simultaneously torque the vehicle. The CMG system also provides momentum exchange for an orbit-referenced (principal axes) inertial flight mode.

The G&C computation concept includes preprocessors that provide both developmental and operational flexibility. The system also uses ISS computations where G&C functions are interrelated with other command and control functions.

The station's navigation concept is based on star-horizon measurements. The concept is mechanized to be performed automatically and autonomously. It works independently of ground support, cloud cover, and communication links and uses sensors that are also used for control. Should the shuttle program develop a more accurate navigation concept such as beacon tracking, the station could utilize the system in conjunction with star-horizon measurements to obtain improved performance.

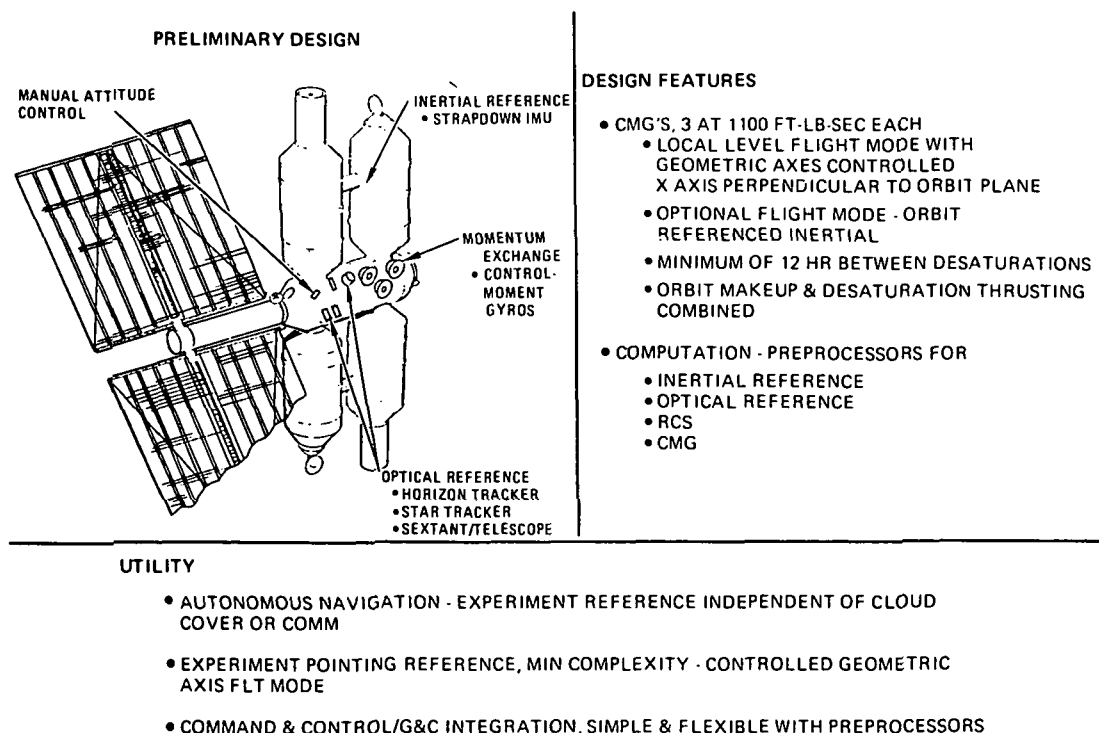


Figure 5-13. Guidance and Control Concept

## Reaction Control Subsystem

Figure 5-14 shows the RCS characteristics, including engines located at each end of the core module on the ZZ axis and the accumulator assemblies which supply the RCS engines with propellants and the ECLSS with oxygen and hydrogen during orbital dark side operations. The RCS engine is shown both in the firing position and sealed for shirtsleeve maintenance (dashed configuration).

The design features of the RCS include oxygen and hydrogen propellants derived from water electrolysis, making water, which is easily transportable and storable, the only resupplied consumable.

The thrusters are independent in that a set of quads at either end of the station can accomplish the RCS functions. The engines operate once every 12 hours to minimize effluent disposal and experiment operations.

Characteristics include the fact that the RCS can adapt to impulse variations by increased frequency of firing and increased electrolysis output.

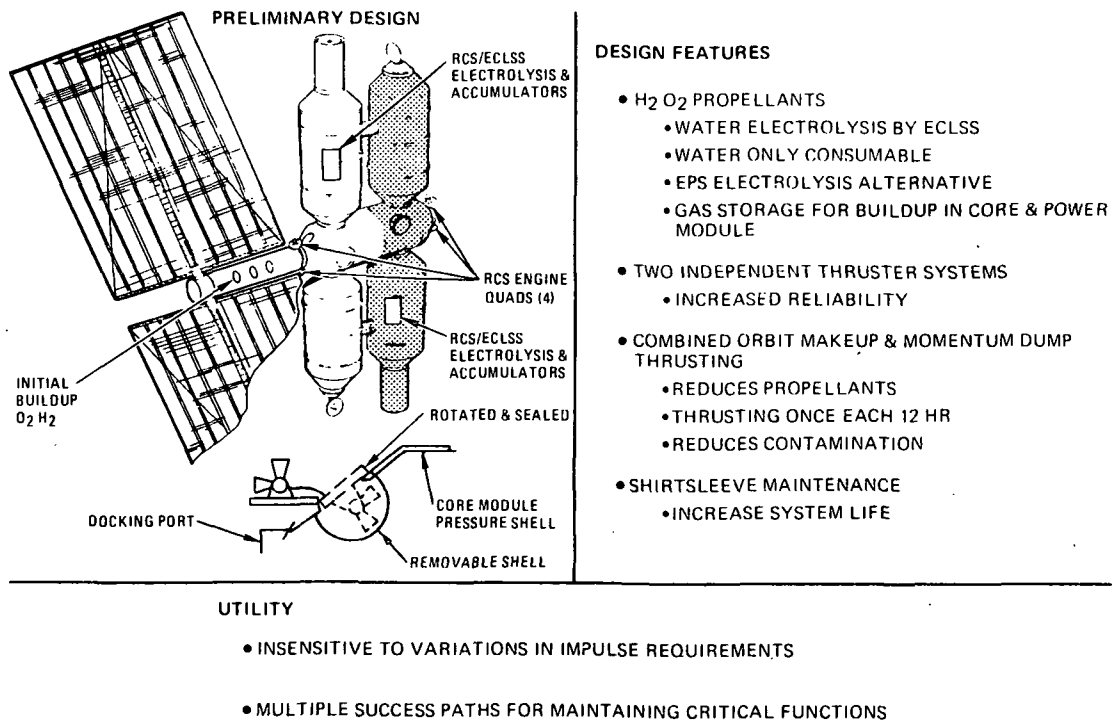


Figure 5-14. Reaction Control Subsystem

## Information Subsystem

The information subsystem (Figure 5-15) is designed with redundant capability to meet the design criteria of the space station. This redundant capability consists of dual control centers, each with a central processor capable of performing the total station subsystem operations. Each control center and central processor has redundancy built within to meet the station failure criteria. One control center is used for station operations while the other backs up this function. The backup control center is used for experiment operation during normal operations and is converted (by software) to station operations only during critical periods or those periods when significant onboard checkout is being performed. A quad redundant digital data bus is provided. Dual communications packages are provided, one on SM-1 and one on SM-4. Each package has the ability to transmit and receive on the K, S, and VHF bands.

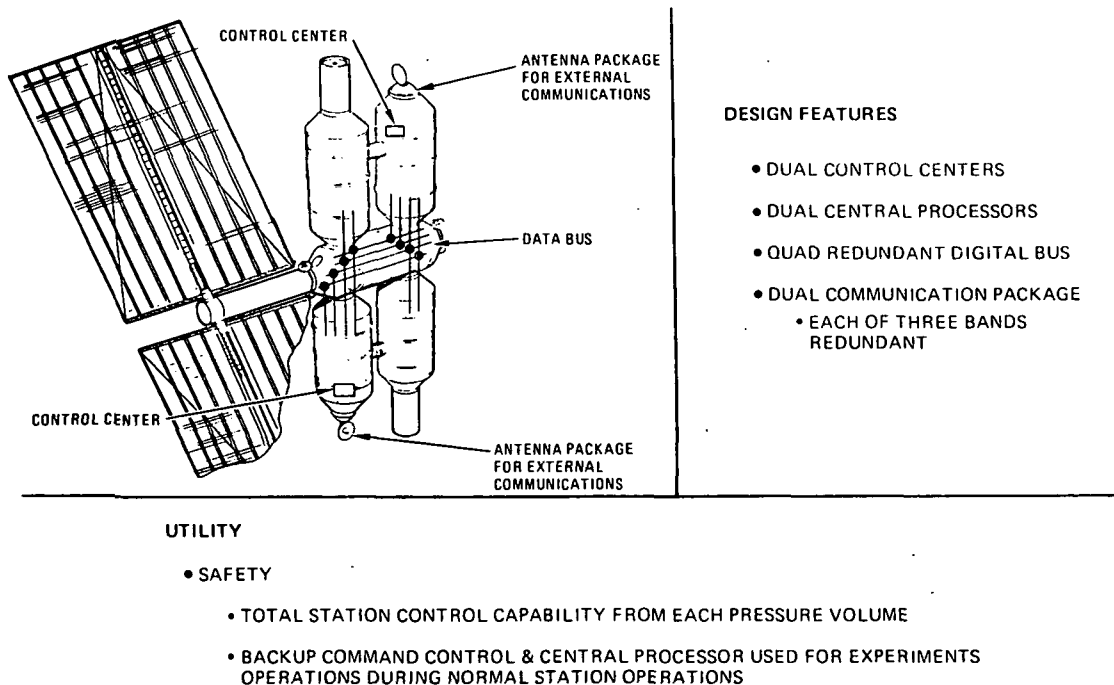


Figure 5-15. Information Subsystem

The concept for the external communications package (Figure 5-16), is one which will simplify the equipment, require less component development, and allow greater equipment flexibility. The mixing of the various data sources and the modulation to S band (low power) is accomplished in the control centers and transmitted to the S-band power amplifiers and K-band up-converter (located in the external communications package). The K-band up-converter multiplies the S band to K band and provides the power for antenna radiation in the K-band mounted electronics. The reception of RF information is accomplished the same way with the receivers located at the antennas.

Four separate buses are provided in the station, each having builtin redundancy.

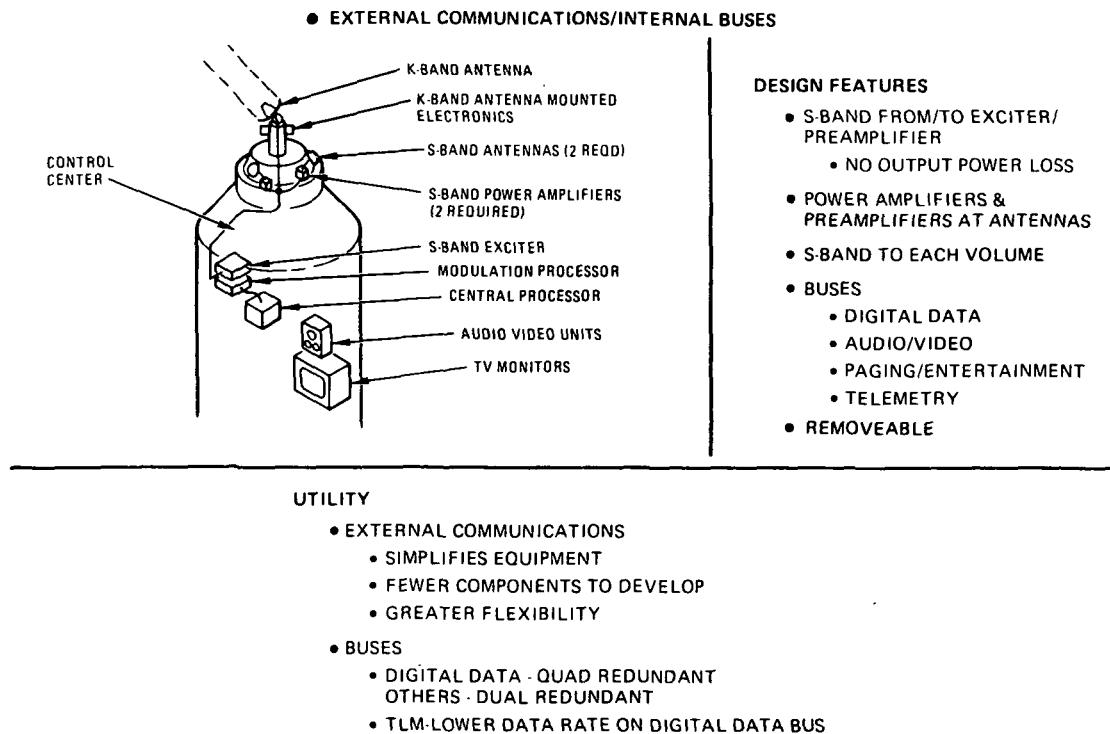


Figure 5-16. ISS External Communications Internal Buses Concept  
Crew Habitability Subsystem

The habitability designed into the modular space station emphasized comfort, a familiar environment, and special conveniences. All facilities have been designed for male and female crewmembers.

The phantom sketch of station Module 4 (Figure 5-17) illustrates several of the key habitability features. With regard to comfort, ceilings and areas are based on the requirements of 95-percentile crewman extrapolated to the 1981 timeperiod; privacy is provided. Other areas are left as open as possible to provide a sense of spaciousness to the maximum extent possible. The up-direction from all floors in the space station are in the same direction to minimize the requirement for crewmen to reorient themselves mentally from one module or location to another. In addition to the conveniences listed, cupboards, closets, and other storage areas are designed within the reach capabilities of 5-percentile female crewmembers.

The emphasis placed on the shaping, sizing, and orientation of interior equipment is intended to provide the crewmen with as large and as familiar an interior environment as possible to assure a favorable crew psychological attitude for long-duration MSS mission stay times (up to 180 days).

Phantom sketches of SM-4 and SM-1 (Figure 5-18) illustrate the location and some of the crew care/exercise primary and backup facilities. The principal functions of these areas are to provide specialized care to injured or ill crewmen, provide the necessary equipment for crew stay time qualification beyond 60 days and up to 180 days, provide equipment to support the life sciences experiments, and provide isotonic equipment for crew conditioning.

**LIVING AREAS**

• **COMFORT**

- MAXIMUM CEILING HEIGHT & AREA DIMENSIONS
- INDIVIDUAL TEMPERATURE CONTROL
- MAXIMUM PRIVACY
- AWAY FROM NOISE, TRAFFIC
- VARIED FOOD, PREPARATION CAPABILITY

• **CONVENIENCES**

- STATEROOMS NEAR CONTROL CENTER
- STATEROOMS NEAR PERSONAL HYGIENE
- ENLARGED COMMANDER'S STATEROOM

• **FAMILIAR ENVIRONMENT**

- RECTILINEAR FACILITY SHAPES
- ALL INTERIOR EQUIPMENT IN UPRIGHT ORIENTATION (EARTH-LIKE)
- CONSISTENT ORIENTATION CUE

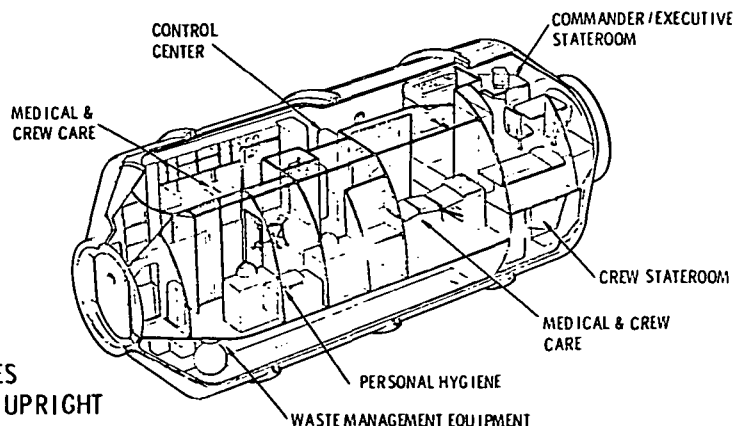


Figure 5-17. Crew Habitability Features

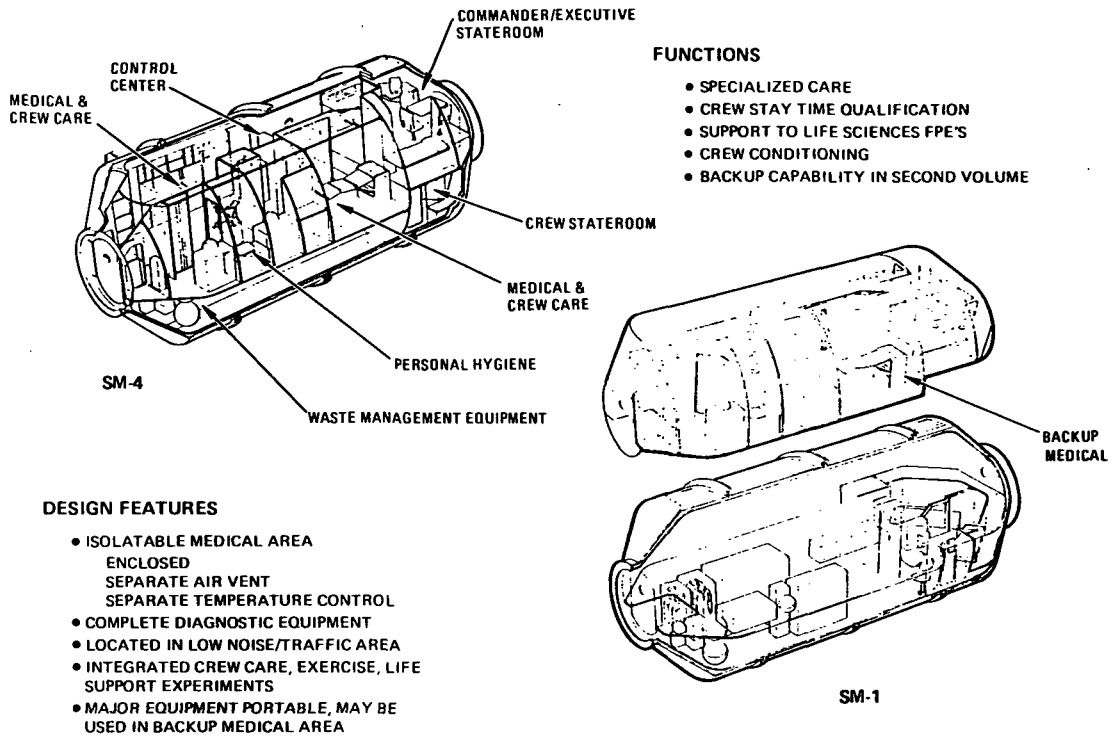


Figure 5-18. Crew Care and Exercise Features

The design features of these areas are listed on the chart. Isolation is required for bacteriological control; i.e., forward and backward contamination (in the primary facility only). Sufficient diagnostic and medical care equipment provides the capability needed by the doctor/technician for decision-making in regard to the necessity for an interim shuttle launch to effect evacuation of a seriously injured or ill crewman.

The isotonic or exercise area located in the backup medical area, across from the primary control center, contains a privacy screen for use by mixed male and female crewmembers.

### 5.3 TRADE STUDIES

As pointed out in Section 4, it was established that the WBS Levels 6 and 7 D&D and TFU costs for the reference configuration were credible and in sufficient depth to conduct valid subsystem trade study options. These costs, which were presented in 1972 dollar values in Section 4, are repeated below in the 1971 dollar values of the original analysis for easy comparison with the detailed trade study costs presented in Modular Space Station Preliminary System Design; Volume VI, Trades and Analysis (SD 71-217-6). The totals (sum of D&D and TFU) in Table 5-1 are meaningful since only one station is planned to be built in this project.

Table 5-1. Summary of Reference MSS D&D and TFU Costs  
 (\$ Million, GFY 1971 Dollar Value)

Subsystem	D&D	TFU	Total
Structure	\$ 71.2	\$ 22.4	\$ 93.6
Environmental control/life support	175.9	29.5	205.4
Electrical power	78.4	58.9	137.3
Guidance & control	54.6	10.9	65.5
Reaction control	69.5	6.9	76.4
Information	149.1*	33.6	182.7
<b>Totals</b>	<b>\$598.7</b>	<b>\$162.2</b>	<b>\$760.9</b>
*Hardware	\$70.3		
Software	78.8		

#### 5.3.1 INTEGRATED TRADE STUDIES

Previous studies of space station subsystems have recognized and incorporated the integration possibilities of various subsystems. For example, the results of the Phase A MSS indicated that the G&C would require some dedicated data processing equipment but could be integrated with the ISS central processing computer for certain computational functions. These results were incorporated into the reference MSS configuration. Subsequently, the EPS, RCS, and ECLSS were identified as candidates for integration. Since the subsystem alternatives included cryogenic gas storage in the cargo modules plus buildup packages, the reference MSS was augmented with cost estimates for cryogenic tank storage and buildup feed controls for the ECLSS and RCS, as summarized in Table 5-2.

Table 5-2. Reference MSS Adjusted for RCS Buildup Package and Cargo Module Cryogenic Tank Storage (\$ Million, GFY 1971 Dollar Value)

	D&D	TFU	Total
Reference MSS	\$598.7	\$162.2	\$760.9
Buildup RCS package and cargo module cryogenic storage	11.0	9.8	20.7
<b>Total</b>	<b>\$609.7</b>	<b>\$172.0</b>	<b>\$781.7</b>

The integrated EPS/RCS/ECLSS options were developed by first establishing candidate options for each subsystem. Approximately 10 options were defined for RCS considering the type of propellant and storage location plus the use of low-thrust resistojets to supplement the regular RCS thrusters. Three EPS options were defined using various combinations of fuel cells, batteries, and hydrazine auxiliary power units (APU) in conjunction with the solar array. ECLSS options included various schemes for CO<sub>2</sub> removal, various storage methods or electrolysis generation of O<sub>2</sub>, N<sub>2</sub>, and H<sub>2</sub> supplies, and cryogenic versus high-pressure storage of repressurized N<sub>2</sub> and O<sub>2</sub>. Figure 5-19 summarizes the subsystem options and designations. Out of these various subsystem options emerged 41 combinations for integration.

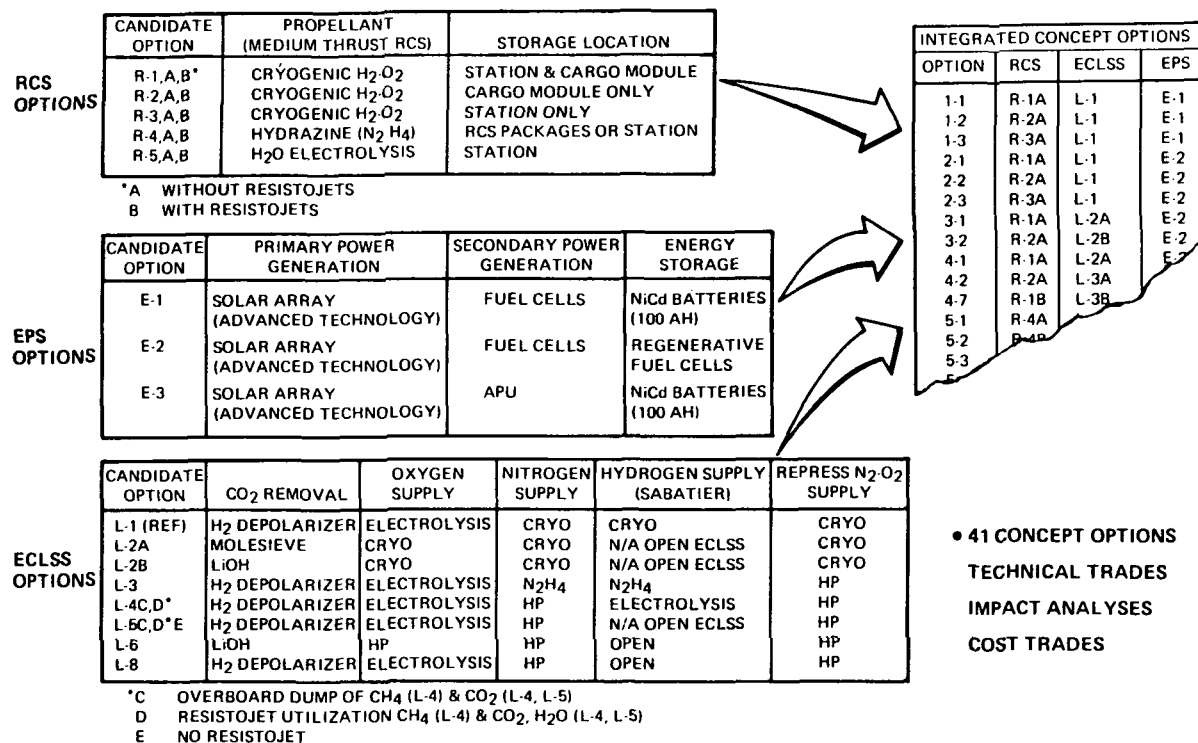


Figure 5-19. Options in Integrated Subsystems Trades



Trade studies were first conducted at the individual subsystem level; these trades deleted those concepts which could not satisfy the MSS requirements or which imposed large drivers or constraints on MSS configurations and mission operations. The options with the lowest potential cost were easily recognized and facilitated the deletion of certain options. These studies resulted in a reduction of the integrated concept options from 41 to 9. These nine combinations are presented in Table 5-3 using concept designations employed during the analysis and with option candidate codes defined in Figure 5-19 and in later tables.

