FEBRUARY 1972

MDC G2708

SPACE STATION

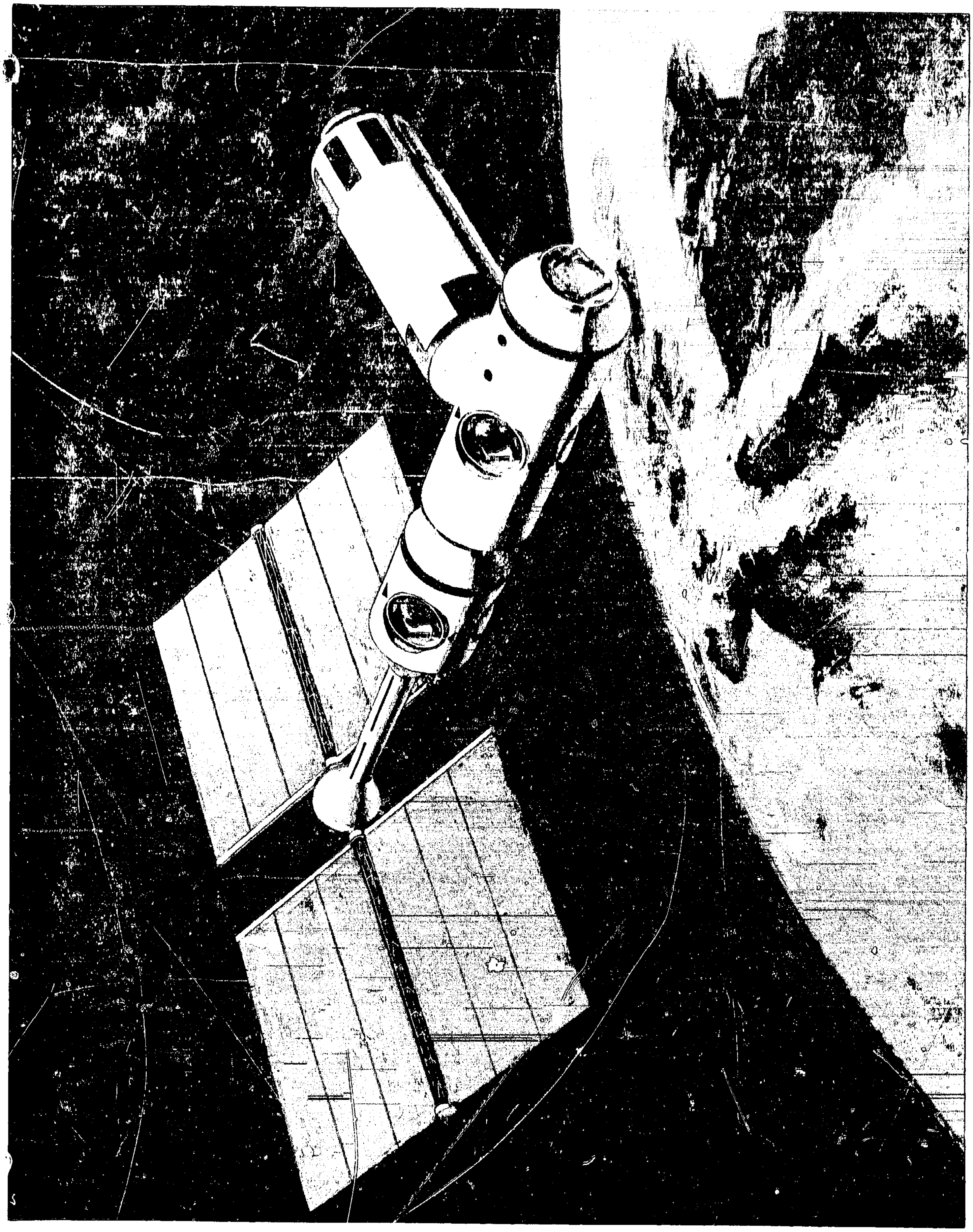
MSFC-DPD-235/DR NO. SE-03

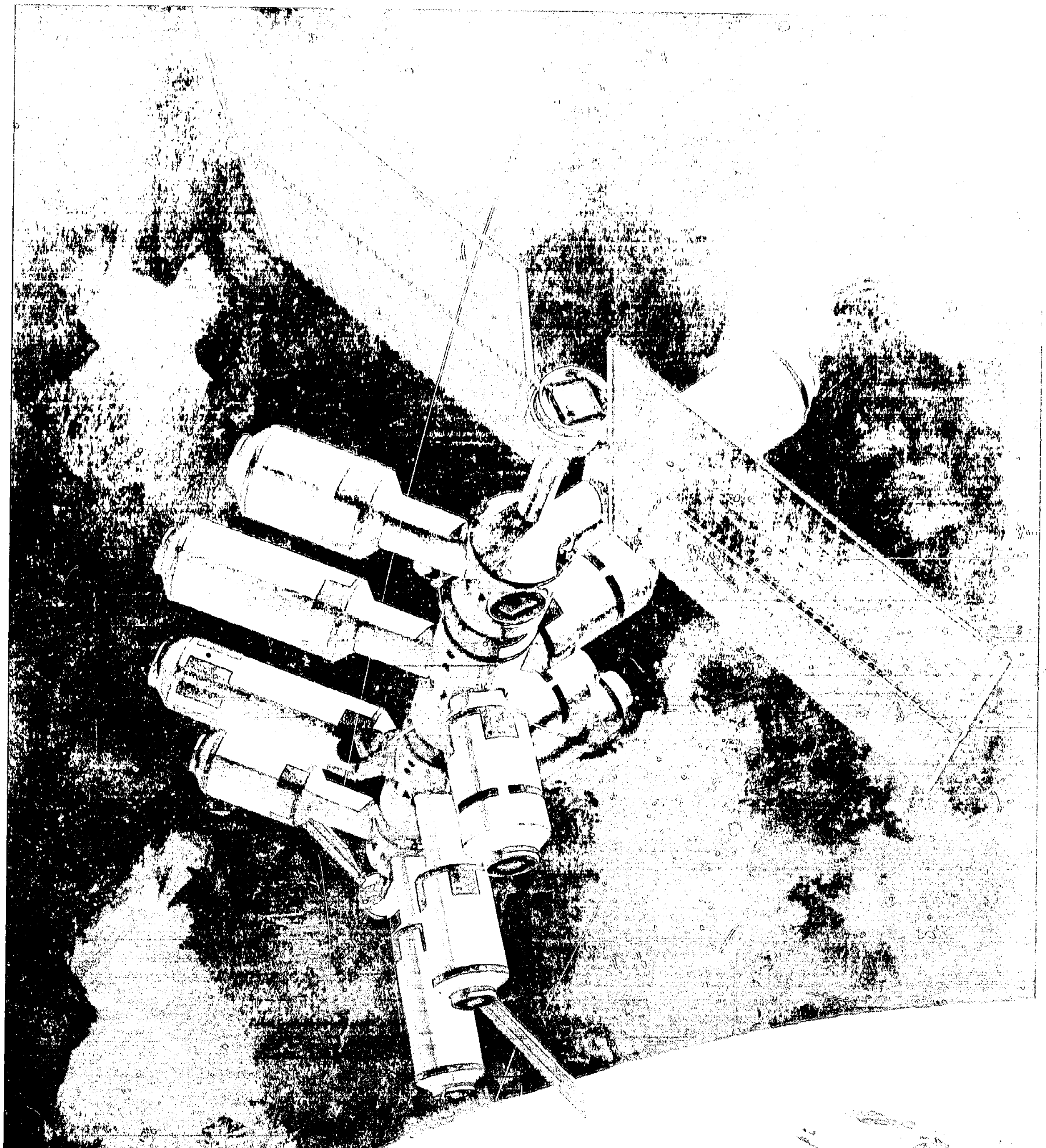
MODULAR SPACE STATION TECHNICAL SUMMARY

CONTRACT NAS8-25140

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MCDONNELL DOUGLAS CORPORATION





PREFACE

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

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

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

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

This report is submitted as Data Requirement SE-03.

DATA REQUIREMENTS (DR'S)
MSFC-DPD-235/DR NUMBERS
(Contract NAS8-25140)

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

FOLDOUT FRAME 1

SUBJECT REFFRENCE MA

LEGEND:

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

	CM				MA		MF	
	CM-01 Space Station Program (Modular) Specification	**CM-02** Space Station Project (Modular) Specification	**CM-03** Modular Space Station Project Part 1 CEI Spec	**CM-04** Interface and Support Requirement Document	**MA-05** Phase C/D Program Development Plan	**MA-06** Program Option Summary Report	**MF-01** Space Station Program (Modular) Cost Estimates Document	**MP-01** Space Station Program (Modular)
2.0 Contractor Tasks								
2.1 Develop Study Plan and Review Past Effort (MA-01)								
2.2 Space Station Program (Modular) Mission Analysis								●
2.3 Modular Space Station Configuration and Subsystems Definition								
2.4 Technical and Cost Tradeoff Studies							●	
2.4.4 Modular Space Station Option Summary								
2.5 Modular Space Station Detailed Preliminary Design								
Mass Properties								
2.6 Crew Operational Analysis								
2.7 Crew Cargo Module								
Mass Properties								
2.8 Integrated Mission Management Operations								
2.9 Hardware Commonality Assessment								
2.10 Program Support					●			
2.11 Requirements Definition								
Space Station Program (Modular)	●							
Space Station Project (Modular)		●						
Modular Space Station Project–Part 1 CEI			●					
Interface and Support Requirements				●				
2.12 Plans					●			
2.13 Costs and Schedules							●	
2.14 Special Emphasis Task Information Management (IMS)								
Modular Space Station Mass Properties								
User's Handbook								
Supporting Research and Technology								
Technical Summary								
MOD 29								
MOD 40						●		

FOLDOUT FRAME 2

SUBJECT REFERENCE MATRIX

MA		MF	MP			SE								
Phase C/D Program Development Plan	**MA-06** Program Option Summary Report	**MF-01** Space Station Program (Modular) Cost Estimates Document	**MP-01** Space Station Program (Modular) Mission Analysis Document	**MP-02** Space Station Program (Modular) Crew Operations Document	**MP-03** Integrated Mission Management Operations Document	**SE-01** Modular Space Station Concept	**SE-02** Information Management System Study Results	**SE-03** Technical Summary	**SE-04** Modular SS Detailed Preliminary Design	**SE-06** Crew/Cargo Module Definition Document	**SE-07** Modular Space Station Mass Properties Document	**SE-08** User's Handbook	**SE-10** Supporting Research and Technology	**SE-11** Alternate Bay Sizes
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Section 1
INTRODUCTION

1.1 BACKGROUND

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

This orbiting laboratory can take many forms and can be configured to house a crew of up to 12 men. The initial study of the 33-ft-diameter Space Station, launched by the Saturn INT-21 and supporting a complement of 12, has been completed to a Phase B level and documented in the DRL-160 series. This series of documents (DRL 235 series) define a modular Space Station comprising smaller, shuttle-launched modules. These modules could ultimately be configured to provide for a crew of the same size as on the 33-ft-diameter Space Station- but buildup would be gradual, beginning with a small initial crew and progressing toward greater capability by adding modules and crewmen on a flexible schedule.

The Modular Space Station Phase A study results are documented in the DRL-231 series. Recent Modular Space Station Phase B study results are documented in the DPD-235 series.

The Space Station will provide laboratory areas which, like similar facilities on Earth, will be designed for flexible, efficient changeover as research and experimental programs proceed. Provisions will be included for such functions as data processing and evaluation, astronomy support, and test and calibration of optics. Zero gravity, which is desirable for the conduct of experiments, will be the normal mode of operation. In addition to experiments carried out within the station, the laboratories will support operation of experiments in separate modules that are either docked to the Space Station or free-flying.

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

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

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

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

The ISS configuration rendering is shown in the frontispiece. The power/subsystems module will be launched first, followed at 30-day intervals by the crew/operations module and the general purpose laboratory (GPL) module. This configuration will provide for a crew of six. Subsequently, two additional modules (duplicate crew/operations and power/subsystems modules) will be mated to the ISS to form the Growth Space Station (GSS) (shown in the frontispiece), which will house a crew of 12.

During ISS operations, five research and applications modules (RAM's) will be attached to the Space Station. In the GSS configuration, 12 additional RAM's will augment those of the ISS phase. Three of the RAM's delivered to the GSS will be free-flying modules.

1.2 SCOPE OF THIS VOLUME

This report is a summary of all significant technical results of the Modular Space Station study. Description of the final design characteristics is emphasized; the reader is referred to the detailed documentation for a justification of the design and operational concepts presented. The topics of this report are listed below together with a reference to assist the reader in the location of the report where the subject is fully documented. Data contained in this report are presented using both International and English units. However, this data was derived generally, in the English system of units.

Section	Topics	Subject Fully Documented in:
2. Program Description	Mission Description	MP-01
	Program Schedule	MF-01, MA-05
	Design Requirements	CM-01, 02, 03, 04
	Program Costs	MF-01
3. Design Characteristics	Configuration	SE-04, 07, MP-02
	Subsystems	SE-04, 02, MP-02
4. Logistics System	Cargo Requirements	SE-06, 07
	Logistics Module Design	SE-06, 07
	Logistics Module Operations	SE-06, MP-01, MP-03
5. Experiment Support Capability	Subsystems Support	SE-04, 08
	General Purpose Laboratory	SE-04, 08
6. Experiment Requirements	Experiment Accommodation	MP-01
	Experiment Schedules and Requirements	MP-01
	Research and Applications Module Interfaces	SE-04, MP-01
7. Operations Analysis	Ground Operations	MP-01, 03
	Flight Operations	MP-01, 02
8. Design Support Analyses	Orbit Selection/Behavior	MP-01
	Radiation Protection	MP-01
	Reliability/Maintainability	MP-01, SE-04
	System Safety	MP-01
9. Shuttle Interfaces		SE-04, 06, CM-04, MP-03

Section 2
PROGRAM DESCRIPTION

The Space Station program (see Figure 2-1) consists of a five-year development period and an extended operational period with provisions for growth during the operational period. For study purposes the operational period is 10 years in duration and a growth step occurs five years after the start of on-orbit operations. The growth step consists of adding two modules to the basic complement of three to increase the crew capability from six to 12 men.

A representative experiment program has been defined in consonance with the January 1971 Blue Book. Fourteen Research and Applications Modules (RAM's) have been identified and scheduled in the 10-year program. The 14 modules consists of three free-flyers and 11 attached modules (three early RAM's are refurbished and reused requiring a total of 17 launches). Orbital stay times of each module vary: the maximum on-orbit complement at one time is nine modules.

2.1 SPACE STATION BUILDUP AND ACTIVATION

ISS buildup and activation operations begin with the launch of the Space Station power module and are completed with the delivery of the fifth and sixth crewmen (as shown in Figure 2-2).

Two crewmen are delivered to orbit as Shuttle passengers with each Space Station module delivery to perform predetermined checkout activities of each module during the shuttle five-day on-orbit stay. The results of the checkout determine the "go" decision for leaving the delivered station module or module return; the two-man activation crew then returns with the orbiter.

On the initial manning flight, two crewmen are brought up together with the initial logistic requirements including carry-on equipment, consumables, and spares. Thirty days later, two more crewmen are delivered, building the crew level to four. In another 30 days the Shuttle delivers the fifth and sixth crewmen, establishing the ISS operational level.

On the first crew rotation Shuttle flight, two crewmen are brought up to

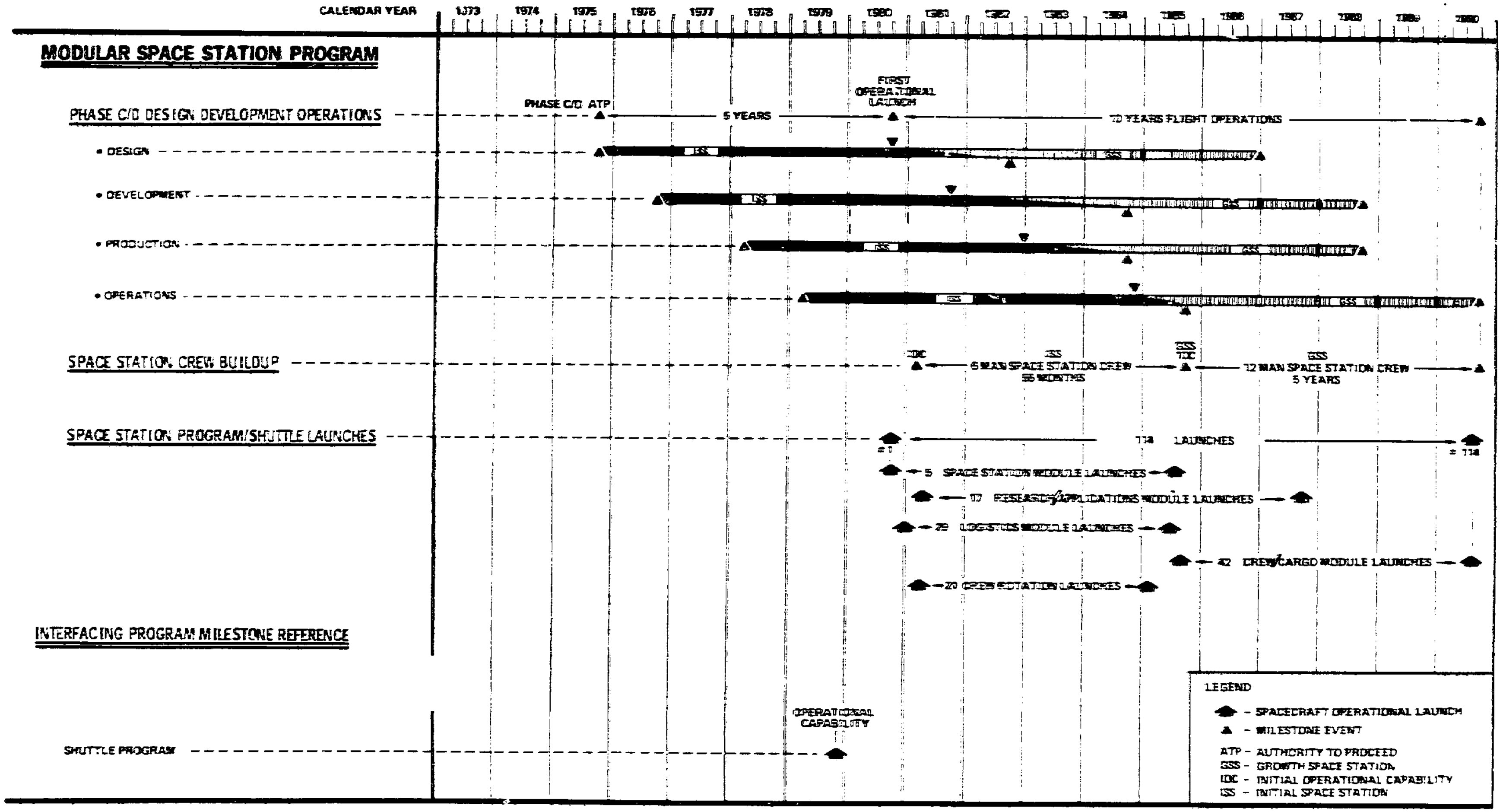


Figure 2-1. Modular Space Station Program Schedule

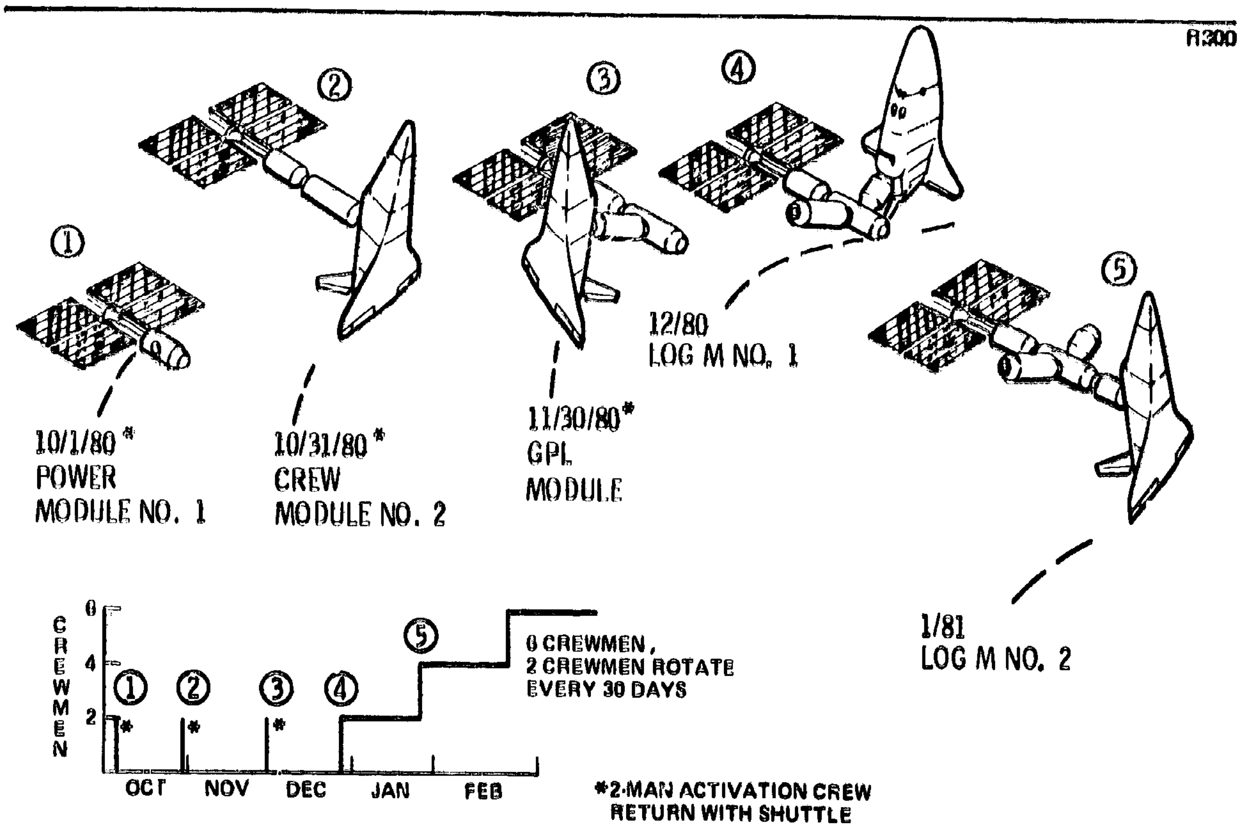


Figure 2-2. Initial Space Station Buildup

rotate with the first and second crewmen. A Shuttle flight is scheduled every 30 days thereafter during ISS operations, rotating two crewmen on a nominal crew rotation cycle of 90 days and bringing logistics as appropriate. An on-orbit crew level of six is sustained throughout ISS operations until the 19th quarter, when GSS buildup operations start.

The basic Initial Space Station (ISS) configuration, consisting of the Power/Subsystem Module, Crew/Operations Module, and General Purpose Laboratory Module, is shown in the frontispiece. Both the Power/Subsystems and the Crew Modules have three radial docking ports for the accommodation of the GPL and RAM's while the end port on the crew module is nominally used for docking the logistics module.

Long-term operations will occur over an extended period utilizing both the experiment capability integral to the GPL and that of the attached RAM's. Approximately four of the crew of six men will be devoted to these experiment operations, while the remaining two men will be responsible for overall station operations and support.

To achieve Growth Space Station (GSS) capability, two additional Space Station modules (power/subsystems and crew/operations) will be added to the ISS cluster as shown in the frontispiece. These modules are nearly identical in design with those deployed for initial capability. These two modules double the capability of the Space Station and enable it to perform all of the functions required for the GSS. As illustrated, the growth configuration is capable of accommodating six attached RAM's or a mix of five attached RAM's and several free-flyers cycled through a single docking port. The sequence of launches to achieve the GSS is such that dedocking is not required in assembly operations.

Since the additional Space Station modules are identical to the ISS modules, these modules, or a third set if desired, could potentially be used in an alternate orbit. This would allow establishment of several smaller stations devoted to specific scientific and/or operational functions without the need for additional design and development.

2.2 REQUIREMENTS SUMMARY

The fundamental NASA guidelines that have shaped the MDAC Modular Space Station are those of minimum cost and compatibility with the Space Shuttle. All system selections have been based upon minimizing total program costs, but particularly the cost prior to IOC. Compatibility with the Space Shuttle limits both the dimensions and mass of individual modules to cylindrical bodies not larger than 14 ft in diameter by 58 ft in length and 20,000 pounds. Compatibility with the Space Shuttle guidelines also imposes a crew size limitation of 2 (orbiter crew) plus 2 (passengers).

NASA also specified that an initial station be capable of supporting six men and growing to a 12-man size after 5 to 6 years and that it be capable of at least 10 years of continuous operation.

Listed below are several of the guidelines established by NASA Headquarters which exercised the greatest influence over the definition and preliminary design of the Modular Space Station. These requirements are included in Performance Specification (DPD-235, CM-01) prepared as part of this study (the numerical designations in parentheses indicate the paragraph in which the requirement appears).

1. Total cost of the program is a primary consideration. Primary emphasis is on minimum cost to the IOC (3.1.1.2).

2. "Commonality" is a primary consideration throughout the study. As a goal, common module structures, systems and subsystems and assemblies for Space Station modules, crew cargo modules, and Research and Applications Modules should be developed (3.1.1.3).
3. Shuttle launch frequency to support the Space Station Program will be no greater than one every 30 days (3.1.3.2).
4. The Initial Space Station will have the capacity for independent operation with the full crew for a period of 120 days. This capacity can be included in a Cargo Module (3.1.3.3).
5. At least 30 days' consumables, including subsystems and experiments, will be available beyond the scheduled resupply mission (3.1.3.5).
6. The Initial Space Station must provide communications with the ground and other cooperating spacecraft, but not necessarily simultaneously. Interruptions in data communications with the ground network for as long as five hr will be acceptable for the Initial Space Station (3.1.3.14).
7. The Initial Space Station will be operational when fully manned (three to six crewmen), and fully configured including a general purpose laboratory capability in addition to at least two Research and Application Modules (3.7.1.1.1).
8. The Growth Space Station will be sized to accommodate 12 crewmen and will have integral laboratory facilities, research support provisions (power, information management, docking ports, etc.) and habitability provisions equivalent to those provided by the 33-ft diameter designs in the Phase B study reported in August 1970 (3.7.1.1.2).
9. The Initial Space Station will be capable of supporting selected, partial, modified, or combined FPE's from the Blue Book (NAS 7150.1). Blue Book experiments and RAM's are to be scheduled in accordance with Station capability. Modified FPE's will require the approval of NASA (3.7.1.1.3).
10. The Growth Space Station will have the capability to accommodate all Blue Book FPE's, but not simultaneously (3.7.1.1.4).

11. The docking port and hatches will provide a nominal diameter of 5 ft and provide utility interfaces within the pressurized volume (3.2.2.3).
12. Maintenance and repair will be accomplished on the ground when cost effective. Module return will be traded against on-orbit repair and replacement (3.2.4.1).
13. Safety is a mandatory consideration through the total program. As a goal, no single malfunction or credible combination of malfunctions and/or accidents will result in serious injury to personnel or to crew abandonment of the Space Station (3.2.6.1.2).
14. The Space Station will be divided into at least two pressurized habitable volumes so that any damaged module can be isolated as required. Accessible modules will be equipped and provisioned so that the crew can safely continue a degraded mission and take corrective action to either repair or replace the damaged module (3.2.6.2.2).
15. Atmospheric stores and subsystem capacity sufficient for one repressurization will be maintained on the Space Station during manned operations to independently supply each pressurized habitable volume (3.2.6.2.3).
16. Personnel escape routes shall be provided in all hazardous situations. A design goal will be to provide alternate escape routes that do not terminate in a common module area (3.2.6.3.2).
17. Provisions and habitable facilities will be adequate to sustain the entire crew for a minimum of 96 hours during an emergency situation requiring Shuttle rescue (3.7.1.4.3).
18. The Space Station structure and subsystems will be designed for an oxygen/nitrogen mixture at a normal operating pressure of 14.7 psia (3.7.1.4.9).
19. Carbon dioxide partial pressures will be maintained below 3.0 mm Hg in all habitable areas (3.7.1.4.10). A CO_2 partial pressure of 7.6 mm Hg will be allowed for seven days during an emergency (3.7.1.4.11).
20. ISS electrical power will be provided by solar arrays. Minimum average load electrical power requirement is 15 KW at the load bus, averaged over a 24-hour period (3.7.1.4.12).
21. As a goal, no orientation restrictions will be imposed by subsystems

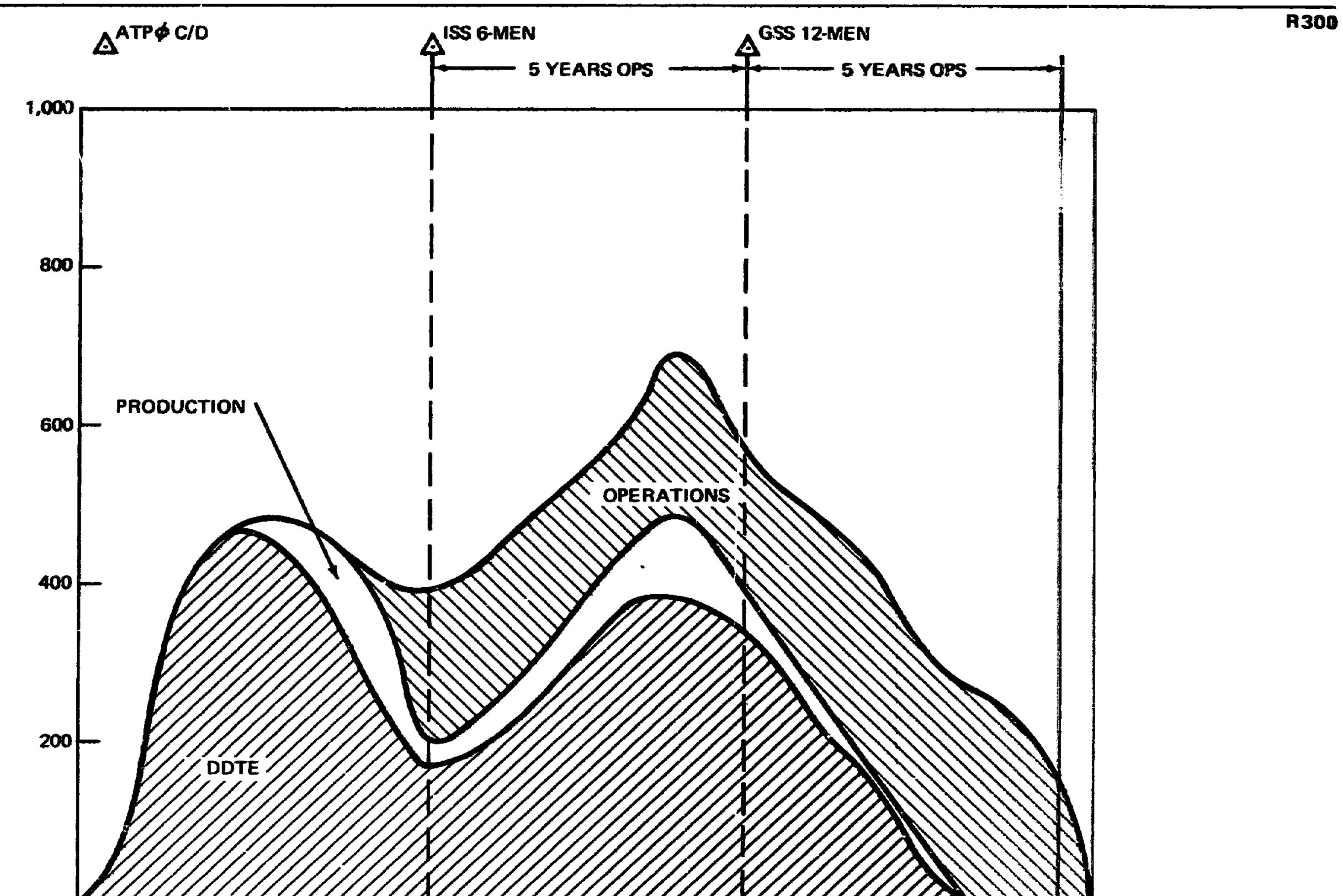
such as electrical power, thermal control, communications, (3.7.1.4.13).

22. The environmental control and life support subsystem will be designed with a closed wash-water loop. Closure of other functional loops will be based on appropriate trade data (3.7.1.4.14).

2.3 COST SUMMARY

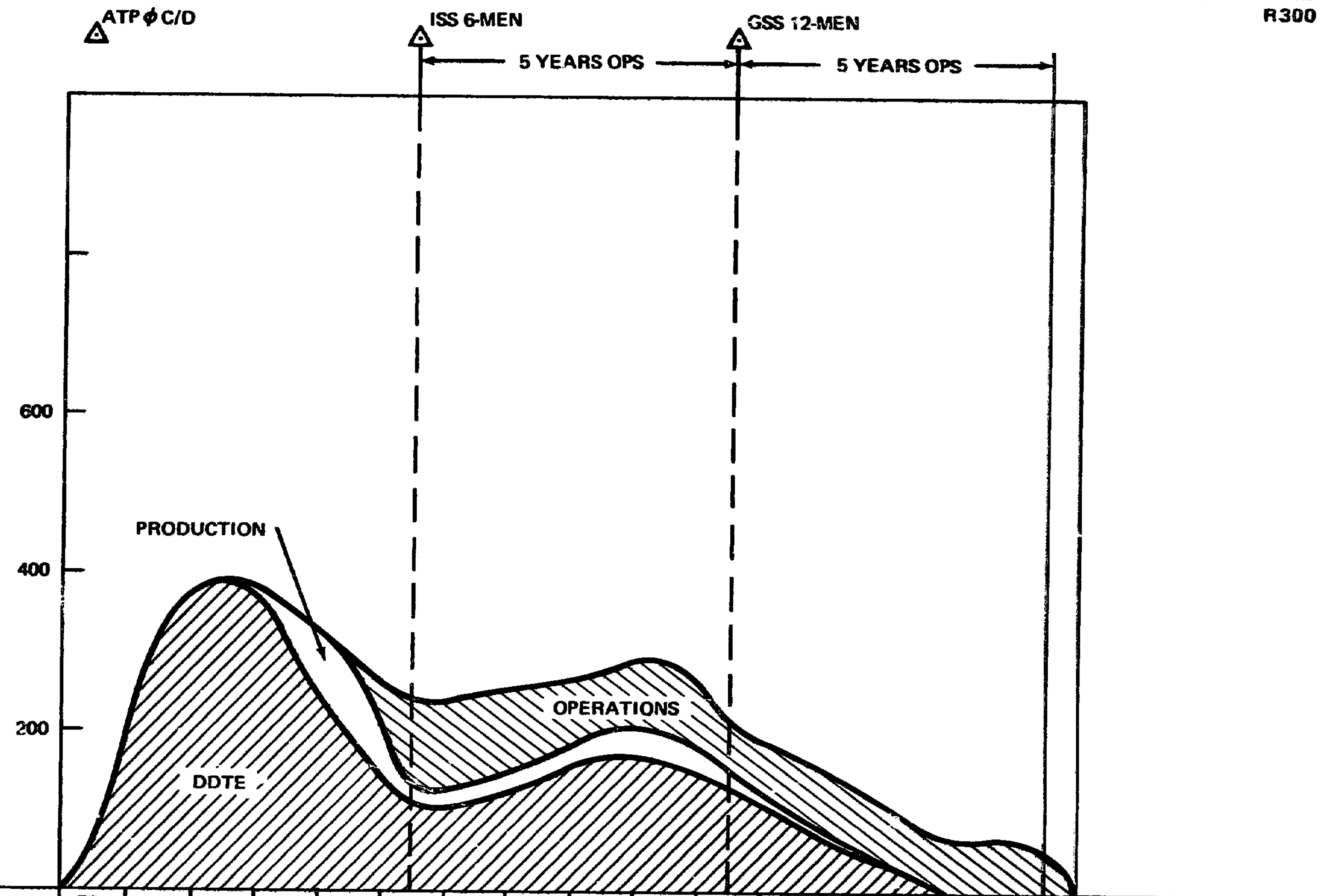
This section presents an overview of the Space Station Program's funding requirements. Total cost of the Space Station Program in GFY 1972 dollars is estimated to be $6,563 million (Figure 2-3). The ISS/GSS Space Station and its 10 years of operation require about $3,500 million, with the experiments and RAM's consuming the remainder. The total program costs are allocated as follows: DD&TE cost is $3,714 million, production cost is $644 million, and operations cost is $2,205 million. These costs include the development, fabrication, and operation of the Research and Applications Modules (RAM's), and the integration of both RAM and Integral experiments into their respective modules. The ISS/GSS program includes 14 attached modules and three free flyers (Because three early RAM's are refurbished, only 14 modules are developed and fabricated). Of the total expended to ISS, approximately 30 percent is for experiment development and installation, 10 percent for Shuttle launches, and the remaining 60 percent for development and operation of the six-man Space Station and its support of the attendant experiment program. Discounted at 10 percent per year, with GFY 1975 as the base year, the total cost of the Space Station Program is estimated to be $3,419 million. This discounted rate is illustrated in Figure 2-4. Both funding and manpower are constrained by the Phase C/D ATP, which is scheduled for October 1975, and the Initial Space Station (ISS) first operational launch, scheduled for October 1980. Operations effort is scheduled to begin prior to the first launch and to continue for 10 years following the launch. The schedule constraints, together with the planned Experiment Program, both integral and RAM's, cause a funding peak of $691 million and a manpower peak loading of about 14,500 in the same fiscal year (FY 1984).

Several low cost experiment program options have been examined and it is concluded that a viable experiment program could be accomplished at costs significantly lower than the Baseline Program described here. This could be



FISCAL YEAR	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL
DDTE	61	342	470	418	288	165	200	270	366	380	340	235	150	29	–	–	3,714
PRODUCTION	–	–	3	60	131	33	46	64	75	102	53	45	22	10	–	–	644
OPERATIONS	–	–	–	–	–	189	194	177	150	209	172	213	253	248	247	153	2,205
TOTAL	61	342	473	478	419	387	440	511	591	691	565	493	425	287	247	153	6,563

Figure 2-3. Baseline Modular Space Station Program (5 Modules) 1972 Dollars in Millions (Mid-Year Plot)



FISCAL YEAR	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	TOTAL
DDTE	61	310	388	313	196	102	112	138	170	161	131	82	47	8	–	–	2,219
PRODUCTION	–	–	2	45	89	20	25	32	35	43	20	15	7	2	–	–	335
OPERATIONS	–	–	–	–	–	117	109	90	70	88	66	74	80	71	64	36	865
TOTAL	61	310	390	358	285	239	246	260	275	292	217	171	134	81	64	36	3,419

Figure 2-4. Baseline Modular Space Station Program Discounted Cost (10 Percent Per Year—GFY 1975 Present Value Factor Equals 0)

done by limiting the Space Station to a six-man capability with a similar reduction in the number of FPE's actually flown. If such a program were defined, total program costs could be reduced to about \$4,400 million, of which about \$3,000 million would be required for the Space Station, and the remaining \$1,400 million for experiments and RAM's.

Section 3
DESIGN CHARACTERISTICS

The modules that comprise the basic Space Station are the Power/Subsystems, Crew/Operations, General Purpose Laboratory, and Logistics Module (since at least one is docked at all times). This section describes the preliminary design of the power/subsystems, crew/operations modules, and the General Purpose Laboratory module (i.e., those design features related to the basic Space Station). The GPL laboratory equipment and facilities are described in Section 5. The preliminary design of the Logistics Module is described in Section 4 as one element of the logistics support system.

The Modular Space Station design philosophy centered on low cost and effectiveness. Low cost was achieved through simplicity of the total concept: a minimum number of basic modules (3), a maximum of commonality (at subsystem and lower levels and for growth to GSS), and long life achieved through maintainability. Effectiveness was accomplished using modern technology which permits automation of station facilities (for subsystem control, failure and warning, fault isolation, etc.) to reduce nonproductive man hours. Man's involvement in the research and applications activities is maximized with the General Purpose Laboratory facility.

The Power/Subsystems Module (Figure 3-1) contains all subsystems necessary to sustain the ISS cluster until assembly is completed and manning and regular logistics resupply are initiated three months later. The module is 4.3m (14 ft) in diameter and 17.7m (58 ft) long. The solar array (not shown) contains 492 m^2 (5,300 ft^2) of panel area providing 16.7 kwe of usable power. The pressure compartment is 9.1m (30 ft) long, incorporates three radial docking ports, and houses subsystems as shown. Space and structural provisions are incorporated to accept CMG's and atmosphere tankage which are later transferred from the Logistics Module. The propulsion system is isolated from the remainder of the compartment by a pressure-tight bulkhead. Thruster modules are located forward and each includes

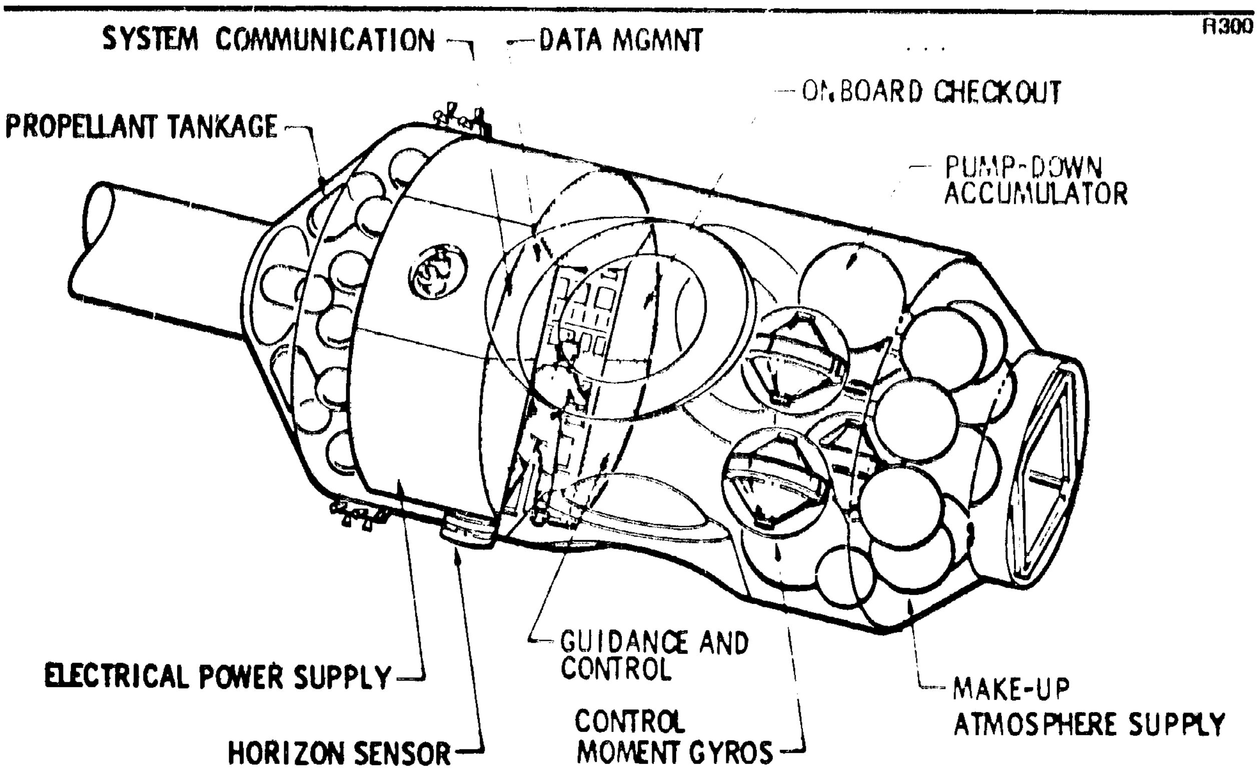


Figure 3-1. Power/Subsystems Module

portions of the high- and low-thrust systems. End docking ports permit station buildup and on-orbit handling of the module.

The Crew/Operations Module (Figure 3-2) is docked to the Power/ Subsystems Module. It provides for the habitability of the flight crew and also contains the control center for the Modular Space Station. The module is 4.3m (14 ft) in diameter and 13.7m (45 ft) long. The internal arrangement uses a zero-gravity longitudinal configuration. There are three private crew quarters and a complete hygiene facility at each end of the module thereby maximizing flexibility to accommodate mixed crews (male and female) or two-shift operations by this separation. The operations control station is located at one end of the wardroom and the galley is located at the other end. The general arrangement provides for ready access to the pressure wall and to consoles for maintenance purposes. Three radial docking ports are located at the midpoint of the module to maximize clearance between attached modules during Shuttle docking operations. The module also contains three high-gain antennas and four propulsion modules (not shown).

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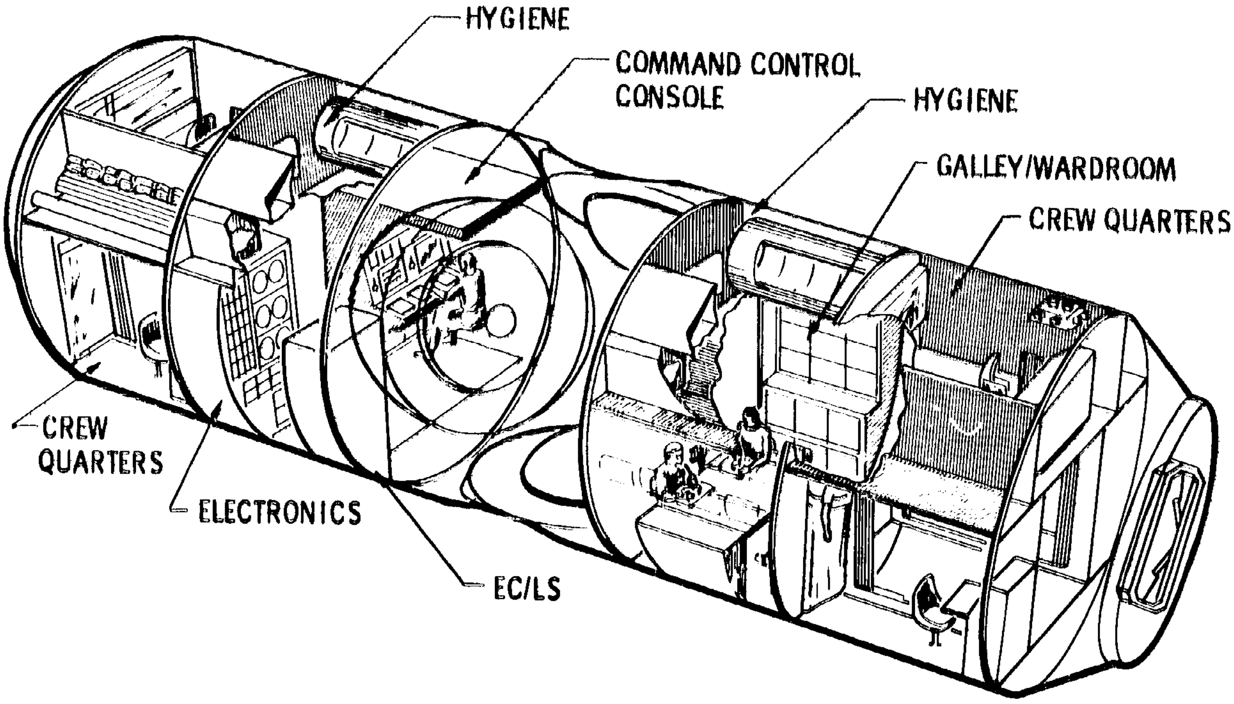


Figure 3-2. Crew/Operations Module

The General Purpose Laboratory is radially docked to the Crew/ Operations Module. The GPL, illustrated in Figure 3-3, is configured to support a 12-man research and applications program at the GSS level. Space is provided within the 4.3m (14 ft) diameter by 13.7m (45 ft) long module for growth capability; that equipment required for ISS is initially installed and space is allocated for planned additions, as required. The GPL also contains a zero-gravity longitudinal interior configuration with equipment arranged in functional groups. This grouping results in the eight laboratories and facilities identified in Figure 3-3 (these labs and facilities are described in greater detail in Section 4). In addition to laboratories and facilities, the GPL houses Data Management, and ECLS equipment. The experiment control console in the GPL also functions as a backup control station to the primary control console located in the Crew/Operations Module. No radial docking ports are located in the GPL.

The Logistics Module is illustrated in Figure 3-4. This module remains on orbit as part of the Space Station cluster during resupply intervals. In this capacity it provides a convenient reservoir for consumables to be used on demand; it provides an additional safe volume for refuge and a contingency

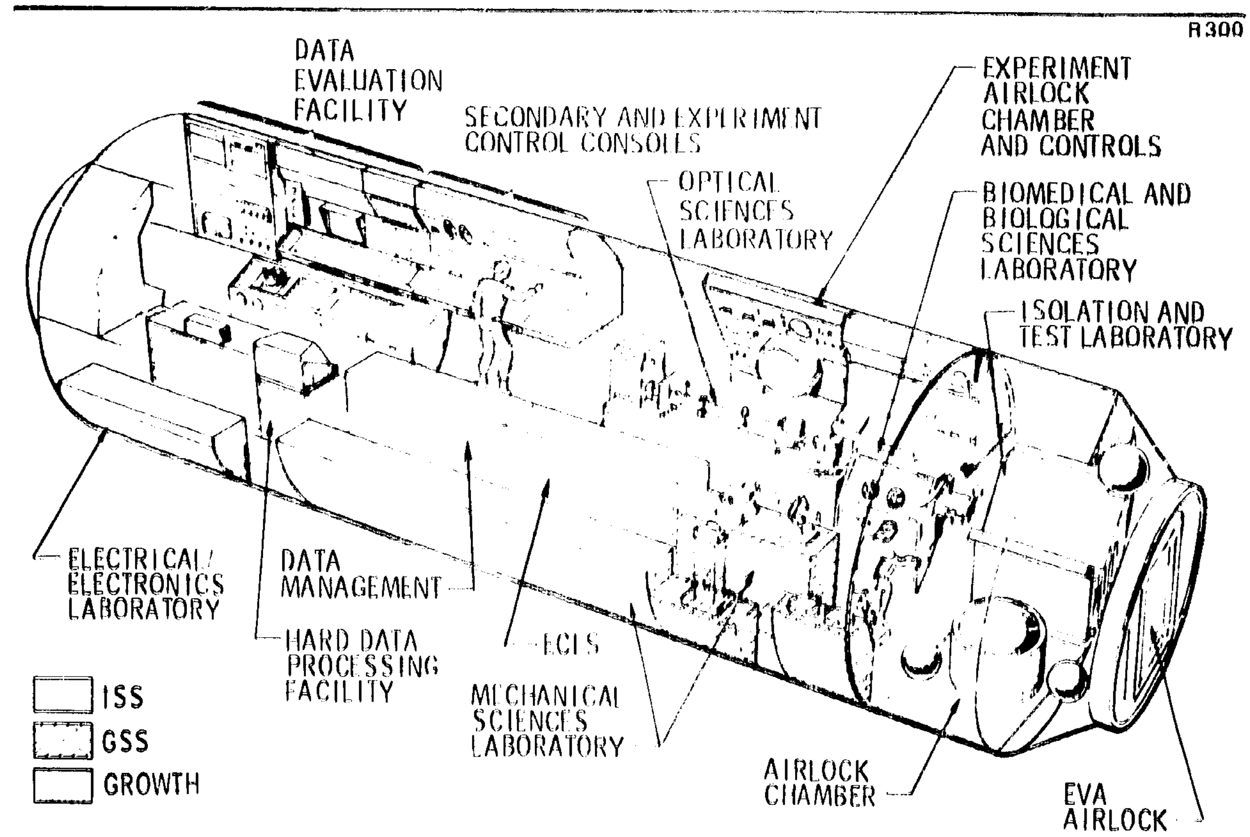


Figure 3-3. Baseline General Purpose Laboratory

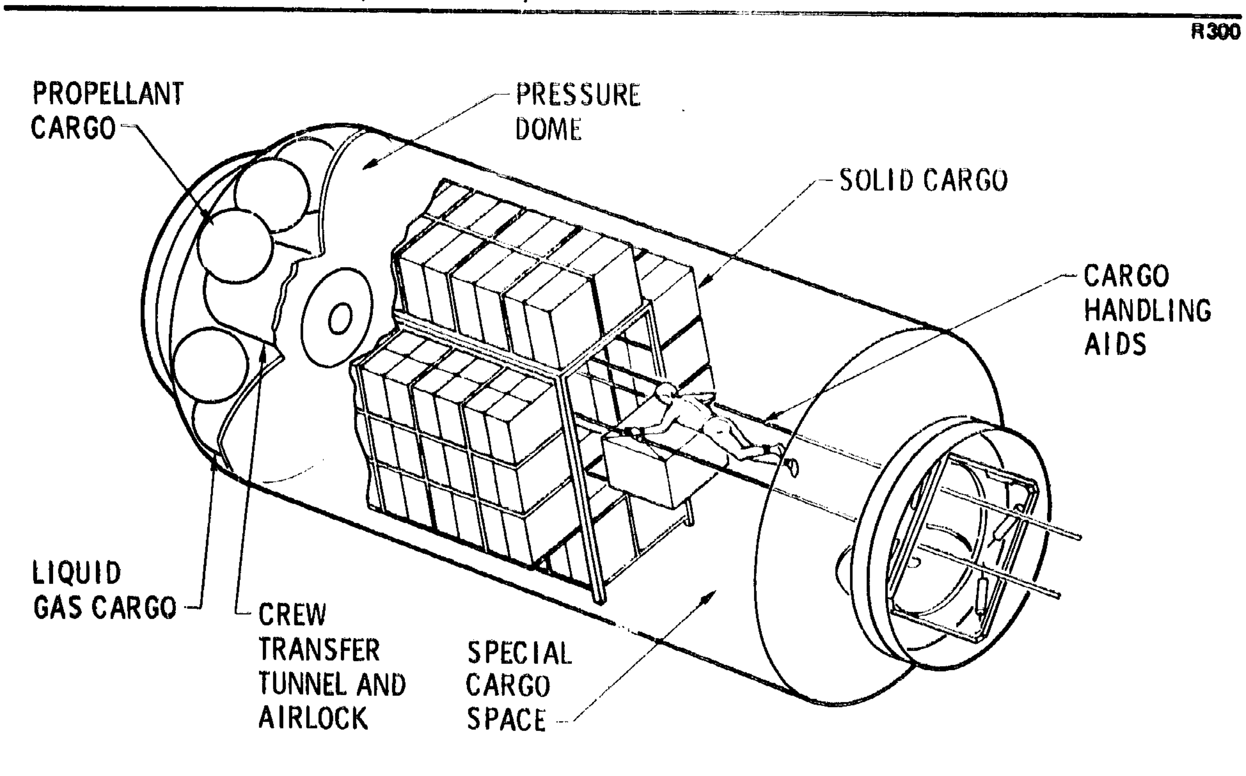


Figure 3-4. Logistics Module

volume for crew isolation and extra crew accommodations. It is used for convenient storage of trash and for returning hard-copy data and experiment equipment to Earth.

The Logistics Module is 4.3m (14 ft) in diameter and 8.5m (28 ft) long. It contains both pressurized and unpressurized compartments. The interior of the pressurized compartment is arranged to accommodate palletized cargo and special cargo. The palletized cargo space is configured to support 0.6 by 0.6m (2 by 2 ft) carry-on containers. The special cargo space is sized to accept items that are planned for offloading (prior to launch) on the three station modules (e.g., CMG's) and for experiment equipment. Cargo handling aids are provided for difficult cargo transfer. Egress/ingress from the orbiter requires a pressurized transfer tunnel which is also used as a two-man EVA airlock for station operations. Active subsystems are not required to support the Logistics Module; all subsystem requirements are supplied by the orbiter or the station. Design features of the Logistics Module are described in Section 4.

To achieve the Growth Space Station (GSS) capability, two additional Space Station modules (Power/Subsystems and Crew/Operations) are a ded to the ISS cluster. These modules are identical in design to those deployed for the initial station. The growth configuration is capable of accommodating several attached RAM's, several free-flying RAM's which share a common docking port, and three Logistics Modules (the GPL occupies the 12th radial docking port). The GSS is arranged to permit complete assembly without dedocking operations to relocate modules.

Since the GPL is sized to accommodate additional equipment required for GSS, only one GPL is required. In the GSS phase of operations a combined Crew and Cargo Module (CCM) is used for delivery and return of six crewmen and cargo.

In the selection of subsystems, emphasis was given to minimizing initial and total program cost and the following additional guidelines: (1) applicability of the design for both ISS and GSS, (2) growth to GSS without new development, (3) commonality and modularity, and (4) on-orbit maintenance and replacement.

Figure 3-5 presents a summary of subsystem characteristics. The six-man module level for EC/LS was selected. One six-man unit is located in the Crew/Operations and one in the GPL Module.

R300

EC/LS
- TWO 6-MAN SYSTEMS + EMERGENCY PACKS
- CLOSED WATER
- OPEN OXYGEN
- SOLAR HEAT COLLECTION

ELECTRICAL POWER
- GIMBALLED FOLDOUT ARRAYS
- TWO-STEP BUILDUP
- 16.7 kWe; 31 kWe (GSS)

PROPULSION
- N_2H_4 HI-THRUST
- CO_2 RESISTOJETS

GUIDANCE, NAVIGATION, AND CONTROL
- CMG'S
- STELLAR/INERTIAL REFERENCE
- TRIMMED HORIZONTAL ORIENTATION
- ALL ATTITUDE CAPABILITY
- MANUAL DOCKING
- GROUND NAVIGATION

COMMUNICATIONS
- S-BAND TO MODIFIED MSFN
- VHF AND K_u-BAND TO RELAY SATELLITE
- GSS-K_u-BAND TO FREE FLYERS

DATA MANAGEMENT
- CENTRALIZED MULTIPROCESSORS AND DISTRIBUTED COMPUTERS
- DATA BUS
- MULTIPURPOSE DISPLAYS
- FILM

ON-BOARD CHECKOUT
- INTEGRATED WITH DMS
- AUTOMATED OPERATION
- FAULT ISOLATION TO LOWEST REPLACEABLE UNIT

STRUCTURAL
- EXTERNAL WAFFLE
- BOLT-ON END DOMES
- INTERNAL BIRDCAGE

Figure 3-5. Baseline Subsystems

A solar heat collector, which provides heat via a fluid loop for EC/LS processes, is located on the solar array structure to take advantage of sun orientation. Thermal control is provided by active, redundant radiator loops on each module.

Double-gimballed foldout solar arrays provide electrical power for the Space Station. The arrays total 492 m^2 (5,300 ft^2) and produce 16.7 kwe average power. GSS requirements, about 31 kwe average, are satisfied with a second Power/Subsystems Module which contains an identical array. The Lockheed (LMSC) foldout panel design concept was selected; this concept, in prototype development, adequately satisfies Space Station mission requirements and offers a corresponding development cost savings.

The 100 amp hr, nickel-cadmium battery under development by Grumman was selected for energy storage. To reduce power losses and equipment weight, 115 vdc was selected as the transmission and distribution voltage.

A thorough analysis of interrelated functions and requirements for the Propulsion, Attitude-Control, and EC/LS Subsystems resulted in the selection of CMG's for primary actuation, low-thrust (0.09N-0.02 lbf) resistojets using CO_2 from the EC/LS Subsystem for orbit-keeping and CMG desaturation, and an N_2H_4 high-thrust (89N-20 lbf) system for the elimination of docking disturbances and for maneuvers.

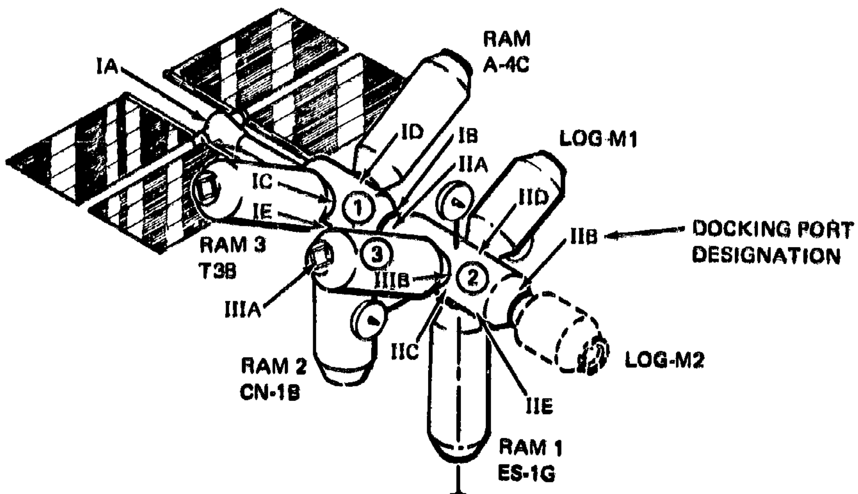
The Communications Subsystem uses the synchronous relay satellite network, which is assumed to be available at the start of the Space Station mission. Data transmission requirements for the Space Station program use only a portion of the satellite network capability. The Data Relay Satellite System (DRSS) is assumed to be an institutional cost which is not charged to the Space Station program.

The Data Management (DMS) and Onboard Checkout (OCS) Subsystems use a centralized computer located in the Power/Subsystems Module. The data bus interconnects the computer with other DMS and OCS components as well as with the other subsystems. A second multiprocessor is located in the GPL and is dedicated to the experiment program. The GPL multiprocessor is configured to act as a backup to the primary computer. Onboard Checkout Subsystem functions are integrated with the DMS and are automated.

3.1 CONFIGURATION

The selected ISS configuration is shown in its maximum cluster arrangement in Figure 3-6. It contains two six-man EC/LS Subsystems in two separate habitable pressurized compartments. Six docking ports are available, two of which will be used for resupply by Shuttle-transported Logistics Modules and four of which may be used for Research and Applications Modules (RAM's). The on-orbit arrangement of the three modules places the Power/Subsystems Module on the forward end of the cluster. The Crew/Operations Module is docked to the aft end of the Power/Subsystems Module. Both the Power/Subsystems Module and the Crew/Operations Module have three radial docking ports spaced at 2.1 rad (120 degrees) on centers. The General Purpose Laboratory Module is radially docked to the Crew/Operations Module at the upper left-hand port (looking forward). Logistic Modules are docked alternately at the upper right-hand port and the end port of the Crew/Operations Module. The remaining four ports, one nadir port on the Crew/Operations Module, and all three ports on the Power/Subsystems Module are used by Research and Applications Modules. The ISS configuration was chosen from a large group of potential module arrangements. The major considerations in this evaluation were cost, crew safety, habitability, efficient accommodation of the experiment program,

R300



MAXIMUM CLUSTER DURING QUARTER 15

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

Figure 3-6. Initial Space Station (ISS)

adaptability to growth to the 12-man Space Station, and compatibility with the Shuttle Orbiter during buildup and resupply. The most important of these considerations was low cost, which dictated a minimum number of modules. (Program cost is increased with an increase in number of modules for the same functional capability. That is, designing the same equipment into more modules results in higher costs. This is principally due to an increase in integration testing as reported in DPD-235-DR/SE-11, "Assessment of Alternate Shuttle Payload Sizes," dated September 1971.) Low initial cost is also made possible by commonality, which is accomplished by a common design for the module cylindrical section and docking interfaces. Other considerations in the selection of the configuration included traffic flow, docking port requirements, maintainability of modules and subsystems, and flexibility for the ever-changing requirements of the experiment program.

The arrangement whereby all crew facilities are contained in a single module enhances the usability of the dedicated space and minimizes the crew traffic between modules. The Space Station General Purpose Laboratory is located in a single facility to achieve maximum spaciousness and to keep experimental functions close together.

An airlock is provided by the back-to-back hatches at the module interfaces. This airlock provides the capability to evacuate a module and reenter without the need to evacuate the adjacent module to equalize pressure. An EVA airlock is provided by the Isolation and Test Facility in the General Purpose Laboratory and a two-man EVA airlock is provided in each Logistics Module.

Figure 3-7 shows the inboard profile of the assembled station.

In the GSS configuration, five additional docking ports are available to accommodate one additional Logistics/Crew Cargo Module and four additional Research and Applications Modules. The GSS configuration with its maximum cluster arrangement is illustrated in Figure 3-8.

The minimum launch weight of the three-module cluster is 22,058 kg (48,629 lb) (see Table 3-1). At the start of operation, the on-orbit weight is increased to 35,310 kg (77,845 lb) due to the addition of supplies and equipment transported via Logistics flights.

A primary consideration in the configuration design was clearance between docking ports to allow direct docking of a module by the Shuttle. Figure 3-9 illustrates the clearances in docking of modules to the GSS. A minimum distance of 10.3m (35.5 ft) between docking port centerlines provides adequate clearance as shown in Figure 3-9.

Figure 3-10 illustrates in schematic form the utility runs through the three modules of the ISS. Figure 3-11 shows the interface pattern used at each docking port. This pattern has an axis of symmetry which is the Z-axis of the module allowing any pattern to match any other pattern. Figure 3-12 illustrates the details of utility run installations.

3.1.1 Power/Subsystems Module

An inboard profile of the Power/Subsystems Module is shown in Figure 3-13. This module contains capabilities for electrical power, guidance and control, propulsion, ground communications, data management, and thermal control. The Power/Subsystem Module is 17.7m (58 ft) long and uses the maximum length of the Shuttle cargo bay. The large cylinder and the conical sections on each end total 9.1 m (30 ft) in length. The cylinder diameter is 4.3 m (14 ft) with protrusions out to 4.6 m (15 ft) diameter. The pressure shell diameter is 4.1 m (13 ft 4 in.). These diameters are common with other modules of the Space Station. The power boom cylinder has

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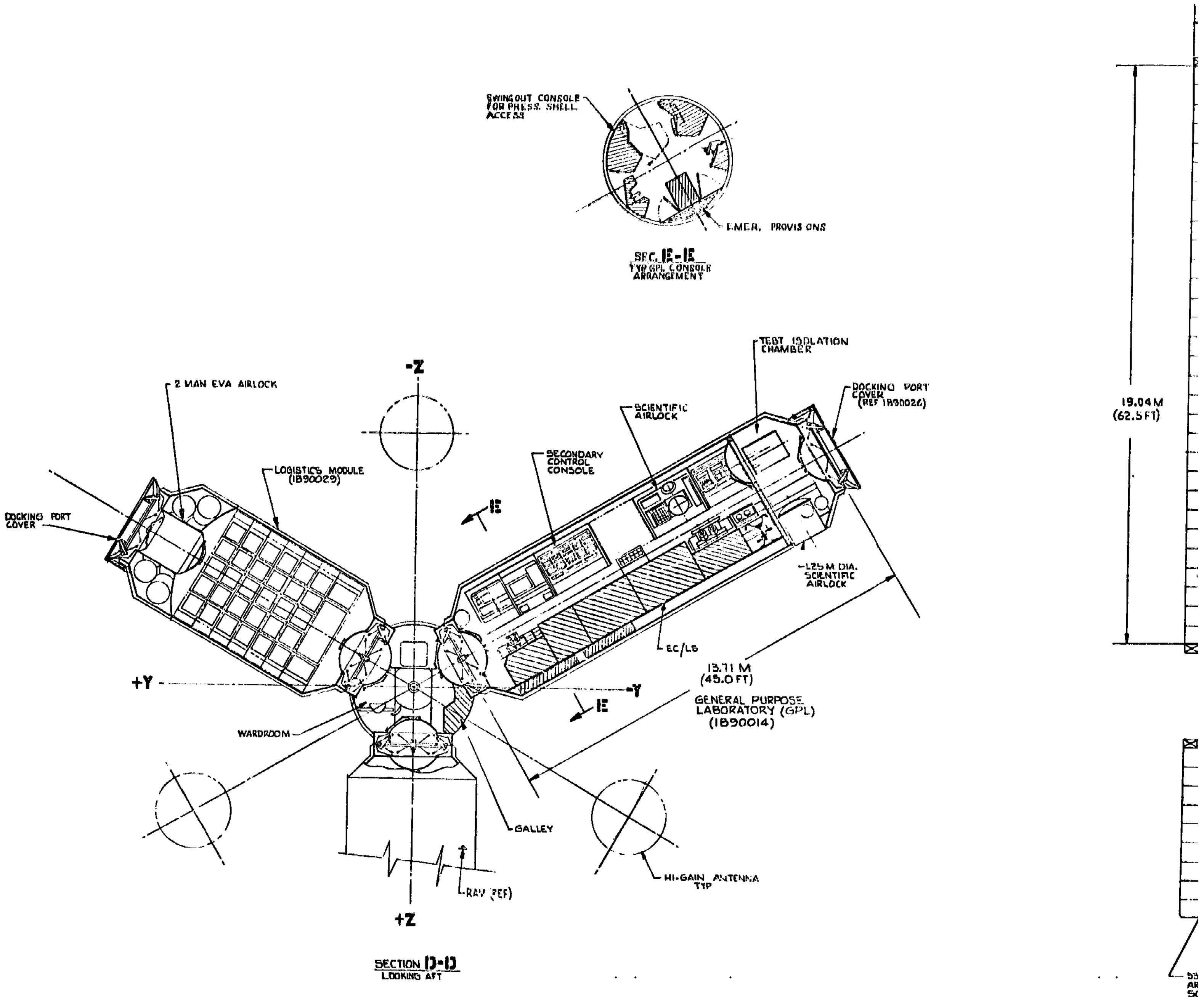

Figure 3-7. ISS Inboard Profile

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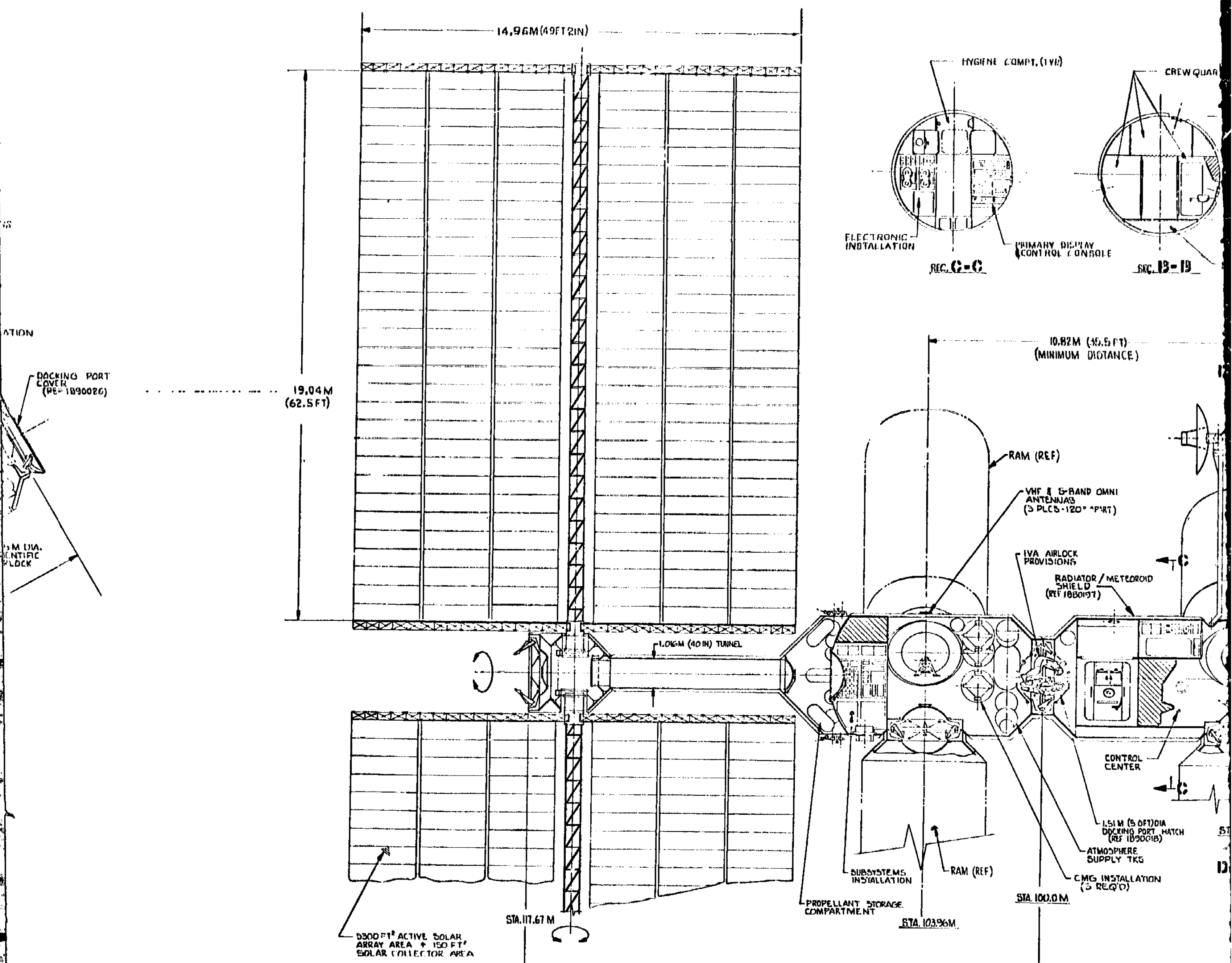

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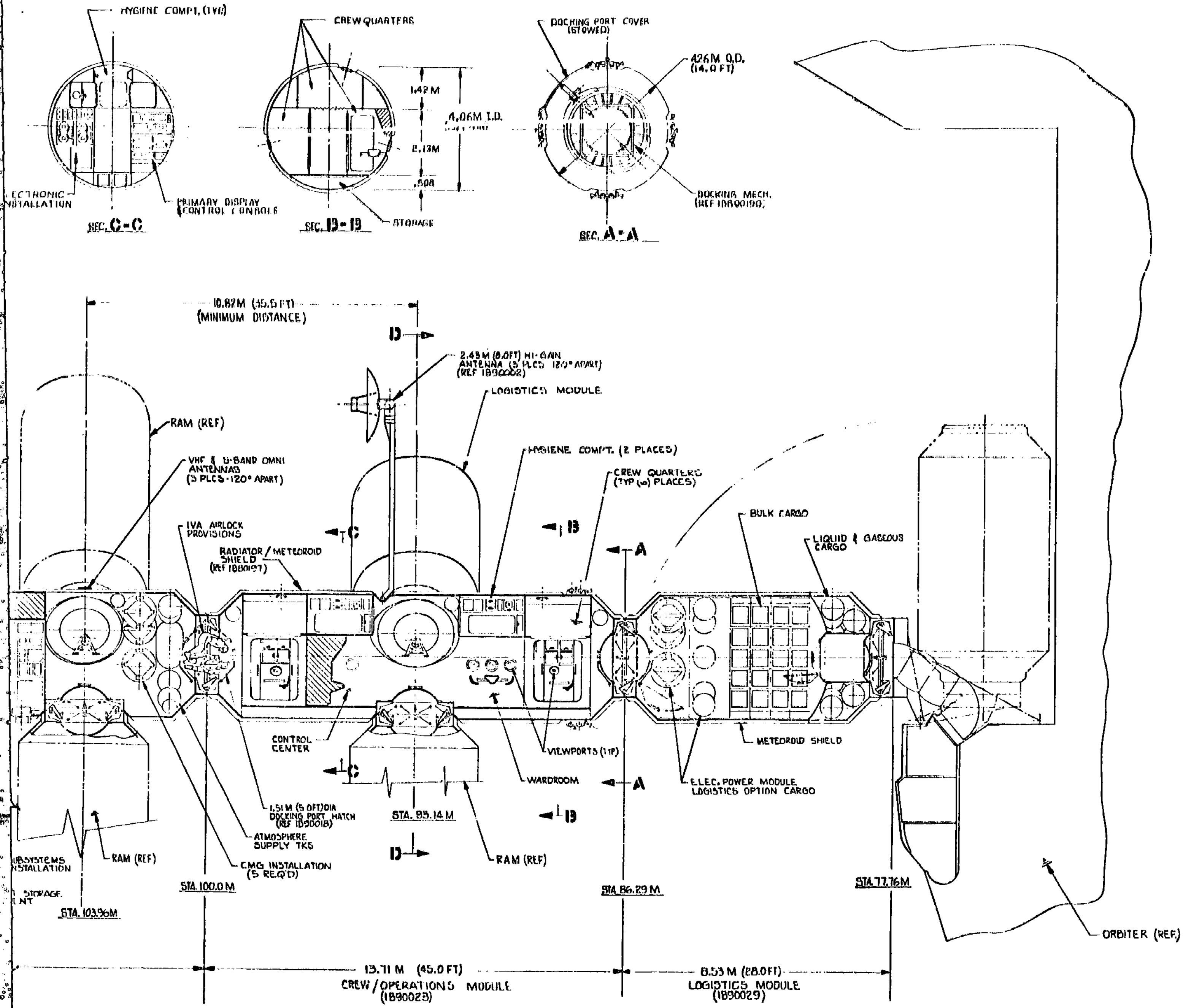

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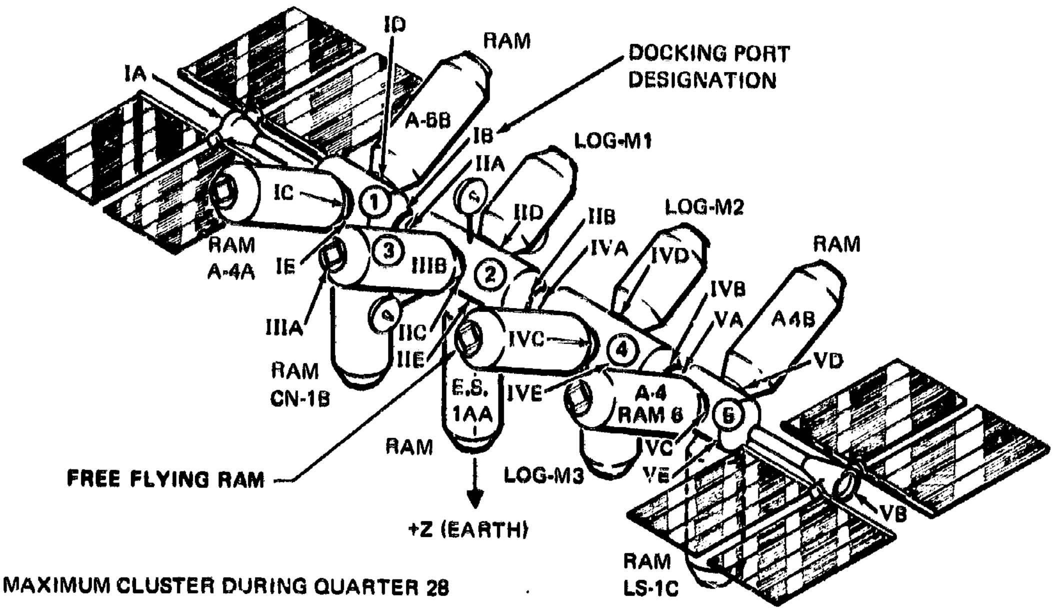

MAXIMUM CLUSTER DURING QUARTER 28

LAUNCH SEQUENCE MODULE	1	2	3	4	5
PRIMARY FUNCTION	POWER/ SUBSYS	CREW/ OPS	GPL	CREW/ OPS	POWER SUBSYS

ISS | GSS

Figure 3-8. Growth Space Station (GSS)

a 1 m (3 ft 4 in.) inside diameter and is 8.5 m (28 ft) long including the forward docking port and the solar array turret.

Externally the module cylindrical section has an end docking port with a thermal cover and three 2.1 rad (120 degrees) radial docking ports with thermal covers. The hatch in each of these docking ports is slightly oval with a minimum diameter of 1.5 m (60 in.). Each hatch contains a central window, 0.2 m (6 in.) in diameter. The hatches can be operated by one crewman and are supported in a stowed position when they are not closed. The pressure shell is encapsulated in a meteoroid shield and radiator and in high performance insulation (HPI) blankets. Four thrustor modules, one in each quadrant, are located on the forward end. A horizon sensor, star sensor, and star tracker are located between the docking ports and the forward end. Three VHF and S-band omni-antennas are located between the radial docking ports.