Table 5-3. Final Nine Integrated Concepts Trade Candidates

Concept Designation	ECLSS Option	EPS Option	RCS Option
1-1*	L1*	E1*	R1A*
2-2	L1	E2	R2A
3-8	L2B	E1*	R2A
5-3	L6	E1*	R4A
6-1	L3A	E2	R4A
6-3	L8C	E2	R4A
6-4	L8D	E2	R4B
8	L4C	E2	R5A
11-2	L5E	E2	R5A

\*Reference MSS configuration adjusted for cargo module cryogenic tankage and buildup package

In choosing among these options, cost was the major evaluation factor. It was found early, even within the subsystem trades, that design, development, and production costs were insufficient to identify the low-cost options. Operational costs of logistics resupply were also necessary to arrive at a true picture of costs, since often low development and production costs for a subsystem implied very high logistics costs. The cost impact of the logistics resupply was determined through a computer program that superimposed the resupply requirements for each of the nine concepts on a selected constant experiment program logistics profile. The computer output was a tab run and cathode ray tube (CRT) plots that gave a required shuttle flight schedule to support each concept. Logistics costs to support each concept were established from these data.

The development of D&D and TFU costs for the options of Table 5-3 are by the methods of Section 3. Traceability of costs are provided by Tables 5-4 through 5-6 for the ECLSS, EPS, and RCS, respectively.

Table 5-4. Traceability of Cost Estimate, ECLSS Options for Low-Cost Integrated Subsystem Trade Studies

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know-How MSS vs Comparative Factor	Rationale
Option L1:				
N <sub>2</sub> conditioning thru mounts and supports	Same as for reference configuration. See Table 4-5.			
Cargo Module - Special life support	Apollo HP storage tanks	1.0	3 vs 3, 100%	
Option L2B:				
Note: Same as Option L1 except the lithium hydroxide (LiOH) assembly replaces depolarizer, Sabatier reactor, and electrolysis unit.				
LiOH Assembly	Similar Apollo ECS item	1.0	2 vs 2, 100%	
Option L3A:				
Note: Same as Option L1 except the atmospheric storage, N <sub>2</sub> conditioning, and airlock pumpdown is replaced by a hydrazine (N <sub>2</sub> H <sub>4</sub> ) dissociator, and H <sub>2</sub> O storage tanks are added to the cargo module.				
N <sub>2</sub> H <sub>4</sub> dissociator	Sabatier Reactor VAC/HS BIP	1.5	4 vs 4, 100%	Complexity caused by toxicity, requires some development effort as well as new design
Cargo Module - H <sub>2</sub> O tank	Similar Apollo ECS item	1.0	3 vs 3, 100%	

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SD 71-226-1

Table 5-4. Traceability of Cost Estimate, ECLSS Options for Low-Cost Integrated Subsystem Trade Studies (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know-How MSS vs Comparative Factor	Rationale
Option L4C:				
<p>Note: Same as Option L1 except HP N<sub>2</sub> tanks, H<sub>2</sub>O tanks and HP O<sub>2</sub> tanks are added to the cargo module. Atmospheric storage is deleted from the MSS. Electrolysis unit and special life support components are larger but use same comparative data and factors.</p>				
Cargo Module HP N <sub>2</sub> tanks HP O <sub>2</sub> tanks	Apollo HP storage tanks	1.0 1.0	3 vs 3, 100% 3 vs 3, 100%	
Cargo Module - H <sub>2</sub> O tank	Similar Apollo ECS item	1.0	3 vs 3, 100%	
Option L5E:				
<p>Note: Same as Option L4C hardware except for component sizing. Comparative data and factors the same.</p>				
Option L6:				
<p>Note: Same as Option L2B except HP N<sub>2</sub> tanks and H<sub>2</sub>O tanks are added to the cargo module, and special life support components are larger. The cost traceability data is the same as Option L4C.</p>				
Options L8C and L8D:				
<p>Note: Same as Option L4C hardware except for component sizing. L8D has less cargo module tankage than L8C. Comparative data and factors same as for L4C.</p>				

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Table 5-5. Traceability of Cost Estimates, EPS Options for  
Low Cost/Integrated Subsystem Trade Studies

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Option E2:				
Regenerative fuel cell	Shuttle fuel cell	100%	<1 vs 4, 10%	Identical to shuttle fuel cells
	Reference MSS ETC/LSS electrolysis	100%	1 vs 3.5, 29%	Uses cell building blocks identical to ETC/LSS components, but greater quantity. Requires integration effort
	Reference MSS RCS accumulator tanks	100%	1 vs 2, 50%	Tanks are identical to one RCS accumulator tank
Plumbing (additional to that included in electrolysis)	Reference MSS plumbing on EPS	100%	3 vs 3, 100% 1st unit 1 vs 1, 100% similar units	Assume four units of tubing and valving, similar to EPS of reference MSS

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Table 5-6. Traceability of Cost Estimate, RCS Options for Low Cost/Integrated Subsystem Trade Studies

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Option R1A:				
Onboard tanks thru mounts and supports	Same as Reference MSS. See Table 4-8.			
Cargo Module tanks	Beech cryo tank (Apollo)	1.2	3 vs 4, 75%	The cargo module tanks are identical to the Beech development tank concept (but smaller), except that they also include a metal diaphragm required for positive expulsion, thus increasing complexity
Buildup package	MSS feed controls (lines, valves, tank, regulator)	1.0	1 vs 2, 50%	Buildup package will contain components already developed for the rest of the system
Option R2A:				
Note: Same as Option R1A except that onboard tanks and gauging are deleted.				
Option R4A:				
Note: Onboard tanks, gauging, heat exchanger, blower, and accumulator deleted. Feed control, engine housing, mounts and support, and buildup package data unchanged except for some weights. Other subassemblies as below.				

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Table 5-6. Traceability of Cost Estimate, RCS Options for  
Low Cost/Integrated Subsystem Trade Studies (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How, MSS vs Comparative, Factor	Rationale
Engines (Hydrazine - N <sub>2</sub> H <sub>4</sub> )	SM RCS engine W/O heater	0.5	2 vs 3, 65%	<p>The monopropellant engines are much less complex than the Apollo RCS engines.</p> <ul style="list-style-type: none"> <li>a. Single N<sub>2</sub>H<sub>4</sub> valve vs two bi-prop (Apollo) valves</li> <li>b. Combustion temperature 2500 °R vs 5600 °R</li> <li>c. Catalyst bed design vs injector design for hypergolic ignition (equal complexity)</li> </ul>
Cargo Module tankage	Apollo CSM RCS hydrazine tanks	1.0	2 vs 2, 100%	All cargo module storage with tanks sized for 10-day RCS requirements
Gas generator (sp maintenance equipment)	Apollo SM RCS monopropellant engine	0.4	2 vs 3, 65%	The gas generator is essentially the same as the Apollo monopropellant engine, with less stringent design requirements on the catalyst bed
Option R4B:				
Note: Same as Option R4A except resistojet engine quads have been added, feed control weight increased, and comparative data and factors unchanged.				

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Table 5-6. Traceability of Cost Estimate, RCS Options for  
Low Cost/Integrated Subsystem Trade Studies (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Engines (resistojet)	Marquardt B&P data	1.0	2 vs 2, 100%	The resistojet is approximately the same complexity as the N <sub>2</sub> H <sub>4</sub> monopropellant engine. It does not require a catalyst but has internal resistive heaters. Resistojets gas temperatures are slightly higher than the monopropellant
Option R5A:				
Note: Same as Option R4A except for deletion of cargo module tankage and gas generator, and use of same engines, housings, and buildup package of Option R1A.				

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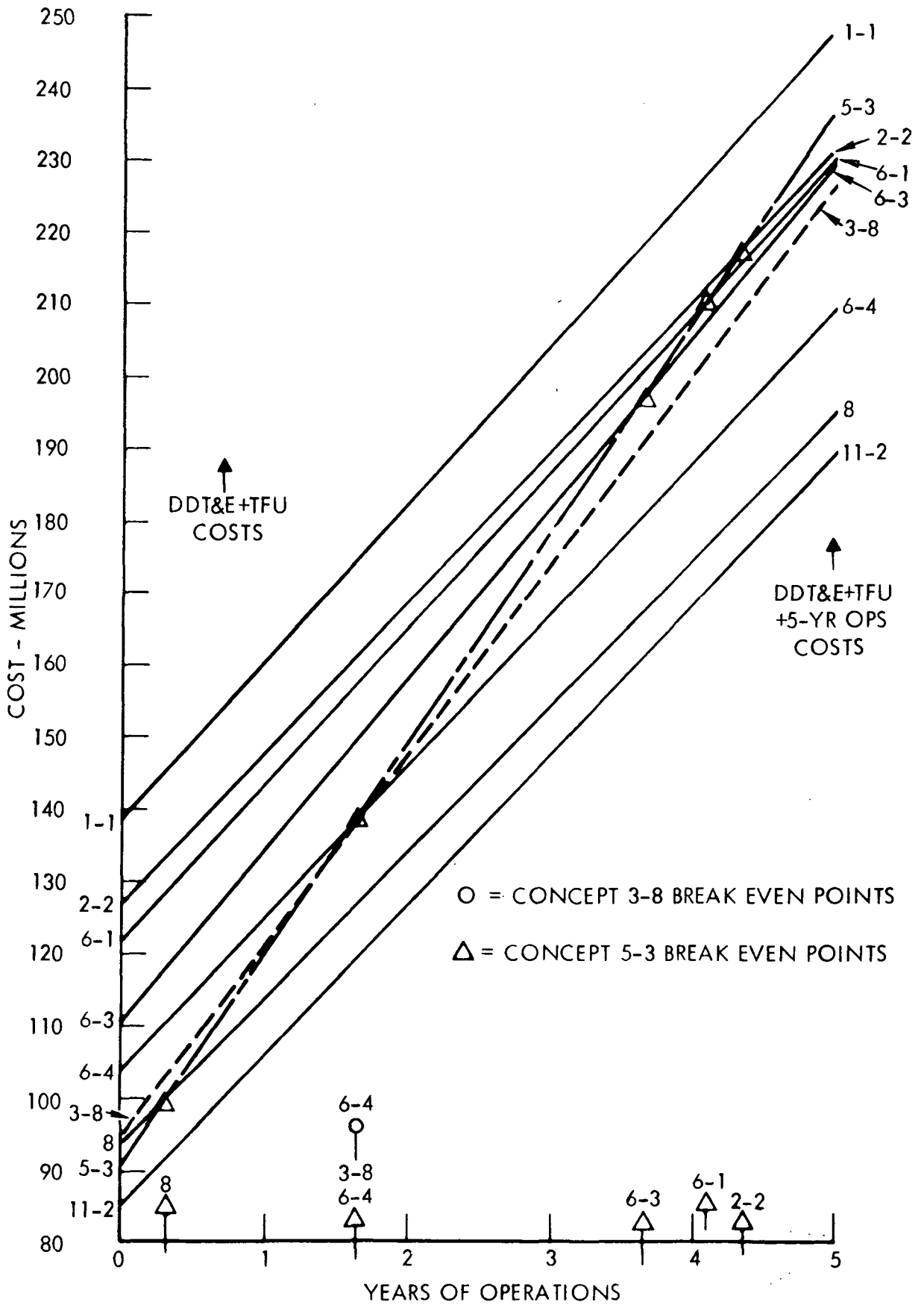


Figure 5-20. Solar Array Replacement Aids

The D&D and TFU costs, for only those subassemblies which change from the reference configuration in the nine final options, are presented in Tables 5-7 through 5-9 for the ECLSS, EPS, and RCS, respectively. Table 5-10 summarizes, by subsystem, the sum of D&D and TFU costs of the affected subassemblies. These costs were adjusted slightly to reflect small variations in array sizes and ISS interface and software requirements. To these adjusted costs were added five years of logistics resupply consumables to arrive at a total for concept comparison. Figure 5-20 shows that costs are also sensitive to operational lifetime and Figure 5-21 shows that some concepts are much more sensitive to logistics costs than others.

After an examination of the results in Table 5-10 and Figures 5-20 and 5-21, Concepts 11-2, 8, and 6-4 were selected for further evaluation. Concept 8 emerged as the preferred choice, based on minimum venting, low cost, low technical risk, lowest logistic requirements, similarity in working fluids and hardware, good, and reliable performance.

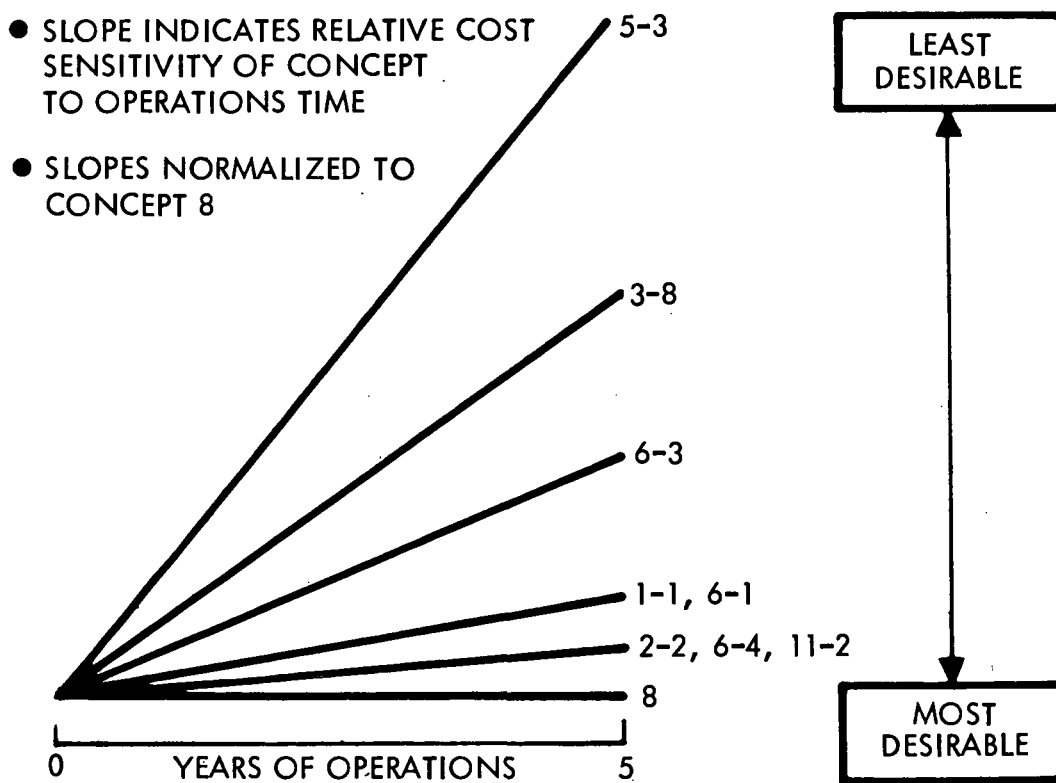


Figure 5-21. Logistics Cost Sensitivity Selected Concepts

Table 5-7 . ECLSS Cost Summary - Selected Subsystems

ECLSS Concept Option	L1		L2B		L3A		L4C		L5E		L6		L8C		L8D	
System Concept	1-1, 2-2		3-8		6-1		8		11-2		5-3		6-3		6-4	
MSS Equipment	D&D	TFU	D&D	TFU	D&D	TFU	D&D	TFU	D&D	TFU	D&D	TFU	D&D	TFU	D&D	TFU
Atmosphere Storage N <sub>2</sub> Conditioning N <sub>2</sub> H <sub>4</sub> Dissociation	6.67	0.97	6.67	0.97	8.70	1.12					6.67	0.97				
CO <sub>2</sub> Management Depolarizer, Sabatier, Electrolysis LiOH	26.85	4.97			27.98	5.18	32.18	6.84	27.36	5.90			24.00	4.57	24.00	4.57
Special Life Support	6.67	0.90	6.67	0.90	7.56	1.77	8.01	2.17	7.77	1.97	7.56	1.77	7.77	1.97	7.77	1.97
MSS Total	40.19	6.66	16.58	2.21	44.24	8.07	40.19	9.01	35.13	7.87	17.47	3.08	31.77	6.54	31.77	6.54
Cargo Modules Atmosphere Storage Water Management Special Life Support	0.140	0.035	0.140	0.035	0.350	0.160	0.140	0.765	0.140	0.665	0.140	1.330	0.140	0.665	-	-
No. Modules		3-4**		4		4		3		3		4		4		3
Total Cargo Modules	0.140	0.035 0.105**	0.140	0.140	0.490	0.780	2.11	3.855	1.99	3.72	0.290	5.46	1.99	5.14	0.150	0.105
Total ECLSS*	40.33	6.695 6.765**	16.72	2.35	44.73	8.85	42.30	12.87	37.12	11.59	17.76	8.54	33.76	11.68	31.92	6.645

\*Cost data are shown only for principal subsystem variables

\*\*Configuration 2-2 requires 4 cargo modules

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Table 5-8. EPS Cost Summary-Selected Subsystems

EPS Concept Option	E-1		E-2	
Integrated Subsystem Concept	1-1, 3-8, 5-3		All Others	
	D&D	TFU	D&D	TFU
MSS Equipment Secondary Generation Fuel Cells Electrolysis	5.70	3.40	11.5	4.4
Energy Storage Batteries	2.00	3.70		
<b>Total EPS*</b>	<b>7.70</b>	<b>7.10</b>	<b>11.5</b>	<b>4.4</b>
<p>*Cost data are shown only for principal subsystem variables.</p> <p>Note: Cost delta's for solar array sizing requirements are included in the <math>\Delta</math> subsystem costs shown in the integrated set cost summary (Table 1-18).</p>				

Table 5-9. RCS Cost Summary - Selected Subsystems

RCS Concept Option	R1A		R2A		R4A		R4B		R5A	
Integrated Subsystem Concept	1-1		2-2 & 3-8		5-3,6-1&6-3		6-4		8&11-2	
MSS Equipment	D&D	TFU	D&D	TFU	D&D	TFU	D&D	TFU	D&D	TFU
Cryogenic Storage	21.99	2.32								
Propellant Conditioning	4.34	0.23	4.34	0.23						
Feed Control	6.71	1.95	6.71	1.95	7.79	2.02	8.68	2.28	2.85	0.54
Accumulators	0.82	0.80	0.82	0.80						
Engine Quads-O <sub>2</sub> H <sub>2</sub>	15.92	1.08	15.92	1.08					15.92	1.08
Engine Quads-N <sub>2</sub> H <sub>4</sub>					12.57	0.85	12.57	0.85		
Engine Quads-Resistojet							9.90	0.72		
Special Maintenance Equipment					9.99	0.47	9.99	0.47		
<b>MSS TOTAL</b>	<b>49.78</b>	<b>6.38</b>	<b>27.79</b>	<b>4.06</b>	<b>30.35</b>	<b>3.34</b>	<b>41.14</b>	<b>4.32</b>	<b>18.77</b>	<b>1.62</b>
<b>Cargo Modules</b>										
Cryogenic Storage	10.92	3.25	10.92	3.25						
Hydrazine Storage					7.70	0.58	7.70	0.39		
Quantity Required		3		4		4		3		3
Cargo Module Buys				11.20		11.20				
<b>Total Cargo Module</b>	<b>10.92</b>	<b>9.75</b>	<b>10.92</b>	<b>24.20</b>	<b>7.70</b>	<b>13.52</b>	<b>7.70</b>	<b>1.17</b>	<b>0</b>	<b>0</b>
<b>Total RCS*</b>	<b>60.70</b>	<b>16.13</b>	<b>38.71</b>	<b>28.26</b>	<b>38.05</b>	<b>16.86</b>	<b>48.84</b>	<b>5.49</b>	<b>18.77</b>	<b>1.62</b>

\*Cost Data are shown only for principal subsystem variables

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Table 5-10. Programmatic Cost Summary - Integrated Set Concepts

Cost Elements \ Integrated Sets	1-1	2-2	3-8	5-3	6-1	6-3	6-4	8	11-2
	R-1A/L1/E1	R2A/L1/E2	R2A/L2B/E1	R4A/L6/E1	R4A/L3A/E2	R4A/L8C/E2	R4B/L8D/E2	R5A/L4C/E2	R5A/L5E/E2
RCS	76.83	66.97	66.97	54.91	54.91	54.91	54.33	20.39	20.39
ECLSS	47.03	47.10	19.07	26.30	53.58	45.44	38.57	55.17	48.71
EPS	14.80	15.90	14.80	14.80	15.90	15.90	15.90	15.90	15.90
Subtotal	138.66	129.97	100.84	96.01	124.39	116.25	108.80	91.46	85.00
Subsystem Costs*	-0-	-2.60	-5.40	-4.70	-2.20	-5.20	-5.20	+2.90	-0-
Adjusted DDT&E + TFU	138.66	127.37	95.44	91.31	122.19	111.05	103.60	94.36	85.00
5-Year Operations Cost**	110.00	105.00	132.00	146.00	109.00	119.00	106.00	102.00	105.00
Total	248.66	232.37	227.44	237.31	231.19	230.05	209.60	196.36	190.00
<p>*Adjustments in concept costs for solar array &amp; ISS 's - Concept 1-1 considered as baseline.  **Costs based on 5-year computer logistics profiles.</p> <p>Note: Subsystem costs do not include costs that are constant across these sets.</p>									

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In summary, the integrated ECLSS, EPS, RCS trade study resulted in the concept changes from the reference configuration to the selected configuration shown in Table 5-11.

Table 5-11. Concept Changes Resulting from Integrated ECLSS, EPS, RCS Trade Study

Subsystem	Change
ECLSS	Change in nitrogen supply and emergency repressurized N <sub>2</sub> and O <sub>2</sub> supplies from cryogenic to high-pressure storage. Hydrogen supply for Sabatier reactor changed from cryogenic storage to electrolysis-generated.
EPS	Regenerative fuel cells and electrolysis unit replace heavy primary and secondary battery storage
RCS	H <sub>2</sub> and O <sub>2</sub> gas generated by electrolysis unit in ECLSS rather than supplied by RCS cryogenic storage

The cost impact of the concept selection resulting from the integrated ECLSS, EPS, and RCS trade study amounts to a reduction of approximately \$62 million in D&D and TFU costs. This difference is apparent by comparing Table 5-12 with Table 5-2.

Table 5-12. Summary of D&D and TFU Costs After Integrated Subsystem Trade Studies  
(\$ Million, GFY 1971 Dollar Value)

<u>Subsystem</u>	<u>D&amp;D</u>	<u>TFU</u>	<u>TOTAL</u>
Structure	\$ 71.2	\$ 22.4	\$ 93.6
Environmental Control/Life Support <sup>(1)</sup>			
Trade Affected Items	40.2 <sup>(2)</sup>	9.0	49.2
Unaffected Items (Appendix E)	<u>135.7</u>	<u>22.8</u>	<u>158.5</u>
	<u>175.9</u>	<u>31.8</u>	<u>207.7</u>
Electrical Power			
Trade Affected Items (sec.gen. & energy stor.)	11.5	4.4	15.9
Unaffected Items (Appendix E)	<u>69.9</u>	<u>51.7</u>	<u>121.6</u>
	<u>81.4</u>	<u>56.1</u>	<u>137.5</u>
Guidance and Control	54.6	10.9	65.5
Reaction Control			
Trade Affected Items	18.8	1.6	20.4
Unaffected Items (Buildup Package) <sup>(3)</sup>	<u>0.5</u>	<u>0.1</u>	<u>0.6</u>
	<u>19.3</u>	<u>1.7</u>	<u>21.0</u>
Information	<u>149.1</u>	<u>33.6</u>	<u>182.7</u>
Subtotal	<u>\$551.5</u>	<u>\$156.5</u>	<u>\$708.0</u>
Cargo Module Adjustment <sup>(4)</sup>			
ECLSS	<u>2.1</u>	<u>3.9</u>	<u>6.0</u>
TOTAL	<u>\$553.6</u>	<u>\$160.4</u>	<u>\$714.0</u>

(1) Excluding cargo module.

(2) Coincidentally amounts to same total as for reference MSS, but with different components.

(3) Not defined for reference MSS, but same for all options. Table 5-9 does not include this, since it does not introduce differences in the options.

(4) Not defined for reference MSS - see differences among options in Table 5-7.

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#### 5.4 EFFECTS OF OTHER CHANGES

In addition to the cost impact of design changes resulting from the integrated trade studies, cost changes resulted from other design changes which materialized as the requirements of the MSS project become better defined. Some of these changes were heavily cost-oriented, such as the use of monocoque structure rather than sheet-stringer in modules other than the core. Another prime example is the elimination of redundancies in the functional program elements by grouping a large part of the equipment with capabilities for servicing many FPE's within the MSS rather than sending a new, and generally different, set of components aloft with each launch of an experiment. Such multi-FPE equipment is housed in the MSS in the current design and has been included within the general-purpose laboratory furnishings subassembly of the structural and mechanical subsystem.

Other cost changes resulted from the weight changes which emanated directly from more well-defined technical requirements alone rather than from any cost consideration per se. As such, they did not involve changes in the know-how and complexity parameters described under cost methodology (Section 3). Only the weight scaling part of the costing process was affected.

The weight breakdown in Table 5-13 shows the differences in weight by subsystem between the selected MSS configuration and the reference MSS configuration, and Table 5-14 summarizes the design changes, regardless of origin or motivation. In addition to the reallocation of subassembly items among assemblies within a subsystem already mentioned for the multi-FPE equipment above and the trade studies already covered, there are other reallocations which are indicated by brackets in Table 5-13 and outlined in Table 5-14. Notable increases in weight occur in primary and secondary structure and the multi-FPE servicing equipment in crew furnishings. Major decreases result from the elimination of batteries and propellant tanks in EPS and RCS, respectively. Overall, the MSS weight (excluding cargo modules) increased by almost 10,000 pounds, or about 10.5 percent over the reference MSS configuration.

In addition to the changes so far discussed, better cost data became available during the course of the Phase B contract. Of major impact were new cost estimating relationships (CER's) for structure (Reference 10) and the solar array based on the latest Lockheed Missile and Space Company study work on space station solar arrays (Reference 11). The generation of costs due to these and other factors are described in the next section.

Table 5-13. Selected MSS Configuration Dry Weight Comparison With Reference  
MSS Configuration (Cont)

Subsystem/Subassembly	DRY WEIGHT (POUNDS)		
	Selected Configuration	Reference Configuration	Increase (Decrease)
Guidance and Control			
Inertial Reference	65	80	(15)
Optical Reference	346	333	13
RCS Electronics	75	107	(32)
Control Moment Gyro	984	1,310	(326)
Subtotal	<u>1,470</u>	<u>1,830</u>	<u>(360)</u>
Reaction Control			
Propellant Accumulators	176	1,600	(1,424)
Propellant Feed Controls	190	610	(420)
Engines	120	120	-
Fluid Storage	0	830	(830)
Propellant Conditioning	0	70	(70)
Subtotal	<u>486</u>	<u>3,230</u>	<u>(2,744)</u>
Information			
Data Processing	1,774	1,678	96
Command/Control and Monitoring	1,099	1,330	} 1,122
External Communications	1,791	1,867	
Internal Communications	1,429	715	
Software Storage	160		
Subtotal	<u>6,253</u>	<u>5,590</u>	<u>663</u>
Crew Habitability			
General/Emergency Equipment	1,438	(in ECLSS)**	1,438
Furnishings	586	(in Structure)*	586
Reaction/Exercise/Crew Care	987	(in ECLSS)**	987
Food Management	844	(in ECLSS)**	844
Subtotal	<u>3,855</u>	<u>0</u>	<u>3,855</u>
TOTAL	<u>103,611</u>	<u>93,667</u>	<u>9,944</u>

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Table 5-13. Selected MSS Configuration Dry Weight Comparison With Reference MSS Configuration

Subsystem/Subassembly	Dry Weight (pounds)		
	Selected Configuration	Reference Configuration	Increase (Decrease)
<b>Structural and Mechanical</b>			
Primary	26,420	19,170	7,250
Secondary	17,201	12,050	5,151
Environmental Shield	4,674	6,195	(1,521)
Berthing	5,190	7,600	(2,410)
Crew Furnishings	0	1,585	} 3,320
General Purpose Furnishings	5,555	650*	
Subtotal	<u>59,040</u>	<u>47,250</u>	<u>11,790</u>
<b>Environmental Control/Life Support</b>			
Gaseous Storage	829	406	423
CO <sub>2</sub> Management	1,494	1,100	394
Atmospheric Control	3,727	1,942	1,785
Thermal Control	7,759	5,355	2,404
Water Management	1,342	781	561
Waste Management	328	258	70
Hygiene	506	491	15
Special Life Support	318	276	42
Food Management	(in crew hab)	828**	(828)
Crew Provisions	(in crew hab)	<u>1,240**</u>	<u>(1,240)</u>
Subtotal	<u>16,303</u>	<u>12,677</u>	<u>3,626</u>
<b>Electrical Power</b>			
Primary Power Generation	6,676 <sup>(1)</sup>	6,920	} (6,332)
Secondary Power Generation	0	704	
Energy Storage	4,966	10,350	} (800)
Power Conditioning	443	1,660	
Distribution Control & Wiring	3,325	2,908	} 246
Lighting	<u>794</u>	<u>549</u>	
Subtotal	<u>16,204</u>	<u>23,090</u>	<u>(6,886)</u>
(1) This is the value in SD71-219. The value pertinent to the costs presented in Form A is based on a larger design which grew out of growth station cost considerations described in subsection 5.5.			

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Table 5-14. Selected MSS Configuration, Changes in Design Features and Subsystem Designations from Reference MSS Configuration

Subsystem	Major Changes
Structural & mechanical	All modules except core module are of monocoque construction. Multi-FPE (as opposed to FPE unique) experiment equipment added to this subsystem as General Purpose Laboratory Furnishings.
Environmental control/ life support system	O <sub>2</sub> and N <sub>2</sub> repressurization tanks added to the atmospheric gaseous storage assembly. Electrolysis units added to CO <sub>2</sub> management assembly to supply RCS. Atmospheric control assembly weight increases due to better definition of requirements, including functional allocations. Thermal control assembly includes larger external radiators due to increased length of modules, the addition of emergency and buildup systems, and better definition of requirements. Water management assembly replaces dual vapor compression reverse osmosis system by a single vapor compression system. Eliminates development cost of a wash water reclamation reverse osmosis system but incurs weight penalty. High-pressure gas storage formerly in special life support assembly reallocated to gaseous storage for RCS usage.
Electrical power	Regenerative fuel cells and electrolysis unit replace heavy primary and secondary battery storage. Minimum amount of batteries retained for station buildup.
Guidance & control	Same subassemblies estimates at lower weight. Number of RCS preprocessors increased.

Table 5-14. Selected MSS Configuration, Changes in Design Features and Subsystem Designations from Reference MSS Configuration (Cont)

Subsystem	Major Changes
Reaction control	H <sub>2</sub> and O <sub>2</sub> gas generated by electrolysis unit in ECLSS rather than RCS storage by cryogenic system of liquid H <sub>2</sub> and O <sub>2</sub> . Eliminates cryogenic fluid storage tanks and many gas accumulator tanks, reduces propellant feed control weight.
Information	Number of operating memory units in central processor increased, mass memory design changed, local processor, terminal unit, and preprocessor deleted by higher central processor capabilities. Station buildup processor added. Display/control subassemblies reduced. Parabolic antenna replaced by two Ku-band antennas. VHF transponder added. Facsimile unit transferred from display/control to internal communications assembly. Communications Assembly broken down into internal and external parts. Significant reduction in software words in memory.
Crew habitability	Not a subsystem designation in the reference configuration. Includes transfer of furnishings from structure; general/emergency equipment, recreation exercise equipment, and food management equipment transferred from ECLSS.

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## 5.5 DEVELOPMENT OF FLIGHT HARDWARE EFFORT COSTS FOR 6-MAN INITIAL SPACE STATION AND SOLAR ARRAY REPLACEMENT

Having selected a final configuration, it then remained to generate costs in the format of Cost Estimate Data Form A. The first step in this process was to generate the flight hardware effort portion outlined in Figure 3-1; that is, the D&D plus tooling and special test equipment in the nonrecurring costs, the TFU (with quantity adjustments, if any) costs with subsystem installation, assembly, and checkout called out separately in the recurring production costs, and refurbishment in the operating costs. The modifications to the basic D&D and TFU building blocks are, by agreement with NASA, to permit better comparability with estimates from other contractors or to promote better cost visibility in the WBS.

In generating the flight hardware effort costs, changes in configuration and comparative data following the integrated trade studies had to be taken into account, and a cost allocation by module had to be developed. Tooling and special test equipment cost estimates were made by module and added to the costs; on the other hand, installation, assembly, and checkout costs were extracted from TFU costs already assumed to include them. Lastly, refurbishment costs were estimated.

### 5.5.1 D&D AND TFU COSTS BY MODULE

Following the conclusion of the trade studies, it was necessary to incorporate weight and other design changes, as summarized in Subsection 5.4, plus more realistic comparative data, in arriving at D&D and TFU costs for the selected configuration. The impact of the weight changes was a straightforward fallout of the weight scaling process, since complexity and know-how factors were not changes once firmly established. Significant changes in comparative data, however, required a recycling of the complexity and know-how estimates for the affected items. Significant changes in this regard occurred in the structures, electrical power, and information subsystems. Minor alterations occurred in comparative data used for the crew habitability subsystem. Another change was made in the interests of accelerating the cost prediction process for the preparation of the cost data forms. Having worked to WBS Level 7 for the trade studies, the aggregates to Level 6 and above were believed to be as credible as could be expected. Hence, the weight scaling and factor applications were performed at Level 6



unless too many Level 7 changes precluded that approach as in the ISS. By this procedure, the costing process was accelerated without losing credibility at Level 5 which is reported in the final cost data forms.

In the case of the structural and mechanical subsystem, changes in the number and sizes of the modules led to major changes in weight and the adoption of monocoque construction reduced the complexity of the primary structure of most of the modules. Complexity at WBS Level 6 was derived by an average based on the product of weight and complexity of each of the WBS Level 7 items. Major changes occurred in the comparative data and weight scaling. The comparative data used for the Reference Configuration were based on S-II CER's developed by NR in February 1971 and consisted of D&D costs which were derived at a program-wide multiple of the TFU costs for each of the comparative items.

In October new CER's became available which incorporate the results of more recent cost studies and permit a less constrained estimate of D&D costs as well as the TFU. Moreover, it became evident that, for the tank and environmental shielding assemblies, the slope used in weight scaling (Figure 3-2) for the reference configuration made the costs too sensitive to weight and understated these costs for the low weights under consideration. Accordingly, slopes which recognize the relatively fixed development costs at even very small weights, and the large numbers of common sections in these assemblies, were used. The assumed sequence of development and production and the revised comparative data for the structures subsystem are given in Tables 5-15 and 5-16, respectively. The costs are summarized in Appendix F in 1972 dollar value, which is assumed to be 5 percent greater than the 1971 dollar value. It should be noted that although SM-1 through SM-4 are referred to as common modules in some of the technical descriptions, they are unique insofar as cost estimating is concerned because so many individual components are different. This statement applies to all subsystems.

In addition to these changes, the structural and mechanical subsystem was augmented to include the multi-FPE equipment as differentiated from FPE-unique equipment in the general-purpose laboratory furnishings assembly of this subsystem. In order to derive the costs of the multi-FPE equipment, the equipment items, some 57 in number, were divided into the following classes:

- Structural and mechanical items - simple and semi-complex
- Electrical items - simple and complex
- Experiment supporting items
- Experiment equipment
- Commercial cameras and microscopes

**Table 5-15. Selected MSS Configuration Structures  
Sequence Matrix of Design and Development  
and Production**

Structure	Core Module	Power Module	SM-1	SM-2	SM-3	SM-4
Primary	$C_{T_1}$ (3)	$PM_{T_1}$ (3)	$(SM-1)_{T_1}$ (2)	$(SM-1)_{T_2}$ (2)	$(SM-1)_{T_3}$ (2)	$(SM-1)_{T_4}$ (2)
Secondary	$C_{T_1}$ (3)	$C_{T_2}$ (2)	$(SM-1)_{T_1}$ (3)	$(SM-1)_{T_2}$ (2)	$(SM-1)_{T_3}$ (2)	$(SM-1)_{T_4}$ (2)
Environmental shield	$C_{T_1}$ (5)	$(PM)_{T_1}$ (3)	$(PM)_{T_2}$ (2)	$(PM)_{T_3}$ (1)	$(PM)_{T_4}$ (1)	$(PM)_{T_5}$ (1)
Berthing						
Passive side ring	$C_{T_1}$ (3), $C_{T_{2...8}}$ (1)	N/A	N/A	N/A	N/A	N/A
Active end ring	N/A	$C_{T_1}$ (3), $C_{T_2}$ (1)	$C_{T_3}$ (<1)	$C_{T_4}$ (<1)	$C_{T_5}$ (<1)	$C_{T_6}$ (<1)
Passive end ring	$C_{T_1}$ (2), $C_{T_2}$ (1)	$C_{T_3}$ (2), $C_{T_4}$ (1)	$C_{T_5}$ (<1)	$C_{T_6}$ (<1)	$C_{T_7}$ (<1)	$C_{T_8}$ (<1)

\*Does not include general purpose laboratory fittings.

(1) Know-how ratings are denoted by the numbers within parentheses in each column. See definitions on another sheet.

$C_{T_N}$  = Nth theoretically (T) derived cost item which is identical to, or a minor modification of, the core module.

$(PM)_{T_N}$  = Nth theoretically (T) derived cost item which is identical to, or a minor modification of, the power module.

$(SM)_{T_N}$  = Nth theoretically (T) derived cost item which is identical to, or a minor modification of, the SM.

Table 5-16. Traceability of Cost Estimate (Structures) for Selected MSS (Initial Station)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know-How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
MODULE CORE				
Primary	S-II tanks CER	1.1	3 vs 4, 75%	<p>The primary structure summarized on this line is further defined as follows:</p> <ol style="list-style-type: none"> <li>1. The core sidewalls are similar to S-II tank sidewalls including skin and stringer construction; however, they become more complex due to the 10 passive berthing ports. Both sidewalls are pressurized and sustain side loads. The state-of-the-art has advanced since 1963; therefore, minimal development will be required</li> <li>2. Elimination of waffle and common bulkhead problems reduces complexity. S-II bulkheads were domed, whereas the core module bulkheads are flat</li> <li>3. Similar to but less complex than the LH<sub>2</sub> tank feedline ports on S-II</li> </ol>
Sidewalls				
Bulkheads				
Fittings				
Secondary	S-II aft skirt	1.0	3 vs 3, 100%	<p>The secondary structure summarized on this line is further defined as follows:</p> <ol style="list-style-type: none"> <li>1. The utility distribution, which consists of electrical wires, hardlines and utility ducts, which, when related to the S-II aft skirt, is much less complex</li> <li>2. The doors/hatches and access domes are of a heavier structure than S-II. Complexity has increased over aft skirt due to hinges, latches, and windows</li> <li>3. Of minor complexity due to MSS item being an I-beam plus structure attachments</li> <li>4. Of minor complexity as item consists of lockers, flat panels and attachments. Because it is interior rather than exterior, no load-carrying and no thermo problems will be encountered</li> <li>5. Less complex than S-II because of smallness of parts as related to the master interface and umbilical disconnect problems of S-II</li> </ol>
Utility distr				
Doors/hatches/ access domes				
Cargo handling				
Storage				
Brackets, Doublers, etc.				
(1) (See footnote at end of table.)				

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Table 5-16. Traceability of Cost Estimate (Structures) for Selected MSS (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know-How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
Environmental shield	Goodyear B&P	1.0	5 vs 5, 100%	The environmental shield consists of HPI-high performance insulation (Mylar). The S-II shielding consisted of sprayfoam, therefore the Goodyear quotation for Mylar has been utilized. The Goodyear Mylar is considered to be the same complexity as the space station, and an advanced state-of-the-art requiring substantial development
Berthing	S-II flt cont CER	1.0	3 vs 4, 75%	The berthing (docking) is compared to the S-II flight control hardware due to the similarity of the quick disconnects and the many lines leading to the berthing ports. The core module berthing ports (10) are all passive, 8 sideports and 2 endports. The passive ports are considered equal to the S-II flight control complexity; however, the know-how has advanced since 1963.
MODULE - INITIAL POWER				
Primary	S-II tanks CER	0.3	3 vs 4, 75%	The primary structure summarized on this line is further defined as follows:
Sidewalls				1. The initial power module sidewalls are of monocoque construction rather than the skin and stringer type of S-II or the space station core module. This results in a lesser complexity than estimated for the MSS core module
Bulkheads				2. Bulkheads are similar to the MSS core module bulkheads, i. e., flat rather than dome shaped
Fittings				3. Similar to the MSS core module fittings
Secondary	S-II aft skirt CER	1.1	2 vs 3, 66%	The secondary structure summarized on this line is further defined as follows:
Utility distr				1. The utility distribution portion of the secondary structure is the same type as the core module utility distribution, therefore less complex than the aft skirt
Doors/hatches/ access domes				2. The doors/hatches and access domes are of less weight than the core doors/hatches and access dome, but are very similar which results in a reduction in the know-how level for the MSS portion. Complexity remains the same as on the core module
(1) (See footnote at end of table.)				

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Table 5-16. Traceability of Cost Estimate (Structures) for Selected MSS (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know-How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
Cargo handling	Goodyear B&P	0.8	3 vs 5, 60%	3. The cargo handling is similar to the core module cargo handling, therefore, the complexity remains the same; however, the MSS know-how is increased
Brackets, doublers				4. The brackets, doublers, etc., weigh less than the core module brackets, doublers; however, they are of similar complexity, with increased know-how
Environmental shield				The initial power module shielding is of the same type as on the core module, but will be less complex because the power module is smaller in diameter and more constant, i. e., no berthing ports on the side-walls. The MSS know-how has advanced as a result of the core module
Berthing	S-II flt cont CER	1.0	<1 vs 4, 20%	The berthing ports on the initial power module consist of two active end ports and two passive end ports. The complexity on the passive docking port is 1.0 as compared to the S-II flight control CER; however, the active docking port is considered to be 1.5 as complex. The know-how has advanced since the S-II flight control was developed and is less (20%) than the passive (75%)
Passive				
Active	S-II flt cont CER	1.5	3 vs 4, 75%	
MODULE - SM-1				
Primary	S-II tanks CER	0.3	2 vs 4, 50%	The primary structure summarized on this line is further defined as follows:
Sidewalls				1. The SM-1 module sidewalls are of monocoque construction, similar to the initial power module sidewalls. The complexity is equal to the power module, therefore less than the core module. The know-how is reduced to reflect an increase as a result of the power module precedence
Bulkheads				2. The SM-1 module bulkheads are similar to the initial power module bulkheads, complexity is equal; however, the know-how has increased
Fittings				3. Similar to the MSS power module fittings
(1) (See footnote at end of table.)				

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Table 5-17 summarizes the comparative data and costing factors for these classes of items. The costs for these items are summarized in Table F-1, Appendix F. Unlike the other assemblies of the structural and mechanical subsystem, the total costs of the GPL furnishings assembly were derived independently of a development sequence. The allocation of GPL furnishings assembly costs by module is obtained by proportioning each of the subassembly costs by weight identified for each of the modules.

Besides the structural elements needed for the initial station only, there are additional hardware items included in the power module costs. These are the D&D and TFU costs of the mechanical aids which are launched with the 10,000-square-foot solar array which replaces the 7,000-square-foot array as the growth MSS is initiated. These aids consist of a launch support structure, a replacement aid, and an adapter. The launch support structure is similar to the initial power boom and is also utilized to return the initial array to earth. The replacement aid is attached in the shuttle bay and is used as a temporary mounting structure during the replacement of one array by the other. The adapter is a device which links the launch support structure to the orientation drive and power transfer (ODAPT) section of the solar array. The shapes of these items are illustrated in Figure 5-22. Each of these items is a new unique design for primary structure, but learning from the previous power module is assumed for secondary structure, shielding, and berthing. The basis for the costs is summarized in Table 5-18, and the costs themselves are given in Table F-2, Appendix F.

The next subsystem which was affected by a change in the comparative data was the electrical power subsystem. Based on developmental work by Lockheed Missiles and Space Company, it was decided to alter the comparative data upon which the solar array and orientation drive mechanism costs are based. Table 5-19 summarizes the changes. In the initial preparation of Cost Estimate Data Form A, it was assumed that a 7,000-square-foot array would be designed for the initial station and a 10,000-square-foot array for the growth station. Upon examination of the large D&D costs for the second design, however, a different approach was adopted. It was decided that a 10,000-square-foot array would be designed from the very beginning in a manner which would allow the attachment and deployment of either the entire 10,000-square-foot solar cell area or a considerably lesser amount of solar cells, the 7,000 square feet needed for the initial station\*. The slightly larger initial design effort is more economical than two separate design efforts. TFU costs are not affected so much. Because only the array is replaced and not the entire power module, the costs of replacement are included in the EPS portion of the power module WBS element of the initial station (see Figure 2-2 and Cost Estimate Data Form A).

\*The ODAPT and mounts and supports of the power generation assembly increased in weight substantially (Table 5-13) to 7,688 pounds. This is the only case in which costs were affected significantly by weight differences frozen for costing purposes and those in SD 71-219.

Table 5-17. Traceability of Cost Estimate (GPL Furnishings Assembly),  
Selected MSS (Initial Station)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(2)</sup> MSS vs Comparative, Factor	Rationale*
Airlock				
Structural and mechanical Items				
- Simple	S-II aft skirt CER	1.0	100%	Mounts and supports, work benches, etc.
- Semi-complex	S-II fwd skirt CER	1.0	100%	Incubator, precision work fixture, etc.
Electrical Items:				
- Simple	Lighting CER from Reference MSS	1.0	100%	Floodlights, electronic flash, etc.
- Complex	Power conditioning CER from Reference MSS	1.0	100%	Variable voltage source, etc.
Experiment support	GE EL - 116A data, 33-ft station, FPE 5.1	1.0	100%	Control console, X-Y plotter,
Experiment equipment	GE EL - 116A data, 33-ft station, FPE 5.1	1.0	100%	Carbon analyzer, lyophilizer, mass spectrometer, etc.
* All comparative data so similar as to assume complexity of 1.0 and know-how factor of 100%				

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Table 5-18. Traceability of Cost Estimate (GPL Furnishings Assembly),  
Selected MSS (Initial Station)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(2)</sup> MSS vs Comparative, Factor	Rationale*
<b>Launch support structure:</b>				
Primary	S-II tanks CER	0.3	3 vs 4, 75%	Monocoque construction much simpler than S-II. New design but no development gives know-how benefit vs S-II
Secondary	S-II aft skirt CER	1.0	2 vs 3, 67%	Learning from initial MSS designs
Environmental shield		Not Applicable		
Berthing	S-II flt control CER	1.0	1 vs 4, 10%	Learning from initial MSS and cargo modules.
<b>Replacement aid:</b>				
Primary	S-II tanks CER	0.2	3 vs 4, 75%	Less complex, truss construction. Within state-of-the art
Secondary	S-II aft skirt CER	0.3	3 vs 3, 100%	Very simple; brackets only
Environmental shield		Not Applicable		
Berthing	S-II flt control CER	1.5	1.5 vs 4, 38%	Active docking same complexity as for initial MSS. Much learning from initial MSS, but slight modification makes know-how greater than unity
<b>Adapter</b>				
Primary	S-II tanks CER	0.3		Monocoque construction
Secondary	S-II aft skirt CER	1.0	1 vs 3, 33%	Approximately same complexity as launch support structure, more learning

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Table 5-18. Traceability of Cost Estimate (GPL Furnishings Assembly),  
Selected MSS (Initial Station) (Cont)

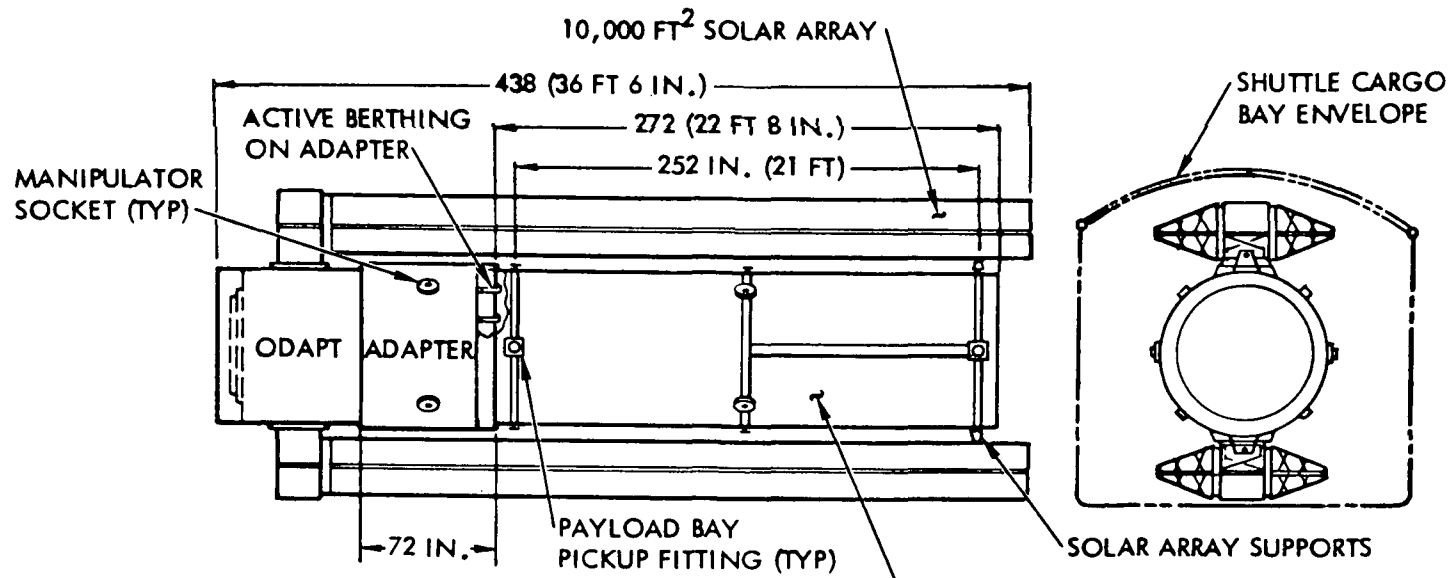
Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(2)</sup> MSS vs Comparative, Factor	Rationale*
Environmental shield	Goodyear B&P	0.8	2 vs 5, 40%	Simpler contours than initial core learning from power module
Berthing	S-II flt control CER	1.0 passive 1.5 active	1 vs 4, 10%	Assumed identical to initial MSS and cargo module pieces with integration effort only

Table 5-19. Traceability of Change in Data EPS for Selected MSS  
(Initial Station)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How MSS vs Comparative, Factor	Rationale
Solar array & Orientation drive mechanism	Business contact record, interchange with Lockheed Missiles & Space Co.	1.0	2.75 vs 3, 92%	Data received from LMSC following reference MSS, data changed basic comparative data costs. Selected MSS design anticipated to be largely but not completely a new design from LMSC developed configuration

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1. LAUNCH SUPPORT STRUCTURE
- SIMILAR TO INITIAL POWER BOOM
  - UTILIZE FOR RETURN OF INITIAL ARRAY

SOLAR ARRAY REPLACEMENT AIDS

1. LAUNCH SUPPORT STRUCTURE
  - SHORT POWER BOOM
  - SAME MONOCOQUE CONSTRUCTION
  - PASSIVE BERTHING PORT
2. REPLACEMENT AID
  - ACTIVE BERTHING PORT
  - MINIMUM STRUCTURE
  - ATTACHED IN SHUTTLE CARGO BAY

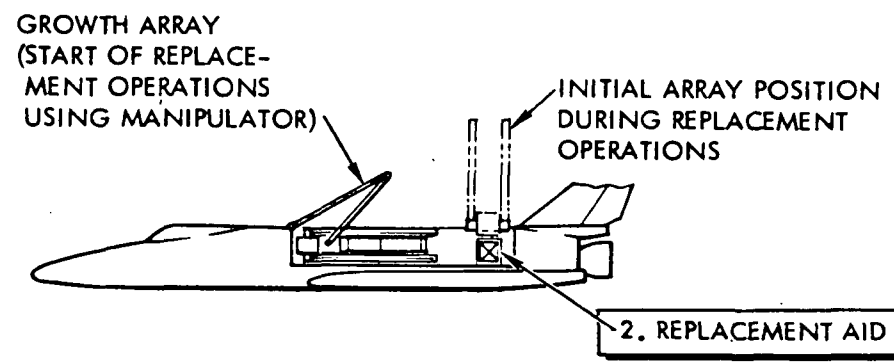


Figure 5-22. Solar Array Replacement Aids

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Allocation of EPS costs by module is based upon the initial location of the assembly in the launch sequence and upon the weight allotted to each of the modules.