Internally, the cylindrical section is divided into two compartments. The larger of these compartments, at the aft end, houses the expendables for station atmosphere supply (four 0.8 m [30 in.] diameter N_2 and three 0.8 m [30 in.] diameter O_2 tanks), cylindrical atmosphere pumpdown

Table 3-1

INITIAL SPACE STATION MODULAR SUBSYSTEM MASS SUMMARY (AS LAUNCHED)

Code	Description	Power/Subsystems Module No. 1 Mass (lbm)	Power/Subsystems Module No. 1 Mass (kg)	Crew/Operations Module No. 1 Mass (lbm)	Crew/Operations Module No. 1 Mass (kg)	GPL Module Mass (lbm)	GPL Module Mass (kg)
02.00	Structure	3,308	1,501	3,480	1,579	3,783	1,716
03.00	Meteoroid/Thermal Protection	2,108	956	2,036	924	2,002	908
04.00	Docking Provisions	1,539	698	1,539	698	615	279
06.00	Propulsion	736	334	316	143	54	24
07.00	Prime Power	4,625	2,098	15	7	15	7
08.00	Power Conditioning and Distribution	673	305	287	130	288	131
10.00	Electronics	1,386	625	2,523	1,145	2,063	935
11.00	Wiring	580	263	794	360	1,032	468
12.00	Atmosphere and Thermal Control	831	377	1,287	583	1,259	571
14.00	Crew Life Support and Interiors	425	193	2,568	1,164	665	302
17.00	Crew Equipment and Crew	0	0	0	0	0	0
18.00	GPL and Experiment Provisions or Cargo	---	---	---	---	3,163	1,435
21.00	Residuals	549	249	684	310	648	294
22.00	Reserves	223	101	---	---	---	---
23.00	Inflight Losses	530	240	---	---	---	---
	Minimum-Launch Total	17,513	7,943	15,529	7,043	15,587	7,070
	Discretionary Margin	2,487	1,129	4,471	2,029	4,413	2,002
	Target	20,000	9,072	20,000	9,072	20,000	9,072

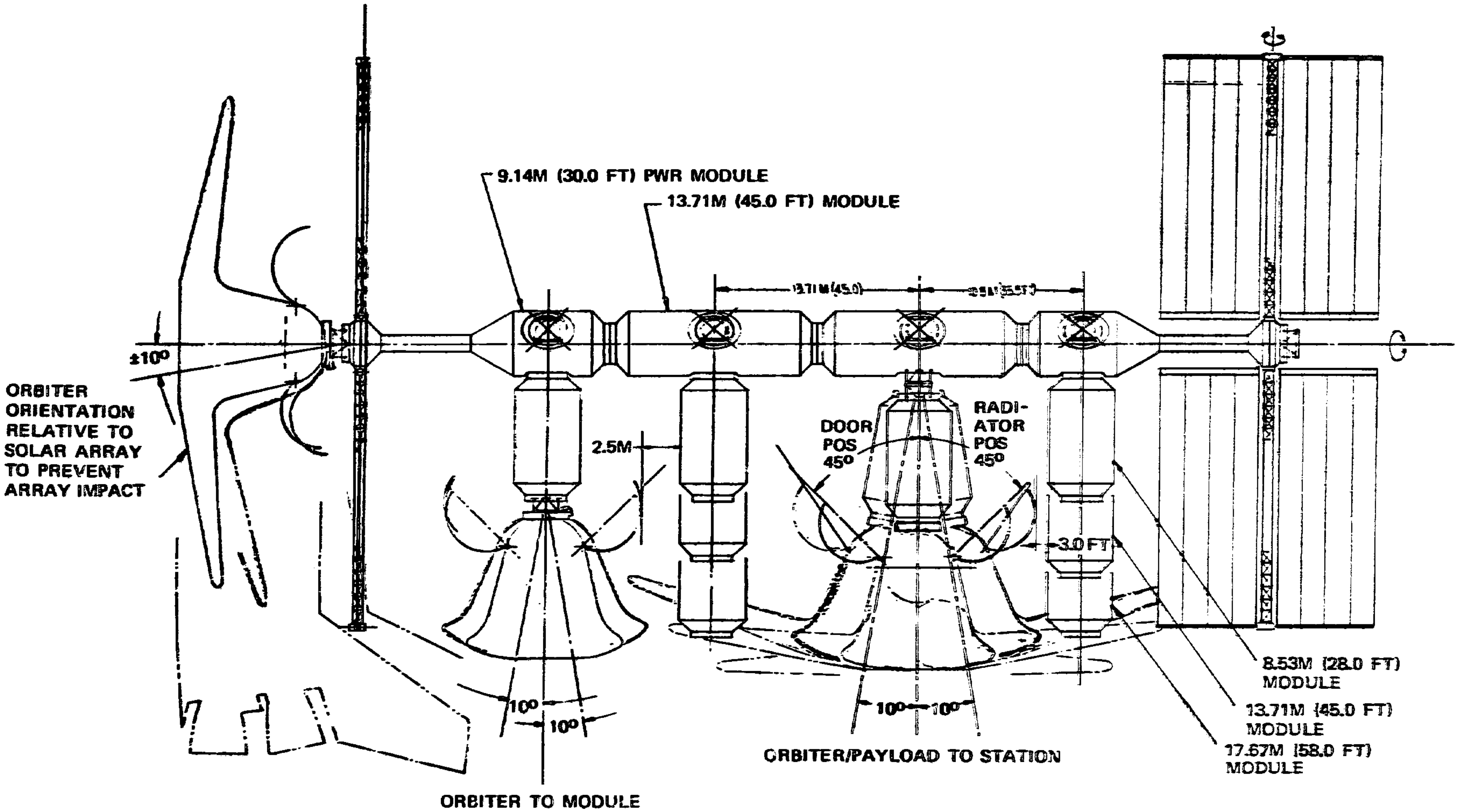

Figure 3-9. Docking Clearance

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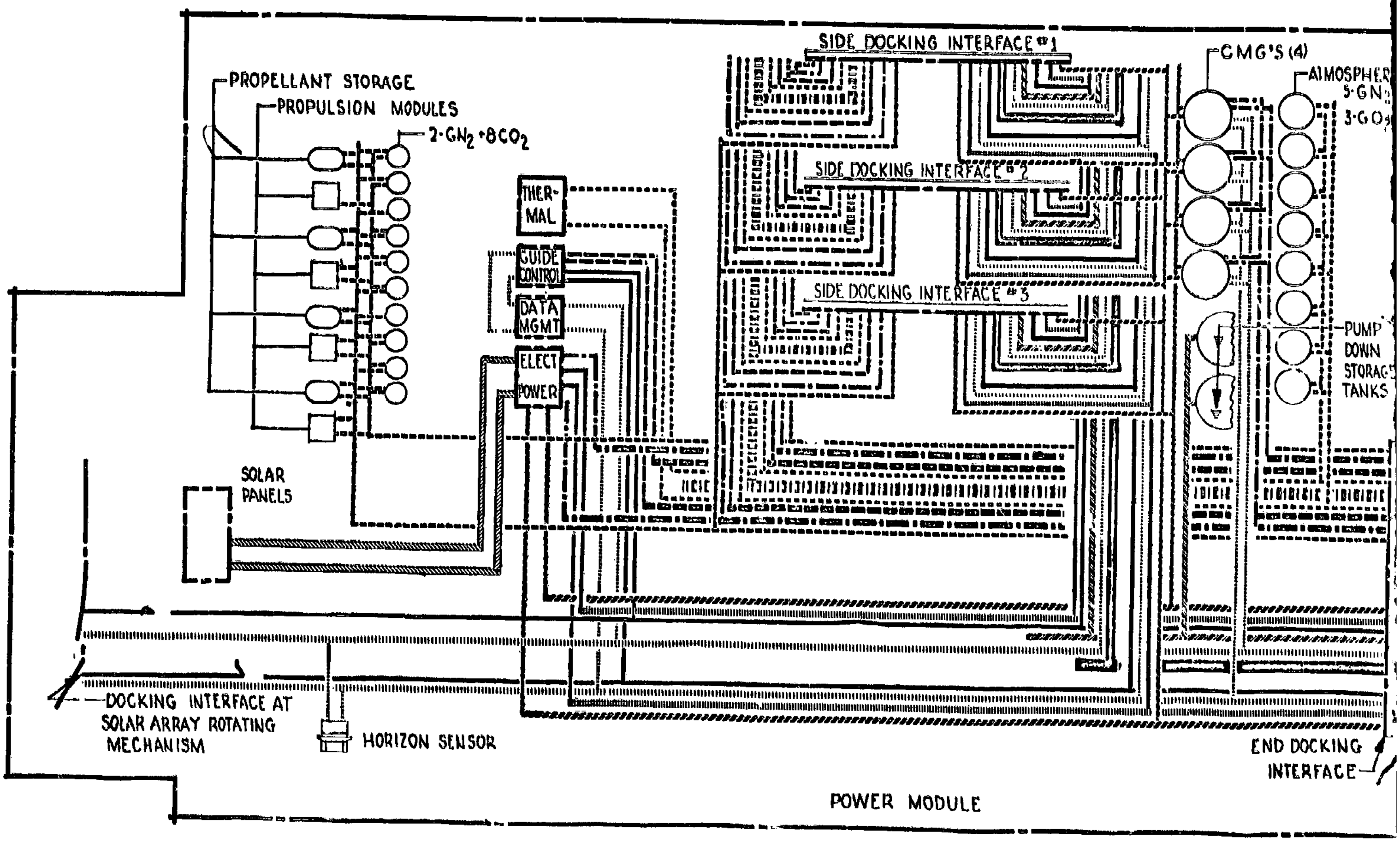

Figure 3-10. Modular Space Station Utility Runs

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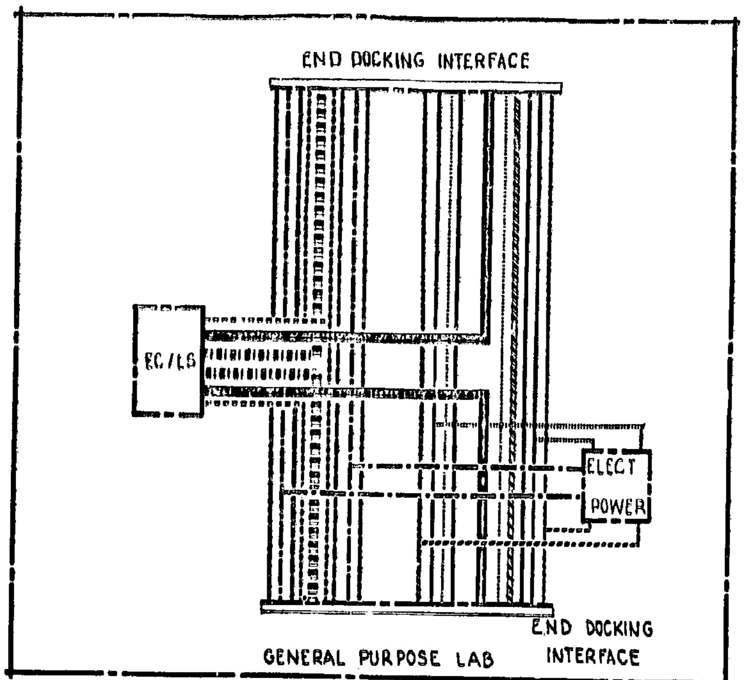

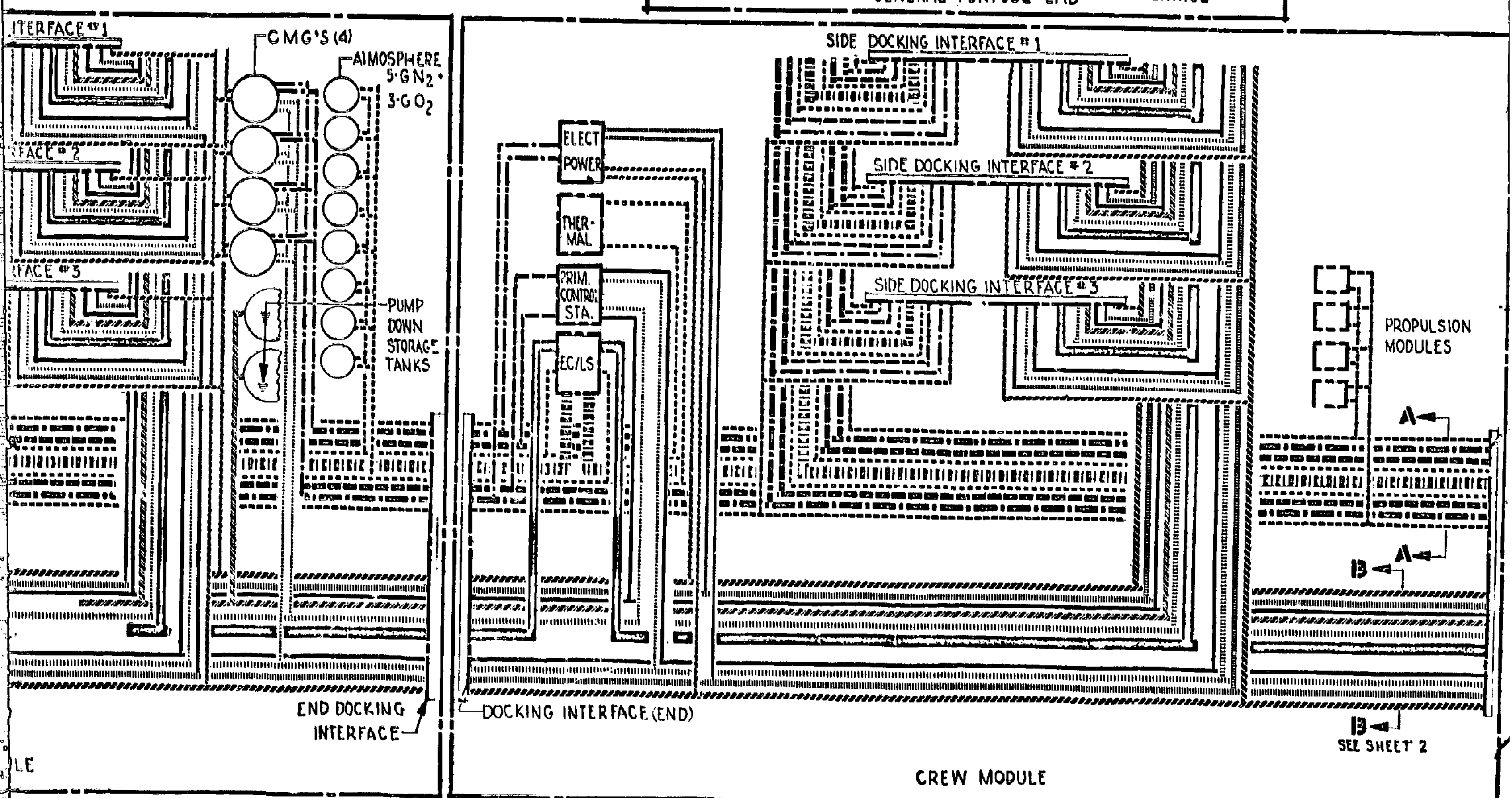

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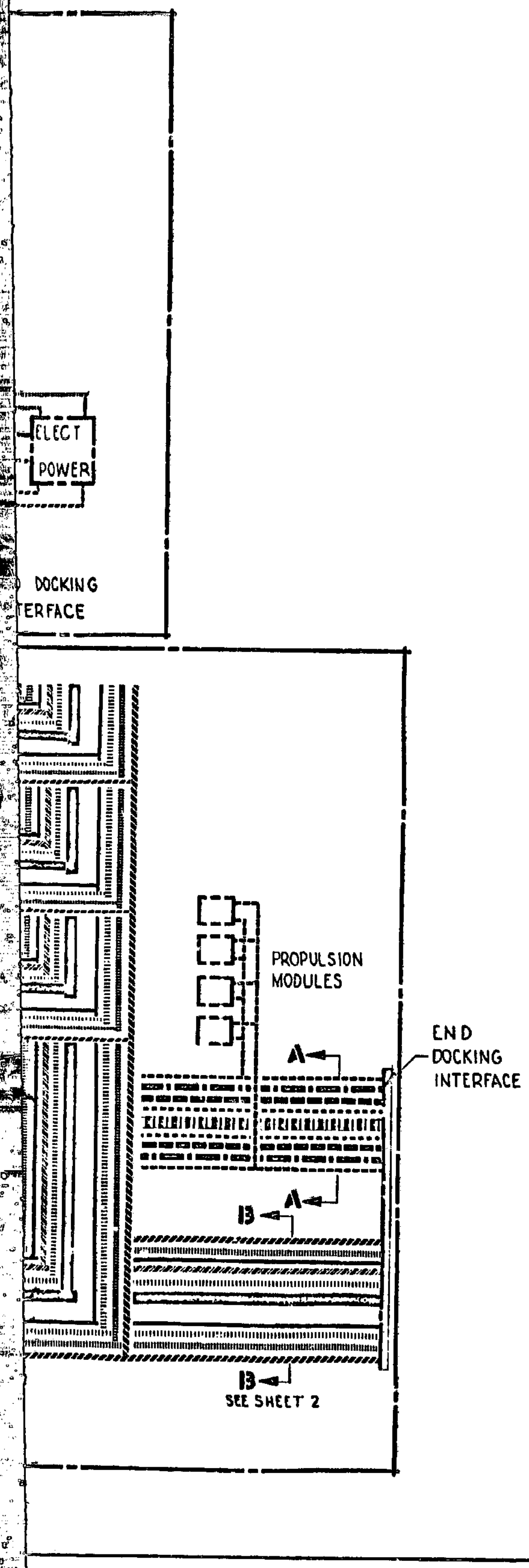

EC/LS
- CONTAMINATED AIR
- CONDITIONED AIR
- PUMP DOWN PIPE
- △ POTABLE H_2O, USED H_2O, GO_2, GN_2, URINE, THERMAL FLUID

PROPULSION FLUIDS
- △ N_2H_4, CO_2, GN_2

CONTROLS (HARD WIRES)
- △ CIRCUIT #1
- △ CIRCUIT #2

DATA BUS
- △ BUS #1
- △ BUS #2

ELECTRIC POWER
- △ DC POWER BUS #1
- △ DC POWER BUS #2
- △ AC POWER
- SOURCE BUS FEEDERS

△ FOR NOTES SEE DWG IB80165 MODULAR SPACE STATION INTERFACE CONNECTIONS

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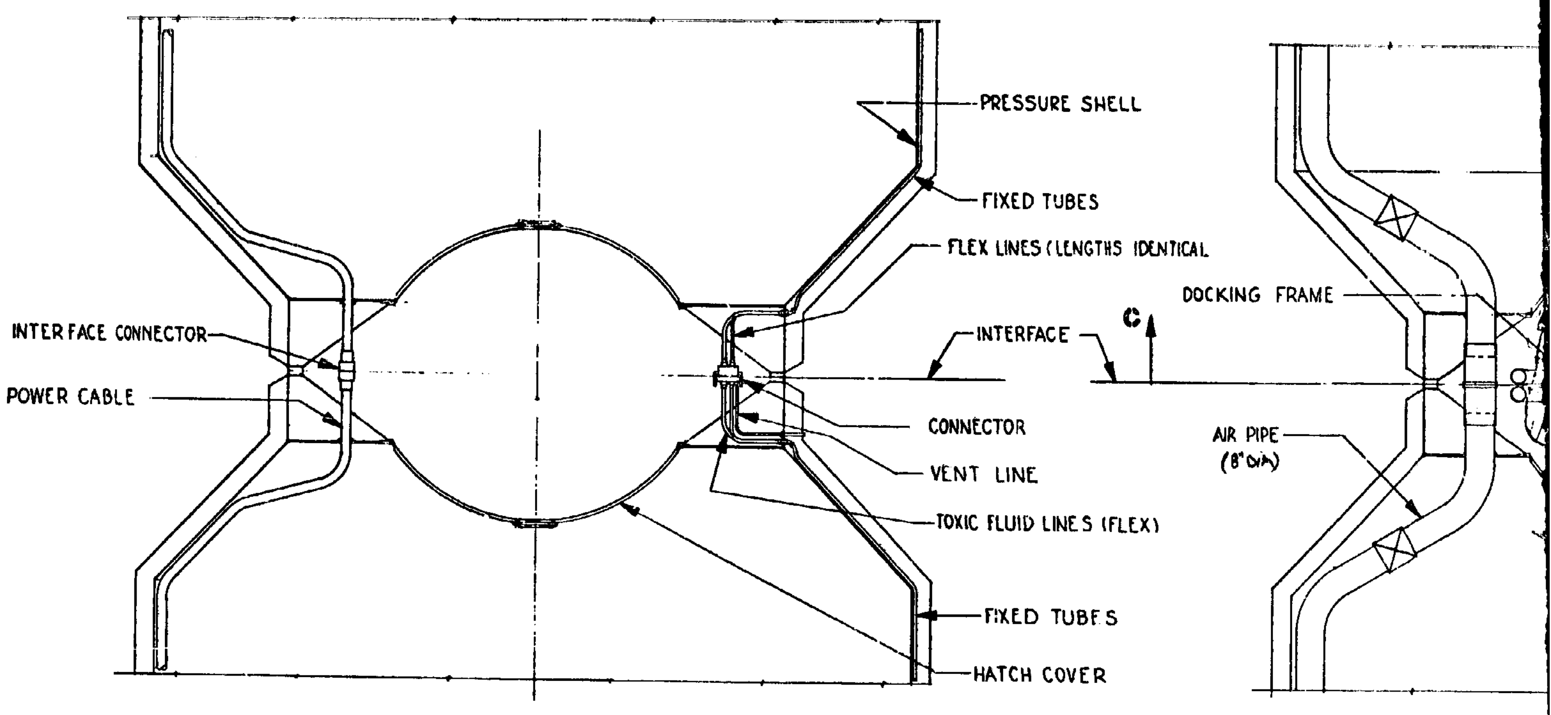

SECTION B - B

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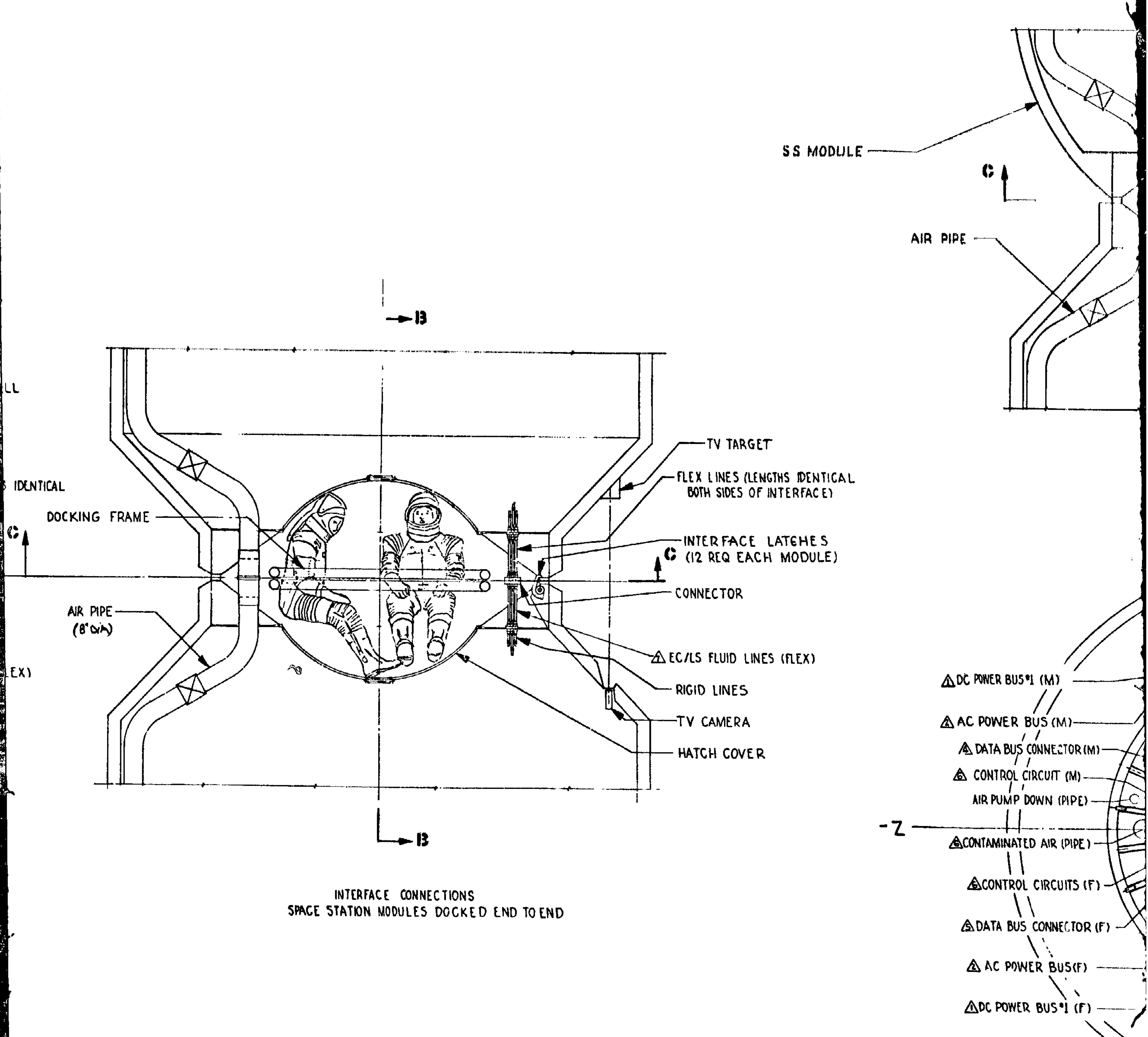
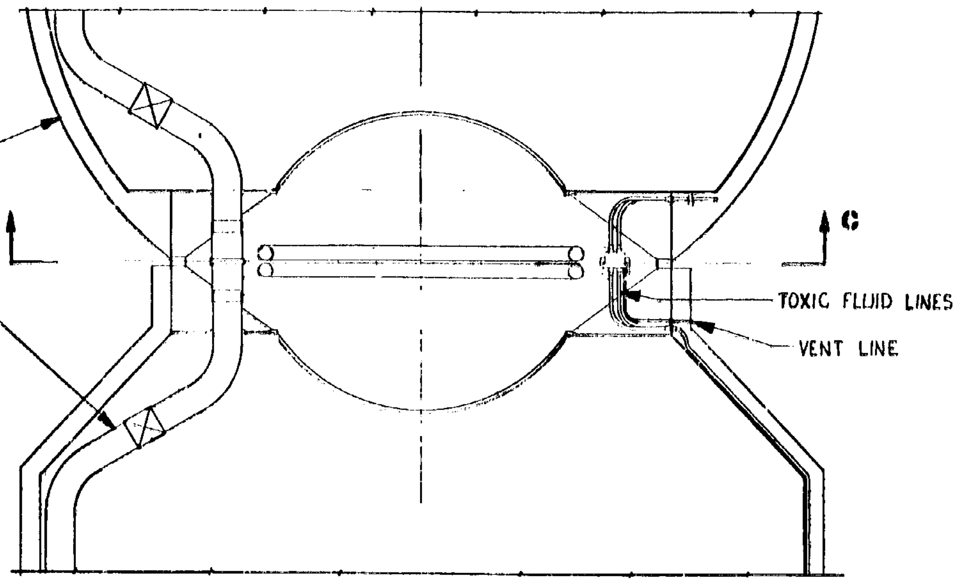
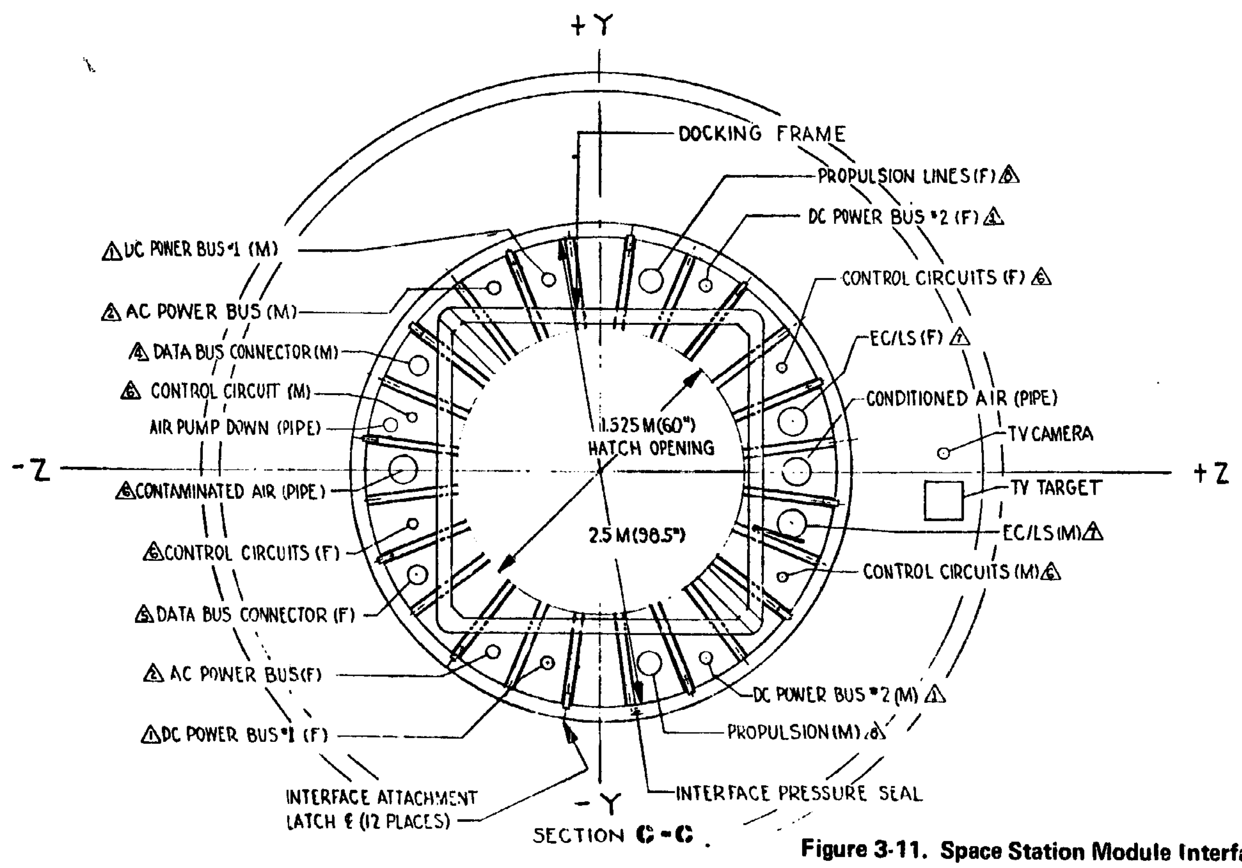


INTERFACE CONNECTIONS
SPACE STATION MODULES DOCKED END TO END



INTERFACE CONNECTIONS
SPACE STATION MODULE END DOCKED TO SIDE PORT

AL



SECTION C-C

Figure 3-11. Space Station Module Interface Connections

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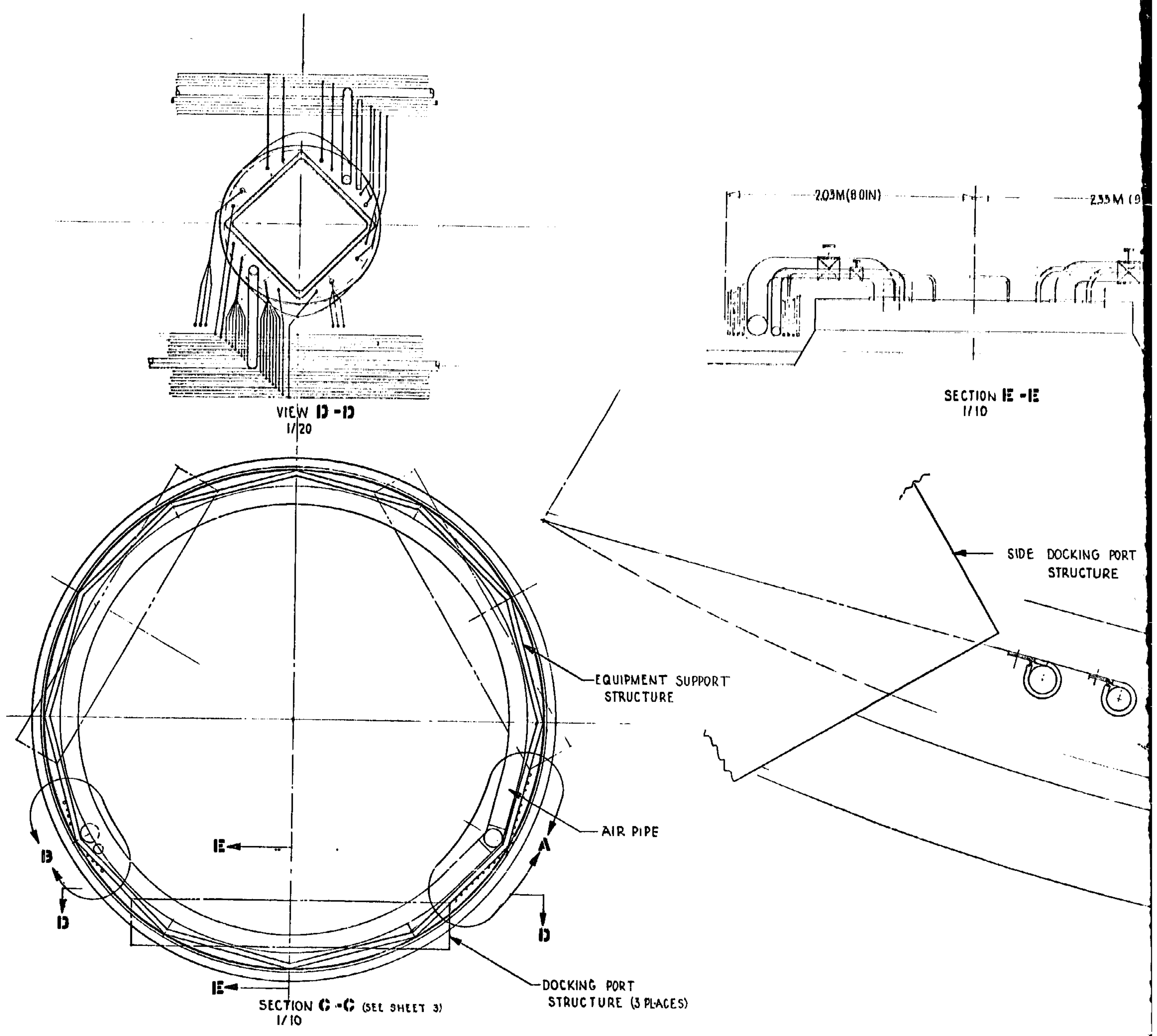

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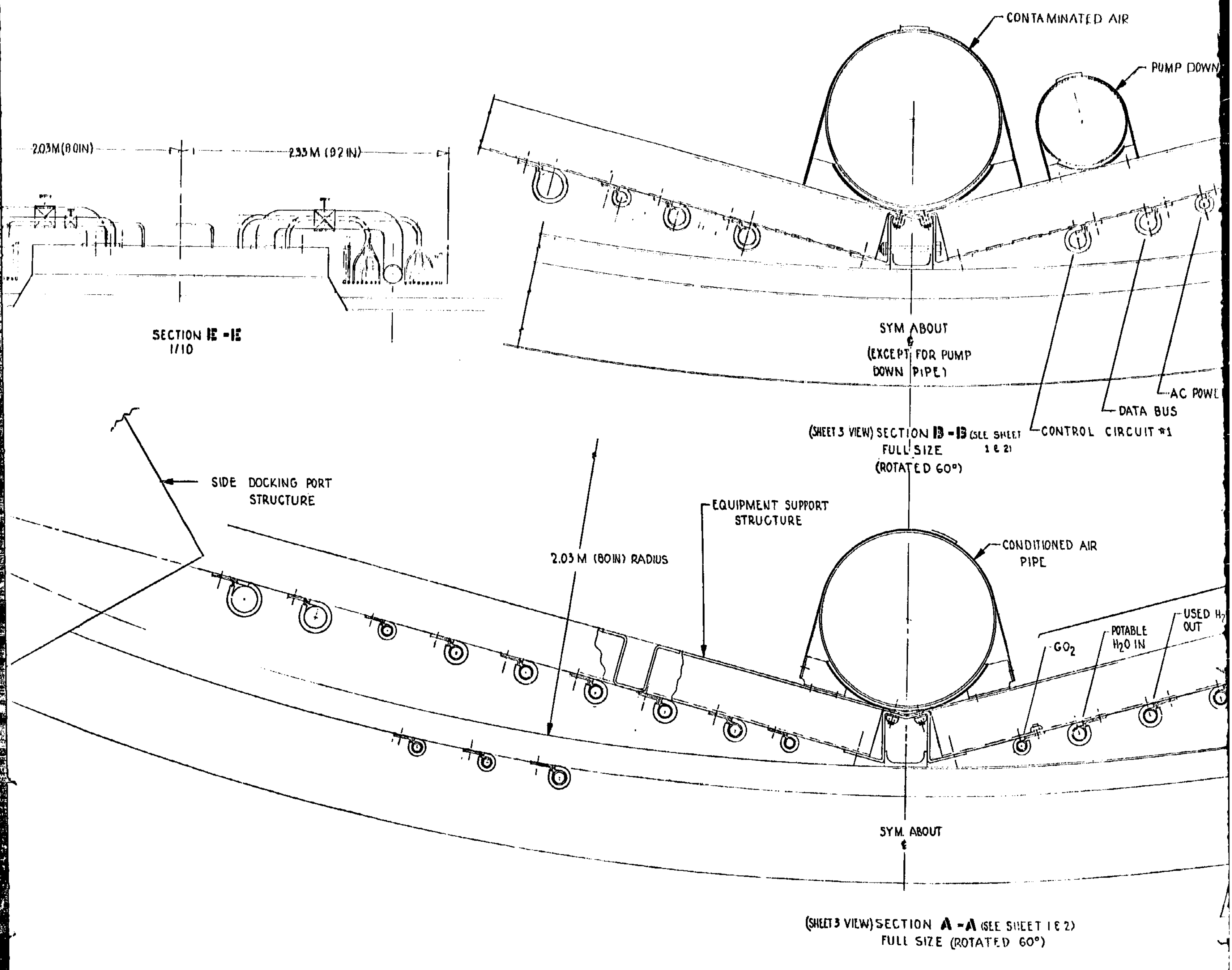
CONTAMINATED AIR
PUMP DOWN
2.03M (80IN)
2.33M (92IN)
SECTION E-E
1/10
SYM ABOUT ℄
(EXCEPT FOR PUMP DOWN PIPE)
AC POWE
DATA BUS
CONTROL CIRCUIT #1
(SHEET 3 VIEW) SECTION B-B (SEE SHEET 1 & 2)
FULL SIZE
(ROTATED 60°)
SIDE DOCKING PORT STRUCTURE
EQUIPMENT SUPPORT STRUCTURE
2.03 M (80IN) RADIUS
CONDITIONED AIR PIPE
USED H_2 OUT
POTABLE H_2O IN
GO_2
SYM. ABOUT ℄
(SHEET 3 VIEW) SECTION A-A (SEE SHEET 1 & 2)
FULL SIZE (ROTATED 60°)

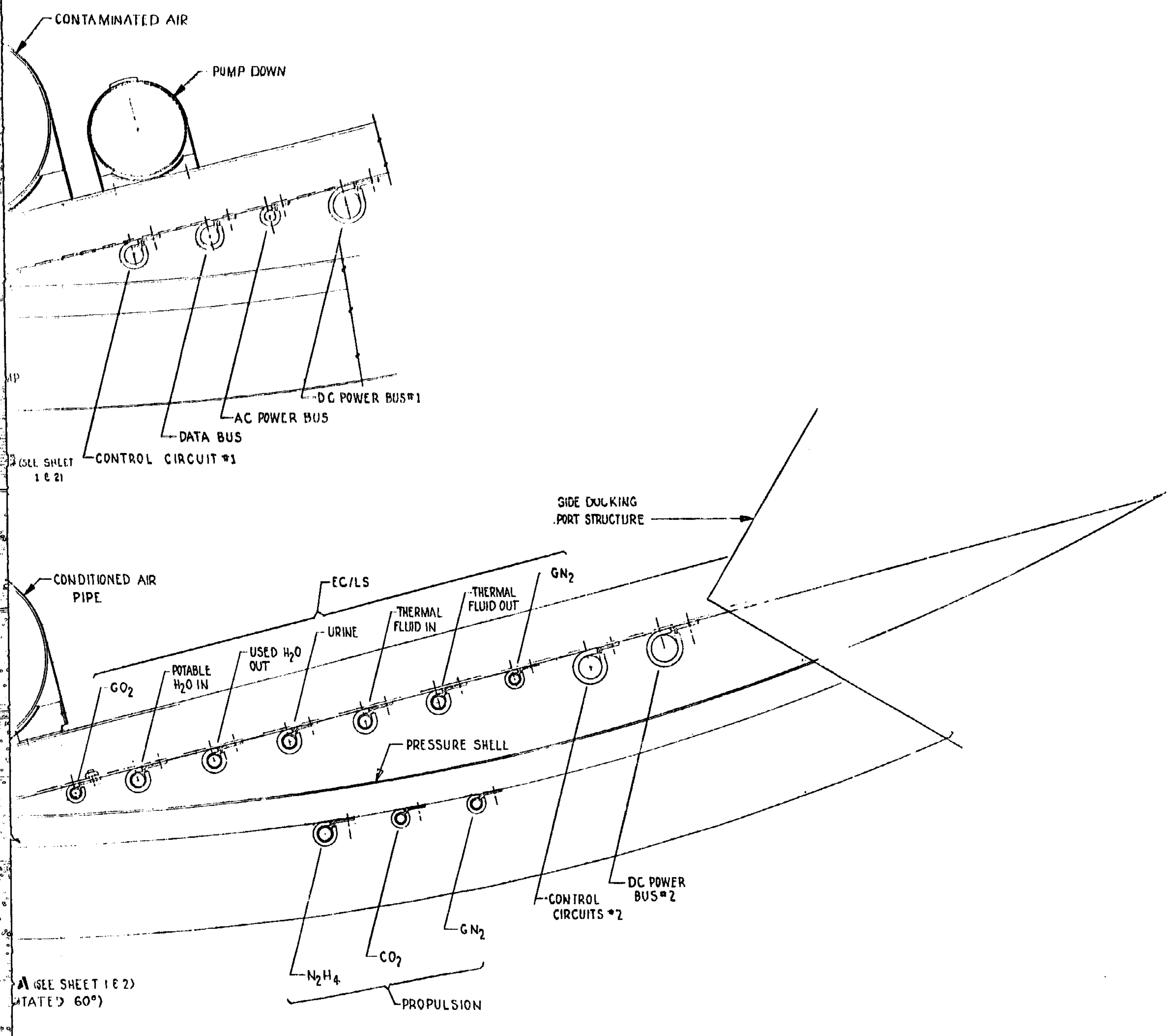

Figure 3-12. Details of Modular Space Station Utility Runs

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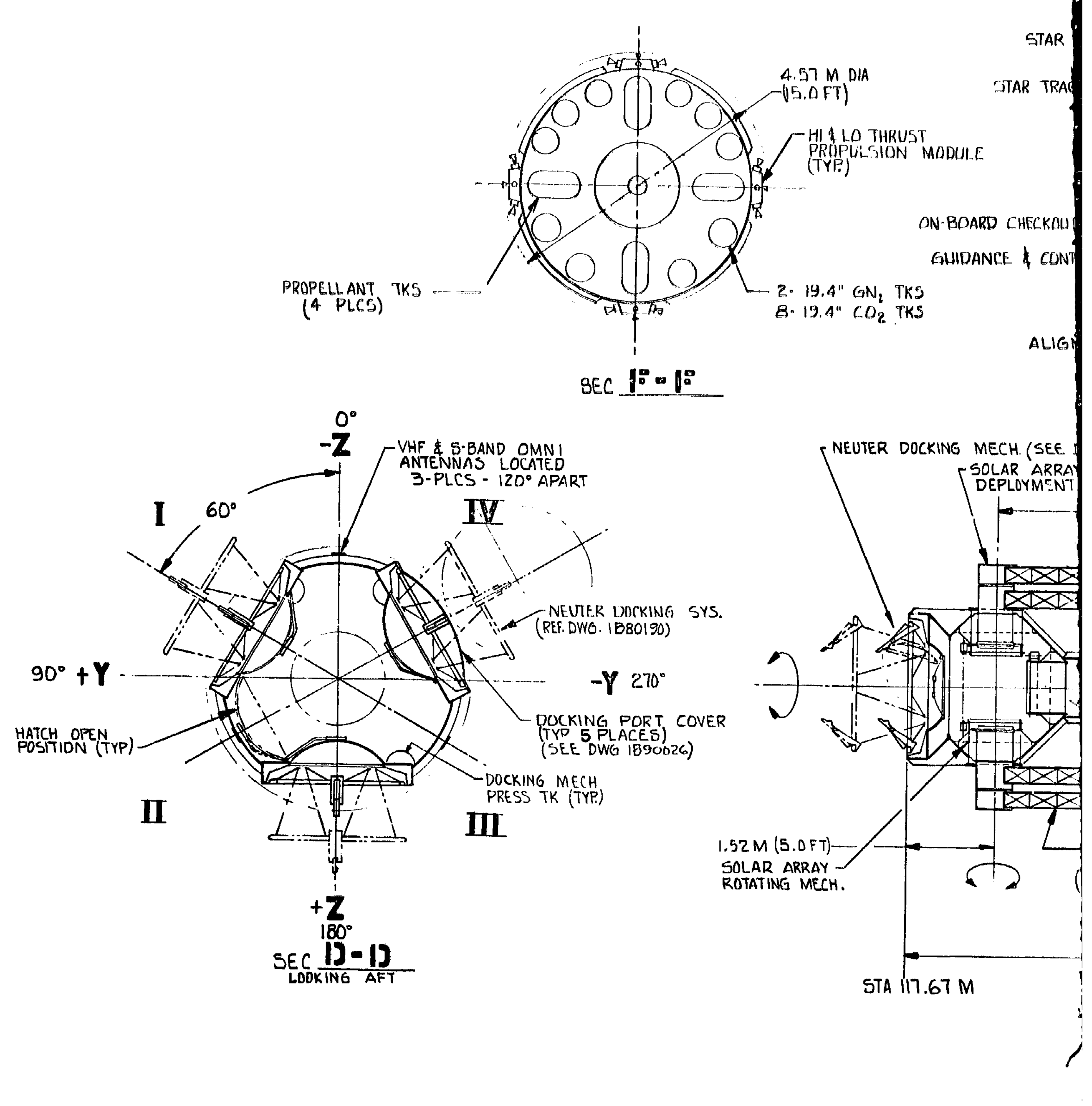

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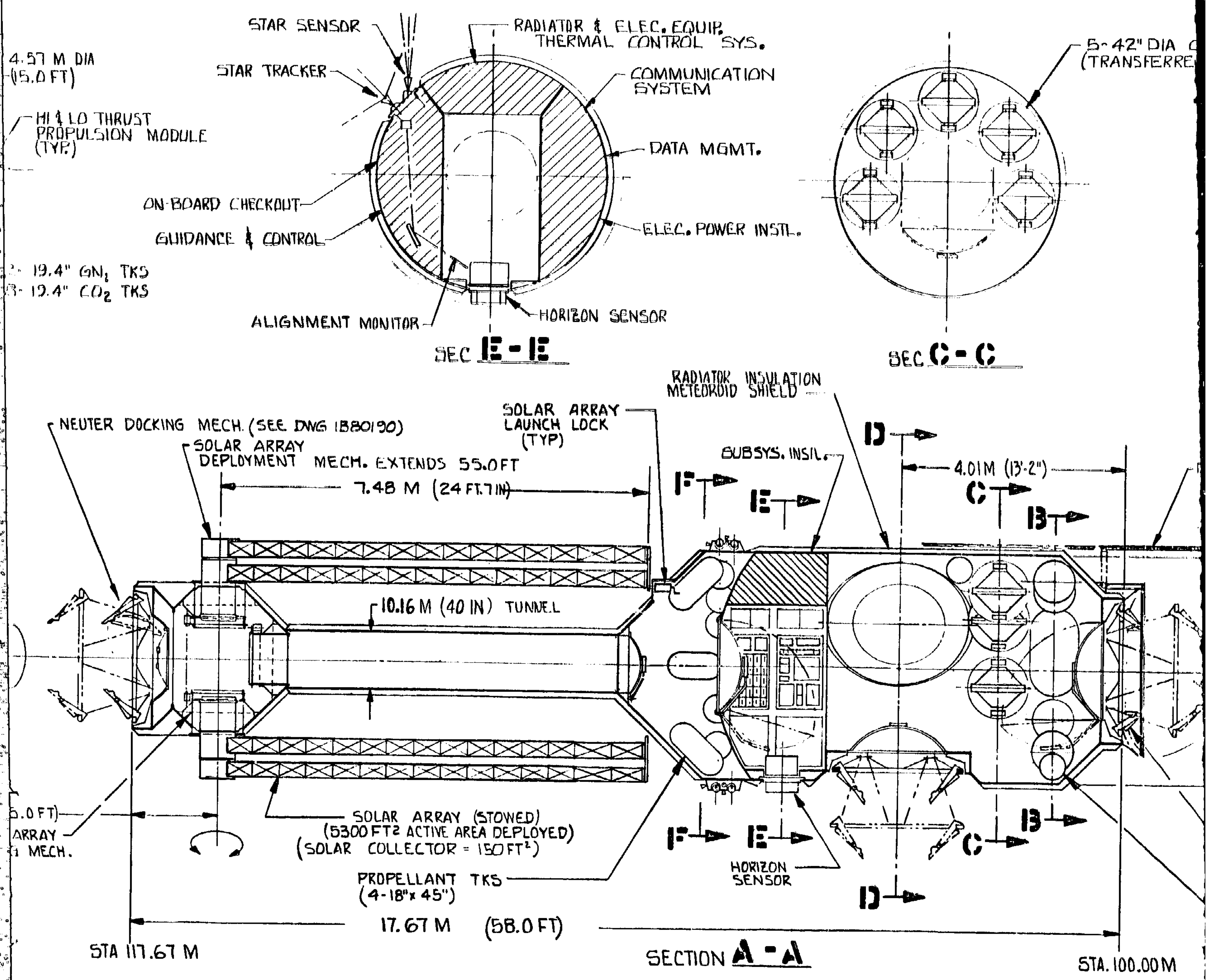

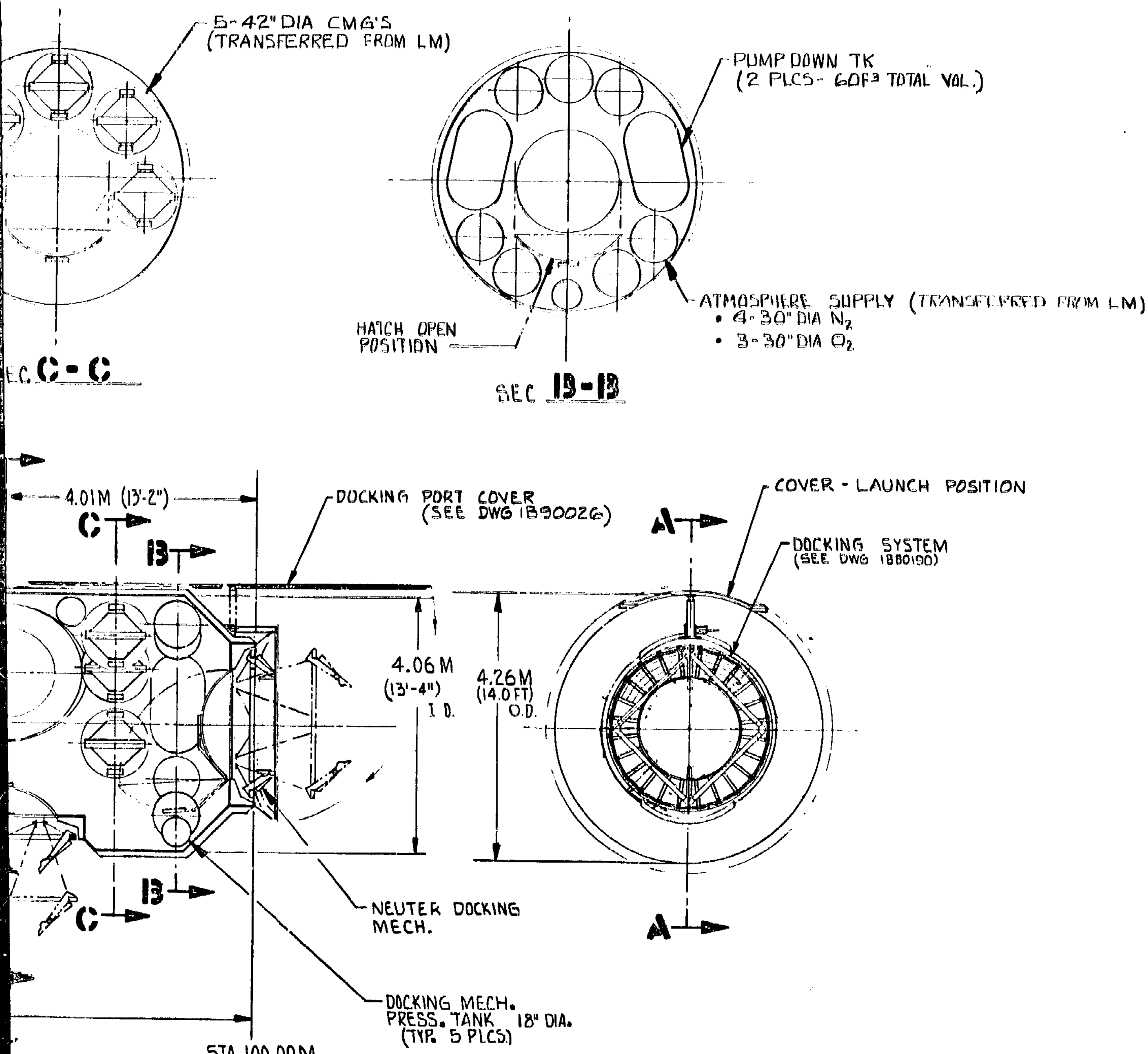

Figure 3-13. Power/Subsystems Module Inboard Profile

tanks (0.9 m [36 in.] long by 1.5 m [60 in.] diameter), and a section where the five 1.1 m (42 in.) diameter CMG's are installed. This section also has a checkout system for use with the other subsystems installed within the module, such as electrical distribution equipment, communications equipment, and the radiator and electrical equipment for the Thermal Control System. The pressurized compartment contains adequate free space for maintenance of all the equipment inside the compartment and for the crew to inspect the vehicle walls by removal of equipment, if this should become necessary. This compartment is normally pressurized and has a habitable shirtsleeve environment. Periodic maintenance and monitoring of subsystems are required but no crew station exists in this module. The average crew residency time in this module is estimated to be about one percent.

Forward of this compartment is a pressurizable compartment which is normally unpressurized; it is vented to vacuum and houses the propellant tanks (4 cylindrical N_2H_4 tanks) 2 GN_2 tanks, and 9 GO_2 tanks. The compartment in which these propellants are stored has adequate free space for maintaining this equipment. The interior of this module is designed for zero-g, i.e., no floors or decks; however, without penalty, equipment is oriented and packaged to accommodate ground test and checkout in a one-g environment.

The power boom supports the solar array gimbal turret and the solar arrays. These double-gimballed arrays in the retracted position are also supported during launch at the opposite end. The solar array incorporates a 14 m^2 (150 ft^2) solar collector which is used to supply heat to the EC/LS Subsystem. The forward end of the turret incorporates a docking port so that, if necessary the Power/Subsystems Module can be separated from the balance of the Station by the Orbiter and returned or replaced with another Power/Subsystems Module. (This is a contingency capability only.) The power boom can be pressurized for shirtsleeve access to maintain equipment in the solar array drives. The power boom has a meteoroid shield and high performance thermal insulation. An EVA hatch in the turret is provided to permit on-orbit inspection and repair of the solar array and the solar collector, if required.

The minimum launch mass of the Power Subsystems Module is 7,943 kg (17,513 lb). Included on the first Logistics Modules are expendables, pumpdown tanks, and CMG's which are not required during buildup.

3.1.2 Crew/Operations Module

The Crew/Operations Module is shown in Figure 3-14. It is 13.7 m (45 ft) long and has a cylindrical diameter of 4.3 m (14 ft), the same as the diameter of the other modules in the ISS. The Crew/Operations Module has two end-docking ports and three radial-docking ports at 2.1 rad (120 degrees) located midway between the two ends. All docking ports have thermal covers. There are three retractable high-gain antennas spaced at 2.1 rad (120 degrees) indexed between the three docking ports, 5.2 m (17 ft) aft of the forward end. Four thruster modules are located at 1.6 rad (90 degrees) spacing at the aft end of the module.

The interior of the Crew/Operations Module contains all of the facilities needed for the crew during the duration of the mission under normal operating conditions. The configuration is specifically oriented for zero-gravity. This results in a high degree of space utilization. However, for ground test and checkout, all facilities are compatible with one-g. The crew accommodations have been arranged so that a mixed crew (male and female) can be accommodated. Crew quarters are divided into two groups of three and there are two complete and separate hygiene facilities. A galley, a wardroom, a recreation and exercise area, the primary control console and its associated electronics are located in this module. One of the two six-man EC/LS Subsystems is also incorporated. This module contains a portion of the onboard complement of batteries and provides for storage of crew and other equipment that is retained on-orbit.

At the forward end of the Crew/Operations Module is a conic section where the 1.5 m (60 in.) hatch is stowed. An area for miscellaneous storage is also provided in this region. Three of the crew quarters are located at the forward end. These quarters, one on each side and one overhead, are approximately 2.1 m (7 ft) by 2.1 m (7 ft) by 1.5 m (5 ft) Each of the three crew quarters contains a closet for the flight crew's personal gear, a sleep restraint, a desk, a restraint for use at the desk, and a window 0.3 m (12 in.) in diameter. If the large, accordion-type doors on three compartments are opened simultaneously, a single spacious compartment is provided. In addition, the entry way from the crew quarters to the wardroom (or control center) can be closed to form a large 22.7 m^3 (800 ft^3) stateroom.

One of the hygiene compartments is located adjacent to the crew quarters and "above" the control center. The hygiene compartments contain a

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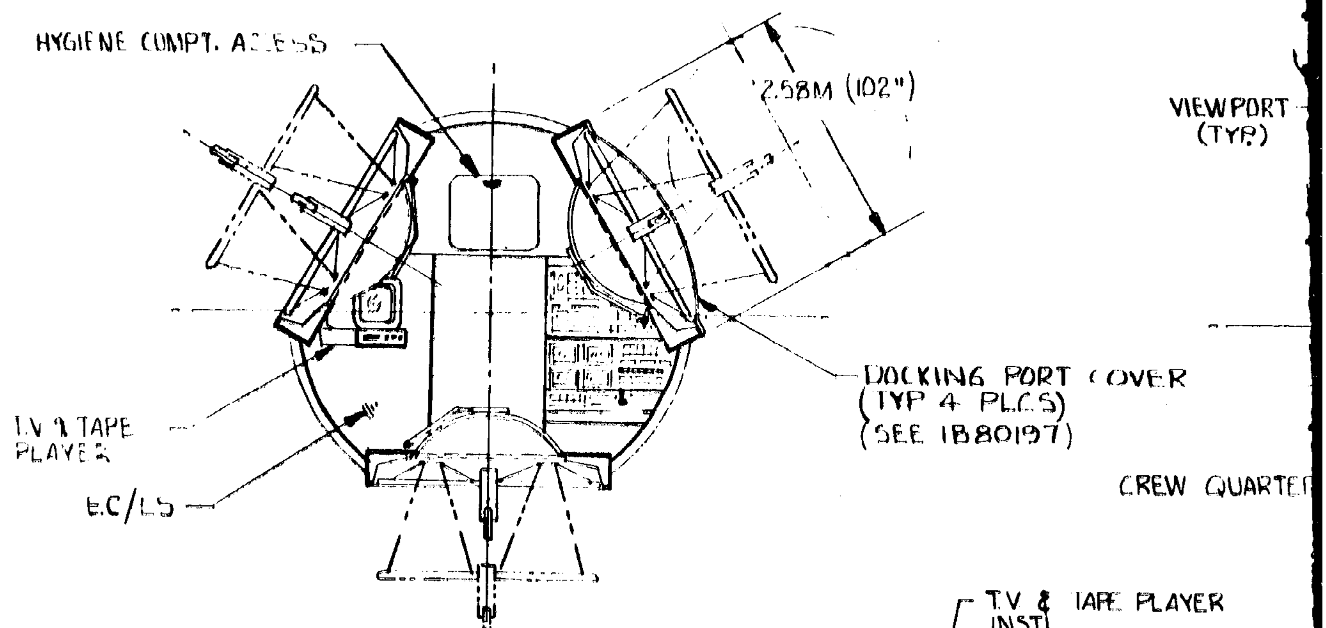

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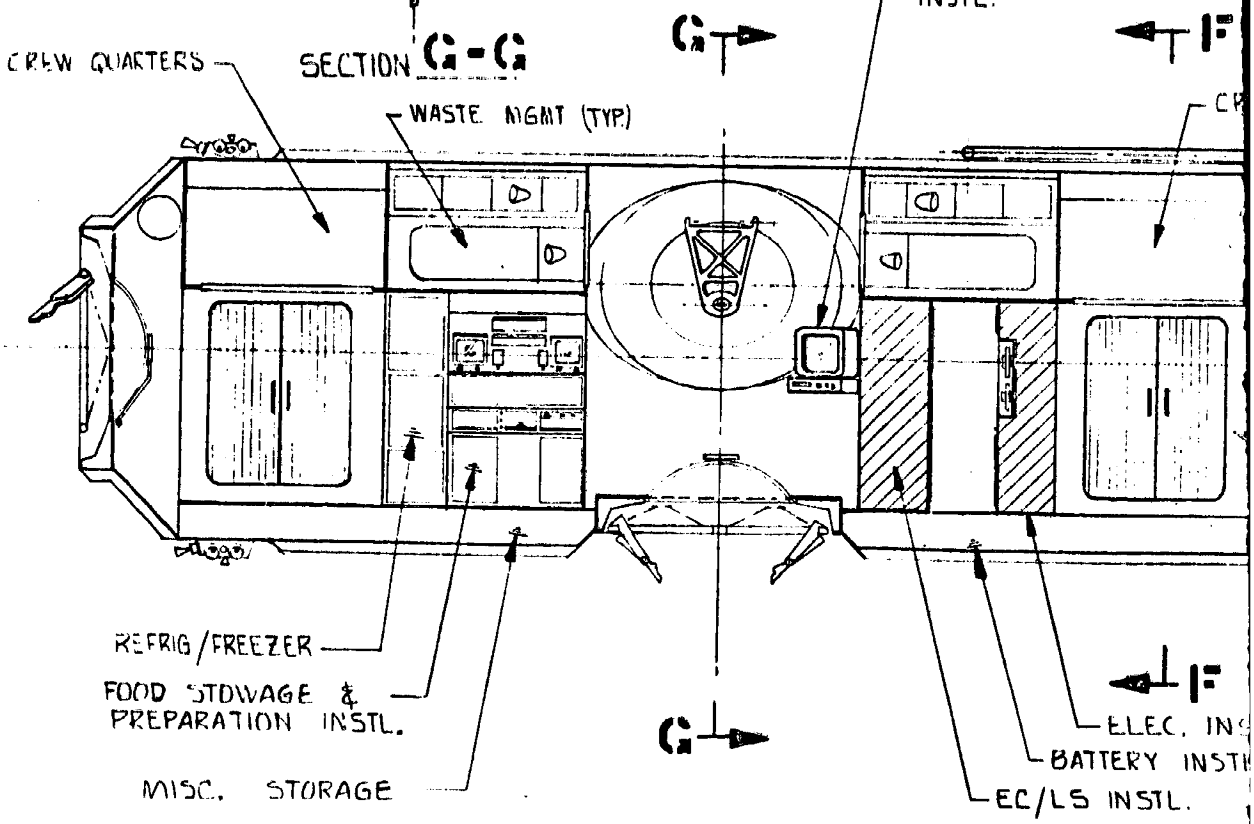

SECTION B-B

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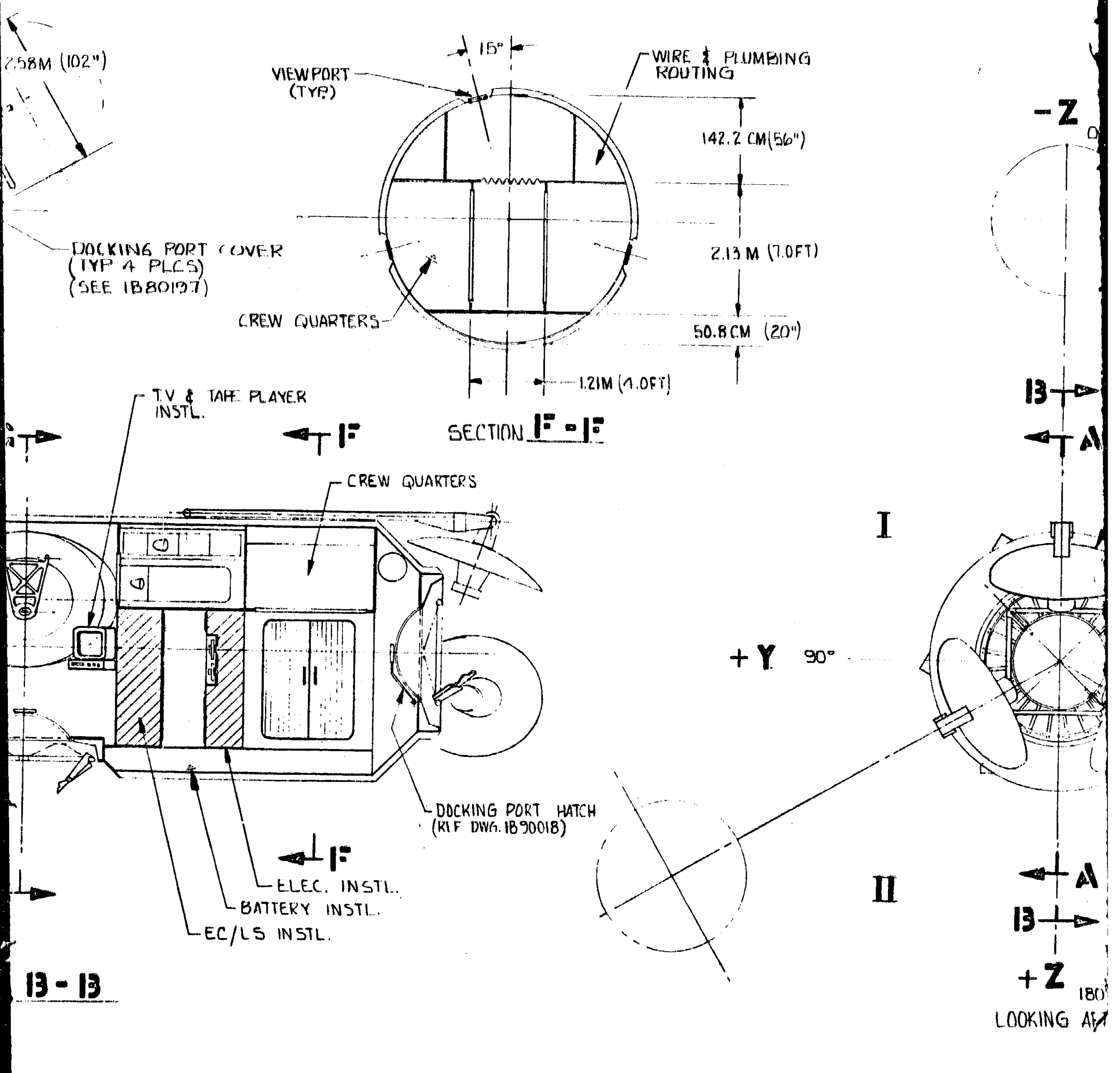

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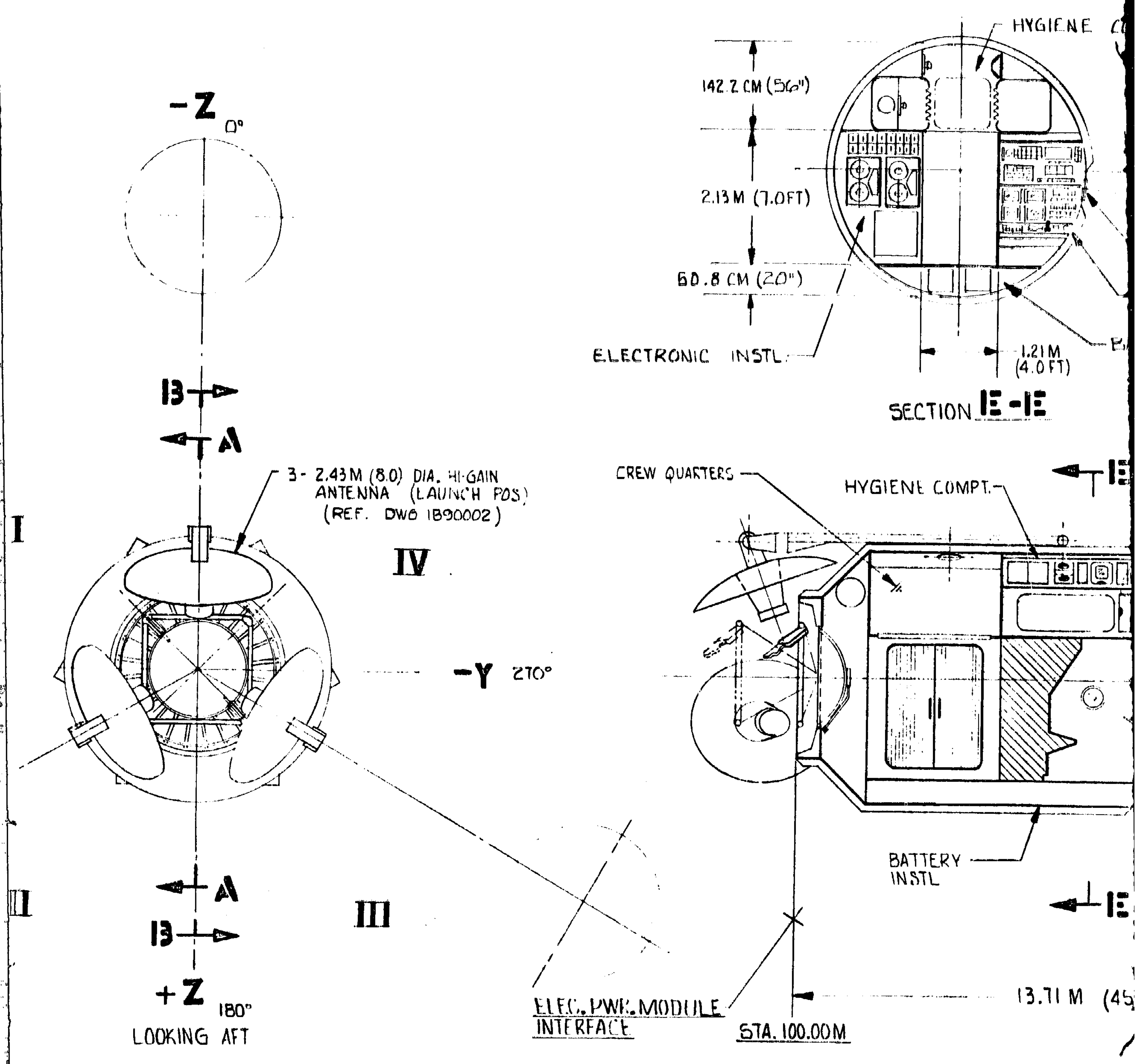

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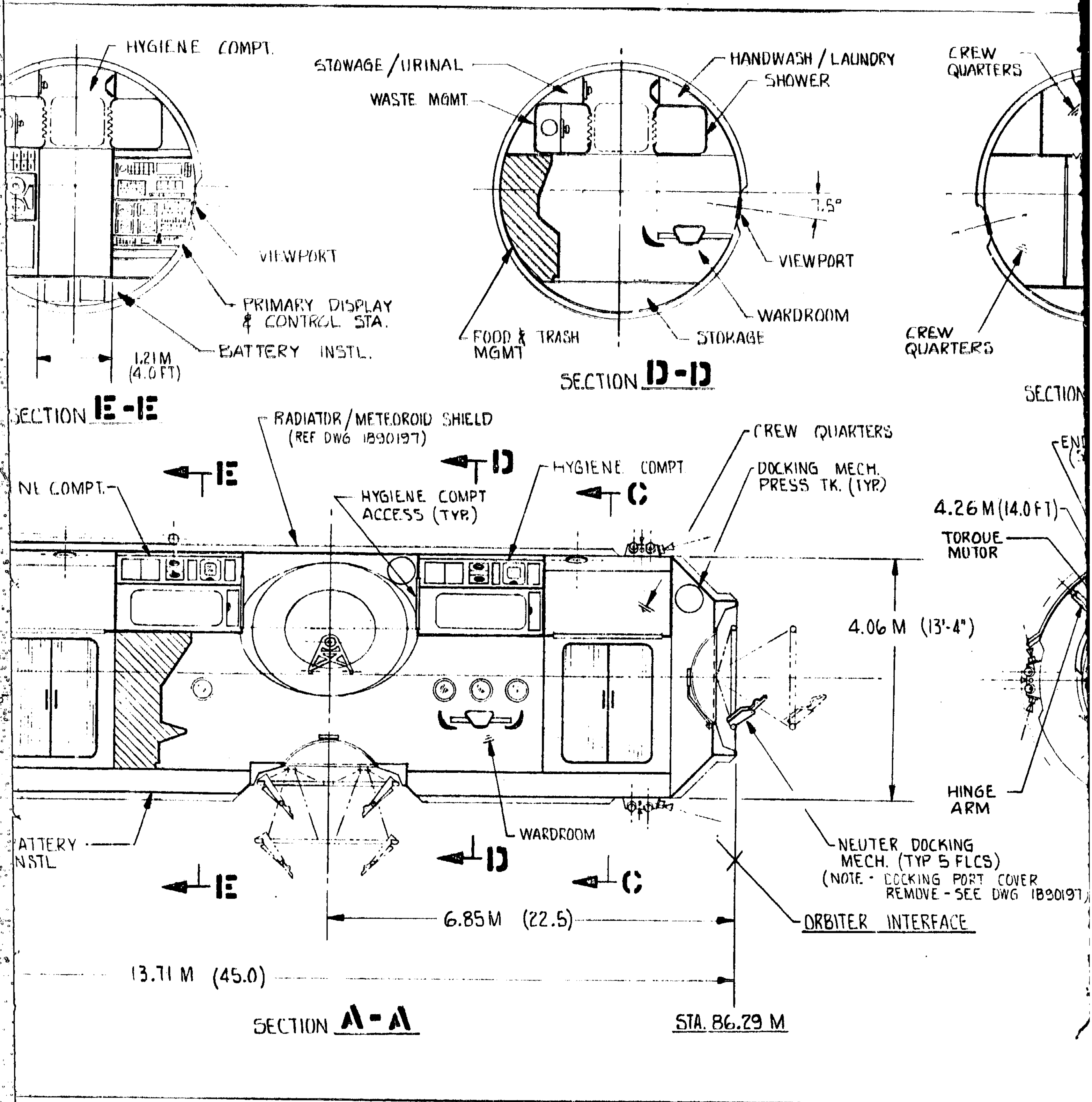

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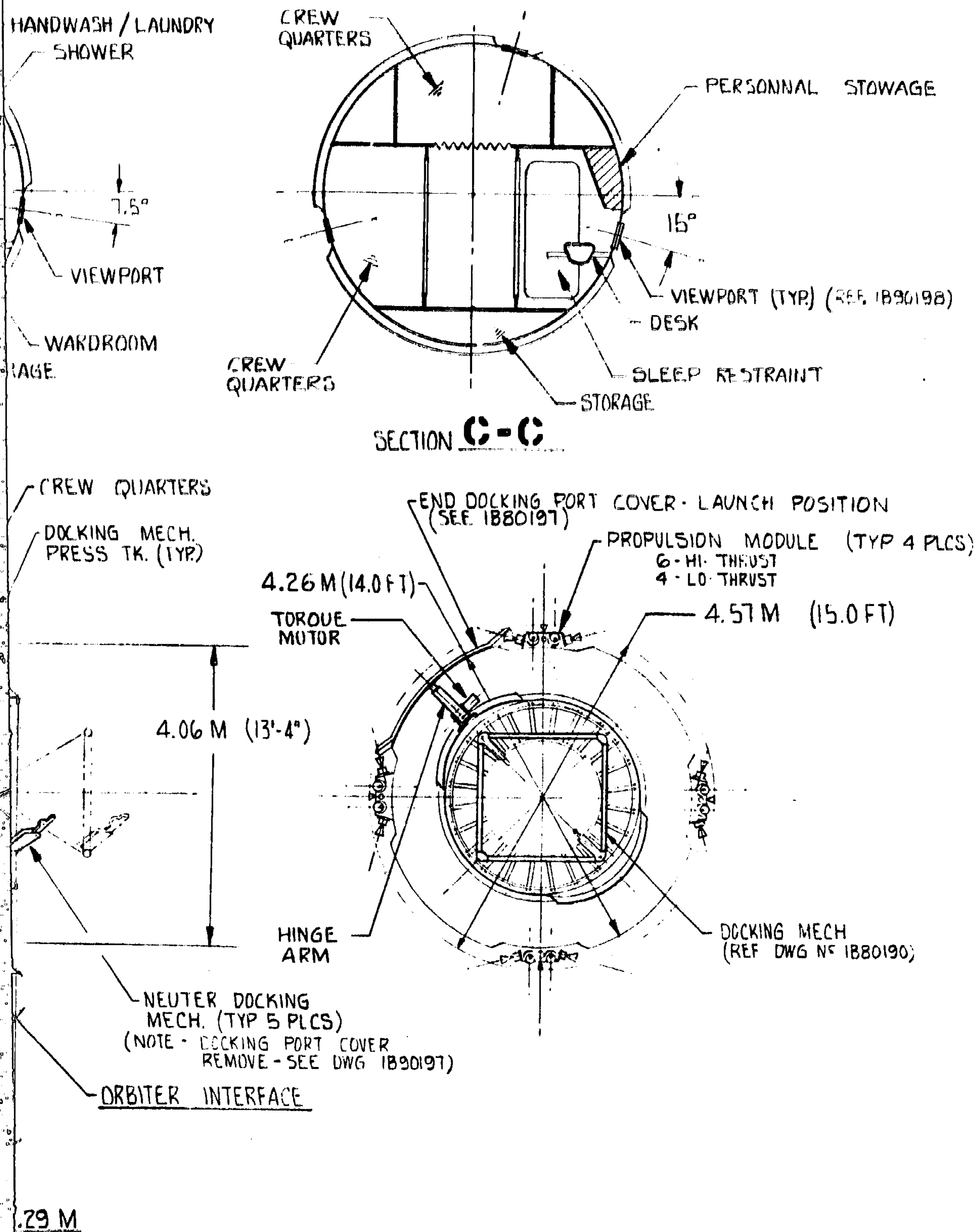

Figure 3-14. Crew/Operations Module Inboard Profile

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hand wash, laundry, shower, urinal, and a waste management system. There is a storage capability for hand wipes and similar equipment inside the hygiene compartment.

The primary control and display console for Station operation is located directly under the hygiene compartment on the right-hand side. This console is normally used by one crewman, but can be used by two when required. The console is in full view of the wardroom area but may be isolated by a curtain when desired. An 0.3 m (12 in.) viewport is located adjacent to the console so that the crewmen will be able to make space and/or Earth observations while seated at the console.

Opposite the primary control console are located the associated electronics and other electrical equipment that are peculiar to the Crew/Operations Module. Immediately "aft" of the electronic equipment console is the EC/LS Subsystems equipment.

In the central region of the Crew/Operations Module are three docking ports. This area is reasonable large and adds considerable spaciousness to the general-purpose area used for recreation and exercise. The dining area is located just aft of the radial docking port on the right-hand side. It has a table with restraints and can accommodate the entire crew. There are three 0.3 m (12 in.) windows in the dining area.

The galley is across from the dining area and contains the food management and trash management equipment. Food management equipment includes storage for a 30-day food supply, an oven, a freezer, and a refrigerator. Adjacent to the wardroom/galley are the other three crew quarters. The end conic section is used for storage.

The minimum launch mass of the Crew/Operations Module is 7,043 kg (15,529 lb). The configuration of the Crew/Operations Module evolved as an iterative design that made use of layouts, small-scale models (1.20), and a number of full scale mockups. This arrangement of the Crew/Operations Module was built as a full scale soft mockup prior to being selected as the configuration for the ISS.

3.1.3 General Purpose Laboratory (See also Section 5.1)

An inboard profile of the GPL Module is shown in Figure 3-15. The General Purpose Laboratory is 13.7 m (45 ft) long and 4.3 m (14 ft) in diameter; dimensionally it is the same as the Crew/Operations Module;

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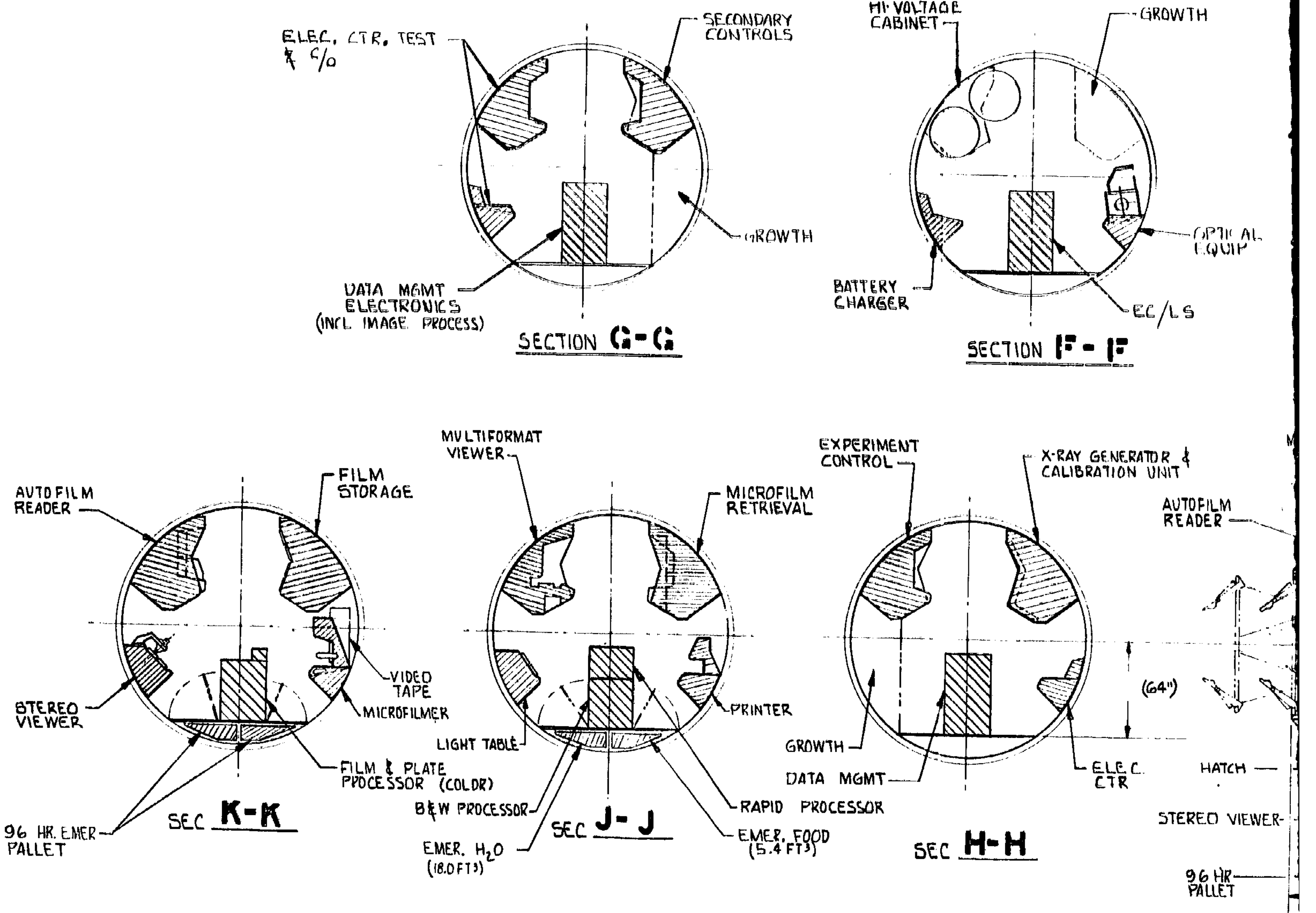

Figure 3-15. General Purpose Laboratory Inboard Profile

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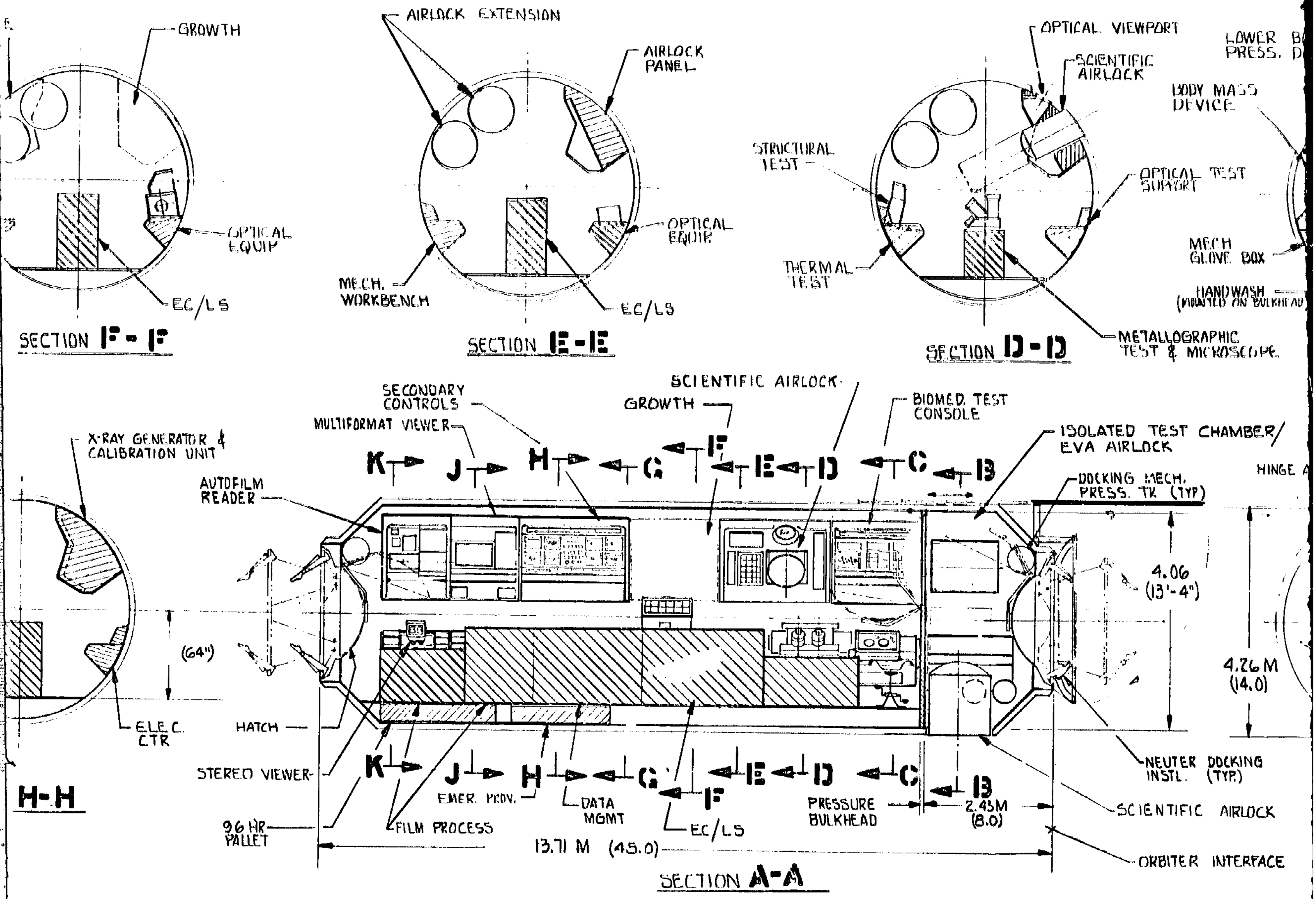

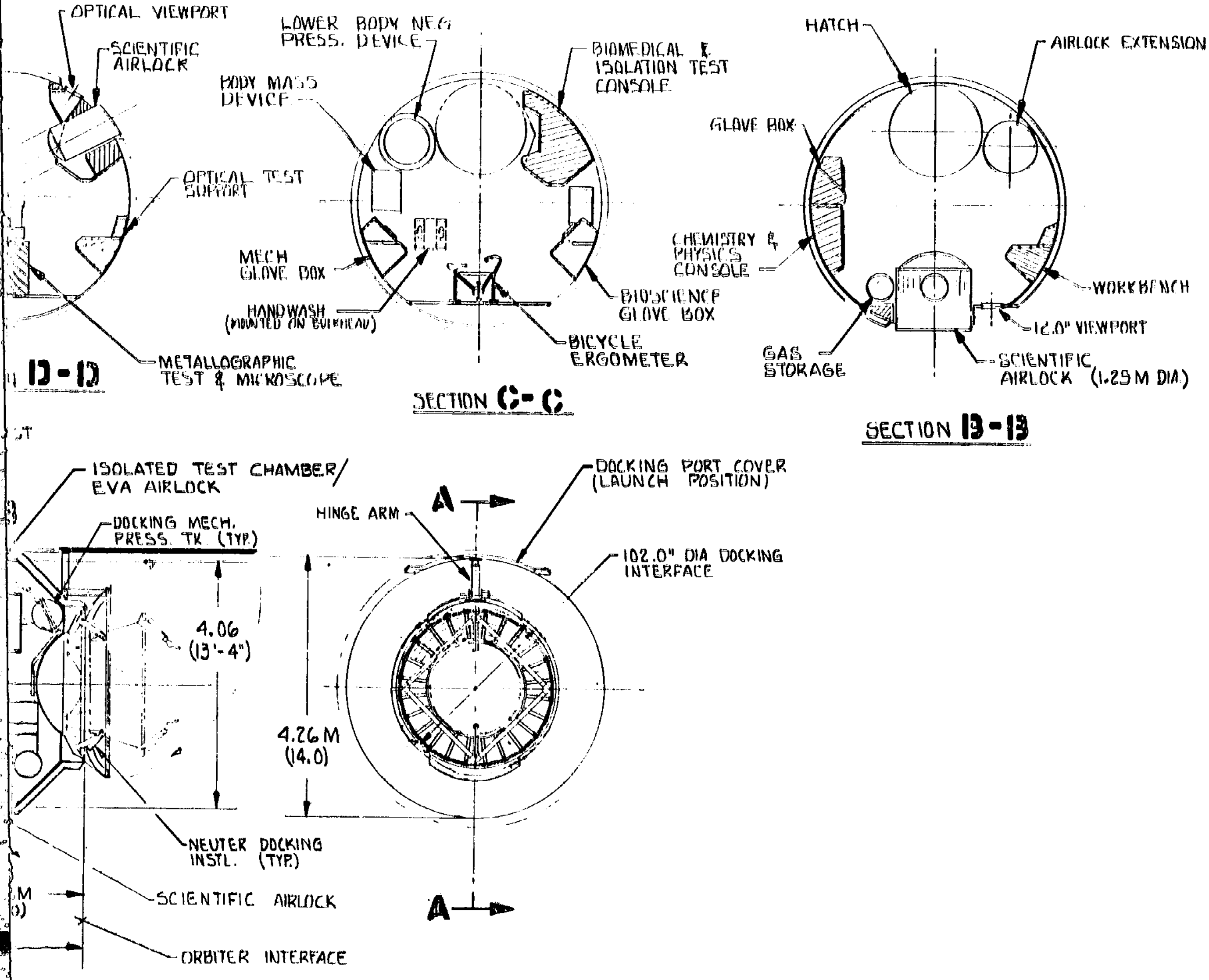
OPTICAL VIEWPORT
SCIENTIFIC AIRLOCK
OPTICAL TEST SUPPORT
METALLOGRAPHIC TEST & MICROSCOPE
D-D
LOWER BODY NEG PRESS. DEVICE
BODY MASS DEVICE
BIOMEDICAL & ISOLATION TEST CONSOLE
MECH GLOVE BOX
HANDWASH (MOUNTED ON BULKHEAD)
BIOSCIENCE GLOVE BOX
BICYCLE ERGOMETER
SECTION C-C
HATCH
AIRLOCK EXTENSION
GLOVE BOX
CHEMISTRY & PHYSICS CONSOLE
WORKBENCH
12.0" VIEWPORT
GAS STORAGE
SCIENTIFIC AIRLOCK (1.29 M DIA)
SECTION B-B
ISOLATED TEST CHAMBER/ EVA AIRLOCK
DOCKING MECH. PRESS. TK (TYP.)
4.06 (13'-4")
4.26 M (14.0)
NEUTER DOCKING INSTL. (TYP.)
SCIENTIFIC AIRLOCK
ORBITER INTERFACE
HINGE ARM
A
DOCKING PORT COVER (LAUNCH POSITION)
102.0" DIA DOCKING INTERFACE
A

however, the General Purpose Laboratory has docking ports on both ends but no radial ports. The open end port can be used for temporary attachment of RAM's or Logistics Modules. Each docking port incorporates a 1.5 m (60 in.) diameter hatch. Covers provide thermal and meteoroid protection for the port when it is not being used. The General Purpose Laboratory has been configured to provide maximum spaciousness, capability for continual growth, and ease of transport of equipment, in or out. The laboratory equipment is generally located in five rows of consoles, one along the bottom center line, one on each side near the bottom, and one on each side near the top.

A pressure bulkhead located near the outboard end of the General Purpose Laboratory separates the normal laboratory functions from activities and equipment that require isolation in a separate facility. This isolated facility can also be used for an EVA airlock.

The General Purpose Laboratory serves as a separate pressurizable, habitable compartment and contains the second EC/LS Subsystem, emergency food, and water storage; it also contains two three-man 96-hour emergency pallets. For convenience and also to provide the second habitable compartment, the GPL Module contains a hand and face wash facility mounted on the pressure bulkhead at the outboard end of the module. To provide ease of inspection, maintenance, and repair of the pressure vessel, the cabinets and consoles in the General Purpose Laboratory are designed to swing away. Those in the upper quadrant pivot about a point near the top of the console. They pivot approximately 45 degrees to expose the pressure shell and rear and sides of the console. Consoles in the lower quadrant pivot about a point on the lower edge. These pivot outward and downward approximately 90 degrees.

The General Purpose Laboratory is likely to require replacement and addition of large pieces of equipment during the program; therefore, a 1.5 m (60 in.) diameter area-way has been provided through the length of the module. This makes it possible to transfer large items into the Crew/Operations Module. Extensive storage area is provided in the inboard end conic, inside most consoles, and under the "floor."

The minimum launch mass of the General Purpose Laboratory is 7,070 kg (15,587 lb). The on-orbit mass of this module is increased by the addition of equipment as the experiment program proceeds. This configuration evolved as an iterative design that made use of layouts, small scale models, and a number of full-scale cardboard mockups. This arrangement of the General Purpose Laboratory was mocked-up in full scale before being selected as the final configuration.

Laboratory equipment and facilities of the GPL are fully described in Section 5.2.

3.2 SUBSYSTEMS

This section contains summary descriptions of each subsystem (listed below) and its associated assemblies.

- Electrical Power
- Environmental Control/Life Support
- Crew Habitability and Protection
- Guidance, Navigation, and Control
- Propulsion
- Data Management
- Communication
- Onboard Checkout
- Structures/Mechanical

Elements of these subsystems are distributed throughout individual modules. Data buses provide key interfaces for command and monitor functions. The schematic in Figure 3-16 illustrates these subsystem interfaces and functional arrangements. (For clarity, some redundant installations are omitted.) The matrix at the left of the schematic lists actual equipment locations.

3.2.1 Electrical Power Subsystem

The electrical power subsystem (EPS) is composed of nine major assemblies as shown in Figure 3-17. The solar-array power source consists of 12 independent flexible panels divided equally between two wings. Each panel contains two electrically independent half-panels, each of which supplies regulated power to either of the two source buses.