The other subsystem in which major changes in comparative data, complexity, and know-how occurred was the information subsystem. Major differences materialized in both hardware and software requirements. The hardware effects are summarized in Table 5-20. The impact on costs is to increase the D&D costs from \$70.2 million to \$87.5 million in GFY 1971 dollar value, and to increase the TFU costs from \$33.6 million to \$45.0 million. In the case of software, the requirements for memory capacity and other word usage were relaxed from the reference MSS as follows:

	Thousands of Words		
	Supervisory Program	Application Program	Data Base
Reference MSS	772	970	11959
Selected MSS	410	730	10480

This relaxation resulted in a cost decrease from \$78.8 to \$66.8 in GFY 1971 dollar value. As in the case of the reference MSS, the costs are contingent upon the development of the HAL procedural language by start of Phase C on the Space Station program. This language is expected to decrease both the cost per instruction and the number of words in comparison with presently available languages.

The costs of the ISS were derived at the station level and then allocated by module. To arrive at the allocation of D&D costs, sequence of design for each subassembly was determined by either initial usage or by the proportionate usage by module as indicated by the weight located therein. This sequence and the associated know-how rating are summarized in Table 5-21. The know-how factor derived from the know-how rating was multiplied by the weight in pounds, and this product for each module was divided by the product's aggregate for all modules to obtain a fraction of the total for the subassembly to determine allocation by module. In the case of recurring production costs, the allocation by module was based on launch sequence and weight, assuming weight to be an index of the quantities of components in the subassembly. In the case of software, all costs were assumed to be D&D and were charged against the SM-1 module where the central processor is first used.

The final changes in comparative data and the associated complexity and know-how factors are in the crew habitability subsystem. In the selected MSS configuration, this is identified as a separate subsystem made up of

Table 5-20. Traceability of Cost Data Changes in ISS for Selected MSS (Initial Station)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative, Factor	Rationale
<b>Data Processing:</b>				
NOTE: Same as reference MSS subassemblies except for the deletion of the local processor, terminal unit, and preprocessor; and the addition of a buildup processor. New requirements on central processor memories, as shown below.				
Central processor, operating memory	CDC 469 preprocessor + extended memory catalog price	1.25 new, 1.0 for unchanged units	2 vs 2, 100%	Now have two central processors with nine operating memories instead of four. Effort to tie these together more complex than for reference MSS. Combining comparative system hardware units is new design effort
Central processor, mass memory	Shuttle mass memory based on Autonetics B&P	1.0, all new	2 vs 4, 33%	Plated wire device like modular device proposed for space shuttle. Requires more trays of electronics, but speed, access, reliability, and environment assumed equivalent. Assumed minor modification of Shuttle-developed device
(1) See footnote at end of table.				

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Table 5-20. Traceability of Cost Data Changes in ISS for Selected MSS (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative Factor	Rationale
Buildup processor	CDC 469 and extended memory catalog price	0.5 new, 1.0 for unchanged units	2 vs 2, 100%	Includes pulse-code modulation equipment, up-data link, timing, and signal conditioning equipment which is simpler than comparative equipment. Plan is to use modification of existing equipment at time MSS is designed. Combining comparative system hardware units is new design effort
Command Control & Monitoring (formerly Display/Control):				
NOTE: Printer and facsimile unit transferred to internal communications assembly, wall clocks deleted.				
Operations control console	Revised list of components at catalog prices	1.0	3 vs 2, 200%	Same as command console in reference MSS except that preprocessor is deleted.
Portable control console (PCC)	Same as terminal unit in reference MSS. Only the designation has been changed.			
(1) See footnote at end of table.				

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Table 5-20. Traceability of Cost Data Changes in ISS for Selected MSS (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative Factor	Rationale
Commander's control console	Systems IV-70, catalog price	1.5	2 vs 2, 100% for wt, in excess of PCC, 1 vs 2, 50% for remainder	Identical to PCC except for the addition of a function select keyboard and a heavier critical digital unit
External Communications:				
NOTE: Includes S-band semi-directional antenna as modified below, and S-band transponder of reference MSS. S-band parabolic antenna deleted. All other items transferred to internal communications assembly. Items below besides semi-directional antenna are new additions.				
K-band antenna	RCA 47 db K-band antenna	1.25	4 vs 4, 100%	Comparative data design is less redundant. MSS design must be more reliable, since antenna is external to MSS and not subjected to maintenance. Assume both comparative data and this design will require development at contract inception
(1) See footnote at end of table.				

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Table 5-20. Traceability of Cost Data Changes in ISS for Selected MSS (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative Factor	Rationale
S-band semi-directional antenna	Apollo Col. Div. IDWA	1.0	3 vs 4, 75%	Know-how factor changed to reflect probability that a similar new design rather than the identical Apollo antenna will be used
VHF antenna	TACSAT telemetry and comm.	0.15	3 vs 3, 100%	Very simple quarter-wave length whip-like configuration shuttle-station link, with shuttle supplying signal stability
VHF transponder	TACSAT TT&C	0.80	3 vs 3, 100%	New design but MSS will use single frequency only, less complex
Buildup comm. VHF	TACSAT TT&C	0.80	3 vs 3, 100%	Low-power receiver and decoder capability to transmit signals to MSS during buildup and to turn on high-power telemetry equipment for monitoring and control
(1) See footnote at end of table.				

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Table 5-20. Traceability of Cost Data Changes in ISS for Selected MSS (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative Factor	Rationale
Buildup comm. (cont)  S-band	VHF transponder	0.25	3 vs 3, 100%	Tracking capability for turn-around ranging using shuttle signals. Much narrower bandwidth, lower exciter frequency than VHF transponder
Internal Communications:				
NOTE: Includes all items of reference MSS communications assembly except antennas and transponder. Hardware intercomm. and TV B&W camera added. Facsimile unit transferred from display/control and changed; printer transferred unchanged.				
Facsimile unit	Magnafax, eng estimate of catalog price	1.5	4 vs 2, 300%	Need not receive and transmit pictures like reference MSS. Transmission only, with reception performed by TV. Do not need high resolution capability.
Hardwire intercomm.	Estimated catalog price, crystal microphone	1.0	1 vs 2, 100%	Energizes headset during buildup, off-the-shelf usage after simple qualification
(1) See footnote at end of table.				

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Table 5-20. Traceability of Cost Data Changes in ISS for Selected MSS (Initial Station) (Cont)

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know How <sup>(1)</sup> MSS vs Comparative Factor	Rationale
TV camera, black and white	TV color camera	0.33	2 vs 2, 100%	Simpler design
<p>(1) Same relationship of factor to know-how rating as for reference MSS.</p>				

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Table 5-21. Selected MSS Configuration, ISS Design Sequence of Subassemblies

	SEQUENCE					
	1	2	3	4	5	6
<b>Data Processing</b>						
Central Processor	SM-1 (2)	SM-4 (1)	-	-	-	-
Buildup Processor	Core (2)	Power (1)	-	-	-	-
RACUs and Other	SM-1 (3)	SM-4 (1)	← Optional, Know-How = 1 →			
<b>Command Control &amp; Monitoring</b>						
Operating Control Console	SM-1 (3)	SM-4 (1)	-	-	-	-
Commander's Control Console	SM-1 (2)	-	-	-	-	-
Emergency G&C Control	Core (2)	-	-	-	-	-
Portable Control Console	SM-1 (2)	SM-4 (1)	-	-	-	-
Other	SM-1 (1)	← Optional, SM-2 thru SM-4, (1) →				
<b>External Communications</b>						
Ku-Band Antenna	SM-1 (4)	SM-4 (1)	-	-	-	-
S-Band Semi-Dir. Antenna & Transponder	Core (3)	SM-1 (1)	SM-4 (<1)	-	-	-
VHF Antenna & Transponder	Core (3)	SM-1 (1)	SM-4 (<1)	-	-	-
Buildup Comm.	Core (3)	-	-	-	-	-
<b>Internal Communications<sup>(1)</sup></b>						
Communication Rack	SM-1 (3)	SM-4 (1)	SM-2 (1)	-	-	-
Recording Unit (Video & Audio)	SM-1 (2)	SM-4 (1)	-	-	-	-
Audio/Video Unit & TV Camera & Other	SM-1 (2)	← Optional, All Other Modules, (1). Not in SM-2 →				
(1) Modulation processor, CTU, facsimile unit, paging amplifier, printer.						

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Table 5-22. Traceability of Cost Data Changes in Items of Crew Habitability Subsystem for Selected MSS Configuration

Subassembly	Comparative Data	Complexity, Factor of Comparative	Know-How MSS Versus Comparative Factor	Rationale
Mobility aids, restraints	S-II Fairing	1.2	2 vs 3, 67%	Complexity increased due to smaller details and more complex configurations.
IVA Umbilicals	CSM Similar hardware	1.0	3 vs 3, 100%	Similar to combination of environmental control structure in comparative data.
Furnishings	S-II Fairing	1.2	2 vs 3, 67%	Same as mobility aids, restraints.

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assemblies which were formerly in the structures and ECLS subsystems of the reference MSS configuration. The changes in comparative data from the reference MSS data are summarized in Table 5-22. The major changes in costs are due to weight changes (see Table 5-13) rather than changes in comparative data. Allocation of costs by module is based upon launch sequence and weight by module.

The D&D and TFU costs for all other subsystems (i. e., ECLSS, G&C, and RCS) made use of the same comparative data used through the trade studies. Thus weight was the only parameter which had changed. The costing was done at WBS Level 6 using weight scaling at the total initial station assembly level. Costs were then allocated to each of the modules using launch sequence and weight distribution by module as the major variables.

To generate cost estimates for assemblies whose comparative data were at the subcontractor level, it was necessary to derive prime contractor engineering and manufacturing support factors. The first step in this process was to reclassify all elements of the work breakdown structure identified in the Apollo CSM 1971 Cost Study (Reference 6) in terms of the appropriate WBS location for the MSS as defined in Figure 2-2 and Appendix A. Following this classification, the cost avoidance items of the 33-foot station study (Reference 7) were assumed to be valid for the MSS. These cost avoidance items were based upon the Apollo experience and were classified in the same manner by WBS as the Apollo CSM 1971 Cost Study data had been.

As indicated in Section 3, the costs before avoidance (Reference 6) were broken down into prime contractor and subcontractor portions. In D&D costs, the cost avoidance items of Reference 7 were then divided into prime and subcontractor portions. Those which were so identified were classified in straightforward fashion. Of those not specifically identified, the total savings in engineering design implementation costs were assumed to be 75 percent for the prime (who would be the prime investor and beneficiary of the new programmatic tools) and 25 percent for the subcontractor, and certain integrated test activity was assumed to be entirely by the prime. The savings were subtracted from the costs prior to avoidance to obtain a revised total. The prime and subcontractor portions of this total were then applied to each of the subsystems in proportion to their fraction of the prime and subcontractor portions, respectively, of the total before cost avoidance. The resulting prime engineering and manufacturing support cost as a percentage of subcontractor cost for assemblies in the respective subsystems, was as shown in Table 5-23.

Table 5-23. Prime Contractor Engineering and Manufacturing Support for D&D Costs

Assembly	Percentage of Subcontractor Cost
ECLS Assemblies	53%
EPS Assemblies (Not applicable to solar array)	37%
G&C Assemblies	48%
RCS Assemblies	17%
ISS Assemblies	32%

All subcontractor comparative data are assumed to contain cost avoidance.

In the case of TFU costs, a similar approach was followed. The benefits of manufacturing and engineering implementation savings were assumed to accrue to the prime. Hence, only items specifically identified as subcontractor savings in Reference 7 were credited to the subcontractor. All subsystems were again expected to benefit proportionally; the resulting percentages are shown in Table 5-24.

Table 5-24. Prime Contractor Engineering and Manufacturing Support Factors for TFU Costs

Assembly	Percentage of Subcontractor Cost
ECLS assemblies	22
EPS assemblies (Not applicable to solar array)	99
G&C assemblies	39
RCS assemblies	30
ISS assemblies	26

Again, comparative data based on subcontractor inputs are assumed to contain cost avoidance.



The impact of all the changes subsequent to the trade studies is summarized in Table 5-25. The change in structures CER's added to the development costs (as did the weight increase), but reduced the TFU costs. Of course, the inclusion of general purpose experiment support items in this subsystem increased costs. Most of the weight effects in ECLSS and RCS have already been included in the trade study results. The use of the later cost data on the solar array increased development costs significantly from those of Table 5-12. Information subsystem costs increased on the hardware side; in the development phase, these were largely offset by software reductions due to relaxed requirements for number of words in the processor memory (Table 4-10). TFU costs increased substantially. The items transferred to crew habitability did not change significantly. The overall impact on the D&D and TFU costs on the 6-man MSS, expressed in 1971 dollar value, is an increase of about \$156 million, as may be seen by comparing Tables 5-25 and 5-12. If the general purpose laboratory equipment is omitted from the structures subsystem, the impact would be approximately a \$125 million increase.

Table 5-25. Initial Space Station Selected Configuration  
D&D and TFU Costs

(\$ Million, CFY 1971 Dollar Value)\*

Subsystem	D&D	TFU	Total
Structural & mechanical	\$116.6	\$ 20.6	\$137.2
Environmental control/ life support	187.5	30.3	217.8
Electrical Power	131.0	61.3	192.3
Guidance & control	51.8	9.8	61.6
Reaction control	17.8	2.5	20.3
Information			
Hardware	87.5	45.0	132.5
Software	66.8	--	66.8
Crew habitability	36.4	5.1	41.5
<b>Total</b>	<b>\$695.4*</b>	<b>\$174.6*</b>	<b>\$870.0*</b>
*Does not include cargo module.			



### 5.5.2 TOOLING AND OTHER FLIGHT HARDWARE EFFORT COSTS

The D&D and TFU production costs just described were modified for purposes of completing Cost Estimate Data Form A. By agreement with NASA, tooling and special test equipment (STE) were added to both D&D and TFU costs, acceptance testing costs were added to the TFU costs, installation, assembly and checkout, and module integration costs were pulled out of the TFU costs for greater visibility, and refurbishment costs were included in recurring operation costs. Refurbishment costs affect WBS Item XX-1XX-07-00, but the other items affect WBS Items XX-1XX-01-00 through XX-1XX-20-00 of the MSS.

The tooling and STE costs were estimated in combination by utilizing both the Apollo CSM and S-II Cost Studies of 1971 (References and ). Nonrecurring tooling and STE costs were expressed as a percentage of D&D costs and derived in two classes. One percentage was for structural and mechanical items, and the other was for all other subsystems. On the basis of similarity to the MSS it was decided to use the S-II value for the structural and mechanical subsystem and the Apollo figure for all other subsystems. Nonrecurring tooling and STE represents the initial tooling and equipment for the production run. Therefore, it is charged against the first assembly fabricated in a group of identical assemblies. Accordingly, little nonrecurring tooling and STE costs are found in SM-3 and SM-4. The recurring tooling and STE costs (assumed to be primarily tooling) were expressed as a percentage of TFU production costs, based upon data from the Apollo CSM 1971 Cost Study. This sustaining tooling effort, unlike the initial tooling, is applied across the board to all modules. The associated dollar figures are presented in Table F-3, appendix F and the percentages used are:

Subsystem	Percent	Base
D&D:		
Structural and mechanical	58	D&D costs of first article fabricated
Other	12	D&D costs of first article fabricated
TFU:		
All	10.7	TFU production costs, all articles

To the recurring costs were also added acceptance testing costs of 6.7 percent of production costs based upon Apollo CSM 1971 Cost Study Data. These are also included in Table F-3.



The subsystem installation, assembly, and checkout costs and module integration, assembly, and checkout costs were derived using data from Shuttle Phase B studies (Reference 10), which in turn were based upon Apollo and S-II cost studies. Vehicle subsystem installation, final assembly, and integrated checkout cost data were used. For subsystem installation, assembly, and checkout on the MSS, the structural and mechanical subsystem was considered more similar to the vehicle final assembly cost element of Reference 1, whereas the other subsystems were likened to the vehicle subsystem installation cost element. These elements were ratioed to the production costs of the applicable subsystems. The ratio resulting for the structural and mechanical subsystem was raised to recognize that the station modules are more complete structural entities than the modules of the shuttle, which are really fuselage portions and the like. The resulting ratio on the other subsystems was decreased to recognize the greater accessibility expected on the station. The subsystems installation, assembly, and checkout costs, expressed as a rough percentage of each of the subsystem TFU production costs, are:

Subsystem	Subsystem Installation, Assembly and Checkout
Structural and Mechanical	6 percent
Other	9 percent

One exception to these percentages for the other subsystems was the EPS solar array. The costs were cut roughly in half because the accessibility to the solar array attachments was considered very great. Table F-4, Appendix F, shows the dollar cost by module.

It should also be noted that installation, assembly, and checkout of major test hardware items are located elsewhere in the WBS costs and are not called out separately in Data Form A as they are for flight hardware.

Finally, in considering the flight hardware effort costs of Figure 3-1, the costs of refurbishment must be included. These belong in the recurring operations costs, and the program plans call for no refurbishment except for cargo modules, which have not yet been costed. The way in which refurbishment has been defined in terms of those costs can be stated, however. In determining refurbishment costs, it was assumed that the costs would constitute a replacement, maintenance, repair, or reconfiguration of each subsystem except structure, of an equivalent of 15 percent of the TFU cost of each subsystem in the cargo module for each flight. Since the plan calls for four cargo module flights per year, an equivalent of 60 percent of the TFU costs of all subsystems except structural and mechanical is expended annually for refurbishment of cargo modules.



## 5.6 NONFLIGHT HARDWARE AND PROGRAMMATIC SUPPORT COSTS

Those activities which are ancillary to the flight hardware efforts but necessary to make a program a success are costed next. These costs include hardware which is used to run integrated tests under simulated environmental conditions and the ground support equipment which is used in handling, checkout, and launch of flight hardware. It also includes contractor facilities to manufacture the hardware, the module integration, assembly, and checkout efforts, and flight and GSE spares. Integration of experiments into the GPL of the MSS, systems engineering support, project management, and operational support prior and during the mission are also included. These costs are discussed in the sequence in which they are numbered in the WBS.

The development of module integration assembly and checkout costs is similar to that of the subsystem installation, assembly, and checkout costs presented in Subsection 5.5. The costs for the structural and mechanical subsystem were likened to both vehicle final assembly and vehicle integrated checkout costs defined for the shuttle in Reference 1, and ratioed to the subsystem production costs. The resulting ratio was decreased to recognize that the structural entities are more complete than on the shuttle preceding both final installation and mating. The subsystem modular integration, assembly, and checkout were assumed to be similar to the vehicle integrated checkout cost element of Reference 1, ratioed to subsystem production costs. This ratio was reduced based on the rationale that interfaces between modules on the station will be more straightforward than those on the shuttle. The module integration, assembly, and checkout costs, in terms of the respective subsystem production costs, are:

Subsystem	Module Integration, Assembly, and Checkout
Structural and mechanical	10 percent
Other	6 percent

EPS values are roughly halved for the solar array because of greater accessibility than other subsystems. A breakdown of production costs showing the flight hardware, subsystem installation, assembly, and checkout and module installation assembly, and checkout is shown in Appendix F, Table F-4.



The major test hardware (MTH) portion of WBS item XX-1XX-50-00, Major Test Programs, is arrived at by defining the test articles of SD 71-222, MSS Integrated Ground Operations, in terms of equivalent TFU articles at the subsystem level. These test articles are summarized in Table 5-26 by first usage, and consist of three types. A mass simulation test article is assumed to cost 5 percent of an equivalent flight article. A prototype article is estimated at 80 percent of TFU costs. An equivalent flight article, of course, is assumed to be 100 percent of the flight article TFU.

The test planning and operations portion of major test programs and several other nonflight hardware and programmatic support costs were derived from Apollo data as adjusted for cost avoidance, in a manner similar to the D&D and TFU costs as described in Subsection 5.5.1. These and other nonflight hardware and programmatic support costs were prime contractor efforts, with cost avoidances limited to the following: engineering design and manufacturing implementation made possible by better phasing of procurement and thereby better balance of sequential and concurrent operations, the related fallout in reliability costs savings, and testing savings due to a better knowledge of test hardware needs and test procedures. The costs remaining after these cost avoidance items were subtracted from Apollo CSM 1971 Cost Study values were then examined by the program manager. Other differences between the MSS program and the adjusted data were identified which resulted in additional cost savings. These differences included the following:

1. Project Management — Documentation and administrative efforts were reduced based on much greater knowledge of system requirements at program inception, plus a greater familiarity with management control systems.
2. Systems Support — Integration and trajectory analysis costs were reduced because these requirements are far fewer on MSS than on Apollo CSM. Although there are more module configurations than on Apollo, then Apollo configurations were more varigated and there were more test configurations and block changes than anticipated on MSS; on balance, therefore, there is a decrease in configuration development effort.
3. Major Test Programs — Overhaul, repair, and modification costs reduced drastically due to better knowledge of test vehicle configurations.
4. Ground Support Equipment — These costs are reduced by a large amount to account for the universal test equipment (UTE) which is expected to result from shuttle development, thereby minimizing GSE for each individual program thereafter.

Table 5-26. Major Test Hardware (MTH) Requirements

	Static and Dynamic Tests	Compatibility Assessment Vehicle	Checkout and Mission Support Vehicle	Total Equivalent Flight Article
<b>Core Module:</b>				
Primary Structure	1	--	--	1
Secondary Structure	1	--	--	1
Other Structural and Mechanical	--	1 <sup>(1)</sup>	--	1 <sup>(1)</sup>
ECLS	0.7 S <sup>(2)</sup>	1 P <sup>(2)</sup>	1	1.84
EPS	0.7 S	1 P	1	1.84
G&C	0.7 S	1 P	1	1.84
RCS	0.7 S	1 P	1	1.84
ISS	0.7 S	1 P	1	1.84
Crew Habitability	--	--	1 P	0.8
<b>Power Module:</b>				
Primary Structure	1	--	--	1
Secondary Structure	1	--	--	1
Other Structural and Mechanical	--	1	--	1
ECLS	1 S	1 P	--	0.85
EPS	0.9 S	1 P	--	0.85 <sup>(3)</sup>
G&C	--	--	--	--
RCS	--	--	--	--
ISS	--	1 P	--	0.8
Crew Habitability	--	--	--	--

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Table 5-26. Major Test Hardware (MTH) Requirements (Cont)

	Static and Dynamic Tests	Compatibility Assessment Vehicle	Checkout and Mission Support Vehicle	Total Equivalent Flight Article
<b>SM-1:</b>				
Primary Structure	--	1	--	1
Secondary Structure	--	1	--	1
Other Structural and Mechanical	--	1 <sup>(2)</sup>	--	1 <sup>(2)</sup>
ECLS	--	0.8 P <sup>(4)</sup>	1 <sup>(4)</sup>	1.64 <sup>(4)</sup>
EPS	--	1 P	--	0.8
G&C	--	--	--	--
RCS	--	--	--	--
ISS	--	1 P	1	1.8
Crew Habitability	--	--	1 P	0.8
<b>SM-2:</b>	N	0	N	E
<b>SM-3:</b>				
Primary Structure	1	--	--	1
Secondary Structure	--	--	--	--
Other Structural & Mechanical	--	1 <sup>(2)</sup>	--	1 <sup>(2)</sup>
ECLS	--	0.8 P	1 <sup>(3)</sup>	1.64 <sup>(3)</sup>
EPS	--	1 P	--	0.8
G&C	--	--	--	--
RCS	--	1 P	--	0.8
ISS	--	0.8 P	0.7	1.34
Crew Habitability	--	--	1 P	0.8

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Table 5-26. Major Test Hardware (MTH) Requirements (Cont)

	Static and Dynamic Tests	Compatibility Assessment Vehicle	Checkout and Mission Support Vehicle	Total Equivalent Flight Article
SM-4:				
Primary Structure	--	--	--	--
Secondary Structure	1	--	--	1
Other Structural and Mechanical	--	1 <sup>(2)</sup>	--	1 <sup>(2)</sup>
ECLS	1.4 S	0.8 P <sup>(3)</sup>	1 <sup>(4)</sup>	1.71 <sup>(4)</sup>
EPS	--	1 P	--	0.8
G&C	--	--	--	--
RCS	--	--	--	--
ISS	1.4 S	1 P	1	1.87
Crew Habitability	1.2 S	--	1 P	0.86
(1) Excludes Environmental Shielding (2) P = 0.80 and S = 0.05 of equivalent flight article (3) Excludes Solar Array (4) Excludes Radiators				

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After incorporating these additional savings, these cost items were expressed as percentages of various bases for estimating purposes, as summarized in Table 5-27 for nonrecurring and recurring production costs. These bases proved convenient because of cost estimates derived earlier and readily available. The impact of cost avoidance is discussed further in Subsection 5.9.

In estimating the integration effort for the experimental equipment in the GPL, the systems support percentage was used as a guide. Based on elements making up system support from the Apollo CSM 1971 Cost Study, and the expectation that experiments would require less effort than the MSS subsystems, it was estimated that 70 to 75 percent of the percentage applicable there would be applicable in the case of experiments. As a result, a value of 4.4 percent of the GPL experiment D&D costs has been used for GPL Experiment Integration, WBS XX-1XX-45-00.

Pre-mission operations, mission operations, and the project management and systems support during the operational phase are based primarily on head count estimates or derivatives. For simplicity in estimating due to the complex manpower assignments which would occur during pre-mission and mission operations, it was arbitrarily decided to put pre-mission operations costs entirely within the nonrecurring phase and mission operations entirely within the operational phase. Pre-mission operations were estimated to require the equivalent of 350 direct heads at \$50,000/year, or \$17.5 million per year. On the same basis, systems support was assumed to require 30 direct heads and project management, 120 direct heads, during the operational phase, or \$1.5 million and \$6.0 million per year, respectively.

Facility costs are in the nonrecurring category and include only those facilities which are expected to be funded directly by NASA under facility contracts to both the prime and subcontractors of the MSS project. The large bulk of the facilities, as outlined below in Table 5-28, are expected to be financed by the prime and subcontractors out of company funds. NASA-operated facilities are excluded.

Spares constitute the final item to be costed in nonflight hardware and programmatic support costs. By agreement with NASA, all spares costs were included in the operational phase. Based on Apollo CSM 1971 Cost Study data, a factor of about 6.8 percent of the production costs including TFU, tooling and STF, acceptance testing, subsystem installation, assembly, and checkout, and with modular installation, assembly, and checkout added, was used.

Table 5-27. Cost Basis for Various Nonflight Hardware and Programmatic Support Efforts

Effort	Percentage	Base Costs
<b>Non-Recurring:</b>		
Major Test Programs excluding MTH	3.2	D&D + TLG & STE + MTH
GSE*	6.9	D&D + TLG & STE + MTH
Systems Support	6.2	D&D + TLG & STE + MTP + GSE
Project Management	6.8	D&D + TLG + STE + MTP + GSE + Systems Support
<b>Recurring Production:</b>		
Systems Support	3.8	TFU- Subsystem I, A & C/O + TLG + STE
Project Management	11.1	TFU- Subsystem I, A & C/O + TLG + STE + Systems Support
*Assumed to be all non-recurring, with spares in recurring costs.		

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Table 5-28. Planned Contractor Facilities, MSS Project  
 (\$ Million, GFY 1972 Dollar Value)

	Company Funds	Facility Contracts
<b>Prime Contractor</b>		
Initial station	\$16.2	\$ 8.4
Growth station	6.0	3.1
Subtotal	\$22.2	\$11.5
<b>Subcontractors</b>		
Initial station	\$18.0	\$ 6.6
Growth station	2.2	-
Subtotal	\$20.2	\$ 6.6
<b>Total included in Data Forms A, B &amp; D</b>	N/A	\$18.1



## 5.7 CARGO MODULES AND GROWTH STATION MODULES

### 5.7.1 CARGO MODULES

Table 5-29 summarizes by subsystem the cost of design and development and three units of flight hardware as estimated for the cargo module, XX-1XX-07-00, WBS Level 4. All estimates, including weights summarized on Table 5-30, are based on a preliminary concept sketch dated 28 September 1971. Space station technology has been reflected in this analysis but the subsystem estimates are based on a conceptual level of design only, as contrasted to the initial station subsystems which were defined to a preliminary design level.

Table 5-29. Summary of Cargo Module D&D and Flight Hardware Costs  
(\$ Million, 1972 Dollar Value)

Subsystem	D&D + TLG & STE	Flight Hardware W/O Subsystem Installation A. & C/O (3 units)	Total
Structural & mechanical	\$14.6	5.3	19.9
Environmental control/life support	32.2	19.1	51.3
Electrical power	1.8	1.2	3.0
Information	0.7	0.8	1.5
Crew habitability	2.2	0.4	2.6
Totals (Missions - '72R)	\$51.5	\$26.8	\$78.3

The method employed to cost cargo modules was to relate the cargo module with space station hardware at the lowest WBS level possible and subsequently derive subsystem costs by using space station cost estimating relationships (CER's) and cargo module weights.

Floating item elements of cost, being WBS Level 4, were calculated against all space station project modules (initial, cargo, and growth) and therefore cost is not identified explicitly for the cargo modules. Rationale for costing floating items is discussed elsewhere in this document.

Table 5-30. Weight Summary (Cargo Module)

	Weight (lb)
Structural & Mechanical	6,260
Environmental Control/Life Support	4,230
Electrical Power	235
Guidance & Control	-
Reaction Control	-
Information	75
Crew Habitability	140
Total	10,940

### 5.7.2 GROWTH MODULES

Tables F-6 through F-13 of Appendix F contain WBS Levels 5 and 6 cost summaries which include growth station modules. These modules are identified as growth core (XX-1XX-08-00), SM-5 (XX-1XX-09-00), and SM-6 (XX-1XX-10-00). The estimated subsystem by weights are shown in Table 5-31. These weights were not estimated in so much detail as were the initial modules and therefore are not reported in the Mass Properties Document, SD 71-219 (DRL 69). The general method used to estimate subsystem weights was to match by similarity the growth module hardware to initial module hardware by assembly (WBS Level 6) and utilize the initial hardware detail weight estimates to compile growth module weights at the subsystem level (WBS Level 5). The costs of growth subsystems likewise were derived from the costs estimated for similar or common assemblies on the initial station modules. This method was appropriate inasmuch as growth module subsystem definitions to the preliminary design level were not within the scope of this contract. In the process of deriving these costs, initial subsystem assemblies was WBS Level 6 were selected from one or more initial station modules which most closely matched the technical requirements or description of the growth assembly. The cost of this assembly was then adjusted for weight differences, if any, and changes in development status or know-how, recognizing development effort previously costed on initial assemblies. Complexity was assumed to be constant.

Table 5-31. Weight Summary (Growth Station Modules)

Func. Code		Core Module	Solar Array Replacement*	SM-5 Sta. Module	SM-6 Sta. Module	Total Dry Weight
1.0	Structural & Mechanical	6,610	3,510	9,176	9,176	28,472
2.0	Environmental Control/Life Support	683	-	4,431	4,431	9,545
3.0	Electrical Power	2,400	6,192	545	545	9,682
4.0	Guidance & Control	-	-	-	-	-
5.0	Reaction Control	90	-	55	55	200
6.0	Information	365	-	1,016	160	1,541
7.0	Crew Habitability	135	-	453	453	1,041
	Totals	10,283	9,702	15,676	14,820	50,481

\*On cost estimate data forms A, B, and C, the costs of the solar array replacement are included in the initial station WBS because it does not constitute a full module.

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Space Division  
North American Rockwell



Floating item elements of cost (i. e., the nonflight hardware and programmatic support costs), are WBS Level 4 items which were calculated against all space station project modules (initial, cargo, and growth) and therefore cost is not identified explicitly for the growth modules. Rationale for costing floating items is discussed elsewhere.

In calculating the production costs of the growth modules and the replacement solar array, startup costs were added to account for the interruption in production. These costs were estimated by assuming that such interruptions would necessitate the hiring of untrained personnel. Assuming fully trained status is achieved in six months and that productivity builds up at a linear rate, the untrained worker performs the same work in 6 months as a fully trained worker in three months. Thus an untrained crew would have to be hired 3 months earlier than a trained crew.

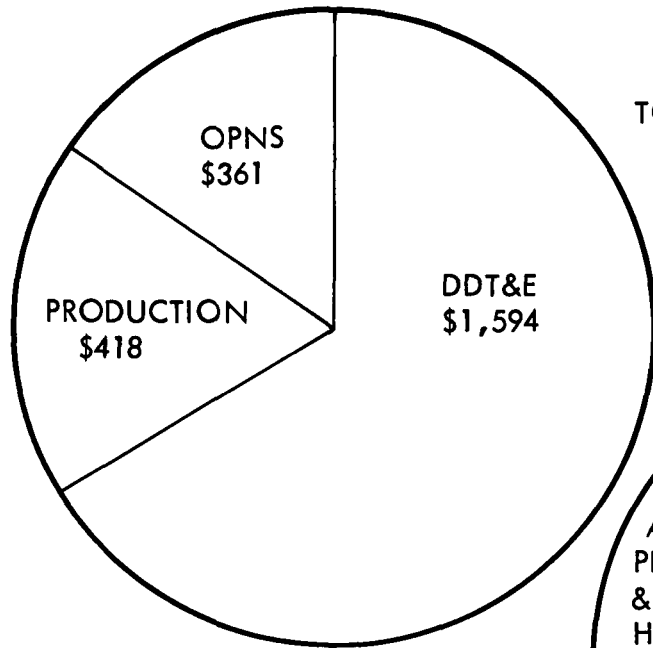
Assuming continual hiring until maximum manning is achieved based on a nominal (trained crew) 50/50 ogive and assuming all people are fully trained before reducing the manning level, the front part of the ogive is loaded an extra amount while the aft end remains the same. By plotting areas under the ogive curves for typical work durations of a trained crew of about 30 months, the startup effort by untrained personnel increases costs by about 18 percent. Thus a factor of 118 percent was applied against the costs derived from the initial station modules as described above.



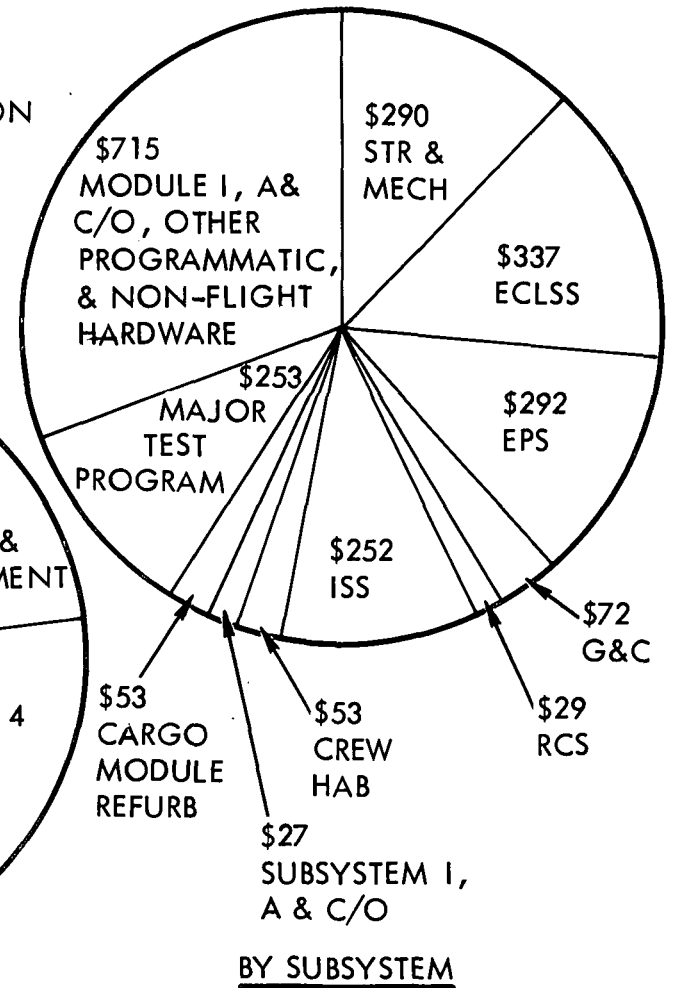
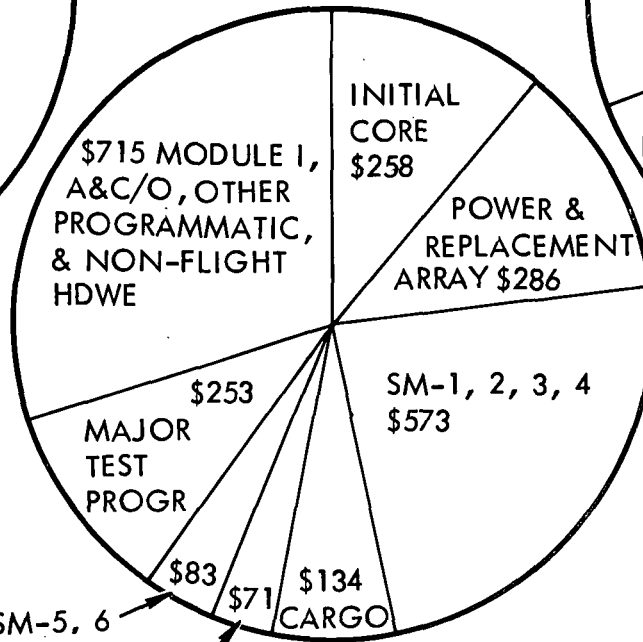
## 5.8 COST SUMMARY, MSS PROJECT

The total MSS project, including the cargo and growth modules, is estimated to total \$2,373 million in 1972 dollar value. Breakdowns by procurement phase, module, and subsystem are presented in Figure 5-23. Note that operations are truncated by the ground rules of Section 2. Under these rules, DDT&E is the largest portion of the costs and operations the smallest. The breakdowns by module and subsystem are also given in detail in Appendix F. It is interesting to note that nonflight hardware and programmatic efforts (including major testing) account for about 40 percent of the entire costs. The lowest cost subsystems are Crew and Habitability and RCS.

It should also be remembered that the costs by module are a function of the development sequence postulated in Section 5 and are valid only in that context. One should not be lulled into thinking, for example, that eliminating SM-1 would save \$250.7 million in D&D costs (see Table F-6, Appendix F), since the design efforts in the subsystems of that module probably preceded other modules. If for some hypothetical reason such a deletion were made such design efforts would in all probability have to be absorbed by some other modules. Care should therefore be exercised in interpreting all the cost figures presented.



TOTAL MSS COSTS, \$2,373 MILLION



BY PROCUREMENT PHASE

BY MODULE

BY SUBSYSTEM

Figure 5-23. Modular Space Station Project - Cost Summary by Procurement, Phase, Module and Subsystem

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## 5.9 COST AVOIDANCE

Throughout the Phase B effort, dollar costs have been avoided wherever possible. Two principal types of cost avoidance have been incorporated into the program planning. Although interrelated, they are considered separately for discussion purposes. One is avoidance by engineering design and the other is programmatic in nature.

Since cost avoidance is a relative matter, it is also important that meaningful reference points be used in measuring these savings.

### 5.9.1 COST AVOIDANCE BY ENGINEERING DESIGN

Costs may be avoided by exercising engineering design ingenuity. A constant effort was made to incorporate low-cost designs into the MSS subsystems and innumerable examples could be cited. It is not always clear, however, where normal design expectations leave off and real design ingenuity begins. For purposes of discussion and quantitative measurement, it is therefore necessary to establish a meaningful reference baseline. The baseline for measuring will be the subsystems before the integrated trade studies of the ECLSS/EPS/RCS combination, and the experiment equipment required for each of the FPE's in the Blue Book.

In Subsection 5.3, it was shown that the integration process resulted in D&D plus TFU cost savings of about \$68 million in 1972 dollar value. When the tooling and STE factors, and a factor of 1.05 to convert to 1972 dollars (Table F-5, Appendix F) and nonflight hardware and programmatic factors at an average program level (Table F-6) are added, the cost savings are increased. The savings would amount to about \$110 million in DDT&E costs and \$17 million in production costs, or a total of about \$127 million, even if the cargo modules and growth modules are not counted. These savings are realized even though other design changes tending to increase costs occurred during the costing cycle after the trade studies.

The other cost avoidance item which is attributable directly to engineering design is the elimination of redundant experiment equipment and the consolidation of equipment items which service several FPE's within the basic station subsystems or general-purpose laboratory furnishings. This redundancy was eliminated by examining the requirements of each FPE as spelled out in GE Space Division Report EL-182 (Reference 1). Some items were identified as redundant. In an NR-sponsored study to determine what equipment items were required to perform a multi-FPE servicing function,



about 55 items were identified. A study also was made to determine approximate cost savings due to the use of a lesser number of such items. This estimate was rather gross and cannot be matched easily against the items costed in Section 6, but is nevertheless indicative of the types of savings to be expected.

The items deleted were counted as a savings and the items added were counted as added costs, with the difference amounting to a net savings. The deleted items were matched insofar as possible against line items in an early version (Reference 12) of an MSFC report on experiments. In some case, a line item in the report, although called something different, was interpreted as applying to a deleted item. In other cases, there was a one-to-one relationship. In other cases, parts of some total cost were used, based on the number of items against some total assembly of aggregate, or based upon the estimated weight as a percentage of the total. The deleted items amounted to total to about \$170 million in CFY 1971 dollar value for both nonrecurring and production costs.

The 50-plus multi-FPE items added were broken down roughly into the following groupings:

- Structural and mechanical items - simple and MSS type
- Environmental control - typical MSS equipment
- Electrical power - simple and semi-complex
- Information - display/control
- Experiment equipment
- Commercial cameras and microscopes

The MSS-type equipment was costed using CER's for typical assemblies for the reference MSS configuration for the station as a whole; complexity and know-how factors were assumed to be unity versus these comparative data and only weight was considered variable in the costing process. The costs of the added items amounted to about \$70 million in GFY 1971 dollar value.

The savings amounted to roughly \$100 million by netting these amounts, or about \$105 million in GFY 1972 dollar value.

Thus the total cost avoidance due to engineering design the sum of the integrated design savings and the elimination of redundant FPE equipment, amounted to about \$230 million in GFY 1972 dollar value.

#### 5.9.2 PROGRAMMATIC COST AVOIDANCE

The programmatic cost avoidance refers to savings which are realized largely due to management techniques. They stem from a policy of phased

procurement and economic scheduling which thus becomes practical, new management tools, and the advances in space technology and experience which make requirements better understood. In quantifying these program avoidance costs, Apollo CSM experience has been used as a baseline. It has been assumed that the types of cost avoidance applicable to the 33-foot station design and reported (Reference 17) under the Phase B contract for that design are applicable to the present design; the only exception being facilities, where the new size of the modular design require the usage of new handling devices.

The programmatic cost avoidance plans in SD 70-154 were based on inputs for various functional departments and are summarized here. It must be remembered that these are, at best, rough estimates. As described in Subsection 5.5, further reductions were incorporated by the program manager to account for other program characteristics unique to MSS.

In engineering, SD 70-154 indicated that the principal savings are expected from a balance of sequential and concurrent operation rather than a fully concurrent approach. In addition, automated systems and devices are expected to provide savings; examples of these are the engineering release system, the pro-draft method, and the automatic drafting machine (ADM). Prerelease coordination with other functions also is expected to enable reduced costs by major reductions in the number of parts unnecessarily produced, inspected, tested, and maintained plus the attendant savings in planning and documentation.

In manufacturing, the use of an automated manufacturing data retrieval system, together with closer coordination with engineering enhanced by less emphasis on concurrency relative to Apollo, is expected to result in substantial savings in planning effort. These savings stem from a major reduction in out-of-phase releases. Another major source of savings is the emphasis which will be placed on the producibility criteria in the engineering tradeoff and design process, thereby reducing fabrication and assembly costs.

In quality and reliability assurance, the prerelease coordination with engineering is expected to reduce drastically documentation and inspection effort due to the smaller number of parts. Further reduction is expected by matching the intensity of inspection efforts to the criticality of the characteristic inspected.

By limiting qualification tests to life cycle testing and performing environmental testing only during the acceptance tests, substantial savings would be realized versus Apollo. Expected from these ground rules would be components for which realistic acceptance environment cannot be established without impairing subsequent performance.

Table 5-32. Cost Avoidance, Programmatic Type  
(\$ Million, GFY 1972 Dollar Value)

	<u>BEFORE COST AVOIDANCE</u>	<u>AFTER COST AVOIDANCE</u>	<u>COST SAVINGS</u>
<b>Non-Recurring:</b>			
D&D Plus TLG & STE	\$ 1,300	\$ 1,009	\$ 291
Project Management	214	99	115
Systems Support	171	85	86
Premission Operations	25	25	-
GPL Experiment Integration	21	21	-
Major Test Programs:			
MTH	569	219	350
Other	101	34	67
GSE	426	84	342
Facilities	<u>18</u>	<u>18</u>	<u>-</u>
Sub-Total	<u>\$ 2,845</u>	<u>\$ 1,594</u>	<u>\$1,251</u>
<b>Recurring Production</b>			
TFU (QTY) Plus TLG & STE + Acceptance Test	\$ 450	\$ 362	\$ 88
Project Management	61	42	19
Systems Support	17	14	3
GSE (1)	<u>N/A</u>	<u>N/A</u>	<u>N/A</u>
Sub-Total	<u>\$ 528</u>	<u>\$ 418</u>	<u>\$ 110</u>
<b>Total, DDT&amp;E and Production</b>	<u><u>\$ 3,373</u></u>	<u><u>\$ 2,012</u></u>	<u><u>\$1,361</u></u>

(1) Recurring GSE in Apollo Data & Spares in MSS Not Included in Impact Analysis

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The test philosophy reduces test site support relative to Apollo by eliminating a large number of major test hardware articles. Also lack of development flight tests, thermal/vacuum tests of a complete vehicle, and maximum use of OBCO versus GSE are beneficial to costs.

Major savings in the reliability program are expected versus Apollo due to better coordination with engineering and balance between sequential and concurrent activities. These are offset by maintainability and resupply activities which are unique to space station and were not a part of Apollo.

The programmatic cost-reduction techniques resulted in discrete amounts which were deducted from the D&D, TFU, and nonflight hardware and programmatic support costs as described in Subsection 5.5. In the D&D and TFU costs, plus their associated tooling and STE, the total (prime and subcontractor portions) costs after applying the programmatic cost avoidance of SD 70-154 for approximately 78 and 81 percent, respectively, of the Apollo CSM 1971 Cost Study values. These factors are used in measuring programmatic cost avoidance in Table 5-37. Other savings are based on support factors before and after cost avoidance adjusted for unique MSS requirements, as discussed in Subsection 5.6. Prepermission operations and GPL experiment integration are assumed to be unaffected by the factors discussed above since comparability with Apollo is remote. The resulting DDT&E and production costs attributable to programmatic cost avoidance amount to slightly under \$1.4 billion, or about under 40 percent less than the cost indicated by historical data accepted at face value.

### 5.9.3 TOTAL COST AVOIDANCE

The total cost avoidance is the sum of savings due to engineering design and savings due to programmatic factors. Measured against the reference baseline defined above, cost avoidance on the MSS Project in the nonrecurring and production phases is expected to total some \$1.6 billion. Although this is a very rough estimate, it is nonetheless significant, amounting to about 80 percent of the estimated MSS Project costs for those phases.



## 6. EXPERIMENT PROJECT AND RESEARCH APPLICATION MODULE PROJECT COSTS

### 6.1 EXPERIMENT PROJECT COSTS

Experiment project costs consist of Experiments Definition, WBS XX-2XX-00-00, broken down by discipline and earth-orbital experiments, WBS XX-3XX-00-00, broken down into aggregates of experiments identified by carrier (or host) spacecraft. The RAM project costs consist of costs, attributable to modules other than MSS modules, in which experiments are performed. They are aggregated by Attached RAM's XX-4XX-00-00, and Detached RAM's, XX-5XX-00-00.

### 6.2 EXPERIMENT DEFINITION PROJECT COSTS

Experiment definition costs are assumed to be entirely nonrecurring. The work content is described in the WBS Dictionary, Appendix A. These costs are based on a level of effort of \$1.5 million per year per discipline. There are eight disciplines, as enumerated in Cost Estimate Data Form A. As indicated in Section 2, the effort in each discipline begins on January 1, 1975 and ends one year following the start of design for the last FPE in that discipline. The experiments definition project costs total about \$115 million in 1972 dollar value, or about 2 percent of the Space Station Earth Orbital Program costs included in this report.

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## 6.3 EARTH ORBITAL EXPERIMENT PROJECT COSTS

The experiment project costs are based on a definition of equipment appropriate to various levels of MSS capability to perform experiments and are aggregated by the type of spacecraft in which the experiments are performed. The costs are derived from NASA-furnished data (Reference 2).

### 6.3.1 Choice of Capability Levels

The first step in the definition of experiment costs is to define the experiment capability levels in terms of experiment equipment groupings appropriate to MSS operations, both recognizing the manpower limitations of the station and the requirement to build in the total Blue Book capability specified by the NASA guidelines.

Throughout NR's Modular Space Station Program Phase B Definition Study, one of the principal objectives has been to define cost-effective means for experiment accommodation. This objective has been achieved principally in two ways. First, several experiment requirements "drivers" which could have resulted in significant cost impact have been reduced or deferred, without compromising experiment accomplishment. Second, a time-phased or evolutionary approach to the buildup of on-orbit experiment capability has been conceived and defined. These analyses are summarized in this section; more detailed discussions of MSS experiment analysis activities are contained in Modular Space Station Preliminary System Design, Volume III, Experiment Analyses (SD 71-217-3).