The deployment and orientation assembly provides (1) initial array deployment from the stowed position along the power tunnel, (2) individual panel retraction for EVA replacement, (3) group panel retraction for stowage and return of the Power/Subsystems Module, and (4) two-axis gimbal orientation on a continuous basis to ensure maximum solar-energy collection

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SUBSYSTEM	ACTUAL EQUIPMENT LOCATIONS PM	CM	GPL	EQUIPMENT ILLUSTRATED BY SCHEMATIC
EC/LS	✓	✓	✓	PM + CM
EPS	✓	✓	✓	PM + GPL
PROP.	✓	✓		PM + CM
GNC	✓	✓		PM + CM
COMM	✓	✓		PM + CM
DMS	✓	✓	✓	PM + GPL
OSCO	✓	✓	✓	CM

ALL MODULES ARE 14 FT IN DIAMETER

SUBSYSTEM

DOCKING PORT INTERFACE SERVICES

EC/LS

- CONDITIONED ATMOSPHERE
- RETURN ATMOSPHERE
- GO_2 AND GN_2 MAKEUP AND CONTINGENCY
- POTABLE H_2O
- USED H_2O
- SOLAR HEATED H_2O
- URINE
- RADIATOR THERMAL INTERTIE
- AIRLOCK/DOCKING PORT PUMPDOWN AND REPRESSURIZATION

EPS

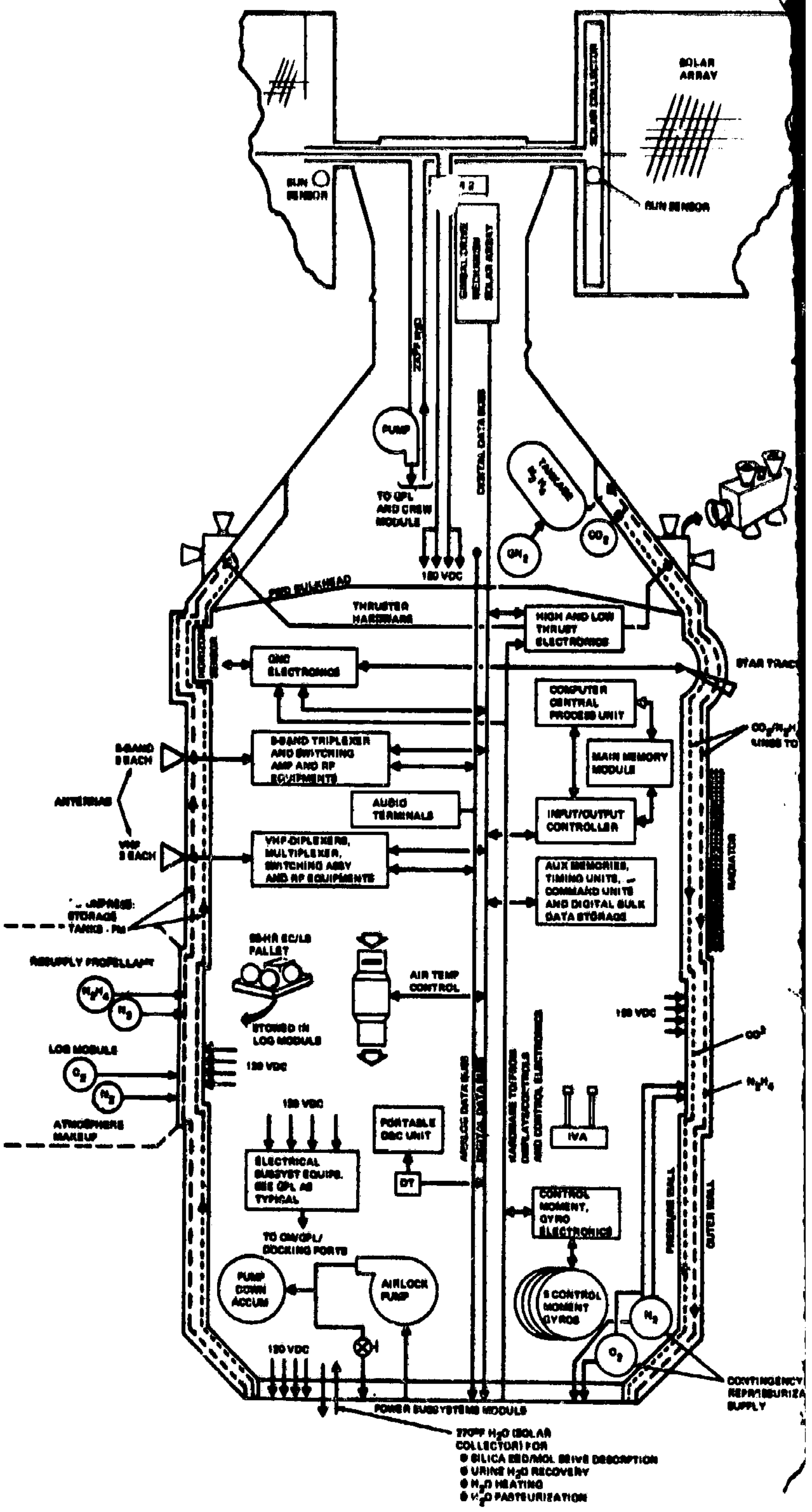
- FOUR BUSES AT 115 VDC

PROPULSION

- N_2H_4 PROPELLANT
- GN_2 PROPELLANT
- CO_2

DMS - COMM - GNC-OSCO

- HARDWIRE
- DATA BUSES (ANALOG AND DIGITAL)



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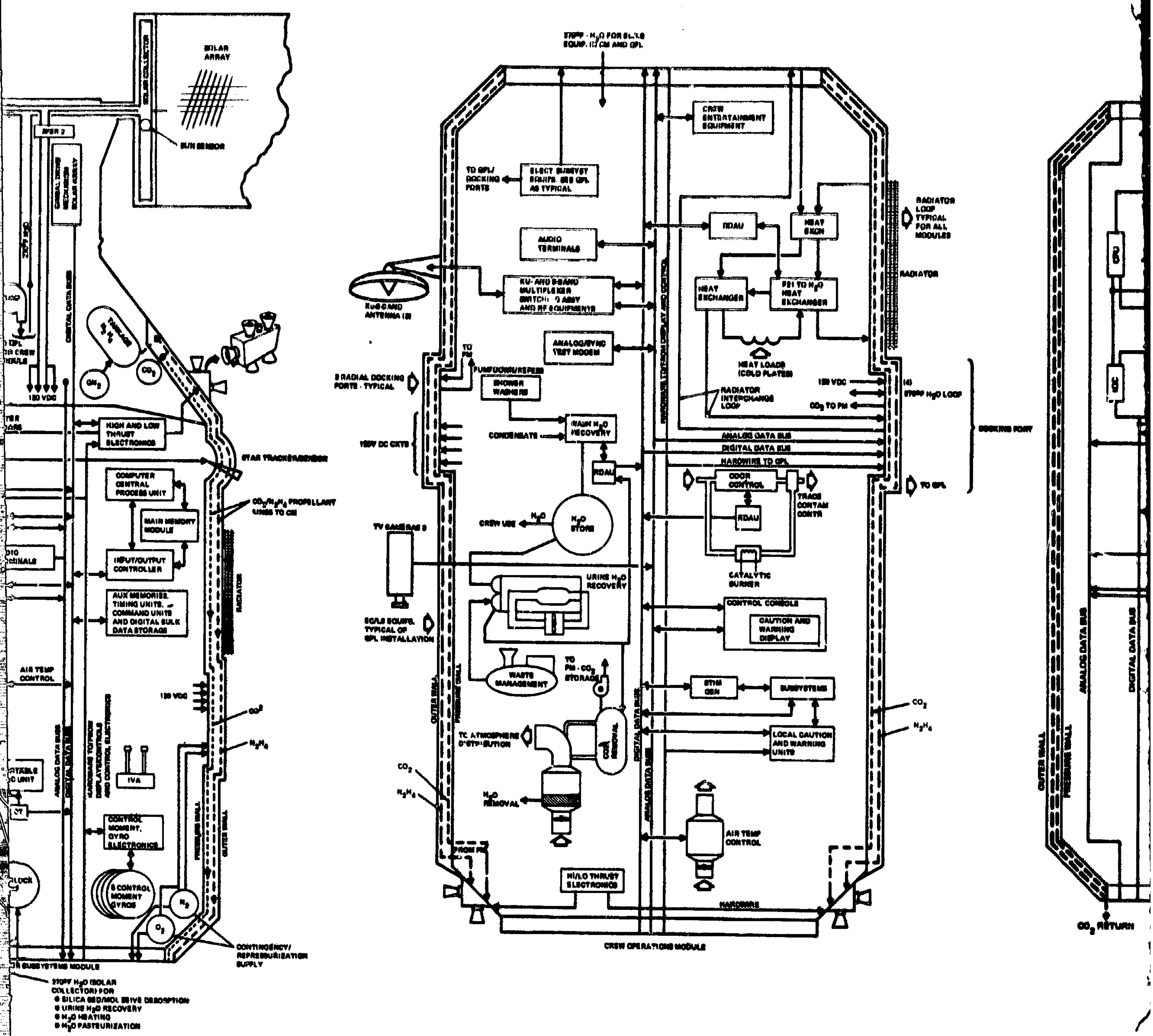

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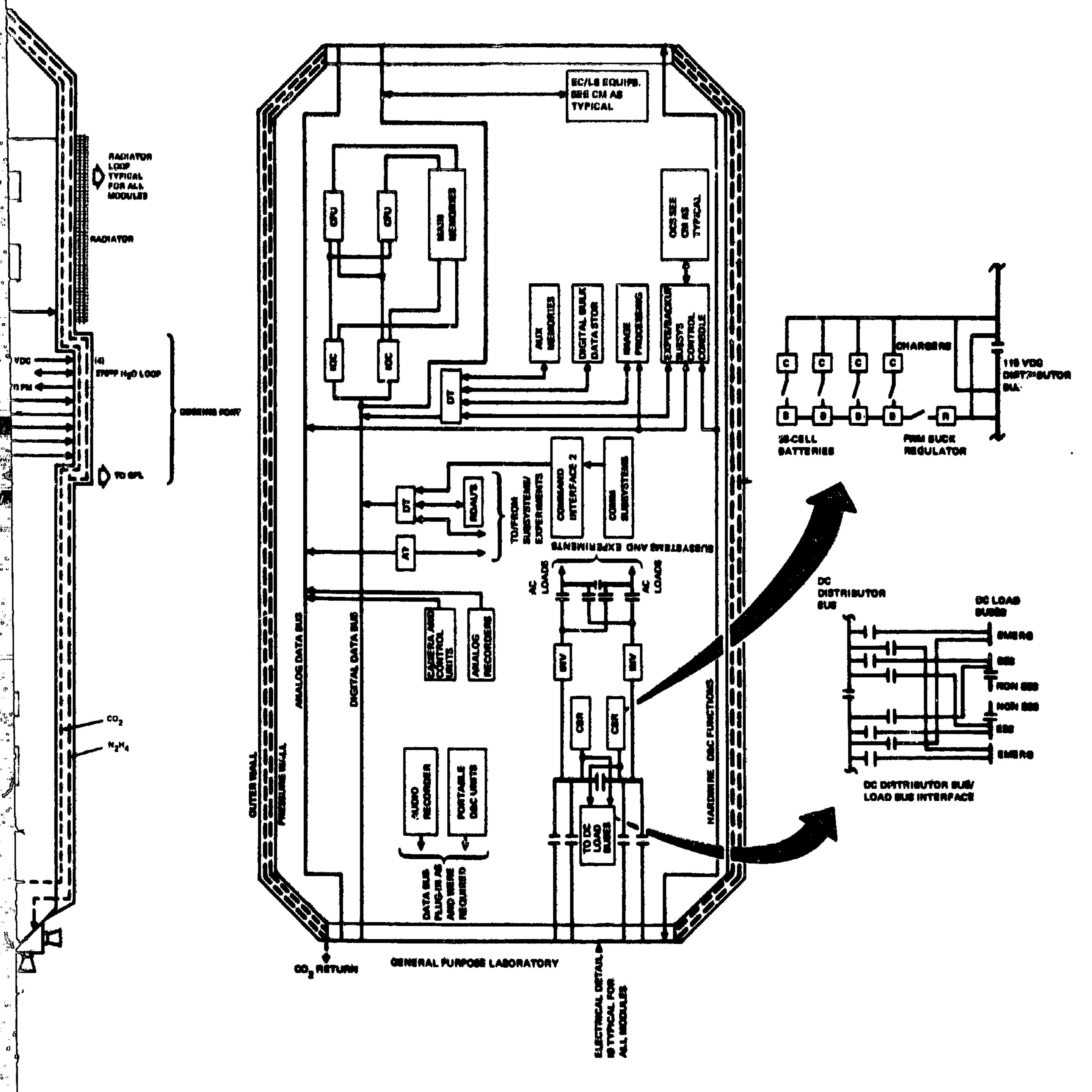

Figure 3-16. Subsystem Schematic

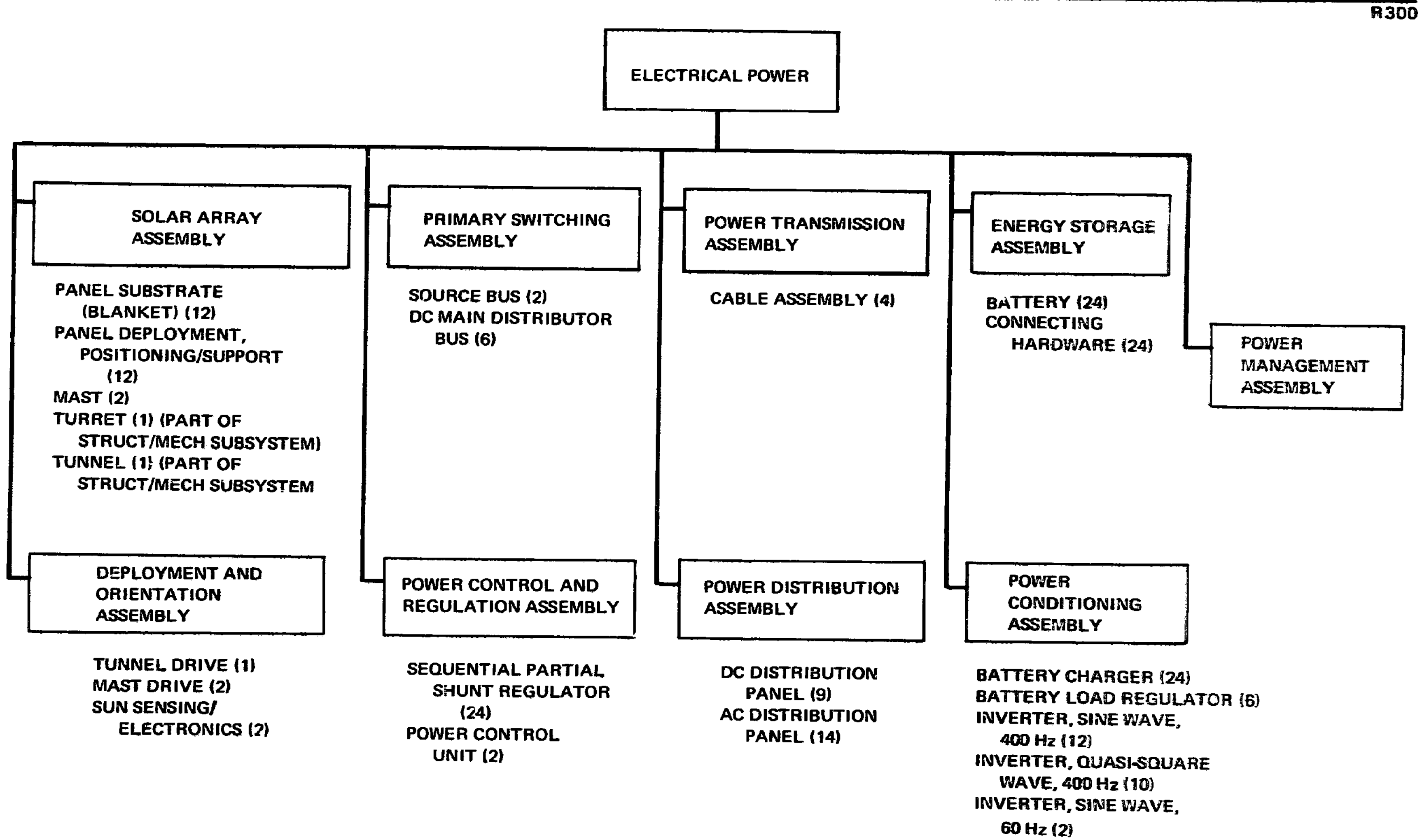

Figure 3-17. Electrical Power Subsystem Assembly Group Breakdown

for all station flight attitudes. The solar panels are "feathered" for minimum drag during eclipse periods, and are recycled prior to reentering the sunlight to windwind the trailing cable which transfers power across the gimbal interfaces.

The primary switching assembly in the turret area provides for (1) control of power flow from the 24 half-panels to either of the two source buses, (2) control of source bus connections for either parallel or isolated operation, and (3) control of power flow from the source buses to the four transmission lines. Primary switching is also provided in each station module to (1) sectionalize the transmission lines, (2) control power flow to the main distribution centers from the selected transmission cables, and (3) sectionalize the main distributor buses.

The EPS is arranged to provide a minimum of two independent systems with two "back-bone" transmission circuits per system. The two systems are normally bused together to meet total power demand, and each system can accommodate full system power.

The energy storage assembly for the Initial Space Station (ISS) consists of hermetically sealed, temperature-controlled, nickel-cadmium batteries, located at the main distributor center in each station module. These batteries provide all of the electrical power during eclipses. They also supply (1) supplemental power during partial reductions of normal solar power, (2) emergency power in the event of loss of solar-array power, and (3) primary launch and ascent power for the Power/Subsystems Module. The batteries are charged concurrently at low voltage by individual battery chargers. The batteries are discharged with four batteries in series to the associated main distributor bus at 115 ± 3 vdc through the pulse width modulated series buckload regulators. The battery energy is available to all station modules through the transmission assembly.

The Power/Subsystems Module is launched with four batteries installed to provide power prior to array deployment. The array is deployed on-orbit and is operated in a minimum-drag (trailing) position until ISS manning occurs. The Crew/Operations Module and the GPL are launched without batteries and use Space Shuttle power until they are docked and electrically connected to the Power/Subsystems Module power-transmission system.

The power control and regulation assembly provides solar-array voltage regulation. The regulation system uses a sequential partial shunt regulation (SPSR) technique to provide a full linear range of voltage control.

The transmission, conditioning, and distribution (TCD) assemblies constitute the power-transfer and power-processing assemblies. These include switching and protection in the transmission and distribution assemblies, battery charging and regulation, and dc/ac inversion in the conditioning assembly. The inverter modules operate in parallel within each station module with no paralleling between modules. Power transfer between major station modules occurs only through the 115-vdc transmission assembly, and power transfer to Logistics Modules and RAM's occurs only through load bus feeders in the distribution assembly.

A single-point ground is provided for each electrically independent (isolated) system. Structure ground points are provided for connections of the negative dc source buses and each ac load bus neutral.

The electrical power management function is provided by integrated subassemblies located in the EPS and the DMS. It includes monitor and processing functions to control EPS switching, array voltage regulation, array orientation drive control as required by sun-acquisition computations and solar-tracking sensors, and battery charging and discharging electronics. It also provides for preprocessing of data to be used for the integrated displays and controls and onboard checkout functions, and it controls the system loads in accordance with established priorities. These functions are performed automatically, with manual backup or overrride capability for all essential management functions.

Table 3-2 provides key specifications for the electrical power subsystem. Figures 3-18 and 3-19 provide a block diagram and schematic diagram for this system.

3.2.2 Environmental Control and Life Support Subsystem

The EC/LS subsystem provides cabin atmosphere control and purification, water and waste management, pressure-suit support, and thermal control for the entire Space Station. Concepts selected for major functions are listed in Table 3-3.

The cabin atmosphere is maintained at sea-level pressure and two six-man atmosphere reconditioning subsystems are provided, one in the crew module and one in the GPL. The crew module unit processes gas for the crew, power, and attached modules. Each module contains separate atmosphere-cooling provisions.

The ISS employs an open oxygen loop initially, but provisions are

Table 3-2

SPECIFICATIONS OF THE ELECTRICAL POWER SUBSYSTEM

Function	Design
Solar Array Source	Flexible, foldout, based on LMSC design.
Array Orientation Drive	Synchronous, continuous drive, MDAC design.
Power Transfer Method	Spiral coil, trailing cable, unwound during eclipse.
Battery Type/Capacity	Nickel-cadmium, 100 ampere-hours.
Battery Charge Control	Electronic switching, cell voltage cutoff, third-electrode backup, parallel charge, series discharge of four batteries.
Voltage Regulation	Array: sequential partial shunt, closed-loop control; battery: PWM series (buck), closed-loop control.
Power Transmission	Dual 100 percent redundant, direct-current, differential protection.
Power Conditioning	Bulk regulation for dc; modular, isolatable or parallel load-sharing inverters for ac; current-limited protection.
Power Switching and Control	Solid-state for low power; electromagnetic for high power. Automatic DMS supervisory control with manual display. Local manual control for isolation and backup. Remote control by telemetry for unmanned operation.

Assembly	Factor	Design
Solar Array	Active Area	5,300 ft^2 at ISS; added 5,300 ft^2 for GSS
	Panels/Wings	12/2
	Panel Area and Dimensions	458 ft^2 (88 by 749 in.)
	Independent Regulated Circuits	24
	Solar Cells	559, 104 cells; 2 cm by 4 cm, N/P silicon, 11 percent efficiency bare at AMO, 28°C; 8-mil cells with 6-mil covers; 2-ohm-cm base resistance
	Regulated Array Voltage	120 ± 1 percent vdc
	Initial Array Power	52.1 kw at mast
	Sunlight/Eclipse Periods	56 min/36 min
	Degradation Rates	30 percent in 5 years; 40 percent in 10 years
Orientation	Gimbal Axes	2
	Gimbal Range	$\alpha = \pm 180$ deg; $\beta = \pm 235$ deg
	Gimbal Angular Rate	4 deg/min tracking; 22 deg/min unwinding
	Orientation Accuracy	±8 deg

Table 3-2

SPECIFICATIONS OF THE ELECTRICAL POWER SUBSYSTEM (Continued)

Assembly	Factor	Design
Energy Storage	Cell Capacity	100 amp-hr
	Replaceable Module Size	4 cells; 40 lb
	Total ISS/GSS Batteries	24/40
	Battery Size	28 cells
	Battery Weight	380 lb
	Initial Launch Weight	1,520 lb (four batteries)
	Total ISS/GSS Weight Onboard	9,120/15,200 lb
	Depth of Discharge	Normal: 15 percent average, 35 percent maximum. Contingency: 30 percent average, 70 percent maximum
	Design Life	Normal: 2-1/2 years; Contingency: 1 year
	Emergency Capacity (24 batteries)	At full charge: 72 kwhr; At minimum (65 percent); charge: 46.5 kwhr
	Temperature Control	10 deg; to 20 deg C range; 13 deg C design point
Transmission	Voltage	115 ± 3 vdc
	Circuits/Cable Size	4/AL-1
Distribution	Load Bus Voltage	115 ± 3 vdc 115/200 ± 2-1/2 percent vac, 400 ± 1 percent Hz, 3-phase, sine-wave and quasi-square wave 115 ± 5 percent vac, 60 ± 1 percent Hz, 1-phase, sine-wave (GPL only)
	Load Bus Average Power	ISS: Initial – 22.7 kw 5-year – 16.7 kw GSS: Initial – 39.5 kw at 5 years 10-year – 30.8 kw
	Load Terminal Voltage	115 + 2-1/2 percent, -7 percent vdc; 115/200 + 2-1/2 percent, -7 percent vac; 400 ± 1 percent Hz, 3-phase, sine-wave and quasi-square wave; GPL only–115 ± 10 percent vac, 60 ± 1 percent Hz

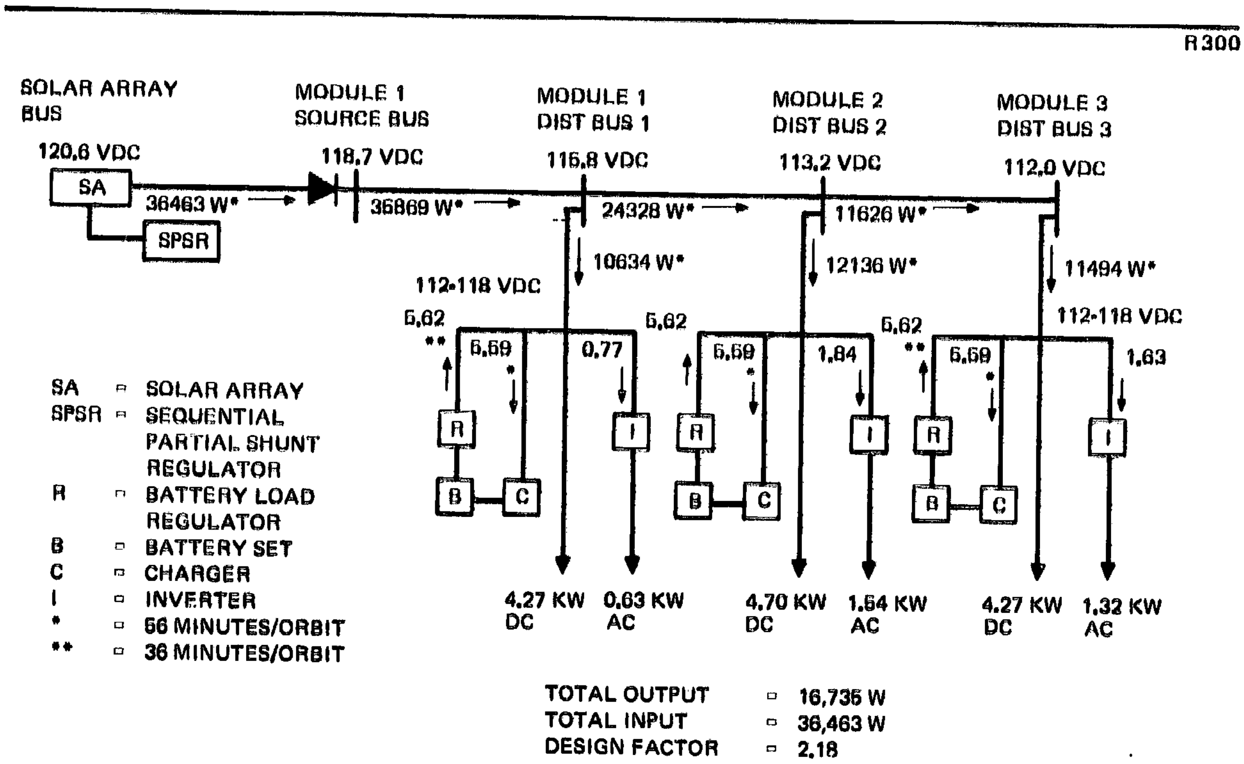

Figure 3-18. Electrical Power Subsystem Block Diagram (for ISS)

included to add oxygen recovery at any time. CO_2 removed from the atmosphere by molecular sieves is used in a resistojet low-thrust propulsion system.

The subsystem has full H_2O recovery; that is, more water is recovered in the Space Station than is required for drinking and washing. A water-management system is located in the crew module, and a 30-day contingency water supply is located in the GPL.

The reverse-osmosis assembly purifies 80 percent of the condensate and wash water; the 20-percent residue is cycled to the air-evaporation urine water-recovery assembly. There, the residue, urine, and urine flush water are purified at a 99-percent efficiency; the only water lost is that contained in the replaceable wicks. The purified water from the water-recovery units provides wash water, water for EVA cooling, and the water consumed by the crew in excess of that provided in the food. Oxygen required for crew metabolic usage is resupplied in the form of gas.

The total heat generated in the Space Station is rejected to space through segmented radiators integrated with the micrometeoroid shield. Each core module contains independent thermal control loops. A separate water loop

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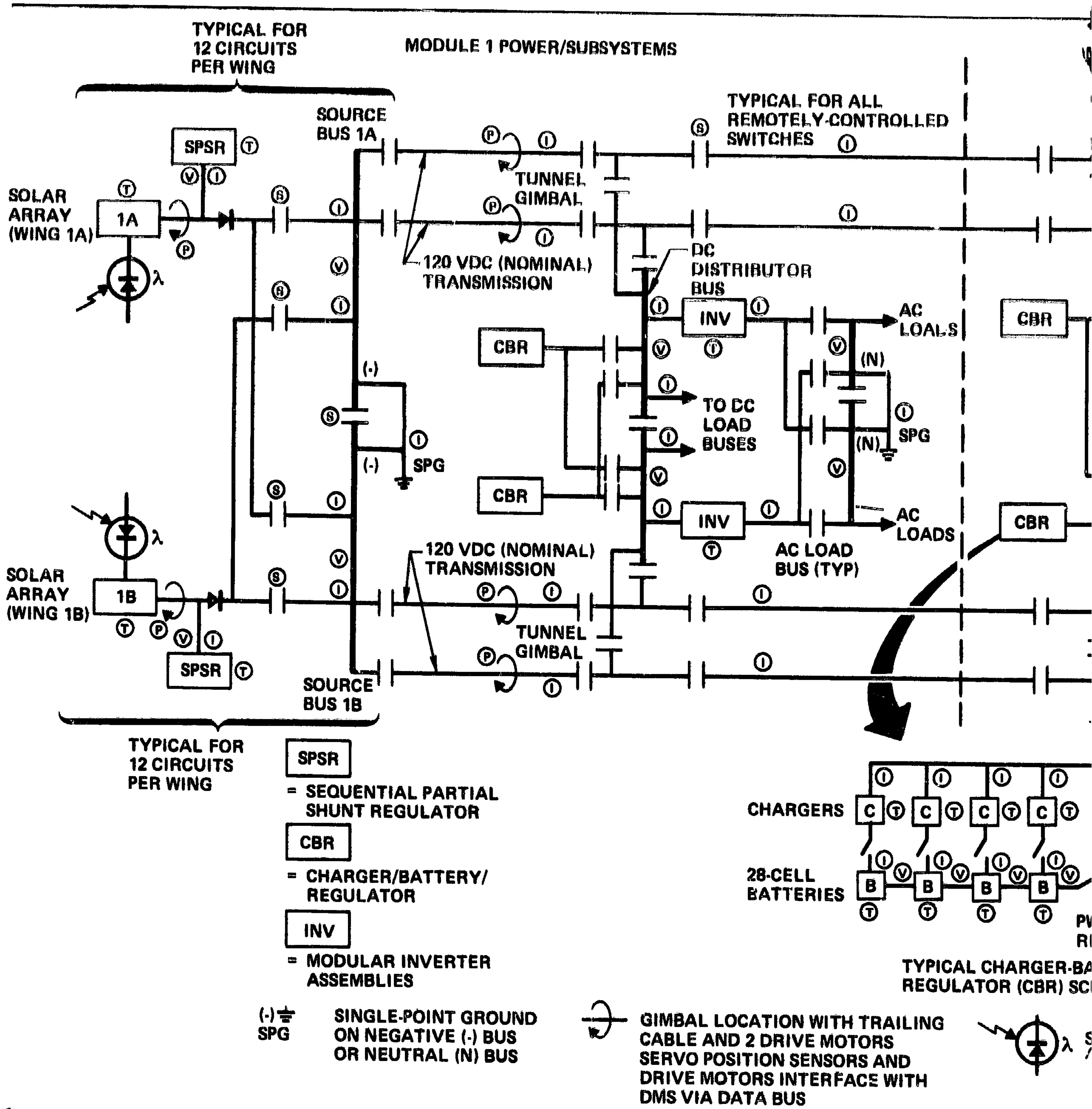

Figure 3-19. Power Subsystem Schematic

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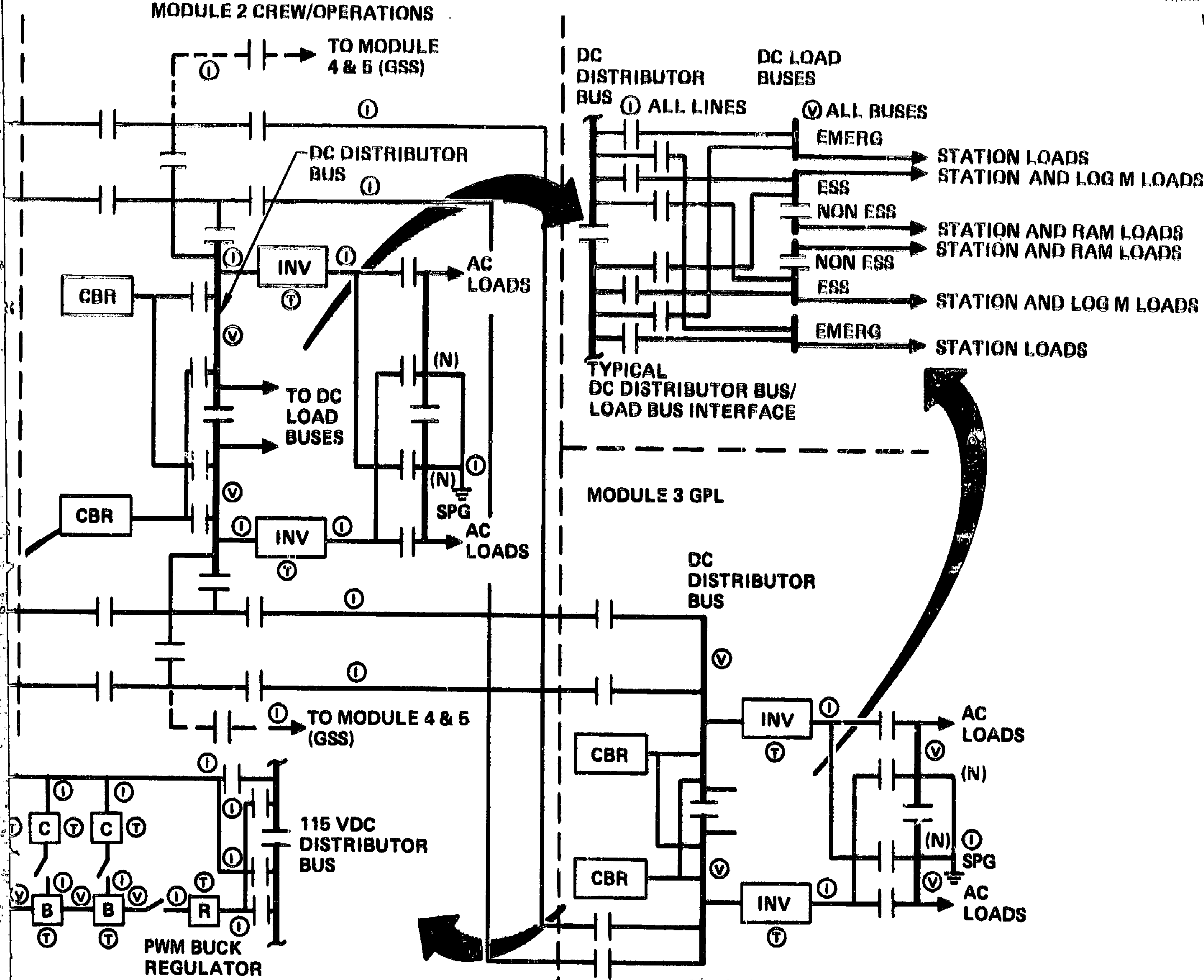


AL CHARGER-BATTERY-
.ATOR (CBR) SCHEMATIC

SUN SENSOR – INTERFACES WITH DMS VIA DATA BUS

SENSOR INPUTS TO DMS VIA DATA BUS:

- Ⓣ TEMPERATURE
- Ⓥ VOLTAGE
- Ⓘ CURRENT
- Ⓟ POSITION (SERVO ANGLE)
- Ⓢ STATUS (OPEN/CLOSE) TYPICAL FOR ALL REMOTELY-CONTROLLED SWITCHES

Table 3-3

LIFE SUPPORT ASSEMBLY SELECTION

Function	Selected Concept
O_2 and N_2 storage	Gaseous at 3,000 psia
Atmosphere temperature control	Module heat exchangers
Humidity control	Condenser-separators
Trace contaminant control	Catalytic oxidation
CO_2 removal	CO_2 save molecular sieve
Ventilation	Central fan-diffusers
Urine water recovery	Air evaporation
Wash and condensate recovery	Reverse osmosis
Water sterilization	Pasteurization
Fecal collection	Heat plus pumpdown for drying
EVA/IVA	PLSS/PLSS or face mask
Thermal control	Two fluid circuits and integral radiator
Process heat	Solar collection

between core compartments provides a sharing of cooling capacity. A solar collector is mounted on the solar-array structure to provide for EC/LS process heat.

Figure 3-20 is an assembly breakdown; key specifications are given in Table 3-4 and a block diagram in Figure 3-21. Schematic diagrams of the ECLS equipment in each module are provided in Figures 3-22, 3-23, and 3-24.

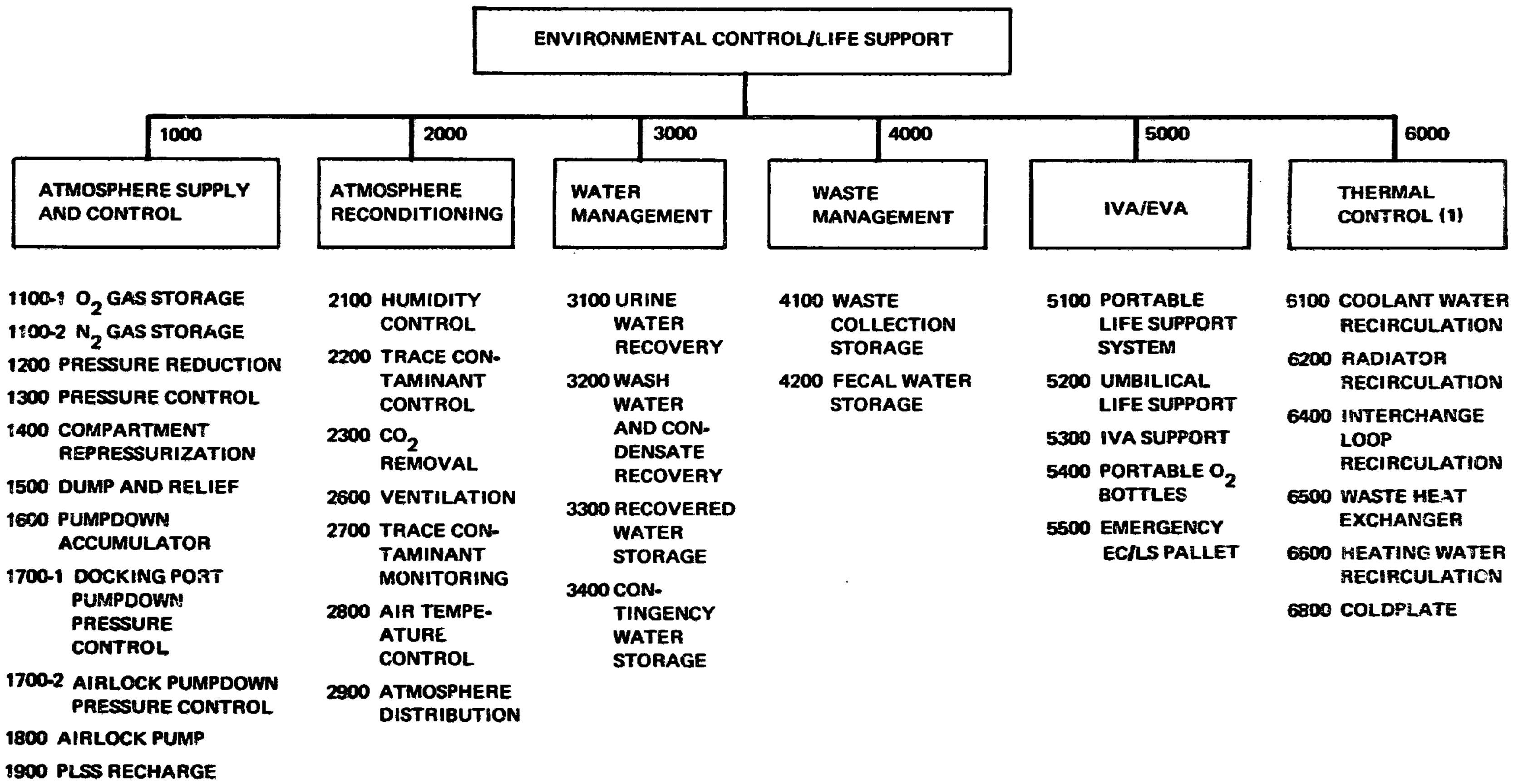
3.2.3 Crew Habitability and Protection Subsystem Description

The crew habitability and protection subsystem (CHPS) provides the crew with living quarters, work stations, and enough provisions to sustain a six-man crew for 90 days.

The food management assembly provides the food stores (both ambient and controlled temperature), equipment, facilities, and supplies required for the storage, preservation, preparation, service, and consumption for six crewmen for 30 days. Onboard storage provisions include a six-man 30-day basic supply and a six-man 30-day contingency supply. The remainder of the food is stored in logistics modules. Equipment is included for hot and cold preparation, cooking, and warming of foods. Zero-g restraints and serving and eating utensils are supplied as required.

A hygiene assembly provides the crew with the equipment and supplies necessary to maintain health and grooming standards. The hygiene assembly consists of subassemblies, such as showers, chamber sinks, personal hygiene kits, and a laundry.

R300



[1]RADIATOR AND INSULATION ARE PART OF STRUCTURE

Figure 3-20. Environmental Control/Life Support Subsystem Assembly Group Breakdown

Table 3-4

SPECIFICATIONS OF THE EC/LS SUBSYSTEM

Capacity: 6 men (with redundancy), 12 men (maximum)
Cabin atmosphere pressure: 10. 13 x 10^4 N/m^2 (14. 7 psia)
Mixture: O_2 and N_2

PO_2: 21. 4 x 10^3 N/m^2 (3. 1 psia)
CO_2 level: 3-mm Hg maximum, 7. 6 mm of Hg emergency maximum for 7 days
Atmosphere velocity: 6. 1 to 15. 24 m/min (20 and 50 ft/min)
Cabin temperature: 18. 3° to 30° C (65° to 85° F)
Mean radiant wall temperature: 15. 6° to 26. 7° C (60° to 80° F)
Maximum internal surface contact temperature: 40. 6° C (105° F)
Water vapor partial pressure: 8 mm of Hg to 13 mm of Hg
Transients: to 6 mm of Hg

Metabolic level: 11. 8 x 10^6 J/day (11, 200 Btu/day)

O_2 and N_2 repressurization: 267 m^3 (10. 13 x 10^4 N/m^2)
(9, 300 ft^3 (14. 7 psia))
Contingency O_2: 159 kgm (30 days) (350 lb (30 days))
Regulated O_2/N_2 pressure from supply (in atmosphere supply lines)
4. 13 x 10^5 N/m^2 (60 psia)

O_2/N_2 pressure: 4. 13 x 10^5 N/m^2 (60 psia)

CO_2 generation: 6. 3 kgm/day (13. 8 lb/day)

Equipment humidity load: 2. 48 x 10^6 J/hr (2, 355 Btu/hr)

Water Supply:

Wash water rate: 22. 7 kgm/man-day (50 lb/man-day)
Wash water temperature: 40. 6° C (105° F)
Potable water rate: (53. 4 kgm/min (peak),
2. 32 kgm/man-day (average), 120 lb/min (peak),
5. 13 lb/man-day (average)

EVA water rate: 1. 04 kgm/day (2. 3 lb/day)
Potable water temperature (hot): 71° C (160° F)
Potable water temperature (cold): 7. 2° C (45° F)

Frequency of defecation: 1/man-day
Frequency of micturations: 6/man-day
Urine water: 1. 56 kgm/man-day (3. 45 lb/man-day)

EVA metabolic rate: 2. 100 x 10^6 J/hr (peak) 1. 267 x 10^6 J/hr (average)
(2, 000 Btu/hr (peak), 1, 200 Btu/hr (average))

IVA metabolic rate: 1, 688 j/hr (peak), 845 j/hr (average)
(1, 600 Btu/hr (peak), 800 Btu/hr (average))
Average number of EVA events: 1. 5 events/month

Number of EVA crewmen: 2 crewmen/event
Radiator design orbit inclination: 55 deg
Orbit altitude: 455 to 500 km (246-270 nmi)
Orientation: no restrictions allowed
Equipment air heating load: 20 percent of total electrical power dissipation
Total cooling required: 101 x 10^6 J/hr for ISS (95, 800 Btu/hr)
Radiator reliability: 99 percent for each module for 10 years

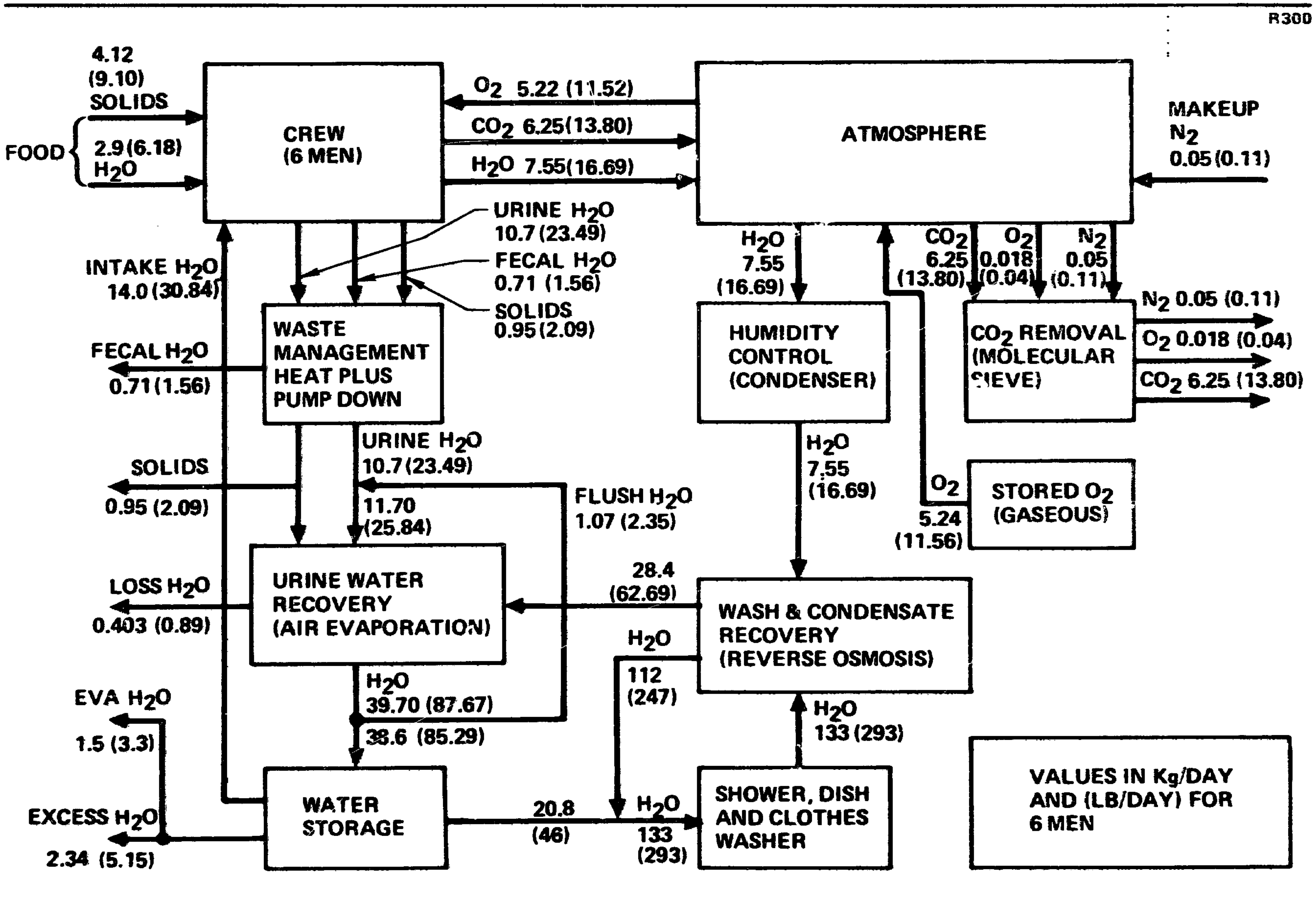


Figure 3-21. Environmental Control/Life Support Subsystem Block Diagram

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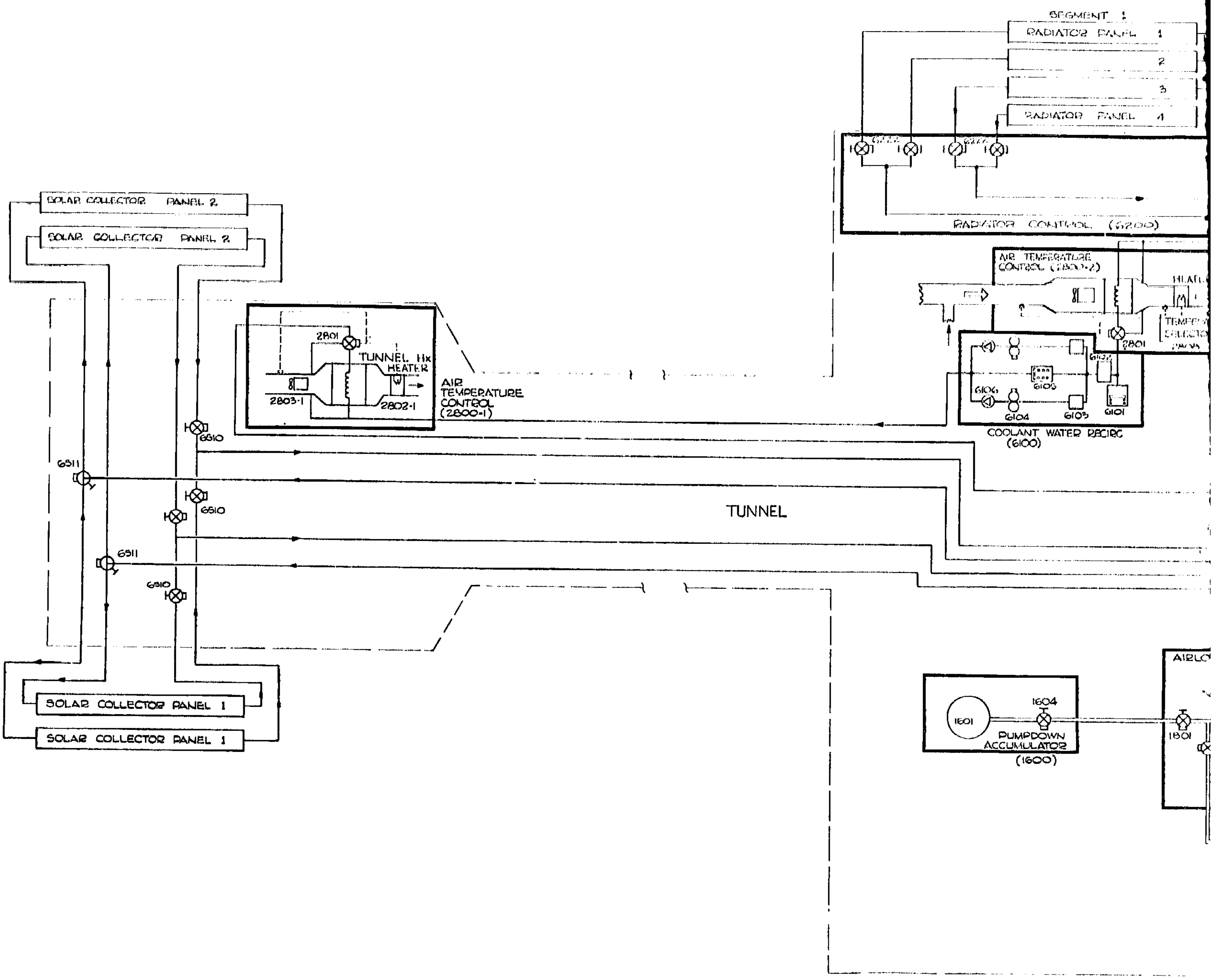

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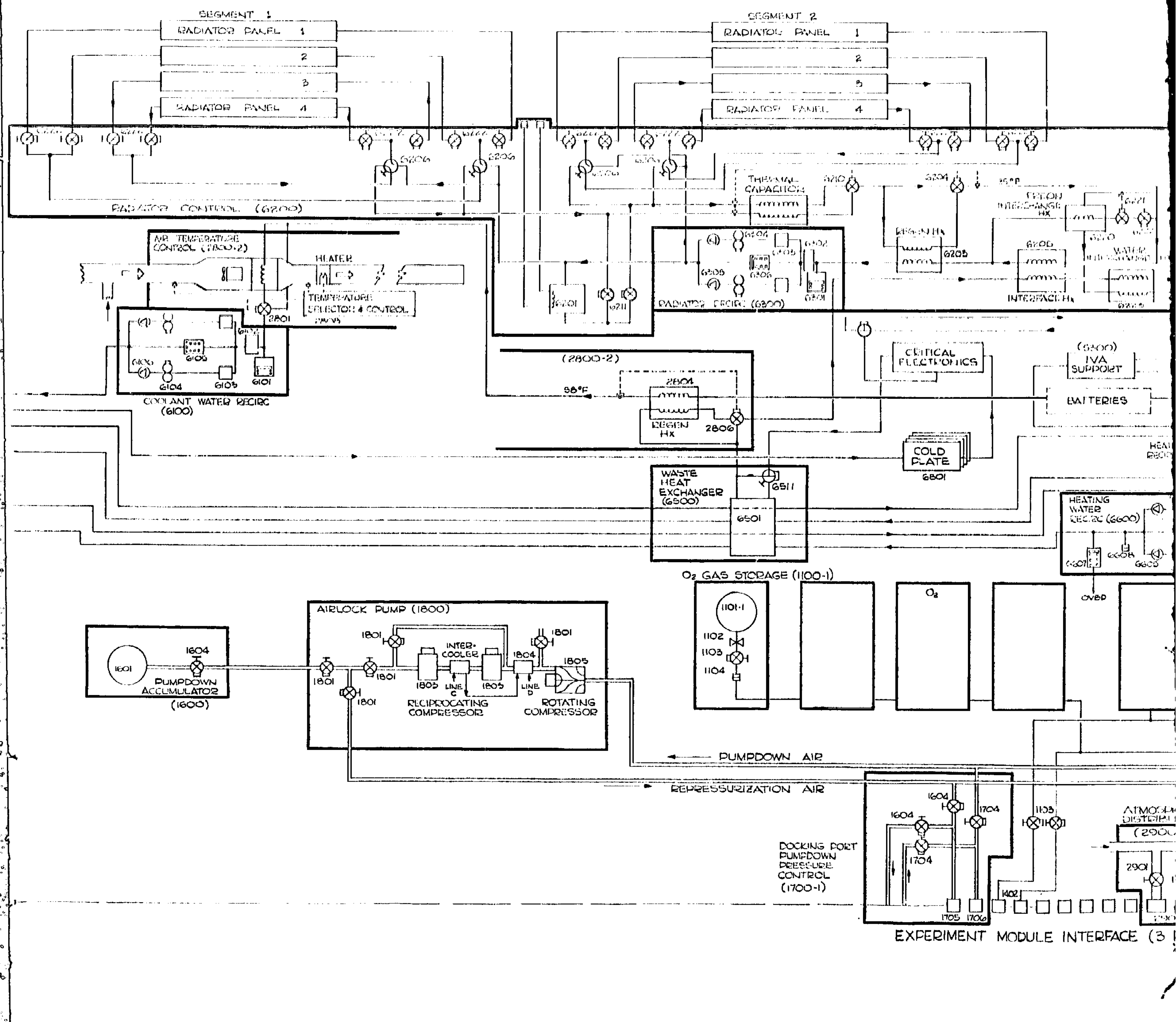

Figure 3

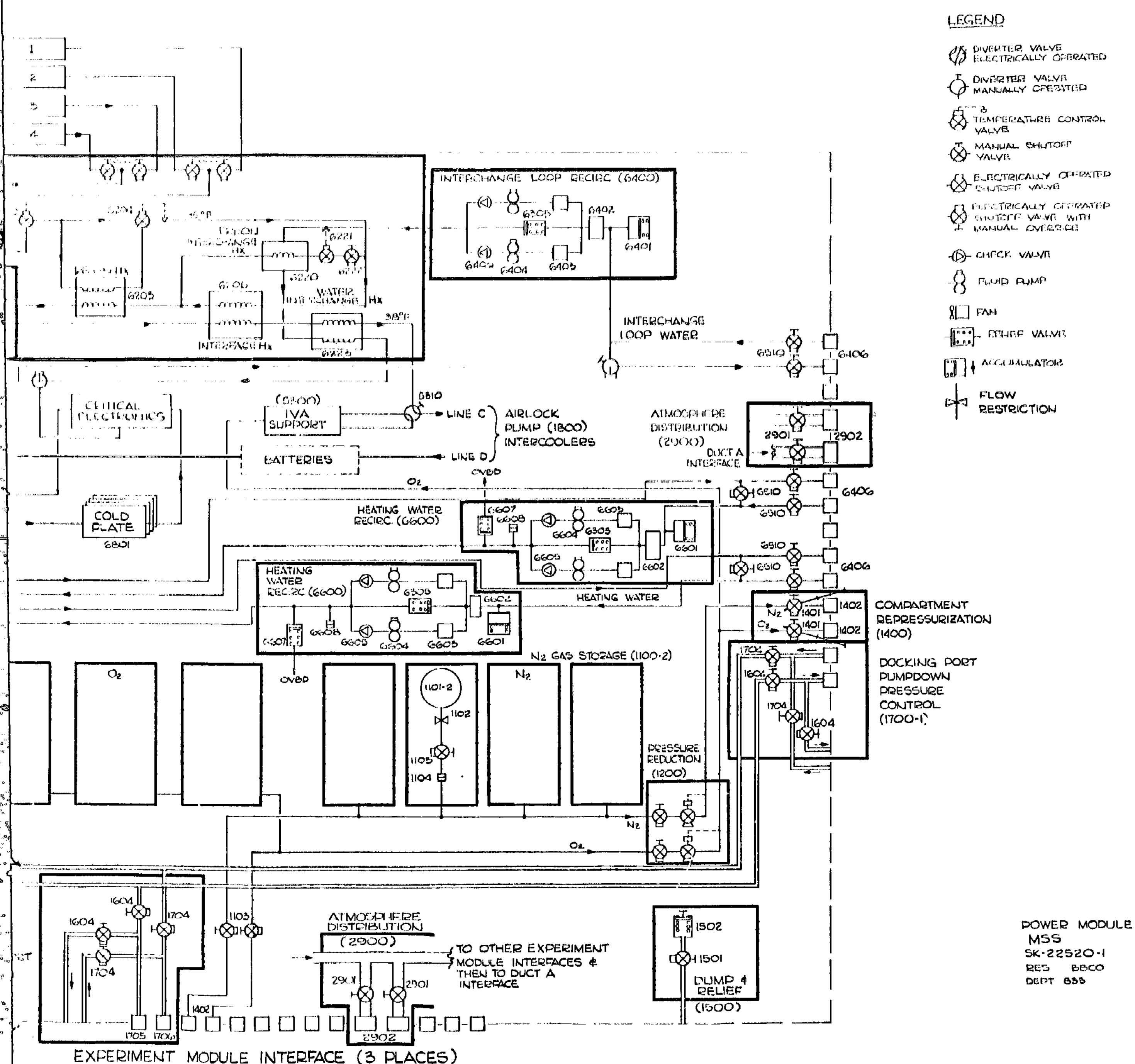

Figure 3-22. Environmental Control/Life Support Subsystem Schematic--Power/Subsystems Module

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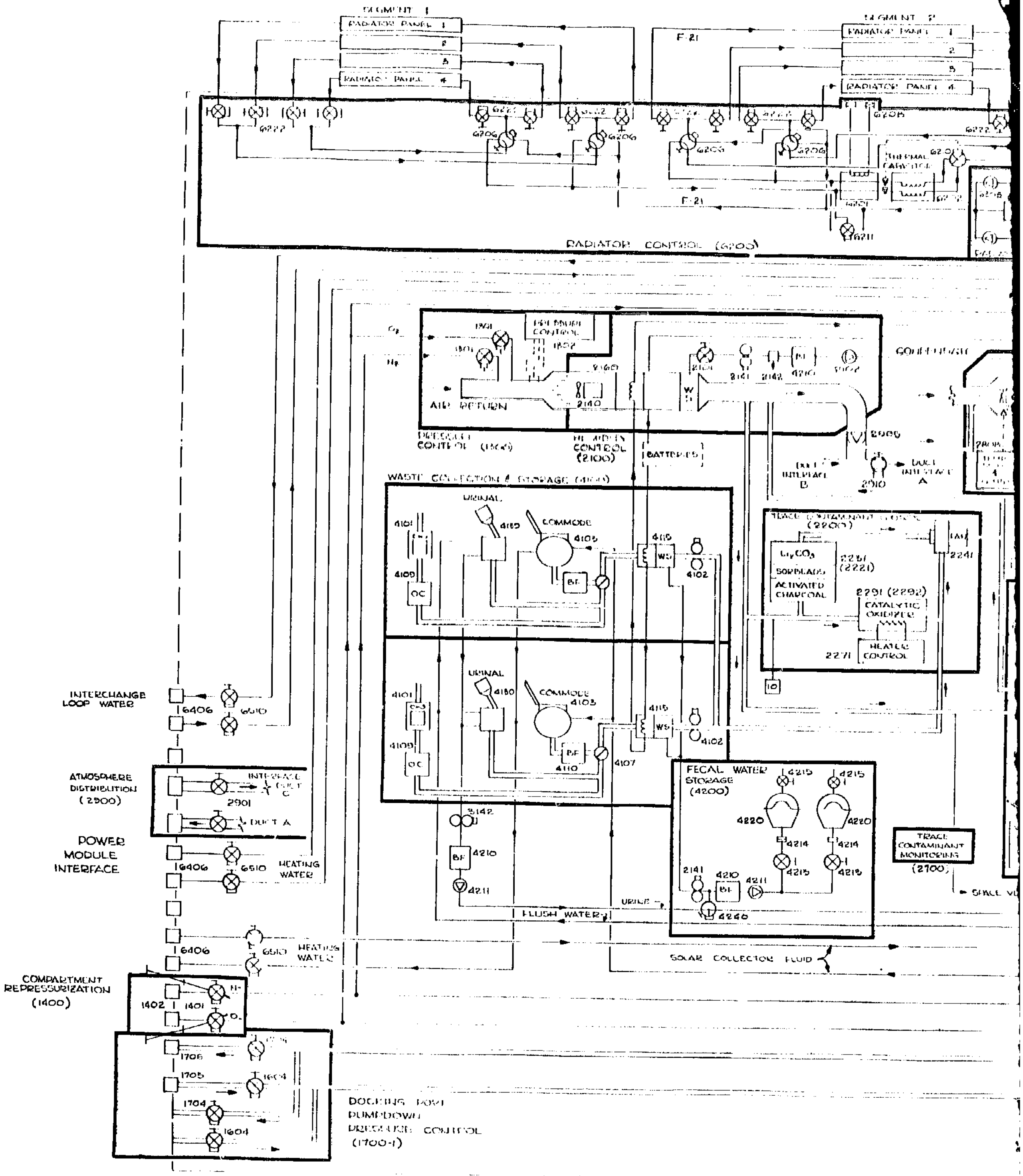

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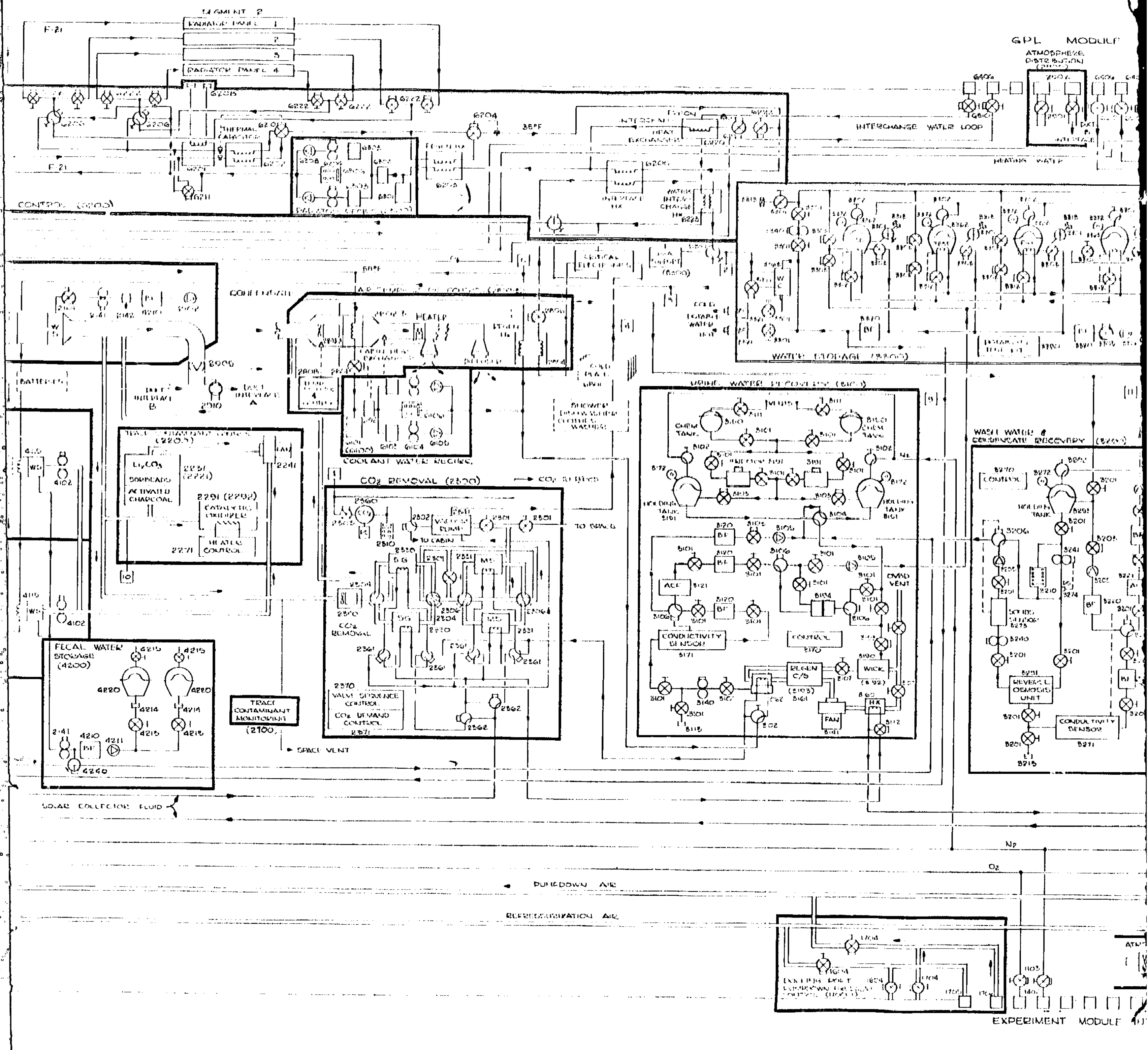

Figure 3-23. En

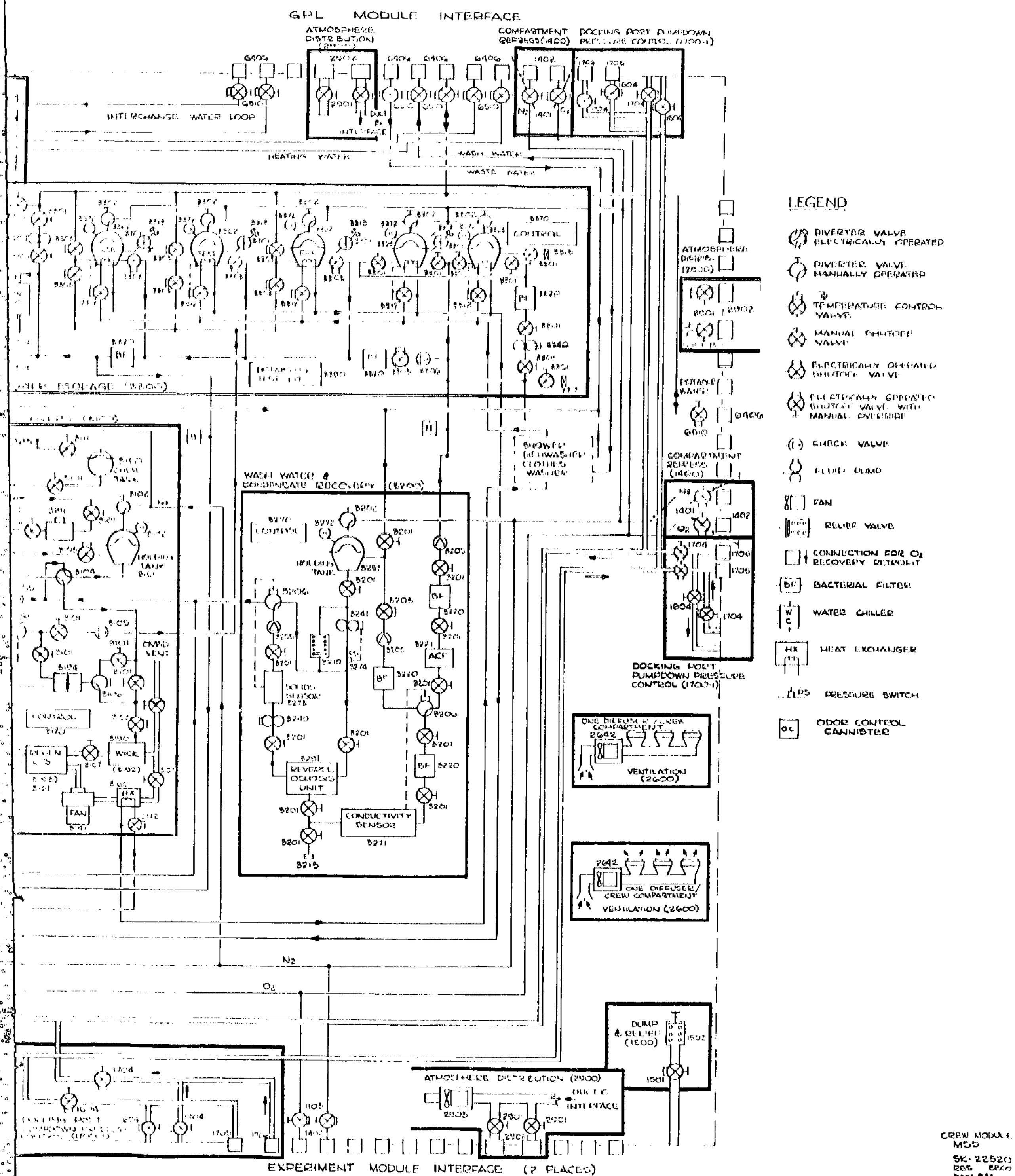

Figure 3-23. Environmental Control/Life Support Subsystem Schematic–Crew/Operations Module

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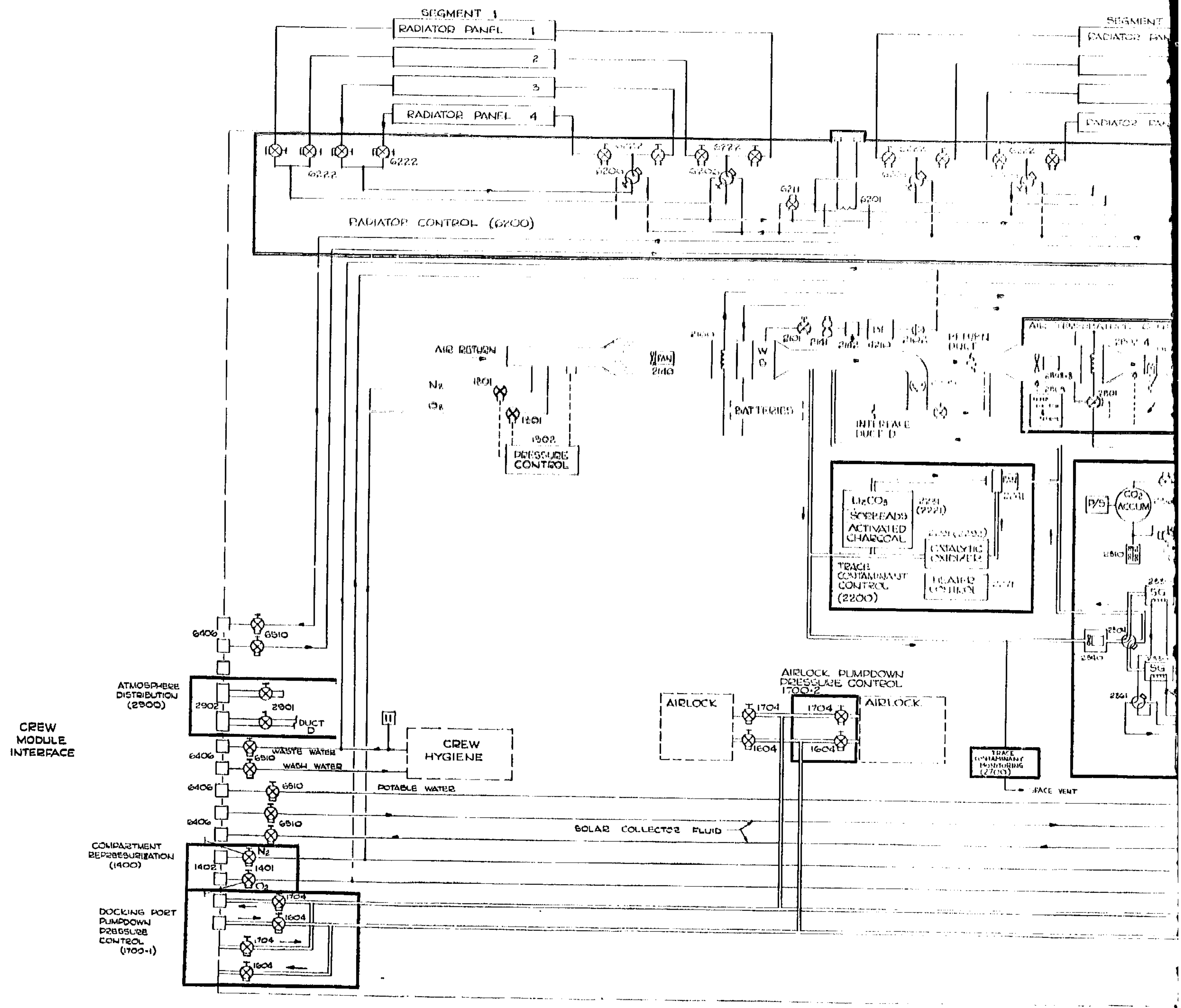

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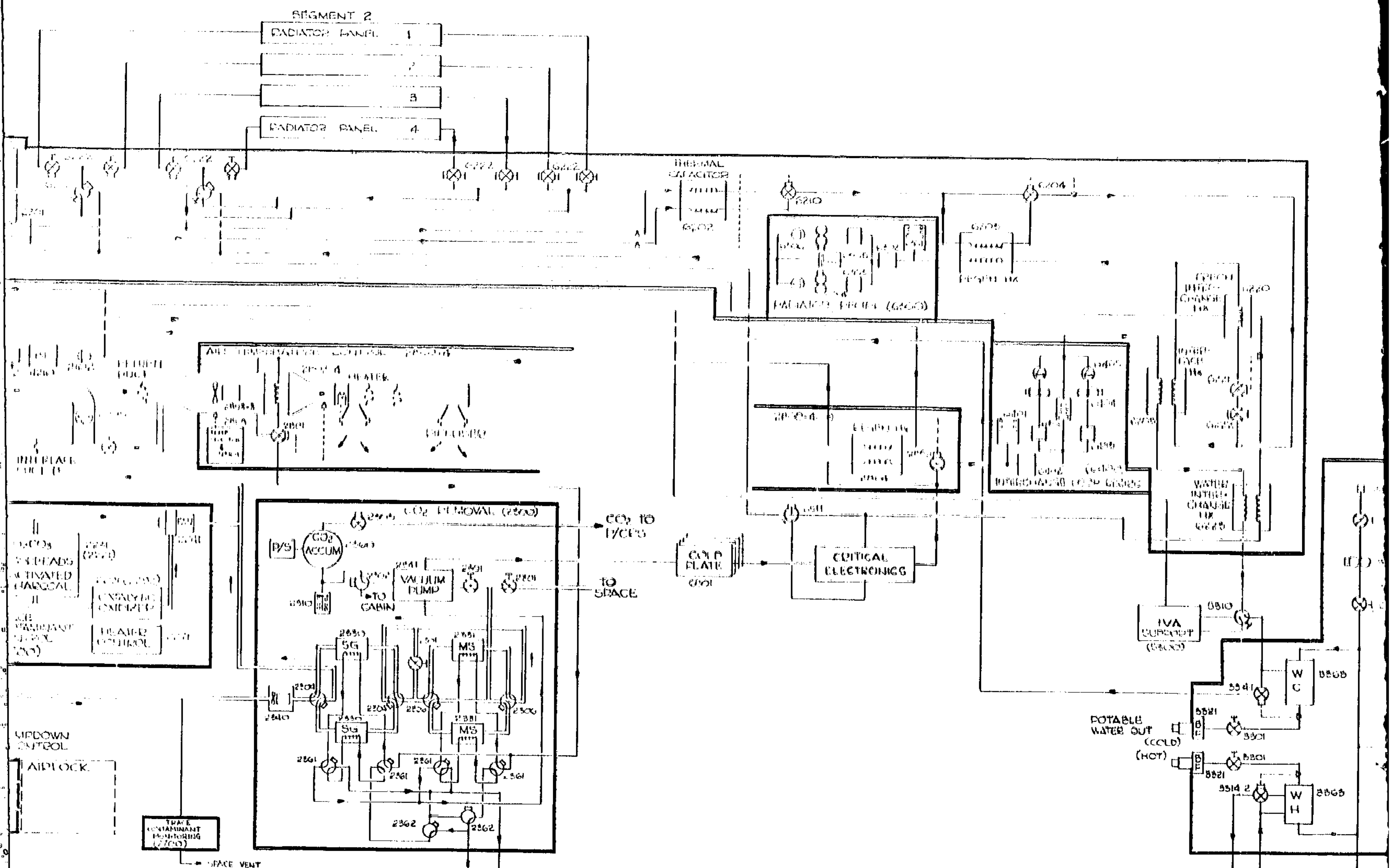

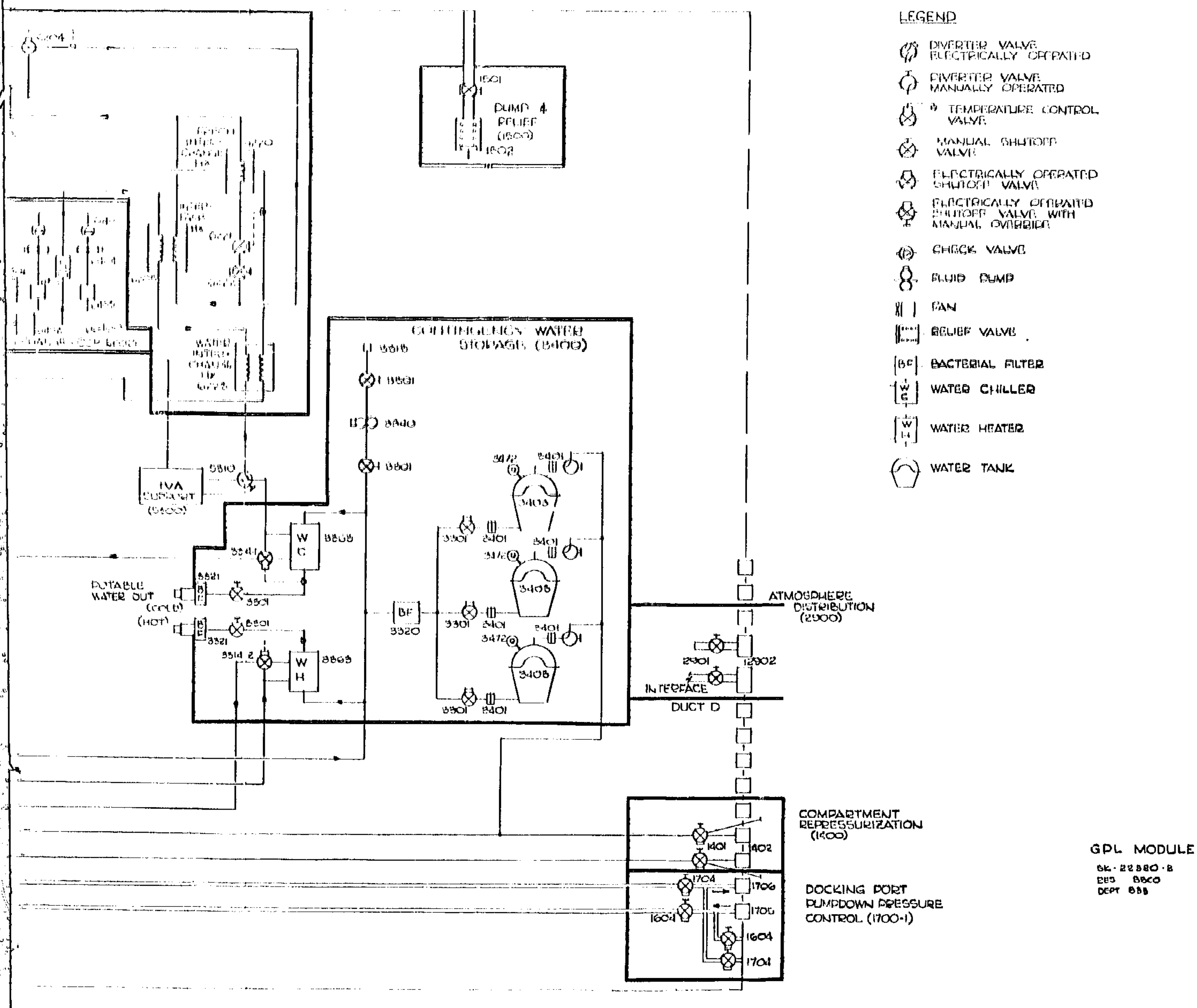

Figure 3-24. Environmental Control/Life Support Subsystem Schematic--GPL Module

The crew accommodations assembly consists of the following subassemblies:

A. Crew quarters provisions: bunk, bed roll, desk, individual light fixture, personal communications, clothing, personal items and expendables.

B. Crew aids: restraints and locomotion devices, tool kit, portable lighting (IVA and EVA), and cargo-handling equipment.

C. Medical support: diagnostic, therapeutic, urinalysis, hematology, and microbiology equipment.

The intravehicular activity (IVA) and the extravehicular activity (EVA) support assembly provides protective garments, emergency oxygen masks, portable oxygen supply, maintenance devices, communications, tethers, and restraints for all emergency and any planned hazardous operations requiring special support equipment. It also provides for special lighting and crew status monitoring.

The housekeeping and trash-handling assembly provides for (1) the collection, containment, decontamination, and transport of all forms of loose debris, trash, and particulate material, (2) cleaning and disinfection of all microbiological contamination, (3) collection, temporary storage, and pretreatment of all trash and waste, (4) deactivation of all bacteria in the collected trash and debris, (5) processed and unprocessed trash compaction, (6) stowage of processed trash, ensuring that deactivated bacteria remain in the deactivation state.

Off-duty equipment is provided to reduce monotony, muscular tension, and stress, and to maintain morale. Individual selection will be provided insofar as practical, and will include reading materials (microfilm and viewer, books, magazines, and journals), writing materials, log books, workbooks, games and hobby equipment (group and individual), and exercise equipment (group and individual).

Crew accommodations are provided in the Crew/Operations Module, the GPL, and the Power/Subsystems Module. The accommodations shall generally be integrated within defined compartments, work stations, or open functional areas.

The primary radiation protection afforded the crew is spacecraft shell and equipment shielding. The radiation protection subassemblies monitor the extent and kind of crew-radiation exposure. The equipment includes onboard and extravehicular dosimetry, which will be tied into the caution and warning systems.

Figure 3-25 is an assembly breakdown of the Crew Habitability and Protection subsystem; Table 3-5 provides key specifications for this subsystem.

3.2.4 Guidance, Navigation, and Control Subsystem

The guidance, navigation, and control (GNC) subsystem provides stabilization, attitude control, navigation, orbit maintenance, and attitude and rate data for experiment support.

The GNC subsystem senses, computes, and receives the commands and data for these functions; and the propulsion subsystem and the control moment gyros generate the actuation forces and torques needed for attitude control. Sensing and computation of station attitude and angular rates are provided within the station, and the navigation data are provided by the ground-tracking network.

The GNC subsystem provides the Modular Space Station with the capability to maneuver and hold any orientation to support the orbital and experiment operations in the presence of the orbital disturbance environment. The station can accommodate any inertial orientation for an indefinite period, subject to propellant expenditure and potential contamination associated with use of the high-thrust system. Normal attitude control is performed by control moment gyros (CMG's), which provide sufficient capacity for the cyclic disturbances of the worst-case orientation.

The primary orientation of the Modular Space Station is trimmed horizontal, which is an Earth-centered orientation. This orientation aligns the Z axis along the radium vector and the body is rotated about the Z axis so that the bias torque on the vehicle is zero, the amount of rotation depends on the particular configuration of the Space Station. Other orientations, such as inertial, may be imposed by the experiment operations.

The GNC subsystem sensors, gyro triads, star sensor, horizon sensor, and star trackers (which provide the all-attitude capability) are located in the power module. The star sensor and gyro triads provide the primary trimmed horizontal reference. The horizon sensors are used to provide the acquisition of the Earth-centered reference; they are also used

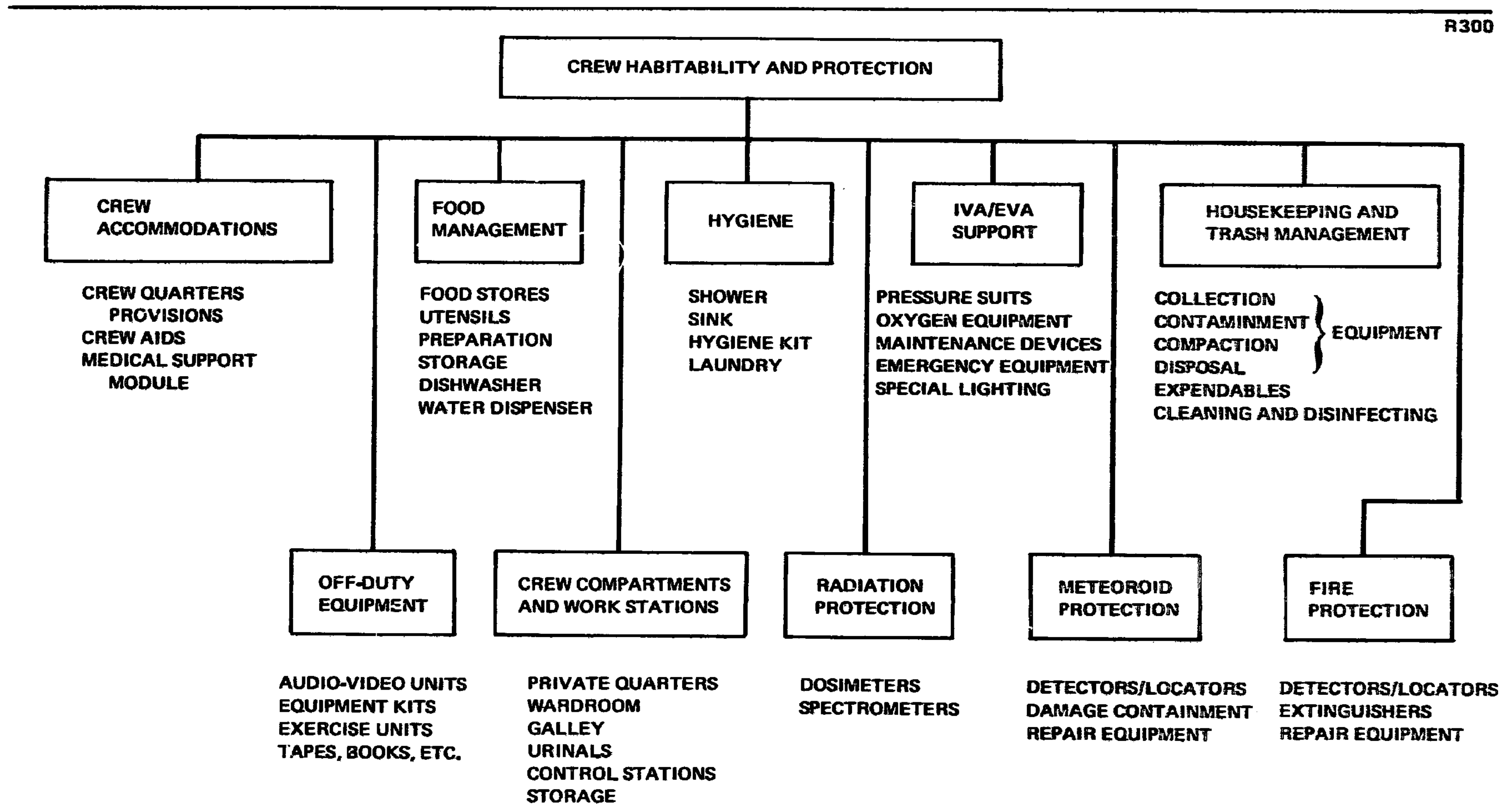

Figure 3-25. Crew Habitability and Protection Subsystem Assembly Group Breakdown

Table 3-5

SPECIFICATIONS OF CREW HABITABILITY AND PROTECTION SUBSYSTEM

Provisions	Six-man crew for 90 days	
Food Storage	Routine—30 days (Crew/Operations Module) Contingency—30 days (ISS proper) Replenishment—30 days (Logistics Module)	
Food Design	Six men, 30 days; crewman weight of 240 kg and volume of 0.5 m^3	
Food Water Requirements	2.8 kg/man/day	
Diet	11.7 MJ (2800 Kcal)/man/day	
EVA	Prebreathing of O_2 for 3 hours; maximum EVA—3 hours	
Emergency Oxygen	15-minute supply per portable bottle; 96-hour supply per emergency pallet	
Private Quarters	Minimum volume of 2.1 by 2.1 by 1.2 m	
Minimum Free Volume per Compartment	2 by 2 by 2 m	
Hygiene/Waste Management	Two enclosed facilities	
Hygiene Compartment Volumes (m^3)	Shower	1.7
	Waste management	1.8
	Urinal/handwash	0.85
	Laundry	0.56
	Free space	1.80
	Total	6.7
Command Center Volumes (m^3)	Equipment	3.1
	Operating space	3.0
	Total	6.1
Wardroom, Galley and Gym	Minimum Volume of 40 m^3	
Medical Support	An assembly shall be provided for first aid, resuscitation, and support measures	
Protection	The following shall be provided for all modules: • Alternative escape routes • Fire prevention and suppressant equipment • Strategically located IVA and EVA suits • Meteoroid and radiation protection and detection.	

with the gyro triads to provide a limited-trim or untrimmed horizontal reference.

The star trackers provide a highly accurate drift-free inertial reference for the Space Station. These inertial reference data are used to support the experiments.

Four control-moment gyros (CMG's) provide primary control actuation. A fifth CMG is maintained in a standby mode. Resistojets are used for orbit keeping and CMG desaturation. The biowaste system has more than sufficient capacity for the trimmed horizontal orientation. High-thrust jets control docking disturbances and provide a backup capability to the resistojets. The high-thrust jets provide the primary control torques for the unmanned phase. The data management computer is used for GNC computations. Station-attitude and rate-reference data are supplied to the dedicated experiment computer in the GPL for user support.

The GNC subsystem is designed to maximize the operational effectiveness of the Modular Space Station throughout the build-up phase with varying Space Station physical characteristics while constraining the required propellant and electrical power resources to a reasonable level.

Figure 3-26 is an assembly-level breakdown and Table 3-6 provides key specifications for this subsystem. A block diagram is provided in Figure 3-27 and a schematic diagram in Figure 3-28.

3.2.5 Propulsion Subsystem

The Modular Space Station propulsion subsystem is a combination monopropellant (N_2H_4) high-thrust (111 N/thrustor, 25 lbf/thrustor) system and a biowaste (CO_2) resistojet low-thrust (0.111 N/thrustor, 0.025 lbf/thrustor) system. The low-thrust system performs orbit keeping and CMG desaturation, and the high-thrust system provides the impulse for attitude maneuvers and the correction of docking and dedocking disturbances when the orbiter is not attached.

The propulsion elements, excepting thrustors, are located in an unpressurized, but pressurizable, bay in the forward conic section of the power module. This provides isolation in the event that system failures cause leakage of propellant or pressurant. Maintenance may be performed in either an EVA or shirtsleeve mode, depending on the nature of the

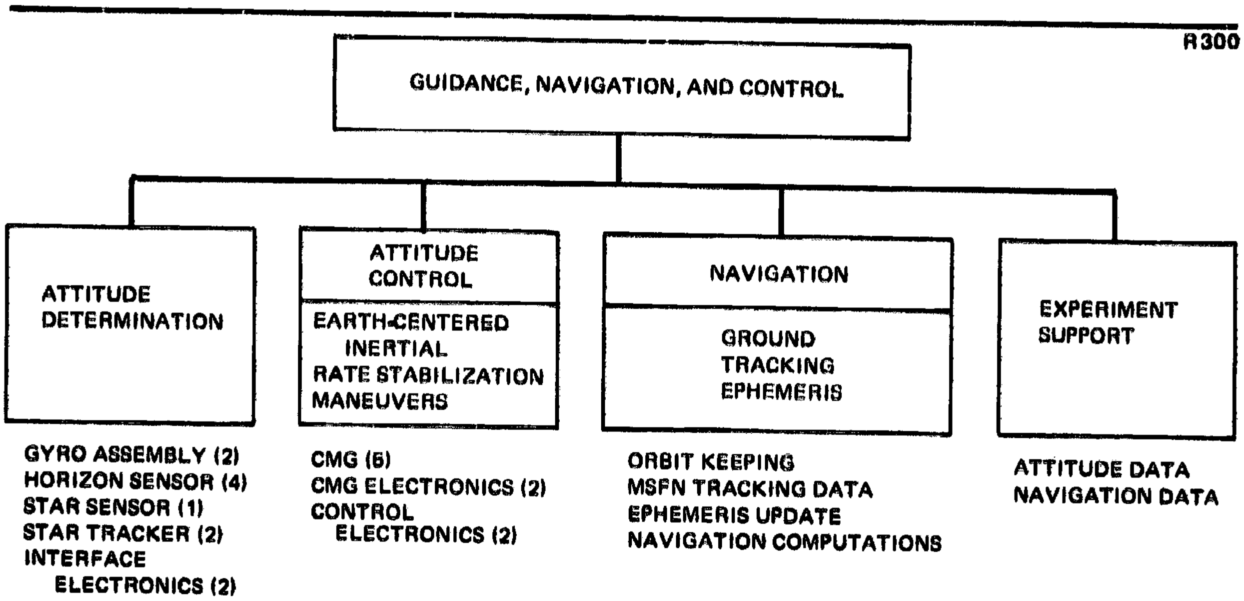

Figure 3-26. Guidance, Navigation, and Control Subsystem Assembly Group Breakdown

maintenance; i.e., most maintenance will not involve opening a propellent system and will be a shirtsleeve operation.

All needs for impulse are determined by the GNC subsystem, which sends commands directly to the thrustor valves, subject to system-status information.

The high-thrust propellant (N_2H_4) is stored in positive-expulsion metal bellows tanks and expelled with regulated GN_2. Of the four propellant tanks required, only one is pressurized and in use at a time. The propellant is routed through dual feed lines to the eight thrustor modules, four of which are located on the forward end of the power module and four on the aft end of the crew module. Use of the high-thrust system will be very infrequent, a few times a month at most.

On-line redundancy is provided in the pressurant storage and regulation, propellant storage and distribution, and thrustor assemblies.

The low-thrust subsystem receives waste CO_2 from the EC/LS subsystem and routes the CO_2 to the power module, where it is compressed and stored in titanium spheres as a gas. The CO_2 is regulated to approximately three atmospheres for distribution to the thrustors, where it is electrically heated and expelled.

Table 3-6

SPECIFICATIONS OF THE GNC SUBSYSTEM

Altitude	455 to 500 km (246-270 nmi)
Orientation	
Primary	Trimmed horizontal
Others	All attitude
Attitude Control (all attitude)	±0.25 deg
Rate Control (stability)	±0.005 deg/sec
Attitude Reference Data	±0.02 deg
Rate Reference Data	±0.001 deg/sec
Navigation	±1.86 km (±1.0 nmi)
Momentum Storage Requirements	
Roll Axis	6,410 N-m-sec (4,720 lb-ft-sec)
Pitch Axis	10,280 N-m-sec (7,580 lb-ft-sec)
Yaw Axis	9,700 N-m-sec (7,160 lb-ft-sec)
Momentum Storage Capacity	Four improved ATM CMG's, 4,070 N-m-sec/CMG (3,000 lb-ft-sec)
Roll Axis	8,140 N-m-sec (6,000 lb-ft-sec)
Pitch Axis	16,280 N-m-sec (12,000 lb-ft-sec)
Yaw Axis	16,280 N-m-sec (12,000 lb-ft-sec)
Propellant Requirements (Biowaste Output—6.35 kg/day)	

Orientation	Attitude Control kg/day	Attitude Control (lb/day)	Orbit Keeping* kg/day	Orbit Keeping* (lb/day)
Earth-Centered				
Trimmed Horizontal	0.23	(0.51)	5.3	(11.7)
Untrimmed Horizontal	17.2	(38)	5.1	(11.3)
Worst Case	204.0	(450)	5.8	(12.8)
Inertial				
Worst Case	118.0	(260)	5.6	(12.4)
Average	18.6	(41)	5.6	(12.4)

*Maximum solar atmosphere at 455 km (246 nmi).

Compression of CO_2 is a nearly continuous function, subject to some changes in supply pressure and quantity. Consumption of CO_2 will also be at a high duty cycle. The propellant (CO_2) requirements for orbit keeping, combined with CMG desaturation, if desired, are approximately equal to the EC/LS output during maximum solar-density years. During low solar-density years, most of the CO_2 will be expelled nonpropulsively through opposing resistojets.

Figure 3-29 is an assembly-level breakdown and Table 3-7 provides key specifications for the high- and low-thrust assemblies. Figures 3-30 and 3-31 show schematically the high- and low-thrust assemblies. Figure 3-32 provides the legend for these schematics.

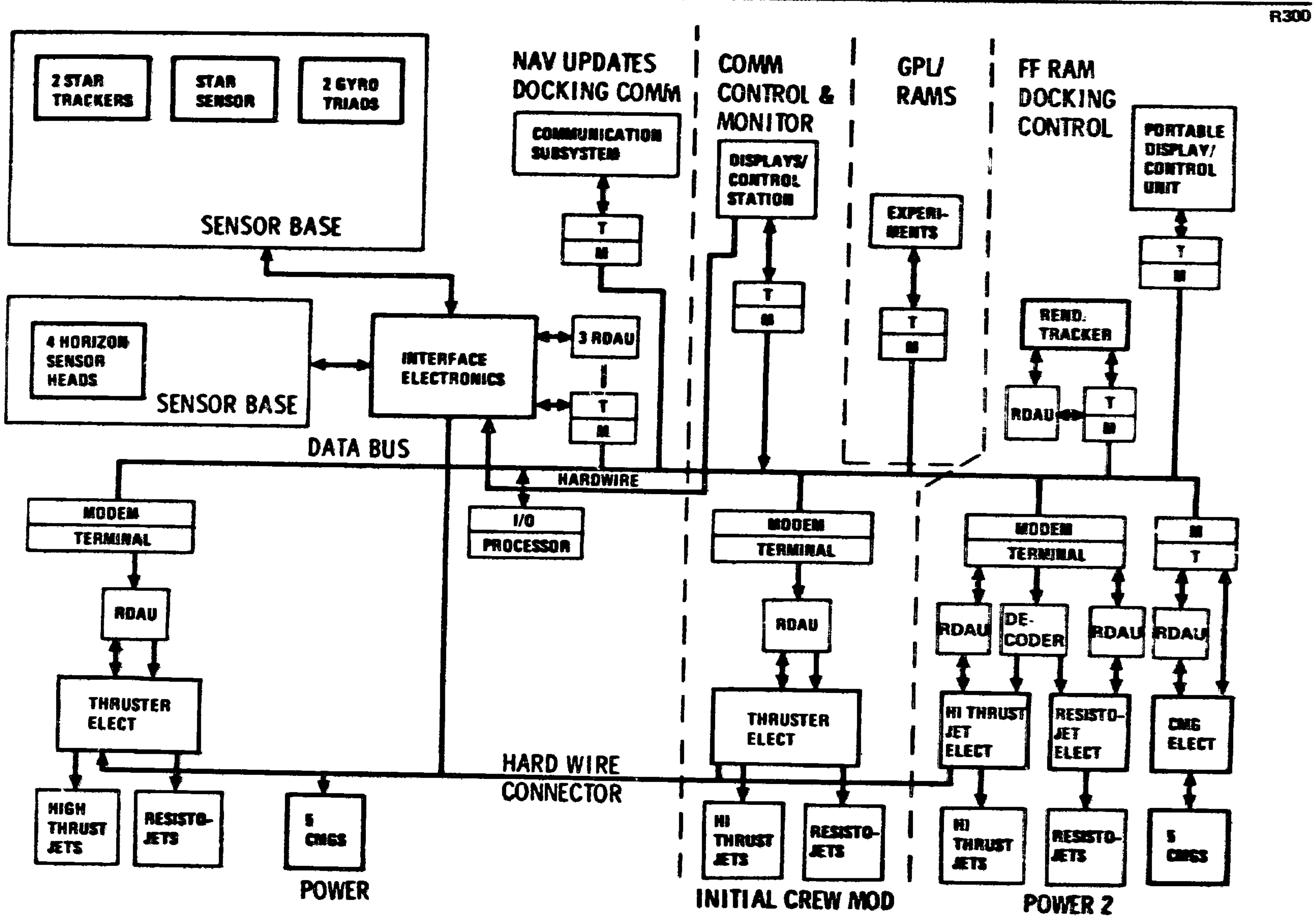

Figure 3-27. Guidance, Navigation, and Control Block Diagram

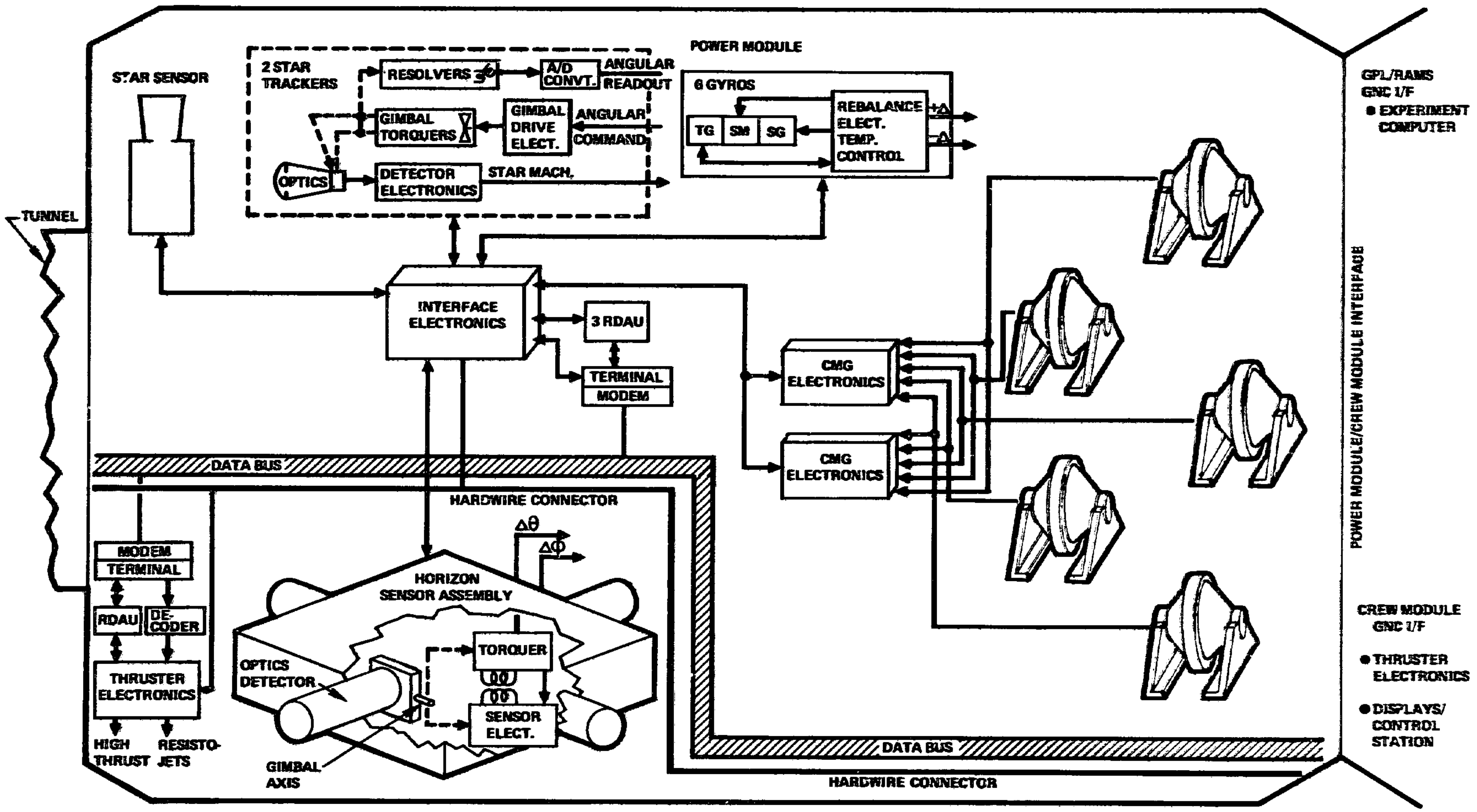

Figure 3-28. Guidance, Navigation, and Control Subsystem Schematic

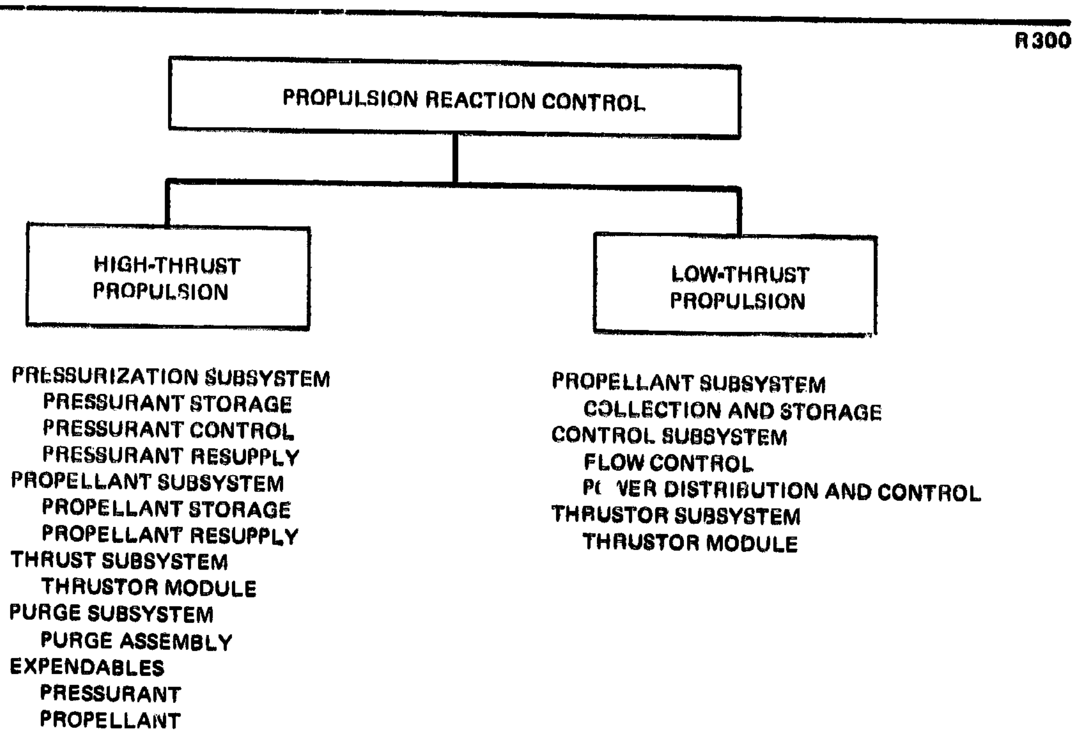

Figure 3-29. Propulsion Subsystem Assembly Group Breakdown

3.2.6 Data Management Subsystem

The data management subsystem (DMS) provides data-acquisition, control, transfer, storage, and processing for Modular Space Station users, subsystems, and experiments. Control of ISS operation is provided through standard data bus terminals and appropriate digital and analog interface equipment under computer control. Crew access to computer operations is provided through keyboard and display equipment.

Two computer complexes are provided, one in the Power/Subsystems Module for subsystem operations and the other in the GPL Module for experiment operations. Each of the computer complexes is a modular multiprocessor. For backup, the experiment multiprocessor can be rapidly reconfigured to perform the subsystem operation functions.

The computer's auxiliary memories provide the capability for reading a variety of stored programs into the computer's main memory on an as-needed basis. New programs, as required, will be generated on the ground and transmitted (via RF links) or carried (via the Space Shuttle) to the Space Station. The crew can also initiate program changes through the alphanumeric keyboards. The file tape transports provide the highest level of memory in

Table 3-7

SPECIFICATIONS OF THE PROPULSION SUBSYSTEM

HIGH-THRUST PROPULSION SYSTEM		
<u>General</u>		
Total Impulse:		
Pulsing	803,000 N-sec	(180,000 lb-sec)
Steady State	1,025,000 N-sec	(230,000 lb-sec)
3 Axis Translation		
Redundant Thrustors		
Thrust Levels:		
±X	222 N (50 lbf) nominal 445 N (100 lbf) maximum	
±Y or Z	445 N (100 lbf) nominal 890 N (200 lbf) maximum	
Torques:		
± Roll	493 N-m (363 ft-lb) nominal 3,940 N-m (2,900 ft-lb) maximum	
± Pitch or Yaw	4,420 N-m (3,250 ft-lb) nominal 8,840 N-m (6,500 ft-lb) maximum	
<u>Propellant System</u>		
Propellant	Monopropellant—N_2H_4	
Capacity	455 kg (1,000 lbm)	
Work pressure	2.07 x 10^6 n/m^2 (300 psia)	
Temperature	10° to 40° C (50° to 105° F)	
Resupply	Bulk transfer	
Storage Tank	Positive expulsion—metal bellows	
Length	1.15 m (45 in.)	
Diameter	0.475 m (18 in.)	
Material	Titanium shell; stainless steel bellows	
Number required	Four	
<u>Pressurant System</u>		
Pressurant	GN_2	
Capacity	29.1 kg (64 lbm)	
Storage Pressure	20.7 to 3.44 x 10^6 N/m^2 (3,000 to 500 psia)	
Temperature	10° to 40° C (50° to 105° F)	
Regulated Pressure	2.07 x 10^6 N/m^2 (300 psia)	
Storage Pressure		
Diameter	0.495 m (19.5 in.)	
Material	Titanium	
Number Required	Two	
<u>Thrustors</u>		
Thrust Level	111 N/thrustor (25 lbf/thrustor)	
Expansion Ratio	50:1	
I_{sp} (Pulsing)	180 sec	
(Steady State)	230 sec	
Chamber Pressure	1.38 x 10^6 N/m^2 (200 psia)	
Catalyst	Shell 405	
Number Required	40	

Table 3-7
SPECIFICATIONS OF THE PROPULSION SUBSYSTEM (Continued)

LOW-THRUST PROPULSION SYSTEM	
General	
Total Impulse:	
Maximum Daily	10, 800 N-sec (2, 420 lb-sec)
Stored	21, 600 N-sec (4, 840 lb-sec)
Three-Axis Translation	
Redundant Thrustors	
Thrust Levels:	
±X	0, 222 N (0, 05 lbf) nominal 0, 445 N (0, 1 lbf) maximum
±Y or Z	0, 222 N (0, 05 lbf) nominal 0, 667 N (0, 15 lbf) maximum
Torques:	
±Roll	0, 493 N-m (0, 363 ft-lb) nominal 1, 97 N-m (1, 45 ft-lb) maximum
±Pitch or Yaw	2, 21 N-m (1, 63 ft-lb) nominal 6, 63 N-m (4, 88 ft-lb) maximum
Propellant System	
Propellant	Biowaste CO_2
Capacity	12, 5 kg (27, 6 lbm)
Storage Pressure	0, 31 to 2, 07 x 10^6 N/m^2 (45 to 300 psia)
Storage Temperature	10° to 40° C (50° to 105° F)
Storage Sphere	
Diameter	0, 787 m (31 in.)
Material	Titanium
Number Required	Two
Thrustors	
Thrust Level	0, 111 N/thrustor (0, 025 lbf/thrustor)
I_{sp}	175 sec (maximum) 55 sec (minimum--cold flow)
Chamber Pressure	0, 31 x 10^6 N/m^2 (45 psia)
Number Required	32

the computation memory hierarchy for infrequently used data, and they are identical to the digital bulk-storage units.

Intermodule communications (data distribution) are accomplished under computer control of the data buses. Terminal-to-terminal transfer of data may also occur within a module. The data bus concept employs a hybrid time division multiplex (TDM), frequency division multiplex (FDM) technique for digital data transfer; the latter is used for analog data transfer. Control is accomplished by a computer input and output controller using standard control words, whi h provide terminal addressing and instructions. (A terminal is defined as any device directly sending or receiving data from a data bus.)

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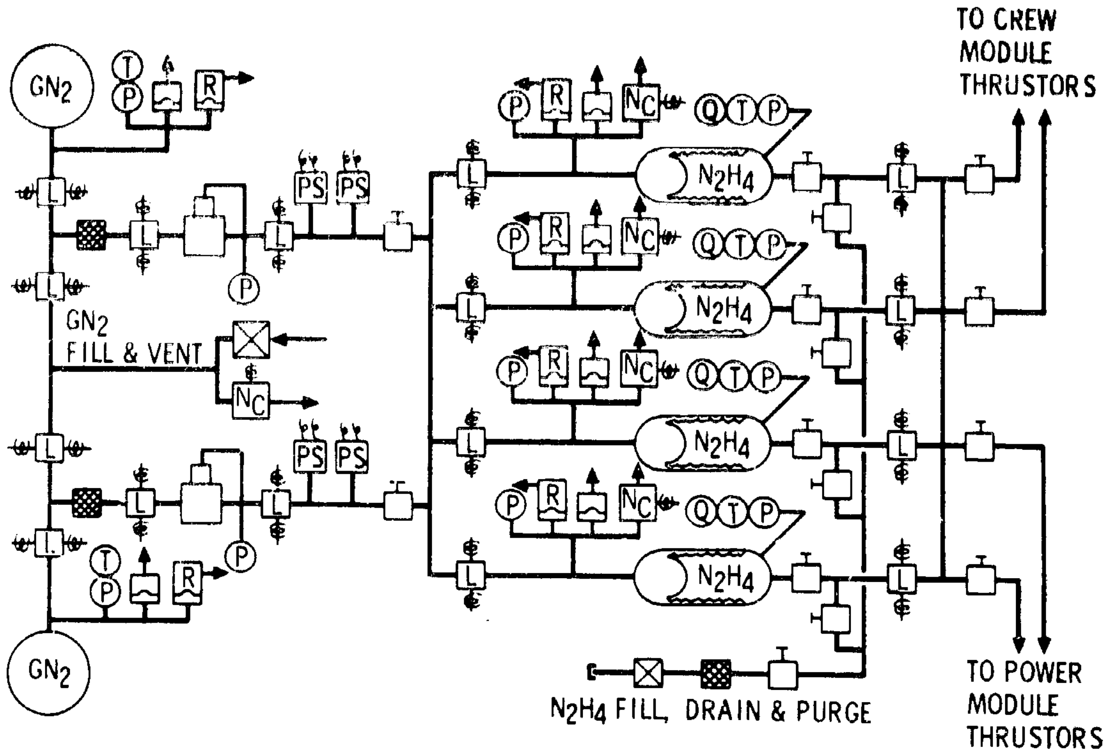

Figure 3-30. High-Thrust Propulsion Subsystem Schematic

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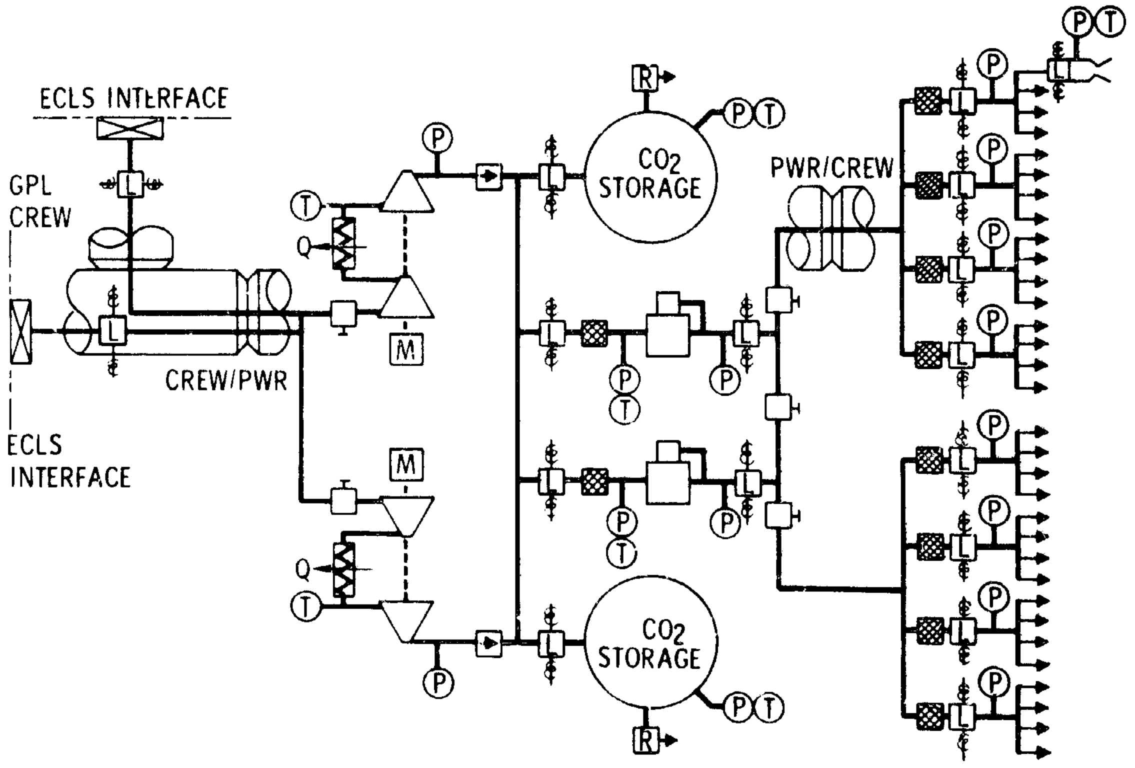

Figure 3-31. Low-Thrust Propulsion Subsystem Schematic

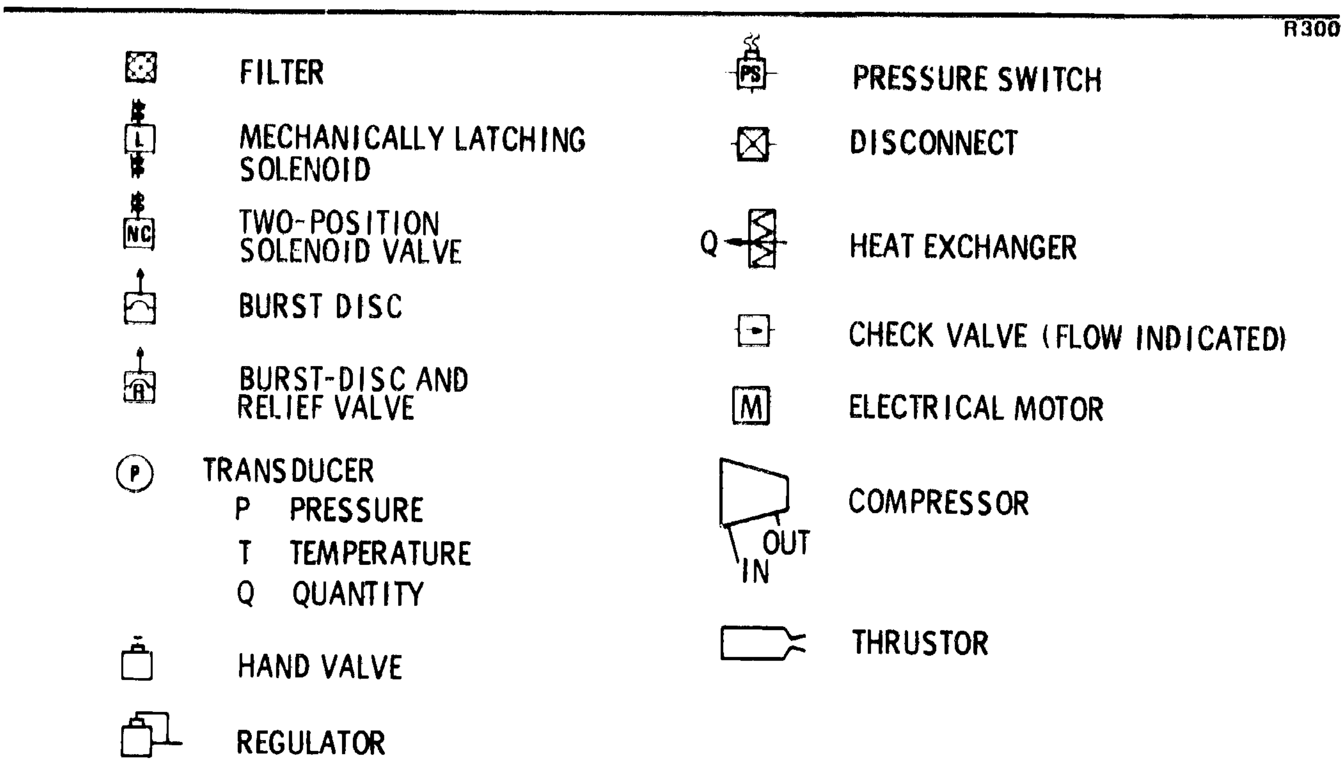

Figure 3-32. Propulsion Subsystem Legends

Data acquisition is implemented by analog and digital terminals, which have the ability to handle eight standard interfaces. The number of channels in a digital terminal may be effectively expanded to 512 by connecting a remote data-acquisition unit (RDAU) to each standard interface. Each RDAU will accept up to 48 (analog or discrete) inputs and output 16 discrete commands. Analog terminals are used to multiplex nonsampled experiment data onto analog bus subcarriers. The analog bus also carries wideband video on individual subcarriers.

Bulk data storage utilizes ultra-high-density magnetic-tape recording techniques and is configured to meet high data-volume-storage requirements and relatively slow access-speed requirements. The storage is used primarily for digital data recording prior to onboard processing or return to Earth via logistics module and shuttle orbiter for ground processing. Magnetic tape recorders also provide for the storage of voice and analog data.

Film is used widely as a storage media for experiment data. Film could also be used for recording certain system performance data and onboard operations. This use is expected to be minimal; however. Capability for storing, calibrating, and processing film are described in Section 5.2, General Purpose laboratory.

Image-processing equipment provides a capability for selected processing of high-resolution video data, for transforming film data into electronic signals, or both. Tape storage for experiment video is also provided.

Displays and controls provide the crew with monitoring and control capability over the Modular Space Station, the subsystem, and experiment program operations. A primary display and control center for subsystem operation is in the Crew/Operations Module. This is similar to the experiment operations center in the GPL which is described in Section 5.2. The experiment operations center can also be used as a backup center for subsystem operations.

Entertainment assemblies provide relaxation for off-duty crew members. The entertainment assemblies in the DMS include TV monitors in the crew quarters and wardroom as well as music through the speaker system. A video reproduction unit provides a source for playing stored program material.

Figure 3-33 is an assembly-level breakdown of the data management subsystem; Table 3-8 provides key specifications and Figure 3-34, a block diagram. Schematic diagrams showing data management equipment in each module are given in Figures 3-35, 3-36, and 3-37.

3.2.7 Communications Subsystem

Direct communication with the ground stations is provided by an S-band transponder, which receives voice, commands, and ranging information at a frequency of approximately 2.1 GHz and transmits voice, telemetry, and ranging data at a frequency between 2.2 and 2.3 GHz. An S-band FM exciter and power amplifier, operating at a frequency between 2.2 and 2.3 GHz, is also provided for the transmission of video and digital experiment data. Two-way voice, low-rate data, and ranging communications with the Shuttle are also provided by the same S-band transponder that is used for direct ground communications. However, a power amplifier operating in conjunction with the transponder is required to provide simultaneous voice, data, and ranging at ranges up to 200 km. A common low-gain S-band antenna system will be utilized for communications with both the ground and the shuttle.

Communications with the DRSS are provided by K_u-band transmitting and receiving systems, operating in the 14.4- to 15.35-GHz and the 13.4- to 14.2-GHz frequency bands, respectively. The design power output operating

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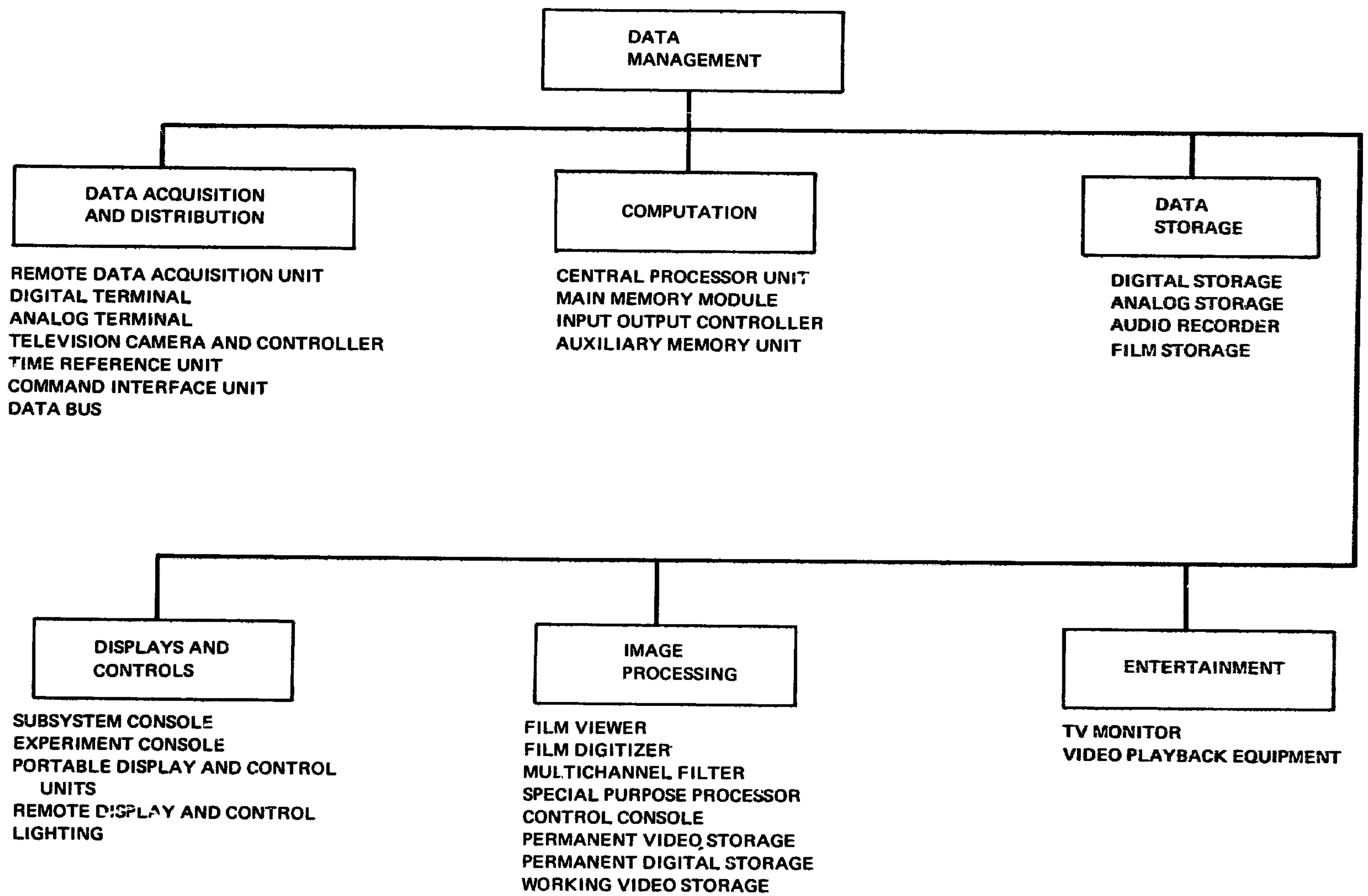

Figure 3-33. Data Management Subsystem Assembly Group Breakdown

Table 3-8

SPECIFICATIONS OF THE DMS SUBSYSTEM

Data Sources	2790 analog (≤10-kHz bandwidth), 24 analog (>10-kHz bandwidth), 1480 discrete, 160 digital serial (data sources and commands)
Digital Serial Rate	1 megabit per second
Discrete Commands	1,480
Analog Data Voltage	0 to 40 millivolts or 0 to 5 volts, full scale
Analog-to-Digital Conversion	8-bit accuracy
Remote Limit Checking	Bit-by-bit comparison of 7-bit words
Number of Digital Data Bus Channels	Three, expandable up to eight
Digital Data Bus Channel Rate	10 megabits per second
Number of Analog Data Bus Channels	One public address, one telephone carrier reference, one emergency call tone, one emergency alert tone, 36 telephones, three entertainment, one television carrier reference, eight television and video, one onboard generated test
Digital Data Bus Terminations	128
Analog Data Bus Terminations	64 maximum
Digital Data Bus Addressing	Up to 1,024 unique devices
Digital Data Transfer Bit Error Rate	$<10^{-6}$
Digital Data Transfer Probability of Undetected Error	$<1.2 \times 10^{-10}$
Computing Processing Rate	At least 1,213,000 operations per sec
Main Memory Capacity	At least 192,000 32-bit words
Auxiliary Memory Capacity	At least 1,376,000 32-bit words
Digital Data Recording Rate	At least 2.5×10^7 bits/second
Digital Data Storage Capacity	10^{10} bits minimum per tape reel
Video Recording Frequency Response	4.5 MHz at 3 db
Video Recording Time	Three-hr minimum per reel
Multipurpose Display Capability	96 ASCII alphanumeric character set, 1,250 characters per frame, 800 linear inches per frame for graphics
Video Display Capability	525 commercial standard TV lines

in conjunction with an 8-ft-diameter high-gain antenna is required to provide for commercial-quality television or high-rate digital data transmissions through the DRSS. Multiple voice channels, medium data rates, and turned-around ranging transmission are provided simultaneously with the wideband transmission on a separate carrier. Simultaneous reception of multiple voice, medium rate data, and ranging information is also provided.

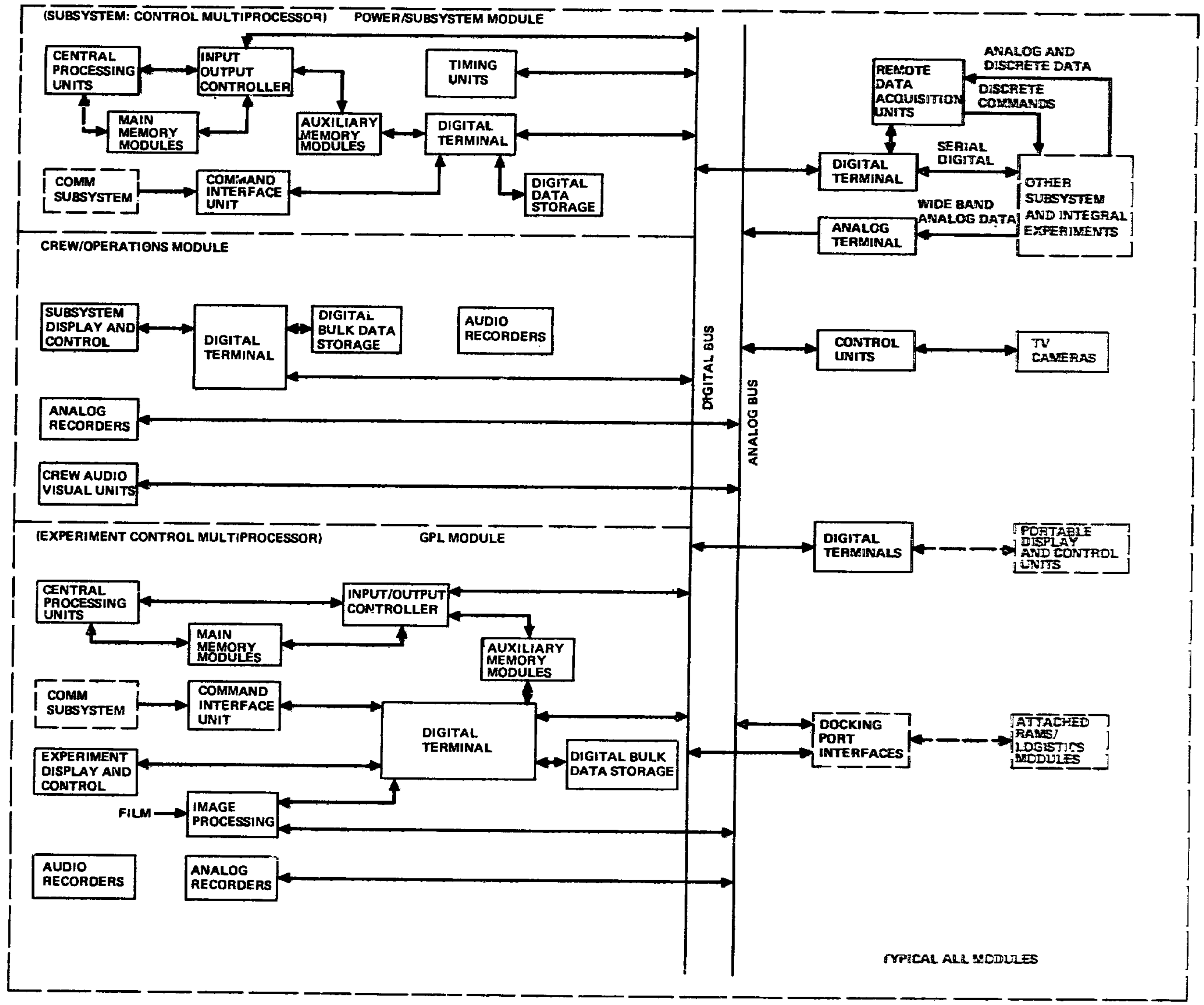

Figure 3-34. Data Management Subsystem Block Diagram

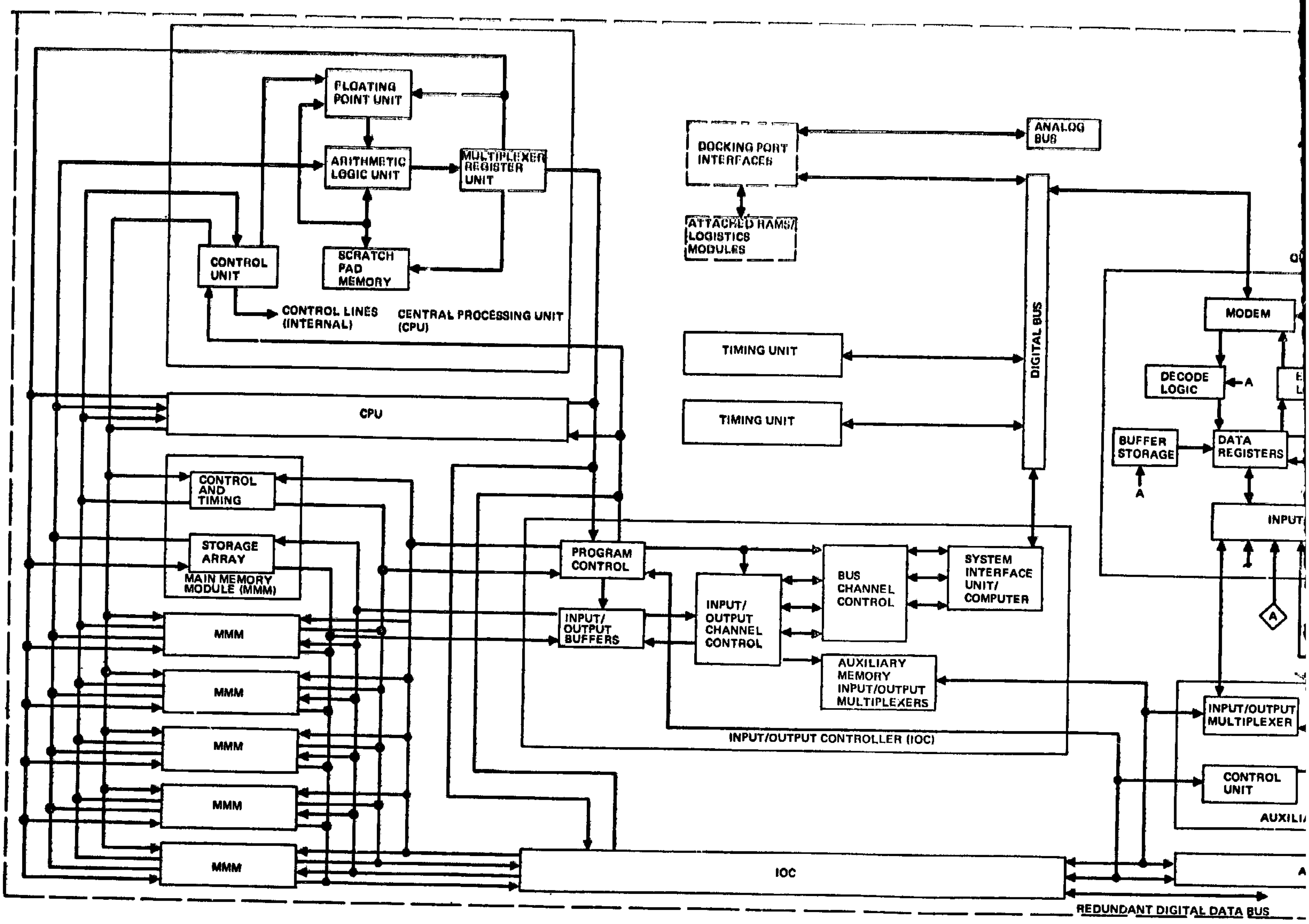

Figure 3-35. Data Management Subsystem Schematic--Power/Subsystems Module

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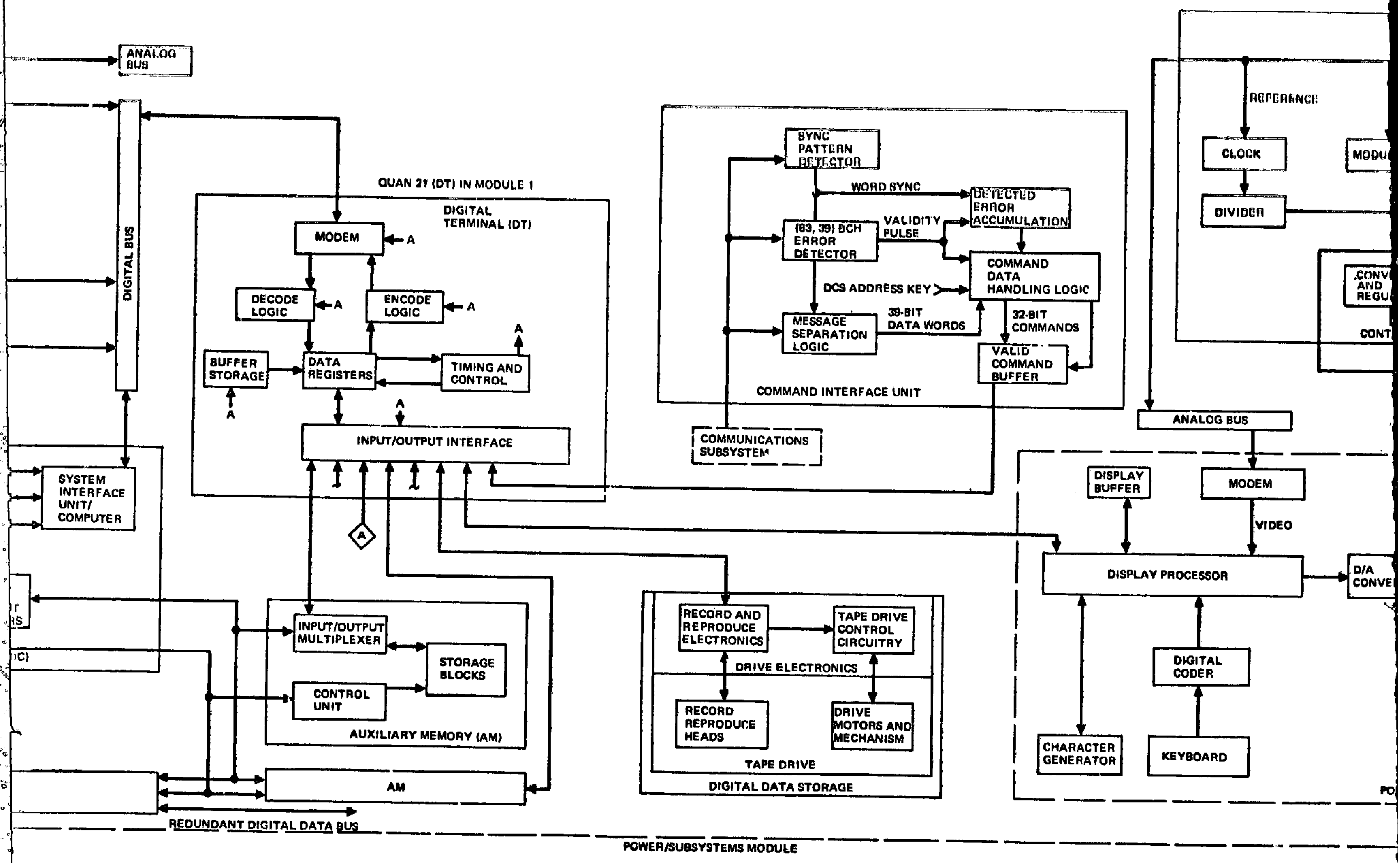

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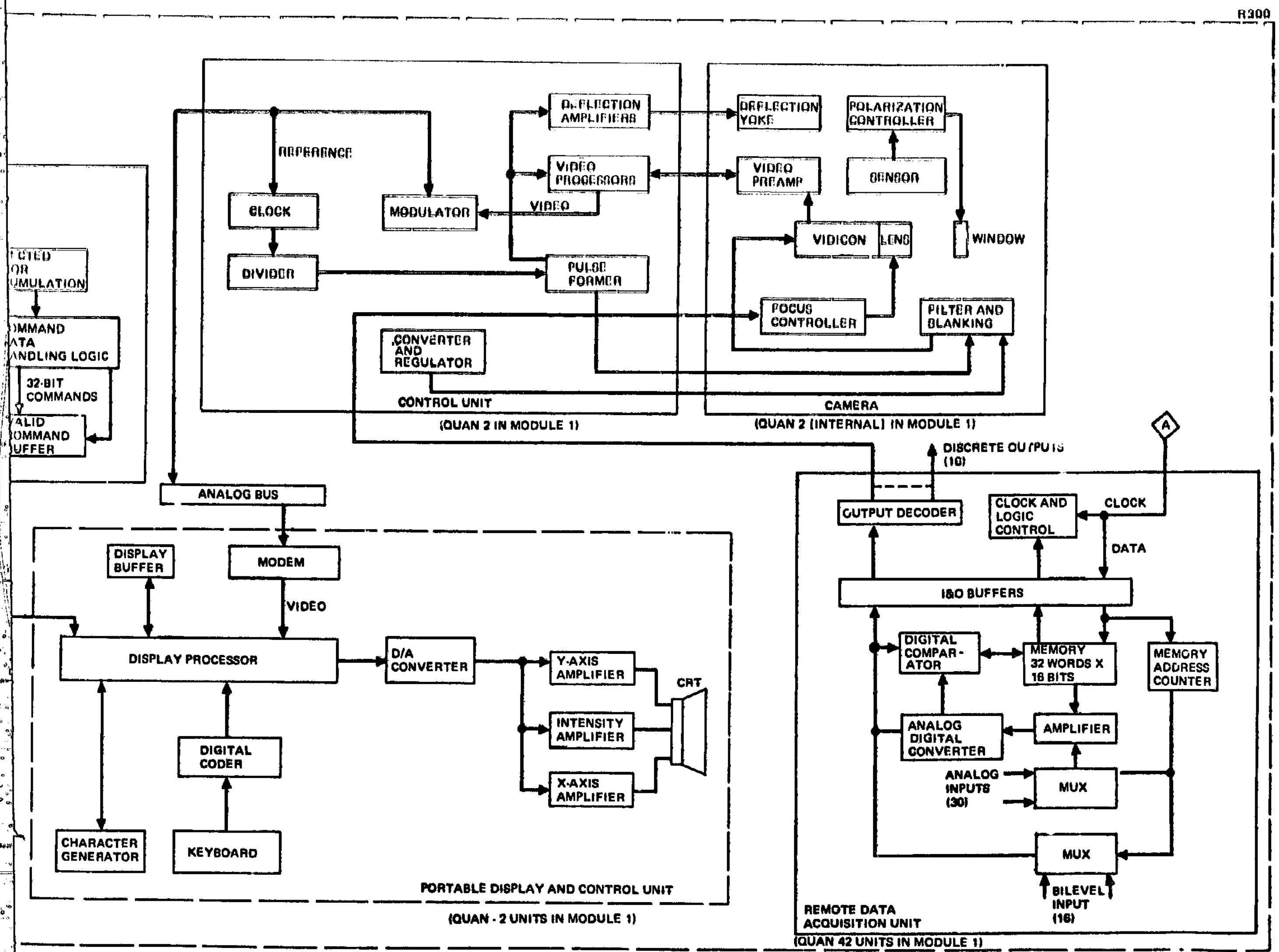

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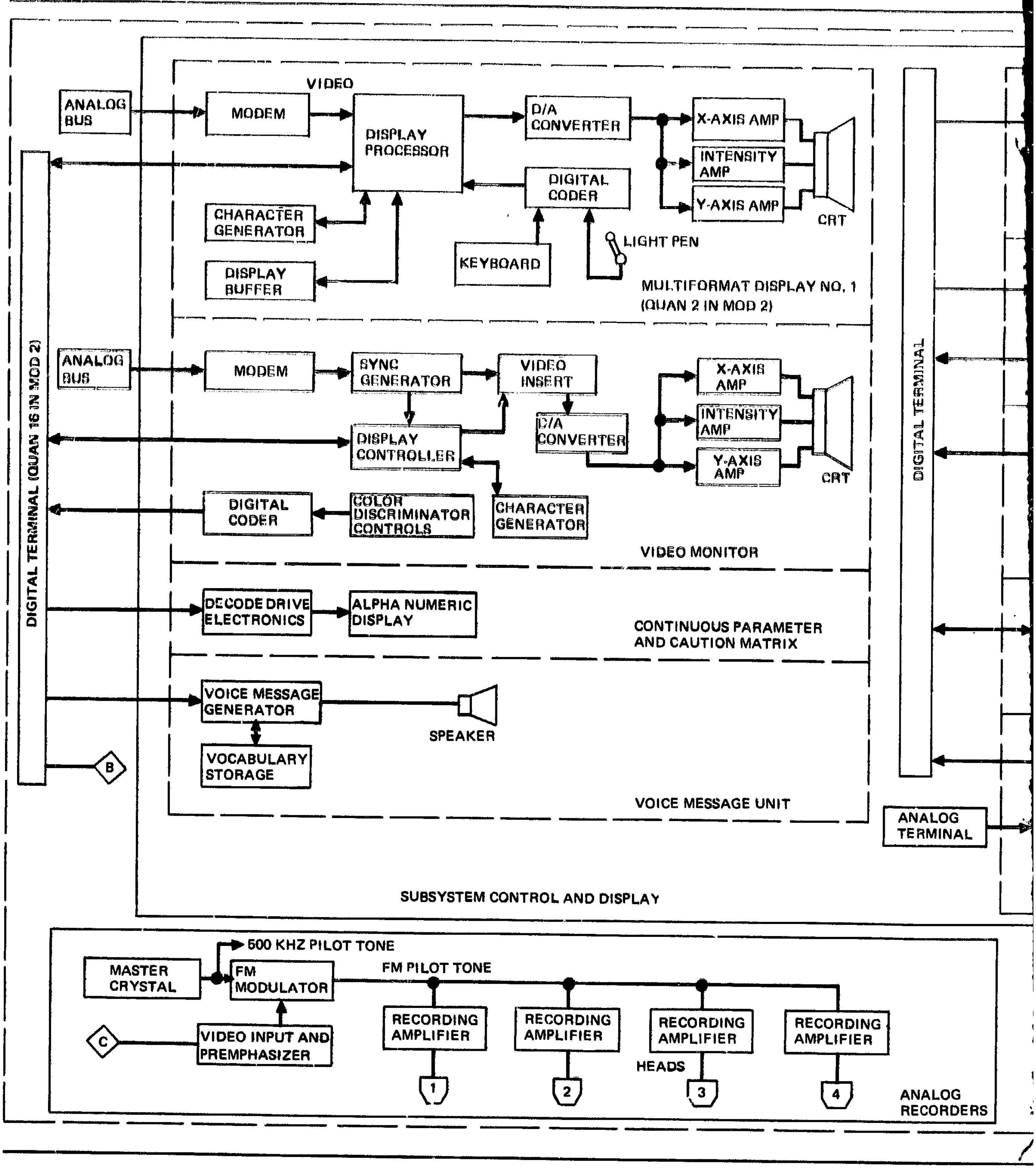

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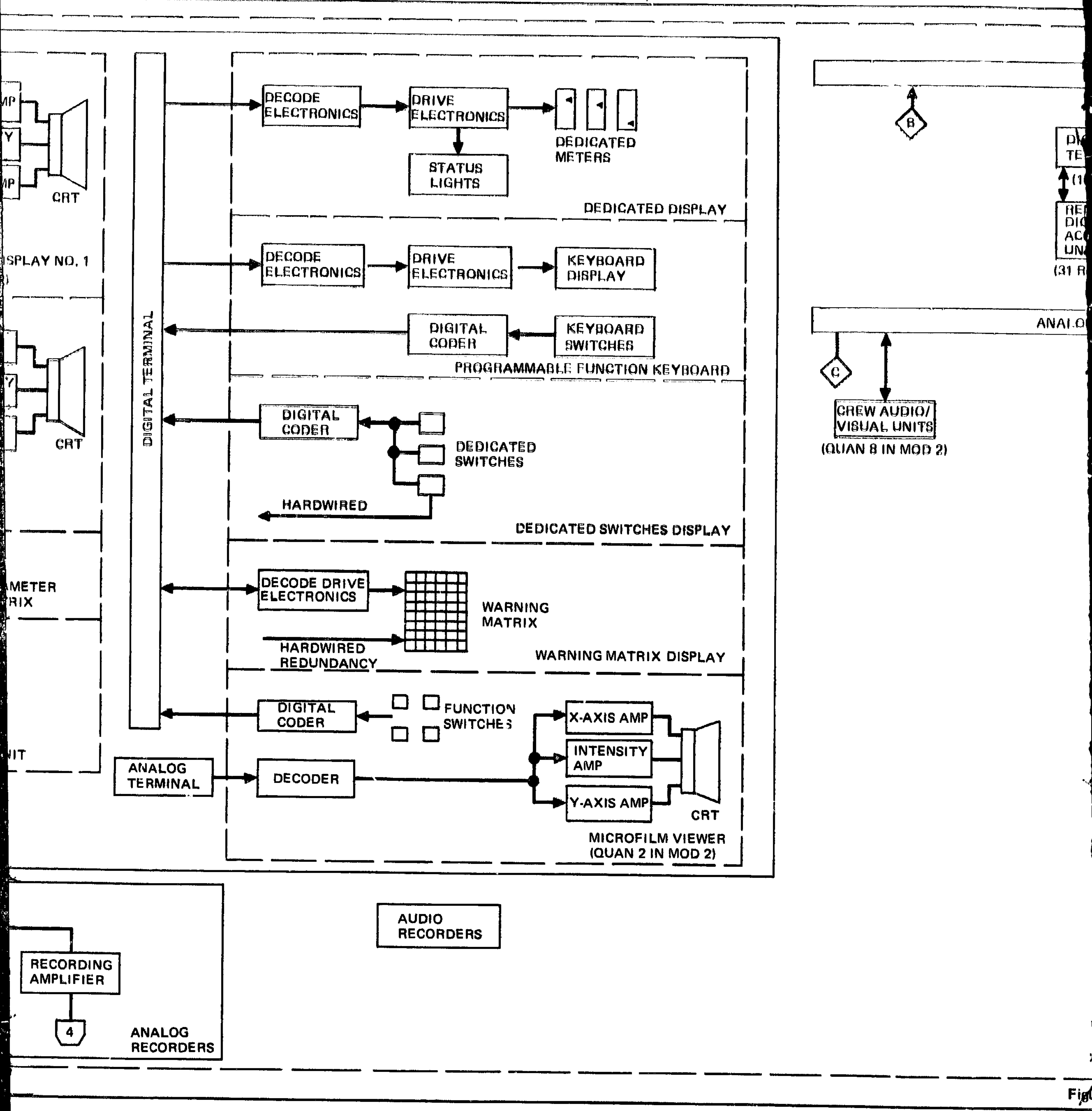

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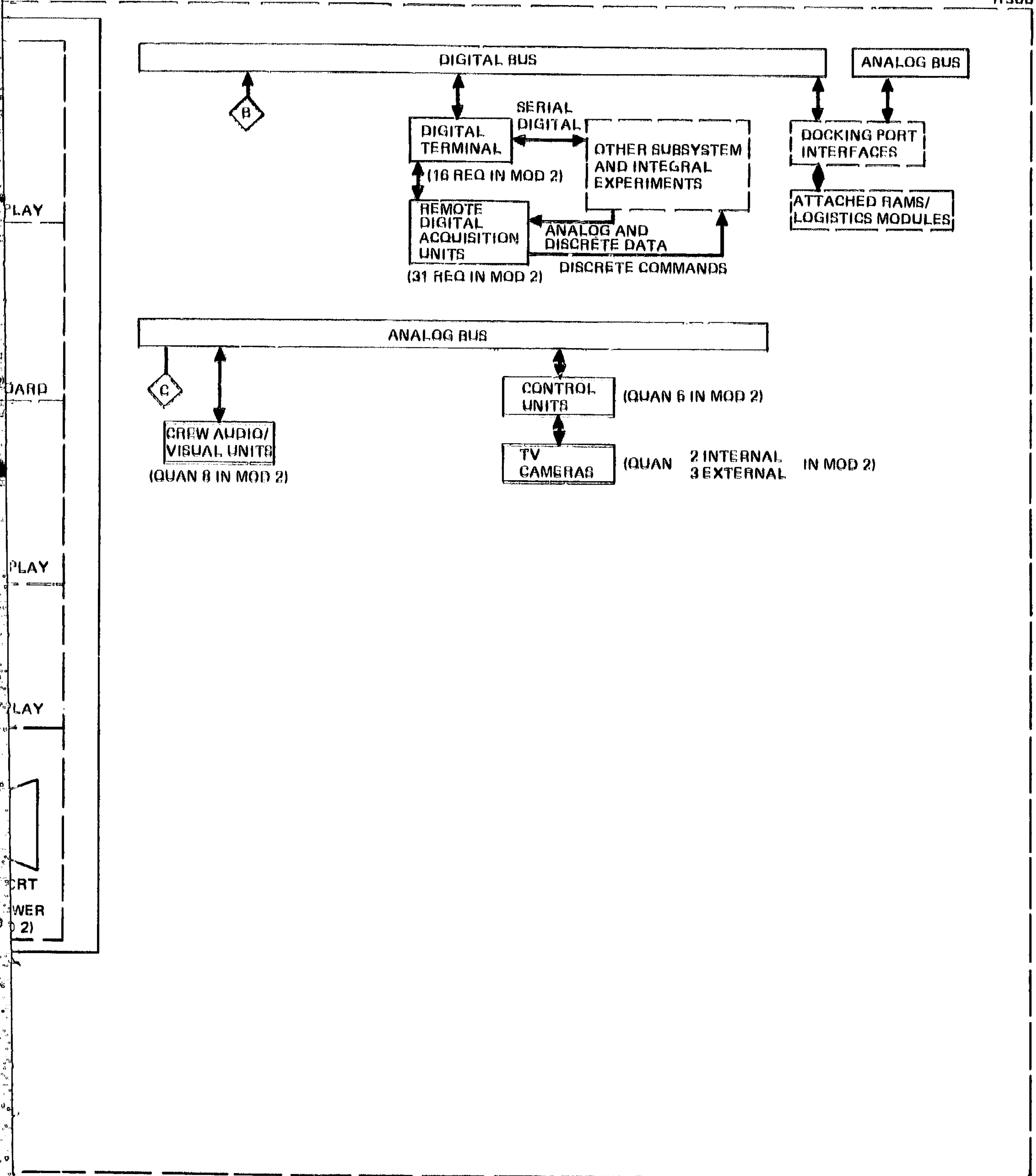

Figure 3-36. Data Management Subsystem Schematic--Crew/Operations Module

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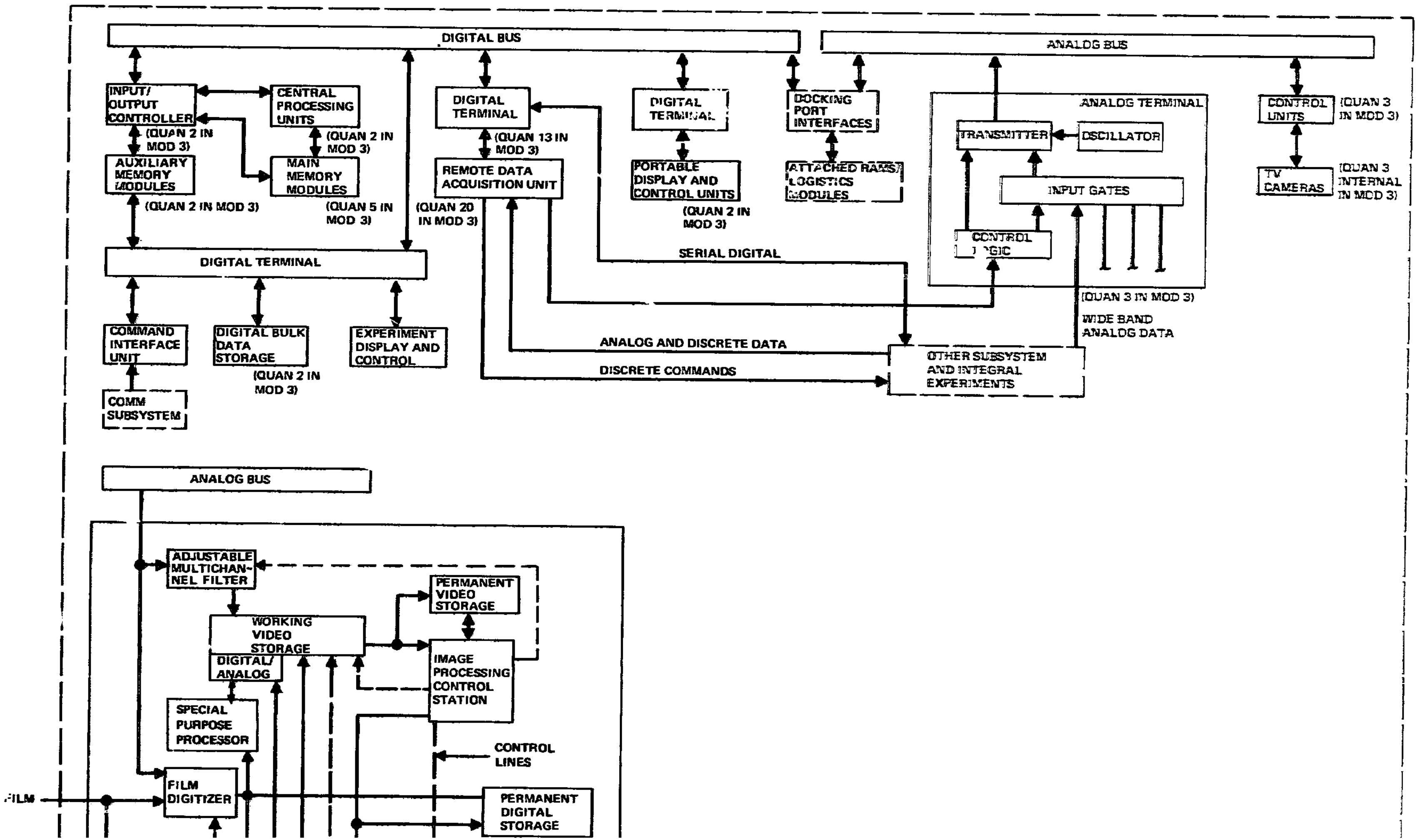
DIGITAL BUS
ANALOG BUS
INPUT/ OUTPUT CONTROLLER
(QUAN 2 IN MOD 3)
CENTRAL PROCESSING UNITS
(QUAN 2 IN MOD 3)
MAIN MEMORY MODULES
(QUAN 5 IN MOD 3)
AUXILIARY MEMORY MODULES
(QUAN 2 IN MOD 3)
DIGITAL TERMINAL
(QUAN 13 IN MOD 3)
REMOTE DATA ACQUISITION UNIT
(QUAN 20 IN MOD 3)
DIGITAL TERMINAL
PORTABLE DISPLAY AND CONTROL UNITS
(QUAN 2 IN MOD 3)
DOCKING PORT INTERFACES
ATTACHED RAMS/ LOGISTICS MODULES
ANALOG TERMINAL
TRANSMITTER
OSCILLATOR
INPUT GATES
CONTROL LOGIC
(QUAN 3 IN MOD 3)
WIDE BAND ANALOG DATA
CONTROL UNITS
(QUAN 3 IN MOD 3)
TV CAMERAS
(QUAN 3 INTERNAL IN MOD 3)
SERIAL DIGITAL
ANALOG AND DISCRETE DATA
DISCRETE COMMANDS
OTHER SUBSYSTEM AND INTEGRAL EXPERIMENTS
DIGITAL TERMINAL
COMMAND INTERFACE UNIT
COMM SUBSYSTEM
DIGITAL BULK DATA STORAGE
(QUAN 2 IN MOD 3)
EXPERIMENT DISPLAY AND CONTROL
ANALOG BUS
ADJUSTABLE MULTICHANNEL FILTER
WORKING VIDEO STORAGE
DIGITAL/ ANALOG
PERMANENT VIDEO STORAGE
IMAGE PROCESSING CONTROL STATION
SPECIAL PURPOSE PROCESSOR
CONTROL LINES
FILM
FILM DIGITIZER
PERMANENT DIGITAL STORAGE

Two-way voice and low-data-rate communications between the Space Station and the DRSS are also provided in the VHF band at frequencies from 126 to 130 MHz and from 136 to 144 MHz. These links use a low-gain antenna system, which will provide nearly omnidirectional coverage.

Full-duplex voice communications with crewmen engaged in extravehicular activity (EVA) and the reception of crew biomedical telemetry are provided. These channels will utilize frequencies in the 250- to 300-MHz band and will be multiplexed into the VHF antenna system used for relay satellite communications.

Figure 3-38 is an assembly-level breakdown of the communication subsystem; Table 3-9 provides key specifications. Schematic diagrams of equipment in the Power/Subsystems Module and the Crew/Operations Module are given in Figures 3-39 and 3-40.

3.2.8 Onboard Checkout Subsystem

The onboard checkout system (OBCO) provides checkout and fault-isolation support of ISS integral subsystems and experiments, as well as limited support of subsystems and experiments within docked modules. Capabilities are included for determining whether or not the ISS subsystem and experiments are operating in an acceptable manner, supplying information for ISS repair and reconfiguration actions, and verifying subsystem and experiment operation following failure correction. The OBCO is utilized as the primary checkout and fault-isolation tool during the postmanufacturing, prelaunch, on-orbit buildup, and on-orbit operational phases.

The OBCO design preferred for the ISS is an automatic, high user-oriented system whose elements are largely integrated with or have design commonality with other onboard hardware and software. The system takes advantage of ISS data-management capabilities in the areas of data acquisition and distribution, computation, storage, display and control, command generation, and operating system software. Special-processing and stimulus-generation capabilities that are integral to other subsystem and experiment equipments are also utilized. Capabilities unique to the OBCO, however, are provided for stimulus generation, critical measurements, and checkout software. The OBCO function of monitoring life-critical warning functions is implemented independently of DMS operation.

Figure 3-41 is an assembly level breakdown of this subsystem; key specifications are listed in Table 3-10. An overall block diagram depicting

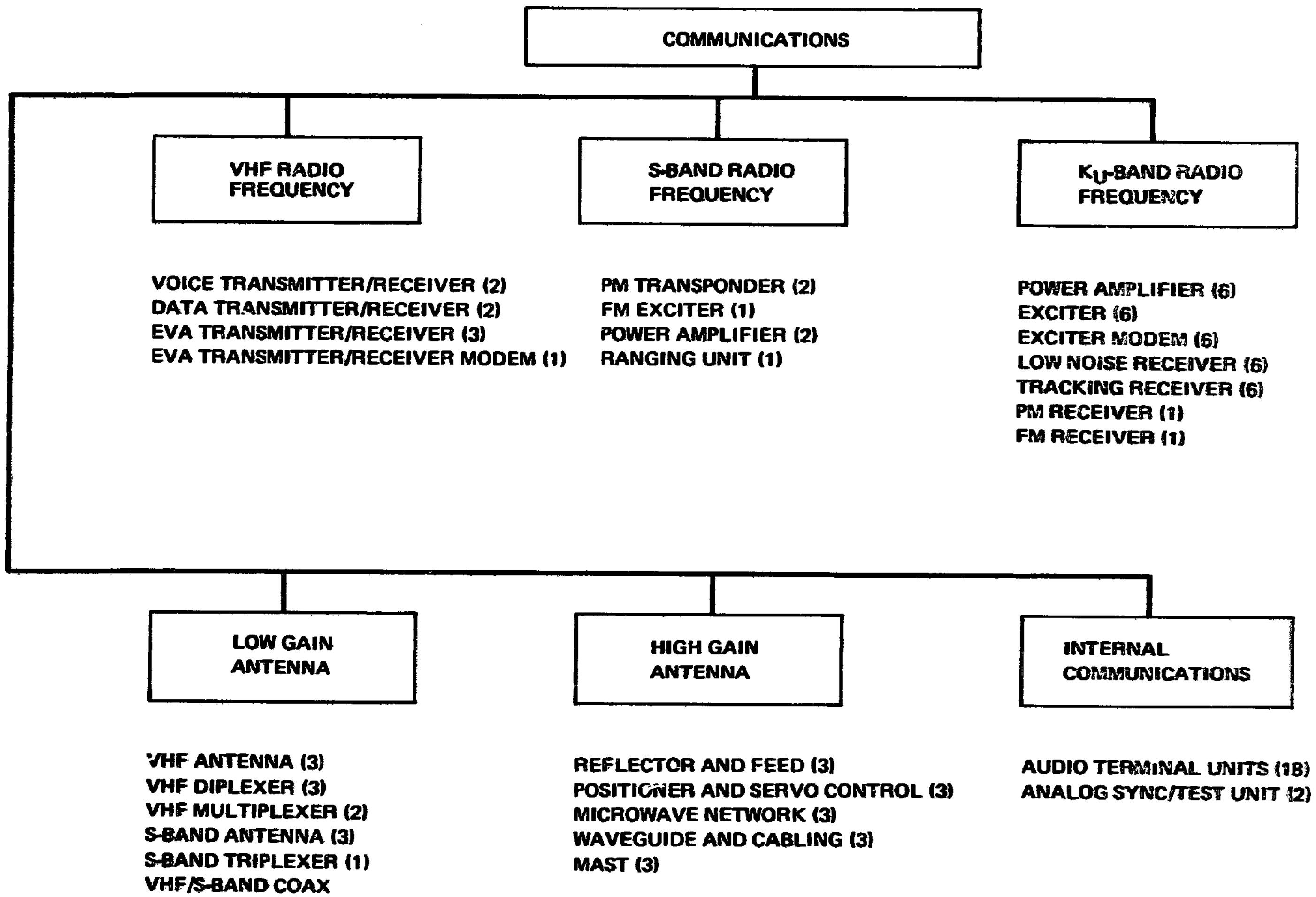

Figure 3-38. Communications Subsystem Assembly Group Breakdown

Table 3-9

SPECIFICATIONS OF THE COMMUNICATIONS SUBSYSTEM

VHF System	
Frequency range	126 to 144 MHz and 250 to 300 MHz
Antenna type	Low gain (omni)
Transmitter power	20 watts and 1 milliwatt
Receiver noise figure	4 db
S-Band System	
Frequency range	2.1 and 2.3 GHz
Antenna type	Low gain (omni)
Transmitter power	20 watts and 1 watt
Receiver noise figure	6 db
K_u-Band System	
Frequency range	13.4 to 15.4 GHz
Antenna type	2.44 m parabolic reflector
Transmitter power	20 watts/channel
Receiving system temperature	1,000°K
Internal Communications System	
Baseband emergency voice channel	
36 audio subcarriers on analog bus	
18 audio terminals	

OBCO elements is provided in Figure 3-42. Stimulus generation, command generation, and data acquisition capabilities are distributed throughout the station as dictated by checkout data-point locations.

Local caution and warning units are located in each habitable compartment, with overall status provided at both the primary and secondary control centers. Display, control, and data-processing functions, on the other hand, are primarily centralized with separate capabilities provided for subsystem and experiment support. Distribution of information between various elements of the system is primarily by the DMS digital data bus. The ancillary test equipment shown in the block diagram is provided as part of the GPL experiment-support capabilities. This equipment is necessary to support checkout and fault isolation, which involves measurement requirements exceeding basic OBCO capabilities. These requirements are due, for example, to the need for measurements of extreme accuracy or range, or to nonelectrical interfaces that are not convertible to OBCO-compatible form. Limited use of the equipment is expected, and it has no direct interface with other OBCO elements.

The OCS design minimizes the need for crew participation in routine checkout functions, but it does allow for crew intervention when special capabilities of the crew are needed or requested. It also operates largely

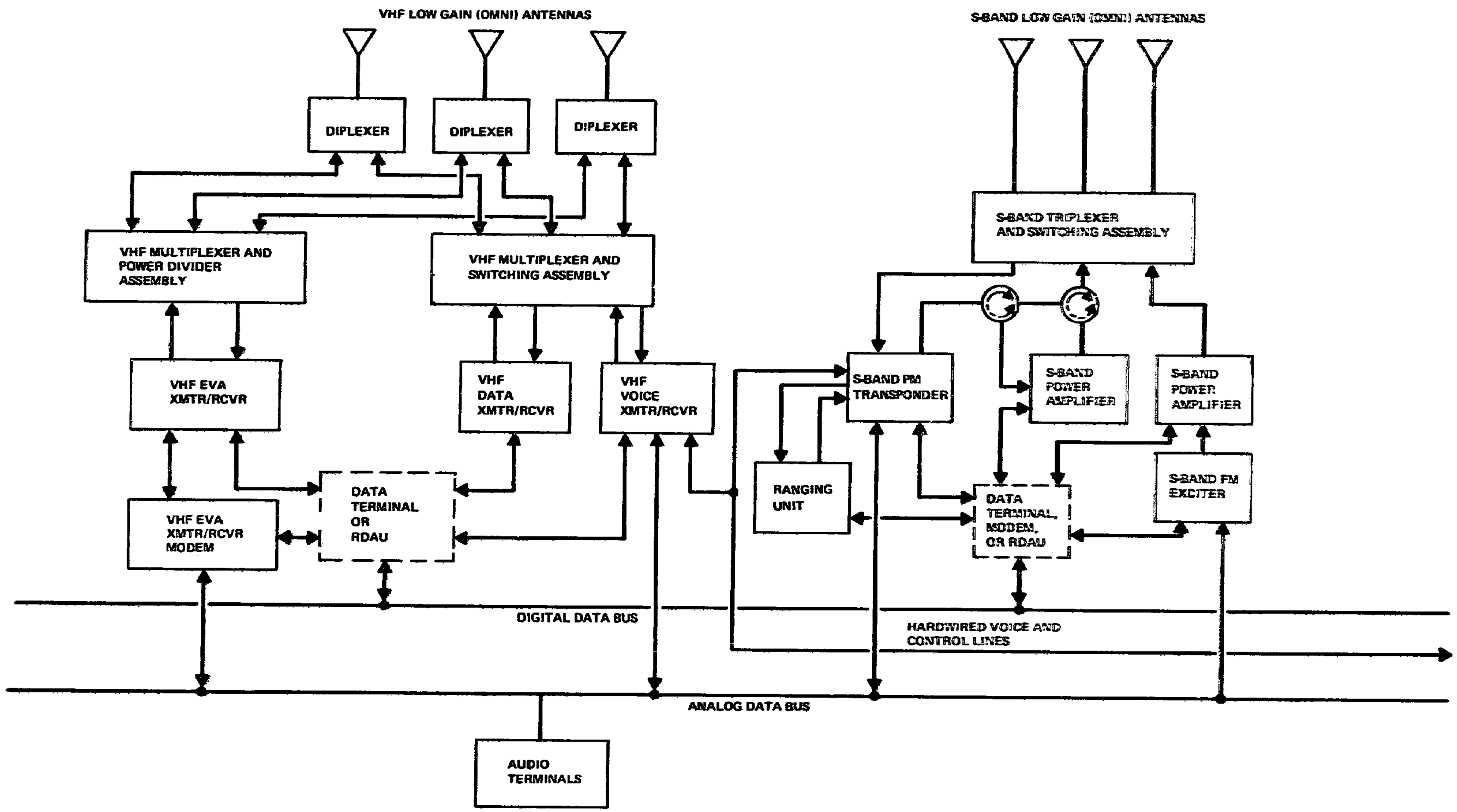

Figure 3-39. Communications Subsystem Schematic--Power/Subsystem Module

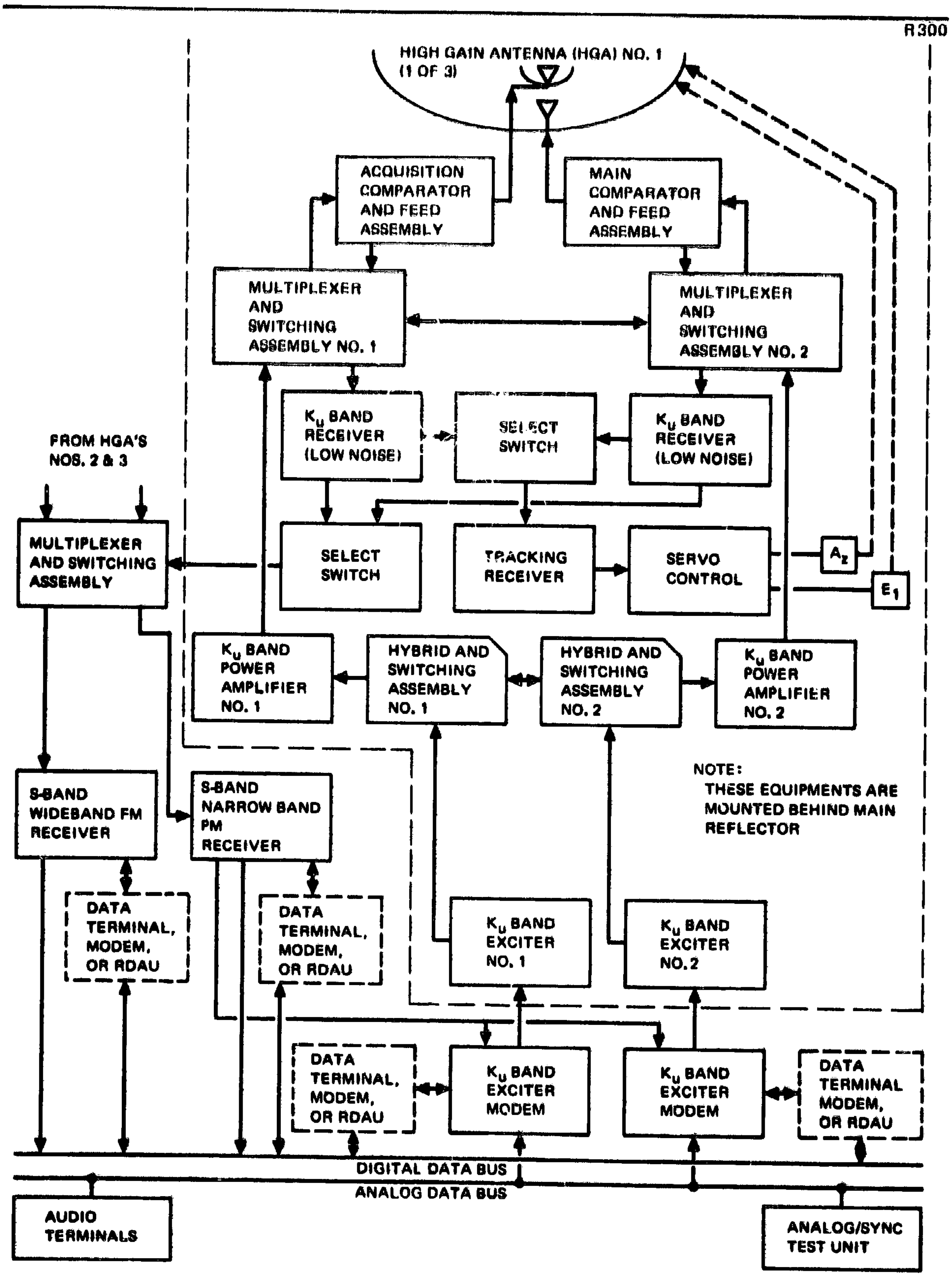

Figure 3-40. Communications Subsystem Schematic--Crew/Operations Module

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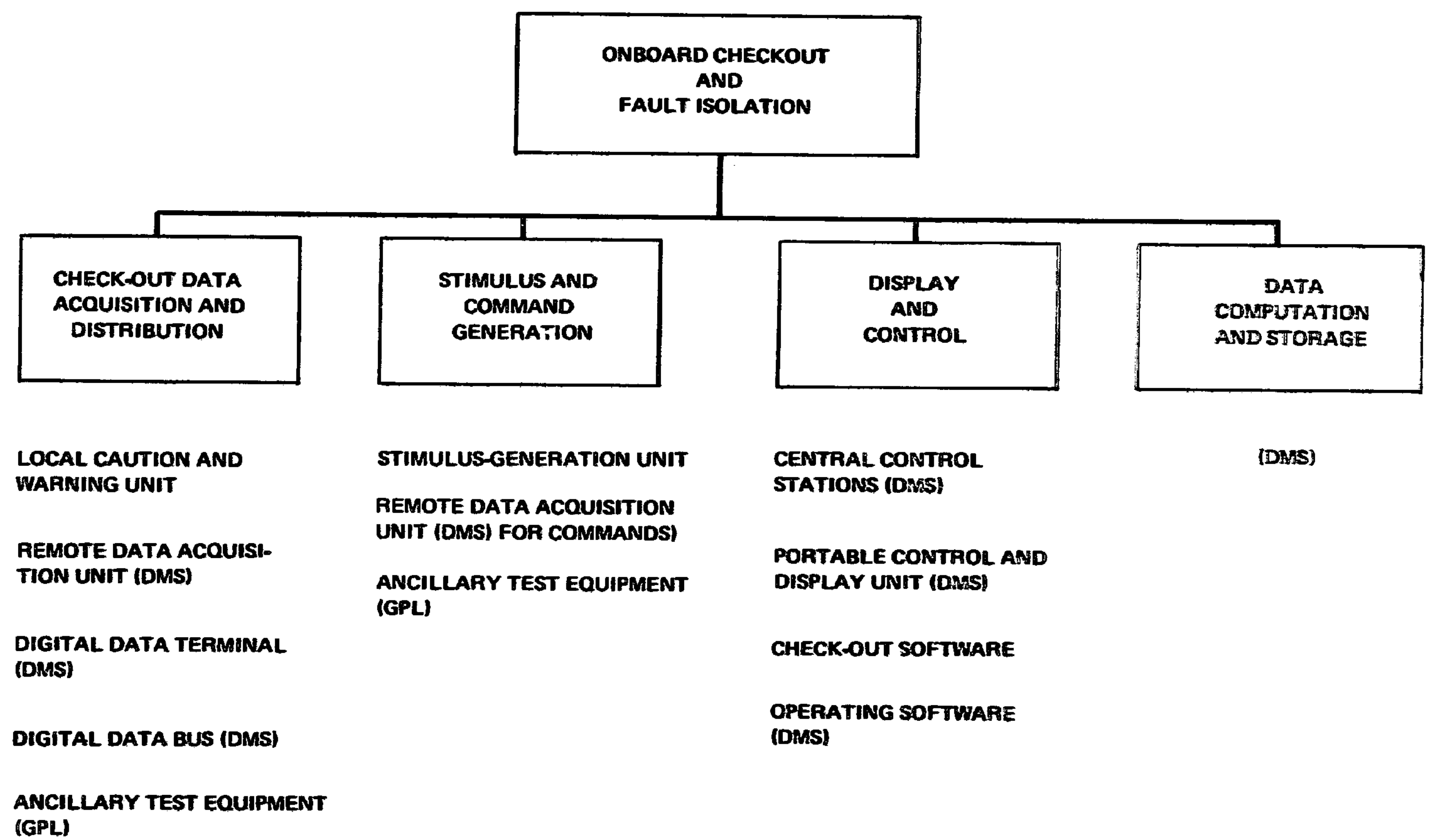

Figure 3-41. Onboard Checkout Assembly Group Breakdown

Table 3-10

SPECIFICATIONS OF THE OBCO SUBSYSTEM

Function	Characteristic	Capacity: Subsystems	Capacity: Integral Experiments	Capacity: ISS Total	Operation
Checkout Data Acquisition	Serial digital inputs: $\leq 1 \times 10^6$ bps per channel	74	8	82	Computer-controlled
	Discrete inputs: 0 or 5 vdc	1,488	128	1,616	Random or sequential sampling
	Analog inputs: 0–40 mv or 0 to 5 vdc processed with $\geq$ 7-bit accuracy	2,790	240	3,030	Remotely programmable limits
Stimulus Generation	Serial digital outputs: $\leq 1 \times 10^6$ bps per channel	37	8	45	Computer-controlled
	Discrete outputs: 0 or 5 vdc	1,488	128	1,616	
	Analog outputs: 0 to 115 vdc	384	128	512	
Critical Measurements	Caution parameters: 0 or 5 vdc discretes 0 to 40 mv or 0- to 5-vdc analog			40 292	Independent warning system Local and central displays
	Warning parameters: 0 or 5 vdc discretes 0 to 40 mv or 0- to 50-vdc analog			18 68	Audio and visual alarms
	Sampling rate: $\leq$ 5 times per second				
Processing	Operations per second: Main memory: 32-bit words	40,000 18,000	48,000* 10,000*	88,000 28,000	Automatic Restructurable application programs
	Auxiliary memory: 32-bit words	43,000	54,000*	97,000	

*Includes integral and RAM experiments

autonomous of ground control, although a high degree of ground system interface is possible. This is because of the system's capability for random access, rapid distribution, and complete control of checkout data. Any or all checkout data points can be selected for transmission to the ground. It is anticipated, however, that ground checkout support will be limited to that required for consulting with the crew on checkout and fault isolation problems; supporting ISS quiescent modes of operation; performing large data-processing tasks, such as long-term trend analysis; and conducting detailed failure analyses through examination of engineering data and failed parts that have been returned from orbit.

Another important aspect of the selected design is that of minimizing the types of OBCO interfaces. This is particularly important since the OBCO must interface with all other subsystems, diversified integral experiments, and docked modules. The minimization of interface types, as well as a high degree of standardized modularity in design, assures responsiveness to station reconfiguration and growth.

Figure 3-43 is a schematic diagram of the OBCO subsystem.