The source document for MSS experiment analyses is NASA Document NHB 7150.1, Preliminary Edition of Reference Earth Orbital Research and Applications Investigations (Blue Book). The Blue Book is organized by discipline into eight volumes as follows:

Volume I	Summary
Volume II	Astronomy
Volume III	Physics
Volume IV	Earth Observations
Volume V	Communications/Navigation



Volume VI	Materials Science and Manufacturing
Volume VII	Technology
Volume VIII	Life Sciences

Each of these is further subdivided into one or more sections, each describing a functional program element. An FPE consists of a group of research and applications investigations ("experiments") related by common objectives or by common requirements. Each FPE is defined physically in the NASA Blue Book, with descriptions of typical equipment which would be provided in a laboratory designed to accomplish designated FPE goals and objectives. Then, descriptions are provided for a set of experiments which typically would be conducted in such a laboratory using the equipment provided.

In NR's approach, MSS laboratories are defined that evolve in capability through three or more discrete levels. One laboratory is defined for each FPE, except in the Life Sciences discipline where four FPE's (LS-2, 3, 4, 5) are accommodated with one laboratory. This approach in Life Sciences results from the high level of commonality which exists among the equipment items required to perform the typical experiments of those FPE's.

In order to reduce equipment redundancy further, a general-purpose laboratory also has been defined. This laboratory is a contractor-furnished facility containing equipment that performs a variety of functions common to several FPE's. Included in the general-purpose laboratory are equipment items which perform, for example, data analysis, photographic processing, selected physical science and life science functions, and mechanical, electrical, and optical maintenance. In addition, the nadir- and zenith-oriented airlocks are included in the GPL, as is all MSS volume provided for the accommodation of experiment-peculiar (i. e., government-furnished) equipment.

The evolution of MSS laboratory capability was guided by a methodology which is summarized in Figure 6-1.

From the total set of objectives assigned to each FPE in the Blue Book, subsets were selected for accomplishment at each of three (or more) capability levels. Level III denotes the capability to perform 100 percent of the Blue Book objectives. Then from the total set of experiments included in the Blue Book, a subset was selected which is consistent with each subset of objectives. Then, the equipment items were identified which are required to perform the selected experiments.

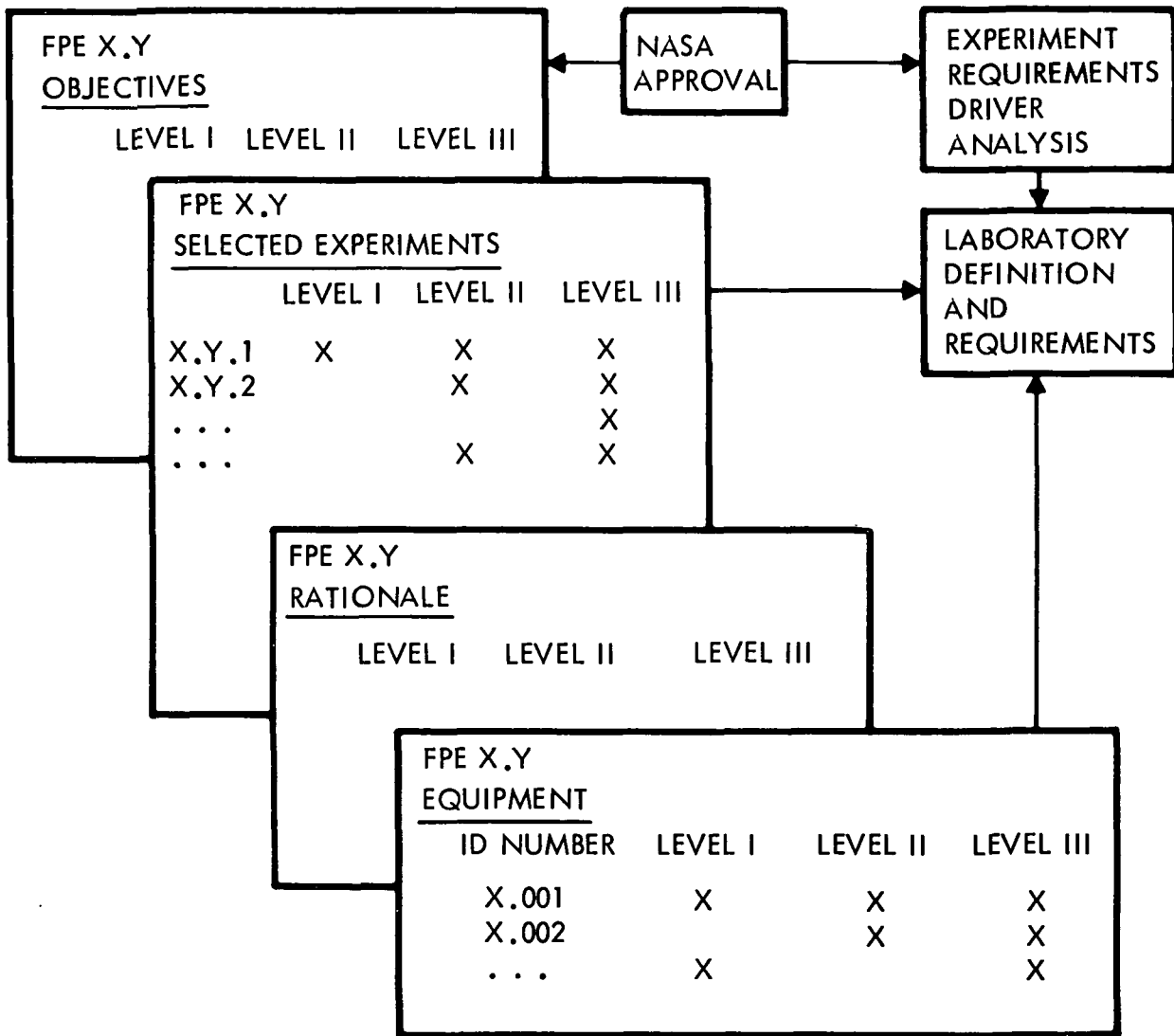


Figure 6-1. Laboratory Definition Methodology

A set of integrated requirements was defined for each laboratory at each implementation level (Table 6-1). These requirements reflect the influence not only of the evolution in laboratory capability, but also the results of the requirements driver analysis. This analysis had as its principal objective the reduction of experiment support requirements on the initial modular space station. This was accomplished, for example, by deferring certain MSS capabilities to the growth space station, by devising

**Table 6-1. Capability Levels of FPE Equipment Groupings by Carrier.  
Spacecraft (Accommodation Mode)**

Experiments		Level I	Level II	Level II-A	Level III
<b>X-Ray Stellar Astronomy (FPE A. 1)</b>					
A. 1. 1	High Resolution X-Ray Telescope Experiments	X	X		X
A. 1. 2	Large Area Moderate Resolution X-Ray Telescope Experiments		X		X
A. 1. 3	Proportional Counter Array Experiments	X	X		X
A. 1. 4	Scintillation Counting				X
A. 1. 5	Crystal Spectrometer Experiments				X
A. 1. 6	Transient X-Ray Phenomena Detection Experiment				X
Accommodation Mode		Shuttle Sortie	Detached RAM		Detached RAM
<b>Advanced Stellar Astronomy (FPE A. 2)</b>					
A. 2. 1	Technology Experiments		X		X
A. 2. 2	Stellar Observation Experiments				X
Accommodation Mode			Detached RAM		Detached RAM
<b>Advanced Solar Astronomy (FPE A. 3)</b>					
A. 3. 1	Photoheliograph Experiments	X	X		X
A. 3. 2	XUV Spectroheliograph Experiments	X	X		X
A. 3. 3	X-Ray Grazing Incidence Telescope Experiments	X	X		X
A. 3. 4	Solar Coronagraph Experiments				X
Accommodation Mode		Shuttle Sortie	Attached RAM		Detached RAM
<b>Intermediate - Size UV Telescopes (FPE A. 4)</b>					
A. 4. 1	Narrow-Field UV Telescope Experiments				X
A. 4. 2	Wide-Field UV Telescope Survey Experiments	X	X		X
Accommodation Mode		Shuttle Sortie	Attached RAM		Detached RAM

**Table 6-1. Capability Levels of FPE Equipment Groupings by Carrier  
 Spacecraft (Accommodation Mode) (Cont)**

Experiments		Level I	Level II	Level II-A	Level III
<b>High Energy Stellar Astronomy (FPE A. 5)</b>					
A. 5. 1	Low Energy X-Ray Telescope Experiments (0. 1-5 KeV)				X
A. 5. 2	X-Ray Source Mapping (1-20 KeV)	X	X		X
A. 5. 3	Narrow Band Spectrometry and Polarimetry (6-10 KeV)				X
A. 5. 4	Large Area X-Ray Counter Measurements (0. 1-100 KeV)	X	X		X
A. 5. 5	Cosmic X-Ray Energy Spectra (6-400 KeV)		X		X
A. 5. 6	Gamma Ray Spectrometry (60 KeV - 10 KeV)		X		X
A. 5. 7	High Energy Gamma Ray Measurements (10 MeV - 30 GeV)				X
Accommodation Mode		Shuttle Sortie	Attached RAM		Detached RAM
<b>Infrared Astronomy (FPE A. 6)</b>					
A. 6. 1	Detector Array Scanning		X		X
A. 6. 2	Radiometry	X	X		X
A. 6. 3	High Resolution Spectrometry	X	X		X
Accommodation Mode		Shuttle Sortie	Attached RAM		Detached RAM
<b>Space Physics Research (FPE P. 1)</b>					
P. 1. 1	Atmospheric and Magnetospheric Sciences	X	X		X
P. 1. 2	Cometary Physics				X
P. 1. 3	Meteoroid Science				X
P. 1. 4	Small Telescope Astronomy	X	X		X
Accommodation Mode		Shuttle Sortie	GPL		GPL
<b>Plasma Physics and Environmental Perturbations (FPE P. 2)</b>					
P. 2. 1	Plasma Wake	X	X		X
P. 2. 2	Plasma Resonances		X		X
P. 2. 3	Wave-Particle Interactions With VLF				X
P. 2. 4	Electron and Ion Beam Propagation	X	X		X
Accommodation Mode		Shuttle Sortie	GPL		GPL



Table 6-1. Capability Levels of FPE Equipment Groupings by Carrier  
Spacecraft (Accommodation Mode) (Cont)

Experiments		Level I	Level II	Level II-A	Level III
Cosmic Ray Physics (FPE P. 3)					
P. 3.1	Charge and Energy Spectra of CR Nuclei		X		X
P. 3.2	Electron and Positron Spectra and Anisotropies	X	X		X
P. 3.3	Isotopic Composition of Light Elements	X	X		X
P. 3.4	Nucleonic Antimatter		X		X
P. 3.5	Extremely Heavy Nuclei				X
Accommodation Mode		Shuttle Sortie	Attached RAM		Detached RAM
Physics and Chemistry Laboratory (FPE P. 4)					
P. 4.1	Molecular Beam Scattering		X		X
P. 4.2	Gas-Surface Interactions	X	X		X
P. 4.3	Flame Chemistry and Reaction Kinetics in Zero-G				X
P. 4.4	Chemical Lasers		X		X
P. 4.5	Quantum Effects at Low Temperature				X
P. 4.6	Gas Reactions in Space	X	X		X
P. 4.7	Heat Transfer in Convectionless Medium				X
P. 4.8	Critical Point Phenomena				X
Accommodation Mode		Shuttle Sortie	GPL		Attached RAM
Earth Observations (FPE ES. 1)					
ES. 1.1	Meteorology and Atmosphere Science	X	X		X
ES. 1.2	World Land Use Mapping	X	X		X
ES. 1.3	Air and Water Pollution		X		X
ES. 1.4	Resource Recognition and Identification	X	X		X
ES. 1.5	Natural Disaster Assessment		X		X
ES. 1.6	Ocean Resources		X		X
ES. 1.7	Special Research				X
Accommodation Mode		Shuttle Sortie	GPL		Attached RAM



**Table 6-1. Capability Levels of FPE Equipment Groupings by Carrier  
Spacecraft (Accommodation Mode) (Cont)**

Experiments	Level I	Level II	Level II-A	Level III
<b>Communications/Navigation (FPE C/N, 1)</b>				
C/N, 1.1 Optical Frequency	Partial	Partial		X
C/N, 1.2 MM-Wave Comm. and Prop.	Partial	Partial		X
C/N, 1.3 Surveillance Search and Res.	Partial	Partial		X
C/N, 1.4 Satellite Nav. Technique		Partial		X
C/N, 1.5 On-Board Laser Ranging		Partial		X
C/N, 1.6 Autonomous Nav. System				X
C/N, 1.7 Transmitter Breakdown	X			Partial
C/N, 1.8 Terrestrial Noise		X		X
C/N, 1.9 Noise Source Identification		X		X
C/N, 1.10 Suscep. of Terrestrial System to Sat. Rad. Energy	Partial	X		X
C/N, 1.11 Tropospheric Propagation		X		X
C/N, 1.12 Plasma Propagation				X
C/N, 1.13 Multipath Measurements				X
Accommodation Mode	Shuttle Sortie	GPL		GPL
<b>Materials Science and Manufacturing in Space (FPE MS, 1)</b>				
MS, 1.1 Metallurgical Processes	Partial	Partial		X
MS, 1.2 Crystal Growth	Partial	Partial		X
MS, 1.3 Glass Processes				X
MS, 1.4 Biological Processing		X		X
MS, 1.5 Physical Properties of Fluids	Partial	X		X
Accommodation Mode	Shuttle Sortie	GPL		GPL
<b>Contamination Measurements (FPE T, 1)</b>				
T, 1.1 Sky Background Brightness Measurements	X	X		X
T, 1.2 Real Time Contamination Measurements	X	X		X
T, 1.3 Surface Degradation Experiment		X		X
T, 1.4 Contaminant Cloud Composition Measurement	Partial	X		X

**Table 6-1. Capability Levels of FPE Equipment Groupings by Carrier Spacecraft (Accommodation Mode) (Cont)**

Experiments		Level I	Level II	Level II-A	Level III
<b>Contamination Measurements (FPE T. 1) (Continued)</b>					
T. 1. 5	Contaminant Dispersal Measurements	Partial	X		X
T. 1. 6	IRTCM Optical Module Evaluation		X		X
T. 1. 7	Active Cleaning Technique Evaluation		X		X
T. 1. 8	Contamination Control Evaluation		X		X
Accommodation Mode		Shuttle Sortie	GPL		GPL
<b>Fluid Management (FPE T. 2)</b>					
T. 2. 1	Liquid/Vapor Interface Stability	X	X		X
T. 2. 2	Boiling Heat Transfer	X	X		X
T. 2. 3	Capillary Studies	X	X		X
T. 2. 4	Condensing Heat Transfer	X	X		X
T. 2. 5	Two-Phase Flow Regimes	X	X		X
T. 2. 6	Propellant Transfer in Space	X	X		X
T. 2. 7	Long Term Cryogenic Storage	X	X		X
T. 2. 8	Slush Propellant Behavior	X	X		X
T. 2. 9	Two-Phase Dynamics	X	X		X
T. 2. 10	Channel Flow Systems	X	X		X
T. 2. 11	Conical Flow Systems	X	X		X
Accommodation Mode		Shuttle Sortie	Detached RAM		Detached RAM
<b>Extravehicular Activity (FPE T. 3)</b>					
T. 3. 1	Astronaut Maneuvering Unit	X	X		X
T. 3. 2	Maneuvering Work Platform				X
Accommodation Mode		Shuttle Sortie	GPL		Attached RAM
<b>Advanced Spacecraft System Tests (FPE T. 4)</b>					
T. 4. 1	Oxygen Recovery and Biowaste Resistojet				X
T. 4. 2	Maintainable Flight Electronics Package	X	X		X
T. 4. 3	Thermal Coating Refurbishment				X
T. 4. 4	Absorption Refrigeration Cycle Experiment	X	X		X

**Table 6-1. Capability Levels of FPE Equipment Groupings by Carrier Spacecraft (Accommodation Mode) (Cont)**

Experiments		Level I	Level II	Level II-A	Level III
Advanced Spacecraft System Tests (FPE T. 4) (Continued)					
T. 4. 5	Leak Detection and Repair	X			X
T. 4. 6	Maintainable Attitude Control Propulsion				X
T. 4. 7	Ball Bearing Lubrication	X	X		X
T. 4. 8	Advanced Guidance Subsystem Evaluation	X			X
T. 4. 9	Space Calibration of Solar Cell Standards	X	X		X
T. 4. 10	Space Exposure Effects - Material Bulk Propulsion				X
T. 4. 11	Space Exposure Effects - Fatigue Propulsion		X		X
T. 4. 12	Fire Sensing and Suppression	X	X		X
Accommodation Mode		Shuttle Sortie	GPL		GPL
Teleoperation (FPE T. 5)					
T. 5. 1	Initial Flight		X		X
T. 5. 2	Functional Manipulation		X		X
T. 5. 3	Ground Control		X		X
Accommodation Mode			GPL		GPL
Medical Research (FPE LS. 1)					
LS. 1. 1	Neurological Function	Partial	X		X
LS. 1. 2	Cardiovascular Function	Partial	X		X
LS. 1. 3	Renal Function				X
LS. 1. 4	Nutrition and Metabolic Function		X		X
LS. 1. 5	Musculoskeletal Function		Partial		X
LS. 1. 6	Pulmonary Function		X		X
LS. 1. 7	Hematologic Function				X
LS. 1. 8	Microbiology and Immunologic Function				X
LS. 1. 9	Endocrine Function				X
LS. 1. 10	Clinical/Therapeutic Function				X
LS. 1. 11	Environmental Factors				X
Accommodation Mode		Shuttle Sortie	GPL		GPL

**Table 6-1. Capability Levels of FPE Equipment Groupings by Carrier  
Spacecraft (Accommodation Mode) (Cont)**

Experiments		Level I	Level II	Level II-A	Level III
<b>Bioscience Research (FPE's LS, 2, LS, 3, LS, 4, LS, 5)</b>					
LS, 2, 1	Role of Gravity in Mammalian Vital Functions			Partial	X
LS, 2, 2	Role of Gravity in Vertebrate Life Processes			Partial	X
LS, 2, 3	Effect of Space Environment on Performance and Behavior			Partial	X
LS, 3, 1	Role of Gravity in Plant Life Cycles and Processes			X	X
LS, 3, 2	Graviception and Tropisms	Partial	Partial	Partial	X
LS, 4, 1	Role of Gravity in Life Process of Organisms/Tissues	Partial	X	X	X
LS, 4, 2	Space Environment on Genetic Subcellular Phenomena	Partial	Partial	Partial	X
LS, 4, 3	Role of Gravity in Interspecies Relationships	Partial	Partial	Partial	X
LS, 5, 1	Role of Gravity in Invertebrate Life Process		Partial	X	X
LS, 5, 2	Space Effect on Invertebrate Behavior	Partial	X	X	X
LS, 5, 3	Space Effect on Invertebrate Genetics				
Accommodation Mode		Shuttle Sortie	GPL	Attached RAM	Attached RAM
<b>Life Support and Protective Systems (FPE LS, 6)</b>					
LS, 6, 1	Water Recovery Methods	X			X
LS, 6, 2	Waste Management Methods				X
LS, 6, 3	Advanced Cooling System Methods				X
LS, 6, 4	Zero-G Whole Body Shower	X			X
LS, 6, 5	Advanced Two Gas Atmosphere Supply and Control				X
LS, 6, 6	Atmosphere Supply Methods				X
LS, 6, 7	Oxygen Regeneration Methods				X
LS, 6, 8	Carbon Dioxide Collection Method				X
LS, 6, 9	Advanced Trace Contaminant Control	X			X
LS, 6, 10	Protective Clothing and Advanced Space Suit Assemblies				X

**Table 6-1. Capability Levels of FPE Equipment Groupings by Carrier  
 Spacecraft (Accommodation Mode) (Cont)**

Experiments	Level I	Level II	Level II-A	Level III
<b>Life Support and Protective Systems (FPE LS, 6) (Continued)</b>				
LS, 6, 11    EVA Suit and Biopack				X
LS, 6, 12    Food Storage and Preparation				X
Accommodation Mode	Shuttle Sortie	GPL		GPL
<b>Man-System Integration (FPE LS, 7)</b>				
LS, 7, 1    Behavioral Effects				X
LS, 7, 2    Performance Capability Assessment	Partial	Partial		X
LS, 7, 3    Habitability and Proficiency				X
LS, 7, 4    Behavioral Effects and Performance in Rotogravitation				X
Accommodation Mode	Shuttle Sortie	GPL		Attached RAM
<b>General Purpose Laboratory</b>				
Level I	Level II		Level III	
<b>EXPERIMENT AREAS</b>				
Communications/Navigation Fluid Management Physics Earth Observations	Earth Observations Contamination Physics Communications/Navigation Biomedicine Material Science		Earth Observations Technology Physics Life Science Communications/Navigation Material Science	
<b>LABORATORY DESCRIPTORS</b>				
Contain Equipment Common to Selected "Suitcase" and Orbit Sensitive Experiment Areas	Contain Equipment Common to Selected Precursor, High Benefit/Low Cost Experiment Areas		Contain Equipment Common to High Crew Involvement and Advanced Systems Develop- ment Experiment Areas	
Provide Support Equipment For, e. g., Command/Control, Minimum Data Display (Engi- neering Data), Sensor Deploy- ment (Small Airlock with Sensor Platform, Boom)	Provide Support Equipment For, e. g., Moderate Level of Data Analysis, Sensor Deployment (Large Airlocks) with Earth and Celestial Viewing		Provide Augmented Data Analysis, Maintenance and Repair, Photo Processing and Other Support Equipment	
Contain Multipurpose Work Area				

alternative means to accomplish certain requirements, by scheduling around requirements peaks, and by assigning the implementation of certain requirements to the experiment-peculiar equipment. These techniques were coordinated with, and approved by, NASA.

The laboratory definitions and requirements which resulted from this analysis were used as input to the experiment scheduling activity.

Each of the experiment laboratories is described in terms of selected experiments and accommodation (or carrier) mode (shuttle sortie, Detached RAM, Attached RAM, or within the GPL). Level I is, in general, aimed at accommodation on shuttle sortie missions. Levels II and III are typically accommodated in the station GPL or in attached or detached (free-flying) RAM's. The MSS GPL is described in the final table of this set

### 6.3.2 Experiment Priorities and Scheduling

The purpose of this section is to describe the results of the NR experiment selection and phasing analyses. The ultimate product of these analyses is the reference experiment program which is used to prepare the mission sequence plan for the MSS program.

The reference experiment program is the time-phased sequence of on-orbit experiment laboratories. Each laboratory, when it is on orbit, consumes resources at a rate which depends on its level of capability. This, in turn, is defined by the typical experiments which have selected for the laboratory at each level of capability.

In general, Level I capability laboratories were defined so as to be compatible with the shuttle sortie mode of implementation. Thus, no Level I laboratory was selected for the MSS reference experiment program which begins at the time of initial operational capability of the initial (6-man) MSS. Similarly, the requirements of Level II laboratories were designed to be compatible with the initial MSS, and Level III capability with the growth MSS, although no constraint was placed, a priori, on the use of either Level II or Level III laboratory equipment groupings in either the initial or growth MSS. Limitations on available crew time (35 man-hours per day for the initial MSS) resulted, however, in some Level II labs and all Level III labs being deferred until the growth MSS. Manpower limitations also mean that the entire set of Blue Book experiments cannot be completed within five years of growth station operations (July 1, 1972) even though the equipment's capability to perform them all is present. Thus, it became necessary to choose criteria other than capability level in specifying the experiments performed by the initial and growth stations. The procedure used to establish priorities for laboratory selection are summarized in the following paragraphs.



The main factors to be considered in time-phasing the experiments in the reference experiment program are: cost, availability of equipment and techniques, scheduling interrelationships and constraints, priority, system capabilities, and experiment requirements. The specific phasing data developed in this analysis consist of scheduling interrelationships and constraints and experiment priority. The latest cost information is contained in the document "Cost Data for Preliminary Edition of the Reference Earth Orbital Research and Application Investigations" published by NASA under Report No. ASR-PD-MP-71-1. Availability dates (for launch) are not known due to programmatic uncertainties relative to the initiation of the experiment development cycles. However, three important indicators may be used to estimate availability:

1. Development time (e. g. , 4 to 6 years) as shown in the NASA cost data book as well as the Blue Book.
2. Technological factors that may prevent the initiation of the development cycle until some functional technology milestone has been achieved.
3. Projected funding constraints driving toward the postponement of the development of high-cost experiment systems having adverse impact on low early yearly funding requirements for the space station program.

The MSS system requirements are available in the form of the Modular Space Station Preliminary Performance Specifications, SD 71-215-1, prepared during the course of the MSS Phase B Study.

The following steps were employed in the phasing of experiments (Steps 1 and 2 were described in the preceding subsection):

1. Experiments were assembled into groupings having commonality of objectives, equipment, and operational requirements. The "facility" or laboratory approach is useful as a criterion in establishing which experiments should be grouped together. Because of the "facility" orientation of the 1971 Blue Book, the FPE is often a good line of demarcation for a facility grouping.
2. A systematic progression in capability for each experiment equipment grouping within an FPE was defined consistent with a logical growth in application or scientific achievement in space.
3. Based on the road map in Step 2, the experiments were ordered chronologically to establish a preferred sequence for conducting the experiments. The interrelationships and scheduling

constraints must be considered in this process. Gradual buildup in experiment yearly funding was treated in at least a gross (qualitative) way.

4. A composite laboratory sequence was assembled from all individual facility groupings (or FPE's), considering priorities, interrelationships, and scheduling constraints.
5. Laboratory requirements were accommodated within the station capabilities and constraints. Priorities were used to resolve conflicts in determining which experiments should take precedence, given a situation where the requirements exceed the station capabilities.