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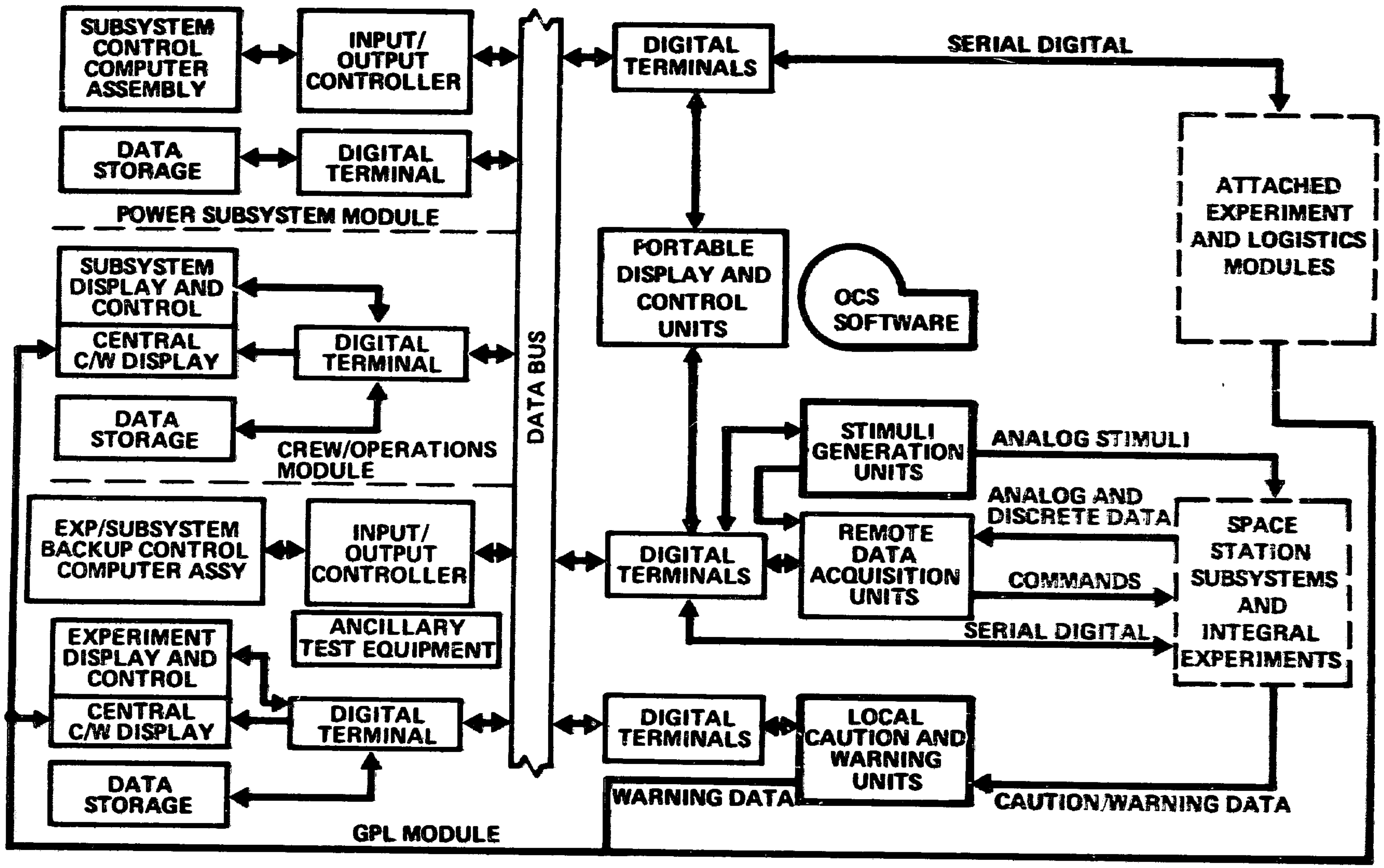

Figure 3-42. Onboard Checkout Block Diagram

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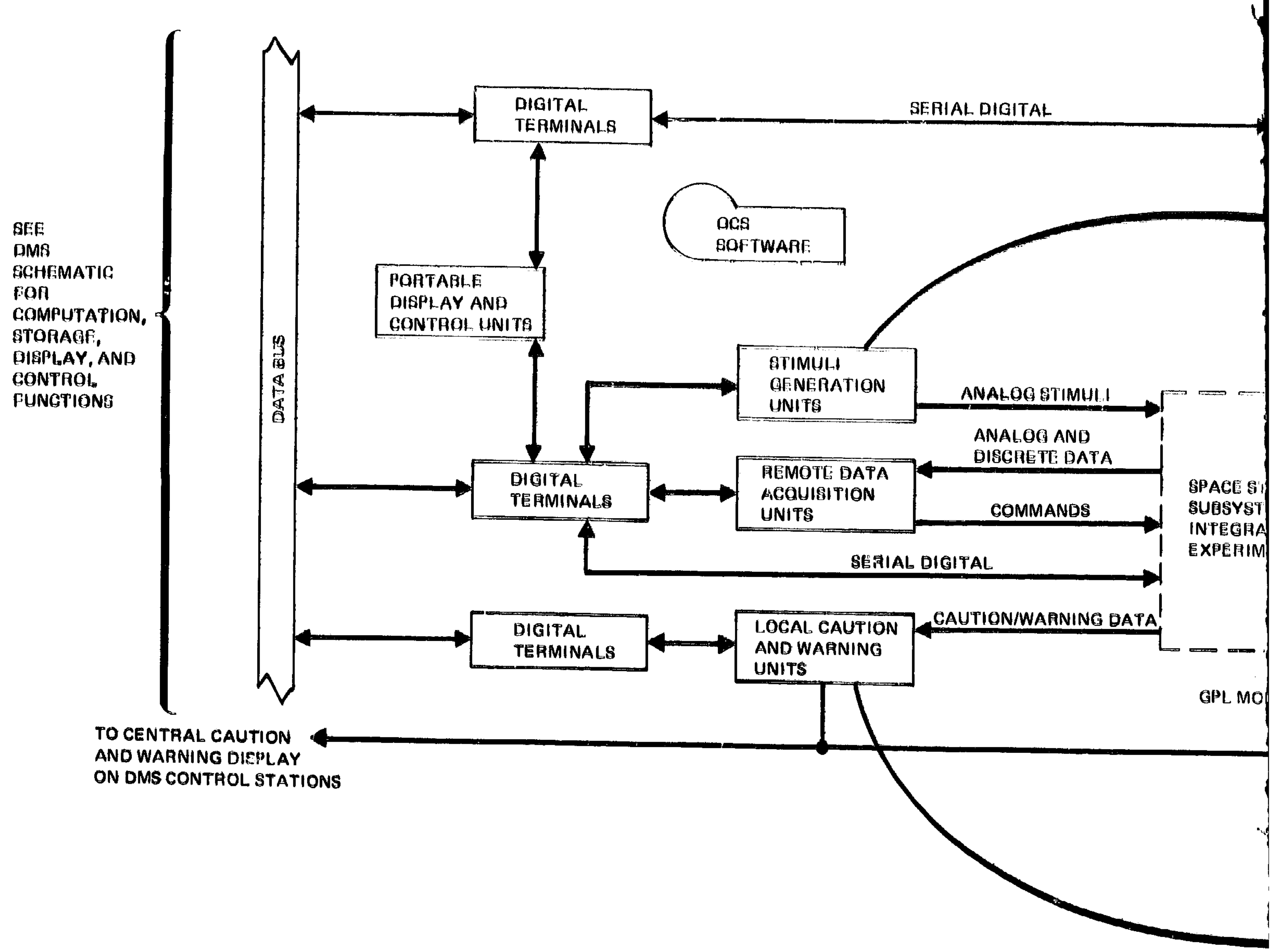

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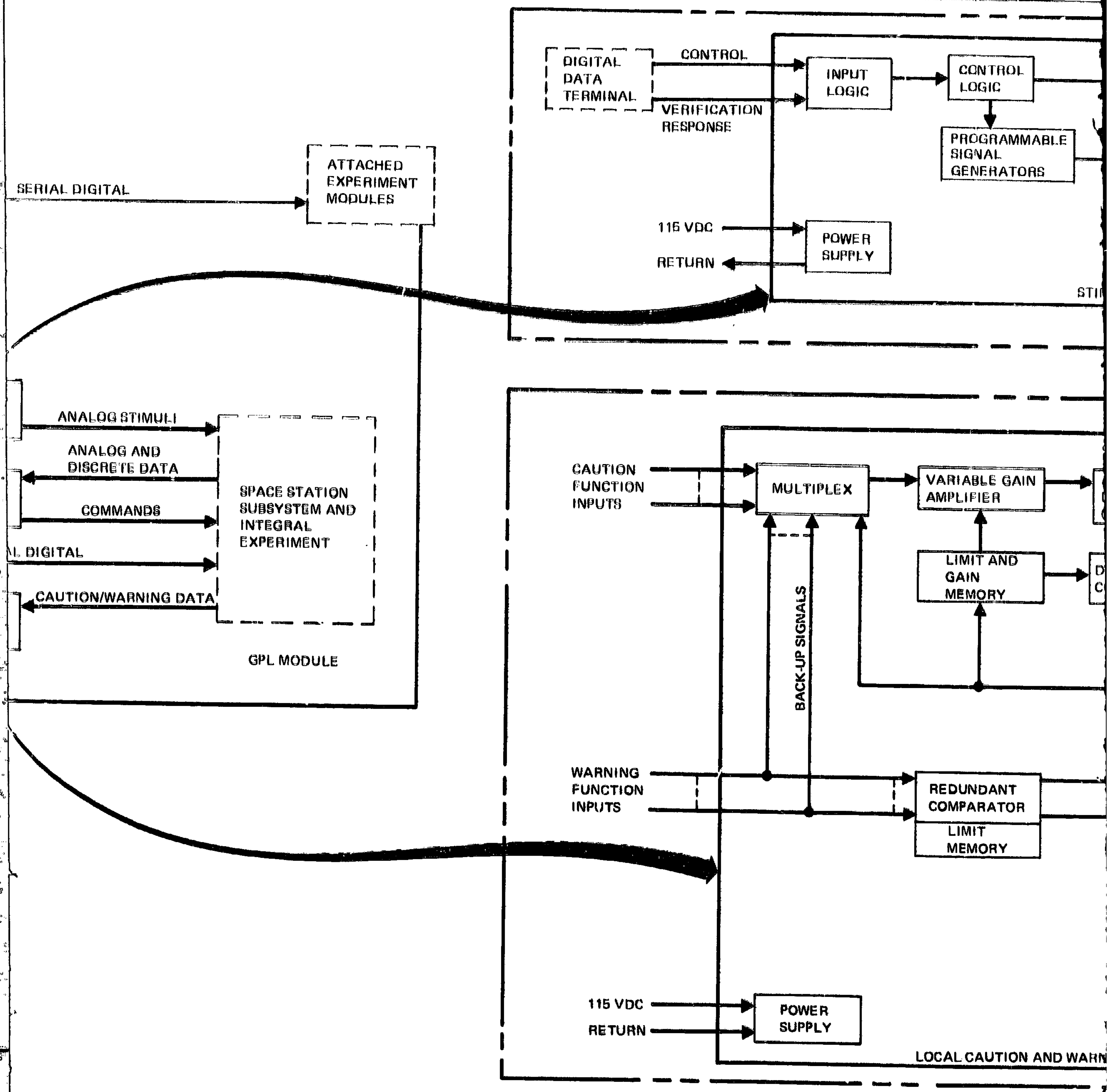

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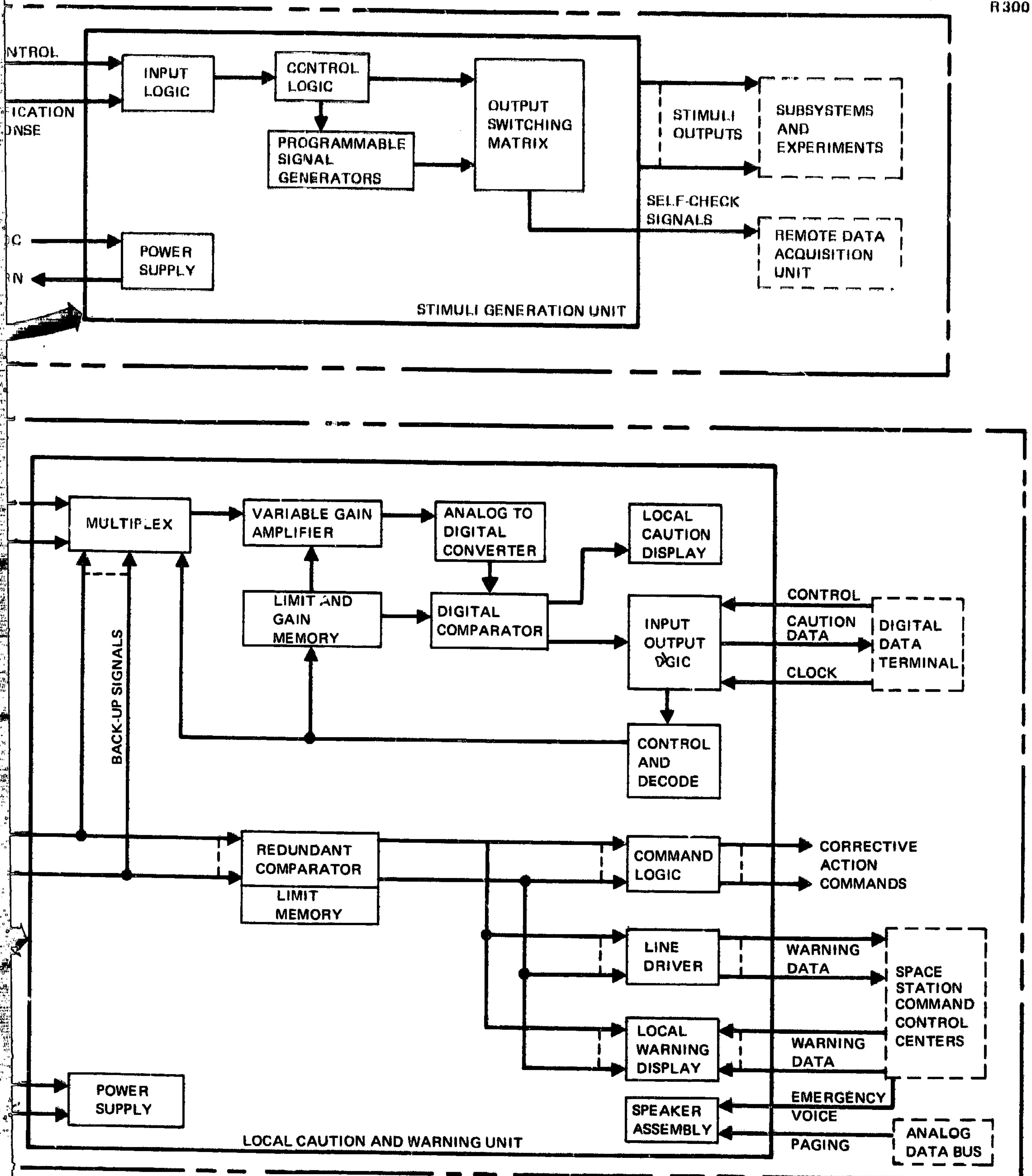

Figure 3-43. Onboard Checkout Subsystem Schematic

3.2.9 Structure/Mechanical Subsystem

The design of the structure/mechanical subsystem is based on the requirement to provide structural integrity during ground operations, shuttle launch, on-orbit operations, and shuttle return. The 10-year life imposes a requirement for a rugged, damage-resistant design that car withstand both meteoroid impact and accidental damage. The structural material also provides thermal protection and radiation shielding.

The pressure shell structure for each of the three modules is of the same basic design. Differences exist only in length and radial docking port cutouts. The cylindrical portion of the shell is 4.1 m (160-in.) inside diameter and is stiffened with 24 equally-spaced integral longitudinal ribs and rings spaced every 20.3 cm (8 in.) along the length. Integral end flanges provide a bolted and sealed interface with the conic transition structure. Figure 3-44 illustrates the shell details for the Power/Subsystem Module. All stiffening ribs are located on the outside surface leaving the internal surface smooth to facilitate on-orbit repairs. This portion of the shell is fabricated from 2219-T87 alloy in three segments and welded along longitudinal seams. The membrane is 0.15 cm (0.060 in.) and the external stiffeners are 2.54 cm

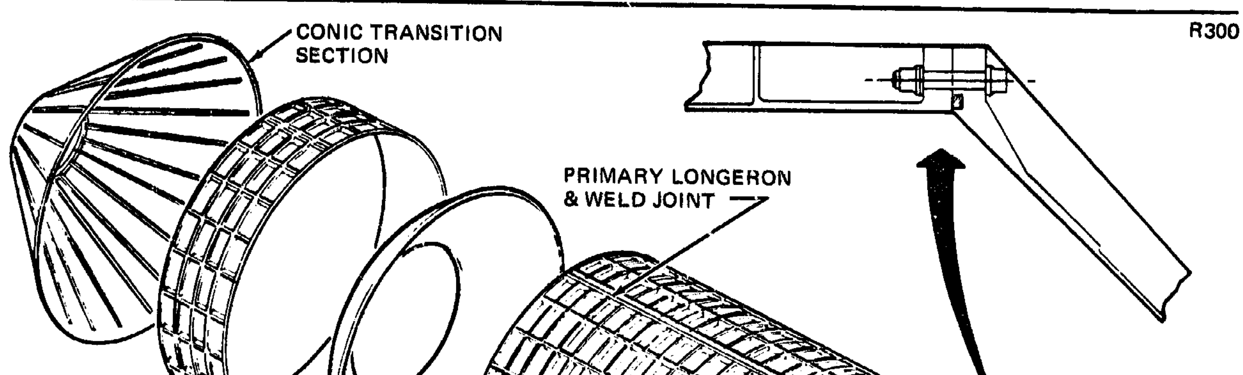

Figure 3-44. Power/Subsystems Module Pressure Shell

(1. 0-in.) high measured from the inside surface. The integrally stiffened conic structures are used on all modules to make the transition from the 4. 1 m (160-in.) diameter to the 2. 59 m (102-9n.) diameter docking interface. This conic is extended on one end of the power module to interface with the solar array support tunnel. A spherical membrane dome 0. 15 cm (0. 060-in.) thick is used only in the Power/Subsystems Module to form an unpressurized compartment to house the Propulsion Subsystem tankage.

A ring- forged fitting is attached to the pressure shell at each docking port cutout. This fitting forms the end closure of the module, provides the structural interface with other modules, provides structural support for the docking mechanism, and forms the frame for the pressure hatch. The fitting is machined from a ring forging of 2219-T87 aluminum alloy. The design allows it to be used for radial or end docking ports.

Figure 3-45 shows the basic structural concept for each of the Space Station modules. An external shroud encapsulates the pressure shell and provides the radiating surface for the EC/LS Subsystem, meteoroid protection, and thermal protection. The 0. 04 cm (0. 016-in.) outer surface is formed from extruded sections which contain flow passages for the EC/LS radiatior fluid.

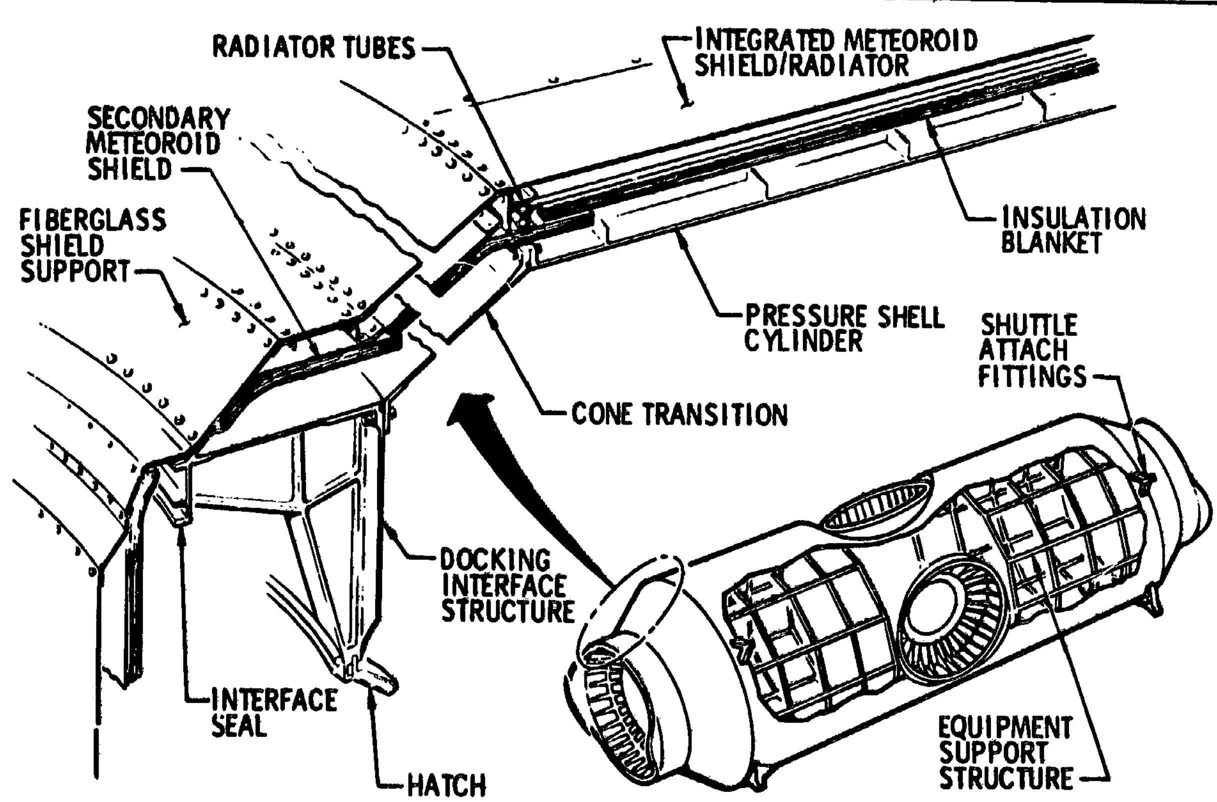

Figure 3-45. Structure Concept

A second bumper, to protect the 1.27 cm (1/2-in.) blanket of high performance insulation, is attached to the radiatior extrusion forming a box section. The assembly is installed over the pressure shell and supported by fiberglass insulators. The outside diameter of the radiatior is 4.3 cm (168-in.) diameter.

Detail design of the Crew/Operations Module and the Power/Subsystems Module is shown in Figures 3-46 and 3-47. The power module solar array support tunnel of 2219-T87 aluminum is 5.59 meters (18.35-ft) long and 1.02 m (40-in.) inside diameter. The tunnel shell is stiffened with integral ribs in an isogrid pattern. The membrane is 0.127 cm (0.050-in.) thick. The tunnel pressure shell is shielded with a spaced double bumper of 7075-T6 aluminum, each sheet of which is 0.03 cm (0.012-in.) thick. Fifty layers of superinsulation (doubly aluminized mylar with interspersed layers of dacron net) are installed on the inner surface of the second bumper with nylon pins.

The power module solar array turret is a truncated sphere of 2219-T87 aluminum which is 2.44 m (8-ft) inside diameter. The sphere is machined in two sections from forged hemispheres which are subsequently welded together with the weld line located 90 degrees from the solar array masts. A pattern of integral ribs stiffens the spherical pressure shell. A 45 degree cone of integrally stiffened 2219-T87 aluminum provides the transition between the spherical turret and a standard machined docking ring which provides a standard docking interface at the solar array end of the Power/Subsystems Module. Conical and cylindrical sections of spaced double bumper with 0.03 cm (0.012-in.) 7075-T6 aluminum faces with 50 layers of doubly aluminized mylar and dacron net on the inside of the second bumper provide meteoroid and thermal shielding for the turret.

The internal support structure is a cage-type structure composed of 12 longerons and interconnecting beams spaced at intervals along the longitudinal axis. These beams connected at the longerons form a dodecagon shape which fits within the 4.1 m (160-in.) diameter of the pressure shell.

The cage is pinned to the pressure shell at one end of each longeron, thus, longitudinal loads, both tension and compression, are transmitted to the shell through these pins. Radial loads are transmitted to the pressure shell through blocks which are spaced along each longeron and attached to the pressure shell. The internal support structure provides the mounting for all internal equipment and allows flexibility of arrangement and assembly.

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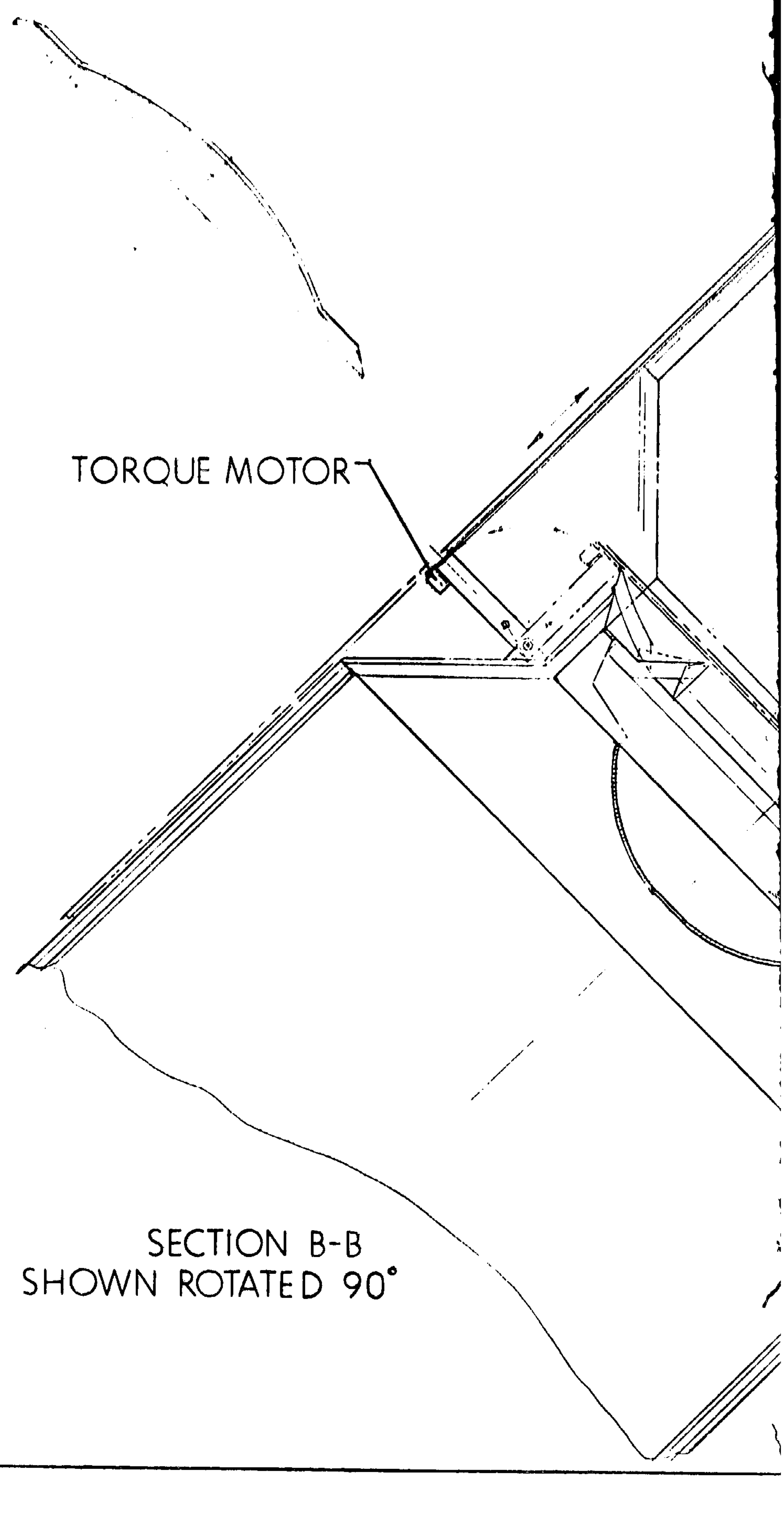

SECTION B-B
SHOWN ROTATED 90°

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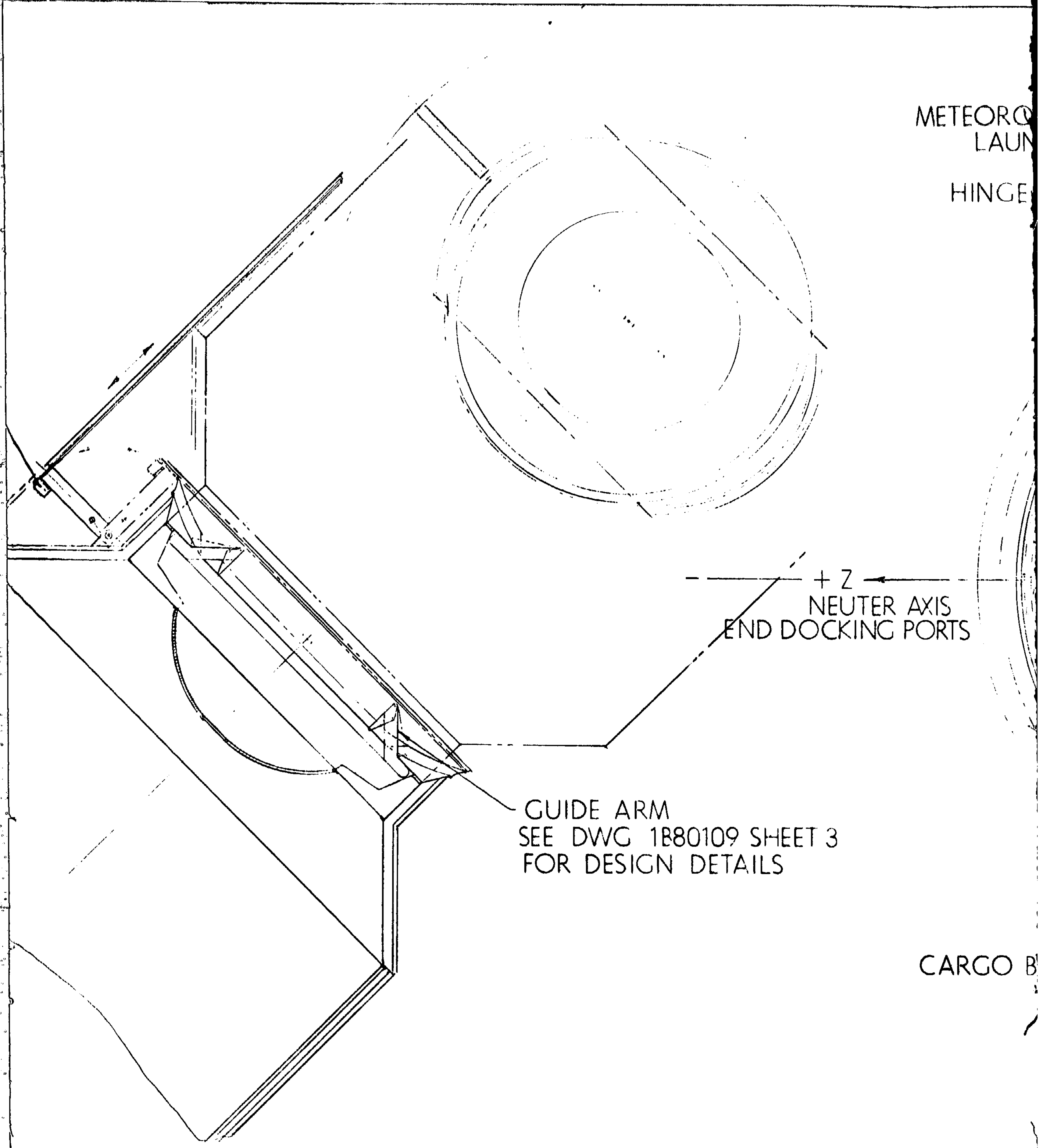

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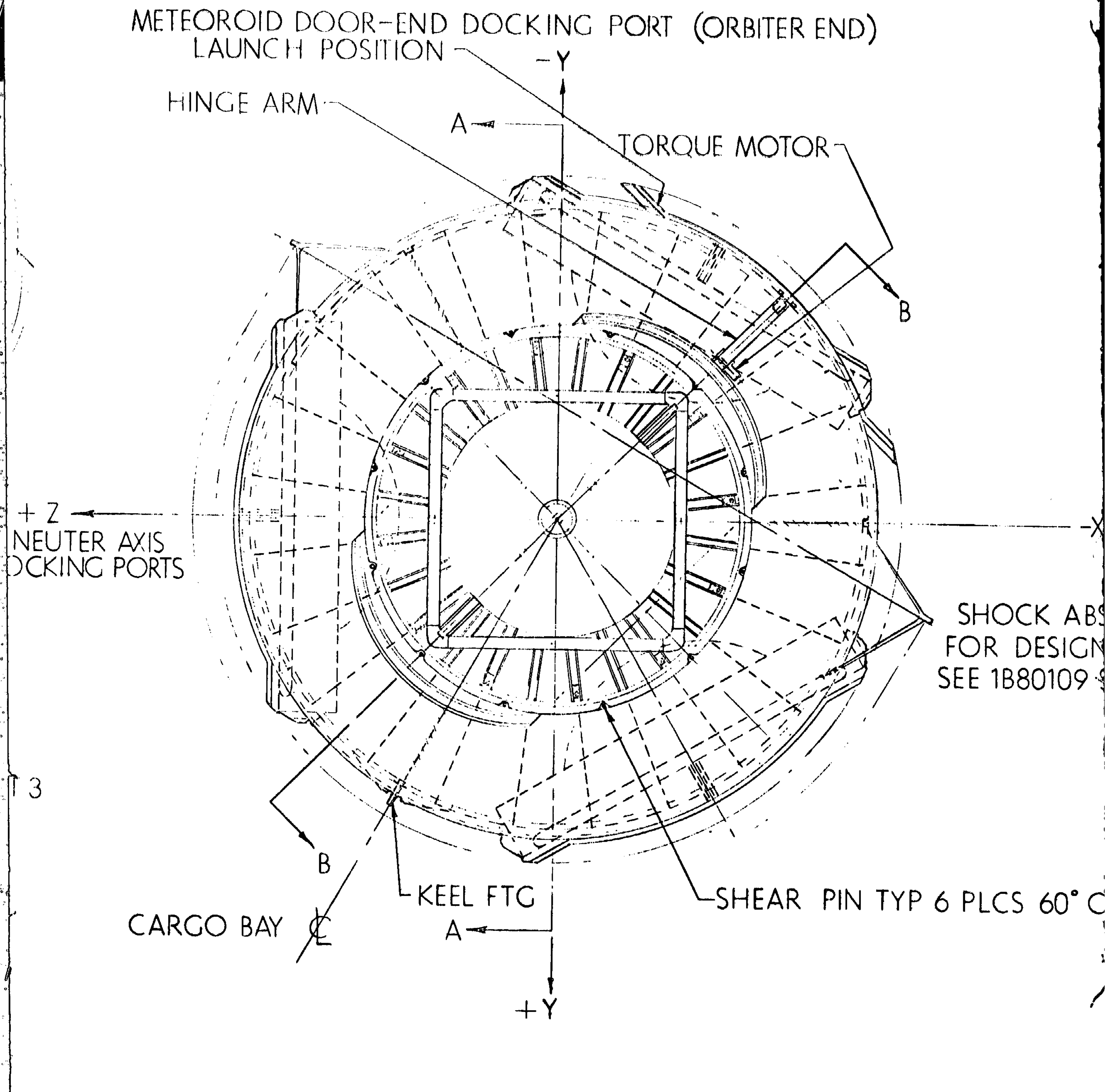

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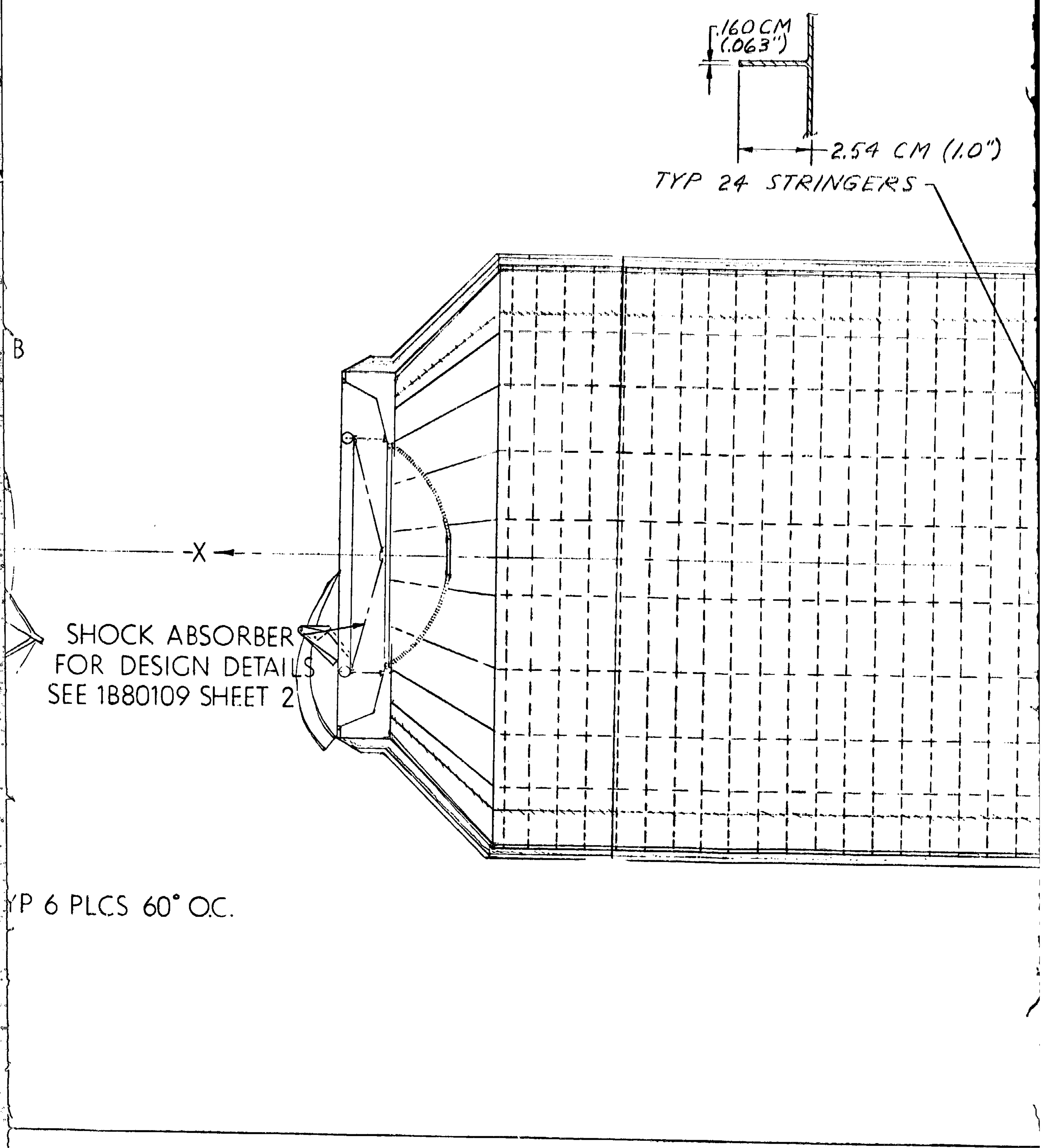

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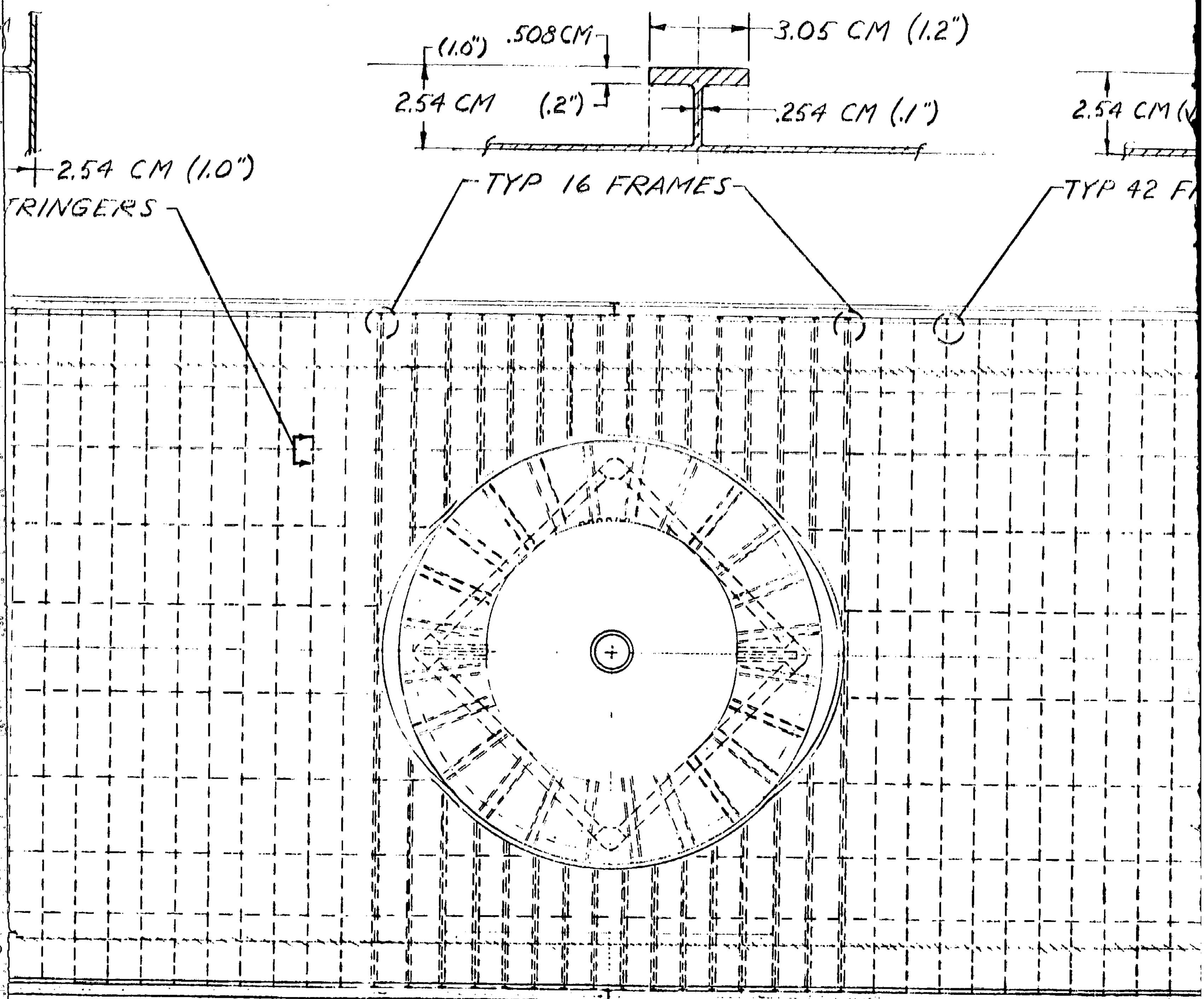

SECTION A-A
SIDE DOCKING PORT PARTIAL
SECTIONS OMITTED FOR CLARITY

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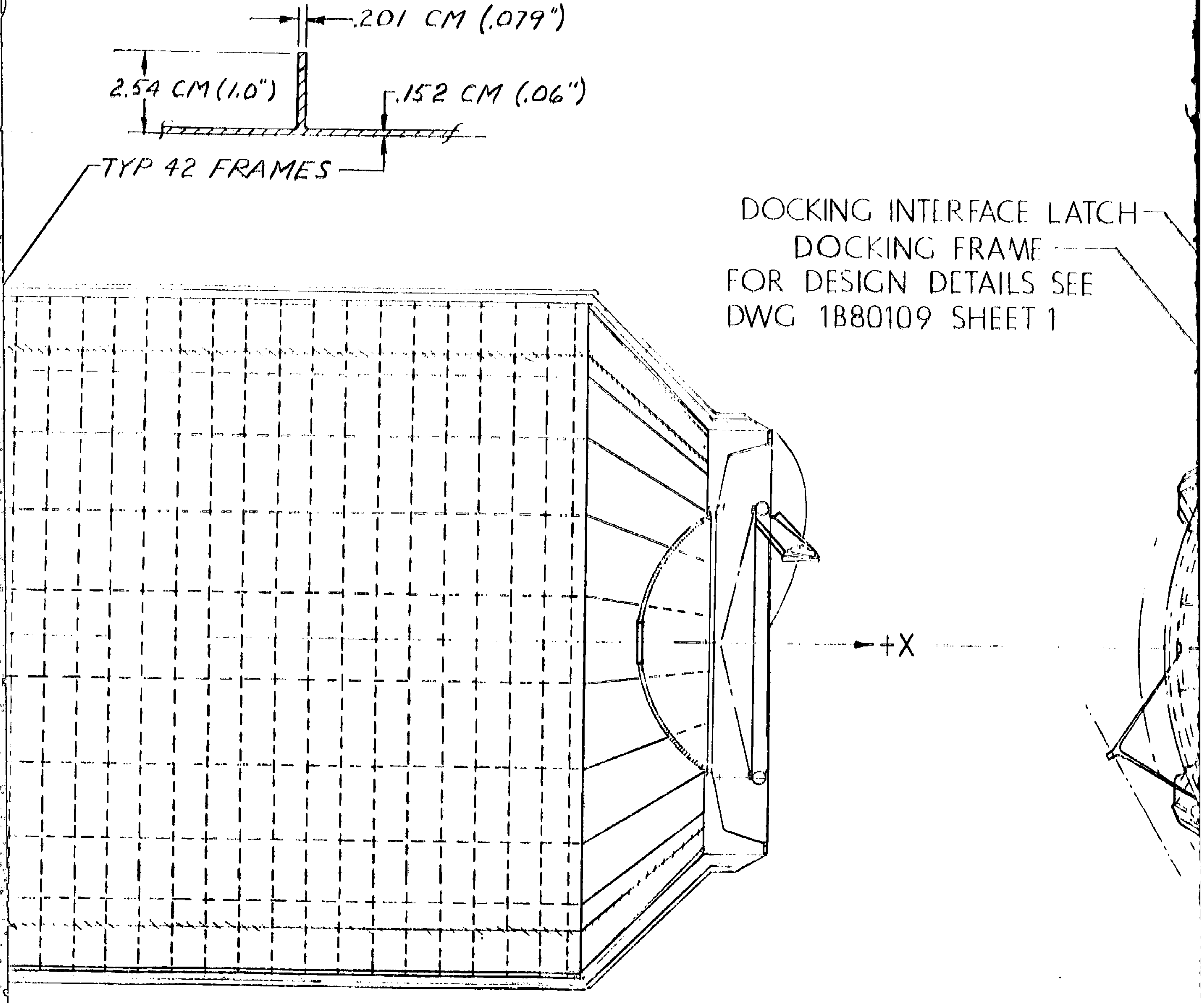

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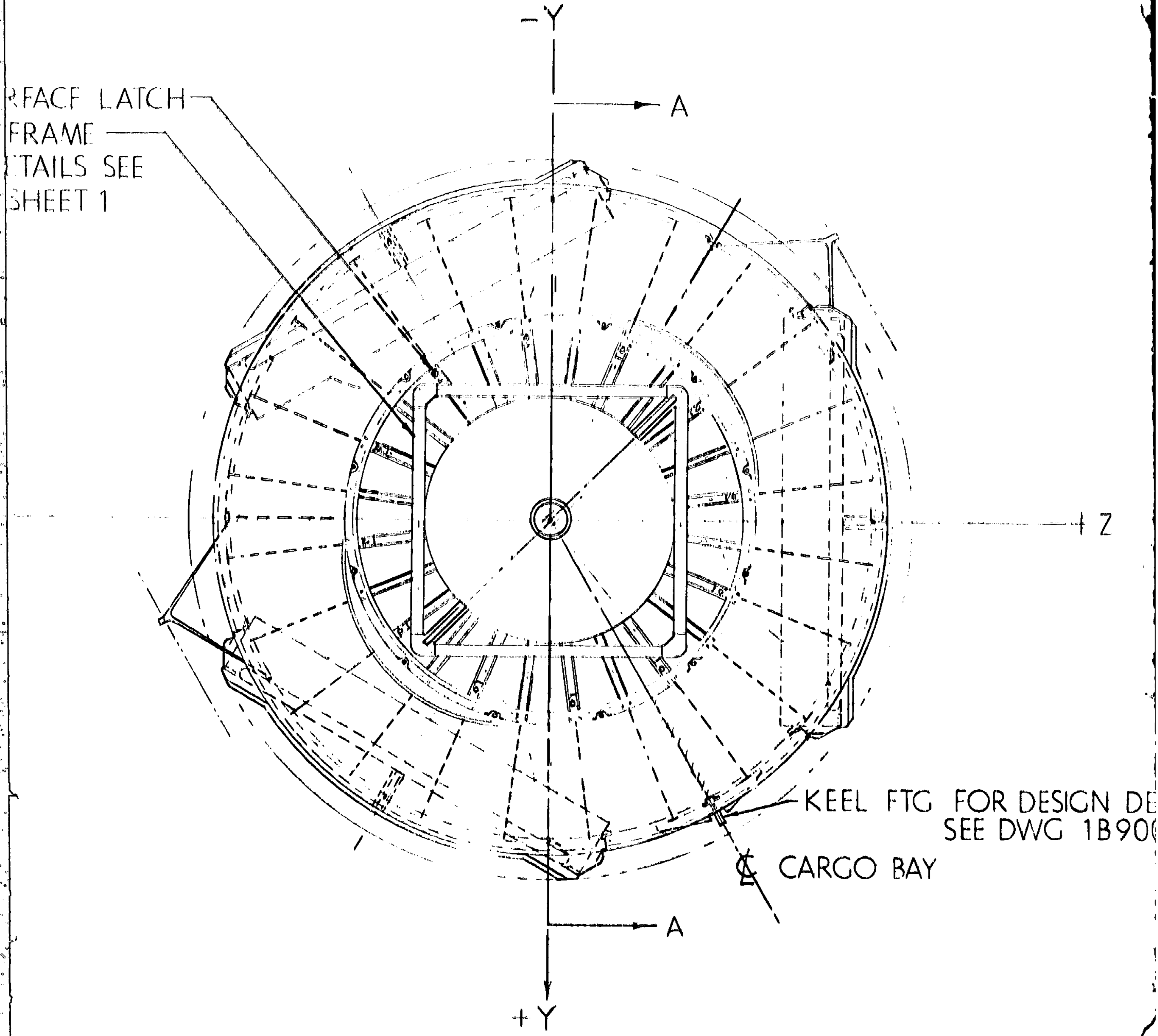

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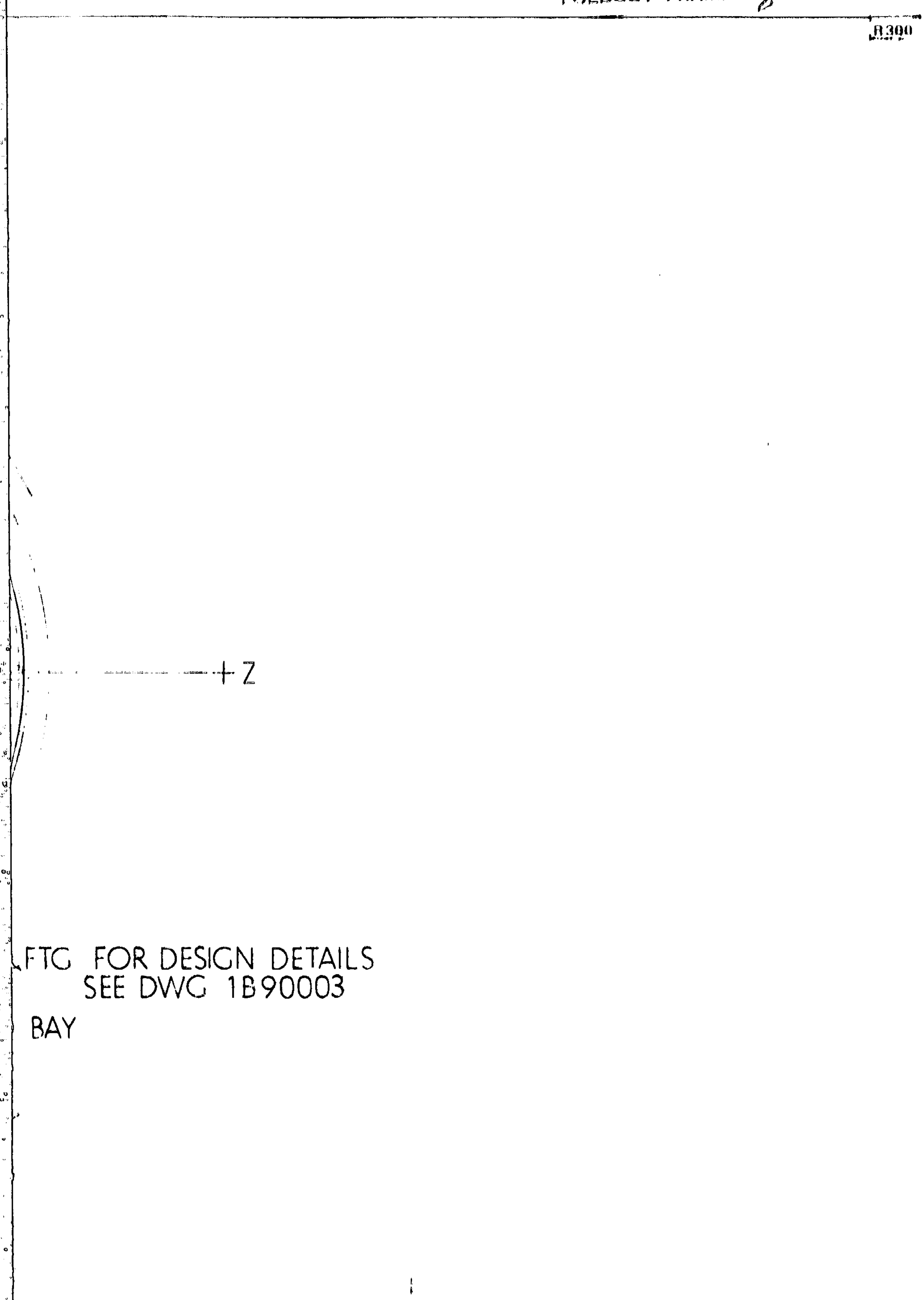

Figure 3-46. Structural Assembly Crew/Operations Module

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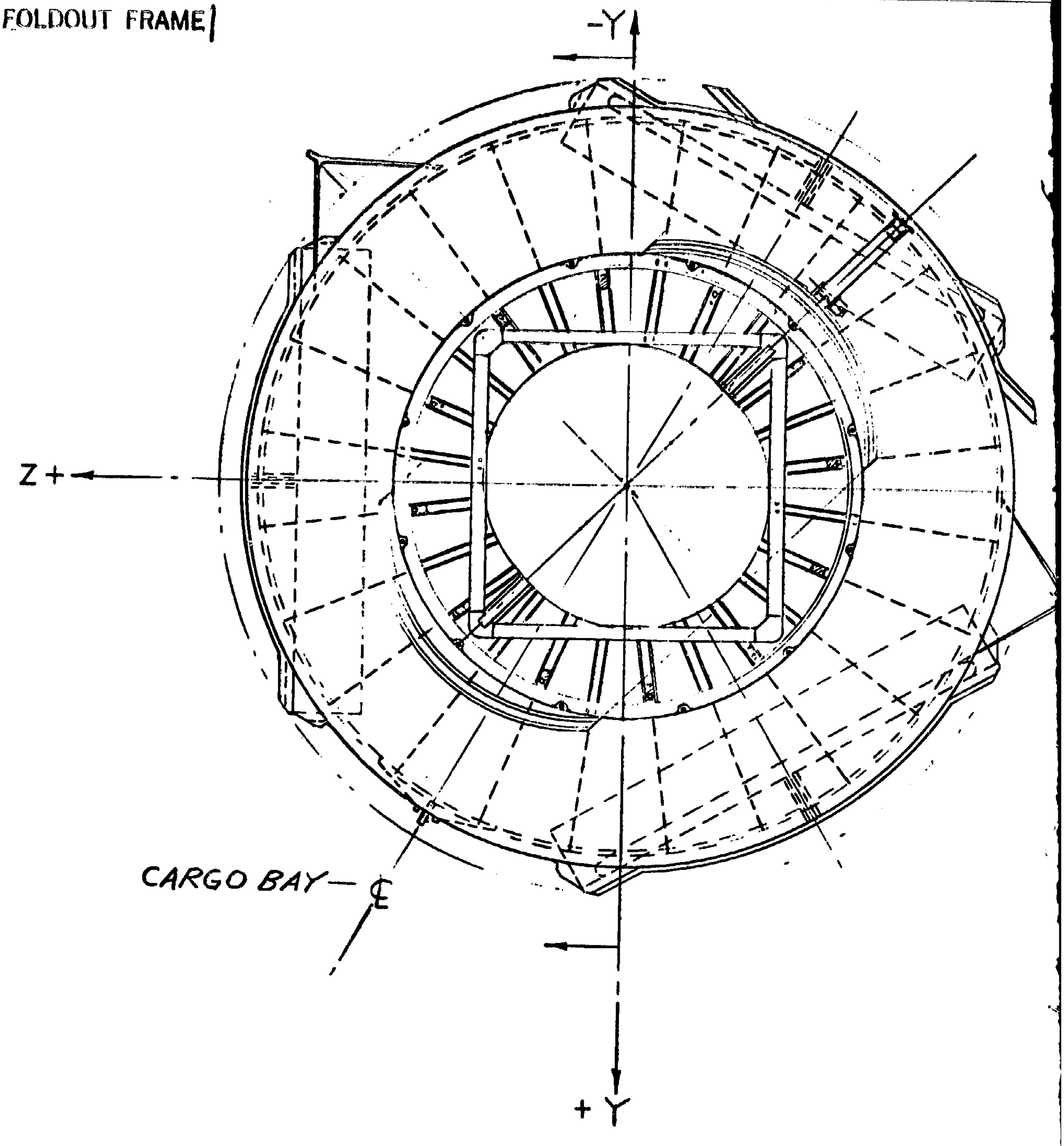

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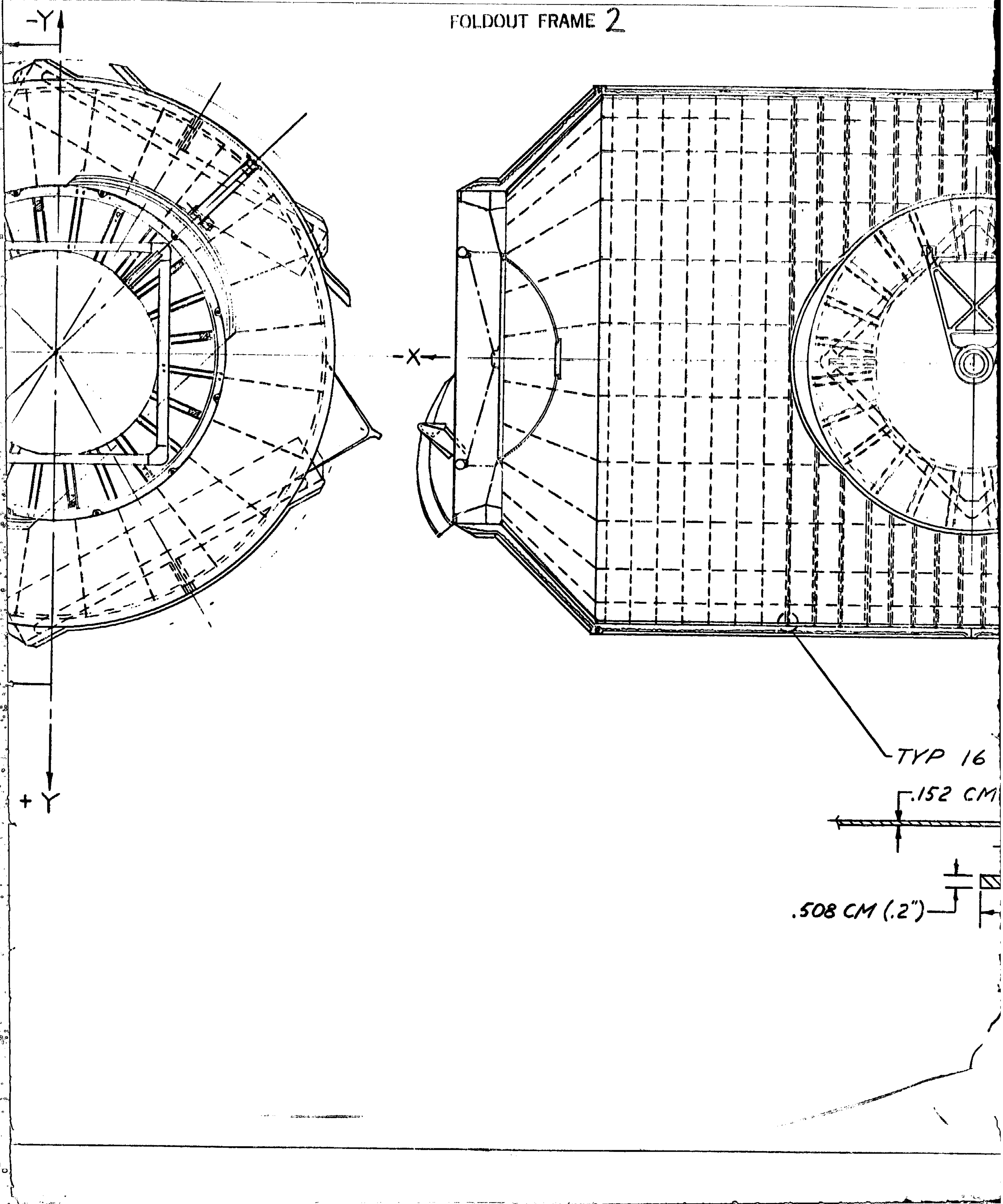

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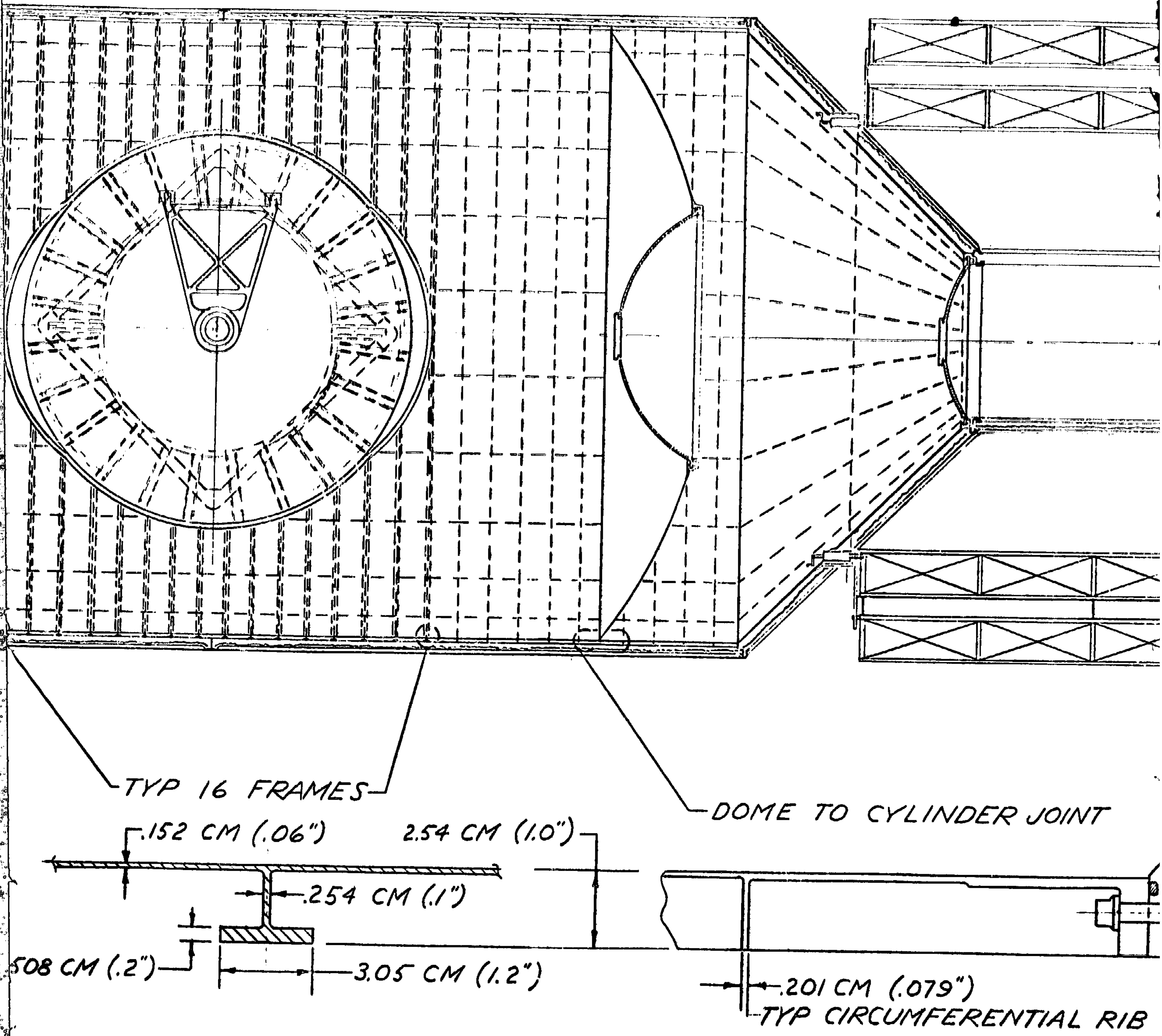

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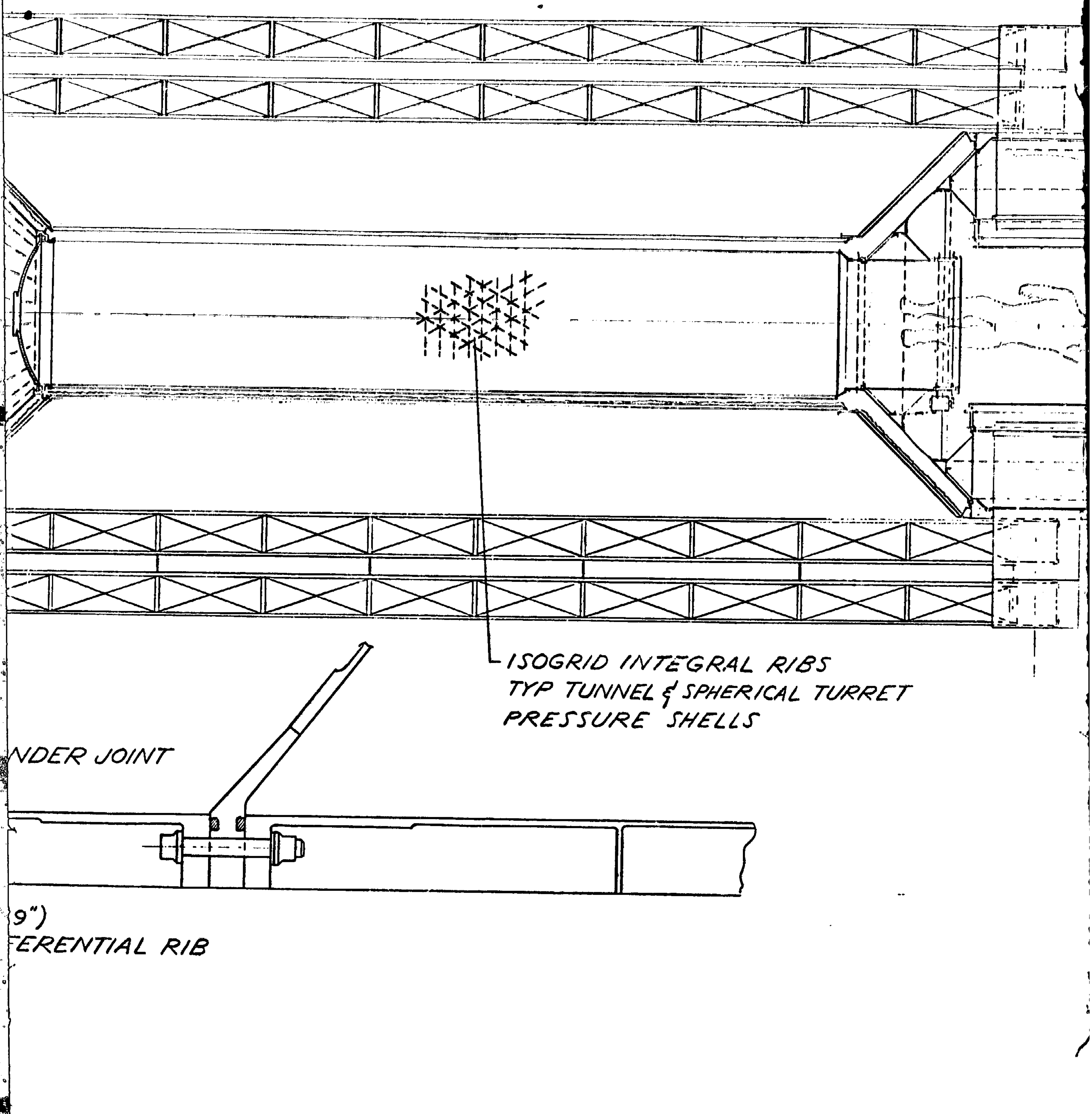

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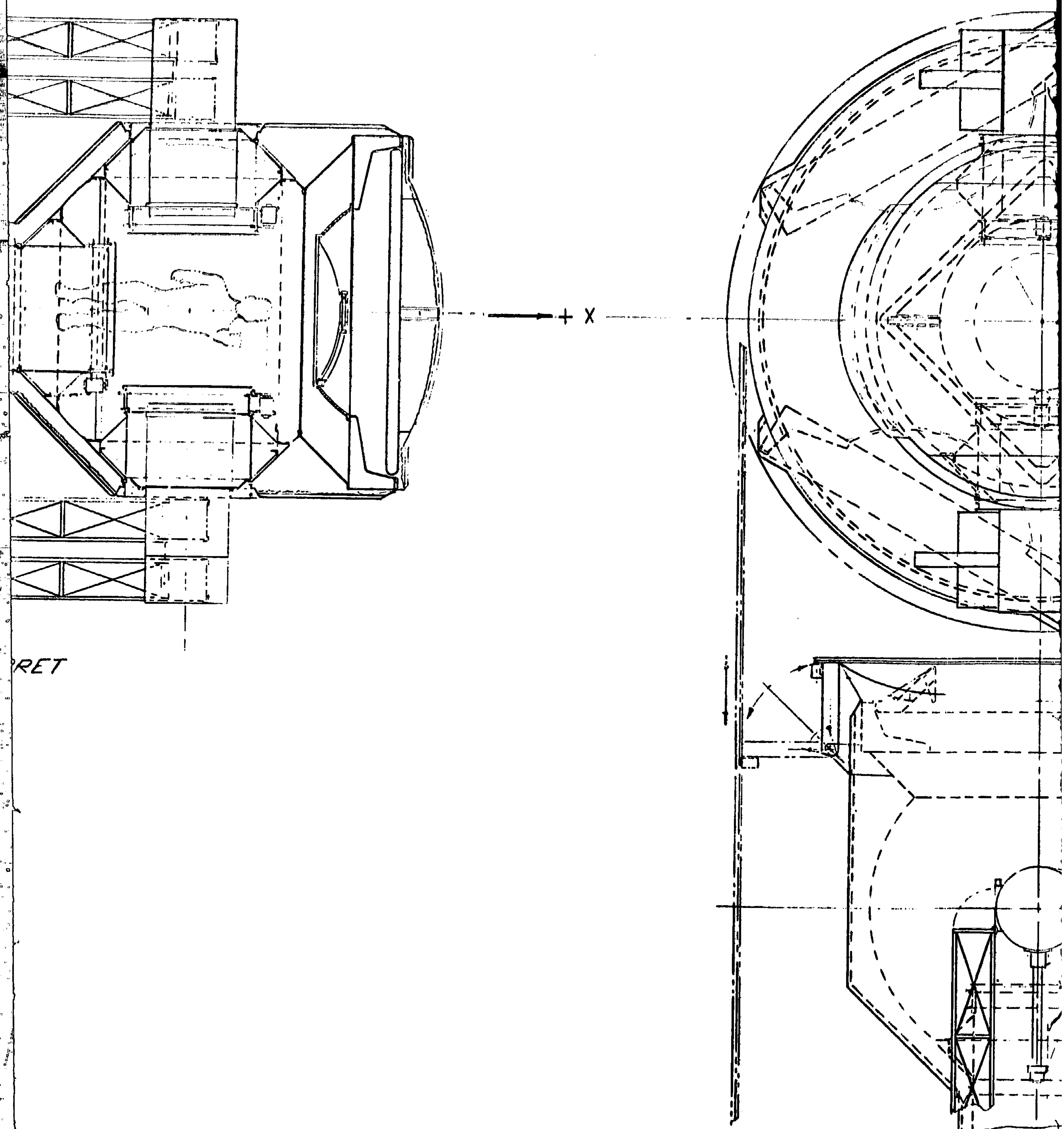

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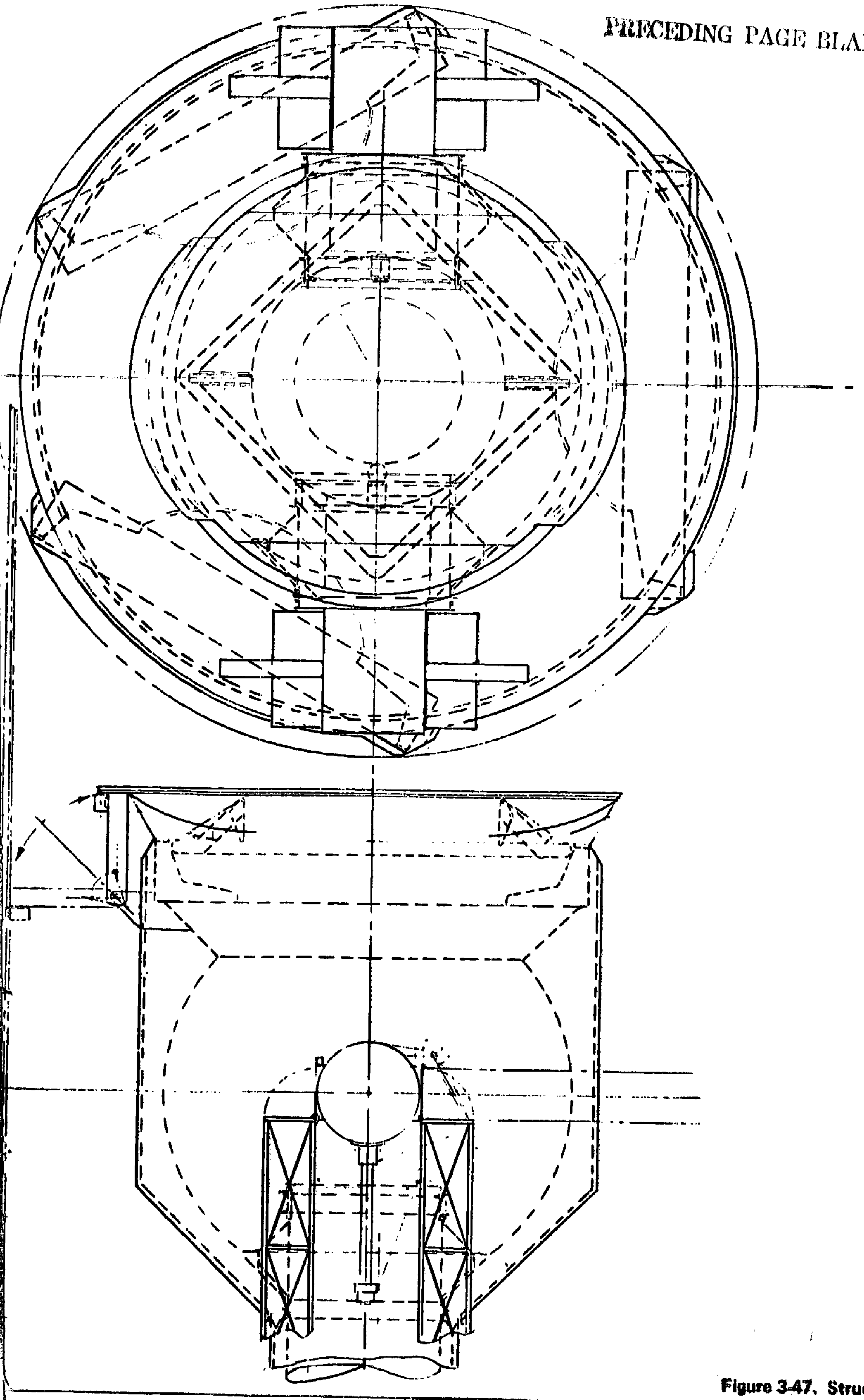

Figure 3-47. Structural Assembly [illegible]

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The docking mechanism for the Modular Space Station is a neuter, clear-center design. The structural interface is 2.59 m (102 in.) in diameter and a clear passage 1.54 m (60 in.) in diameter is provided. Each docking interface is the same, therefore, any module may be docked with any other. The mechanism consists of a square frame with guide arms and capture latches mounted in two opposite corners. The frame is supported by eight hydraulic shock absorber/actuators. The displacement of the frame against the force of the actuators absorbs the docking impact energy. After stabilization, the actuators are retracted, the structural latches engaged, and the pressure seal inflated. After two modules are docked, pressurized access to the docking mechanism and structural latches is inherent in the design.

Each of the docking ports which may be exposed for extended periods of time on orbit must be protected from meteoroids and insulated thermally. Protective covers are therefore provided. Since the module end-port cover must be open during Shuttle transport, the cover must be stowed within a 3.8 m (15 ft) diameter envelope. The end-port covers have the same shape as the radial-port covers and are stowed on the outside cylindrical surface of the module when the docking port is exposed. A track and hinge mechanism moves the cover along the longitudinal axis and then rotates it over the end port. The radial covers are simply hinged and must remain closed during Shuttle transport. The curvature of the docking structure-cover interface provides clearance for the guide arms of the docking mechanism. The covers are driven by electromechanical actuators.

A common hatch design is used throughout the Space Station. All hatches are domed, eliptical sections, aluminum honeycomb sandwich construction, and capable of differential pressure in either direction. A dual-seal arrangement is used which consists of an inflatable seal plus a static O-ring seal. Two sizes of hatches are used. Most provide 1.54 m (60-in.) clearance. Three smaller hatches provide 1.03 m (40-in.) clearance. When two modules are docked, the domed hatches provide an intermodule IVA airlock which allows two suited crewmen to gain access to an unpressurized module. The selected design provides this feature with essentially no weight penalty. Each hatch contains a 15.3 cm (6-in.) diameter viewport.

In addition to the hatch viewports, 30.6 cm (12 in.) diameter viewports are installed in each crew compartment, three in the wardroom, one at the primary command and control console, and one adjacent to each scientific airlock in the GPL. The viewports are designed with dual panes to provide protection against meteoroids and internal damage. A mechanism for the replacement of a viewport assembly has been designed which allows viewport removal and replacement without depressurizing the module.

Figure 3-48 illustrates schematically the solar array drive and orientation mechanism. The array is driven about two axes. The longitudinal axis drive is located between the fixed tunnel and the turret. Two independent drives, attached to the turret, rotate the array wings in the transverse axis. All drive mechanisms are identical and use an electromechanical power source and a harmonic drive for gear reduction and torsional stiffness. The interior of the turret is pressurized allowing the drive mechanisms to operate in an atmosphere and allowing shirtsleeve maintenance. Each drive incorporates a pressure balance arrangement to eliminate static load on the bearings.

Design of the GPL module is the same as the crew/operations module except that it does not have radial docking ports and includes a test and isolation chamber. The test and isolation chamber pressure bulkhead, which

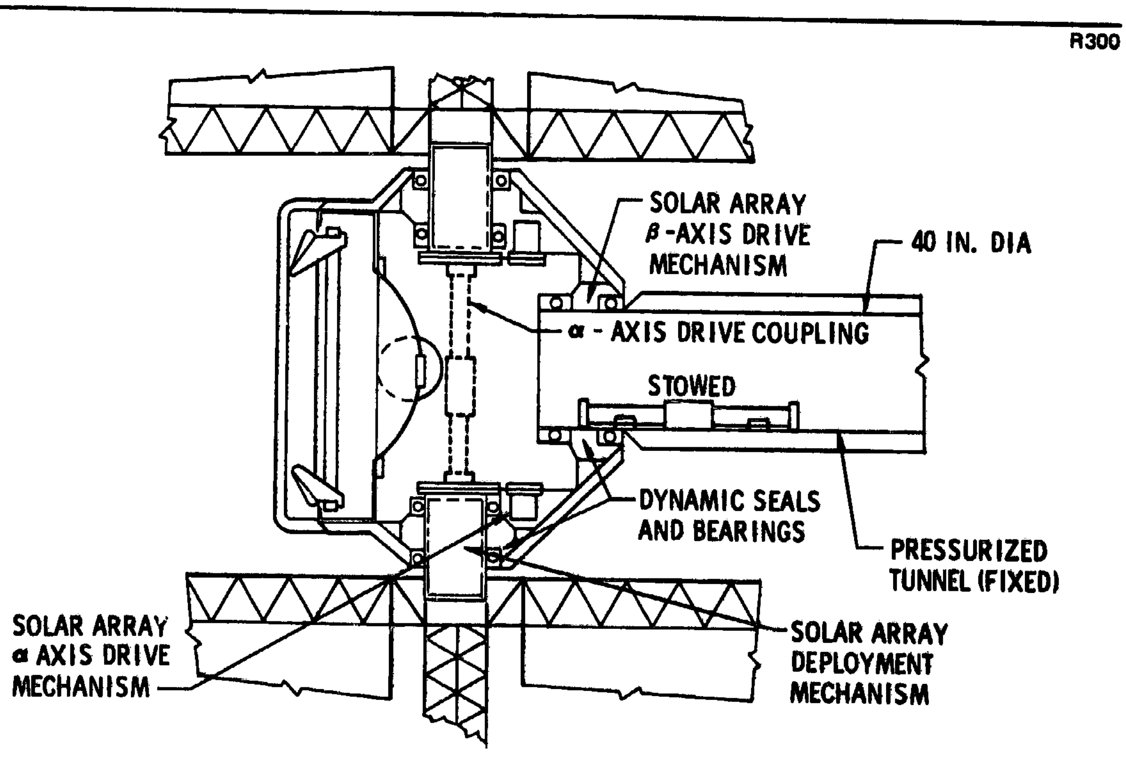

Figure 3-48. Solar Array Drive and Orientation Mechanism

separates the GPL into two separate pressurizable compartments is flat and 15.2 cm (6-in.) thick. It is fabricated of aluminum honeycomb sandwich, contains a 1.54 m (5-ft) diameter hatch opening and is designed to take full differential pressure in both directions. The bulkhead is bolted and sealed between two sections of cylindrical pressure shell.

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Section 4
LOGISTICS SYSTEM

The Space Station logistics system provides for transportation of cargo to and from the Space Station, rotation of the Space Station crews and rescue of the entire crew in an on-orbit emergency situation. A logistics system was defined based on a shuttle crew carrying capability of 4 (including 2 orbiter crew). Two crew rotation options were evaluated for the ISS phase. These are (1) transportation of crews in the orbiter and (2) use of a crew cargo module carried in the orbiter cargo bay. Rotating two men in the Shuttle at 30-day intervals (required for rotation of entire six man crew every 90 days) results in the highest operational costs due to the required frequency of Shuttle flights. In addition, it is necessary to rotate crews on RAM delivery flights since two men must be rotated on every flight due to Shuttle flights being limited to one every 30 days (study guideline). With this option, a rescue module is required for emergency return of the six-man crew within 96 hr of an emergency. (Design of a module solely to rescue six men does not provide the capability to transport six men in normal operations; differences in design requirements arise from the fact that the rescue module is manned only during the descent phase of a mission and that emergency rescue is a contingency operation having a low probability of occurrence.)

The development cost of a six-man Crew/Cargo Module, however, is higher than an unmanned Logistics Module. The total difference in DDT&E is $24.8 million, in production it is $14.1 million per article or $56.4 million for four flight articles. In the case of a logistics-only module, one flight article is designed for use as a rescue flight article. The cost difference between these two approaches is therefore $71 million. These do not include additional Shuttle costs to accommodate a Crew/Cargo Module. For example, means of emergency egress from the cargo bay and ground support systems for rapid transport of the crew to a safe area would be required. Therefore, the lowest initial program cost is achieved by development of a cargo-only module.

Since minimum initial cost to the IOC is the overriding study guideline, the selected approach for planning and costing purposes is to rotate Space Station crews two at a time in the Shuttle with flights every 30 days. It should be noted, however, that the design of the Space Station does not preclude the utilization of a Crew/Cargo Module, and that this approach could be readily implemented.

For rotation of GSS crews, a Crew/Cargo Module is required. Crew rotation is accomplished six men at a time and therefore the Crew/Cargo Module is sized to accommodate six men.

The Logistics Module provides a major supplement to the Space Station on-orbit cluster because it remains attached to the Station during resupply intervals. The Logistics Module provides for (1) storage of consumables; (2) storage of return cargo (such as wastes and experiment hard copy data); and (3) storage of equipment (such as CMG's) which is carried onboard and installed to complete the Space Station buildup. The storage volume provided in the Logistics Module minimizes the storage space required in Station modules. In addition, it has contingency uses, such as extra crew accomodations, during the Shuttle loiter on orbit.

Figure 4-1 shows the Logistics Module in perspective and indicates the cargo storage concept and the transfer of a large item of cargo. Routine items of cargo are stored in standardized modules and submodules which are moved into the Station on demand. Large items of cargo are transferred by the crew with the assistance of a cable and brake device which is temporarily installed for that purpose.

4.1 REQUIREMENTS

Maximum discretionary payload for the Space Station modules is obtained by transporting some equipment and expendables in the Logistics Module. Candidate items for logistics transport are not mission-critical during activation and are designed for periodic replacement or have a simple installation interface. Items currently considered as logistics options for the Power/Subsystems Module, Crew/Operations Module, and General-Purpose Laboratory are shown in Table 4-1.

The first Logistics Module, concurrent with the first operational crew, would transport expendables and most of the crew-related items. The second Logistics Module launch would bring up additional expendables, two additional

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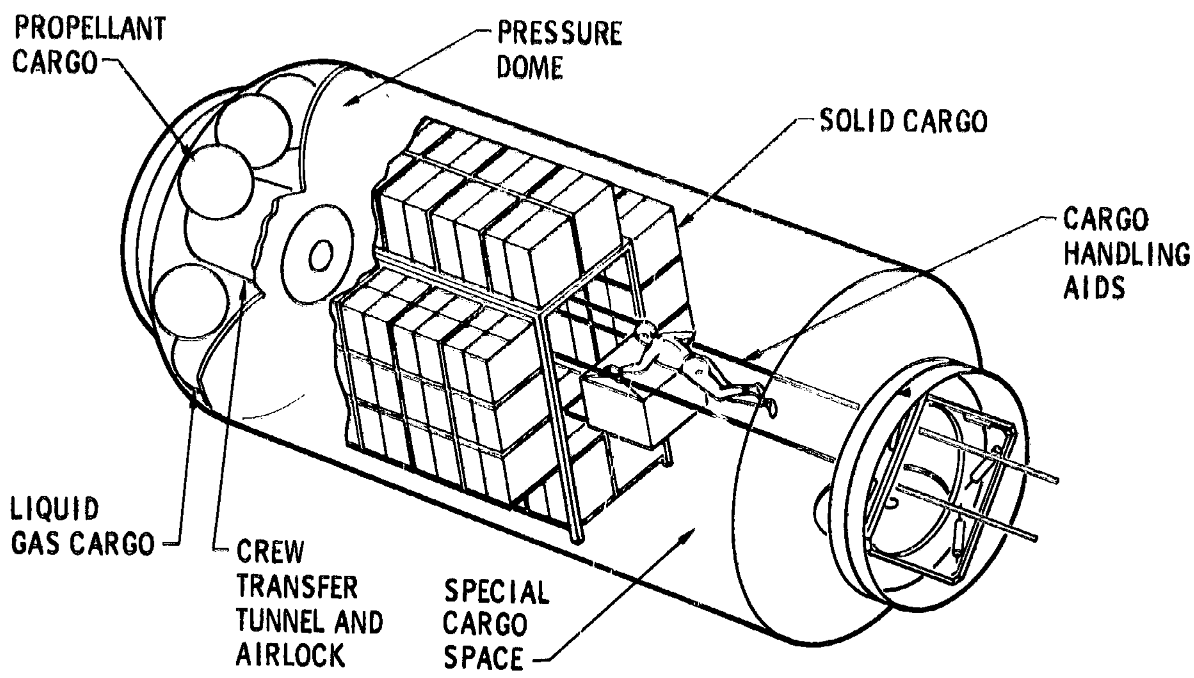

Figure 4-1. Logistics Module

crewmen, and crew equipment needed for them. Logistics options not required for early operation (mainly GPL equipment) will be transported to orbit as the logistic payload permits.

While some propellants are listed in Table 4-1 as options, sufficient propellant is onboard the modules when they are launched for 120 days of unmanned operation and activation. Similarly, batteries are logistics options, but sufficient batteries for activation operations are launched onboard, although complete repressurization gases are considered an acceptable option prior to manned operation. A portable checkout unit is included for use of the activation crew.

Table 4-2 defines the supplies required for an average 90-day-resupply period. Items identified with an asterisk in Table 4-2 are planned for replacement at cycles longer than 90 days. As an example, batteries are replaced every two years on a scheduled basis. The battery weight shown represents the average weight required for each 90-day increment.

The packaging weight required for solid cargo is generally 10 percent of the item weight. For certain items such as food, batteries, and CMG's, the packaging weight was established based on the nature and characteristics of

Table 4-1

LOGISTICS OPTIONS FOR SPACE STATION BUILDUP

	First Logistics Flight		Second Logistics Flight	
	(kg)	(lbm)	(kg)	(lbm)
POWER/SUBSYSTEMS MODULE				
CMG's (4)	728	1,605	---	---
Battery Set No. 2	---	---	724	1,596
Repressurization O_2 (1 tank)	133	293	---	---
Repressurization N_2 (4 tanks)	481	1,060	---	---
Metabolic O_2 (reserve)	163	359	163	359
Metabolic O_2 (contingency)	163	359	163	359
Computers No. 5 and 6	18	40	---	---
Pumpdown Accumulators (2)	---	---	146	322
Spares/Miscellaneous	49	108	TBD	TBD
	1,735	3,824	1,196+	2,636+
CREW/OPERATIONS MODULE				
Battery Sets (No. 1 and 2)	724	1,596	724	1,596
Water (contingency)	246	523	246	523
Portable Life Support Units	111	245	111	245
Food and Container (backup)	143	315	143	315
Food and Container (nominal usage)	143	315	286	631
Trash Compactor-Dryer	50	110	---	---
Trash Canisters	51	112	TBD	TBD
Housekeeping Items	33	73	48	106
Furnishings	190	419	156	344
Personal Hygiene	14	31	28	62
Exercise Gear	34	75	TBD	TBD
Spares/Miscellaneous	31	68	TBD	TBD
	1,770	3,882	1,742+	3,507+
GENERAL-PURPOSE LABORATORY MODULE				
Battery Sets (No. 1 and 2)	724	1,596	724	1,596
CO Units (2)	90	198	---	---
B&C Microfilm Viewer, Hand Controller, etc.	40	88	---	---
Data Management Recorders and Film Digitizer	198	437	---	---
Film Vault (3,500 lb) Launch No. 3	---	---	---	---
Microfilm Retrieval Unit (700 lb) Launch No. 1	318	700	---	---
Miscellaneous GPL Gear (620 lb)	---	---	---	---
	1,370	3,019	724	1,596

FOLDOUT FRAME |

Table 4-2

MODULAR SPACE STATION (ISS) AVERAGE 90-DAY RES

LEGEND: S = Solids, L = Liquids, G = Gases, Pkg = Packaging, * = See Item J

Subsystem	Resupply Item Type	Resupply Item Description	Delivery W Including Pa (lb) Item Weight
A. Structural/Mechanical	S-Spares	Latches, seals, motors, etc.	*
	L or G	None required	(See sub-system G)
B. Electrical Power			
Power Distribution and Power Conditioning	S-Spares	Relays, switches, converters	*
	L or G	None required	--
Primary power	S-Expend	Batteries	932 + 47
C. Propulsion			
High Thrust	S-Spares	Valves, regulators, burst disc, seals, etc.	*
	L-Fuel	N_2H_4 at 250 psig	20 + 4
	G-Press	GN_2 at 3,000 psig	1.5 + 1.6
Low Thrust	S-Spares	Valves, seals, etc.	*
	F-Fuel	--	--
	G-	None required	--
D. Navigation and Guidance	S-Spares	Sensors, electronics actuators	*
	S-Spares	CMG bearing	2 + 0.5 ft
	L or G	None required	--
E. Vehicle Electronics			
Onboard Checkout	S-Spares	Sensors, circuit boards displays	*
	L or G	None required	--
Communications	S-Spares	Switches, relays, tube, motors, etc.	*
	L or G	None required	--
Data Management	S-Spares	Switches, displays, lights, electronics	*
	S-Consum	Video tape, voice cart, TV film, digital tape, etc.	250 + 25
	L or G	None required	--
Wiring	S-Spares	Wire, connectors, J-boxes	5 + 0.25
F. Crew Systems			
Crew Life Support	S-Spares	Valves, sensors, restraints, lights, etc.	*
	S-Consum	Food (frozen, dehydrated, wet pack, perishable)	1,376 + 335

Table 4-2

N (ISS) AVERAGE 90-DAY RESUPPLY REQUIREMENTS

= See Item J

	Delivery Weight Including Packaging (lb)		Delivery Volume (ft^3)	Return Weight Including Packaging (lb)		Return Volume (ft^3)
	Item Weight	Total Weight		Item Weight	Total Weight	
rs, etc.	*		*	*		*
	(See sub- system G)		--	--		--
verters	*		*	*		*
	--		--	--		--
	932 + 47	979	3.0	932 + 47	979	3.0
urst	*	*	*	*	*	*
	20 + 4	24	1.0	2 + 4	6.0	1.0
	1.5 + 1.6	3.1	0.5	0.1 + 1.6	1.7	0.5
	*	*	*	*	*	*
	--	--	--	--	--	--
	--	--	--	--	--	--
ctuators	*	*	*	*	*	*
	2 + 0.5 ft	2.5	0.25	2 + 0.5	2.5	0.25
	--	--	--	--	--	--
ls	*	*	*	*	*	*
	--	--	--	--	--	--
,	*	*	*	*	*	*
	--	--	--	--	--	--
ghts,	*	*	*	*	*	*
, TV c.	250 + 25	275	7.0	230 + 25	255	7.0
	--	--	--	--	--	--
oxes	5 + 0.25	5.25	0.1	1 + 0.25	1.25	0.1
raints,	*	*	*	*	*	*
ted,)	1,376 + 335	1,711	53.5	10 + 335	345	53.5

FOLDOUT FRAME 1

Table 4-2

MODULAR SPACE STATION (ISS) AVERAGE 90-DAY RESUPP

LEGEND: S = Solids, L = Liquids, G = Gases, Pkg = Packaging, * = See Item J

Subsystem	Resupply Item: Type	Resupply Item: Description	Delivery W... Including Pa... (lb): Item Weight
F. Crew Systems (Continued)	S-Consum	Wipes, liners, soap, wicks, charcoal, towels, bedding, vacuum bag liners, personal equipment	353 + 70
	S-	Trash container	75 + 5
Crew Equipment	S-Spares	Exercise equipment, medical facility	*
	C-Consum	Medical supplies, paper, hobby, sports, etc.	25 + 3
	L or G	None required	--
G. IVA/EVA Portable Life Support	S-Spares	None required	--
	C-Consum	Battery modules 5.5 lb/4 hr LiOH 5 lb/4 hr O_2 1.6 lb/4 hr; 108 hr/yr	82 + 5
		2 EVA/IVA suits	140 + 7
H. Environmental and Life Support Environmental Thermal Control and Atmosphere Reconditioning	S-Spares	Heat exchangers, valves, pumps, control assembly, accumulators, sensors, etc.	*
	S-Consum	Wicks, charcoal beds, filters, water transfer disks, etc.	380 + 38
	L-	None required	--
	G-Consum	O_2 (metabolic)	1,058 + 1,267
	G-Consum	O_2 airlock make-up	15.3 + 18.4
	G-Consum	GN_2 airlock make-up	58.2 + 10.0
I. Life Support Pallet	S-	Replacement unit (Average weight/90 days)	88 + 5
J. Items Identified by *	S-Spares	Spares for all subsystems to include both wearout and random failure based on an initial inventory	330 + 33
Totals			5,195 + 1,937

FOLDOUT FRAME 2

Table 4-2

AVERAGE 90-DAY RESUPPLY REQUIREMENTS (Continued)

See Item J

	Delivery Weight Including Packaging (lb)		Delivery Volume	Return Weight Including Packaging (lb)		Return Volume
	Item Weight	Total Weight	(ft^3)	Item Weight	Total Weight	(ft^3)
icks, ding,	353 + 70	423	23.5	130 + 70	210	23.5
	75 + 5	75	105	433 + 5	438	105
	*	*	*	*	*	*
',	25 + 3	28	1	5 + 3	8	1
	--	--	--	--	--	--
	--	--	--	--	--	--
4 hr	82 + 5	87	3	170 + 5	1.75	3
/yr	140 + 7	147	14	140 + 7	147	14
s, bly, , etc.	*	*	*	*	*	*
ilters, etc.	380 + 38	418	24	380 + 38	418	24
	--	--	--	--	--	--
	1,058 + 1,267	2,327	34	3 + 1,269	1,272	34
	15.3 + 18.4	33.7	1.5	0.5 + 18.4	18.9	1.5
	58.2 + 10.0	128.2	5.5	1 + 70.0	71.0	5.5
ys)	88 + 5	93	10	88 + 5	93	10
ns and n an	330 + 33	363	8	330 + 33	363	8
				2,519 (O_2;GN_2)		
	5,195 + 1,937	7,132	295	2,726 + 1,937	4,663	295

the item. The average 90-day resupply required to sustain ISS subsystems and crew is 7, 132 lb with a volume of approximately 295 cu ft.

The open-loop oxygen system of the EC/LS subsystem requires 32. 5 percent of the resupply weight. (Gaseous oxygen is stored in the Logistics Module on orbit.) The battery energy storage system accounts for 14 percent of the resupply weight while food accounts for 24 percent of the 90-day resupply weight.

Return cargo requirements for the crew and Space Station subsystems are also shown in Table 4-2. All return cargo (except for trash) will be packaged in the replacement cargo container and transferred to the same storage rack, bin, etc., assigned to the up-cargo item. Empty trash containers will be delivered to exchange with the full containers. The average 90-day return cargo is 4, 663 lb requiring 295 cu ft of storage volume.

The experiment resupply and initial experiment equipment requirements depend on the experiment program selected. SE-06 lists the initial, resupply, and return requirements for consumables, expendables, and spares for each FPE. Down-cargo requirements are also provided for each item.

Based on the FPE schedule of case 534G (baseline), the average 90-day experiment resupply during ISS operations weighs 5, 200 lb and during GSS it weighs 8, 835 lb. These values include all experimental equipment, solids, liquids, and gases to support the operation of integral, attached, and free-flying RAM's, but not include the delivery or return of the actual RAM's.

4. 2 LOGISTICS MODULE DESIGN CHARACTERISTICS

4. 2. 1 Configuration and Structural Design

The recommended Logistic Module configuration is shown in Figure 4-2. The nominal design weight of the module is 3, 011 kg (6, 638 lb) leaving a discretionary cargo payload capacity of 6, 061 kg (13, 362 lb) (Table 4-3). The configuration shown in Figure 4-2 is a typical internal arrangement for the module, consisting of space for containerized and bulk solid cargo, and tankage for both volatile and nonvolatile fluid transport. This configuration provides a capacity for 13. 6 cu m (480 cu ft) of solid cargo in 60 by 60 by 60 cm (2 by 2 by 2 ft) standard containers, approximately 3, 40 cu m (120 cu ft) of bulk solid cargo and 5. 95 cu m (147 cu ft) of liquid and gaseous cargo. An unpressurized compartment is equipped with permanent tankage for transport and storage of high-quantity fluids utilizing an on-orbit hard-line transfer

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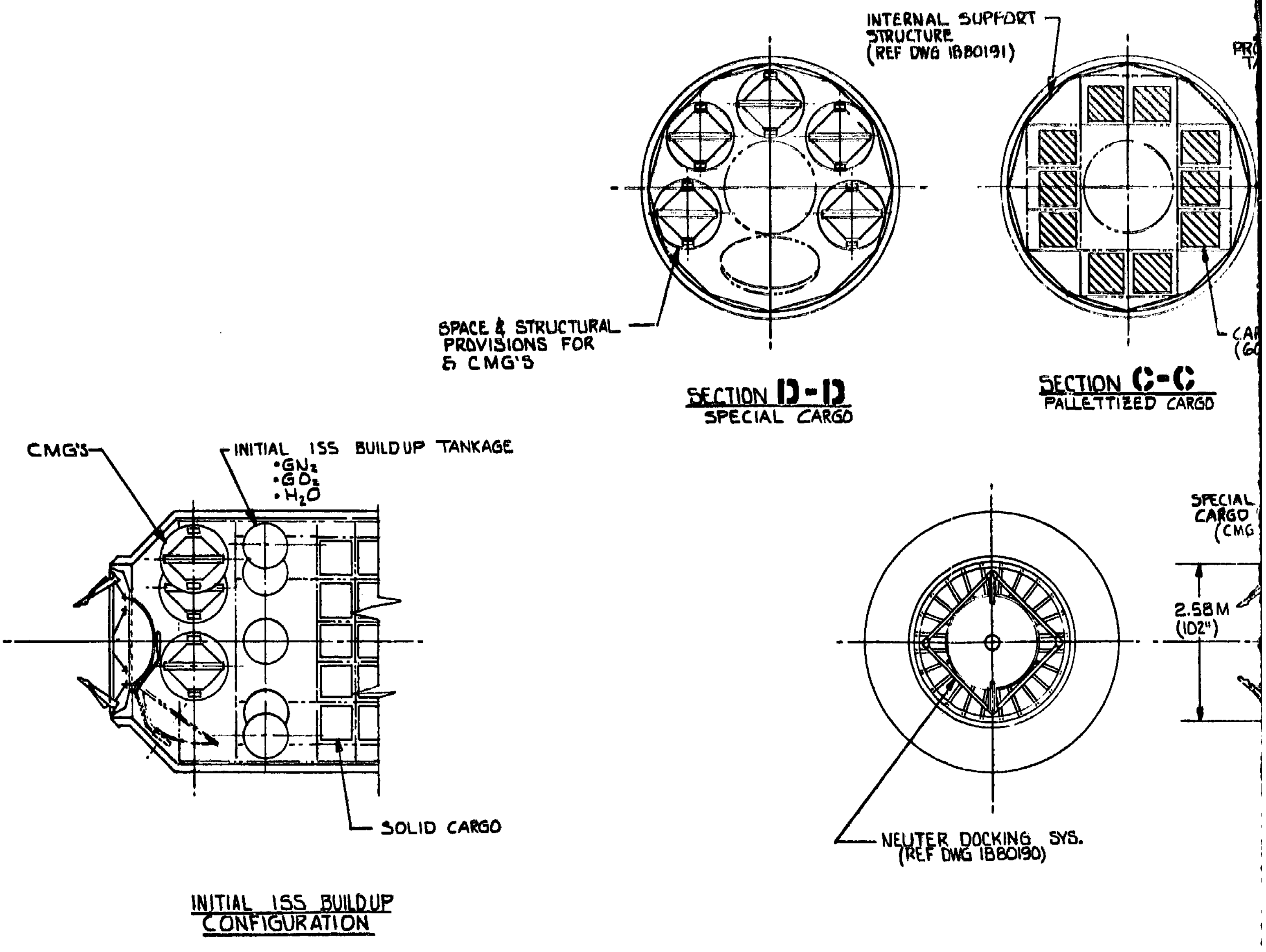

Figure 4-2. Logistics Module Configuration and Structural Design

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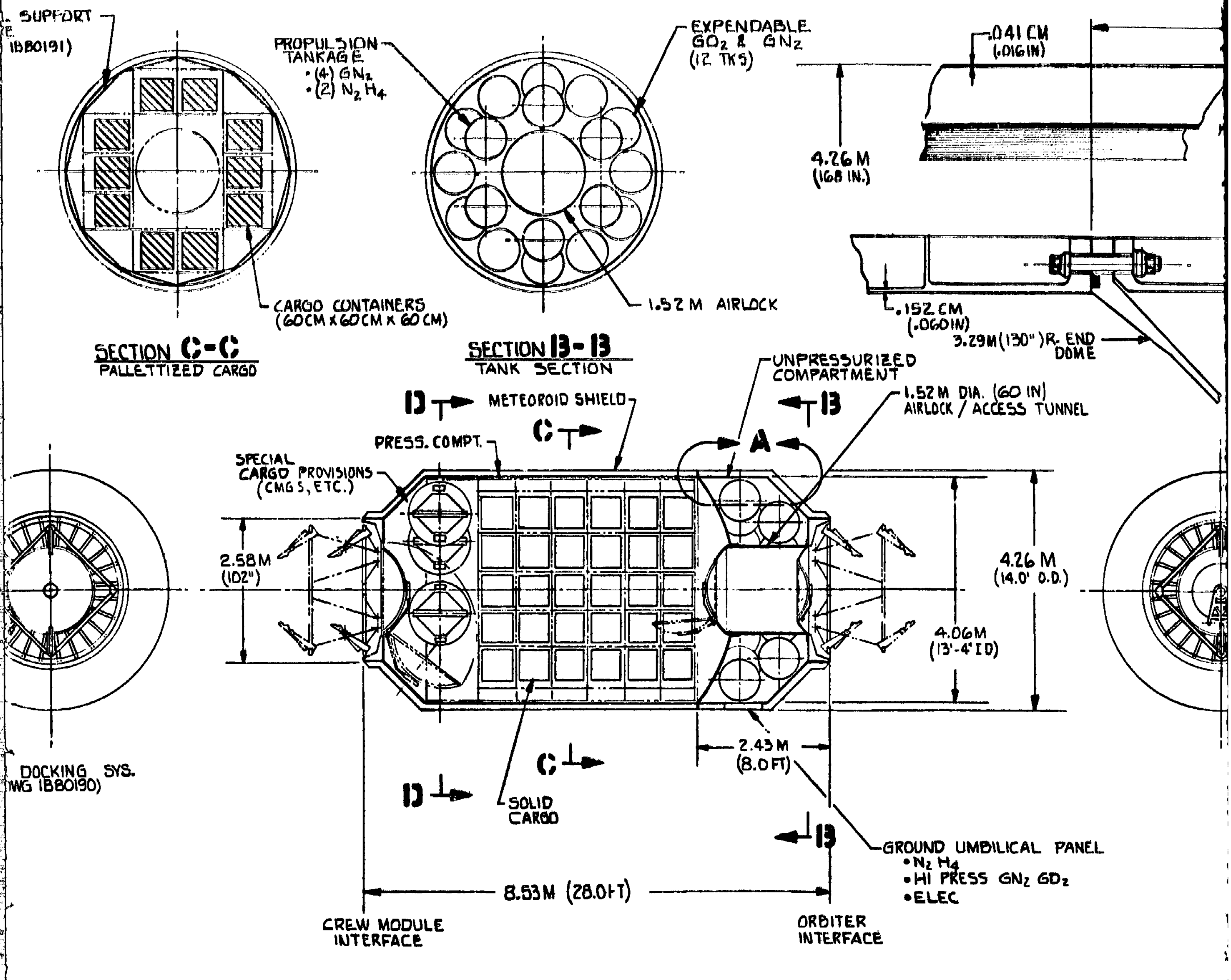

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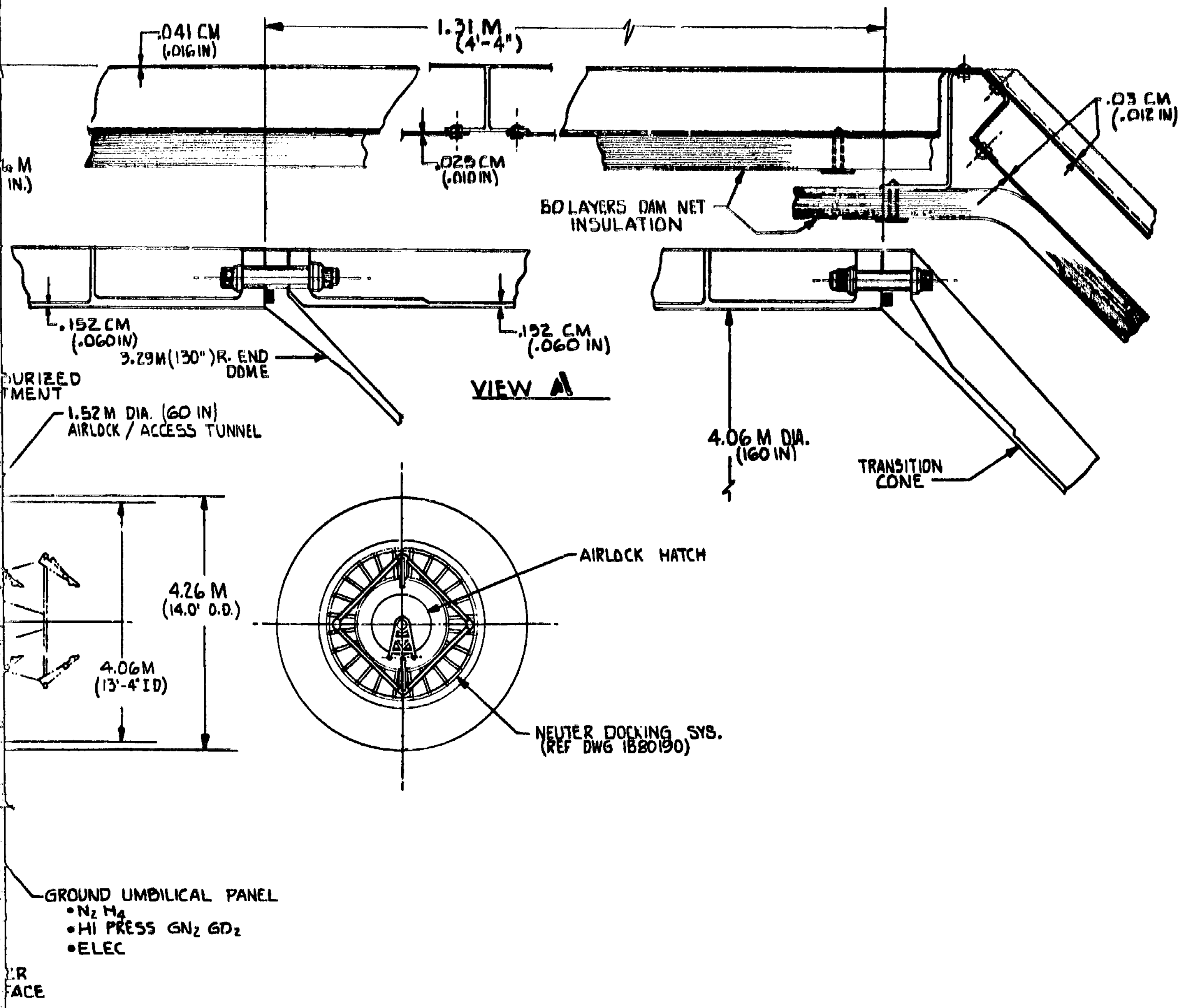


.041 CM
(.016 IN)
1.31 M
(4'-4")
.03 CM
(.012 IN)
.025 CM
(.010 IN)
50 LAYERS DAM NET
INSULATION
.152 CM
(.060 IN)
.152 CM
(.060 IN)
3.29M(130")R. END
DOME
VIEW A
URIZED
TMENT
1.52M DIA. (60 IN)
AIRLOCK / ACCESS TUNNEL
4.06 M DIA.
(160 IN)
TRANSITION
CONE
AIRLOCK HATCH
4.26 M
(14.0' O.D.)
4.06M
(13'-4" I.D)
NEUTER DOCKING SYS.
(REF DWG 1880190)
GROUND UMBILICAL PANEL
•N₂ H₄
•HI PRESS GN₂ GO₂
•ELEC
R
ACE

Table 4-3

LOGISTIC MODULE MASS SUMMARY

Code	Description	Mass (kg)		Mass (lbm)	
02.00	Structure	1,200		2,647	
02.10	Unpressurized Compartment		0		0
02.11	Pressurized Compartment		1,183		2,609
02.15	Finish, Seals, and Spares		17		38
03.00	Meteoroid and Thermal Protection	501		1,104	
03.02	Passive Thermal Protection		155		342
03.04	Meteoroid Protection		346		762
04.00	Docking Provisions	279		616	
04.05	Docking Structure		279		616
06.00	Propulsion	72		158	
06.07	Fuel Container		14		30
06.09	Pressurization and Control		23		50
06.10	Fuel Distribution and Control		6		13
06.14	Umbilical		14		30
06.15	Support Structure		15		35
08.00	Power Conditioning and Distribution	35		77	
10.00	Electronics	207		456	
10.01	Guidance and Control		3		7
10.02	Onboard Checkout		103		227
10.03	Data Management		28		61
10.06	Communication		29		64
10.15	Displays and Controls		44		97
11.00	Wiring	75		165	
12.00	Atmosphere and Thermal Control	336		40	
12.02	Atmosphere Control and Supply		336		40
14.00	Crew Life Support and Interiors	197		435	
14.01	Hand Rails and Restraints		31		69
14.03	Cargo Handling		23		51
14.04	Interior Furnishings		143		315
21.00	Residuals	109		240	
21.13	Other Residuals		109		240
	Total	3,011		6,638	

mode for fluid movement. The design provides a 1.52 m (5 ft) diameter two-man airlock which serves as a crew transfer tunnel across the unpressurized compartment-orbiter interface and provides EVA capability to the basic Station.

The Logistic Module is an integral structure design which can accommodate a variety of cargo mixes through the use of a cage-type, dodecagon-shaped or 12-sided internal support structure and secondary mounting adapter units. The pressurized section, which is approximately 7.32 m (24 ft) in length, is formed by the cylindrical shell with a conic and docking port structure at one end and an internal module membrane-type, dome-shaped bulkhead at the other. The unpressurized section is formed by the internal bulkhead wall, the cylindrical shell, conic end, and a 1.52 m (5 ft) tunnel section.

The cylindrical portion of the module structure shell employs the same design as other modules. It is stiffened with 24 integral, longitudinal ribs and rings spaced every 20.32 cm (8 in.) along the length. The 0.15 m (0.060 in.) spherical membrane dome and the integrally stiffened conic structures will be fabricated from 2219-T87 alloy material as will the cylindrical shell. Bolted joints are used to assemble the major structure sections (pressure shell, conics, bulkhead, etc.) to facilitate manufacture and assembly of the module.

Meteoroid protection for the Logistics Module is achieved by using a double-wall meteoroid bumper design. The double wall consists of an 0.016-in.-thick inner shield separated 1.125 in. by ring frames on 20.32 cm (8 in.) centers. High-performance insulation is mounted beneath the inner shield, supported on the inner shield, supported on the inner leg of the ring frame stiffeners. The insulation blanket design provides the thermal characteristics needed to maintain the pressure shell wall temperature above that of the ambient module air to eliminate wall condensation.

The Space Station interface end of the module contains the standard 2.58 m (102 in.) diameter docking ring structure and neuter docking mechanism utilized on all other modular station modules. A 1.52 m (5 ft) diameter clear opening hatch is provided at this interface for ground loading of cargo and on-orbit transfer.

The orbiter interface end of the module is also equipped with a standard docking port mechanism and interface structure. The cylindrical tunnel section is 1.52 m (5 ft) in. diameter and is 1.52 m (5 ft) long. Hatches of

1.02 m (40 in.) in diameter have been incorporated in the airlock. Size selection was based upon personnel transfer as the prime function. The hinged hatch can be opened from either side and is identical to the hatch proposed for the turret end (orbiter docking end) of the basic Station Power Subsystems Module.

The tunnel section through the unpressurized compartment undergoes structural deflection between the internal bulkhead and docking frame as a result of pressure differential in the module compartments during ascent and descent. A soft joint at one of the tunnel-support structure interfaces accommodates this structural deflection and provides the required thermal isolation in a single design.

The design criteria for the structure-mechanical subsystem of the Logistics Module is essentially the same as for the basic Station modules. Environmental stresses occur periodically for the Logistics Module due to its multimission usage; however, the overall influence of these effects is minimal, being well within the limits of the design of the basic Station modules. A high degree of commonality therefore exists between the Logistics Module and the basic station modules. Foremost in this commonality is the carryover in the structure-mechanical subsystem. Specifically, this includes the pressure shell sections (different only in length), the end conics, docking interface structure and docking mechanism as well as the dodecagon-shape internal support structure. The hatch designs as noted earlier are used on the basic Station modules. Similarly the internal membrane dome bulkhead is used in the Power/Subsystem Module.

4.2.2 Cargo Accommodation

The internal support structure provides the primary interface for the individiaul or modular cargo support adapters. This cage-type structure is composed of 12 longerons and interconnecting beams spaced at intervals along the longitudinal axis. These beams connect to the longerons and form a dodecagon shape which fits within the 4.06 m (160 in.) diameter of the pressure shell. The cage is pinned to the pressure shell at one end of each longeron; thus, longitudinal loads, both tension and compression, are transmitted to the shell through these pins. Radial loads are transmitted to the pressure shell through blocks which are spaced along each longeron and attached to the pressure shell. Using this structure as an effective strongback, considerable flexibility is achieved in cargo mix and arrangement with little impact upon the primary structural elements of the modules.

Palletized cargo is accommodated in this system through a modular framing adapter designed to support various standard-sized pallets in increments of 60 cm (2 ft) cubes. In the baseline configuration, six bays of 10 pallets each can be accommodated. This modular framing adapter is nominally configured by removal or relocation of support members to accept cargo up to the size that will pass through the 1.52 m (5 ft) diameter docking hatch.

The forward or docking end of the module is utilized for stowage of bulk or special cargo items. This area is sized to accept items such as CMG's, food freezers, a trash compactor, and experiment items of a shape and size not conducive to efficient volumetric palletized packaging. The support concept for these items includes the use of special adapters tailored to the individual cargo units for support and interface to the strongback cage-type support structure described earlier.

As the need arises, the bulk cargo volume can be increased by the removal and replacement of bays or rows of the modular support structure for palletized cargo with additional special support adapters. Using this technique, nearly unlimited flexibility and versatility of cargo mix is provided in the pressurized compartment.

The unpressurized compartment tankage required for the worst case mix and quantities expected is as follows:

Fluid	30-in. Tanks Required
Metabolic Gaseous Oxygen	8
Experiment Support Gaseous Oxygen	3
Propulsion System GN_2	4
Atmospheric GN_2	1
Propellant (N_2H_4)	2
	18 Tanks

The 30-in.-diameter tank size was selected for the Logistics Module to retain commonality with the pneumatic tanks used in the basic Station modules.

4.2.3 Rescue Module Configuration

The Logistics Module provides a six-man rescue capability. Since the module is manned only during the descent phase, seat orientation and crew egress requirements need consider only the reentry and landing conditions. The configuration shown in Figure 4-5 is a modified Logistics Module with six crew seats installed. The seat design is a simple web structure mounted between rails that extend between top and bottom attach points on the module internal support structure. The seats are adjustable from an upright seated position to a fully reclined position. The adjustment is made by sliding the back section up the rails and locking it in the desired position. The seats are oriented in a rearward-facing position for proper alignment for reentry and landing forces. The web structure of the seat provides a large body contact area for the g forces of deceleration and landing. The flexibility provided in the seat position, as shown in Figure 4-3, allows the crewman to assume any desired position.

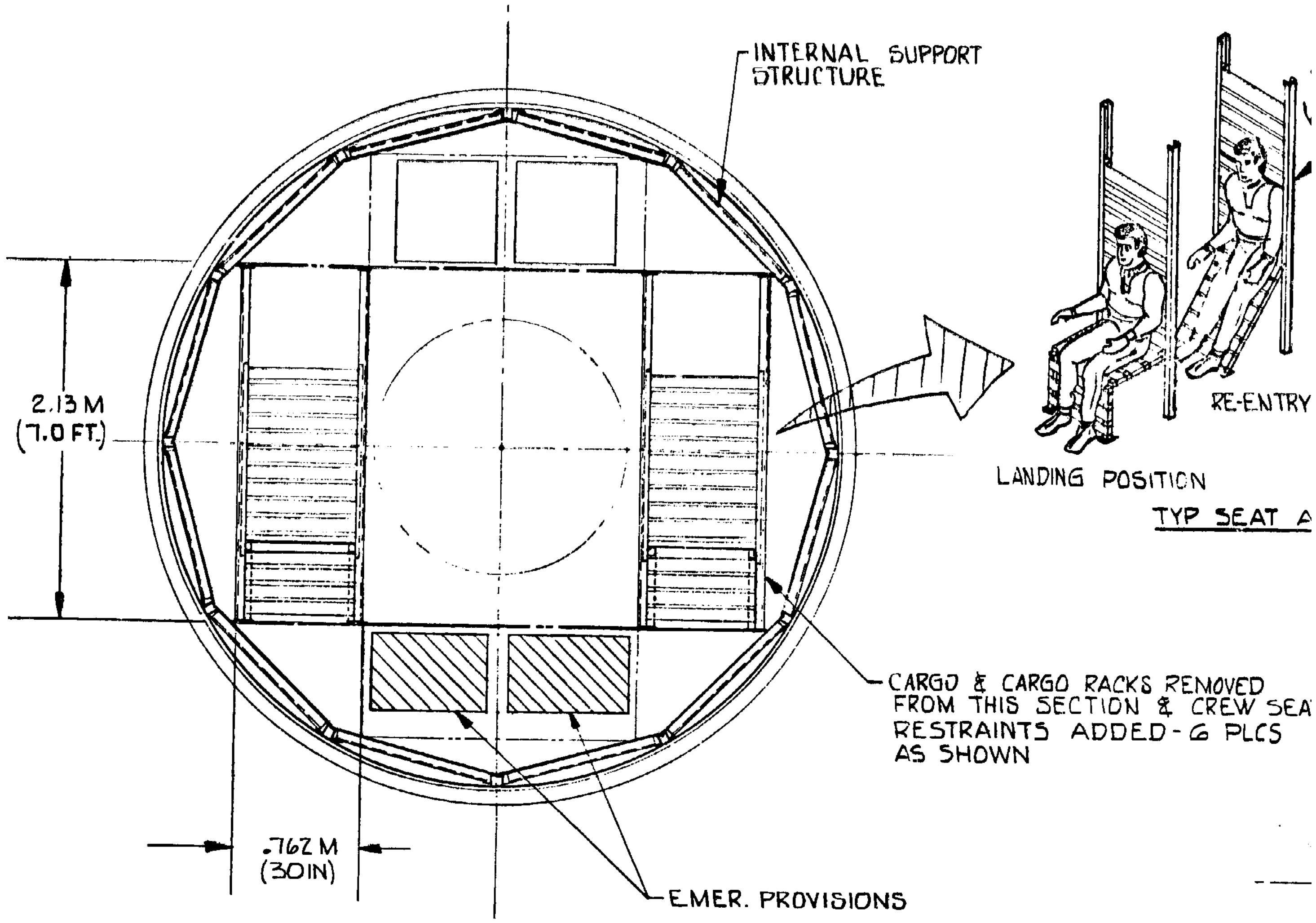
Simplicity of the seat design allows installation in the module to be performed in a relatively short time. Each seat is an independent unit for ease of entry through the 1.52 m (5 ft) diameter hatch. The seats are arranged in two rows, three deep, with a center aisle between the rows for ingress and egress. Arranged in this fashion, the seat modules are identical.

Support services including power and communications are supplied from the orbiter subsystems. Each seat station will be equipped with an emergency oxygen mask and portable oxygen bottle supply. Space is also available in the module for incorporation of contingency equipment such as survival gear, if these provisions are not available from the orbiter.

Normal egress from the module after landing occurs is through the orbiter tunnel interface; the orbiter crew provisions are used for alighting to the ground.

4.2.4 Subsystems

The Logistics Module requires only minimal subsystems since it (1) is unmanned except when on orbit and when used for a rescue mission and (2) receives support services from the Space Station and orbiter vehicle. These support services consist of power, conditioned air, and monitoring, warning, and display of parameters associated with module habitability, (on-orbit only) system status and cargo status. This section describes the



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SCALE 1/20

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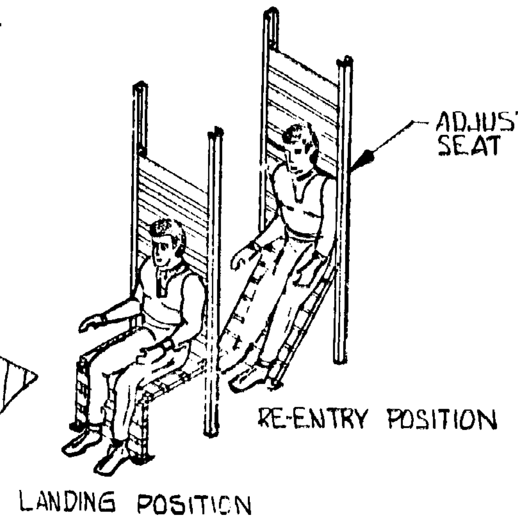
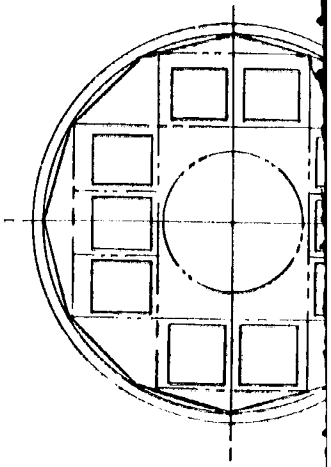
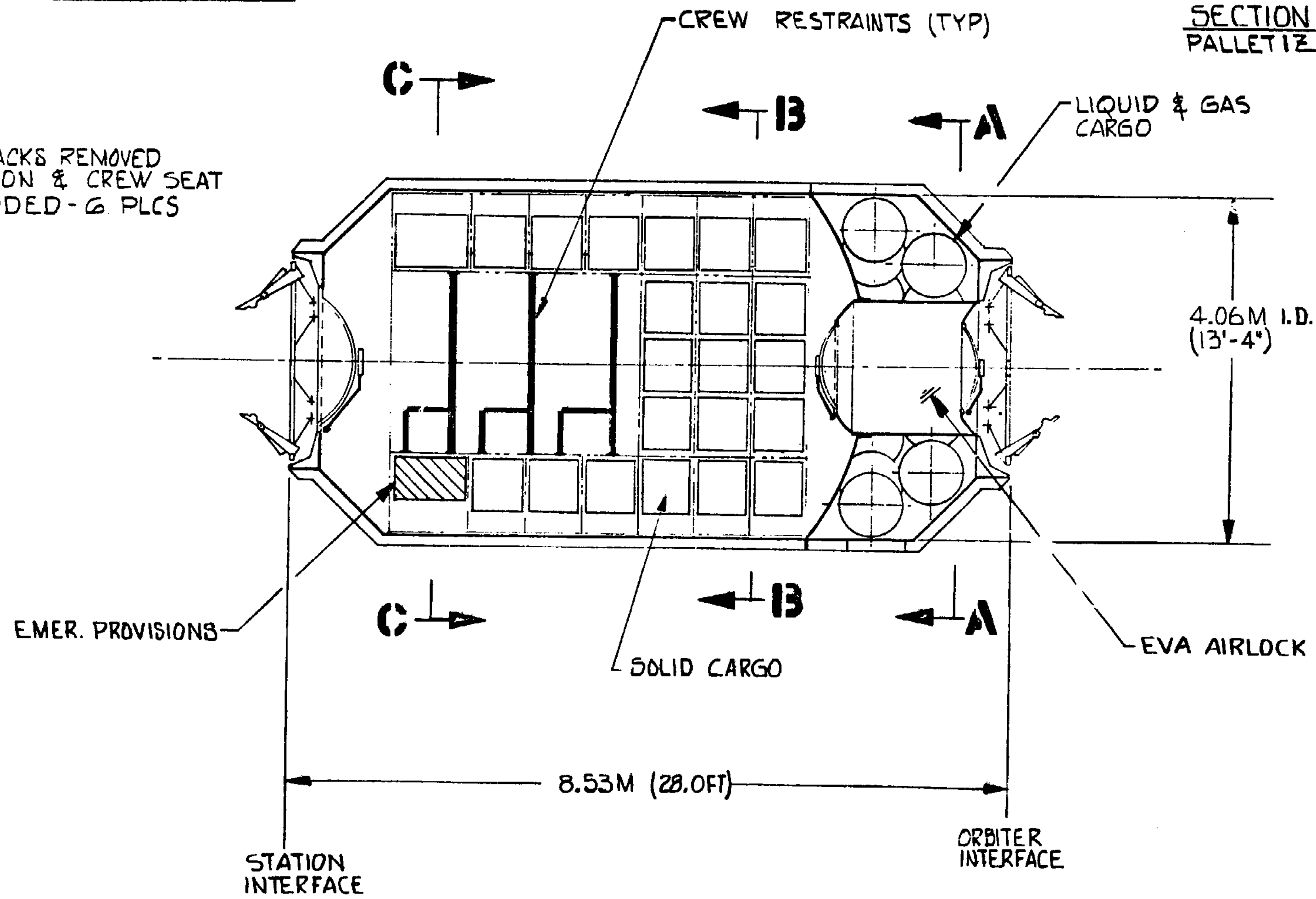




& CARGO RACKS REMOVED
THIS SECTION & CREW SEAT
RAINTS ADDED - 6 PLCS
HOWN



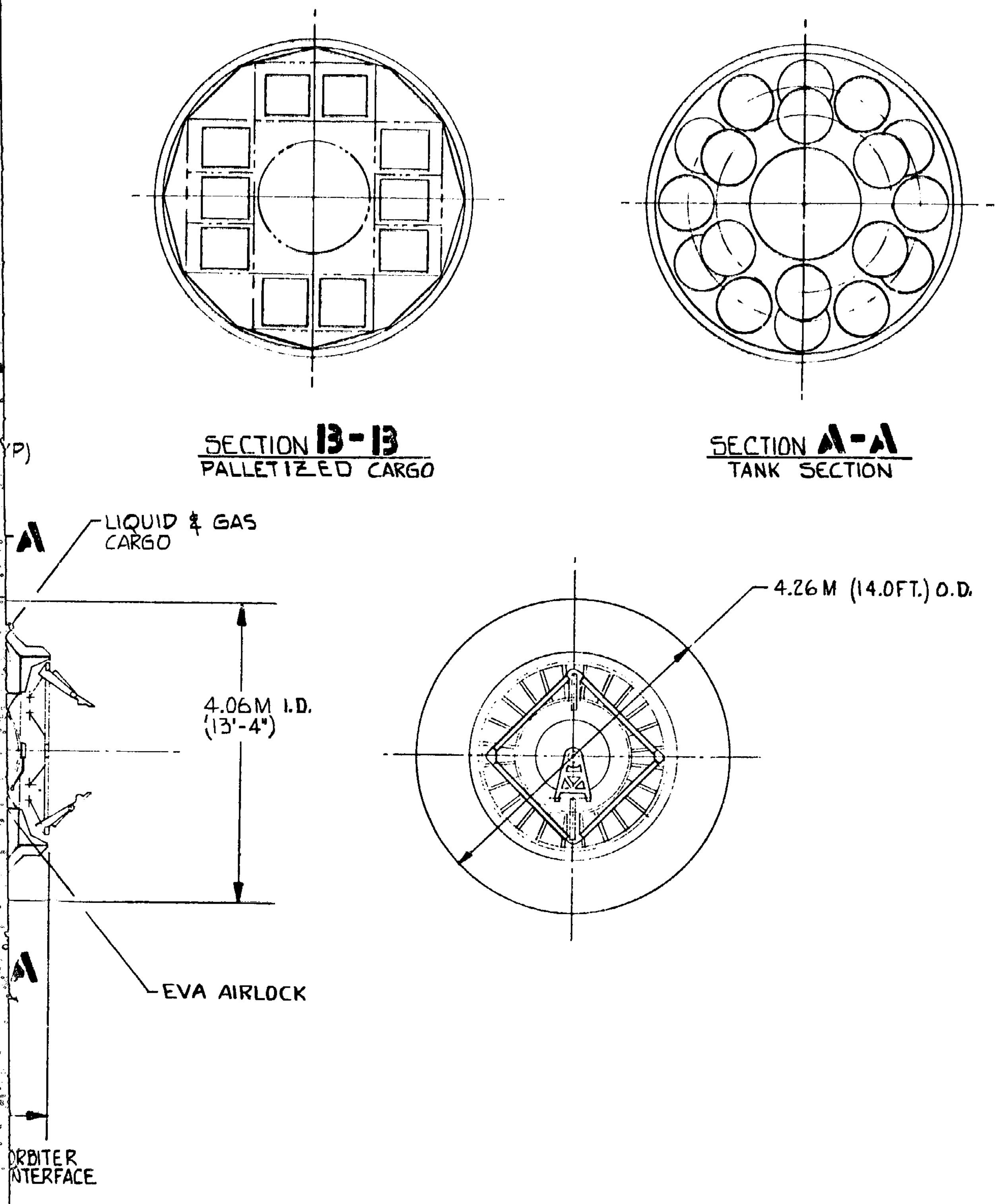


Figure 4-3. Modular Space Station Logistics Module Rescue Configuration

environmental control and data management/communications provisions of the Logistics Module (the structural-mechanical design is described in Section 4.2.1).

4.2.4.1 Environmental Control

The environmental control system provides atmosphere distribution, atmosphere dump and relief, module pressurization, resupply gas pressure regulation, pumpdown pressure control, and postlanding ventilation during normal operation. Atmosphere conditioning on-orbit is provided by interchange air from the core modules.

Emergency provisions are included in the design to provide essential EC/LS functions when the Logistics Module acts as a crew refuge or an emergency rescue vehicle. Essential services include metabolic O_2 supply, humidity and CO_2 control, cooling, emergency food, waste management, and medical supplies.

An active thermal control system is not required during normal operation; the thermal capacitance of the structure and low heat-leak prevents excessive interior temperature excursions. Cooling is required during emergency crew occupancy and this is provided by the water boiler in the 96-hr pallet. During normal operation when the Logistics Module is attached to the Station, thermal control is provided by the interchange of air from the core modules.

The Logistics Module must be maintained as a habitable volume during both normal and emergency operation. Detailed performance requirements are given in Table 4-4. Figure 4-4 is a schematic of the selected design for the Logistics Module. Conditioned air is provided by the EC/LS equipment located in the basic Space Station modules and distributed in the Logistics Module with a fan (item code 2903) and distribution duct. The distributed air picks up humidity, CO_2, and contaminant loads in the module; they are returned to the basic Space Station EC/LS system through a return duct to be processed.

The normal resupply O_2 and N_2 is stored in tanks at 2.06×10^4 kN/sq m (3,000 psia). As a safety precaution, the gas is reduced in pressure before being withdrawn for use in the Space Station. Pressure-regulating valves (1202) reduce the pressure to 410 kN/sq m (60 psia) at the tank outlet lines.

Table 4-4

ENVIRONMENTAL CONTROL SYSTEM PERFORMANCE REQUIREMENTS

Atmosphere Supply and Control	
Atmosphere Relief	Relieves cabin pressure at 105.5 ± 1.4 kN/m^2 (15 ± 0.2 psia). Dump largest compartment to 6.89 kN/m^2 (1 psia) or less in 3 min
Atmosphere	
Oxygen Partial Pressure	21.4 kN/m^2 (3.1 psia)
Total Pressure	101 kN/m^2 (14.7 psia)
Atmosphere Reconditioning	
CO_2 Partial Pressure	Normal - 0.4 kN/m^2 (3 mm Hg) or less Emergency 1.0 kN/m^2 (7.6 mm Hg) maximum for 7 days
CO_2 Generation Rate, Peak/Average	0.354/0.260 kg/hr (0.78/0.575 lb/hr)
O_2 Use Rate, total Average	0.218 kg/hr (0.481 lb/hr)
Free Moisture in Atmosphere	None allowed
Metabolic Levels	Normal - 136 w (465 Btu/hr) for 24 hr Design - 235 w (800 Btu/hr) (2 men)
Atmosphere Temperature	18.4 to 23.9°C (65 to 85°F)
Dew Point Temperature	7.2 to 14.5°C (45 to 58°F) with transients allowed to 4.5°C (40°F)
Velocity in Occupied Regions	0.1 to 0.25 m/sec (20 to 50 ft per min)
Design Latent Load	310 w (1,060 Btu/hr)

The airlock located at the end of the Logistics Module is used as an EVA airlock during normal mission operations. To conserve airlock gas during crew egress, the design provides for airlock pumpdown. The system, located in the Crew/Subsystems Module, pumps the air from the airlock. The pump-down air is stored in an accumulator in the Power/Subsystems Module. Upon crew ingress, the airlock is repressurized with the accumulator air.

A post-landing ventilation capability has been included in the design to allow ambient air to be drawn into the module when used as an emergency rescue vehicle. An investigation has shown that the cargo bay temperature in the Shuttle will be sufficiently low near landing so that ambient air

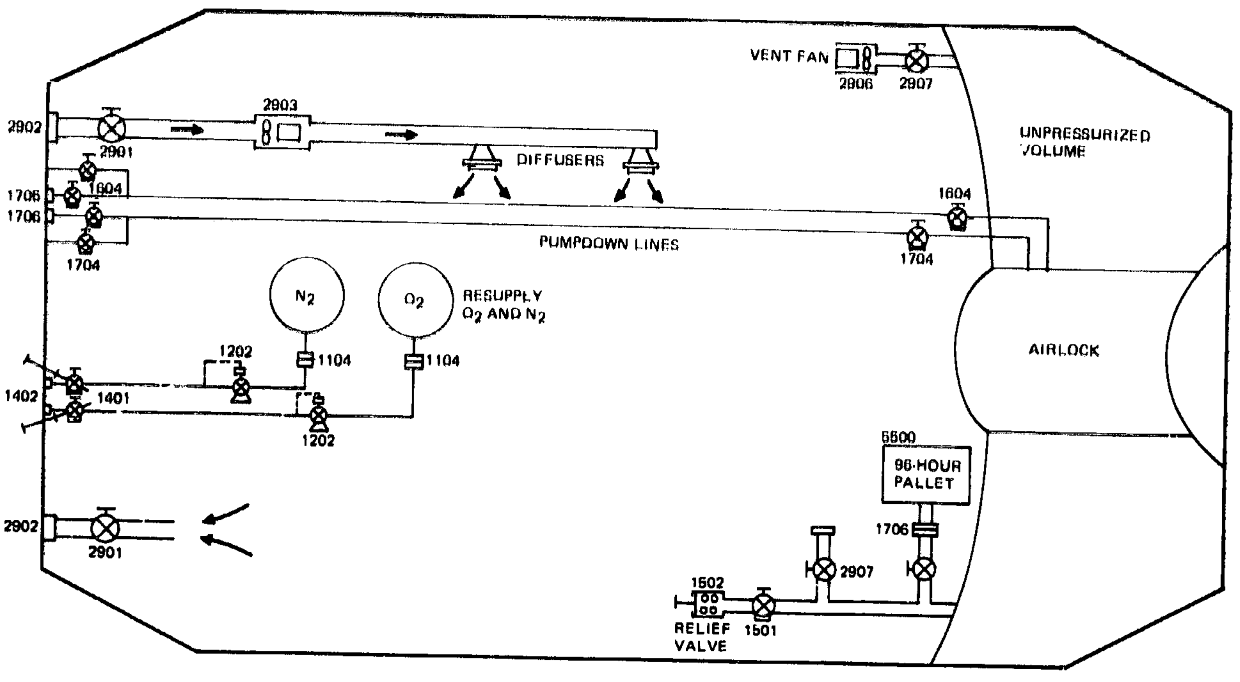


Figure 4-4. EC/LS System Schematic

ventilation can be used. The air is drawn into the module through a vent fan (2906).

During normal Logistics Module use, a 96-hr pallet (5500) is located onboard for crew use during an emergency. The pallet provides essential services for a three-man crew and relies in no way on other Space Station support.

The Logistics Module serves as backup function for crew rescue. The module is outfitted with restraints and essential services for return of the six-man crew. Two 96-hr pallets are used during this mode to support the crew. The pallet provides crew metabolic O_2, potable water, food, waste storage, and emergency medical supplies. A water boiler is provided which cools the atmosphere and condenses out excessive humidity. The boiler functions while in orbit and during reentry until the atmosphere is encountered. There is sufficient thermal capacitance in the module atmosphere and equipment to absorb thermal loads and humidity until the postlanding fan is activated prior to landing. Maximum interior temperature is estimated to be 37.8° C (100° F). A canister of LiOH removes crew-produced CO_2 from the air. Sufficient batteries are included to operate the pallet equipment and provide for minimal lighting.

Thermal control during prelaunch operations is not required because the bay is purged with dry, temperature-controlled gas. Also, the cold radiation environment from the lower bay will be compensated for by the warmer upper-bay environment; the pressure shell is sufficiently thick to preclude large temperature gradients around the periphery of the module. Super insulation will provide sufficient insulation to prevent large losses of heat from the module. During prelaunch and launch, no appreciable electrical power will be generated in the module.

The module is subjected to temperatures during launch of up to 149° C (300° F) in the Shuttle bay. In this environment, a surface of zero thermal capacitance would become hot (82.2° to 110° C or 180° to 230° F). The Logistics Module has considerable thermal capacitance, especially around the pressure shell, and therefore excessive temperatures are not expected

Since mylar super insulation can be distorted by temperatures above 107° C (225° F), the outer layers of insulation should be made of Kapton, which can tolerate temperatures up to 426° C (800° F).

Once the Logistics Module achieves orbit, the super insulation is effective in maintaining a low heat exchange between the module and the surrounding Shuttle bay. This is due in part to the low emissivity in the current design for the Shuttle bay interior walls.

While the Logistics Module is attached to the Space Station, conditioned atmosphere will be supplied from the Space Station EC/LS system. As much as 136 cfm may be supplied, which enters the module near the selected Space Station temperature. Assuming the air enters the module at 24° C (75° F) and leaves at 18.3° C (65° F), about 420 w (1,430 Btu/hr) of heating is provided. In a similar manner, about the same amount of cooling can be provided. By reduction of heat shorts in the structure and by proper outer surface coating design, the heat loss or gain through the module surface can be kept below these values.

During descent, local surface temperatures on the module may approach 93.3° C (200° F) in areas with small thermal capacitance. With the outer few layers of insulation made of Kapton, the anticipated temperature levels should not present a problem.

Frozen food is stored in well-insulated containers which are transferred to the Space Station freezers after arrival. Frozen food reaches -9.5° C

(+15° F) about 84 hr after loading if it is initially subcooled to -54° C (-65° F). This is adequate time to effect transfer. Fresh perishable foods are also carried in insulated containers.

4.2.4.2 Data Management and Communications

The data management/communications subsystem in the Logistics Module supports the following functions: (1) voice communications; (2) monitoring of critical measurements; (3) determination of system compartment status; (4) periodic subsystem checkout; and (5) spares and consumables management. The interface between the various elements of the subsystem is a data bus accepting and transferring both video and digital data. An additional interface is provided in the form of hard wire for critical or safety measurements. Since the Logistics Module must operate in conjunction with the payload support system of the Shuttle during ground checkout and ascent to orbit and the Space Station while on orbit, their bus systems will either be identical or interface adapter will be required in the Shuttle. Figure 4-5 shows the manner in which system assemblies are interconnected and the functions performed by each. It also indicates that the primary equipment providing the services for the Logistics Module is actually resident in the payload support system of the orbiter or the Space Station. As a result, equipment located in the Logistics Module consists only of input and output devices such as data acquisition units, sensors, and display devices.

The data bus within the Logistics Module is an extension of the Station bus system which is coupled to the main bus via branch couplers. Ingress and egress to the bus is accomplished through data terminals using data-bus terminal couplers.

Sixty-four channels on the analog data bus spaced at 4-kHz intervals between 60 and 316 MHz are apportioned between 48 audio terminal units (ATUs). Three of these terminal units have been assigned to a Logistics Module; i.e., each module would contain ATU's with individual transceiver frequencies to which they would respond. Each ATU would also include amplifiers for operating at baseband, this mode to be used for emergency alert or public address.

The monitoring of critical measurements will be performed locally using standard local display and monitor units. These units process and display all such data which generate caution or warning audio and visual alarms.

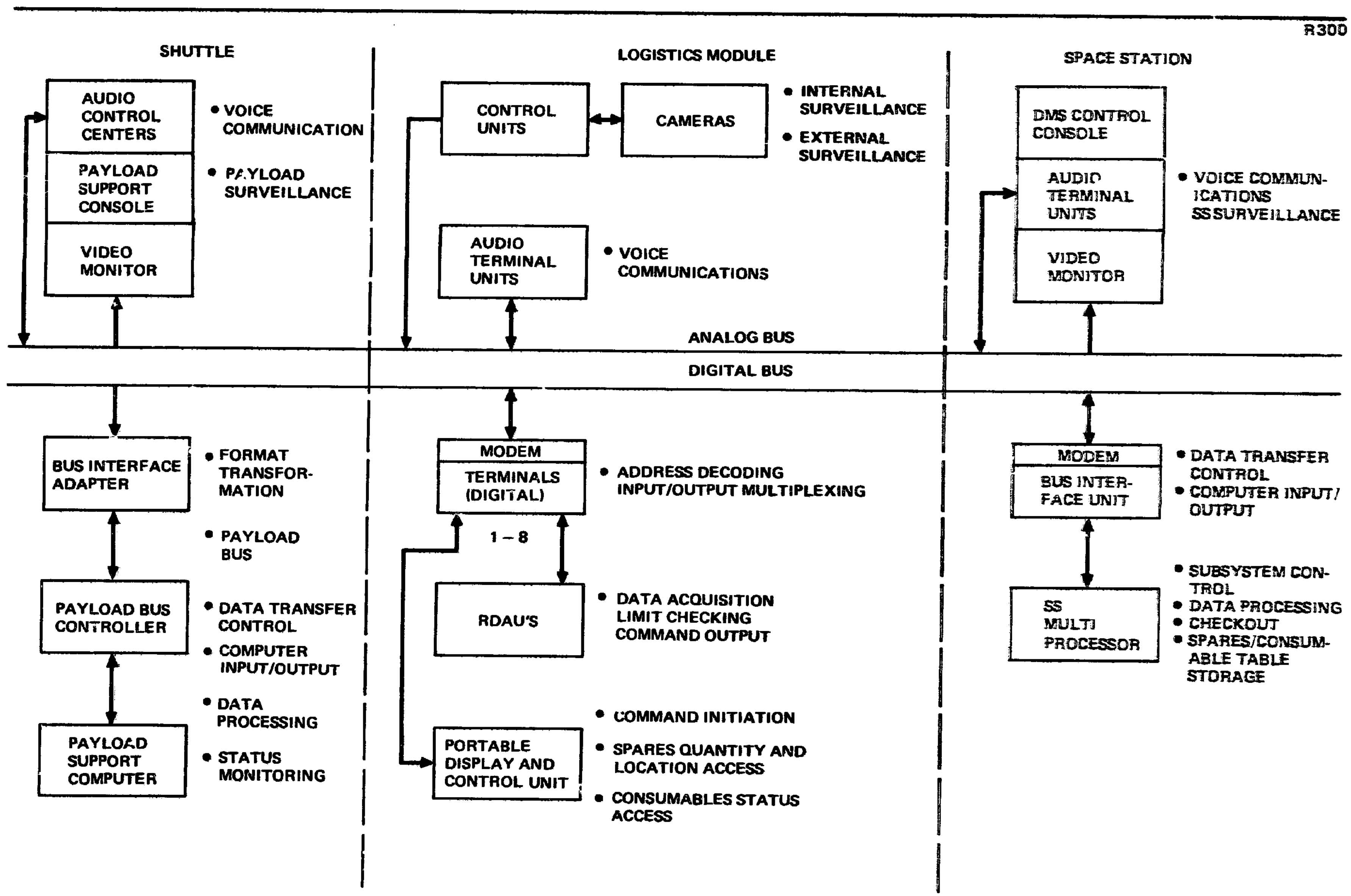


Figure 4-5. Logistics Module Interface Block Diagram

Signals of the caution type are then relayed to the central control facility via the data bus while warning signals are transferred via hard wire. Three such units are located in the Logistics Module monitoring environmental parameters such as O_2, N_2, CO_2, temperature, and pressure as well as safety-status signals from airlock monitoring transducers, leak detectors, fire detectors, interlocked controls, etc. A small panel will be located in the air-lock in conjunction with pressurizing and evacuation controls to inform crewmen engaging in EVA activities when hatches may be opened.

System status is provided by remote data acquisition units operating in conjunction with data bus terminal units. Checkout of the Logistics Module will be performed utilizing equipment such as remote data acquisition units and terminals provided for system status determination

An additional piece of equipment, the portable monitor and control unit, is provided for local checkout and maintenance in the module. It consists of a keyboard, CRT, and associated electronics allowing the crewman to display particular parameter values, ascertain trends, and obtain procedural information as to how to perform repair or replacement operations. The portable monitor and control console is also used as an input-output device for determining the level of spares or consumables available and the location of spares in the storage bins of the module. Withdrawals and additions (where parts are shifted from one Logistics Module to another) are entered via the keyboard after call-up of a particular item's name or part number which would also result in a display of the quantity of spares remaining and their bin location.

The communications and data management subsystems will require the components or assemblies shown in Table 4-5. Also included in the table are power and weight resource requirements.

Table 4-5

COMMUNICATIONS AND DATA MANAGEMENT

Name	Quantity	Weight (lb)	Power w (max)
Remote Data Acquisition Unit	12	12	60
Terminal	3	15	60
Bus (Couplers + Coax)	N/A		
ATU	3	12	12
Portable Monitor and Control Unit	1	100	125
TV Camera	2	4	N/A
Camera Control Unit	2	16	30
Local Display and Monitoring Unit	3	12	21
Wiring	N/A	89	0
Total		262	308

4 9

Section 5
EXPERIMENT SUPPORT CAPABILITY

5.1 SUBSYSTEMS SUPPORT

The resources provided by the Space Station to support experiment and applications programs are:

A. Power level of 4.8 kw at 115 vdc for experiments and experiment support with growth to 8.5 kw.

B. Color TV, high-resolution black-and-white TV, high bit-rate digital data (approximately 10^9 bps), analog data and high-resolution film (black-and-white, color, infrared, ultraviolet).

C. Digital, analog, and TV data transmission in real time to Earth.

D. Payloads up to a five-ft-dia sphere and up to 2,000 lb initial weight with growth capability to 8,000 lb.

E. Three attached experiment and applications modules with growth to eight.

F. All orientation capability (i.e., Earth-oriented, inertial, solar, gravity gradient, etc.)

G. An attitude-hold capability of ±0.02 deg in the Earth-oriented mode and ±0.05 deg in the inertial mode.

H. A stabilization rate of ±0.001 deg/sec.

I. A gravity level down to 4×10^{-5}g (quiescent) to 1×10^{-4}g (crew movement).

5.2 GENERAL PURPOSE LABORATORY

The General Purpose Laboratory (GPL) provides the capability to perform and support experiments and to support RAM's and experiments in RAM's. It is capable of supporting a broad range of experimentation and operations. The support for experiments and subsystems provided by the GPL includes (1) physical accommodation to perform experiments, (2) equipment to perform experiments, (3) calibration of experiments and operational equipment, (4) analysis and test, (5) disassembly, assembly, and repair, and (6) parts storage (spares, operational equipment, etc.).

The GPL is divided functionally and physically into eight laboratories and facilities combining related activities. Figure 5-1 shows the location of these facilities and laboratories in the GPL. Facilities are permanent throughout the operational mission life, but equipment for test, calibration, alignment, and the like can be reconfigured for experiment program changes.

Design requirements for the GPL were determined from an analysis of each FPE and FPE subgroup, which resulted in identification of support equipment necessary to perform the experiments. Equipments provided in the GPL have common application to a number of experiments and in addition include those normally required in a multicapability laboratory. A list of major GPL equipment is provided in Table 5-1.

Table 5-2 summarizes the principal accommodation requirements of each laboratory and facility and its interfaces with the Space Station.

5.2.1 Data Evaluation Facility (Figure 5-2)

The data evaluation facility includes equipment related to or associated with film, video, analog, and digital data and the handling, processing, and evaluation of such data. This facility is both an experiment and operations

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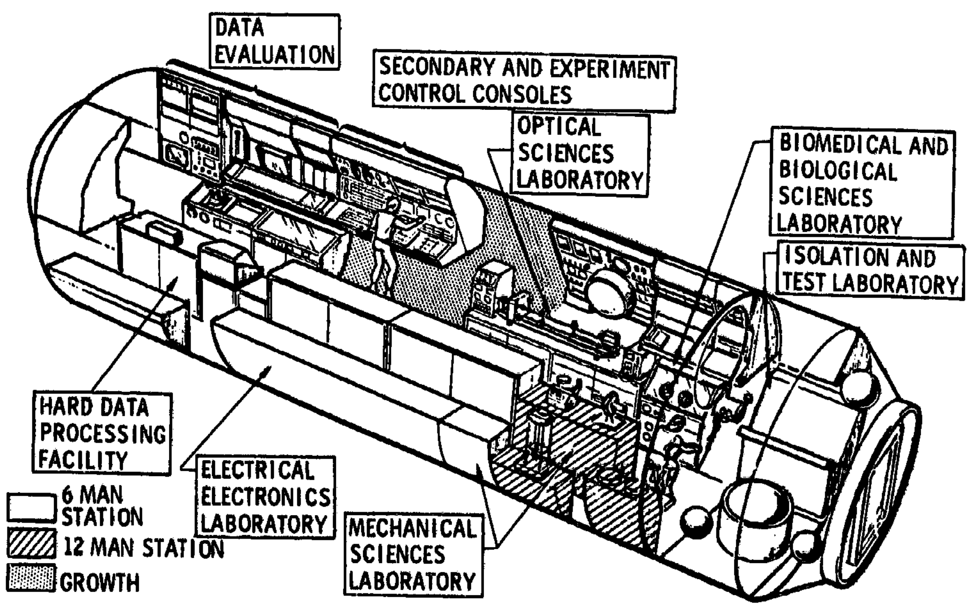


Figure 5-1. General Purpose Laboratory

FOLDOUT FRAME /

Table 5-1

GENERAL-PURPOSE LABORATORY MAJOR

Item
Data Evaluation Facility
Multiformat Viewer Editor
Microfilm Retrieval System
Automatic Film Reader
Copy Machine
Stereo Viewer
Image Processing and Data Management Control Station
Working Image Storage
Permanent Video Storage
Permanent Digital Storage
Time Reference Unit
Printer
Video Tape Unit
Scientific Computer
Analog Recorders
Digital Storage
Mechanical Sciences Laboratory
Mechanical Workbench
Experiment and Isolation Test Laboratory Monitor Panel
Laminar Flow Vacuum Glove Box
Specimen Structural Tester
Metallographic Tester and Microscope
Thermostructural Test Equipment
X-ray Generator
Precision Work Fixture
Optical Sciences Laboratory
Optical Work Station
Optical Bench
Precision Work Fixtures
Microdensitometer
Monochromator Spectrometer
Modulation Transfer Function Measurement System
Optical Spectrum Analyzer
Scientific Airlock Chamber
Precision Optical Window
Hard-Data Processing Facility
Film Processor—Rapid
Film and Plate Processor—Color
Film Processor—Black and White
Film Storage
Microfilmer
Light Table
Spectrophotometer
Densitometer
Experiment and Te
Hazard Detect
Electrical and
Hydraulic/Pne
Cryogenic and
High-Pressur
Airlock/Envir
Chemistry and
Chemistry and
Electronic/Electri
Electronic Wo
Multiinstrume
Battery Charg
High-Voltage S
High-Energy C
Miniature Glov
Biomedical/Bioscie
Biochemical an
Bioscience Glo
Bicycle Ergom
Lower-Body N
Body Mass Me
Biomedical Dis
Experiment/Second
Multipurpose D
Video Surveilla
Color Discrimi
Alphanumeric D
Warning Matrix
Caution Display
Voice Message
Status Lights
Microfilm View
Dedicated Displ
Programmable
Dedicated Switc
Hand Controller
Printer

FOLDOUT FRAME 2

Table 5-1

ENERAL-PURPOSE LABORATORY MAJOR EQUIPMENT

	Item
	Experiment and Test Isolation Laboratory
	Hazard Detection System
	Electrical and Vacuum Power Center
	Hydraulic/Pneumatic Work Station
	Cryogenic and Fluid Storage
	High-Pressure Gas Storage
rol Station	Airlock/Environmental Chamber
	Chemistry and Physics Glove Box
	Chemistry and Physics Analysis and Storage Unit
	Electronic/Electrical Laboratory
	Electronic Work Station
	Multiinstrument Test Bench
	Battery Charger
	High-Voltage Source
	High-Energy Counter Calibration Equipment
	Miniature Glove Box
nitor Panel	
	Biomedical/Bioscience Laboratory
	Biochemical and Biophysical Analysis Unit
	Bioscience Glove Box
	Bicycle Ergometer
	Lower-Body Negative Pressure Device
	Body Mass Measuring Device
	Biomedical Display and Control Unit
	Experiment/Secondary Control Center
	Multipurpose Display
	Video Surveillance Monitor
	Color Discriminator
stem	Alphanumeric Displays
	Warning Matrix
	Caution Display
	Voice Message Generation Unit
	Status Lights
	Microfilm Viewer
	Dedicated Displays
	Programmable Function Keyboard
	Dedicated Switches
	Hand Controller
	Printer

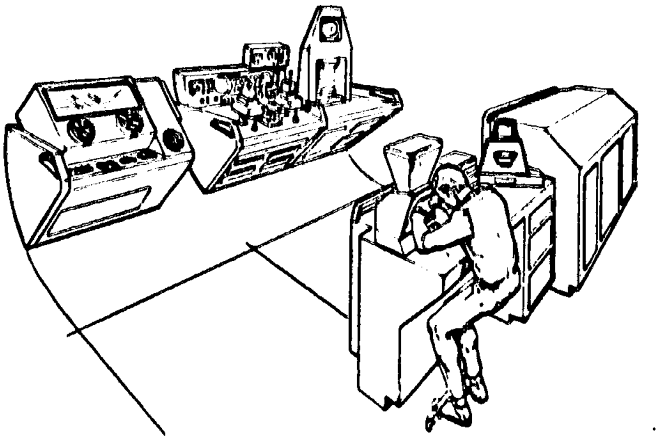
Table 5-2

ACCOMMODATION REQUIREMENTS AND SUBSYSTEM INTERFACES

Facility	Requirements	Major Interfaces	Remarks
Data-Evaluation Facility	Fluid tight equipment, filter system, light closure	Data management, ECLS, power	
Mechanical Sciences Laboratory	X-ray safety, cleaning and purging, glove box mechanical assembly and disassembly, metals testing, storage space for FPE equipment	Power, ECLS, waste management	Experiment and test isolation facility in mechanical laboratory
Optical Sciences Laboratory	Light closure, storage space for FPE equipment, heat exchanger for high-energy light sources, rigid optical flat and optical bench	Power filter	Airlock and viewport in facility
Hard-Data Processing	Fluid-tight equipment filter system; light tight closure	Water system, ECLS, power	
Experiment and Test Isolation Laboratory	Isolation for pressurized gases, fluids, and cryogenics. Airlock with heat exchanger, hydraulic/pneumatic test bench, must take reverse pressure	ECLS, power	Remote detection for environment required
Electrical/Electronics Laboratory	Power to electronic equipment, high voltage and power safety	Power	
Biomedical/Bioscience Laboratory	Fluid-tight equipment; filtered atmosphere in equipment	Water, ECLS power, data management	Operational for astronaut well-being and experiments

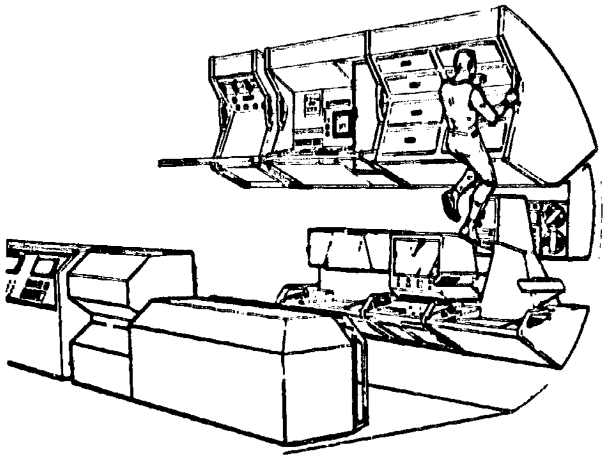
FOLDOUT FRAME 1

MECHANICAL LABORATORY



- MATERIAL TESTING AND ANALYSIS
- MECHANICAL WORK STATION
- GLOVE BOX

HARD DATA PROCESSING FACILITY



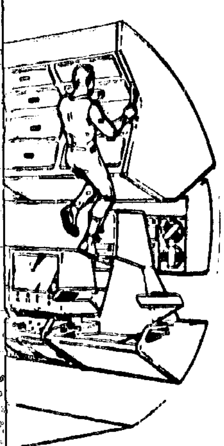
- BLACK AND WHITE COLOR FILM PROCESSING
- EMULSION PLATE PROCESSING
- MICROFILM
- FILM VAULT

DAT

- ANALYZ CALIBR
- ELECTR PROCES

FOLDOUT FRAME 2

NG FACILITY



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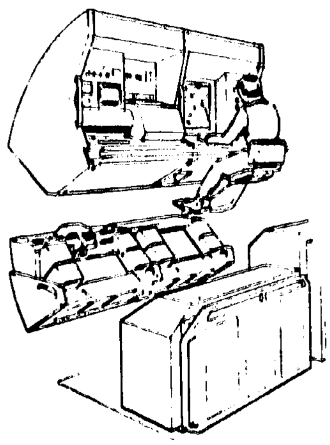
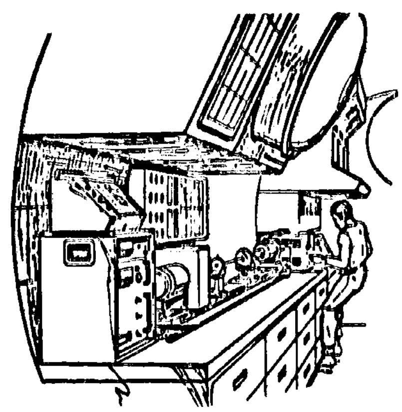
DATA EVALUATION FACILITY



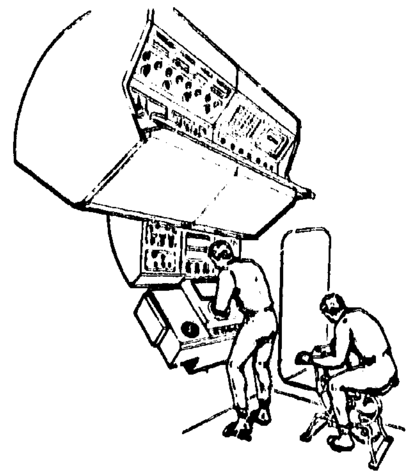
- ANALYZE, DIGITIZE AND CALIBRATE FILM
- ELECTRONIC IMAGE PROCESSING

OPTICAL SCIENCES LABORATORY



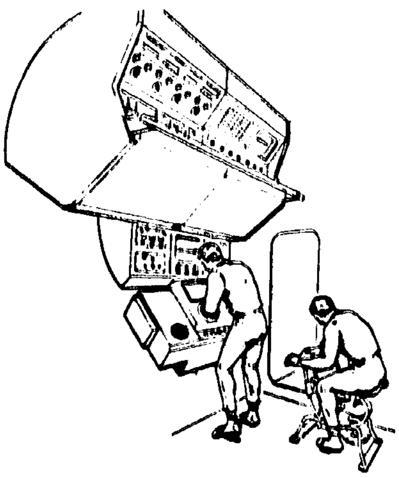
- CALIBRATE INSTRUMENTS
- OPTICAL ANALYSIS
- SCIENTIFIC AIRLOCK
- SUPPORT OPTICAL EXPERIMENTS

BIOMEDICAL/BIOSCIENCE LABORATORY



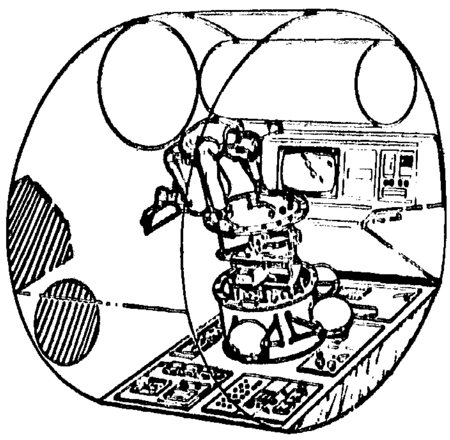
- FLIGHT CREW WELL–BEING
- BIOSCIENCE RESEARCH
- SPECIMEN PREPARATION
- FLUID ANALYSIS

BIOMEDICAL/BIOSCIENCE LABORATORY



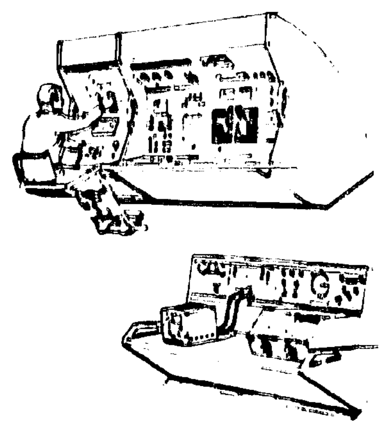
- FLIGHT CREW WELL–BEING
- BIOSCIENCE RESEARCH
- SPECIMEN PREPARATION
- FLUID ANALYSIS

EXPERIMENT AND TEST ISOLATION LABORATORY



- ISOLATED EXPERIMENT OPERATIONS
- CHEMISTRY AND PHYSICS EXPERIMENTS
- SCIENTIFIC AIRLOCK
- REMOTE OPERATION

ELECTRONIC/ELECTRICAL LABORATORY



- ELECTRONIC CALIBRATION
- CHECKOUT AND DIAGNOSTIC STIMULI
- MULTI–INSTRUMENT TEST STATION
- ELECTRONIC WORK BENCH

Figure 5-2. General Purpose Laboratories and Facilities

support facility and, as such, provides services to all experiments and subsystems. The data evaluation facility is an integral part of the data management subsystem. Many items of equipment that are located in this facility are part of the data management subsystem.

The multiformat viewer-editor can accept film widths from 35 mm up to 9 in. and film plate. It projects images and film frames at up to 30 times magnification, has the capability of producing hard copy of selected frames, and has a film-advance control which allows searching for a specific frame.

The microfilm retrieval system is capable of storing 30 million frames of data with a maximum search time of 20 sec; when the system is loaded to lower than the 30-million frame capacity, it has a proportionally shorter search time. The microfilm retrieval system can be updated using the microfilmer and the hard-data processing facility. A retrieval system displays full-size image copies of pages of data and it has the capability of sending the selected image frames on the video system to any TV monitor on the station or to the ground through the data bus. The retrieval system is also capable of producing hard copies in the size of the original data document.

The copy machine in the data evaluation facility is a Xerox-type which can produce high-contrast copies of black and white documents on a multiple or single basis. The stereo viewer is a standard piece of equipment utilized for stereo film evaluation and analysis.

The data evaluation facility printer is capable of producing contact prints of negative and positive film strips (both still and motion picture) and also making high-resolution copies of film and other data. It can enlarge sections of a segment of a frame or make one-to-one sized copies. This equipment is a composite of printers and copiers now currently within the state of the art and in widespread use.

5.2.2 Mechanical Sciences Laboratory (Figure 5-2)

Many types of mechanical, electromechanical, and chemical functions can be accommodated by the equipment in the mechanical sciences laboratory. The laboratory features a laminar-flow glove box for heavy-duty and light-duty repair, replacement, purging, and cleaning of experimental equipment subassemblies. The glove box provides zero-g holddown for items subject to this assembly as well as for removed elements and high replacement parts which require clean facilities, chemical washing, or treating and must be isolated from the Space Station environment and flight crew.

The mechanical sciences laboratory also contains such equipments as a metallograph, thermostructural tester, x-ray generator, tensile and compression tester, and a mechanical work bench on which is mounted the tensile and compression tester. This equipment is typical of that in a metallurgical mechanical research laboratory for performance and analysis of material sciences experiments. Other equipment utilized for mechanical sciences experiments which might be provided at a later date for detailed and complex scientific analysis of materials includes x-ray diffraction units and a scanning electron microscope.

5.2.3 Optical Sciences Laboratory (Figure 5-2)

The optical sciences laboratory is used to perform maintenance and operations requiring optical support. The laboratory includes equipment and facilities for a wide range of optical calibrations, maintenance, measurements, and tests.

The laboratory contains a scientific airlock chamber for performance and deployment of experiments. Associated with the airlock chamber is an optically flat, broad-spectrum transmission window which allows viewing and photography of external experiments and external phenomena. Because this window has broad-spectrum transmission during normal Space Station operation, a filter must be placed over the window to shut out ultraviolet rays for astronaut safety. The scientific airlock chamber is 0.61 m in diameter.

An experiment and airlock display and control unit is mounted adjacent to the airlock for control and operation of the experiments associated with the optical sciences laboratory in the experiment airlock chamber. An airlock chamber extension is provided which allows the chamber to accommodate experiment packages up to 7 ft in length. The laboratory also has a heat-dissipation unit which will work in conjunction with a high-intensity light source when used on the optical bench.

When working in the optical sciences laboratory, a swing-aside light suppressing panel need be drawn around the optics bench to cut off extraneous light from the equipment and to close off the laboratory from outside interference.

5.2.4 Hard-Data Processing Facility (Figure 5-2)

The hard-data processing facility provides all the equipment utilized for film storage, handling, processing, spectral and density calibration, and quick-look strip evaluation. The hard-data process facility services all experiments and operations that utilize film and as such is used widely.

Film and plate storage is provided in this facility under controlled temperature and humidity conditions. Shielding by the film vault is required to prevent emulsion fogging by natural radiation. If required, low tempe- tures can be used to lengthen film shelf life. The film and plate processors are based on current technology spray-type processors with double barriers and seals to prevent potential emission of toxic fluids or gases. The rapid film processor can use a dry or semi-dry process. This type of processor is proven, highly reliable, and produces fairly high-resolution quality copy of negative or positive formats. The processed film is of archival quality and as such can be stored aboard the Space Station for return, kept on board for further evaluation, microfilmed, analyzed in the data evaluation facility, or copied on the contact printer or the photo copier.

5.2.5 Experiment and Test Isolation Laboratory (Figure 5-2)

The experiment and test isolation laboratory is a separate compartment within the GPL which can take reverse or positive pressure. Access to vacuum is provided by an airlock chamber which is an integral part of the facility and by the total facility itself, which can be sealed and depressurized for EVA or for experiment deployment. The isolation laboratory is used for all experiments and maintenance that require isolation from the Space Station environment for safety, toxicity, or other purposes for which a single barrier or glove box of similar capability does not suffice. The isolation laboratory is used for experiments and testing which are potentially hazardous, such as those involving welding, cryogenics, high-pressure fluids, and high temperatures. A remote console for the isolation and test laboratory is located outside the sealed wall of the laboratory to allow monitoring and control of isolated experiments during operations. A viewport is provided to observe activities inside the isolation laboratory. Hazardous experiments to be conducted in the isolation facility will be set up with the astronaut in the facility and the facility pressurized but sealed off from the remainder of the Space Station. Cryogens, toxic fluids, and high-pressure gases are stored in the isolation facility as required.

The experiment and test isolation laboratory also contains an isolation test work bench which provides the capability for calibration and repair of hydraulic, pneumatic, and other types of equipment which utilize high pressures and fluids and can produce a hazard in the Space Station. This isolation and test work bench provides all the plumbing and capability to test, monitor, and measure fluid flow, fluid pressures, and gas flow and pressures.

5.2.6 Electrical/Electronics Laboratory (Figure 5-2)

The electrical and electronics laboratory provides the instrumentation, test, stimuli, controls, and displays necessary for testing and electronic calibration and maintenance functions. As with other GPL laboratories and facilities, the equipment will be modularized so that carry-on equipment can be utilized and the laboratory can be reconfigured.

As a minimum, this laboratory will include the following items: an oscilloscope, hard-copy strip recorders, voltmeters, power supplies, signal generators, signal analyzers, test sets, small patch panels, test connectors, continuity checkers, multimeters, timers, frequency counters, test sets, function generators, special hand tools, and mounting fixtures. As required, this equipment will be augmented by modular plug-in test equipment for support of experiments when special equipment is required to supply stimuli for checkout and test of experiments or to calibrate experiments.

The main service facility is a multiinstrument test console which provides the capabilities for bench checkout, calibration, and contingency repair. The instruments in the multiinstrument test bench can be unplugged and utilized in a remote location as portable test equipment. Built into the electrical and electronic test and checkout work bench is a miniature laminar-flow glove box for cleaning, assembling, diassembling, soldering, and spot welding.

5.2.7 Biomedical/Bioscience Laboratory (Figure 5-2)

The requirements of a small bioscience research program and monitoring of astronaut well-being have been combined into a single laboratory because of commonality of equipment and like equipment functions. The equipment for bioscience experiments consists of plant, invertebrate and microbiological incubation facilities, photo and TV coverage, specimen identification, plant and cell chemistry analysis, biological fluid handling, macro and micrography, specimen preparation, preparation of microtomes (microscope slides and sections) a liquid-separation centrifuge, and refrigerator and freezer capability for storage and preparation of specimens for return to Earth.

The biomedical equipment will be capable of measuring heart functions with an electrocardiogram and a vectorcardiogram, work performance with a bicycle ergometer, body mass with a body mass measurement device, and effects of weightlessness on the physiology of astronauts using a lower-body, negative-pressure device.

Biochemistry of body fluids will be performed using some equipment shared with the bioscience laboratory. The equipment will have the capability of performing automated urine analysis, automated blood analysis, and specimen mass measurement.

A biological glove box is provided for work in any of the biomedical or bioscience areas requiring isolation or separation from the Space Station environment due to contamination. The glove box will also be used for dissection and specimen preparation.

5.2.8 Experiment/Secondary Control Center (Figure 5-3)

The experiment/secondary command and control center is a centralized operations station for monitoring and management of experiments. In addition, it provides emergency and backup vehicle and subsystem control in the event the crew is forced to evacuate the Crew/Operations Module. Display and control hardware at the center is basically the same as at the primary command and control center with additional dedicated experiment displays and controls for monitoring and control of experiments. The configuration of the center allows for fully independent two-man capability so that one operator can concentrate on one set of experiments without interference from the other operator.

The major assemblies of the experiment/secondary command and control center are as follows:

A. Multipurpose Display and Input Devices—The primary display element is a computer driven cathode ray tube device which permits information to be displayed upon a single time-shared device as requested or through cycling procedures. The CRT display is capable of presenting computer-generated data such as characters, vectors, and tabular data as well as dynamic real-world TV imagery provided by Vidicon cameras and other analog sensors. These two

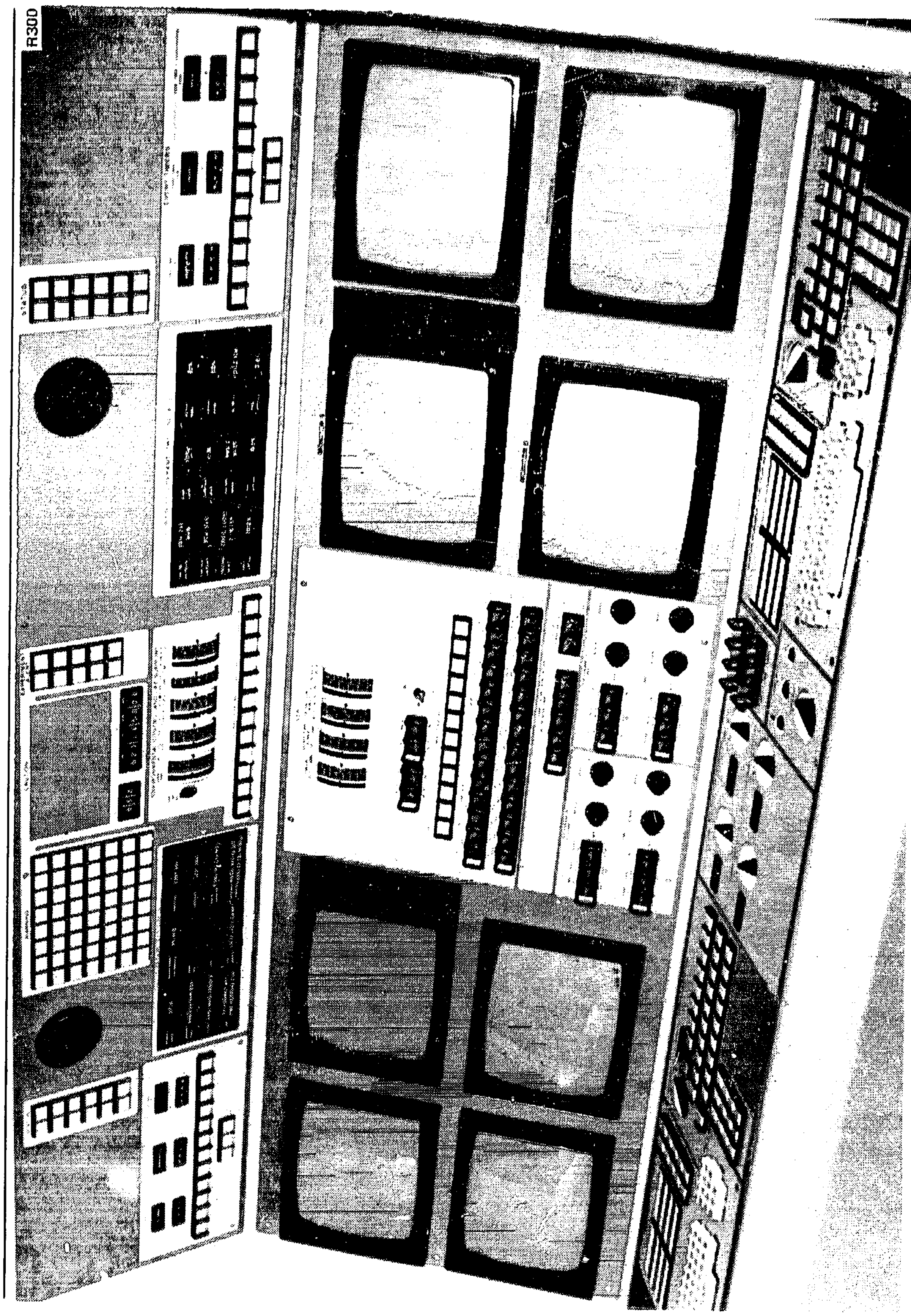


Figure 5-3. Experiment Control Console

sources of data can be shown independently, adjacent to each other or superimposed to provide complete flexibility and visibility of computer processing and data control operations.

B. Video Surveillance Monitor—A surveillance monitor is included at the command and control centers to provide internal and external surveillance capability over designated areas of the Space Station. This display can also be used for monitoring experiment data, programs, and parameters available within the system on a real-time basis or from stored memory as directed by the operator.

C. Color Discriminator—Color discriminator capability is provided to enhance data comparison operations, and to highlight those parts of the data in a particular spectral range. This feature may be used to highlight data that would otherwise be difficult or impossible to visualize.

D. Alphanumeric Displays—Alphanumeric readouts are used to continuously display selected parameters that are considered critical to Space Station integrity, important to certain mission phases, or to provide information of general interest in the form of computer-generated digital data. These readouts are liquid crystal cell displays which incorporate the advantages of high reliability and lifetime, wide-angle viewing having little or no parallax, continuous brightness independent of ambient lighting, and microwatt power.

E. Warning Matrix—Continuous monitoring of subsystem critical parameters is performed as part of the onboard checkout subsystem with a matrix of annunciators at the command centers to display and alert the crew to failed or out-of-tolerance conditions. The warning functions consists of an array of dedicated light annunciators that are hard-wired to the onboard checkout subsystem detection equipment.

F. Caution Display—Display of caution-level functions is by a liquid crystal cell display which indicates a message determined by the multiprocessor. This display interfaces with the multiprocessor via the data bus and operates in a manner similar to the alphanumeric displays. The lower portion of the display will permit storage of past caution alerts and allow recall capability of functions that have not been corrected. In this manner, status of caution functions can be determined by activating a switch to call up the message for uncorrected caution conditions.

G. Voice Message Generation Unit—A voice message generator is provided which permits spoken voice messages to be generated by computer control. This unit supplements the caution and warning functions.

H. Status Lights—Status lights and monitors will be provided to show subsystem and experiment operating conditions. These monitors will be used to indicate active or passive conditions, depict normal or alternate modes, provide positive control feedback response, and in general indicate subsystem status and experiment conditions.

I. Microfilm Viewer—A microfilm viewer is provided to assist the crew member in trouble-shooting procedures, maintenance techniques, control operation procedures, and other related information.

J. Dedicated Displays—Several dedicated meters and other display devices are required for unique and emergency or contingency conditions. It is expected these will be utilized in the event of emergency response, power failure conditions, and other contingency conditions as well as for subsystems and experiment control.

K. Programmable Function Keyboard—A programmable function keyboard is supplied at each operator station as an input device for access to the computer. This keyboard-display-computer loop allows one operator to sequentially select from a computer-listed "menu" and progressively construct command code for computer initiation of the required operation. Through a series of fixed-programmed select keys and a series of function keys the operator can select the desired operation. The fixed program keys are typically push-button switches, while the display function keys are activated by the operator touching the nomenclature with his finger. This technique allows the operator to implement control capability without requiring a dictionary of the computer command codes.

L. Dedicated Switches—Rotary and toggle switches are provided to supplement the previously described control devices. The controls may be utilized for specific subsystem and experiment functions as well as for emergency and contingency capability. Critical control functions and backup functions are hard-wired for maximum reliability.

M. Hand Controller—Depending on mode selection, the hand controller is used to perform manual steering operations, operate attitude and translation thrusters, and aim sensors/cameras to track landmarks and targets. The hand controller provides emergency direct-attitude control capability through hard-wired interfaces.

N. Printer—A printer provides a record of ground communications in the event that the console is not manned during a ground contact period. The printer can be used as a means of producing a hard-copy record of instructions, computer programming changes, and subsystem data.

Section 6
EXPERIMENT REQUIREMENTS

This section includes a description of the mode of accommodation of experiments, the baseline experiment program and sensitivity of requirements to the experiment program, and a description of Research and Applications Modules with emphasis on interfaces with the station.

A list of FPE's and FPE subgroups is provided in Table 6-1. These were derived from the NASA Blue Book to facilitate the analysis of experiment requirements. The use of identical double letters (for example, ES-1AA, Earth Observations Sequential) indicates that many of the Blue Book defined packages have been incorporated into one larger package. For this example, ES-1A, B, C, D, and F are included in ES-1AA.

6.1 EXPERIMENT ACCOMMODATION

The possible modes of accommodation include:

A. Integral—In General-Purpose Laboratory.

B. Dedicated Module—Attached module dedicated to a single experiment or experiment group.

C. Free-Flying Module—Module operating detached from station.

In the selection of the modes of accommodation, resource requirements for each FPE and experiment subgroup were compared to the Space Station g-level, pointing stability, available volume, and contamination environment.

Table 6-2 summarizes the mode of accommodation results.

6.1.1 Gravity Level

Crew motion sets a lower limit on ambient acceleration levels (gravity level). This gravity level is 1.4×10^{-4}g for the ISS and 1.2×10^{-4}g for the GSS. The plant research activity of the Life Sciences FPE has a requirement for less than 10^{-5}g 90 percent of the time and 10^{-4}g 10 percent of the time. Certain chemistry experiments require 10^{-4}g and the material science experiments desire 10^{-5}g, but will accept 10^{-3}g. Allowable acceleration

Table 6-1

FPE/SUBGROUP DESIGNATIONS

A-1	X-ray stellar astronomy	ES-1G	Minimum payload (core)
A-2	Advanced stellar astronomy	CN-1	Communications/navigations facility
A-2A	Intermediate stellar telescope	CN-1A	Communications/navigations Subgroup A
A-3AA	Advanced solar astronomy	CN-1B	Communications/navigations Subgroup B
A-3CC	ATM follow-on	MS-3A	Crystal growth, biological and physical processes
A-4A	0.9-m narrow field UV telescope	MS-3B	Crystal growth from vapor
A-4B	0.3-m wide field UV telescope	MS-3C	Controlled density materials
A-4C	Small UV survey telescope	MS-3D	Liquid and glass processing
A-5A	X-ray telescope	MS-3E	Supercooling and homogeneous nucleation
A-5B	Gamma ray telescope	T-1A	Contamination experimental package
A-6	IR telescope	T-1B	Contamination monitor package
P-1A	Atmospheric and magneto science	T-2A	Long-term cryogenic storage
P-1B	Cometary physics	T-2BB	Short-term cryogenic storage
P-1C	Meteoroid science	T-3A	Astronaut maneuver unit
P-1D	Thick material meteoroid penetration	T-3B	Manned work platform
P-1E	Small astronomy telescopes	T-4A	Long-duration system tests
P-2A	Wake measurements from station and booms	T-4B	Medium-duration tests
P-2BB	Wake, plasma, wave particle, electron beam	T-4C	Short-duration tests
P-3	Cosmic ray physics laboratory	T-5A	Initial flight teleoperator
P-3C	Plastic/nuclear emulsions	T-5B	Functional teleoperator
P-4A	Airlock and boom experiments	T-5C	Ground control teleoperator
P-4B	Flame, chemistry, and laser experiments	LS-1A	Minimal medical research facility
P-4C	Test chamber experiments	LS-1B	Minimal life science research facility
ES-1	Earth observation facility	LS-1C	Intermediate life science research facility
ES-1AA	Earth observational sequential	LS-1D	Dedicated life science research facility

Table 6-2
MODES OF ACCOMMODATION

FPE or Subgroup	Mode of Accommodation	Primary Determining Factors: Attitude Stability	G-Level	Contamination	Size	Remarks
A-1	FF	X		X	X	
A-2	FF	X		X	X	
A-2A	FF	X		X	X	FF —Free Flyer
A-3AA	FF	X		X	X	
A-3CC	FF	X		X	X	
A-4A	AM			Clean	X	
A-4B	AM			Clean	X	
A-4C	AM			Clean	X	AM —Attached Module with
A-5A	FF			X	X	approximately one-
A-5B	AM				X	half volume, as
A-6	AM			Clean	X	airlock accommodates
P-1A, B, C, D, E	I			Clean		more than one experi-
P-2BB	AM				X	ment group
P-2A	I					I —Integral to station or
P-3	AM				X	pressured section of
P-3C	I					AM
P-4A, B, C	I					
ES-1	AM			Clean	X	
ES-1AA	AM			Clean	X	
ES-1G	AM			Clean	X	
C/N-1A, B	AM				X	
MS-3A, B, C, D, E	I				X	
T-1A, B	I					
T-2A	FF					
T-2BB	FF		X			
T-3A	I					
T-3B	AM				X	
T-4C	I	(Partial)				
T-4A, B	I					
T-5	I					
LS-1A	I					
LS-1D	AM				X	
LS-1B, 1C, 1D	AM					

levels for astronomy are primarily determined by attitude stability requirements. The astronomy experiments requiring less than 10^{-4}g require free flyers to satisfy other criteria. The allowable gravity level for astronomy instruments accommodated in an attached module is within station limits.

Fluid physics experiments require continuous discrete acceleration levels from 10^{-5} to 10^{-3}g for long time periods (approaching 5,000 hr). A free-flying module must be used, since it is not practical to accelerate the station.