In Step 4, scheduling constraints are required to prepare a laboratory sequence as an input of the scheduling process. The constraints used in this analysis are summarized in Table 6-2.

In Steps 4 and 5, experiment priorities are required to permit the selection of a resource-limited subset of laboratories from the overall set. The methodology employed in the analysis of experiment priorities considered the two components that constitute a measure of the value of an experiment:

1. Benefit Category - A classification of the type of return to mankind, expected from the accomplishment of the stated objectives. This is expressed in terms of the following broad categories: socio-economic benefits or scientific knowledge. These are further classified according to the following criteria: direct or indirect benefits and actual (measurable) or potential benefits.
2. Worth Rating - A relative level in a scale of 1 through 5, indicate the degree to which the experiment will contribute to the goals or objectives of the related discipline. A 3 indicates "moderate" support, a 4 indicates significant support of an important nature, while a 5 indicates support of such magnitude that very important results will be derived in an application sense or in terms of expansion of the scope of human knowledge.

A numbering system was devised in which a roman numeral followed by an arabic number define the benefit category. The definitions of the various category combinations are as follows:

- I.1 Experiment directly supports objectives leading to actual socio-economic benefits.

Table 6-2. Schedule Constraints Within a Typical FPE

FPE Title	FPE No. (Expt No.)	Constraints	Rationale	Remarks
X-Ray Stellar Astronomy	A-1 (A-1.2)	Experiment A-1.2 - Large area moderate resolution. X-Ray telescope experiment should precede high resolution X-Ray telescope experiments whenever possible (A-1.1). However, A-1.2 launch date is 1981 or later.	Large area experiment will catalog position, intensity, and spectral distribution of X-Ray sources. High resolution X-Ray will make detailed studies. 7 year lead time required for instrument procurement.	Long focal length. Large mirror required. Difficult construction.
Advanced Stellar Astronomy Intermediate UV Telescopes	A-2 A-4	Space Physics - P-1 (P-1.4) Small telescopes could precede A-2 and A-4 by at least one year and could also be conducted concurrently with A-2 and A-4 i.e., Space Shuttle followed by GPL - Initial Station.	Use of P-1.4 early could show value of space telescopes in this configuration and intensify efforts on A-2 and A-4.	P-1.4 small telescope experiments physics P-1. Supplements A-2 and A-4, but could also do early precursor work of high interest phenomena.
Advanced Stellar Astronomy Advanced Stellar Astronomy	A-2 A-2	Launch schedule 1981 or later.	Diffraction limited, optical system development limiting.	
Advanced Solar Astronomy	A-3	Launch schedule 1979 or later.	Photobeliograph thermal control system development limiting.	
Infrared Astronomy	A-6	Launch schedule 1982 or later.	Cryogenic cooling system development limiting.	
Contamination Measurements X-Ray Stellar Astronomy Advanced Stellar Astronomy Advanced Solar Astronomy Intermediate UV Telescope Infrared Astronomy Earth Observations	T-1 A-1 A-2 A-3 A-4 A-6 ES-1	Contamination related experiments T-1 should be performed 2 years prior to astronomy experiments could be concurrent with ES-1 on initial station.	Contamination will aid in incorporation of proper countermeasures.	
Contamination Measurement Plasma Physics and Environmental Perturbations	T-1 P-2	Accomplish in same time frame (6 mo.)	Related experiments.	Spacecraft wake studies could be useful in gaining an understanding of the phenomena of contaminant dispersion.
Advanced Space System Tests	T-4 (T-4.8)	Advanced guidance system should be accomplished on first available FF module.	Data on maximum limits of accuracy and stability which can be achieved in orbit should be obtained as soon as possible.	Extreme stability required for astronomy experiments.
Physics and Chemical Lab Contamination Measurement Life Support and Protective Systems	P-4 T-1 LS-6	Accomplish in same time frame if feasible.  LS-6.11- EVA	Both FPE's use airlocks. Same airlocks could be used.	Experiments could be accomplished early or late in program with airlock leakage penalty minimized.
Plasma Resonances	P-2.1- P-2.4	Subsatellites required for these FPE's could be designed for common use. Experiments accomplished in same time frame, if possible.	Subsatellite deployment is driver on station. Least number of satellites and least number of deployments is most economical.	
Communication and Navigation	C/N-1.1- C/N-1.5 C/N-1.12			
Cosmic Ray Physics	P-3	Launch schedule 1981 or later.	P-3- Physics. 6 year development time. High energy astronomy observatory (HEOS) scheduled 1973-75. HEOS should precede P-3.	

- I. 2 Experiment indirectly supports objectives leading to actual socio-economic benefits.
- I. 3 Experiment directly supports objectives leading to potential socio-economic benefits.
- I. 4 Experiment indirectly supports objectives leading to potential socio-economic benefits.
- II. 1 Experiment directly supports objectives leading to actual scientific benefits.
- II. 2 Experiment indirectly supports objectives leading to actual scientific benefits.
- II. 3 Experiment directly supports objectives leading to potential scientific benefits.
- II. 4 Experiment indirectly supports objectives leading to potential scientific benefits.

Each of the FPE's and, where necessary, experiments to be performed in the MSS laboratories, were evaluated and categorized in accordance with the preceding methodology; that is, they were each assigned a benefit category and a worth rating. The experiments were then ranked to produce a "balanced" list of priorities in which high worth (5) experiments, whether in the socio-economic or scientific benefit categories, are listed first, followed by experiments of lower worth. Similarly, direct benefits take precedence over indirect, and actual over potential. Differences in rank between adjacent entries are not significant. The balanced list of experiment selection priorities is shown in Table 6-3.

On applying the scheduling constraints, the order of experiment implementation is established. Certain experiments of relatively low priority were placed high in order of implementation as a result, for instance, of their precursor nature. Examples of this type of rearrangement are some of the contamination monitoring and control experiments of FPE T. 1, Contamination Measurements. These have fairly low priority in themselves but are scheduled early because they are a necessary support to other more important experiments. With resource requirements for experiments defined at the laboratory level, the next step in experiment scheduling is to arrange the laboratories into a sequence which best accomplishes the desired order of experiment implementation. This sequence is shown in Table 6-4.



Table 6-3. Experiment Selection Priorities

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

Table 6-4. Laboratory Scheduling Sequence

FPE No.	Laboratory	Preferred Sequence	
		Level II	Level III
P-4	Physics and Chemistry	1	3
T-1	Contamination Measurements	1	1
P-2	Plasma Physics and Environmental Perturbations	1	12
ES-1	Earth-Observations	2	1
A-3	Advanced Solar Astronomy	3	2
LS-1	Medical Research	4	3
A-1	X-Ray Stellar Astronomy	5	4
A-5	High-Energy Stellar Astronomy	5	4
P-3	Cosmic Ray Physics	5	4
P-1	Space Physics Research	6	5
MS-1	Materials Science and Manufacturing in Space	7	6
C/N-1	Communications/Navigation	7	6
T-4	Advanced Spacecraft Systems Test	8	7
T-5	Teleoperation	9	7
A-2	Advanced Stellar Astronomy	9	8
A-6	Infrared Astronomy	9	8
LS-2, 3, 4, 5	Biosciences Research	10	9
LS-6	Life Support and Protective Systems	11	10
LS-7	Man-System Integration	11	10
T-3	Extravehicular Activity	12	11
A-4	Intermediate-Size UV Telescopes	13	12
T-2	Fluid Management	14	13

The laboratory schedule which resulted from this procedure, and the simultaneous application of constraints such as available crew man-hours, is shown in Figure 1-7. The figure shows the relative time-phasing of the laboratories, their implementation levels, and carrier spacecraft modes. This is the experiment project which forms the basis for experiment costing and which has been incorporated into the mission sequence plan. The funding cutoff point defined in the ground rules for Section 2 is also shown.

### 6.3.3 Cost Estimates

Having determined the experiment groupings for each of the capability levels and the sequence in which these groupings are to be used, NASA MSC-furnished data in MSFC Report No. ASR-PD-MP-71-1 (Reference 3) were employed to cost the experiments. A list of hardware items was compiled by carrier spacecraft (accommodation mode) for each of the experiments and capability Levels II and III shown in Table 6-1. Insofar as possible, these lists were matched against the items listed in ASR-PD-MP-71-1. Many cases occurred in which direct matching was not possible. In such cases, an interpretation of the terminology in ASR-PD-MP-71-1 was made. The costs associated with each experiment grouping at each capability level and each host (carrier) spacecraft were then estimated for DDT&E, production (TFU, since only one unit of each grouping is planned), and annual operating rate.

The DDT&E and TFU costs are assumed to include all applicable costs in ASR-PD-MP-71-1 through launch year "L", where year L is now defined by the Mission Sequence Plan (Figure 1-7) and spelled out in Section 2. Since ASR-PD-MP-71-1 did not separate DDT&E costs from production costs, it was necessary to make a breakdown for Cost Estimate Data Form A. Ratios of DDT&E costs to TFU costs were approximated by matching the current FPE's against similar FPE's in the 33-foot station Phase B study (Reference 3). The ratios vary from as low as 3-to-1 to as high as 30-to-1. The lead times were approximated directly from NASA Report No. ASR-PD-MP-71-1, with availability for installation as outlined in Section 2. For scheduling and funding purposes, it was arbitrarily assumed that the non-recurring DDT&E cost portion would consume the first 60 percent of the lead time, and production the last 40 percent, with no provision for overlap. A 50-50 ogive cost distribution curve is used for both nonrecurring and production elements based on previous studies (Reference 21). All integration costs in ASR-PD-MP-71-1 are assumed to include integration into a functional laboratory or facility, with costs of integration into the carrier spacecraft charged against that spacecraft. It was also decided that interface hardware in this report would be charged to the experiment project since the interface equipment is FPE-peculiar. The DDT&E and TFU costs (in 1971 dollar value) which finally resulted were then multiplied by 1.05 to convert them to 1972 dollar value.

The operating costs were defined at an annual rate, because ASR-PD-MP-71-1 does not make adequate provision for the manpower and other constraints which play such a prominent role in fashioning the mission sequence plan. Accordingly, these costs were applied against the operational duration defined in the mission sequence plan or longer if data interpretation by principal investigators was considered to necessitate a longer duration. Conversion to a 1972 dollar value was made as described in the previous paragraph.

Report ASR-PD-MP-71-1 treated each scientific discipline as an entity. The costs estimated therein were adjusted by reducing the equipment list to account for the ability of the station's general purpose laboratory to service numerous FPE's and experiments with the same equipment. The approximate impact on the total cost estimates thus effected are described in Subsection 5.9.

Refurbishment costs for experiments were assumed for all experiments in which the mission sequence plan shows a gap in operations exceeding three months. Refurbishment costs were estimated to be 15 percent of the production costs of the equipment already used, and were included in the operations phase.

In each of the procurement phases, the costs thus generated were aggregated by host spacecraft and the aggregate figures are shown in Section 7. The numbering system used in the WBS (see Figure 2-2 and Cost Estimate Data Forms A) permit easy identification of Experiment Project (XX-3XX-00-00) costs by carrier spacecraft in the sixth and seventh fields. Thus, the -YY-00 and ZZ-00 aggregate experiment costs can be readily related to the -YY-00 and ZZ-00 RAM costs for corresponding host spacecraft.

#### 6.3.4 Total Experiment Cost Summary

The earth-orbital experiment project costs amount to an estimated \$2,602 million in 1972 dollar value for the projects as defined by the ground rules of Section 2. These costs exceed the MSS project costs by almost \$230 million, and constitute about 47 percent of the total space station earth-orbital program costs included in this report.



#### 6.4 RESEARCH AND APPLICATIONS MODULE PROJECT COSTS

Two types of RAM's have been identified for use with the modular space station. The attached RAM's are physically attached to the MSS during the performance of experiments. Detached RAM's are free flyers in the proximity to the MSS during the experiment operation. For costing purposes the attached RAM (A-RAM) is assumed to consist of a module called the experiment equipment module (EEM). The detached RAM (D-RAM) is assumed to consist of an EEM plus a support section module (SSM) which provided utilities to the EEM in the absence of attachment to the MSS, and is thus equivalent to an A-RAM, or EEM, plus an SSM.

The number of A-RAM EEM's and D-RAM EEM's and SSM's required is a function of the mission sequence plan and efficiency in module utilization. The FPE's which begin in an A-RAM and end up in a D-RAM, or begin in a D-RAM, are the following: A. 1, A. 2, A. 3, A. 4, A. 5, A. 6, and T. 2. Figure 6-2 shows the sequence in which SSM's are to be used and indicates that two are required for the mission sequence; this plan eliminates overlapping needs for more SSM's. Allowing provisions for a backup results in a total of three SSM's for costing purposes. All SSM's are charged to the D-RAM Project, WBS No. XX-5XX-ZZ-00.

The mission sequence plan in Figure 1-7 also shows that RAM's for P. 3, P. 4, ES. 1, A. 3, A. 4, A. 5, A. 6, L.S2-5, L.S6, and LS. 7 are of the attached type for intermediate or Level III capability experiments following Level II capability experiments in the GPL of the MSS, or represent Level II capability implementation initially. Thus, ten EEM's are needed for these experiments and the costs of these EEM's are charged against A-RAM DDT&E and production costs in WBS No. XX-4XX-YY-00, but only nine are included in the costs since LS. 6 is not operational before 1993 (see ground rules in Section 2). On the other hand, FPE's A. 1, A. 2, and T. 2 are initially accomplished in D-RAM's, necessitating three EEM's which are charged against the D-RAM Project, WBS No. XX-5XX-ZZ-00. Only two of these can be included in the costs in view of the Section 2 ground rules, T. 2 not becoming operational until 1996.

The contractor's estimate of costs for experiment modules (RAM's) at WBS Level 3 are summarized in Table 6-5. These values reflect 1972 dollars and include all floating item elements of cost.

Table 6-5. RAM Project Cost Summary  
 (\$ Million, 1972 Dollar Value)

Project	WBS ID No.	DDT&E	Production	
			Qty	Cost
Attached RAM's	XX-4XX-00-00	\$158.4	9	\$ 49.9
Detached RAM's (Including support sections)	XX-5XX-00-00	123.3	2	64.7
Total		\$281.7	3	\$114.6

The scope of this study did not include design of RAM's; therefore, costs were derived on the basis of physical similarity to items for which cost estimates had previously been generated.

Subsystem costs other than structural and mechanical were based on experiment module estimates for other subsystems that were developed for the 33-foot diameter earth-orbital space station program and are documented in SD 70-154, dated July 1970. For the attached and detached RAM's, the two most typical modules (space biology and X-ray astronomy) were selected and an average cost computed. This cost was then used for the first RAM with an assumed 15 percent added for unique subsystem development on each successive RAM. For the support sections, each assumed to be the same configuration, the five most typical modules were selected and an average cost computed.

Structural and mechanical subsystem costs for the attached and detached RAM's were based on MSS technology and assume that all assemblies except the secondary structure were derivatives of initial Station Module 2 with significant know-how benefits. The secondary structure was considered an all new assembly with full development on the first RAM and a 40 percent new development for each successive RAM.

In addition to the DDT&E and production costs summarized above, \$61.3 million has been included under recurring operations for modification and refurbishment of RAM project elements. This includes modification of two RAM's from an attached to a detached mode and modification of four support sections to accommodate experiment payload changes, plus refurbishment of two attached and two detached RAM's. These costs are predicated on a 20 percent subsystem cost delta each time a modification



was anticipated, and 15 percent of the production costs of subsystems already used, with the exception of structural and mechanical, for refurbishment.

The DDT&E costs of both attached and detached RAM's include factors for space station and experiment integration. The RAM-to-station integration is estimated at \$1 million per year for the total development and operational phases and the experiment integration costs are included at 4.4 percent of the experiment costs.

Recurring production costs include experiment integration, assembly, and checkout and are based on 17 percent of the experiment cost applicable to each RAM project.



## 7. COST ESTIMATE DATA FORM A

This section presents cost estimates for each WBS item to Level 5 on the Modular Space Station Project (XX-1XX-00-00) and to Level 4 of the WBS for the Experiments Definition Project (XX-2XX-00-00), Earth-Orbital Experiments Project (XX-3XX-00-00), Attached RAM Project (XX-4XX-00-00), and the Detached RAM Project (XX-5XX-00-00). Costs are displayed in three categories; nonrecurring (DDT&E), recurring production, and recurring operations.

Cost Estimate Data Form A lists the WBS level, identification number, name and item cost; the number of units, the reference unit, and the learning index; Td (development time); Ts (lead time); spread function, and the milestone data (completion of five years' operation for the growth space station).

The following steps describe the contents of each column in Table 7-1 Cost Estimate Data Form A. The form is categorized by three separate cost items: nonrecurring (DDT&E), recurring production, and recurring operations.

1. Work breakdown structure (WBS) identification number. From the WBS (13-digit coding system); XX (program level), -XXX (project level), -XX (system), -XX (subsystem), -XX (assembly), and -XX (component). Only the program, project, system, and subsystem elements are used to identify the WBS element to Level 5, as shown (XX-XXX-XX-XX).
2. WBS item name. Identification by alphanumeric nomenclature of the item from the WBS.
3. WBS item cost. The appropriate cost estimate for the given WBS element. In the production and operations forms, the WBS item cost is the total cumulative cost for the number of units.
4. Number of units. The quantity of units used to obtain the cost for each WBS item for program production and operational phases. This column does not appear in the nonrecurring (DDT&E) portion.
5. Reference Unit. The production sequence number for the first unit used in the program's recurring phase.



6. Learning index. The numerical index of a learning rate that is applied to the first unit in Item 3 (WBS item cost) to obtain unit cost estimates for subsequent production. No entries are made since only one of each station module is produced, and cargo modules and RAM's are not costed accurately enough to warrant learning curve application.
7. Td. The development or production time in months required to design and develop, produce, or operate the activity. Td is, therefore, the cost duration for the WBS activity.
8. Ts. The lead time in months measured from the start of cost accrual for the WBS item to the milestone date.
9. Spreading Function. An index number representing a cost distribution curve from which the estimator recommends the time phasing (WBS item cost) over the period shown under Td. The first number denotes the percentage of work completed in the first 50 percent of the time period; the second number, the work percentage completed in the last 50 percent of the period. All cost distribution curves used in Cost Estimating Data Form A are illustrated in Appendix D.
10. Milestone Date. The date used in conjunction with Ts. Specifically, this is the scheduled date for completion of five years' operation of the growth space station.

The rationale for the spreading functions deserves further comment. The 40-60 spread for the nonrecurring costs on the initial station subsystems, major test programs, and ground support equipment is based on a paced schedule and the provision for the incorporation of considerable testing results in the aft end of the period, as contrasted with a rushed front-loaded schedule with most testing early. Cargo and growth modules are front-loaded a little more to recognize the know-how acquired on the initial modules.

Special time spreads were made up for the structural and mechanical subsystem of the initial core module and power module, on which the tooling and STE effort was considered large enough to alter the funding spread for that subsystem significantly from the 40-60 spread. These spreads were constructed by assuming that most of the tooling effort would be completed within the first 30 percent of the production cycle of the module, and STE would precede system installation by about one year. The tooling and STE were added to a 40-60 agree for the remainder of the nonrecurring effort, using rough estimates of the respective amounts, to arrive at the spread shown in Appendix D.

Table 7-1. Cost Estimate Data - Form A

X Nonrecurring (DDT&E)  
 - Recurring (Production)  
 - Recurring (Operations)

WBS Level	WBS Identification Number	WBS Item Name	WBS Item Cost	Units	Unit	Learn. Index	T <sub>d</sub>	T <sub>s</sub>	Spread. Func.	Milestone Date
2	XX-0XX-00-00	Space Station Earth Orbital Program	3,853.7	N/A	N/A	N/A				7-1-92
3	XX-1XX-00-00	Modular Space Station Project	1,593.9							7-1-92
4	XX-1XX-01-00	Initial Core Module	219.7							7-1-92
5	XX-1XX-01-00	Structural & mechanical subsystem	65.4				69	201	Special	7-1-92
5	XX-1XX-01-02	ECLS subsystem	24.4				69	201	40/60	7-1-92
5	XX-1XX-01-03	Electrical power subsystem	24.2				69	201	40/60	7-1-92
5	XX-1XX-01-04	Guidance & control subsystem	60.9				69	201	40/60	7-1-92
5	XX-1XX-01-05	Reaction control subsystem	18.7				69	201	40/60	7-1-92
5	XX-1XX-01-06	Information subsystem	16.3				69	201	40/60	7-1-92
5	XX-1XX-01-07	Crew habitability subsystem	9.8				69	201	40/60	7-1-92
4	XX-1XX-02-00	Power Module	172.3							
5	XX-1XX-02-01	Structural & mechanical subsystem	25.9				69	201	Special	7-1-92
5	XX-1XX-02-01	Structural & mechanical subsystem (growth)	15.3				56	124	Special	7-1-92
5	XX-1XX-02-02	ECLS subsystem	11.4				69	201	40/60	7-1-92
5	XX-1XX-02-03	Electrical power subsystem	118.0				69	201	40/60	7-1-92
5	XX-1XX-02-03	Electrical power subsystem (growth)	1.0				56	124	50/50	7-1-92
5	XX-1XX-02-06	Information subsystem	0.4				69	201	40/60	7-1-92
5	XX-1XX-02-07	Crew habitability subsystem	0.3				69	201	40/60	7-1-92
4	XX-1XX-03-00	Control/Crew Module (SM-1)	250.7							7-1-92
5	XX-1XX-03-01	Structural & mechanical subsystem	29.4				69	201	40/60	7-1-92
5	XX-1XX-03-02	ECLS subsystem	72.7				69	201	40/60	7-1-92
5	XX-1XX-03-03	Electrical power subsystem	7.7				69	201	40/60	7-1-92
5	XX-1XX-03-06	Information subsystem	134.4				69	201	40/60	7-1-92
5	XX-1XX-03-07	Crew habitability subsystem	6.5				69	201	40/60	7-1-92
4	XX-1XX-04-00	Labs/ECLSS Module (SM-2)	108.7							7-1-92
5	XX-1XX-04-01	Structural & mechanical subsystem	29.8				69	201	40/60	7-1-92
5	XX-1XX-04-02	ECLS subsystem	71.6				69	201	40/60	7-1-92
5	XX-1XX-04-03	Electrical power subsystem	2.6				69	201	40/60	7-1-92
5	XX-1XX-04-05	Reaction control subsystem	1.7				69	201	40/60	7-1-92
5	XX-1XX-04-06	Information subsystem	1.2				69	201	40/60	7-1-92
5	XX-1XX-04-07	Crew habitability subsystem	1.8				69	201	40/60	7-1-92
4	XX-1XX-05-00	Labs/ECLSS Module (SM-3)	48.7							
5	XX-1XX-05-01	Structural & mechanical subsystem	16.7				69	201	40/60	7-1-92
5	XX-1XX-05-02	ECLS subsystem	17.4				69	201	40/60	7-1-92

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Table 7-1. Cost Estimate Data - Form A (Cont)

X Nonrecurring (DDT&E)  
 - Recurring (Production)  
 - Recurring (Operations)

WBS Level	WBS Identification Number	WBS Item Name	WBS Item Cost	Units	Unit	Learn Index	T <sub>d</sub>	T <sub>s</sub>	Spread. Funct.	Milestone Date
5	XX-1XX-05-03	Electrical power subsystem	0.5				69	201	40/60	7-1-92
5	XX-1XX-05-05	Reaction control subsystem	0.5				69	201	40/60	7-1-92
5	XX-1XX-05-06	Information subsystem	0.6				69	201	40/60	7-1-92
5	XX-1XX-05-07	Crew habitability subsystem	13.0				69	201	40/60	7-1-92
4	XX-1XX-06-00	Control/Crew Module (SM-4)	60.4							7-1-92
5	XX-1XX-06-01	Structural & mechanical subsystem	12.2				74	201	40/60	7-1-92
5	XX-1XX-06-02	ECLS subsystem	18.7				74	201	40/60	7-1-92
5	XX-1XX-06-03	Electrical power subsystem	1.5				74	201	40/60	7-1-92
5	XX-1XX-06-06	Information subsystem	18.0				74	201	40/60	7-1-92
5	XX-1XX-06-07	Crew habitability subsystem	10.0				74	201	40/60	7-1-92
4	XX-1XX-07-00	Cargo Modules	51.5							7-1-92
5	XX-1XX-07-01	Structural & mechanical subsystem	14.6				75	201	50/50	7-1-92
5	XX-1XX-07-02	ECLS subsystem	32.2				75	201	50/50	7-1-92
5	XX-1XX-07-03	Electrical power subsystem	1.8				75	201	50/50	7-1-92
5	XX-1XX-07-06	Information subsystem	0.7				75	201	50/50	7-1-92
5	XX-1XX-07-07	Crew habitability subsystem	2.2				75	201	50/50	7-1-92
4	XX-1XX-08-00	Growth Core Module	51.4							7-1-92
5	XX-1XX-08-01	Structural & mechanical subsystem	31.4				56	124	50/50	7-1-92
5	XX-1XX-08-02	ECLS subsystem	6.3				56	124	50/50	7-1-92
5	XX-1XX-08-03	Electrical power subsystem	6.7				56	124	50/50	7-1-92
5	XX-1XX-08-05	Reaction control subsystem	2.6				56	124	50/50	7-1-92
5	XX-1XX-08-06	Information subsystem	3.7				56	124	50/50	7-1-92
5	XX-1XX-08-07	Crew habitability subsystem	0.7				56	124	50/50	7-1-92
4	XX-1XX-09-00	Crew/ECLSS Module (SM-5)	34.6							7-1-92
5	XX-1XX-09-01	Structural & mechanical subsystem	7.0				59	124	50/50	7-1-92
5	XX-1XX-09-02	ECLS subsystem	9.5				59	124	50/50	7-1-92
5	XX-1XX-09-03	Electrical power subsystem	1.2				59	124	50/50	7-1-92
5	XX-1XX-09-05	Reaction control subsystem	0.8				59	124	50/50	7-1-92
5	XX-1XX-09-06	Information subsystem	14.9				59	124	50/50	7-1-92
5	XX-1XX-09-07	Crew habitability subsystem	1.2				59	124	50/50	7-1-92
4	XX-1XX-10-00	Crew/ECLSS Module (SM-6)	10.7							7-1-92
5	XX-1XX-10-01	Structural & mechanical subsystem	6.8				59	124	50/50	7-1-92
5	XX-1XX-10-02	ECLS subsystem	2.7				59	124	50/50	7-1-92
5	XX-1XX-10-03	Electrical power subsystem	0.3				59	124	50/50	7-1-92
5	XX-1XX-10-05	Reaction control subsystem	0.3				59	124	50/50	7-1-92