6.1.2 Pointing Stability

The Space Station pointing and stability capability are adequate for all but astronomy, communications/navigations, and the advanced guidance system experiment that is flown piggyback on the advanced stellar astronomy module. Of these, the UV survey, high energy, and IR astronomy experiments can be accommodated on the Station with the use of a gimbal system. The advanced x-ray, stellar and solar experiments require free-flying modules. FPE's with pointing requirements are accommodated as follows:

A. Within basic Station pointing capability
   1. All physics.
   2. Technology (except for A-2 Module piggyback).
B. Accommodated on Station with gimbal system
   1. Earth observations.
   2. Intermediate UV telescopes, A-4.
   3. High-energy astronomy, A-5.
   4. IR astronomy, A-6.
C. Require free flyer
   1. X-ray stellar astronomy, A-1.
   2. Advanced stellar astronomy, A-2.
   3. Advanced solar astronomy, A-3.

6.1.3 Size

Experiments not requiring large depressurizable volumes or very large dedicated facilities can be accommodated integrally. Large experiments require a dedicated pressurized module. These are:

A. Intermediate size UV-telescopes, A-4A and B.
B. Plasma physics experiments using subsatellite, P-2BB.

C. X-ray and gamma-ray telescopes A-5A, A-5B.

D. IR astronomy, A-6.

E. Earth observations ES-1.

F. Communications/Navigation C/N-1A, C/N-1B.

G. Dedicated life science facility, LS-1D.

H Cosmic-ray physics laboratory, P3.

6.1.4 Contamination

Optical contamination effects and countermeasures are summarized in Table 6-3. X-ray imaging instruments have severe sensitivity to contamination due to the refraction and absorption by very thin contamination layers on grazing incidence optics. At the far UV end of the spectrum, extreme absorption is also encountered. At wave lengths in near-UV and visible spectra, the susceptibility to condensables is moderate. At IR wavelengths, the effects are low but the use of cryogenically cooled mirrors greatly increases the sticking coefficient and therefore the contamination buildup rate.

Degradation produced by scattering from the contamination cloud surrounding the station is worst in the UV, visible, and IR wavelengths.

Table 6-3

CONTAMINATION SUSCEPTIBILITY AND COUNTERMEASURES

Instrument Wavelength	Susceptibility to Condensables	Susceptibility to Scattering	Replacement	Active Cleaning	Calibration
X-ray (imaging)	Extreme	Low	Alignment very difficult	Difficult without degrading surfaces	Difficult due to weak sources
Ultraviolet	Absorption high for shorter wavelengths	High	Okay for small optics, if provided in design	Promising concepts (most require vacuum). Slight degradation must be recalibrated	Observe standard stars or built-in sources
Visible	Moderate	High	Okay for small optics	Techniques available (use solvents in pressurized envelope)	Observe standard stars or built-in sources
Infrared	Low (but increased rate with cryogenic mirror)	Low	Okay for small optics	Techniques available (use solvents in pressurized envelope)	Observe standard stars or built-in sources

Contaminants exist for at least several orbits after a substantial EC/LS or RCS dump. The time for dispersal is substantially extended by condensation on cool Space Station surfaces with subsequent vaporization when reheated by solar radiation.

The most promising countermeasures include replacement, active cleaning, and calibration to take account of changes in reflectivity or transmissibility. Replacement of x-ray grazing incidence optics is difficult due to extreme alignment accuracies required and the absence of strong stellar calibration sources. Replacement of small UV visible and IR optics (i.e., on the order of 0.3 m or 1 ft diameter or less) is feasible if provision is made in the design. Calibration can be supplemented using built-in or standard stellar sources.

Active cleaning techniques for x-ray optics do not appear feasible due to the complexity of structures such as the grazing incidence venetian blind collimator. The x-ray mirror surface finish is unacceptably roughened by active cleaning techniques which are sufficiently vigorous to remove most contaminants. There are several promising active cleaning techniques for UV reflectors; for example, ion bombardment. At visible and IR wavelengths, solvent cleaning procedures can be used if the optics are in pressurizable carriers. Conclusions related to contamination are that the A-1 and A-5A x-ray telescope and A-2 stellar and A-3 solar telescopes require free flyers.

6.2 MODEL EXPERIMENT PROGRAM AND SENSITIVITIES

The experiment program analyses resulted in the derivation of resource requirements, a model or baseline experiment program, and alternative experiment programs. A large number of experiment programs were structured to evaluate resource parameters, particularly cost and experiment crew size. A principal objective of the analysis was to define an experiment program having minimum cost but which effectively utilizes other resources of the Station (particularly crew time).

Figure 6-1 is the experiment flight schedule for Case 534G, the Baseline Experiment Program. The figure indicates the accommodation of each experiment (GPL, attached RAM, free-flying RAM). LS-1A, the Minimal Medical Research Facility, is launched with the Modular Space Station during the first quarter of experiment operations. Several technology experiments are also performed during the first quarter. The first RAM, Communications/

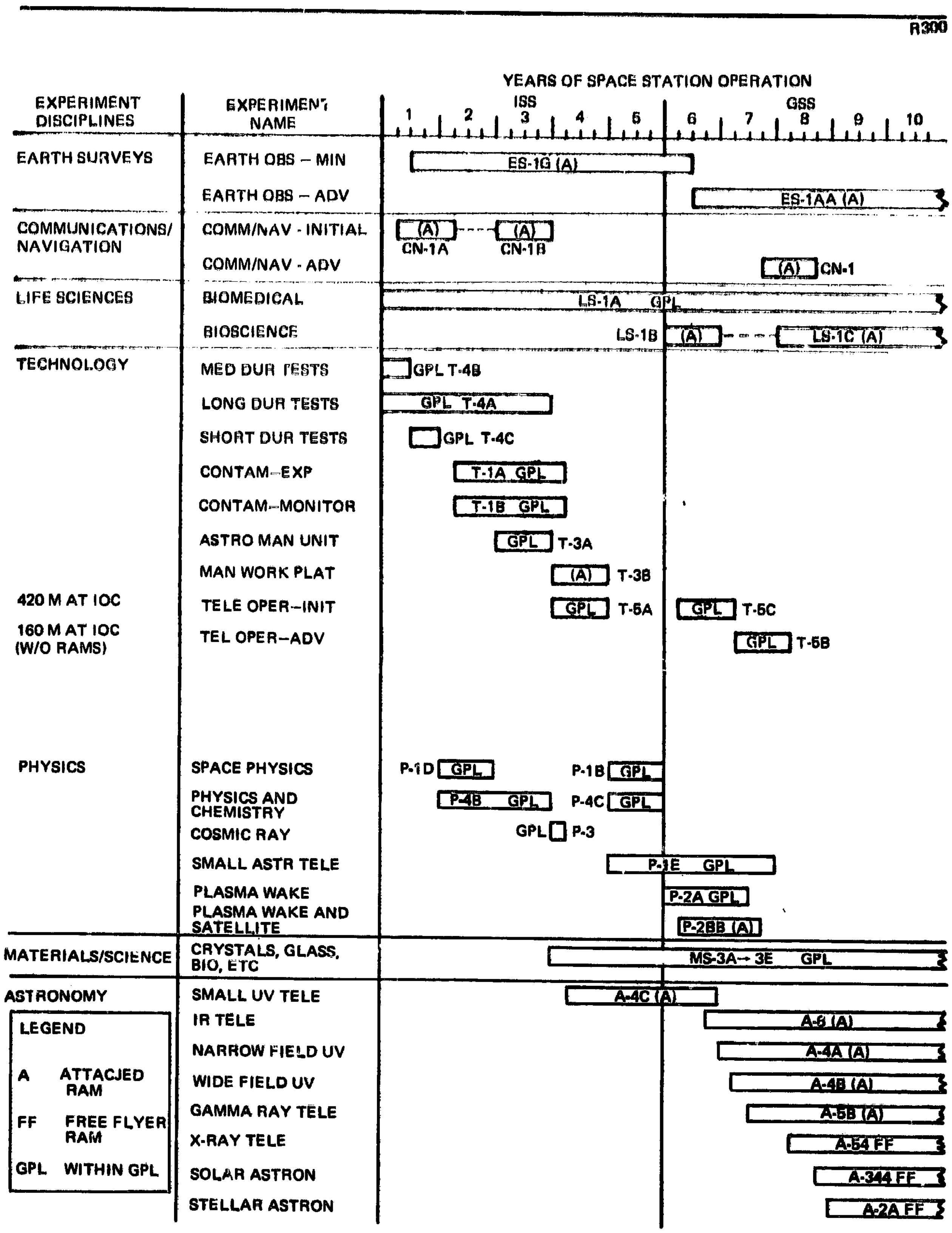


Figure 6-1. Baseline Research and Applications Program

Navigation Subgroup A, is brought up in the second quarter. During the third quarter, the second RAM (ES-1G, Earth Survey Core package) is brought up. CN-1A is returned to Earth for refurbishment and launched as CN-1B in the ninth quarter. Material Science, MS-3A through MS-3E, should be considered as one facility brought up in increments. T1-3B, an attached RAM, is brought up after the conclusion of the Communications/Navigation CN-1B package. Shortly thereafter, the UV Astronomy Module, A-4C, is launched in the 14th quarter. The remainder of the ISS portion of the baseline experiment program continues with the addition of five more physics experiments carried in the GPL.

Figure 6-2 is the docking port load for the baseline experiment program. It can be seen that during the ISS portion, three experiment docking ports are required and during the GSS portion of the program, eight experiment docking ports are required.

Resource requirements for Case 534G are shown in Figures 6-3 (cost), 6-4 (manpower), 6-5 (power), and 6-6 (logistics). It was determined that the resources did not vary greatly during the ISS portion of the experiment

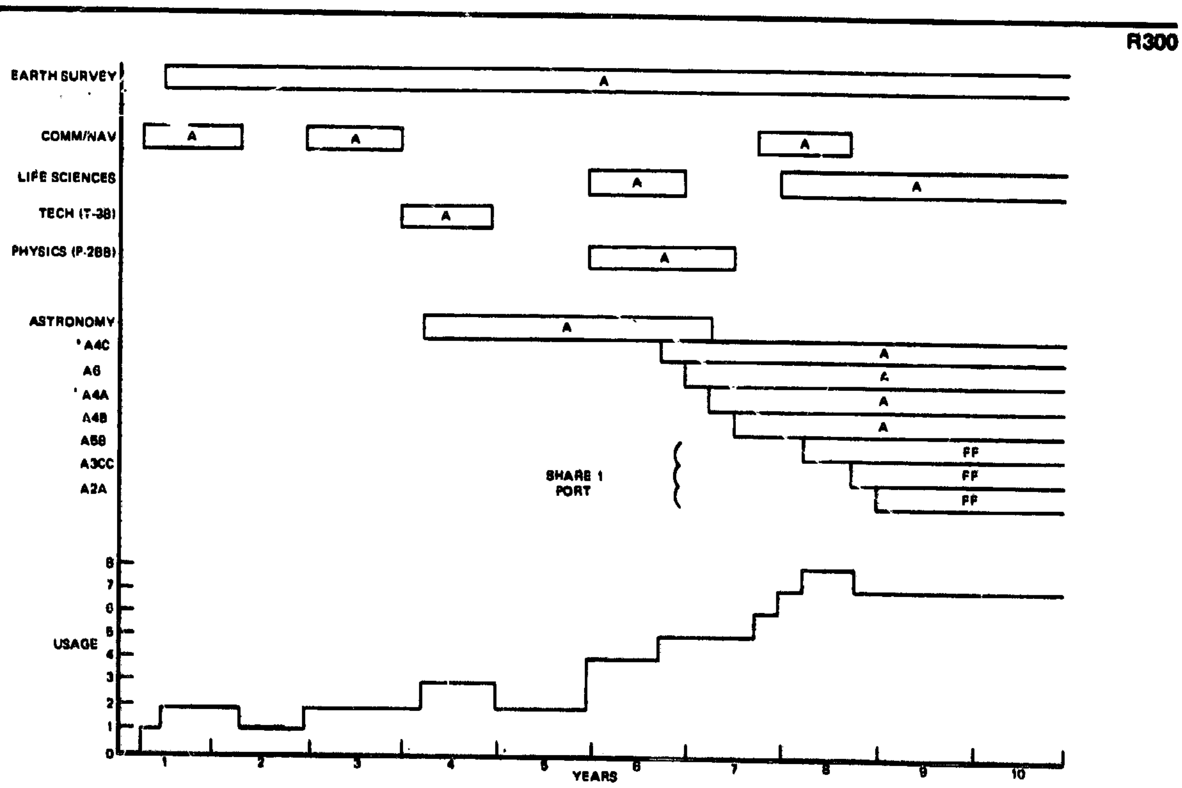


Figure 6-2. Docking Port Utilization (Case 534G)

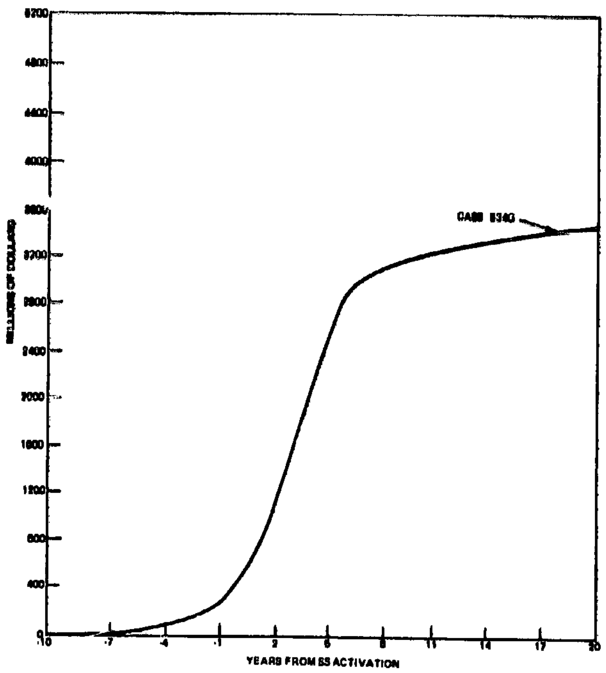


Figure 6-3. Cumulative Costs (Baseline Program)

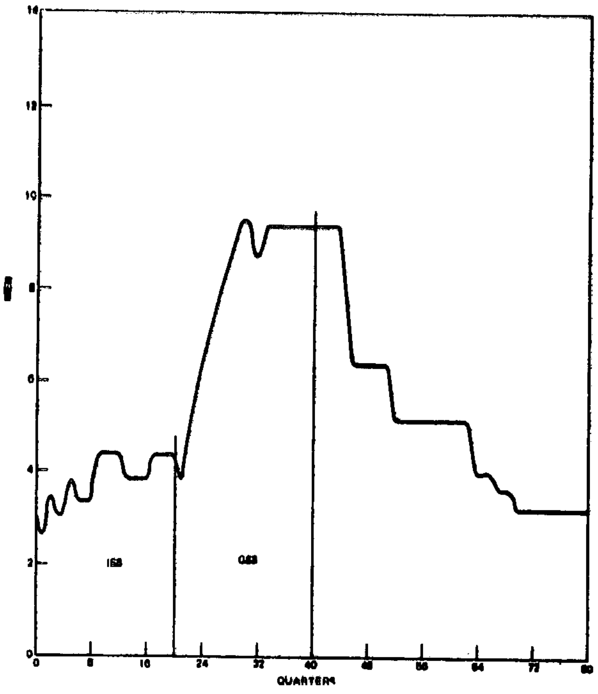


Figure 6-4. Manpower Requirements (Baseline Program)

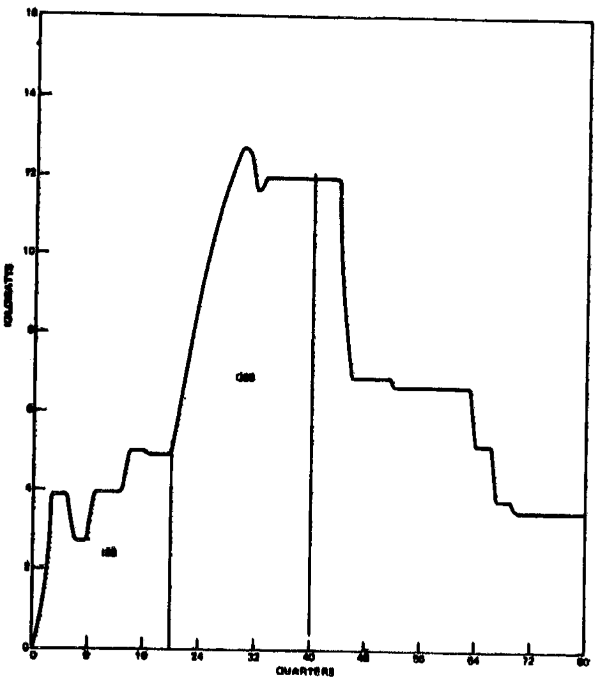


Figure 6-5. Power Requirements (Baseline Program)

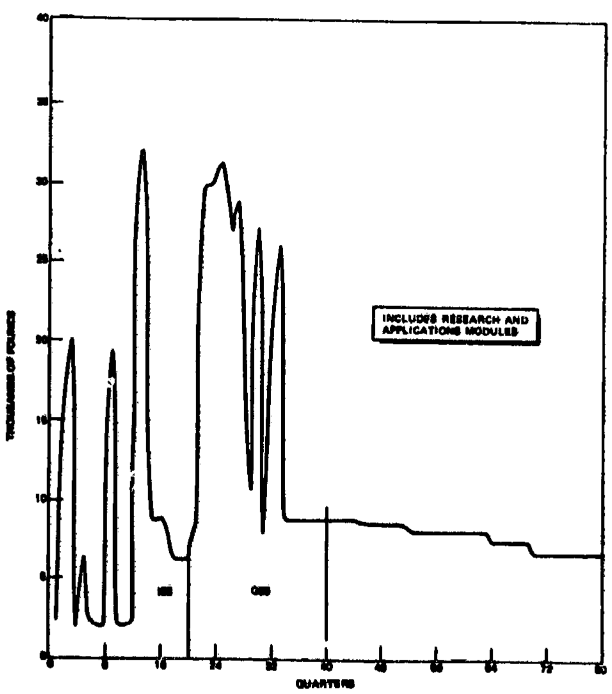


Figure 6-6. Logistic Resupply Requirements (Baseline Program)

program over a large case sample. This was due to the imposition of cost constraints.

A life sciences emphasis, non-cost-constrained experiment program was generated (see Figure 6-7). In this program, both LS-1A (Minimum Medical) and LS-1 (the Minimum Life Science Research Facility) were launched initially. LS-1B was launched in an attached module. After one year, it was returned to ground for refurbishment and relaunched as LS-1C, the Intermediate Life Science Research Facility. It extended past the end of the ISS one year into the GSS, and at that time it was joined by LS-1D, the Dedicated Life Science Research Facility, also in an attached module. The primary parameter of interest is the cost at the beginning of the ISS, $767 million. An astronomy emphasis program was also run as Case 538A. As many modules were made to fly during the ISS as were consistent with available resources other than cost. Here, the cost at Space Station launch was $1, 207 million.

6.3 RESEARCH AND APPLICATIONS MODULES

To establish requirements for the Space Station preliminary design, a set of Research and Applications Modules (RAM's) were defined. This section describes the modules selected to accommodate those Blue Book FPE's that have been assigned to RAM's as a result of the mode-of-accommodation analysis and their interface with the Space Station. A total of 23 experiment groups require modules. Eight module configurations were developed to meet the requirements of these experiment groups.

6.3.1 Module Description

The eight module types are discussed below with reference to Figure 6-8. The experiment groups accommodated in each type are noted in Figure 6-8.

6.3.1.1 Type 1 Module

Due to launch weight limitations on x-ray stellar astronomy and advanced and ATM follow-on solar astronomy, only the module volume containing subsystems is pressurized for shirtsleeve access. The primary optics and experiment sensors are supported in an unpressured structural framework.

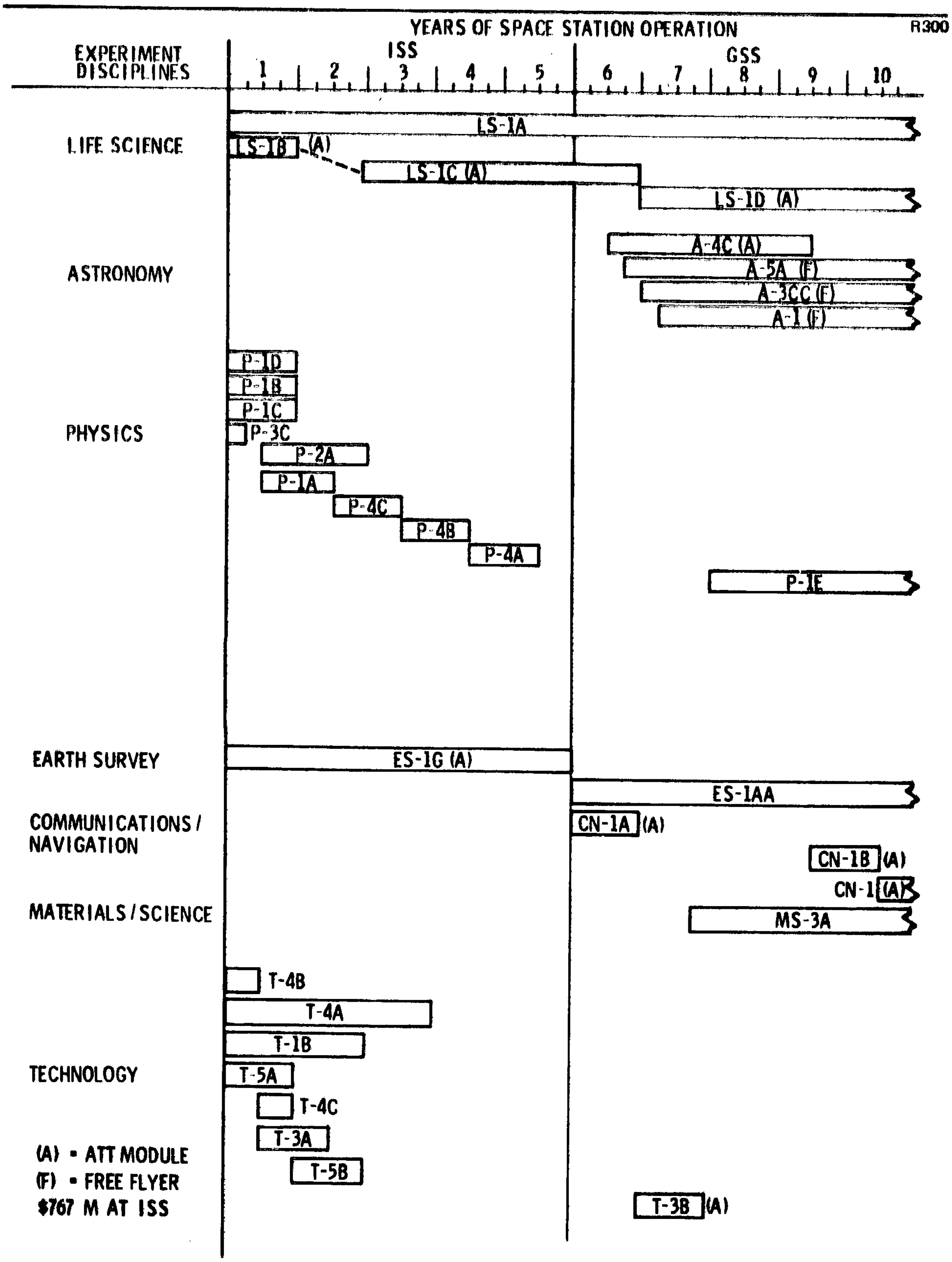


Figure 6-7. Life Science Emphasis Program

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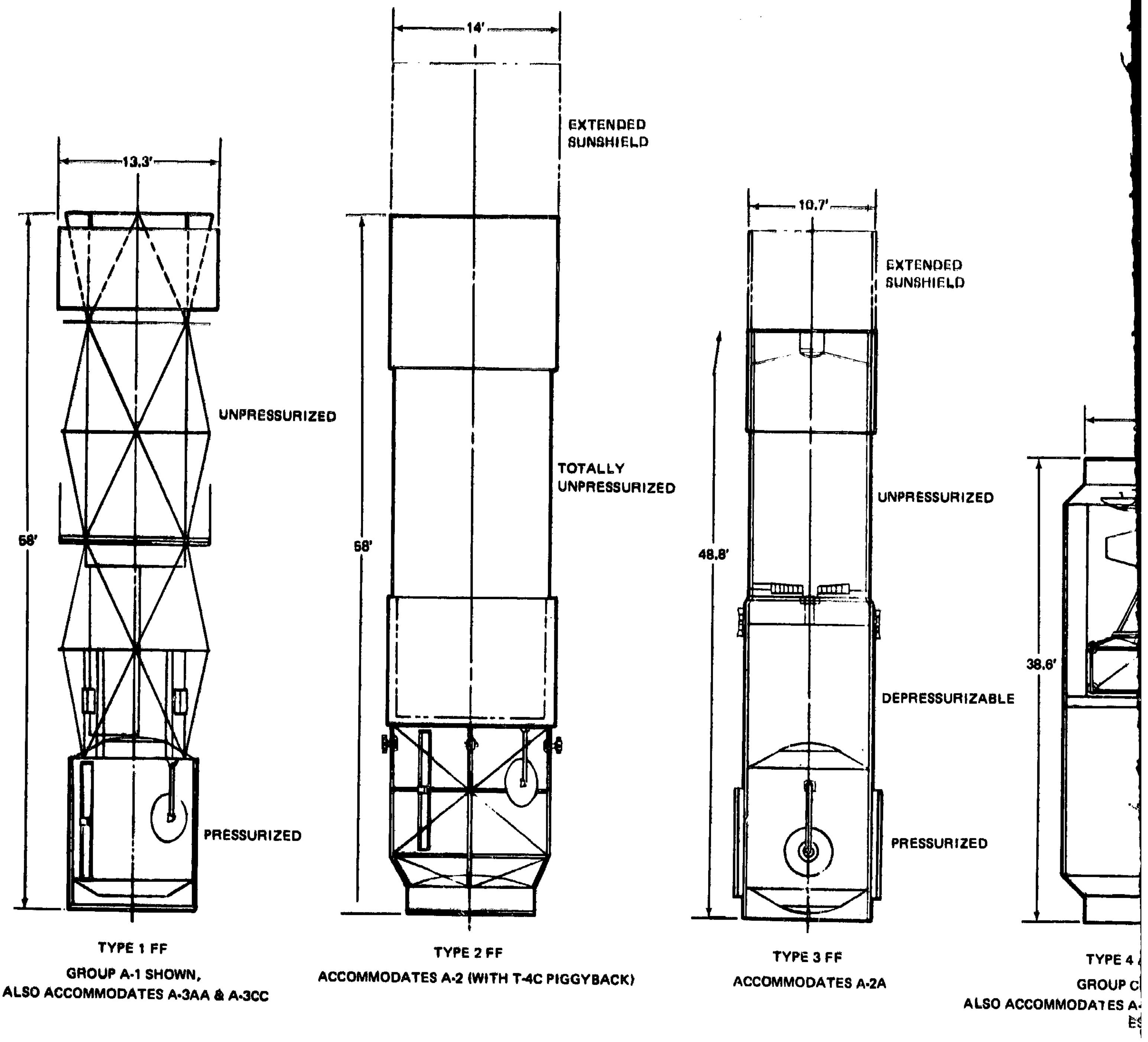

Figure 6-8. Module Structural Types

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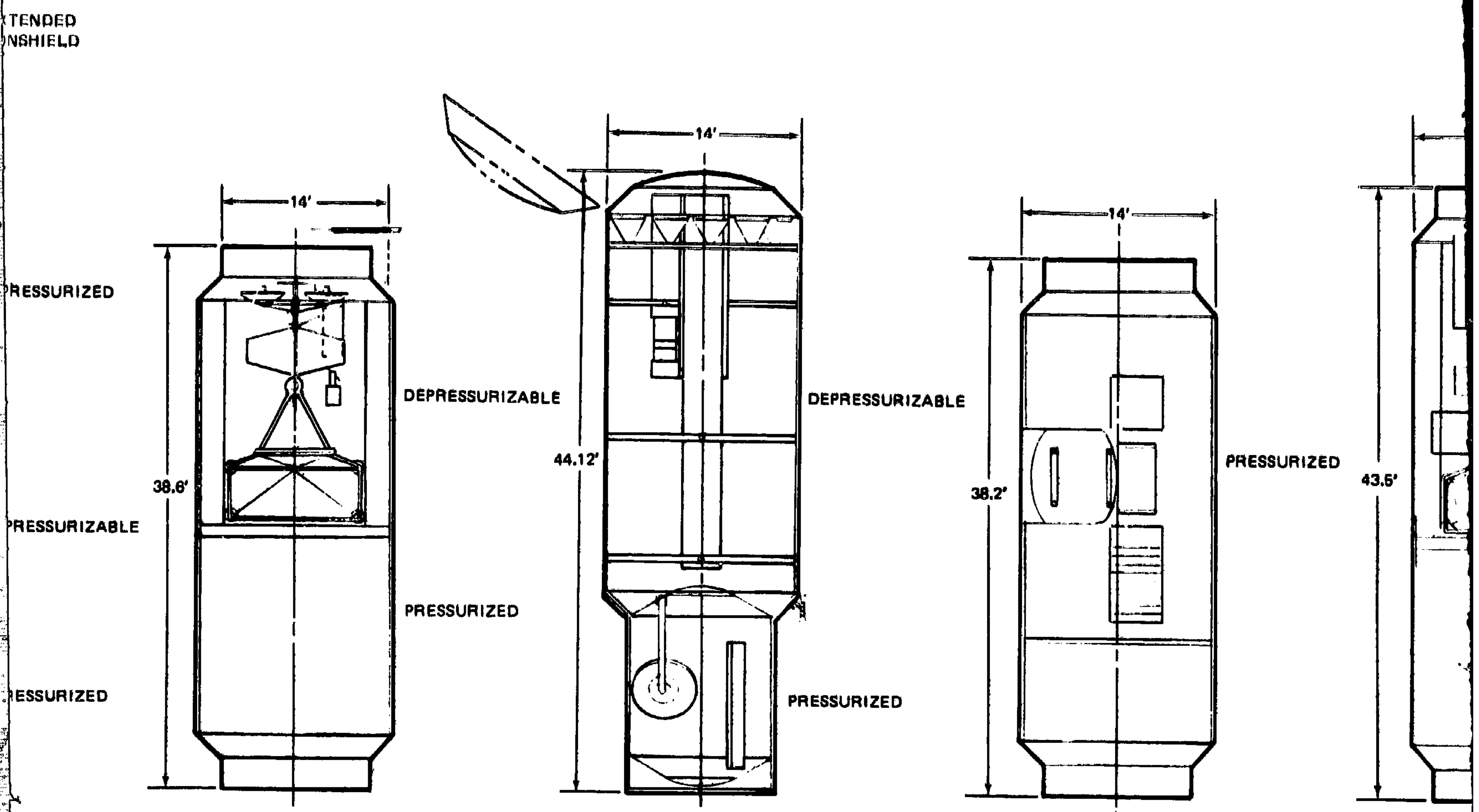


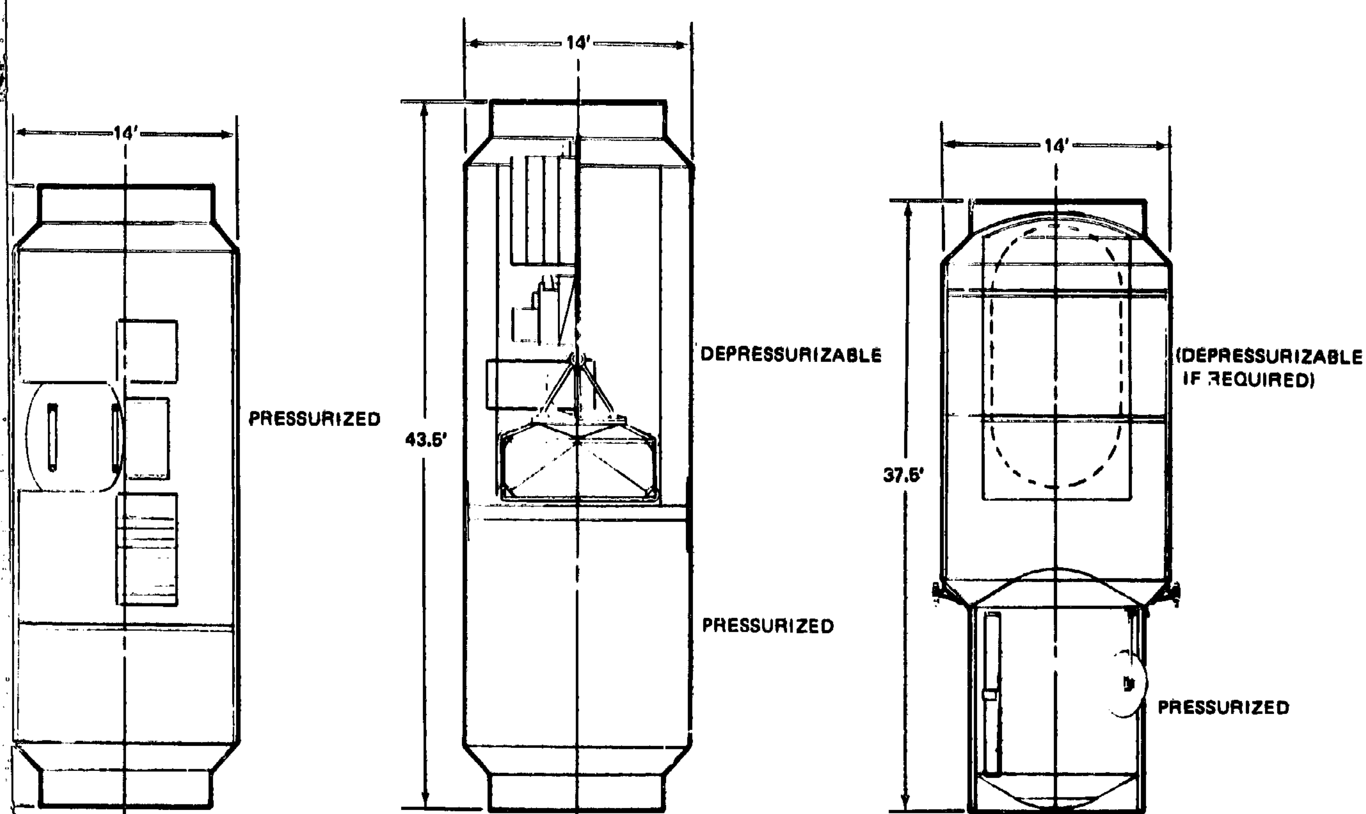
TYPE 4 ATTACHED
GROUP CN-1B SHOWN,
ALSO ACCOMMODATES A-4A, A-4B, A-4C, A-5B, P-2BB
ES-1AA, ES-1G, CN-1, CN-1A, T-3B

TYPE 5 FF
GROUP A-5A SHOWN

TYPE 6 ATTACHED
GROUP P-3 SHOWN,
ALSO ACCOMMODATES LS-1B THROUGH D

TYPE
ACCO

R300



TYPE 6 ATTACHED
GROUP P-3 SHOWN,
:OMMODATES LS-1B THROUGH D

TYPE 7 ATTACHED
ACCOMMODATES ES-1

TYPE 8 FF
GROUP T-2A SHOWN,
ALSO ACCOMMODATES T-2BB

6.3.1.2 Type 2 Module

The 6,300 kg (13,800 lb) mass of the 3-m advanced stellar astronomy telescope (exclusive of module and subsystems) precludes the inclusion of a pressurizable volume. The module could, however, be launched in two sections and a pressurized volume provided.

6.3.1.3 Type 3 Module

The 2-m intermediate stellar telescope is flown in a three-sectioned module. The subsystems chamber is continuously pressurized. The experiment sensor chamber can be pressurized for changing sensors and maintenance and depressurized for operation. Weight limitations still require the primary optics volume to remain unpressurizable.

6.3.1.4 Type 4 Module

The airlock module configuration accommodates the most experiments with the 12 groups noted in Figure 6-8 in the airlock volume, plus appropriate manned support equipment in the pressurized volume.

6.3.1.5 Type 5 Module

Weight of the small x-ray telescope package allows the use of a fully pressurizable free-flyer design.

6.3.1.6 Type 6 Module

The all-up dedicated life science research facility, and the cosmic ray physics laboratory are located in dedicated modules.

6.3.1.7 Type 7 Module

Accommodation of the entire Earth surveys experiment complement on a large gimbal platform requires a dedicated module with a depressurizable volume.

6.3.1.8 Type 8 Module

This free flyer provides the long-term linear acceleration required for cryostorage experiments. The volume containing the experiments can be depressurized if required for proper environment simulation.

6.3.2 Module-Space Station Interfaces

6.3.2.1 Module Pumpdown

Table 6-4 shows pumpdown volume requirements. The Space Station supplies the pumping system and 1.2 cu m (42 cu ft), 2,070 kN/sq m (300 psi) storage tanks for up to 23.2 cu m (820 cu ft) of gas. Additional storage volumes required for module Types 4, 5, and 7 are supplied by similar auxiliary tanks located in the modules.

6.3.2.2 Electrical Power

The dedicated life sciences module requires the most power with an average load of 6.6 kw which exceeds the power available for attached modules and experiments during the ISS phase of operations. This module can be accommodated in the GSS phase because additional power is available. Most of the modles require approximately 1 to 2 kw average power, including control and display and pumpdown power. This power is supplied from the station when modules are docked.

6.3.2.3 Weight

Table 6-4 shows that the 9,072 kg (20,000 lb) module "design-to" weight limit is exceeded in two cases, even after off-loading of easily removable subsystems and initial logistics. The 9,280 kg (20,420 lb) weight of the A-1 module could be reduced to almost 9,072 kg (20,000 lb) if the control moment gyros are installed in orbit. The 10,900 kg (24,000 lb) launch weight of the A-2 module cannot be substantially reduced without a radically different design approach.

The eight modules weighing exactly 9,072 kg (20,000 lb) all have some carry-on logistics required.

6.3.2.4 Data

During attached mode operation, data are transferred to the Space Station data bus. The primary signal processing equipment on the modules includes signal conditioners, remote acquisition units, a data programmer, modulator and demodulator system, and duplex intercom system. All photographic film and other hard-copy processing is accomplished in the GPL.

Free-flying modules transmit data to the Station at a range of up to 1,850 km (1,000 nmi). Transmitters operating at Ku-band are used with both omni and 1.22-m (4-ft) diameter directional antennas.

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Table 6-4

EXPERIMENT MODULE REQUIREMENTS

Module Type	Experiment Group	Launch, kg (lb)	Carry-on, kg (lb)	Depressurizable Pumpdown Volume, m^3 (ft^3)
1	A-1	9,270 (20,420)	518 (1,140)	None
	A-3AA	9,072 (20,000)	14 (30)	None
	A-3CC	6,483 (14,280)	----	None
2	A-2	10,896 (24,000)	463 (1,020)	None
3	A-2A	8,077 (17,790)	----	33 (1,163)
4	A-4A	7,105 (15,650)	----	68 (2,407)
	A-4B	6,846 (15,080)	----	68 (2,407)
	A-4C	6,687 (14,730)	----	68 (2,407)
	A-5B	8,303 (18,290)	----	68 (2,407)
	A-6	8,762 (19,300)	----	68 (2,407)
	P-2BB	9,072 (20,000)	586 (1,290)	68 (2,407)
	ES-1AA	8,917 (19,640)	----	68 (2,407)
	ES-1G	8,662 (19,080)	----	68 (2,407)
	CN-1	6,805 (14,990)	----	68 (2,407)
	CN-1A	6,633 (14,610)	----	68 (2,407)
	CN-1B	6,678 (14,710)	----	68 (2,407)
	T-3B	9,072 (20,000)	195 (430)	68 (2,407)
5	A-5A	8,930 (19,670)	----	115 (4,078)
6	P-3	9,072 (20,000)	12,163 (26,790)	None
	LS-1D	9,072 (20,000)	232 (510)	None
7	ES-1	9,072 (20,000)	1,094 (2,410)	88 (3,102)
8	T-2A	9,072 (20,000)	3,500 (7,710)	None(4)
	T-2BB	9,072 (20,000)	4,372 (9,630)	None

Notes:

(1) Maximum daily average electrical power delivered to module from Station, plus control ar module operation. Power for docked or attached modes only.

(2) Maximum daily average power supplied by free-flying module power subsystem.

(3) Average includes yearly replacement of superconducting magnet/dewar.

(4) Assumes that experiments normally operate in pressurized chamber, but could be depress experiments.

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Table 6-4

PERIMENT MODULE REQUIREMENTS

:arry-on, kg (lb)	Depressurizable Pumpdown Volume, m^3 (ft^3)	Electrical Power Station Power(1) (kw)	Free-Flyer Power(2) (kw)
518 (1, 140)	None	0. 10	1. 42
14 (30)	None	0. 11	1. 49
----	None	0. 10	1. 42
463 (1, 020)	None	0. 12	1. 10
----	33 (1, 163)	0. 53	1. 51
----	68 (2, 407)	2. 22	N/A
----	68 (2, 407)	2. 28	
----	68 (2, 407)	1. 95	
----	68 (2, 407)	2. 20	
----	68 (2, 407)	2. 31	
586 (1, 290)	68 (2, 407)	2. 02	
----	68 (2, 407)	4. 57	
----	68 (2, 407)	3. 90	
----	68 (2, 407)	2. 14	
----	68 (2, 407)	2. 05	
----	68 (2, 407)	2. 07	
195 (430)	68 (2, 407)	1. 79	
----	115 (4, 078)	1. 56	1. 29
163 (26, 790)	None	1. 62	N/A
232 (510)	None	6. 61	
)94 (2, 410)	88 (3, 102)	5. 79	
300 (7, 710)	None(4)	0. 10	1. 33
372 (9, 630)	None	0. 15	1. 41

red to module from Station, plus control and display and pumpdown power supporting
d modes only.
-flying module power subsystem.
onducting magnet/dewar.
pressurized chamber, but could be depressurized if required for some particular

6.3.2.5 Control, Display, and Checkout

The primary monitor and control console for the free-flying modules is located in the GPL. When docked, the local control and display for free-flying modules is provided by a portable unit containing a computer-addressable keyboard, CRT display, and associated controls and electronics. This unit interfaces with the data bus.

Onboard checkout is accomplished through the data management system. To a large extent, routine stimuli generators and response analysis will be computer-controlled for automated monitoring. Many of the modules have as many as 2,000 to 3,000 checkout points to accomplish this. The crew can override these operations for flexible adaptation to specialized conditions.

6.3.2.6 Guidance and Control

Attitude reference data for gimbal/platform pointing on attached modules is supplied from the Space Station.

6.3.2.7 Propulsion

The propulsion system for free flyers uses monopropellant hydrazine. Propellant is supplied from a nitrogen-pressurized, blowdown-positive expulsion system using bellows-type tanks. These tanks are filled from the Station through a coupling at the docking interface.

6.3.2.8 Atmosphere Control

Atmosphere for shirtsleeve operations in attached modules and docked free-flyers is supplied from the Space Station. Filters to increase the cleanliness to Class 10,000 are required for most of the astronomy telescopes located in pressurizable chambers. As previously noted, pumpdown is accomplished using the pump/reservoir system on the Station with additional reservoir tanks on the modules as needed.

The atmosphere in the life sciences cages and glove boxes is isolated from the Space Station atmosphere by a separate EC/LS System.

6.3.2.9 Thermal Control

Heat is not transferred across the Station-module interface (except via air circulation). Therefore, attached modules and docked free flyers independently reject heat. The modules are thermally isolated using high-performance multilayer insulation. The module thermal control systems use two circulating fluid loops coupled by a heat exchanger. Water is used in the cold-plate loop to ensure a nontoxic condition in the event of a leak.

Section 7
OPERATIONS ANALYSIS

The operations analyses performed on the Modular Space Station are reported in this section. The ground operations are summarized in Section 7.1 while the flight operations analysis is included in Section 7.2.

7.1 GROUND OPERATIONS

Ground operations for the Modular Space Station encompass development, manufacturing, launch-site and sustaining support activities. The following discussion of ground operations includes predelivery and refurbishment activities and overall test philosophy as they affect launch site operations.

7.1.1 Space Station

Space Station ground operations include all launch-site activities necessary to activate the site and to process (receive, service, install in orbiter, and launch) all modules required to complete the orbital buildup of the Space Station. The first three modules launched (see Figure 7-1, overall launch schedule) will comprise the ISS, while a second group of two modules that may be launched five years later would provide for growth to the full 12-man station. Hence, the concepts for training and maintaining of ground personnel and the disposition of GSE form an important part of prelaunch and launch operations. KSC is assumed to be the Shuttle launch site for this analysis.

7.1.1.1 Development and Test

Pre-delivery activities are based on the test philosophy developed for the Space Station. Some of the most important guidelines of the test philosophy are as follows:

A. The Space Station is controlled by a single CEI specification with final assembly test, and integration done by a single contractor at one facility.

B. Imposed environment testing, both development and qualification, will be concentrated at the assembly hardware level and lower,

R300

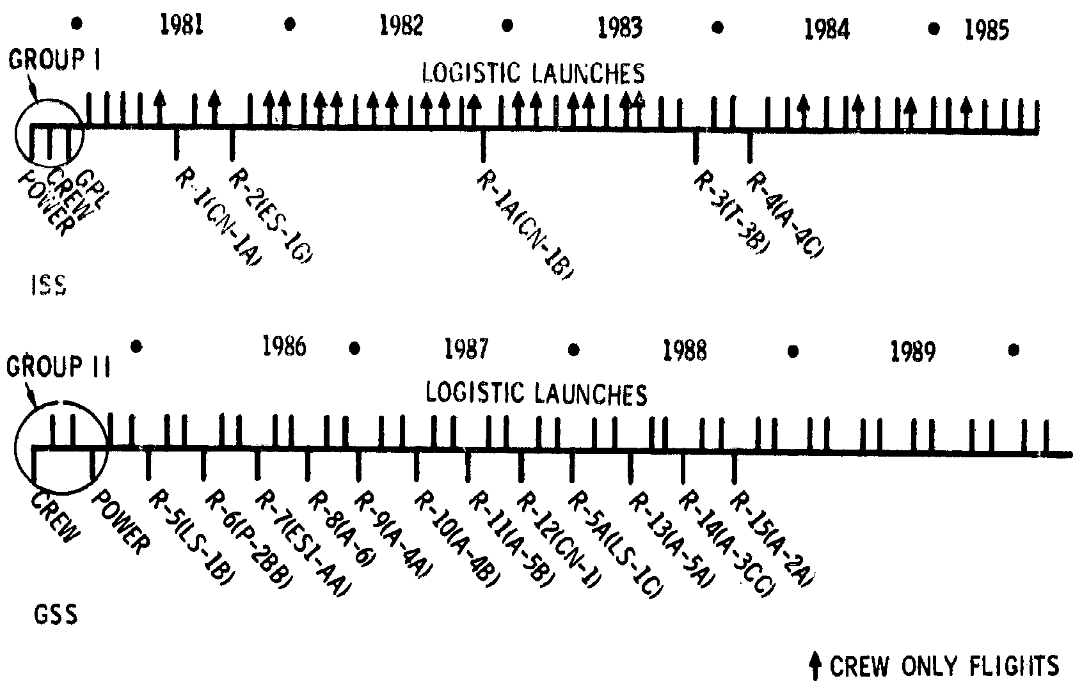

Figure 7-1. Space Station Launch Schedule

there will be no environmental testing at the systems (module) level.

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

1. Design development tests utilizing a functional model (FM) that is an electrical, electronic, and data subsystem breadboard of the ISS modules.
2. Design-qualification demonstrations utilizing a flight integration tool (FIT) that is a physical and functional replica of the ISS modules. (The FIT is also used for sustaining support of mission operations are discussed later.)
3. Hardware-acceptance tests of flight modules. Implicit in this test philosophy is the intent to eliminate environmental mission profile qualification testing at the module level or above, and to minimize repetition of integrated systems tests, whether performed at the factory or launch site.

D. A policy of shipping an orbit-ready module from the factory will be followed. However, should launch site testing be unavoidable, it will be no more rigorous than acceptance testing performed at the factory. Major disassembly and tests at lower levels of assembly will not be permitted in the field except when necessary to isolate malfunctions. Launch checkout will be accomplished with onboard checkout instrumentation, supplemented, as necessary with external GSE for control and monitoring purposes.

E. Tests will be assembled into an overall test plan covering all aspects of testing so that (1) tests conducted at lower hardware levels generally will not be repeated at higher levels, and (2) development testing is performed so that sensors and parameters which will ultimately be used for acceptance testing will have a credible data base. Similarly, acceptance and prelaunch testing will be constrained to those sensors and parameters previously utilized in the development qualification testing programs.

The functional model, Figure 7-2, will be used as a breadboard for development of electrical, electronic, and data systems and module-to-module electrical interfaces. The FIT modules, Figure 7-2, will be developed in parallel using refurbished test specimens from the qualification test program. The FIT modules will be used as production prototypes to develop cable and wire runs, assembly techniques, etc. Each of the FIT modules will be tested utilizing production GSE after which it will be substituted for its counterpart in the functional model. After all three have been substituted in the FM, they will be assembled into the ISS configuration utilizing split interface adapters.

The production flight articles will then be manufactured (Figure 7-3). They will be substituted for the FIT modules, one by one, and operations verified. The flight articles will be assembled into the ISS configuration and integrated operation verified. By this technique, both the FIT modules and the flight articles can be proven to operate as assembled ISS configurations. The interchange of modules between the two verifies the intermodule interface and overall operation of the flight articles and the FIT, which will support the 10-year program on the ground for integration of subsequent changes and new hardware. After this integrated test which must verify readiness for orbital operations, the modules will be disassembled, the items to be off-loaded removed, and the modules individually shipped to the

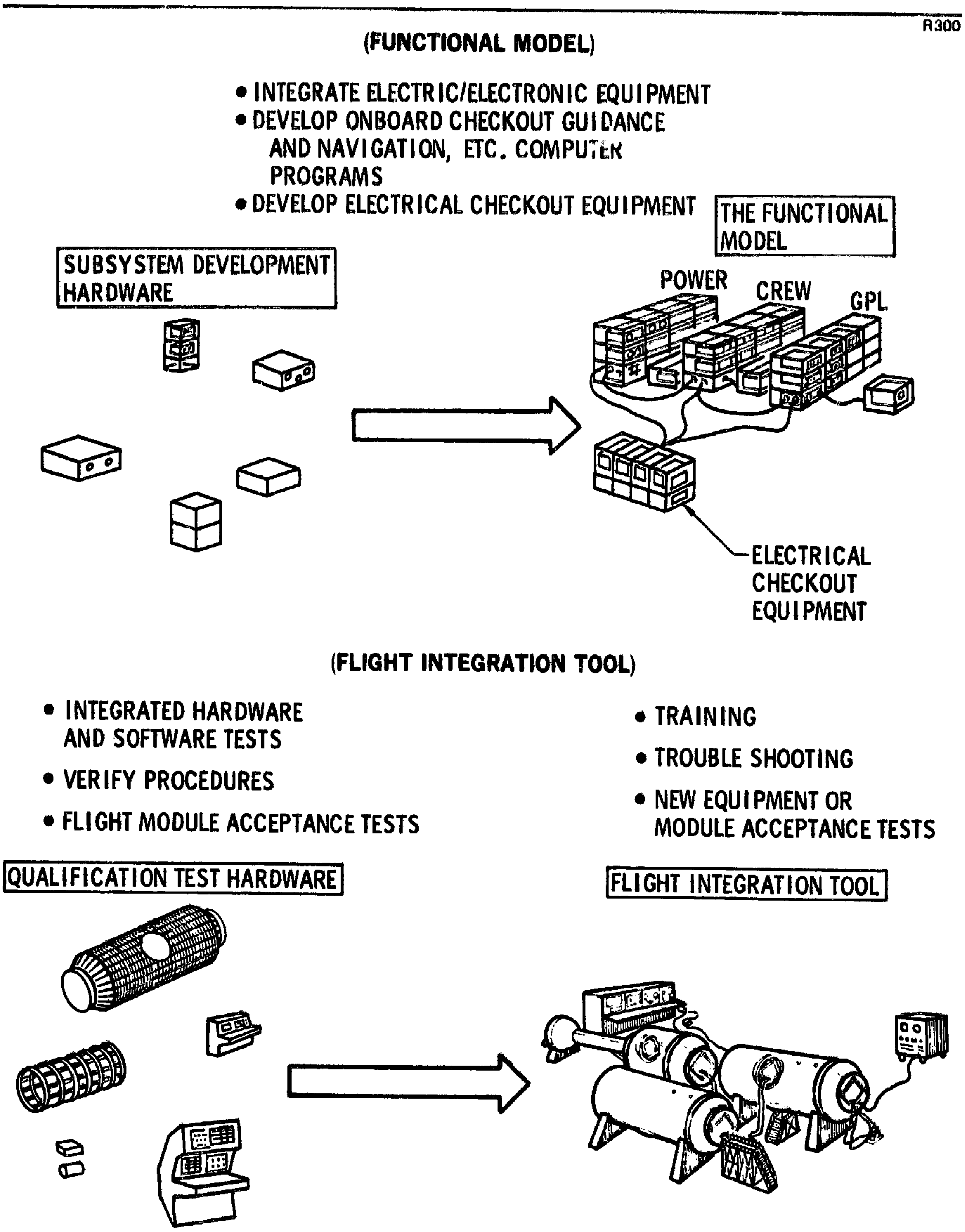

Figure 7-2. Space Station Functional Model and Flight Integration Tool

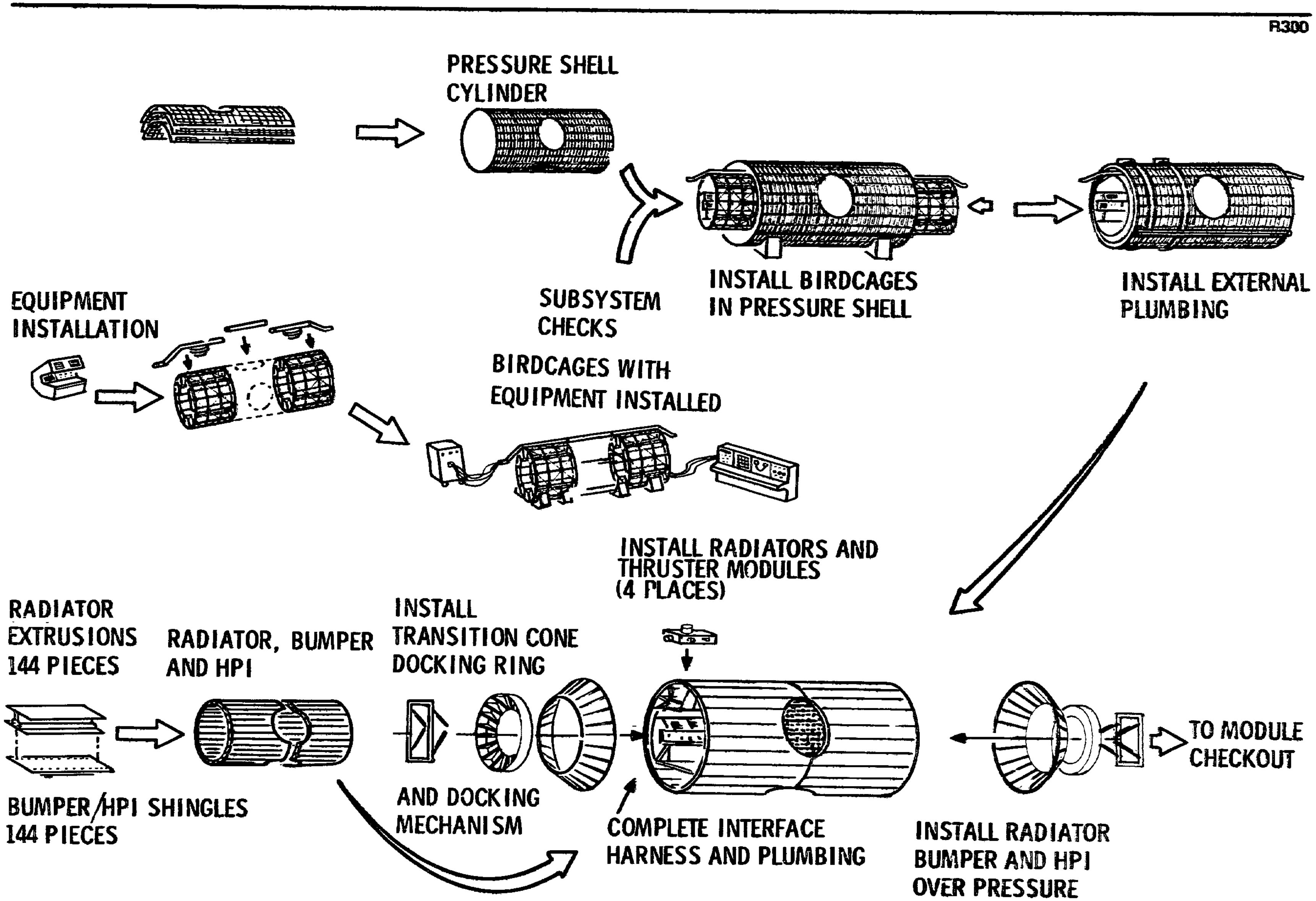

Figure 7-3. Flight Module Manufacturing Operations

Shuttle launch site for loading in the orbiter and subsequent launch. This process is illustrated in Figure 7-4.

Mating of the ISS flight modules for integration could be performed at the contractor's facility or at an integration facility at the launch site. Mating at the launch site would allow integration to be accomplished immediately before launch of the first module without cross-country transportation between integration and launch.

An alternative approach would be to perform the integration at both the factory and launch site; however, this would duplicate testing and require the off-loading of subsystems which will be later delivered to the Space Station to be done at the launch site where the installation experience does not exist. Performing the flight module integrated testing only at the launch site invites schedule slip and cost increase in that the flight modules would be first assembled there and any difficulties encountered in initial assembly of modules would have to be accomplished remote from the engineering and production sites. Also the FIT and all the GSE to operate the FIT and flight module cluster would have to be shipped to the launch site and set up in a specific facility. Since integration at the manufacturing site minimizes program cost it is recommended.

After the ISS development, the FIT should be located at a site that most conveniently accommodates the majority of its continuing activities as noted in Table 7-1.

7.1.1.2 Prelaunch and Launch Operations

Prelaunch and launch operations include all launch site activities required to prepare and launch the Space Station modules. It is assumed that launch will be from Complex 39 (LC-39) of KSC by Shuttle launch vehicle. Space Station operations described in this section have been developed according to the overall test philosophy and integration concepts delineated in Section 7.1.1.1. The three ISS modules equipped with the integral experiment hardware installed in the GPL will be fully assembled and a complete integrated test performed at the manufacturing site. The entire Space Station will be acceptance tested, the three modules demated, and designated items off-loaded to bring the module gross weight within the Shuttle cargo weight limit.

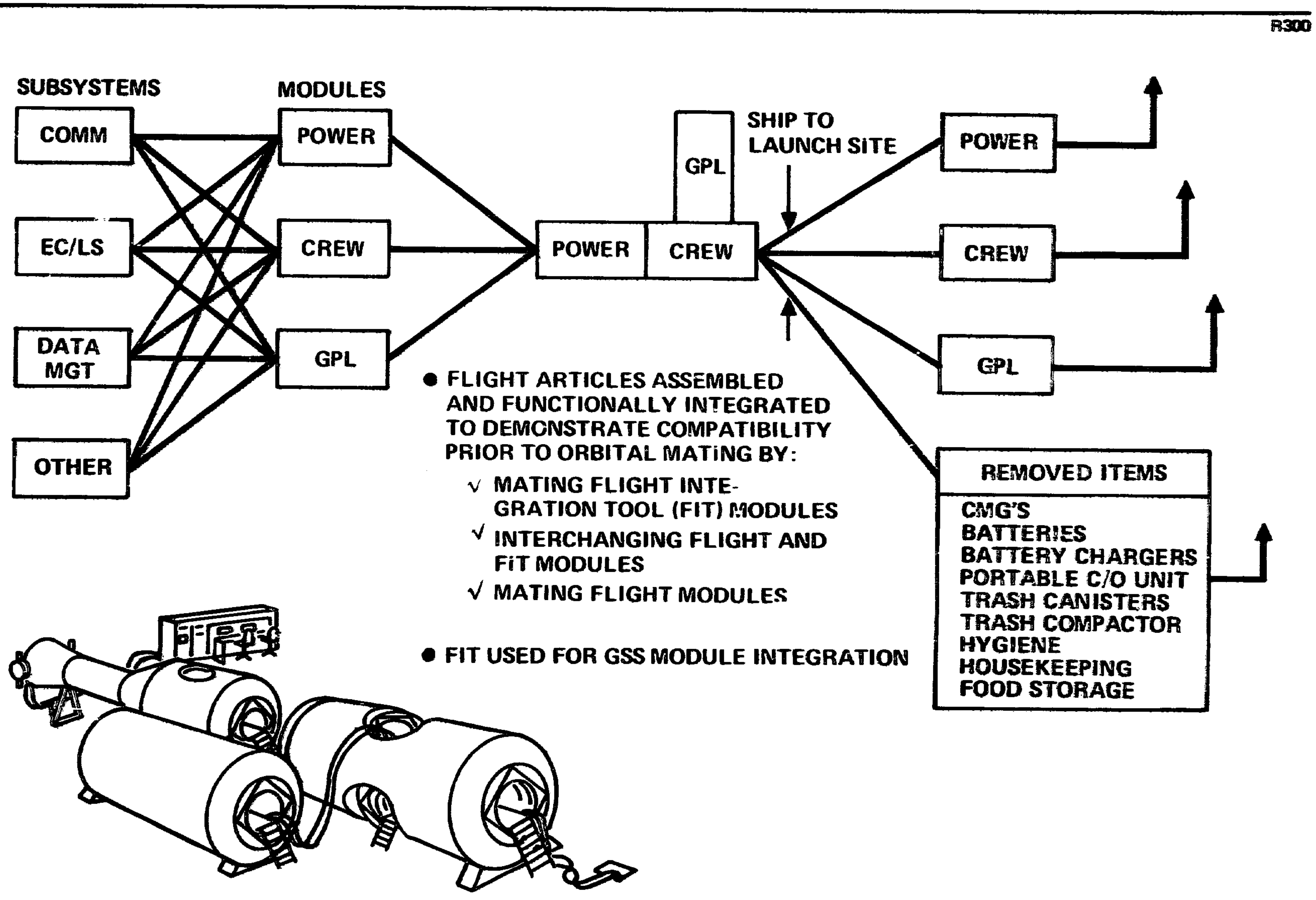

Figure 7-4. Modular Space Station ISS Hardware Flow (Ground)

Table 7-1

MISSION SUPPORT FUNCTIONS FOR THE FLIGHT INTEGRATION TOOL

Aid configuration control of the orbiting Space Station.
Aid trouble-shooting of orbital problems which cannot be solved by the flight crew.
Provide for functional and physical integration of new or modified Space Station flight hardware, experiments, and experiment modules (RAM's).
Provide for functional integration of new or modified software.
Aid flight crew proficiency training.
Provide for verification of the Space Station-Flight Control Center functional interface.
Aid in development and revision of maintenance plans and procedures.
Aid principal investigator orientation.
Qualification testing of software.
Indoctrination of the scientific community.

Modules will be transported to the launch site by air, serviced for flight, loaded in the Shuttle orbiter, and interfaces verified.

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

The overall general operational flows for each of the Space Station modules is identical (Figure 7-5), differing only in details. The duration of launch site operations ranges between 15 and 21 days from landing at the launch site to lift-off. At present, the Power Subsystem Module requires the longest time due to battery installation at the launch site.

7.1.2 Logistics and Crew/Cargo Module Operations

Two types of modules are used for logistics support of the Space Station. The Logistics Module used during ISS operations is unmanned while in the Shuttle. The Crew/Cargo Module will be used during GSS operations and is similar to the Logistics Module except that it will contain a life support system and carry six passengers to accommodate rotation of the larger crew. In both cases, the onboard subsystems require little in the way of ground

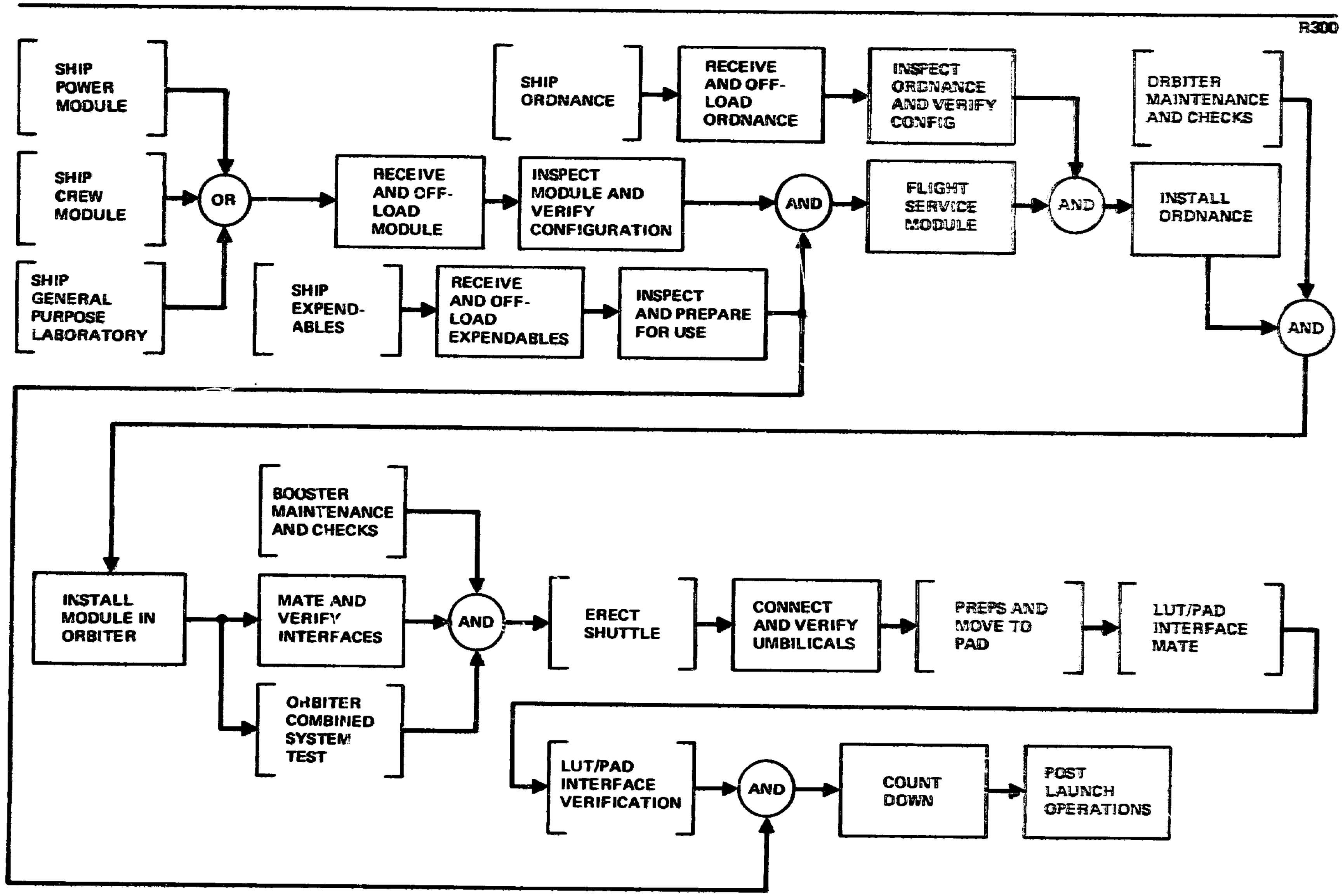

Figure 7-5. Typical Module Operational Flow

checkout. The basic concept for Logistics and Crew/Cargo Module operations is as follows:

A. Existing facilities will be used for the Logistics Module and CCM operations (the VAB low bay area).

B. Logistics Module and CCM operations will be a continuing effort for the duration of the Space Station program with up to one launch per month except when superseded by a Space Station module or Research and Applications Module launch.

C. There will be no impact on flight operations support (in terms of Logistics Module and CCM mission control facilities and GSE) beyond that required for Space Station and Shuttle mission control operations.

The overall operational flow for the Logistics Module at KSC and the related cargo-handling flows are shown in Figure 7-6. The flow has three major branches: the flow for the initial flight of a Logistics Module, originating at the factory with manufacturing and shipment to KSC; the flow for repeated flights of a Logistics Module returned from orbit; and the flow for cargo and supplies to be loaded on the Logistics Module. These branches converge to a common flow for later stages of Logistics Module operations, beginning with final checkout of the Logistics Module and terminating with launch.

Figure 7-7 shows a schedule of Logistics Module turnaround and maintenance activities. Logistics Modules will be maintained through an airline method of operation as illustrated (i. e., preflight and postflight checks, correction of malfunctions experienced during flight, and periodic maintenance.) Crew Cargo Module prelaunch and launch operations are essentially the same with the addition of servicing and checkout required for the manned systems.

7.1.3 Experiment Operations

Experiments require the following types of support at the launch site:

I. Specialized or Unique Facilities.

II. Maintenance of Unique Protective Environment.

III Test and Checkout.

IV. Prelaunch Servicing of Consumables.

V. Active Support at Lift-off.

VI. Installation During Countdown.

VII. Program-Peculiar Functions.

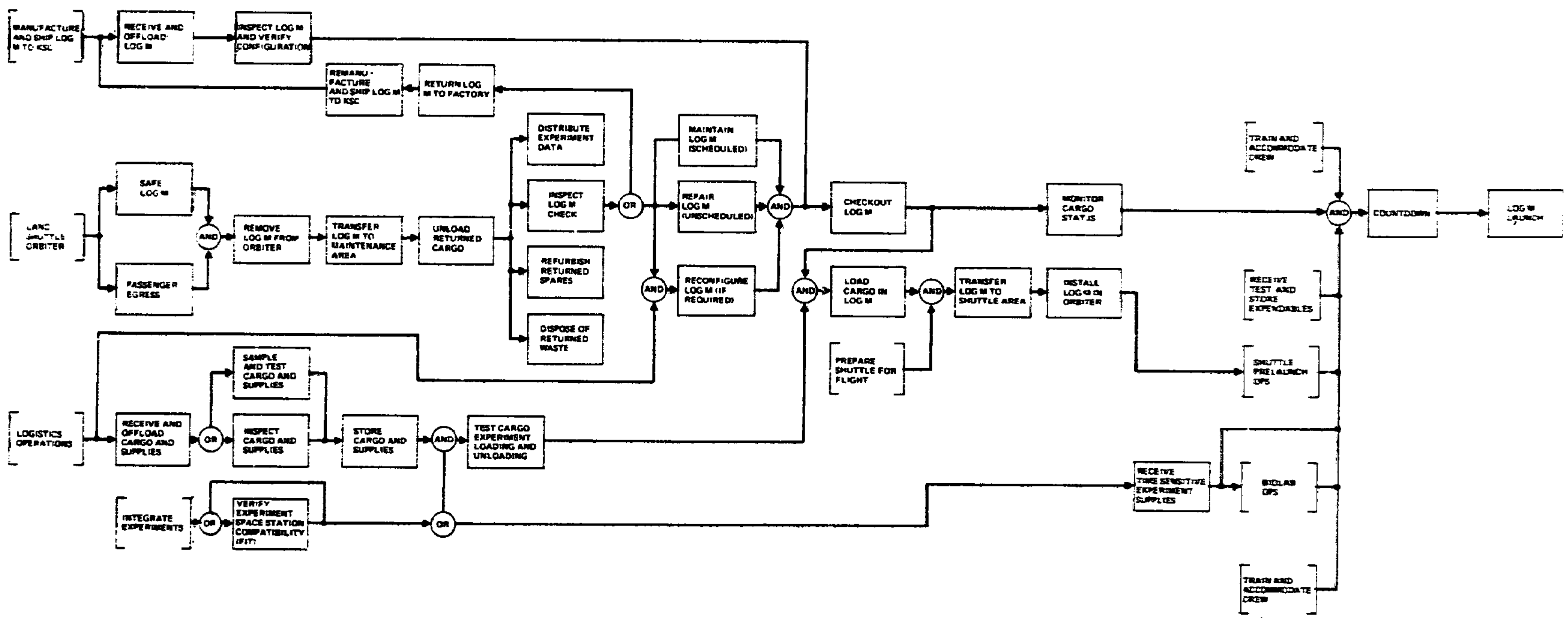

Figure 7-6. Logistics Module Prelaunch and Launch Operations

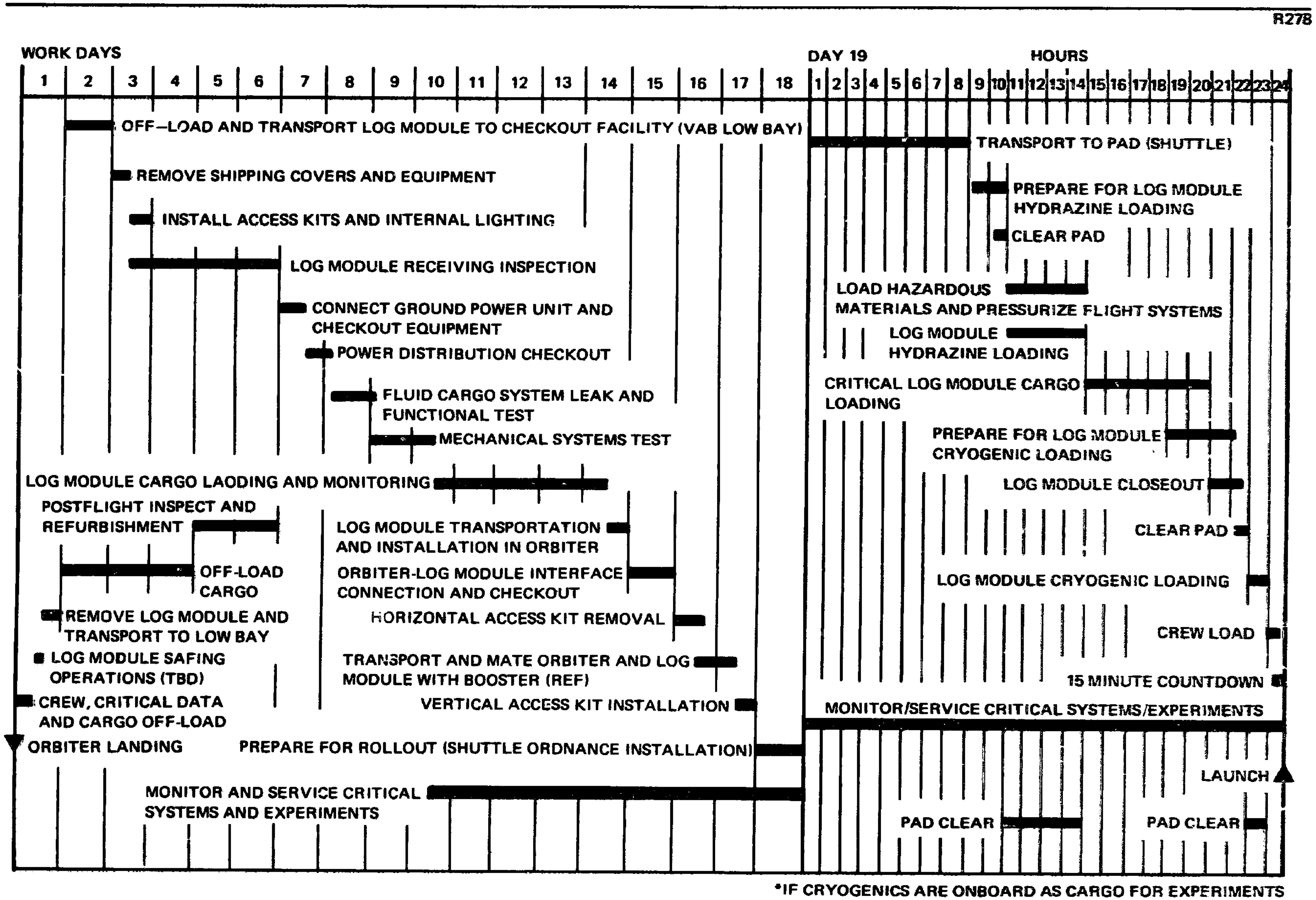

Figure 7-7. Preliminary Master Schedule-Logistics Module

Table 7-2 shows the types of support which each FPE subgroup scheduled in the Case 534G Flight Plan require (FPE's launched with the GPL are excluded.) When the FPE's and FPE Subgroups are grouped according to common support requirements, six distinct groups are apparent, as shown in Table 7-2. A typical sequence and description of operations at KSC was defined for each group. These are presented in MP-03, Integrated Mission Management Operations. Supporting facilities and GSE required at KSC were also defined and included in MP-03. A brief summary is included in Section 7.1.5 of this document, and some unusual support requirements are noted below:

A. Space Biology Experiments—The operational activities associated with the specimens for the space biology experiments represent the major effect of the experiment program on the launch site. A biological laboratory must be provided for specimen storage, care, feeding, and flight preparation. It is desirable that this facility duplicate insofar as possible the orbital configuration.

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

C. Time-Sensitive Installations—All films and emulsions will be stored in a refrigerated and radiation-shielded vault. These items will be installed prior to module-orbiter mating.

7.1.4 Mission Support Operations

The 10-year continuous operation of the orbiting Space Station, the multiple project interfaces, and the requirements for continued resupply generate a requirement for a different form of mission management than employed in the past.

Mission management for the Space Station must be developed considering its relationship to other projects and programs and NASA's overall scientific

Table 7-2
KSC REQUIREMENTS GROUPING SUMMARY

Criteria / FPE Sub-group	I Specialized or Unique Facilities	II Maintenance of Protective Environment Not Normally Provided by Launch Site Facility	III Test and Checkout	IV Prelaunch Servicing of Consumables	V Active Support at Lift-Off	VI Installation During Countdown	VII Program-Peculiar Functions
A-1		X	X	X			
A-2		X	X	X			
A-2A		X	X	X			
A-3AA		X	X	X			
A-3CC		X	X	X			
ES-1		X	X	X			
ES-1AA		X	X	X			
ES-1G		X	X	X			
P-3		X	X	X			
T-2A			X	X			
T-2BB			X	X			
T-3B			X	X			
A-4A	X	X	X				
A-4B	X	X	X				
A-4C	X	X	X				
A-5A	X	X	X	X			
A-5B	X	X	X	X			
A-6	X	X	X	X			
CN-1	X	X	X				
CN-1A	X	X	X				
CN-1B	X	X	X				
P-2BB	X	X	X	X			
LS-1B	X	X	X	X	X	X	
LS-1C	X	X	X	X	X	X	
LS-1D	X	X	X	X	X	X	
P-3C			X				X
P-4A			X	X			X
P-4B		X	X	X			X
P-4C		X	X	X			X
T-3A			X	X			X
T-4C			X				X
T-5A			X	X			X
T-5B			X	X			X
T-5C			X	X			X
P-1A	X	X	X	X			X
P-1B							X
P-1C	X		X				X
P-1E	X		X				X
P-2A	X	X	X				X
T-1A	X		X				X
T-1B	X		X				X
MS-3A		X					X
MS-3B							X
MS-3C							X
MS-3D							X
MS-3E							X

program. Figure 7-8 illustrates these relationships. The scientific programs are independent of the support elements shown on the right of the figure, with the Space Station supporting only a part of the scientific payloads. An integrated scientific orbital program management organization having the functional elements illustrated, will have to be established to coordinate the total scientific orbital program anticipated during the Space Station era.

The Space Station program is different from other manned space flight in that the Station must operate as an orbiting operational facility (as opposed to an R&D program) that is both economical and convenient to use by the scientific community, commercial enterprise, and anyone else who might need to perform activities in an orbital environment. It must provide this operational facility for 10 years. The 10-year operations cannot be accurately predicted to any depth in advance; shifting emphasis in national goals, new techniques, scientific breakthroughs (perhaps brought about by the experiments onboard the Station), and new equipment that may become available will obviously result in changes. Therefore, an overall mission management concept is required that will integrate all Space Station mission support operations in a manner that will be responsive to program changes that may develop during the 10 year program.

There are three separate activities associated with management of the operational Space Station program. The first is coordination with user agencies, the second is development of new program elements, and the third is conduct and support of the active program. Accomplishment of these activities will require an overall Space Station program management structure for planning and controlling the future directions of the program. The first two are the responsibility of NASA program management. The third activity has significant impact on ground operations and is discussed in the following sections.

As shown in Figure 7-9, this activity will consist of (1) logistics operations support, (2) mission analysis and planning, (3) flight operations support, and (4) experiment operations support.

7.1.4.1 Logistics Operations Support

Logistics operations support includes inventory management to ensure that all required crew, materials, and supplies are delivered to the Space Station at the proper time and in the proper quantity so that the mission can always be conducted at maximum capability. The logistics support

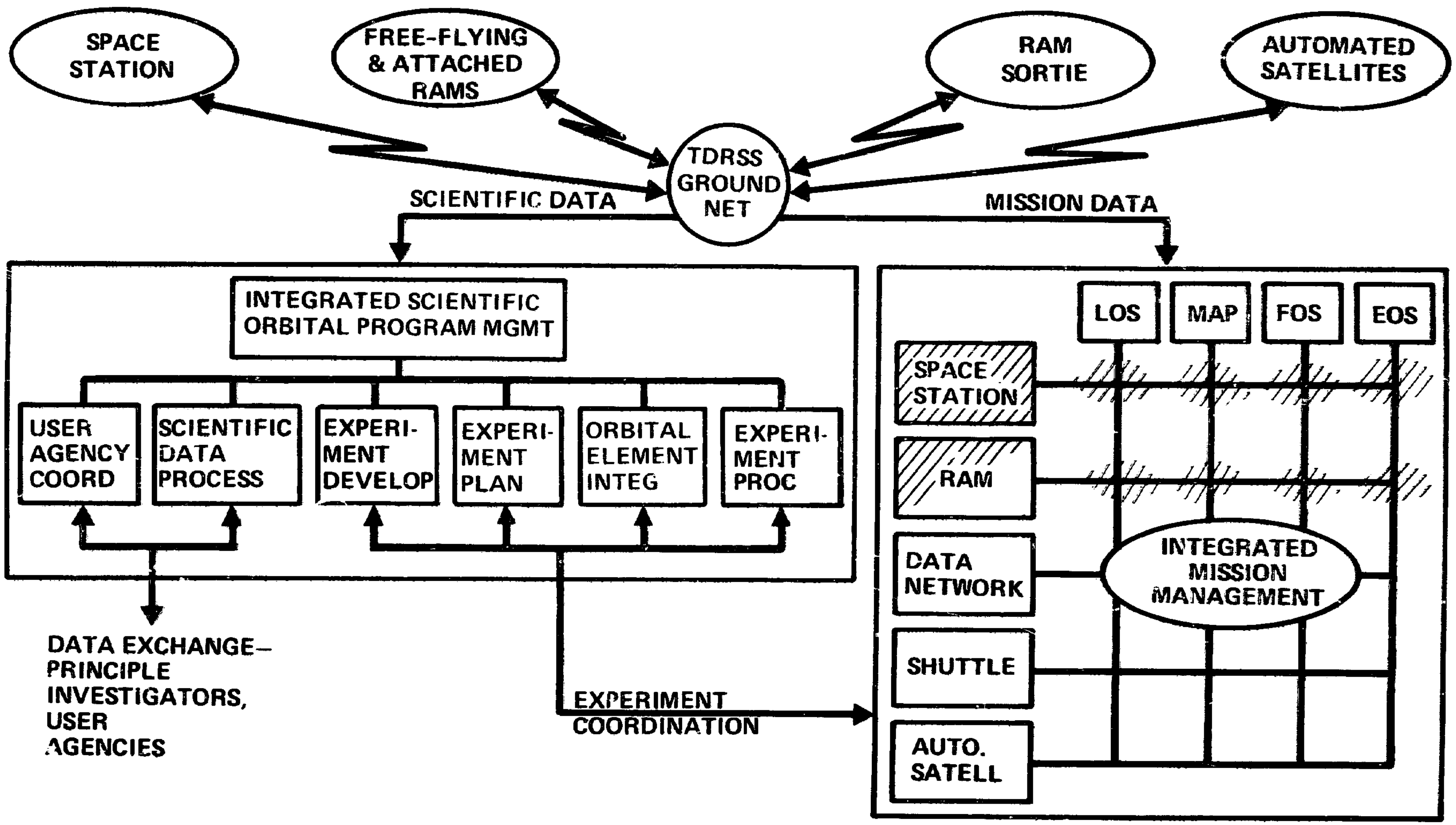

Figure 7-8 Support Elements of an Integrated Scientific Orbital Program

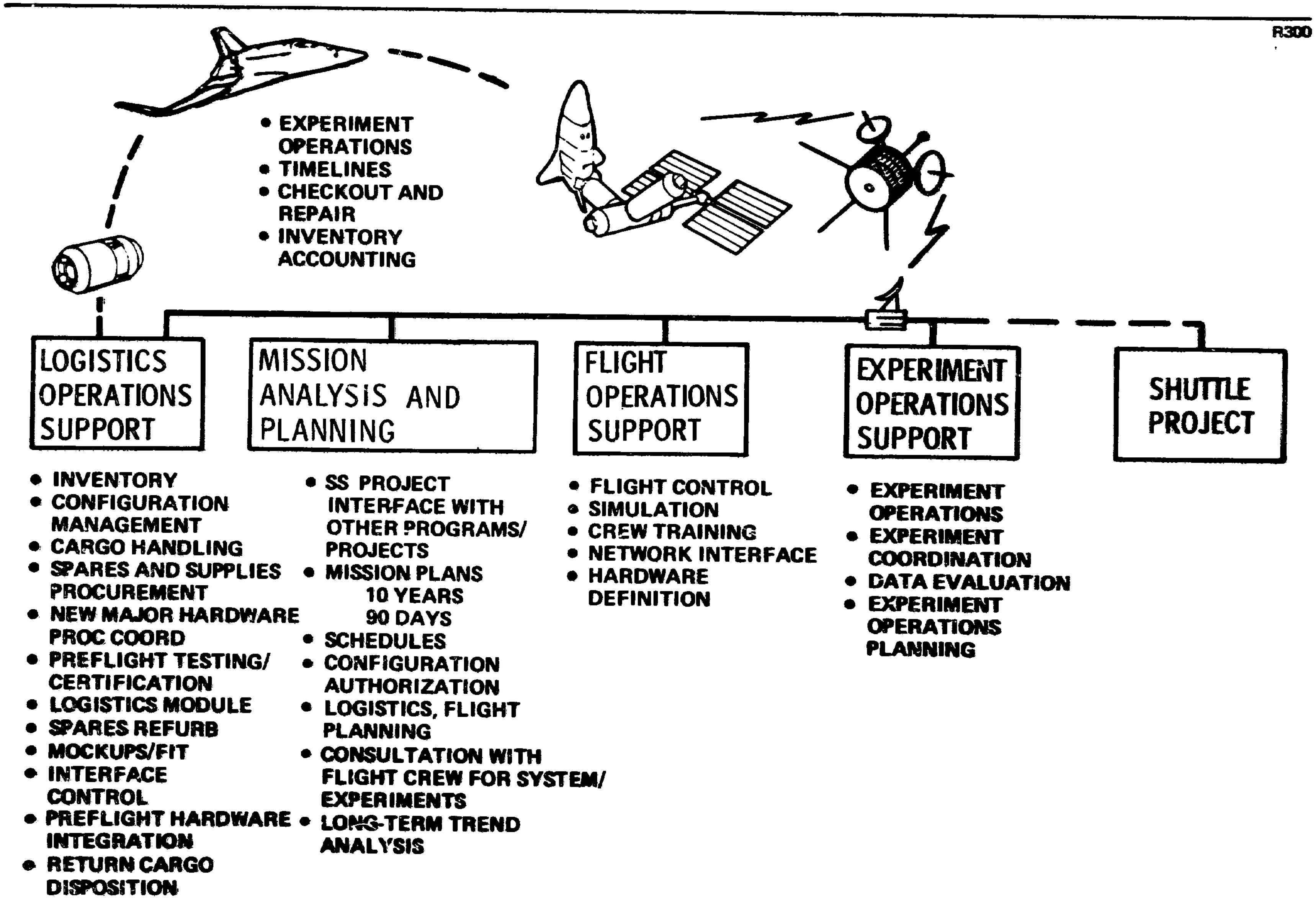

Figure 7-9. Space Station Mission Management Operational Functions

operations will provide configuration management so that there will always be knowledge on the ground of what the exact orbital configuration is including experiment hardware. The logistics operations will also perform the more classical logistics functions of cargo handling, packaging, procurement, and transportation. Another function of logistics is testing, particularly testing or certification of new equipment to make sure that it will fit and function properly. All the hardware to be flown with the Space Station is subject to interface control under the Space Station. Verification will be by preflight hardware integration on the FIT. In the case of experiment hardware, adequate certification testing for compatibility is required.

7.1.4.2 Mission Analysis and Planning

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

7.1.4.3 Flight Operations Support

During the orbit operations phase, flight operations support will perform what has in the past been called mission control, supporting on-board status monitor and fault isolation and analysis. Flight operations support will also coordinate all system status and trend data for crew training, simulation, and other activities associated with preparation for flight operations.

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

From lift-off through early orbit, flight operations support will perform significant flight control duties. The mission director and his staff will run the mission during buildup and until the first operational flight crew boards the Space Station and has it fully operational. The flight operations support personnel will play key roles in supporting orbital readiness tests (ORT) performed on-orbit and providing data analysis to verify that the assembled Space Station is certified to support a 10-year scientific program. After initial manning, the flight operations personnel will revert to a low level of activity and after the first year, only periodic ephemeris updates will be prepared for comparison with onboard data. Subsystem status will be monitored for long-term trend analysis and consumables management.

7.1.4.4 Experiment Operations Support

The fourth function of mission management is experiment operations support to assist in planning experiments, establish their procedures, and provide the capability for principal investigators to participate (on the ground) in their experiments while they are in orbit. The experiment operations support will provide storage for and analysis of data and reduction of data to allow real-time analysis by principal investigators. Most of the experiment data will go directly to the integrated scientific orbital program for distribution to the users.

Research and Applications Module data will be analyzed by experiment module specialists to predict long-term failures. Ground support of RAM's may be more critical than Space Station systems data because of the developmental nature of the experiment modules.

7.1.5 GSE Facilities, and Manpower

The GSE and facilities for the Space Station program are treated in Sections 3 and 4 of MP-03, Integrated Mission Management Operations, and have been identified on the assumption that the Kennedy Space Center will be the Shuttle launch site.

The Logistics Module will be housed in low bays of the VAB which is near the Shuttle maintenance area. Cargo will be stored in the Supply, Shipping, and Receiving Building behind the Mission Support Operations Building (MSOB).

Mission planning and analysis, flight operations support, and experiment operations support could be located at KSC, however, at least during buildup operations, which include 90 days of predominantly unmanned operations, these functions should be located at MSC where mission control facilities, ground network ties, etc., presently exist. Logistics support operations should be located at KSC for the continued support of a 10-year program. Economies could result from centralizing all elements of mission management at KSC. Were these functions to be at KSC, all would be located in the MSOB. The CIF computer capability would be required in support of mission management. Further effort to determine the optimum location for the various mission management functions, facilities, and equipment is recommended.

The experiment modules and experiment hardware could be housed in the MSOB high bay area. This will provide the clean area, vacuum chambers, and adequate space for offices and laboratories. This would also be the location of the FIT if located at KSC.

Of the four mission management functions, logistics operations support should be at the launch site due to critical schedules and the actual cargo to be delivered to orbit. The Space Station module launch crew decreases after the third module launch and the launch crew for the Logistics Modules is increased in anticipation of many further Logistics Modules. This provides an essentially flat-loaded task between the logistics and single-launch crews as noted on the right hand side of Figure 7-10.