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Table 7-1. Cost Estimate Data - Form A (Cont)

X Nonrecurring (DDT&E)  
 \_\_\_\_\_ Recurring (Production)  
 \_\_\_\_\_ Recurring (Operations)

WBS Level	WBS Identification Number	WBS Item Name	WBS Item Cost	No. of Units	Ref Unit	Learn. Index	T <sub>d</sub>	T <sub>s</sub>	Spread. Funct.	Milestone Date
5	XX-1XX-10-06	Information subsystem	0.3				59	124	50/50	7-1-92
5	XX-1XX-10-07	Crew habitability subsystem	0.3				59	124	50/50	7-1-92
4	XX-1XX-25-00	Project Management	98.7				137	201	∑	7-1-92
4	XX-1XX-30-00	Systems Support	84.8				137	201	∑	7-1-92
4	XX-1XX-35-00	Premission Operations	25.0				75	201	50/50	7-1-92
4	XX-1XX-45-00	GPL Experiment Integration	21.1				216	201	50/50	7-1-92
4	XX-1XX-50-00	Major Test Programs	252.8				36	176	40/60	7-1-92
4	XX-1XX-60-00	Ground Support Equipment	84.7				41	174	40/60	7-1-92
4	XX-1XX-65-00	Facilities	18.1				137	201	Special	7-1-92
3	XX-2XX-00-00	Experiments Definition	114.6							7-1-92
4	XX-2XX-01-00	Astronomy (A)	16.0				128	210	Constant	7-1-92
4	XX-2XX-02-00	Physics (P)	14.0				112	210	Constant	7-1-92
4	XX-2XX-03-00	Earth observations (ES)	9.1				73	210	Constant	7-1-92
4	XX-2XX-04-00	Communications/navigation (C/N)	17.6				141	210	Constant	7-1-92
4	XX-2XX-05-00	Material science & manufacturing (MS)	9.0				72	210	Constant	7-1-92
4	XX-2XX-06-00	Technology (T)	15.0				120	210	Constant	7-1-92
4	XX-2XX-07-00	Life sciences (LS)	16.3				130	210	Constant	7-1-92
4	XX-2XX-10-00	Experiment planning	17.6				141	210	Constant	7-1-92
3	XX-3XX-00-00	Earth Orbital Experiments	1,863.5							7-1-92
4	XX-3XX-NN-00	GPL experiments (aggregate)	480.6				165	210	50/50*	7-1-92
4	XX-3XX-YY-00	Attached RAM experiments (aggregate)	789.3				154	203	50/50*	7-1-92
4	XX-3XX-ZZ-00	Detached RAM experiments (aggregate)	593.6				104	155	50/50*	7-1-92
3	XX-4XX-00-00	Attached RAM Project	158.4							7-1-92
4	XX-4XX-YY-00	RAM's (aggregate)	158.4				178	182	40/60*	7-1-92
3	XX-5XX-00-00	Detached RAM Project	123.3							7-1-92
4	XX-5XX-ZZ-00	RAM's (aggregate)	123.3				144	154	40/60*	7-1-92

\*Spreading functions are for individual experiments and modules. See Form D for aggregate spreads.

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Table 7-1. Cost Estimate Data - Form A (Cont)

- Nonrecurring (DDT&E)  
 X Recurring (Production)  
 - Recurring (Operations)

WBS Level	WBS Identification Number	WBS Item Name	WBS Item Cost	No. of Units	Ref. Unit	Learn. Index	T <sub>d</sub>	T <sub>s</sub>	Spread. Funct.	Milestone Date
2	XX-0XX-00-00	Space Station Earth Orbital Program	708.9							7-1-92
3	XX-1XX-00-00	Modular Space Station Project	418.0							7-1-92
4	XX-1XX-01-00	Initial Core Module	38.0	1						7-1-92
5	XX-1XX-01-01	Structural & mechanical subsystems	5.9				13	155	50/50	7-1-92
5	XX-1XX-01-02	ECLS subsystem	2.8				33	174	50/50	7-1-92
5	XX-1XX-01-03	Electrical power subsystem	9.7				33	174	50/50	7-1-92
5	XX-1XX-01-04	Guidance & control subsystem	10.3				33	174	50/50	7-1-92
5	XX-1XX-01-05	Reaction control subsystem	1.8				33	174	50/50	7-1-92
5	XX-1XX-01-06	Information subsystem	2.4				33	174	50/50	7-1-92
5	XX-1XX-01-07	Crew habitability subsystem	1.6				33	174	50/50	7-1-92
5	XX-1XX-01-08	Subsystem instal, assy & C/O	3.5				10	141	50/50	7-1-92
4	XX-1XX-02-00	Power Module	113.7	1						7-1-92
5	XX-1XX-02-01	Structural & mechanical subsystem	1.3				8	147	50/50	7-1-92
5	XX-1XX-02-01	Structural & mechanical subsystem (growth)	1.1				33	104	50/50	7-1-92
5	XX-1XX-02-02	ECLS subsystem	1.4				33	172	50/50	7-1-92
5	XX-1XX-02-03	Electrical power subsystem	53.1				33	172	50/50	7-1-92
5	XX-1XX-02-03	Electrical power subsystem (growth)	48.5				36	104	50/50	7-1-92
5	XX-1XX-02-06	Information subsystem	2.4				33	172	50/50	7-1-92
5	XX-1XX-02-07	Crew habitability subsystem	0.1				33	172	50/50	7-1-92
5	XX-1XX-02-08	Subsystem instal, assy & C/O	5.8				5	139	50/50	7-1-92
4	XX-1XX-03-00	Control/Crew Module (SM-1)	38.3	1						7-1-92
5	XX-1XX-03-01	Structural & mechanical subsystem	3.0				13	153	50/50	7-1-92
5	XX-1XX-03-02	ECLS subsystem	7.4				33	172	50/50	7-1-92
5	XX-1XX-03-03	Electrical power subsystem	2.9				33	172	50/50	7-1-92
5	XX-1XX-03-06	Information subsystem	20.7				33	172	50/50	7-1-92
5	XX-1XX-03-07	Crew habitability subsystem	0.8				33	172	50/50	7-1-92
5	XX-1XX-03-08	Subsystem instal, assy & C/O	3.5				5	139	50/50	7-1-92
4	XX-1XX-04-00	Labs/ECLSS Module (SM-2)	15.4	1						7-1-92
5	XX-1XX-04-01	Structural & mechanical subsystem	5.8				12	151	50/50	7-1-92
5	XX-1XX-04-02	ECLS subsystem	6.7				33	171	50/50	7-1-92
5	XX-1XX-04-03	Electrical power subsystem	0.4				33	171	50/50	7-1-92
5	XX-1XX-04-05	Reaction control subsystem	0.5				33	171	50/50	7-1-92
5	XX-1XX-04-06	Information subsystem	0.5				33	171	50/50	7-1-92
5	XX-1XX-04-07	Crew habitability subsystem	0.4				33	171	50/50	7-1-92
5	XX-1XX-04-08	Subsystem install, assy & C/O	1.1				4	138	50/50	7-1-92

\*Spreading functions are for individual experiments and modules. See Form D for aggregate spreads.

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Table 7-1. Cost Estimate Data - Form A (Cont)

\_\_\_\_\_ Nonrecurring (DDT&E)  
X \_\_\_\_\_ Recurring (Production)  
 \_\_\_\_\_ Recurring (Operations)

WBS Level	WBS Identification Number	WBS Item Name	WBS Item Cost	No. of Units	Ref. Unit	Learn. Index.	T <sub>d</sub>	T <sub>s</sub>	Spread. Funct.	Milestone Date
4	XX-1XX-05-00	Labs/ECLSS Module (SM-3)	15.1	1						7-1-92
5	XX-1XX-05-01	Structural & mechanical subsystem	3.6				14	149	50/50	7-1-92
5	XX-1XX-05-02	ECLS subsystem	6.9				33	168	50/50	7-1-92
5	XX-1XX-05-03	Electrical power subsystem	0.4				33	168	50/50	7-1-92
5	XX-1XX-05-05	Reaction control subsystem	0.5				33	168	50/50	7-1-92
5	XX-1XX-05-06	Information subsystem	1.1				33	168	50/50	7-1-92
5	XX-1XX-05-07	Crew habitability subsystem	1.5				33	168	50/50	7-1-92
5	XX-1XX-05-08	Subsystem instal, assy & C/O	1.1				5	135	50/50	7-1-92
4	XX-1XX-06-00	Control/Crew Module (SM-4)	36.1	1						7-1-92
5	XX-1XX-06-01	Structural & mechanical subsystem	1.9				11	145	50/50	7-1-92
5	XX-1XX-06-02	ECLS subsystem	7.0				33	166	50/50	7-1-92
5	XX-1XX-06-03	Electrical power subsystem	2.2				33	166	50/50	7-1-92
5	XX-1XX-06-06	Information subsystem	20.2				33	166	50/50	7-1-92
5	XX-1XX-06-07	Crew habitability subsystem	1.4				33	166	50/50	7-1-92
5	XX-1XX-06-08	Subsystem instal, assy & C/O	3.4				5	133	50/50	7-1-92
4	XX-1XX-07-00	Cargo Modules	29.9	3						7-1-92
5	XX-1XX-07-01	Structural & mechanical subsystem	5.3				13	143	50/50	7-1-92
5	XX-1XX-07-02	ECLS subsystem	19.1				33	164	50/50	7-1-92
5	XX-1XX-07-03	Electrical power subsystem	1.2				33	164	50/50	7-1-92
5	XX-1XX-07-06	Information subsystem	0.8				33	164	50/50	7-1-92
5	XX-1XX-07-07	Crew habitability subsystem	0.4				33	164	50/50	7-1-92
5	XX-1XX-07-08	Subsystem instal, assys & C/O	3.1				7	133	50/50	7-1-92
4	XX-1XX-08-00	Growth Core Module	19.3	1						7-1-92
5	XX-1XX-08-01	Structural & mechanical subsystem	3.7				20	91	50/50	7-1-92
5	XX-1XX-08-02	ECLS subsystem	1.5				33	105	50/50	7-1-92
5	XX-1XX-08-03	Electrical power	7.4				33	105	50/50	7-1-92
5	XX-1XX-08-05	Reaction control subsystem	1.1				33	105	50/50	7-1-92
5	XX-1XX-08-06	Information subsystem	3.3				33	105	50/50	7-1-92
5	XX-1XX-08-07	Crew habitability subsystem	0.6				33	105	50/50	7-1-92
5	XX-1XX-08-08	Subsystem instal, assy & C/O	1.7				7	71	50/50	7-1-92
4	XX-1XX-09-00	Crew/ECLSS Module (SM-5)	25.3	1						7-1-92
5	XX-1XX-09-01	Structural & mechanical subsystem	1.9				13	83	50/50	7-1-92
5	XX-1XX-09-02	ECLS subsystem	9.6				33	103	50/50	7-1-92
5	XX-1XX-09-03	Electrical power subsystem	0.4				33	103	50/50	7-1-92
5	XX-1XX-09-05	Reaction control subsystem	0.2				33	103	50/50	7-1-92
5	XX-1XX-09-06	Information subsystem	9.6				33	103	50/50	7-1-92

\*Spreading functions are for individual experiments and modules. See Form D for aggregate spreads.

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Table 7-1. Cost Estimate Data - Form A (Cont)

- Nonrecurring (DDT&E)
- X Recurring ( Production)
- Recurring (Operations)

WBS Level	WBS Identification Number	WBS Item Name	WBS Item Cost	No. of Units	Ref. Unit	Learn. Index	T <sub>d</sub>	T <sub>s</sub>	Spread. Funct.	Milestone Date
5	XX-1XX-09-07	Crew habitability subsystem	0.9				33	103	50/50	7-1-92
5	XX-1XX-09-08	Subsystem instal, assy & C/O	2.7				5	69	50/50	7-1-92
4	XX-1XX-10-00	Crew/ECLSS Module (SM-6)	12.7	1						7-1-92
5	XX-1XX-10-01	Structural & mechanical subsystem	1.4				12	81	50/50	7-1-92
5	XX-1XX-10-02	ECLS subsystem	8.2				33	101	50/50	7-1-92
5	XX-1XX-10-03	Electrical power subsystem	0.3				33	101	50/50	7-1-92
5	XX-1XX-10-05	Reaction control subsystem	0.2				33	101	50/50	7-1-92
5	XX-1XX-10-06	Information subsystem	0.8				33	101	50/50	7-1-92
5	XX-1XX-10-07	Crew habitability subsystem	0.8				33	101	50/50	7-1-92
5	XX-1XX-10-08	Subsystem instal, assy & C/O	1.0				5	68	50/50	7-1-92
4	XX-1XX-20-00	Module Integration, Assy & C/O	18.6				1	134	50/50	7-1-92
4	XX-1XX-25-00	Project Management	41.8				112	174		7-1-92
4	XX-1XX-30-00	Systems Support	13.8				112	174		7-1-92
4	XX-1XX-75-00	GFE/GFP & Integration	(No effort identified)							7-1-92
4	XX-1XX-80-00	Experiment, Instal, Assy & C/O	(No significant effort identified)							7-1-92
3	XX-3XX-00-00	Earth Orbital Experiments	176.3							7-1-92
4	XX-3XX-NN-00	GPL experiments (aggregate)	41.3				142	161	50/50*	7-1-92
4	XX-3XX-YY-00	Attached RAM experiments (aggregate)	87.2				140	160	50/50*	7-1-92
4	XX-3XX-ZZ-00	Detached RAM experiments (aggregate)	47.8				96	118	50/50*	7-1-92
3	XX-4XX-00-00	Attached RAM Project	49.9							7-1-92
4	XX-4XX-YY-00	RAM's (aggregate)	49.9	9			138	146	50/50*	7-1-92
3	XX-5XX-00-00	Detached RAM project	64.7							7-1-92
4	XX-5XX-ZZ-00	RAM's (aggregate)	64.7	2			118	128	50/50*	7-1-92

\*Spreading functions are for individual experiments and modules. See Form D for aggregate spreads.

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Table 7-1. Cost Estimate Data - Form A (Cont)

\_\_\_ Nonrecurring (DDT&E)  
 \_\_\_ Recurring (Production)  
X Recurring (Operations)

WBS Level	WBS Identification Number	WBS Item Name	WBS Item Cost	No. of Units	Ref. Unit	Learn. Index	T <sub>d</sub>	T <sub>s</sub>	Spread. Funct.	Milestone Date
2	XX-0XX-00-00	Space Station Earth Orbital Program	984.4	N/A	N/A	N/A				7-1-92
3	XX-1XX-00-00	Modular Space Station Project	361.2							7-1-92
4	XX-1XX-07-00	Cargo Modules	52.9							7-1-92
5	XX-1XX-07-09	Module refurbishment	52.9				124	124	Constant	7-1-92
4	XX-1XX-25-00	Project Management	66.0				174	174	∑	7-1-92
4	XX-1XX-30-00	Systems Support	16.5				174	174	∑	7-1-92
4	XX-1XX-40-00	Mission Operations	201.3				138	138	Constant	7-1-92
4	XX-1XX-70-00	Spares	24.5				174	174	Constant	7-1-92
3	XX-3XX-00-00	Earth Orbital Experiments	561.9							7-1-92
4	XX-3XX-NN-00	GPL experiments (aggregate)	336.8				126	126	Constant*	7-1-92
4	XX-3XX-YY-00	Attached RAM experiments (aggregate)	168.0				119	119	Constant*	7-1-92
4	XX-3XX-ZZ-00	Detached RAM experiments (aggregate)	57.1				83	83	Constant*	7-1-92
3	XX-4XX-00-00	Attached RAM Project	0.4							7-1-92
4	XX-4XX-YY-00	RAM's (aggregate)	0.4				45	53	Constant*	7-1-92
3	XX-5XX-00-00	Detached RAM Project	60.9							7-1-92
4	XX-5XX-ZZ-00	RAM's (aggregate)	60.9				85	85	Constant*	7-1-92

\*Spreading functions are for individual experiments and modules. See Form D for aggregate spreads.

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The time spread for system support was based on a composite of the time spreads for all other MSS WBS elements except project management, since system support is in support of all of them. Similarly, the project management spread is a composite of all other spreads including system support.

Nonrecurring experiment definition assumes a constant level of effort for each discipline over the duration of that discipline. RAM spreading functions are the same as those of the typical station modules of the initial station, while experiments are on a 50-50 give based on the 1970 Phase B station studies.

The recurring production cost spreads (50-50) are based on an orderly well-paced production effort with a good balance of concurrency vis-a-vis the DDT&E effort. System support and project management again are composites of the activities they support. Experiments and RAM's also are on 50-50 spreads.

The elements of operations costs are individually based on a constant level of effort, except for system support and project management. The composite effort depends on the phasing of the support section modules on the RAM's, as well as the other elements.

The pie charts in Figure 7-1 show the relative proportion of cost by phase of the program and by project, readily portraying the large part of the costs due to the DDT&E phase and large contribution of the MSS and Experiment Projects to the total program.

Figure 7-2 shows schematically the funding of the program and the consequences of the ground rules that eliminate all in-process costs for items not operational by July 1, 1992, and the truncation of all activities already operational by July 1, 1992.

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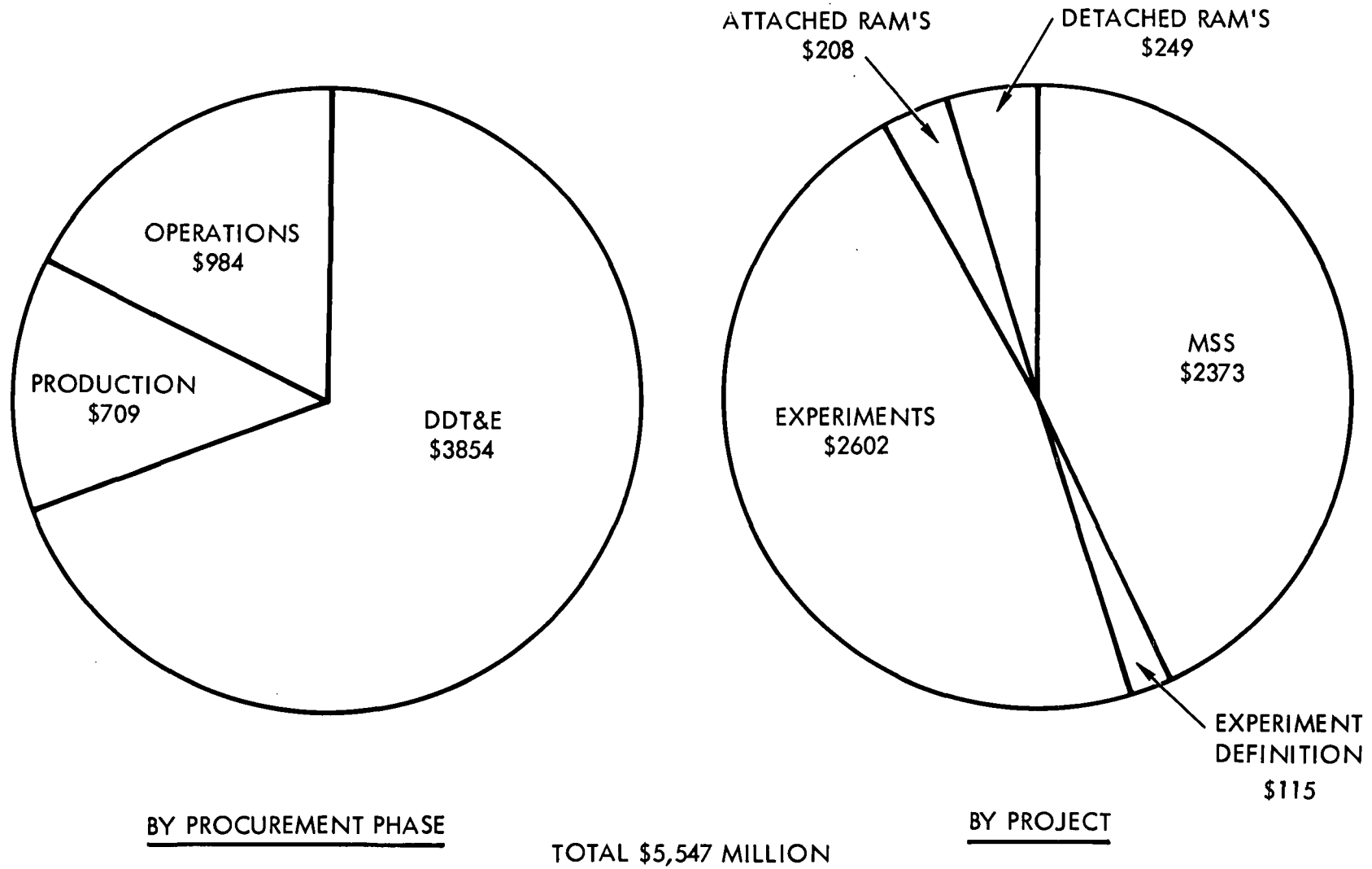


Figure 7-1. Space Station Earth Orbital Program Cost Summary Breakdown By Procurement Phase and Project

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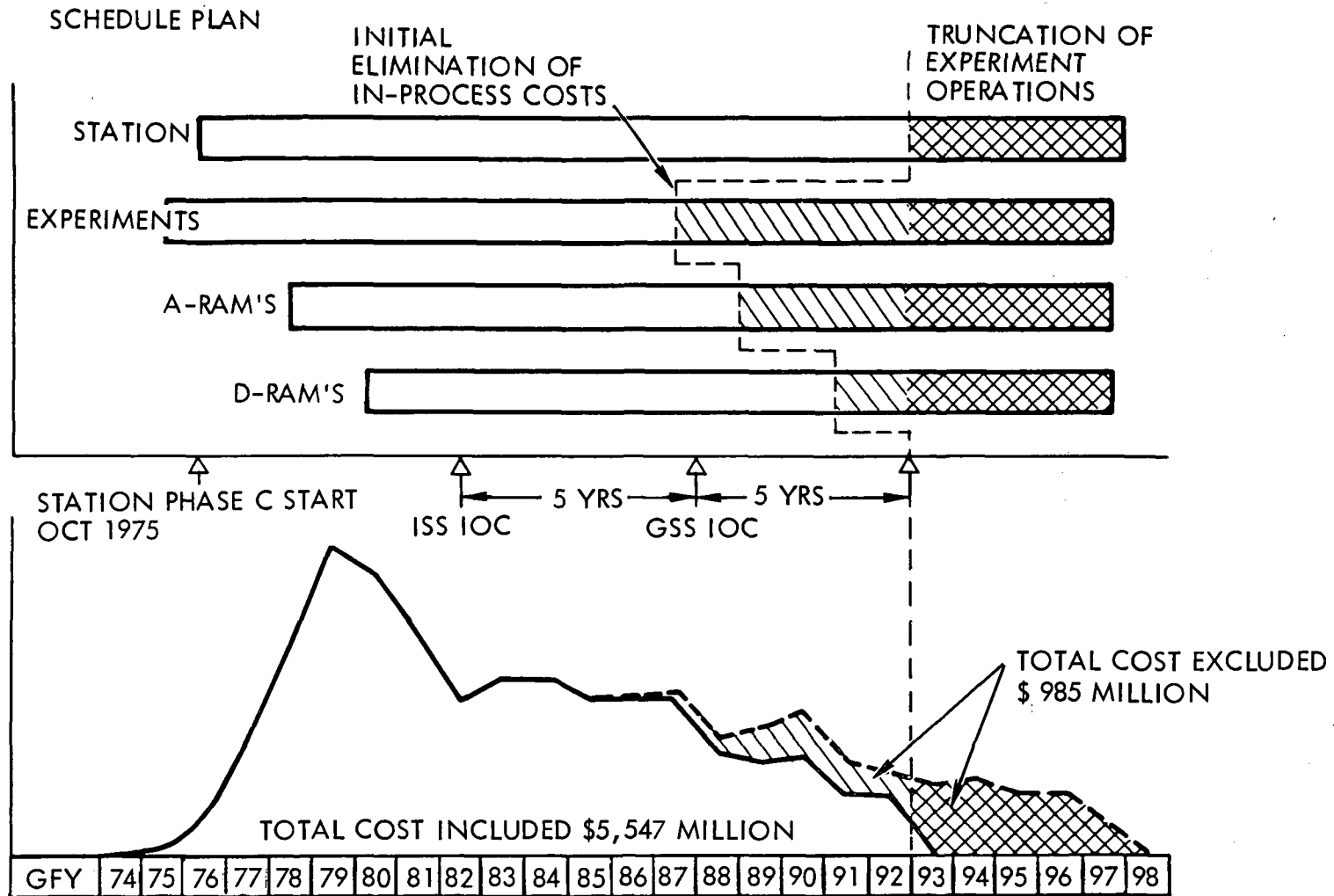


Figure 7-2. Some Cost Effects of Cost Ground Rules



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