The sum of the manpower required for the other three functions of mission support also results in flat-loaded manpower. Mission planning and analysis at the first launch will settle down to a smaller crew than will be required for preflight planning. Flight operations support will increase at

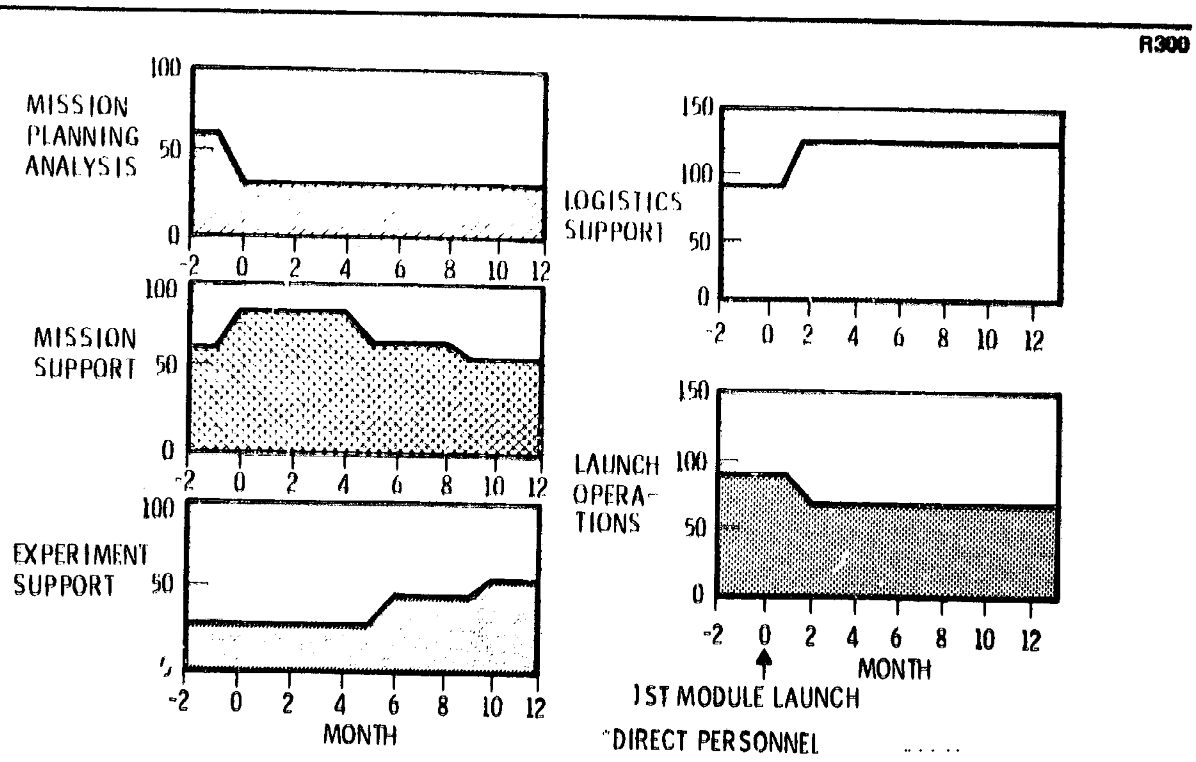

Figure 7-10. Mission Management Manning in Buildup

the first launch and settle down after shakedown operations and arrival of the first two RAM's. Experiment operations support, a project-oriented function with a mix similar to the orbiting scientific crew, will increase on the arrival of each of the first two RAM's and then stabilize.

7.2 FLIGHT OPERATIONS

Flight operations encompasses three major activities: (1) buildup and activation, (2) sustained operations, and (3) logistics support.

7.2.1 Buildup and Activation

Space Station buildup events are summarized in Figure 7-11. This phase of the mission covers the first 60 days (three launches) of the Space Station program. During this phase of the mission, two assembly crewmen will accompany each of the Space Station modules to orbit as passengers in the Space Shuttle. These assembly crewmen will perform the interface mating, checkout, and operational functions on the Space Station while the Space Shuttle remains attached to the configuration. During their orbital stay and until the flightworthiness of the completed Space Station is certified, these

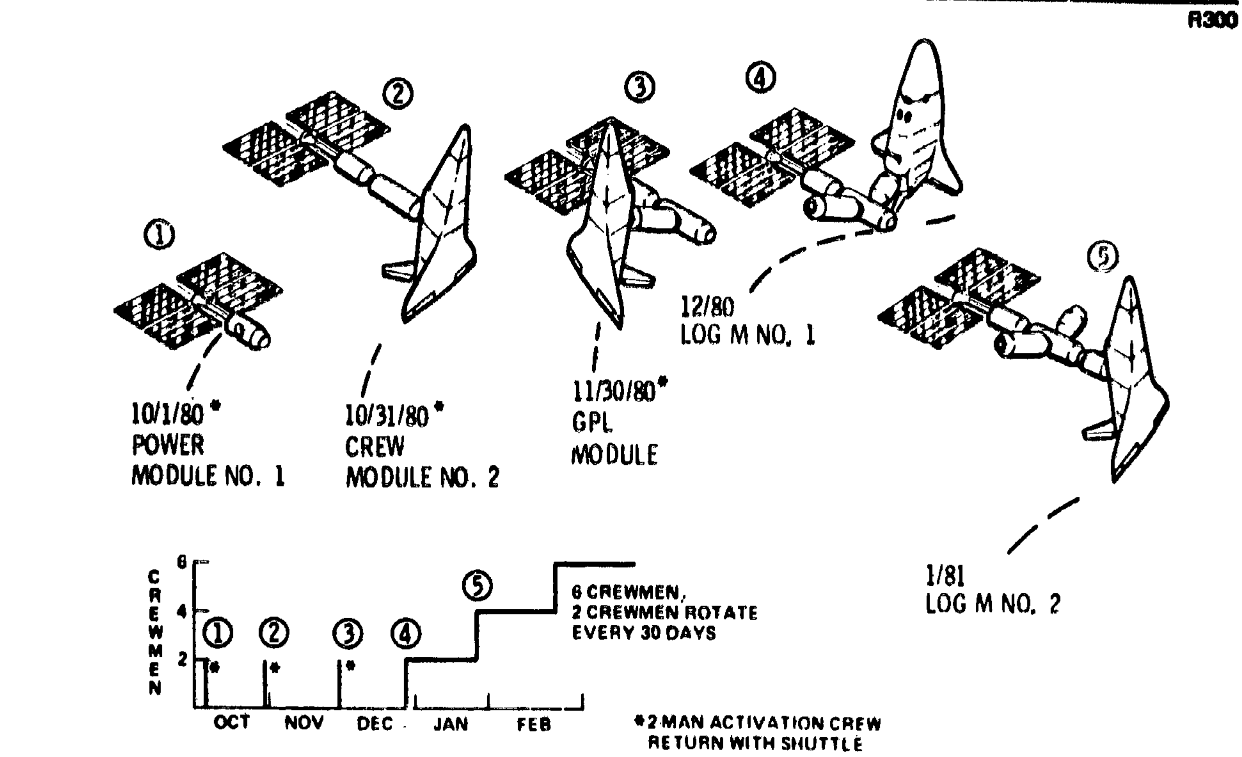

Figure 7-11. Space Station Buildup Operations

crewmen will depend upon the Shuttle for life support and living accommodations while working in the Space Station modules; the Shuttle will act as the on-orbit support facility during buildup.

7.2.1.1 Power/Subsystems Module

The Power/Subsystems Module buildup timeline is presented in Figure 7-12. While shirtsleeve operations are planned, this timeline includes suited operations so that the resulting task times are conservative and provide for suited operation if required. As shown in the figure, at approximately four hours ground-elapsed time (GET), the Space Shuttle bay door will be opened, the module deployed on the payload interface pallet, and the atmosphere supply flow into the module will be activated. The air supply will utilize the nominal atmosphere distribution system in the module.

The two assembly crewmen then enter the Space Shuttle airlock in IVA suits. An expandable tunnel will be used for crew transfer from the Space Shuttle to the Power/Subsystems Module hatch. At the module hatch, there is a viewing window and a habitability verification readout station. The crew can equalize pressure across the entry hatch at this location and can activate

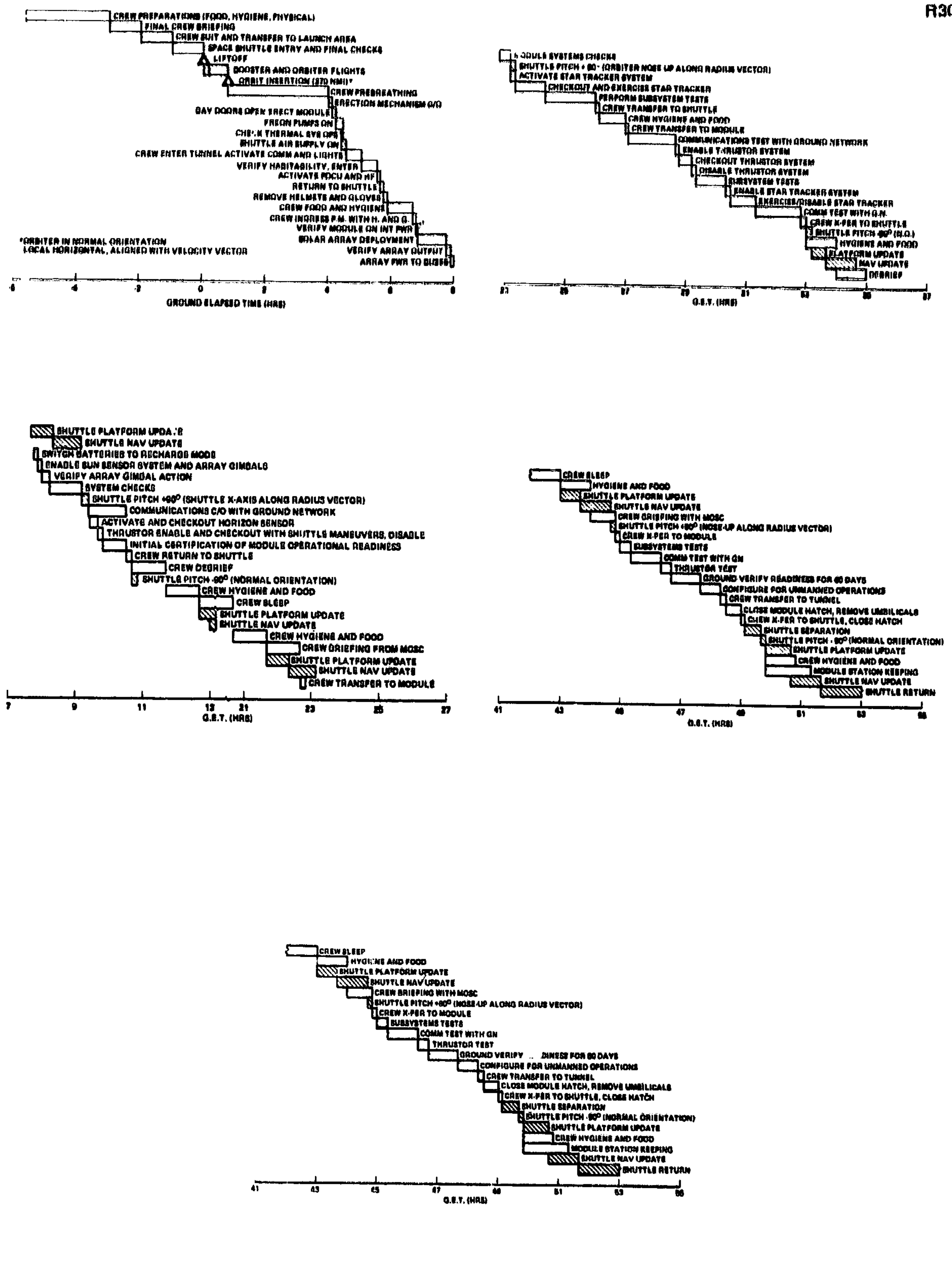

Figure 7-12. Buildup Timeline—Power Module

the internal communication systems and lighting systems of the module. The interface between the module and the Shuttle is illustrated in Figure 7-13.

Following entry, the crew will use the portable display and control unit. It operates with the computer and has the functional capabilities of the console scheduled for delivery in the Crew/Operations Module, but it operates in a manual, one-command-at-a-time mode. The PDCU can thus be used for command activities and for diagnostic routines for fault detection and isolation.

The first activation operation is deployment of the solar array system. Once deployed, the crew checks the system and switches to array power.

The solar array orientation control system will be activated and checked out. Proper system response and panel operation can be evaluated by the crew while the Space Shuttle maintains the orbital rate of the total configuration. The assembly crew will conduct communication tests on the VHF and S-Band systems with the ground network. Propulsion system checks will be conducted by means of a series of controlled tests that are repeated several

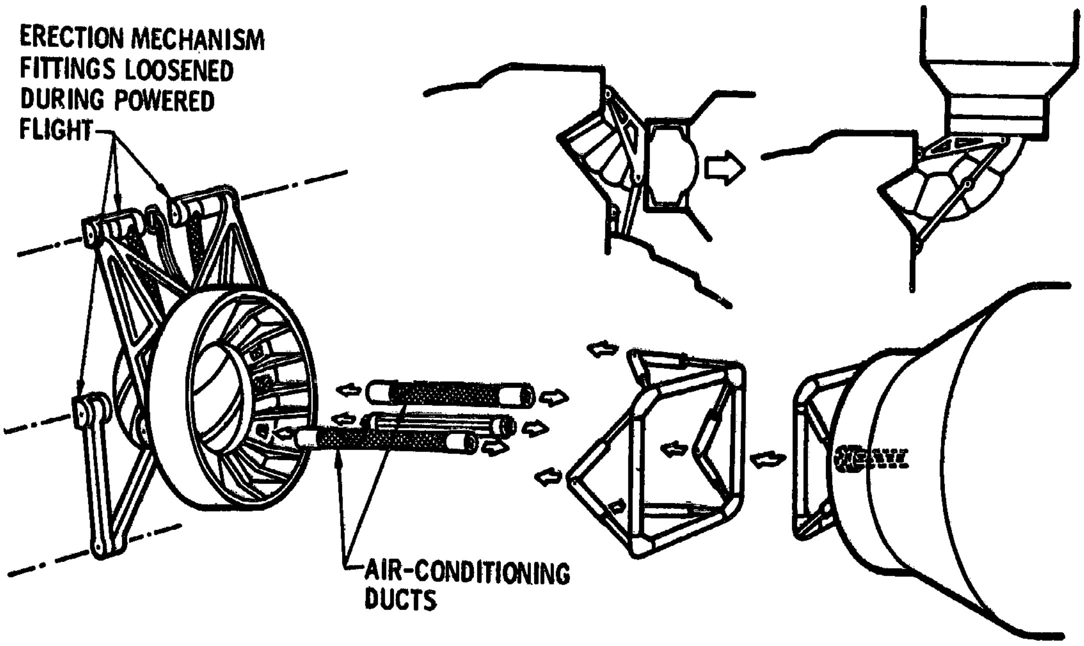

Figure 7-13. Shuttle/Module Interface

times to accumulate a reasonable amount of operating time in the space environment and by horizon sensor and star-tracker system checks.

Once the on-orbit crew and the ground support personnel have established the module's readiness for 60 days of unmanned operations, the power Subsystems Module will be configured for unmanned operations by activation of the atmosphere supply onboard the module. The crew will then disconnect the umbilicals across the interface, enter the Space Shuttle airlock, and depressurize the tunnel. The Space Shuttle will then separate from the Power/Subsystems Module, with the module propulsion system activated and the hatch cover closed over the exposed docking port by RF command from the Space Shuttle.

7.2.1 Crew/Operations Module

The Crew/Operations Module is directly docked to the Power/Subsystems Module by the Space Shuttle. To assist the orbiter pilot in the performance of manual docking, aids are provided on the Space Station (see Figure 7-14).

The docking aid chosen to apprise the pilot of displacement errors is a T-bar device. The T-bar is located above the target docking hatch and when viewed through the Space Shuttle docking telescope, its image will yield information relative to lateral and vertical displacement of the Space Shuttle. In addition, target image diameter calibrations will yield data relative to distance-to-the-docking-interface-plane. The T-bar and the target circle are both electroluminescent, and the Space Shuttle will provide lights for docking illumination to relieve lighting constraints on docking operations.

To ensure collision avoidance (docking clearances are defined in Section 3)—a lighting system provides a positive cue to the pilot, should the Shuttle inadvertently maneuver to a position where collision is possible. In addition, the collision lights have a slight inward cant (4 deg) so that at distances greater than 91.5 m (300 ft), the lights may be seen at all times as an acquisition and rendezvous aid.

Figure 7-15 presents the buildup timelines for the Crew/Operations Module delivery mission. As shown in the figure, at a ground-elapsed time of approximately five hours, the Space Shuttle will have completed rendezvous with the Power/Subsystems Module and the Shuttle bay door will be opened and the module deployed for docking. During ascent of the Space Shuttle, the mission operations support personnel have completed their

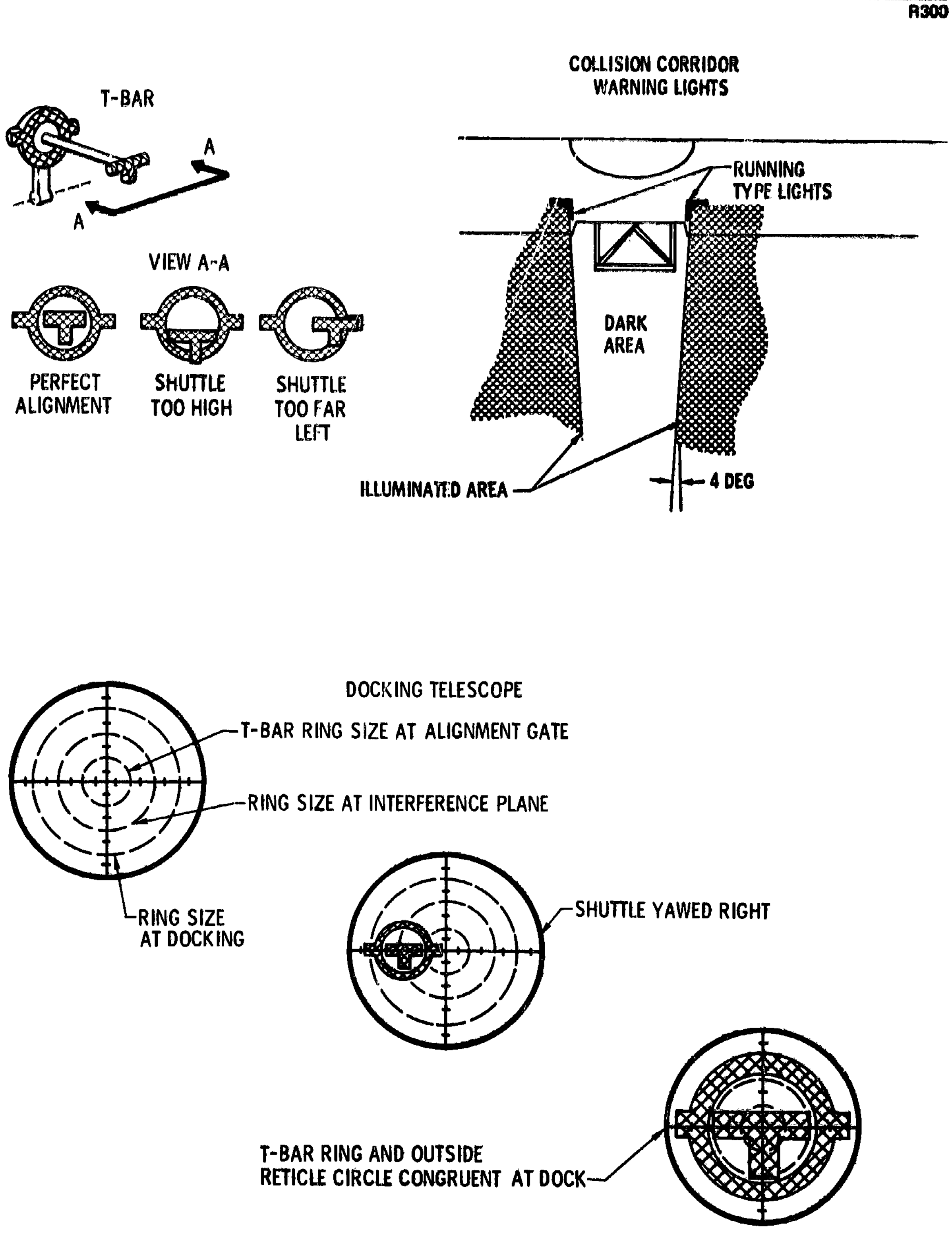

Figure 7-14. Docking Aids

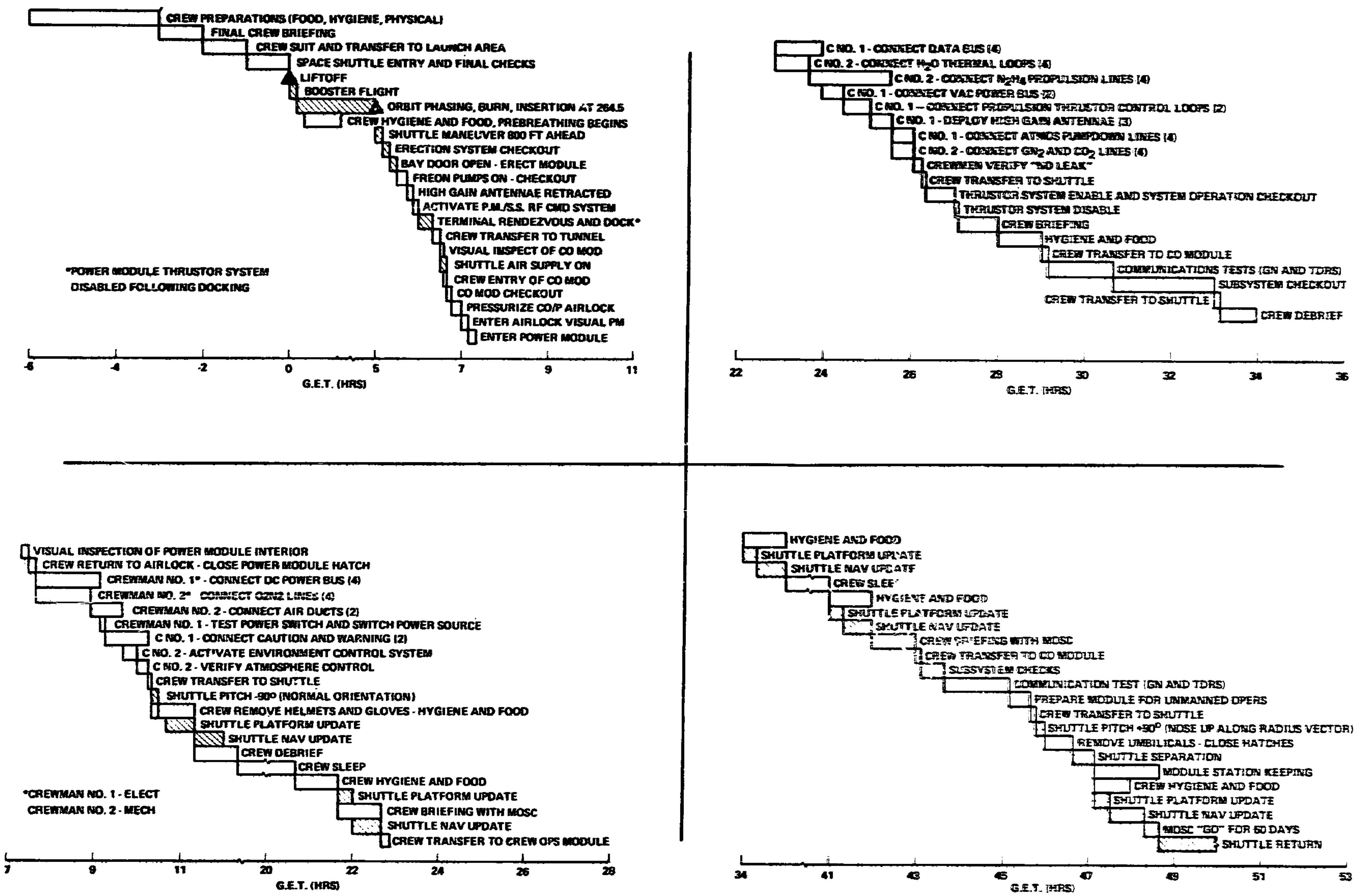

Figure 7-15. Buildup Timelines—Crew/Operations Module

operational commands to the target module, activating the rendezvous and docking aids and deploying the hatch cover over the target docking port. This also verifies the RF link.

To eliminate any interference with docking operations, the high-gain antenna is rotated to the docking orientation. Immediately following docking completion, the Space Station attitude control system will be deactivated and the orbiting configuration attitude orientation will be controlled by the Space Shuttle until completion of the on-orbit activities.

The crewmen will enter the Crew/Operations Module and begin mating the interface connectors. Until the electrical power interfaces are mated and checked out, the Crew/Operations Module is dependent on the Space Shuttle for its electrical supply. This supply is limited to 500 w nominal and 800 w peak, with a total energy of 20 kwh. The dc power bus interface connectors will be the first items to be mated. Figure 7-16 presents a typical electrical interface connector. All electrical connectors are standard except the power plugs which incorporate a nonarcing feature in case of accidental demating. By incorporating a high-resistance outer sheath, such as a carbon rod with an appropriate inert binder, as an extension to the regular pin

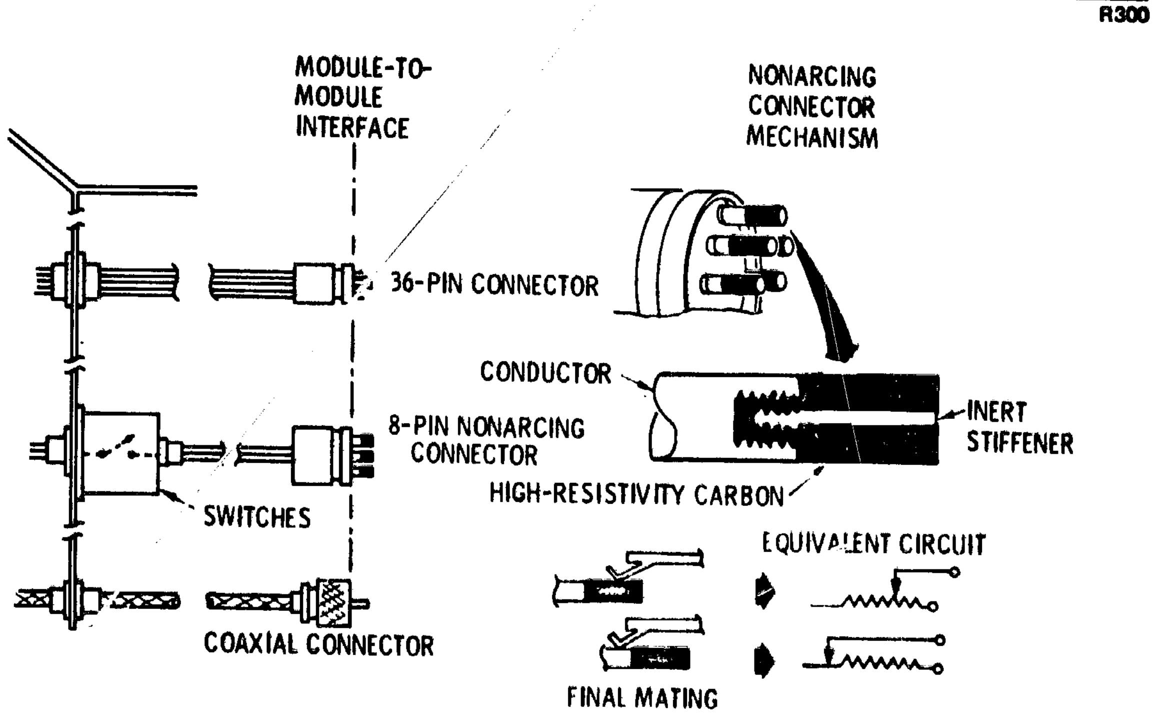

Figure 7-16. Electrical Interface Connection Concepts

contact, the power plug will automatically eliminate arcing during mating and demating. While the first assembly crewman is completing the power interface, the second assembly crewman will mate the oxygen, nitrogen, and air ducting interfaces. Approximately two hours after the initiation of the interfacing mating, the Crew/Operations Module will be on the Space Station power source.

Table 7-3 presents the detailed requirements for interface connections between the Power/Subsystems Module and the Crew/Operations Module, in terms of time required for total subsystem completion. The interfaces connected by the second crewman employ quick disconnects with interlocks to the shutoff valves for emergencies.

Once the atmosphere interfaces are mated and the module is on Space Station power, the crew will activate the environmental control system and verify proper atmospheric control. The next activity is the mating of the hydrazine propulsion lines. Since N_2H_4 is considered a hazardous fluid, it is transferred inside an evacuated sleeve (Figure 7-17). The interface surfaces of both the fluid line and the outer sleeve are joined by appropriate means (bolts, V-band clamps, etc.). The outer sleeve can be retracted for ease of connection of the inner line. By proper valve manipulation, these lines will then be evacuated, and the propellant lines filled from the source tanks in the Power/Subsystems Module. The thruster system will be enabled and the propulsion system of the Crew/Operations Module operated to verify system integrity.

Table 7-3

POWER AND CREW MODULES – DETAIL INTERFACE ESTIMATES

Connection	Number	Hookup Time (min)	Checkout Time (min)	Total Time (min)
Air Ducts	2	42	6	48
Atmosphere Supply	4	64	12	76
Power (vdc)	4	70	20	90
Caution and Warning	2	42	20	62
H_2O Thermal	4	24	20	44
Atmosphere Pumpdown	4	24	12	36
Propulsion (N_2H_4)	4	72	40	112
Propulsion (GN_2, CO_2)	4	24	12	36
Data Bus	4	24	40	64
Power (vac)	2	10	20	30
Thruster Control	2	18	20	38
		Total time = 636 man-min		

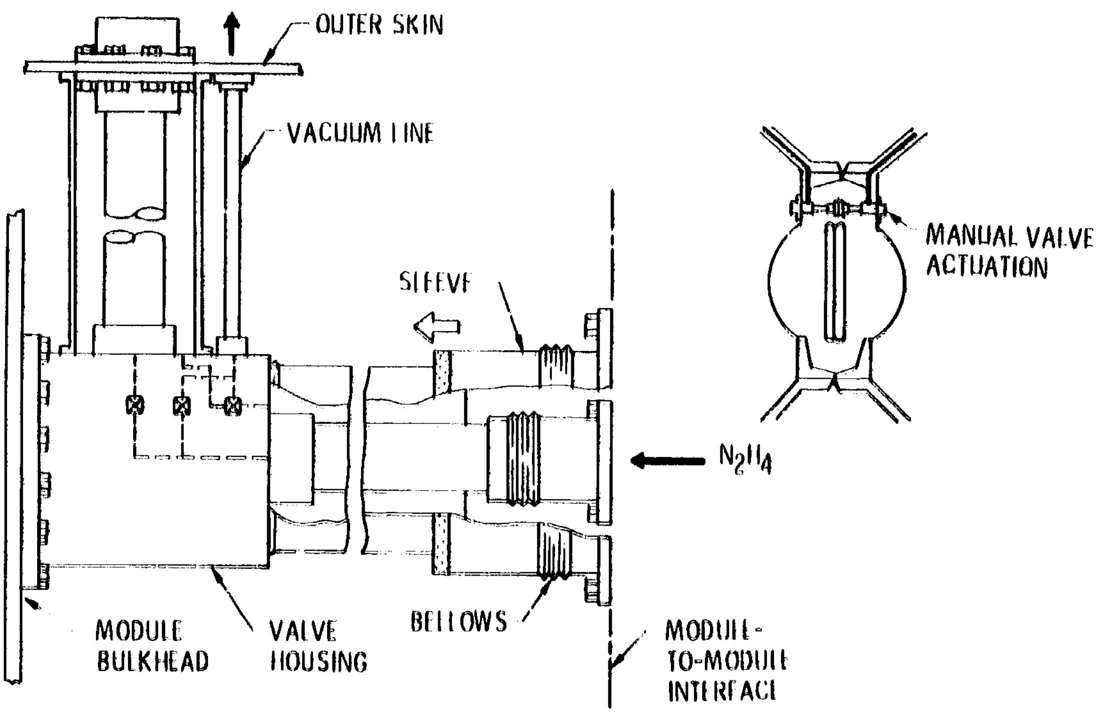

Figure 7-16. N2H4 Interface Connection Concept

Table 7-4 summarizes the various interface connections and their safety backups. The high-gain antennas will be deployed to their normal position and communications tests conducted with the high-gain antennas. Because the Space Shuttle structure tends to obscure the antennas, orientation of the cluster must permit continuous viewing for checking acquisition and hand-over operations. The orientation will depend on the position of the orbit relative to the data relay satellites.

Following the initial communications tests, the assembly crew will perform 10 hr of subsystem tests on primary, redundant, and backup systems to establish the operational readiness of the two modules.

7.2.1.3 General-Purpose Laboratory

The third and final flight of the buildup operations is the delivery and mating of the GPL to the Crew/Operations Module, as time-lined in Figure 7-18. The crew will transfer to the GPL, activate its systems, perform the required interface mating operations, and perform subsystem operations and checkout to verify the operational readiness of the configuration. Following these activities, preseparation operations will be begun. The

Table 7-4
INTERFACE CONNECTOR TYPES

Line Type	Connection	Safety Backup
Fuel (N_2H_4)	Conoseal/flange	Evacuated outer sleeve*
High pressure, (3500 psi, N_2)	Conoseal/flange	Pressure bag*
Medium pressure (300 psi; air)	Quick disconnect	Pressure bag*
Low pressure (15 psi; N_2, O_2, CO_2)	Quick disconnect	---
Ambient air and vacuum	O-ring/flange	---
Fluid (H_2O)	Quick disconnect	Condensation bag*
Electrical (hard-wire signals)	36-pin standard plug	---
Electrical (power)	8-pin standard plug	Nonarcing connector
Electrical (data bus)	Coaxial cable	---

*Gas and fluid lines can have electrical interlocks installed so that in the event of accidental demating, shutoff valves automatically close.

remaining crew and Space Shuttle activities parallel those described previously for separation, station-keeping, and return.

7.2.1.4 Activation

The activation phase of the Space Station mission includes the first three launches (30 days apart) of the Logistics Modules. During this phase of the mission, certain noncritical equipment, which was off-loaded from the Space Station modules to meet the 9,072 kg (20,000 lb) Space Shuttle launch limit, will be delivered to orbit on the logistics flights for assembly into the module.

As presented in Figure 7-18, rendezvous with the orbiting Space Station occurs approximately seven hours after lift-off. The crewmen will enter the Logistics Module and begin the interface mating between it and the Crew/Operations Module. Total time for interface hookup and checkout is 450 man-min. Once the interface operations have been completed, the crew will begin transfer of equipment off-loaded from the Space Station modules for launch. Table 7-5 indicates the items which are candidates for off-loading from the Space Station modules and their number. An approximate distance and time for transfer are also shown in the table along with the estimated installation time.

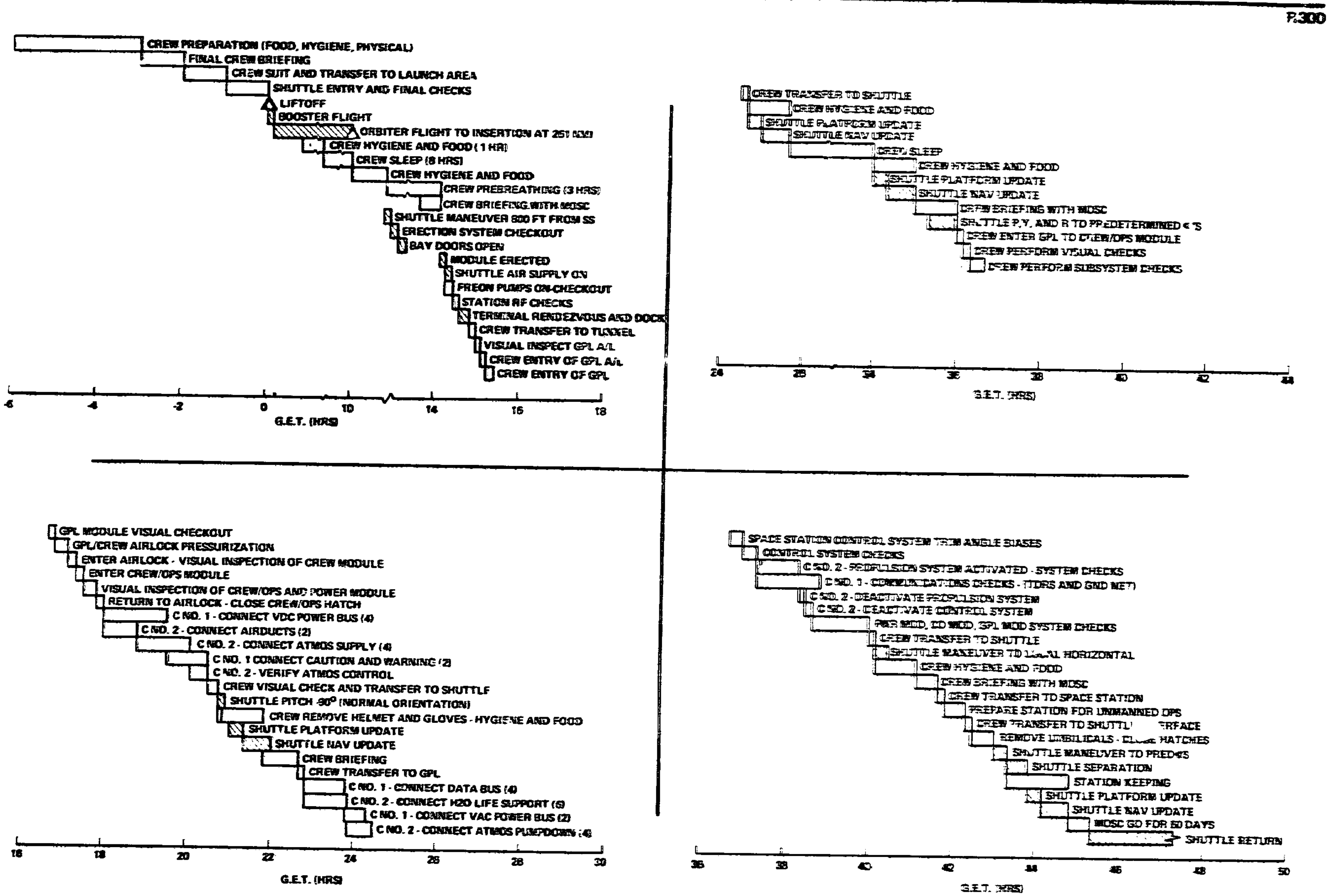

Figure 7-18. Buildup Timelines—General Purpose Laboratory Module

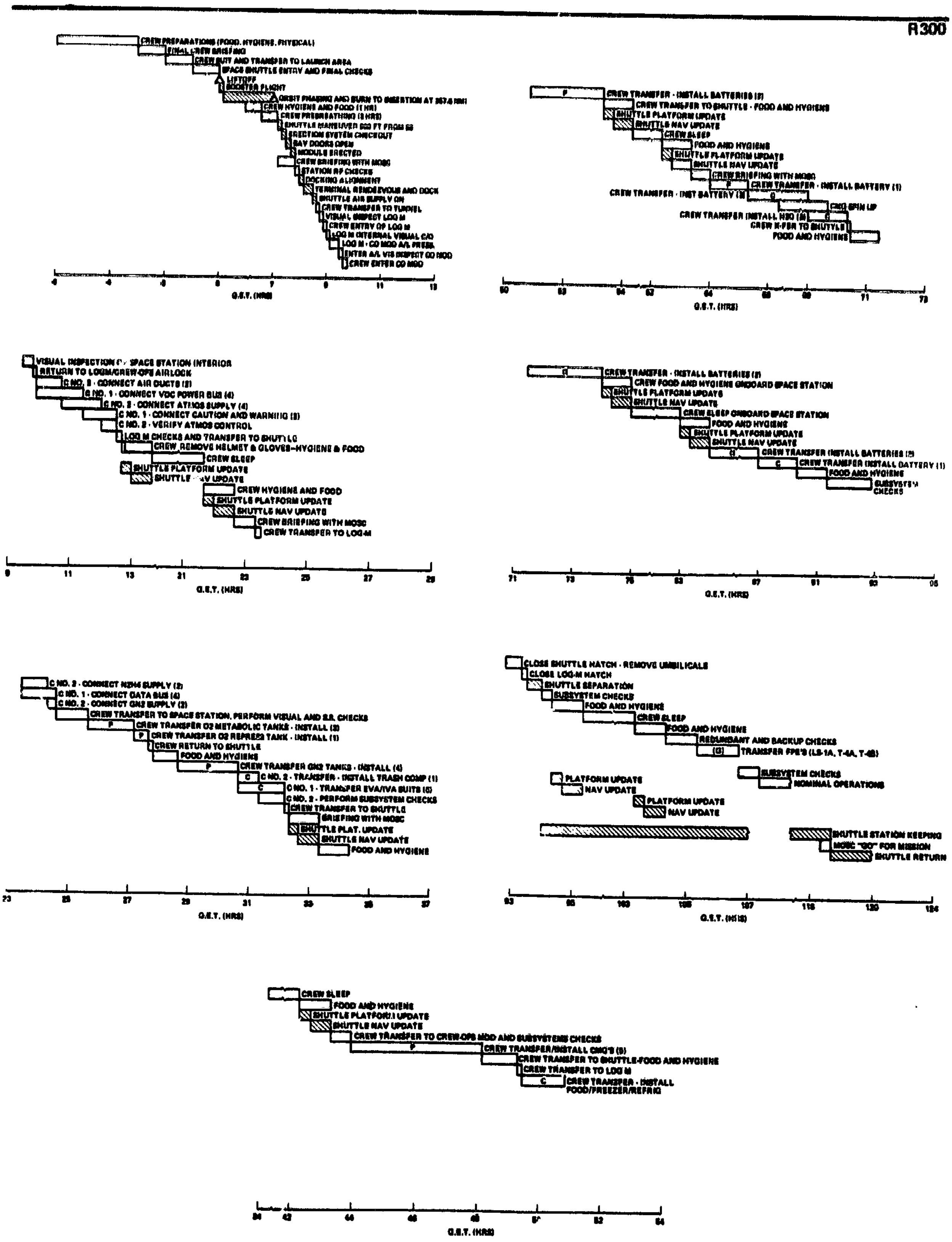

Figure 7-19. Buildup Timeline — Logistics Module

Table 7-5
EQUIPMENT TRANSFER AND INSTALLATION

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

Following the transfer and installation of the off-loaded items, the newly installed equipment will be checked out and its operability verified. An orbital readiness test is performed subsequent to final assembly. In this test, the activation crew runs through the entire set of onboard checkout routines to verify the operability and status of each subsystem. The Station cannot be certified as operational until all subsystems are functioning properly.

7.2.2 Sustained Operations

Crew tasks required for housekeeping and maintenance activities have been minimized to provide the largest possible number of man-hours on-orbit for experiment operations. The general functions for the on-orbit crew include the following:

A. Experiment Operations

1. Space Station interfaces.
2. Experiment scheduling.
3. RAM control and operations.

4. FPE checkout and operation.
5. Objective accomplishment.

B. Space Station Operations

1. Subsystem operations.
2. Logistics vehicle checkout and operation.
3. Resource planning.
4. Station maintenance.
5. Food preparation

All of the daily routine operations for the Space Station will be automated to the extent practical. For example, switching to redundant or backup systems in the event of failure will be automated as much as possible. During each duty shift, one crewman will be assigned the responsibility of monitoring the control console located in the Crew/Operations Module. When these operations are minimal, the console operator will perform other duties, but will be available if malfunction or emergency conditions arise requiring his attention.

During the ISS, one crewman (Space Station commander) will be assigned the responsibility for Space Station operations and maintenance. A second crewman, the experiment officer, is primarily responsible for all experiment operations and partially responsible for Space Station operations. The four remaining crewmen are assigned to the experiment operations. Principal investigators may be included in the group of four experiment operations personnel. The scientific crew will require a minimum of astronaut training, i.e., only that related to safety, emergency procedures and personal tasks, such as hygiene.

Crew overlap during crew rotation is nominally planned for 12 hr, though this period could be reduced, if required. The Space Station subsystems have been designed to provide the capability for single or dual shift operations on-orbit. Evaluation of work loads, power requirements, responses to emergencies, equipment loading, and experiment targets has indicated that a two-shift per day cycle is the more efficient approach. This two-shift cycle would be comprised of two 12-hr tours of responsibility, with each crewman performing 10-hr of work; that is, 12 hr of responsibility would be assigned half the crew, with freedom to perform the assigned hours of duty and other individual tasks while remaining available to respond to any contingency. There would be six tours of duty and seven tours of responsibility for each crewman during the week.

7.2.3 Logistics Support

The Space Station is required to provide 30 days of consumables past the next scheduled resupply for support of on-orbit operations. The technique employed to satisfy this requirement is to store 30 days of operating spares, consumables, and expendables onboard the Space Station, and to store the logistics required until the next appointment onboard the Logistics Module. The time between Logistics Module flights varies from 30 to 90 days. Consequently, the Logistics Module has been designed for loading of up to 90 days of expendables.

The GSS operations require a minimum of two flights each 90-day period to rotate the 12 crewmen. The cargo capability of two CCM's every 90 days will be sufficient to support Space Station operations.

Supplies will be transported to the Space Station as needed in a pantry mode of operation. Selected liquids and gases will be transferred from the Logistics Module (by a system controlled from the Space Station control console) to subsystem using points (RCS, RAM, GPL, etc.) throughout the Station. The fluid or gas will be pumped or gas pressure-fed to effect transfer. Each docking port on the Modular Space Station has the interface connectors and capability to mate to the Logistic Modules for these transfer operations.

Small quantities of special fluids or gases required for experiment operations will be transferred the same as solid cargo. Solid cargo transfer will primarily be accomplished by the crew on an as-needed basis or scheduled periodically.

The majority of solid cargo items can be safety handled and transferred by the crew without the aid of a cargo-handling system. However, the characteristics of some items exceed the capability of a crewman to safely control and constrain their movement without the assistance of a mechanical aid. Since the usage rate of a transfer system is periodic, a simple system that can be easily installed and removed is desired. A concept for such a system is shown in Figure 7-20. To operate the system, the crew would first attach the cable runs. The trackers and guide cables can then be adjusted to the proper tension to constrain the cargo. The tracker brake will be released while the crewmen provides the force to translate the item.

R300

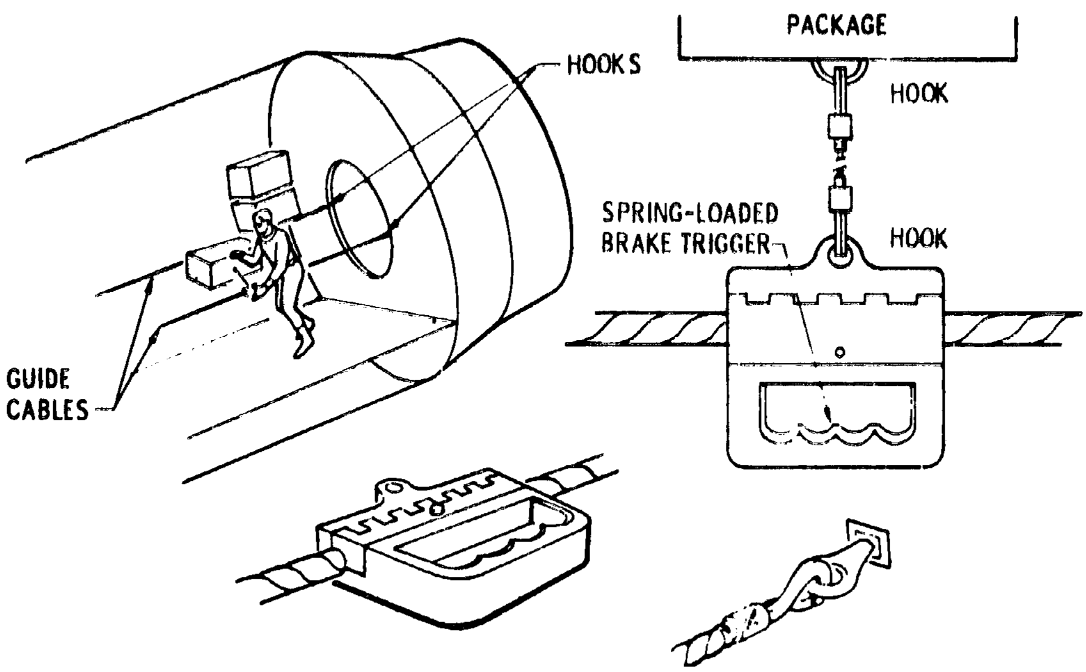

Figure 7-20. Cargo Handling System Components

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Section 8
DESIGN SUPPORT ANALYSES

This section contains the results of analyses in the following areas: orbit selection and behavior, radiation environment and protection, long-life, and safety.

8.1 ORBIT SELECTION AND BEHAVIOR

The Space Station orbit envelope specified by NASA has an altitude between 444 km (240 nmi) and 500 km (270 nmi) at an inclination of 55 deg. The baseline orbit altitude is 456 km (246 nmi). (456 km or 246 nmi is an average altitude; it corresponds to an altitude of 242 nmi at the equatorial crossing.) This altitude was selected primarily to provide good Earth coverage.

The Space Station experiment program can be accommodated within the specified envelope of 444 km to 500 km (240 to 270 nmi) at a 55-deg inclination. Earth survey activities dictate the specific orbit selection since a satisfactory orbit for these activities is acceptable to other disciplines and Earth surveys is most affected by orbit selection.

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

The Earth coverage profile of the Space Station in the baseline orbit is illustrated in Figure 8-1. The ground trace behavior pattern for this orbit along the equator is presented in Figure 8-2. The abscissa is degrees of longitude with the range of 24 deg being the longitude shift between successive

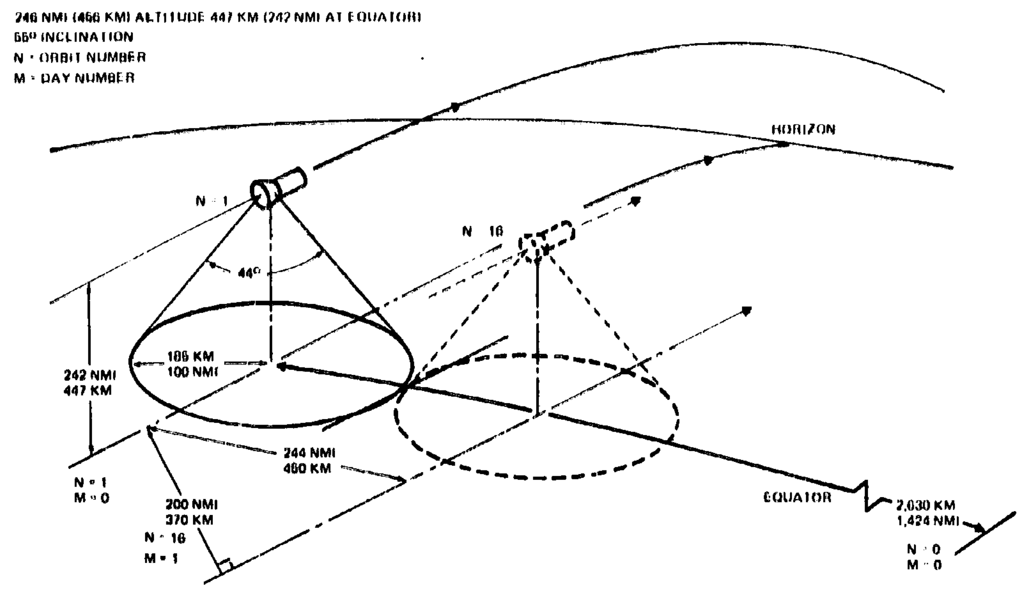


Figure 8-1. Earth Coverage Profile

orbit equatorial crossings. The coverage of the remaining fourteen 24-deg segments of the Earth surface would be similar.

The successive orbits cover the ends of this 24-deg range on Day 0, as shown in Figure 8-2. For example, these could be Orbits No. 5 and 6 crossing at the 24- and 0-deg longitude points. On the next day, Orbit No. 6 crosses the equator at 4 deg, shifted $\Delta\phi_0$ degrees east from its previous day's crossing point ($\Delta\phi_0$ is the angle equivalent of the 244 nmi shift shown in Figure 8-2). Note that these are ascending crossings. The 24-deg segment was also crossed at the 2^+-deg point on the descending crossing of Orbit No. 6. On succeeding days, this same orbit crossing shifts at $\Delta\phi_0$ increments to cover the entire 24-deg segment shown in 5.89 days and in a similar manner as the other 14 segments, thus completing one cycle.

On the next cycle beginning with the sixth day (second row of Figure 8-2), the trace repetition begins anew, but from a point shifted about 1/2 deg from the first cycle. This 1/2 deg ($\Delta\lambda'$) shift occurs on each succeeding cycle.

The ground coverage profiles for the metric camera are shown in Figure 8-3. This sensor has approximately 55 percent overlap cross-track coverage from a 456 km (246 nmi) altitude orbit on each succeeding day's

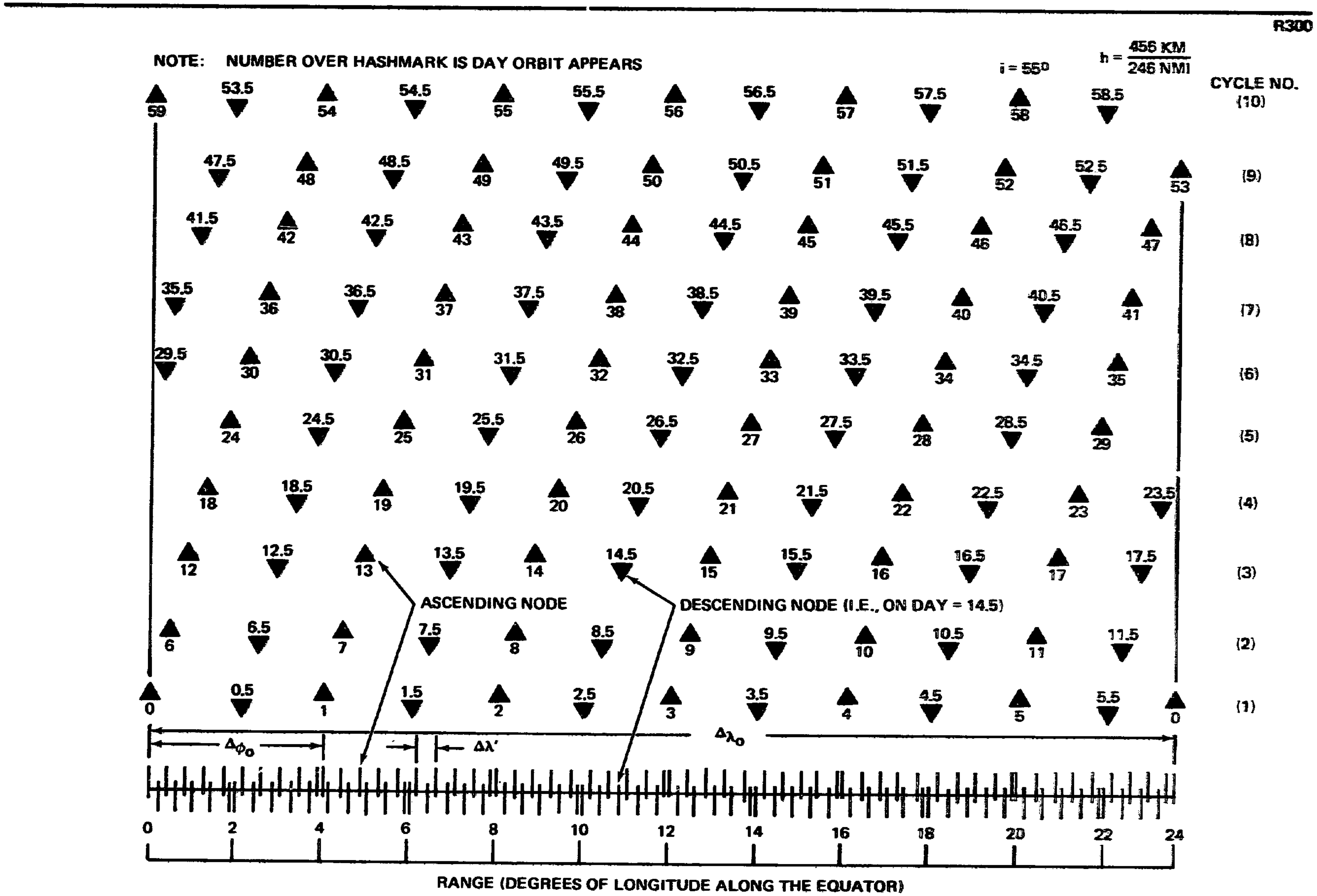


Figure 8-2. Space Station Orbit Trace Pattern Development

R300

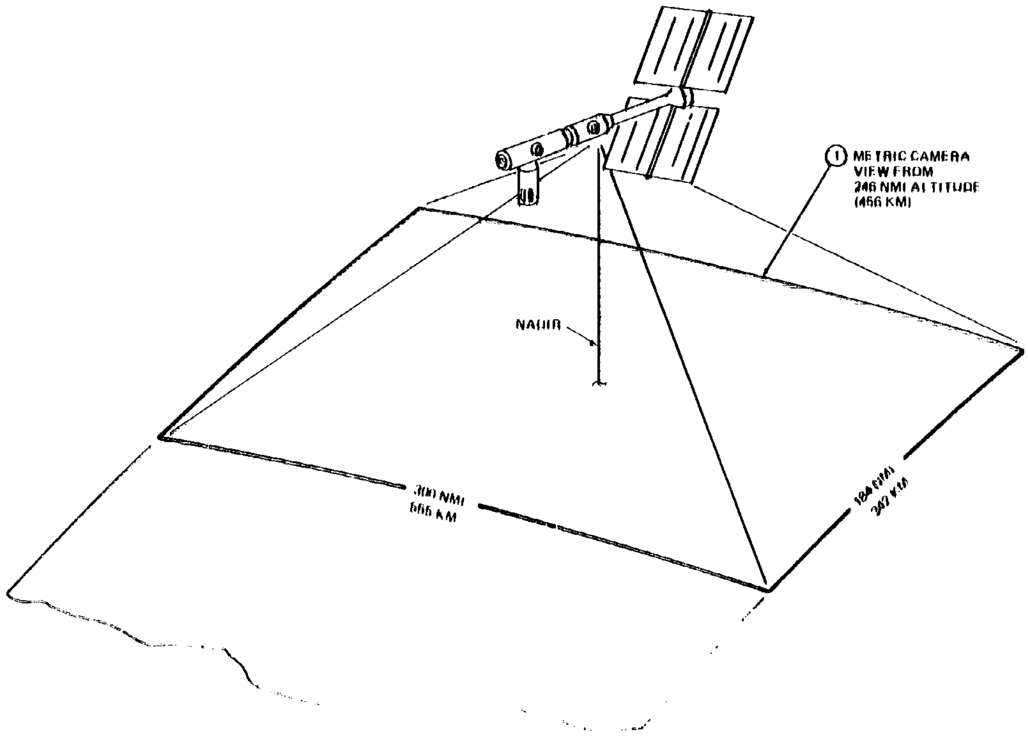


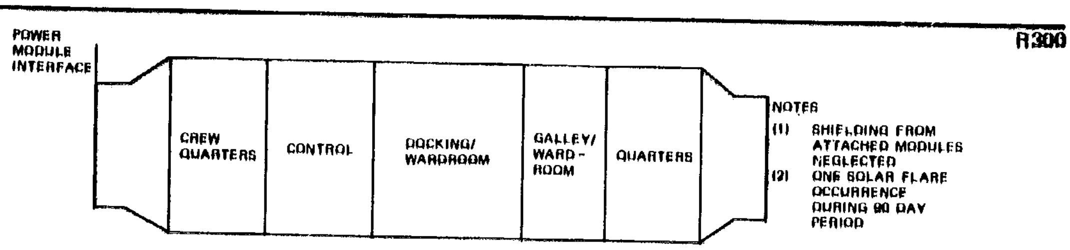
Figure 8-3. Metric Camera Field of View

adjacent ground track pass. A 55-percent overlap along the track is required in the Blue Book. At higher altitudes, the ground swath increases, the adjacent ground tracks on succeeding days occur closer together, and the number of days required to return to a target locale increase. The baseline orbit of 456 km (246 nmi) altitude and 55-deg inclination therefore yields a sufficient overlap in near-minimum time.

8.2 RADIATION ANALYSIS

Results of the radiation analysis are given in Figure 8-4, which shows the 90-day doses received by the three dose points (skin, eyes, and blood forming organs) in each of the five Crew Module compartments. Only the Crew Module is included in the model shown in Figure 8-4 for the following reason. Typically, a crewman spends 83 percent of his time within the Crew Module and the remaining 17 percent in one of the radially docked modules. The crew stations in the radially docked modules are similar in terms of shield capability with the control station in the Crew Module. This 17 percent was therefore added to the control station residency.

The dose shown in Figure 8-4 can be factored by the residency percentages shown to arrive at the total doses received. Two shield cases are



	CREW QUARTERS	CONTROL	DOCKING/ WARDROOM	GALLEY/ WARD-ROOM	QUARTERS	TOTAL DISTRIBUTED DOSE	ALLOWABLE
RESIDENCY-% (TYPICAL CREWMAN)	0	46	8	8	38		
SKIN							
EXTERIOR SHIELD	89	62	63	64	110	83	105
TOTAL SHIELD	70	16	27	21	66	44	
EYES							
EXTERIOR	62	62	63	64	71	64	52
TOTAL	38	18	20	24	42	28	
BFO							
EXTERIOR	14	16	16	16	16	16	35
TOTAL	8	7	9	8	11	9	

Figure 8-4. Dose Summary (90 Day)

included: the first is for the exterior shield only, including the basic and miscellaneous structure ($\bar{t}$ = 0.247 in.); the second includes the shield of the equipment distributed within the Space Station.

The total doses received are compared with their respective allowables in the columns on the right of Figure 8-4. The dose received in the first case (exterior structure only) is less than allowable for the skin and blood-forming organs. The eye dose is exceeded by 12 rem for this case. When the total shield capability including the equipment is considered, the skin, eyes, and blood-forming organs doses are 44, 28, and 9 rem, respectively, well within the respective allowables of 105, 52, and 35.

The location that would best serve as a biowell (place to reside during a solar cosmic event) is the control station of the Crew Module. If this is utilized as the biowell, the dose received there plus the remaining dose from the background sources is 16, 21, and 8 rem for the skin, eye, and blood-forming organs dose points, respectively. These show a marked reduction from the totally distributed doses of Figure 8-4; thus, the appropriateness of a biowell is apparent.

The duration of a typical major solar flare would vary from one to four days. To take maximum advantage of the biowell concept, the crew should remain in the biowell for the duration. Time spent outside the biowell should obviously be limited, but is certainly allowed.

The radiation analysis has shown that an adequate amount of material is available for radiation shielding; the optimum distribution of this material for maximum shielding does, however, warrant further assessment.

The basic dose data generated during the above analysis was used to determine film vault requirements. Figure 8-5 shows the film dose received as a function of vault thickness for various types of radiation. The dose allowable for typical films is also shown in Figure 8-5 for the case where film is allowed to remain undeveloped for 90 days in the suggested storage mode. The data in Figure 8-5 assume film applications limited to fogging densities associated with film types as shown. The weights of variously sized spherical aluminum film vaults are shown in Figure 8-5. It appears that films with allowable radiation dose levels below 1 to 2 rad should not be used since the vault requirements become very large.

Film stacking so that the least sensitive film would provide additional shielding for the more sensitive types would reduce these shield requirements. Careful design and inventory control would be required to maintain this advantage.

Also, by reducing the storage temperature below ambient (since the sensitivity of film to radiation varies inversely with temperature), these shield requirements could be reduced. Resupply of film at 30-day intervals would also reduce the film vault requirements by about 300 lb (the requirements shown are for a 90-day exposure).

8.3 LONG LIFE

The Space Station is designed for total maintenance on-orbit. Return of modules to Earth is therefore required only if major damage occurs, such as fire or a docking collision. This section describes the reliability of the system during the buildup phase while unmanned, limited-life items and spares requirements, and maintenance requirements.

8.3.1 Premanning Reliability

The initial buildup time period prior to manning is critical for system survival. The probability of success during the buildup time is shown in

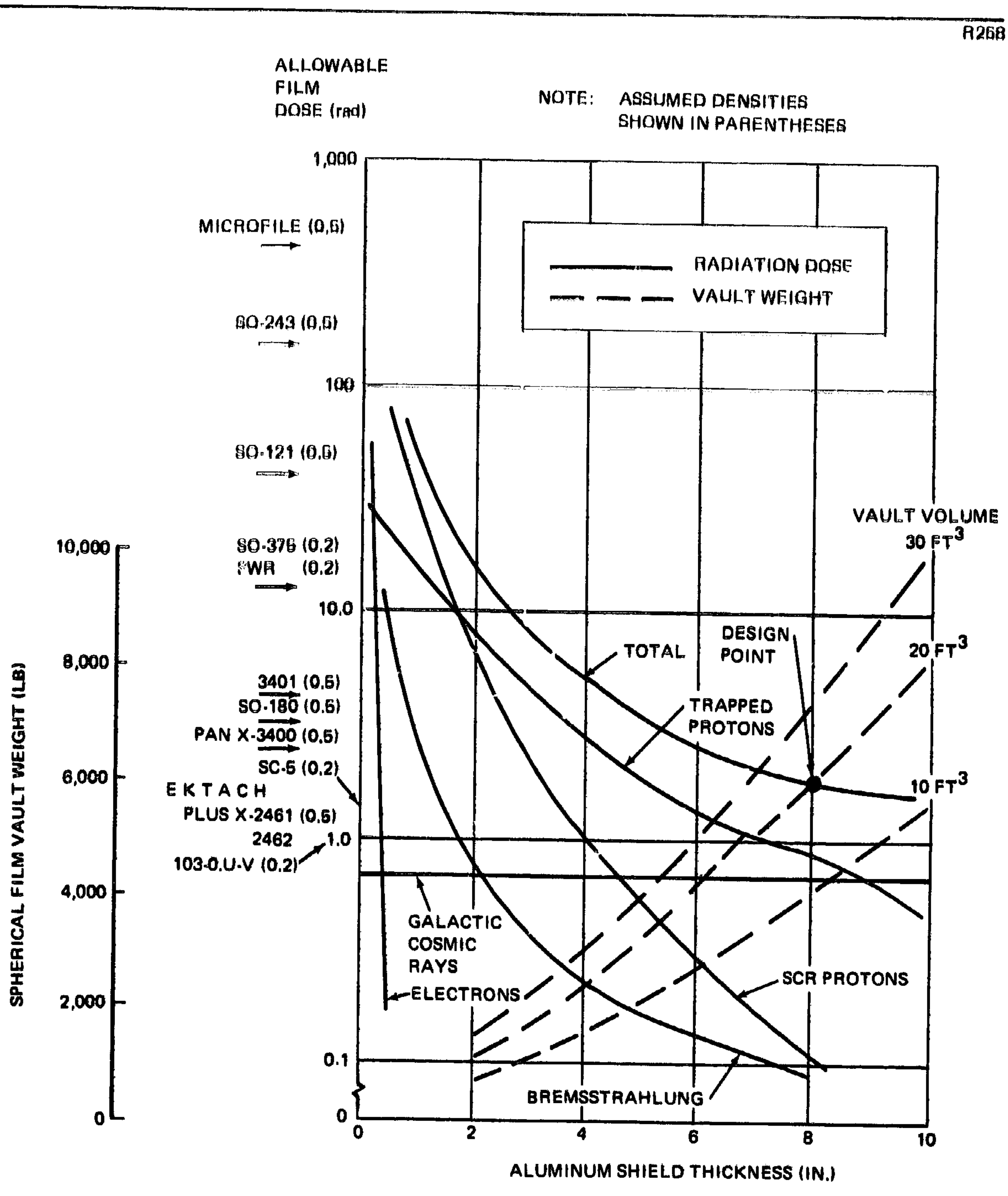


Figure 8-5. Film Vault Shield Requirements—90-Day Dose

Figure 8-6. The initial decrease in probability shown is associated with potential solar panel deployment failures and the initial start-up of required subsystems. The probability of 0.929 for survival to manning without maintenance was considered unacceptable; accordingly, the assembly crew will have the capability to repair critical failures at each buildup step. This would reduce the risk and increase the probability of Space Station availability to 0.973, as shown in Figure 8-6.

8.3.2 Limited-Life Items and Spares Requirements

The Space Station design provides that all items with limited life be replaceable. Items with a limited life are defined in Table 8-1, together with their quantity, generic life, and operating time. The total quantity of line-replaceable items, which includes the limited-life items of Table 8-1 plus items subject to failures which are predominantly random, is shown in Table 8-2.

Weights of spares are shown in Table 8-3 in terms of the quantity onboard and the quantity resupplied. The scheduled replacement items shown include limited-life items plus other replacement items such as filters.

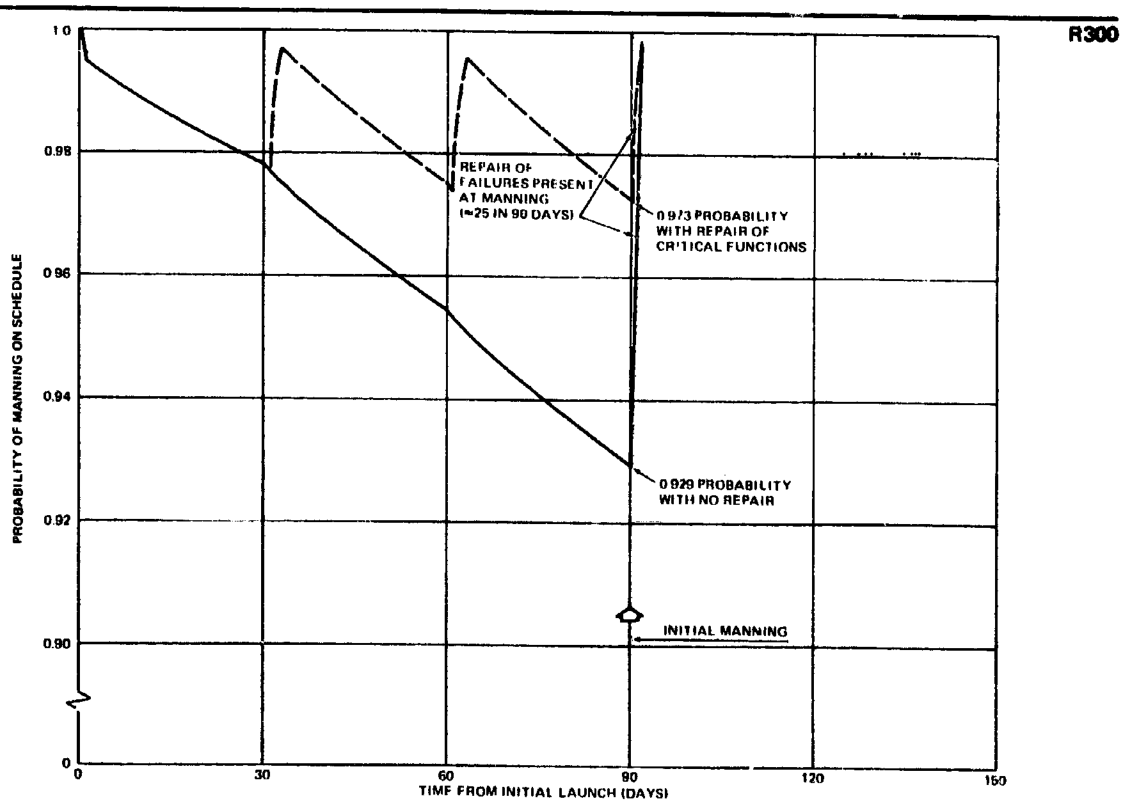


Figure 8-6. Space Station Availability (Premanning)

Table 8-1

POTENTIAL LIMITED-LIFE ITEMS (ISS)

Subsystem/Item	Quantity	Generic Life	Operating Time (10 yr)
EC/LS			
Tribed cartridge	2	1,080 hr	87,600 hr
Catalyst oxidizer cartridge	2	43,800 hr	87,600 hr
Water transfer disks	2	43,800 hr	87,600 hr
Bacteria filters—laboratory	2	43,800 hr	87,600 hr
Charcoal filters	1	480 hr	87,600 hr
Urine pretreatment	1	43,800 hr	87,600 hr
Bacteria filters	2	480 hr	87,600 hr
Bacteria filters	2	480 hr	87,600 hr
Reverse osmosis cartridge	1	43,800 hr	87,600 hr
Filters	4	1 each 360 hr	87,600 hr
Fans	20	50,000 hr	87,600 hr
Pumps	8	20,000 hr	17,520 hr
Valves	80	150,000 cycles	18 cycles/month
Regulators	4	40,000 hr	87,600 hr
Compressors	4	20,000 hr	87,600 hr
Motors	8	20,000 hr	17,520 hr
Pressure switches	4	30,000 hr	87,600 hr
Solar collectors	2	35,000 hr	53,436 hr
Radiators—thermal control	3		87,600 hr
Electrical Power			
Batteries	24	21,900 hr	87,600 hr
Circuit breakers	250	35,000 cycles	50 cycles/month
Gears	6	20,000 hr	8,760 hr
Motor drives	3	20,000 hr	8,760 hr
Bearings	6	100,000 cycles	16 cycles/day
Sun sensors	2	35,000 hr	53,436 hr
Switches	300	300,000 cycles	30 cycles/month
Solar panel	2	---	53,436 hr
Shunt regulator	2	40,000 hr	53,436 hr
GNC			
Control moment gyros (bearings)	4/5	17,500 hr	87,600 hr
Star trackers	2	17,500 hr	17,520 hr
Horizon sensors	4	17,500 hr	87,600 hr
Attitude gyros	6	50,000 hr	76,600 hr
Propulsion			
High thrustors	40	20/hr	1 hr/mo
Low thrustors	32	20,000 hr	8,760 hr
Regulators—high	2	40,000 hr	87,600 hr
Valves—high	30	150,000 cycles	240 cycles
Filters—high	3	45,000 hr	87,600 hr
Regulators—resistojet	4	40,000 hr	87,600 hr
Valves—resistojet	20	150,000 cycles	36,500 cycles
Filters—resistojet	18	45,000 hr	8,760 hr
Pumps—resistojet	4	20,000 hr	17,520 hr
Data Management			
Recorders	9	17,000 hr	8,760 hr
Keyboard and display		17,000 hr	21,900 hr
Printers	1	17,000 hr	4,380 hr
Auxiliary memory units	4	25,000 hr	29,200 hr
Cathode ray tubes	10	17,000 hr	8,760 hr
Traveling wave tubes	4	17,000 hr	8,760 hr
Potentiometers	60	50,000 cycles	500 cycles
Film tape transport	2	10,000 hr	29,200 hr
Onboard Checkout			
Transducers/sensors	800	350,000 cycles	7,300 cycles
Total	1,810		

Table 8-2

LINE-REPLACEABLE UNITS (LRU'S)

Subsystem	LRU's
Electrical Power	949
EC/LS	810
G/N&C	67
Data Management/Onboard Checkout	270
Propulsion	341
Communications	96
Structure and Docking	400
Crew Habitability	70
Lighting	450
Total	3,453

Table 8-3

SPARES WEIGHTS

Onboard Stock

	Initial	Sustained
ISS	1,814 kg (4,000 lb)	1,633 kg (3,600 lb)
GSS		2,041 kg (4,500 lb)

Resupply Weights per 90 Days

	Scheduled Replacement*	Random Failures		Total/90 Days
ISS	594 kg (1,310 lb)	109 kg (240 lb)	=	703 kg (1,550 lb)
GSS	1,034 kg (2,280 lb)	177 kg (127 lb)	=	1,211 kg (2,670 lb)

*Includes batteries.

8.3.3 Maintenance Requirements

The maintenance concept for the Space Station is fault isolation to the component level and component replacement to correct failures or wearout. On-line maintenance will be used wherever possible to reduce downtime. Subsystems are designed to be tolerant of downtime required for maintenance without detracting from experiment support capability. Redundant capability is provided where necessary to ensure adequate maintenance reaction time and is used as a means to reduce requirements for EVA maintenance excursions.

The system is designed to minimize maintenance which requires EVA. There are some items of equipment that must be installed on the outer surfaces and which have some risk of failure; EVA has been found to be the most cost-effective method for repair of these items.

Figure 8-7 shows anticipated distribution of repair time for three equipment classes in the Space Station. The electrical and electronic data indicate that 50 percent of these types of repairs can be accomplished in 1.2 hr or less and only 10 percent will require over 2.8 hr (90th percentile). If an available time for repair of 8 hr is chosen, there is an 0.998 probability that any failure can be corrected in that time.

The maintenance work load is expected to be almost evenly divided between corrective maintenance and preventive maintenance as shown in Figure 8-8. Failure prediction estimates indicate an average of 13 failures per month for the ISS configuration. The EC/LS subsystem accounts for the largest portion of the failures. This is partially due to the large number of components that must be on at all times and partially to the electromechanical nature of the components. Fans and thermal-control pumping equipment are expected to provide the greatest number of maintenance actions in this subsystem.

Preventive maintenance includes all scheduled replacement of hardware items such as those listed in the potential limited-life item list, and their adjustment and verification after exchange. It does not include housekeeping tasks. The estimate for preventive maintenance is only 30 man-hours per month.

The total preventive and corrective maintenance work load is 65 man-hours per month for the ISS. This represents an average replacement of 13 random failure items and 15 scheduled replacement items out of the total

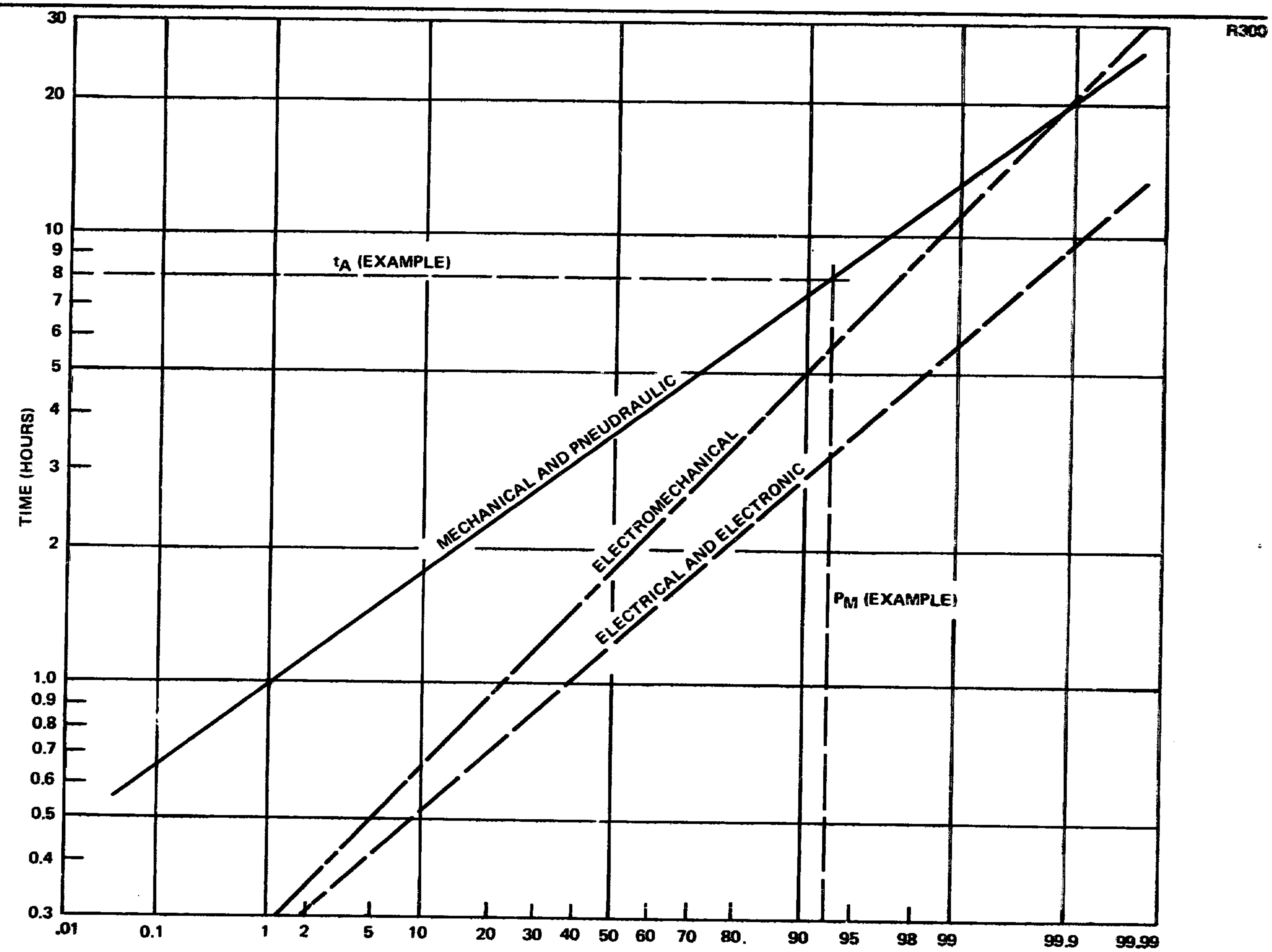


Figure 8-7. Distributions of Space Station Repair Times by Equipment Class

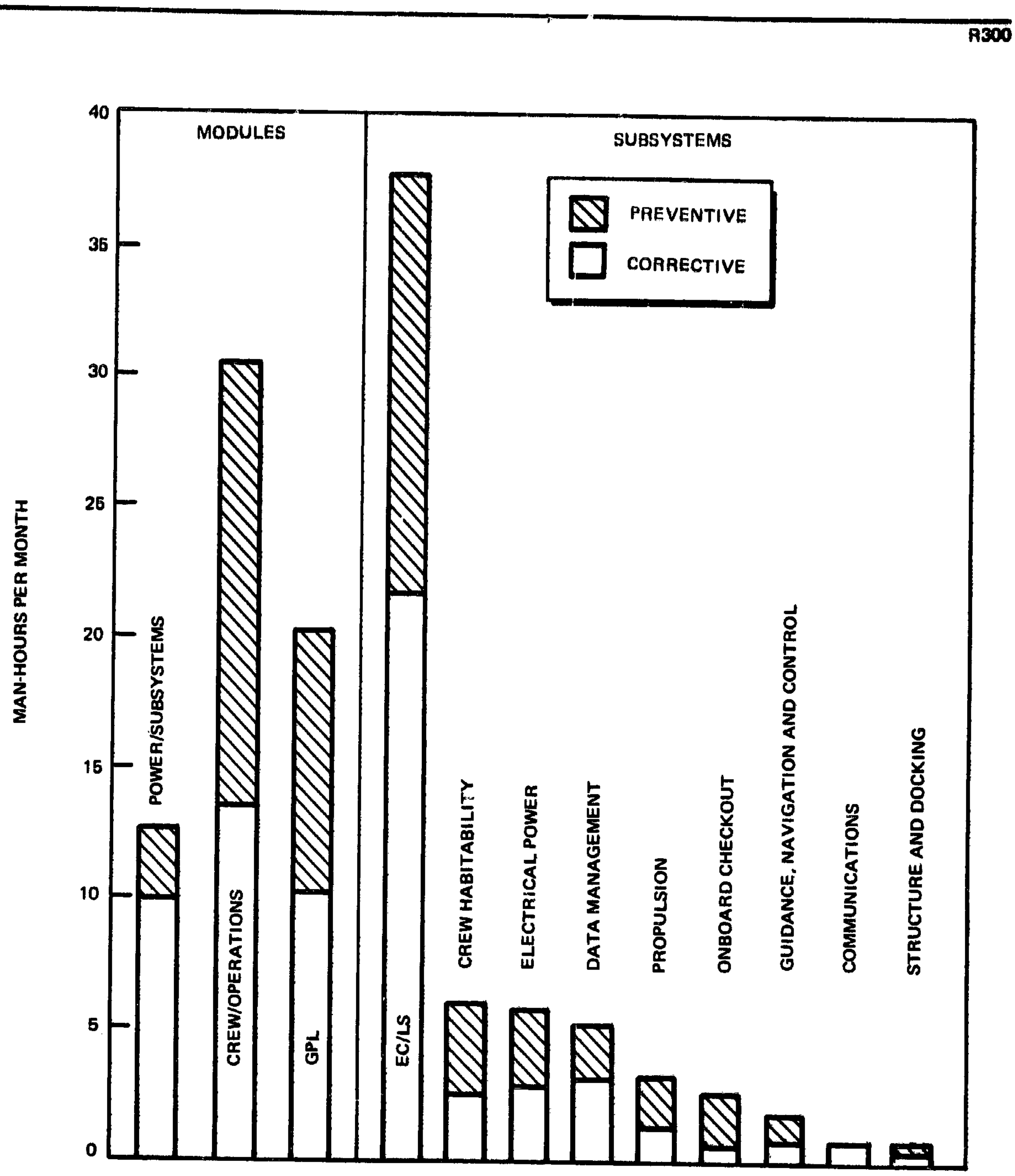


Figure 8-8. Maintenance Workload (ISS)

3,453 line-replaceable units per month. Preventive maintenance tasks are scheduled for crew convenience, while corrective maintenance task scheduling depends upon the category of equipment involved in the individual failure.

8.4 SYSTEM SAFETY

The approach to achieving a high level of safety for the Modular Space Station is retreat-refuge (and recovery) rather than abandonment. First-level backup provisions permit operation from either the Crew Operations Module or GPL with full recovery possibilities if retreat from either module is required. Lower-level alternatives are available by making every module (including RAM's) a safe refuge area for a minimum of 96 hr. If recovery from a contingency is not possible, Shuttle rescue is always available as the final backup.

The ISS configuration optimizes escape paths and rescue potential to the highest degree. Time and distance to a safe area for any crewman are minimized by providing each module with two escape routes that do not terminate in a common area and providing each module with a minimum of 96 hr of life support capability. Size of hatches permits free passage of IVA- and EVA-suited crewmen, as appropriate.

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

The risks associated with any pressure-suited operation have been minimized by designing to avoid the need for EVA and IVA to the maximum practical extent.

8.4.1 Backup Life Support Capability

One of the most significant safety features is the division of the Space Station into two pressurized habitable volumes so that any damaged module can be isolated. Accessible modules are equipped and provisioned so that the crew can safely continue a degraded mission and take corrective action to repair or replace the damaged module.

The two primary separate habitable volumes at the ISS level are the Crew Operations Module and the GPL. Each is equipped and provisioned so that the six-man crew can remain in it for an indefinite period in the event the other module becomes uninhabitable. Independent control centers are provided in each module. The primary control center is located in the Crew Operations Module and the secondary center in the GPL. Each center is capable of providing all essential Space Station command and control functions, including fault isolation and detection, caution and warning, and monitoring and control of Space Station subsystems.

The life support capability for nonnominal modes of operations is as follows:

A. Contingency Consumables

A contingency supply of consumables to continue normal operations for 30 days beyond the next scheduled resupply date is located as follows:

1. Atmospheric supply—180 man-days of gaseous oxygen stored in two separate tanks, located in the Power/Subsystem Module.
2. Food—180 man-days of freeze-dried food is located in the GPL.
3. Water—180 man-days of potable water is stored in the GPL.

B. Degraded Mission Mode

A degraded mission mode normally results from a major system failure and may continue for an indefinite period, until repairs are made or until the crew has returned. In a degraded mode of operation crew facilities and provisions need not be of the same standard as during normal operations. In a degraded mode in which the GPL module (one of the two dual compartments) is uninhabitable, no additional crew provisions are required to continue the mission until repairs are made. In the event the crew is isolated in the GPL (Crew Operations Module uninhabitable) provisions are available for their support:

1. Atmosphere supply and control is accomplished with a fully independent EC/LS system located in the GPL. Access to the normal atmosphere stores in the Logistics Module and the Power/Subsystems Module is provided through the redundant interface connections and lines.
2. Water is initially provided from the accumulator in the Crew Operations Module through the potable water supply line into the GPL. Depending on the level in the accumulator, up to

12 man-days of potable water may be available. As mentioned previously, the 30-day contingency water is located in the GPL and would next be used should repairs to restore habitability in the other compartment not be completed.

3. Food is of the freeze-dried type which is reconstituted with water. The necessary utensils and supplemental containers are part of this contingency supply.
4. Waste collection provisions will be of the Apollo type (or further improved). Quantity sufficient for 30 days will be stored in the GPL.
5. Sleep restraints are stored in the GPL.

C. Emergency Mode

The emergency mode of operation occurs if normal and even contingency provisions cannot be relied on to continue operations safety. It may range from a situation in which one or more crewmen are isolated in a module to a situation where the safety of the entire crew is jeopardized by a catastrophic incident resulting in failure of both (redundant) life support systems, e.g., a complete power failure. Use is made of a 96-hr pallet containing critical supplies of oxygen, lithium hydroxide for CO_2 control, a water boiler for thermal control, food, water, waste collection bags, and a battery power supply. A pallet sized for three men for 96 hr which weighs about 160 kg or 350 lb best satisfies emergency requirements. Location of three-man pallets is as follows:

1. Two three-man pallets in the GPL under the floor.
2. One pallet required initially in the Power/Subsystems Module, but can be removed when a RAM is attached.
3. One pallet in each attached RAM.
4. One pallet in the Logistics Modules.

8.4.2 Dual Egress

The design of the Space Station provides, as required, the capability for a crewman to egress from any module in more than one way. This is accomplished as follows:

A. Crew Operations Module—The Crew Operations Module is docked to the Power/Subsystems Module, GPL, Logistics Module, and a

RAM. Each provides a safe refuge, the GPL for an indefinite time, the others for a minimum of 96 hr. Four different routes are thus available from the Crew Operations Module.

B. Power/Subsystems Module—Three RAM's and the Crew Operations Module are docked to the Power/Subsystems Module. In addition to these routes, another is available through the solar array tunnel. The latter would be used only if all the other routes were blocked.

C. GPL—The GPL is radially docked to the Crew Operations Module. It is divided into two compartments: the laboratory portion of the module has dual egress into the test and isolation facility (which is also an EVA airlock) or into the Crew Module.

D. Logistics Module—The Logistics Module is always radially docked or end-docked to the Crew Operations Module. The end of the Logistics Module which is always away from the Space Station contains the primary EVA airlock. Thus, the two routes out of the Logistics Module are into the Crew Module or refuge into the airlock.

E. RAM's—RAM's are radially docked to the Power Module or to the Crew Module. Each RAM is required to have an EVA airlock. The two exits out of a RAM are into the Power or Crew Module and into the EVA airlock.

Thus, at least two alternate shirtsleeve routes are provided from every normally habited compartment. Each route terminates in a different safe area.

8.4.3 EVA/IVA

The modular Space Station design and experiment program precludes EVA to the maximum extent possible. However, pressure suit assemblies and associated support equipment are required for limited planned and emergency IVA and EVA operations. The EVA suits and backpacks and IVA suits and umbilicals are stored for ready access from all points in the station. For the ISS, there will be a total of eight pressure suits onboard at all times. This provides a suit for each crewman plus two spares. Two individually fitted EVA and IVA suits will be located in the Logistics Module adjacent to the EVA airlock at the primary suit station. Two other EVA and IVA suits will be located in the GPL near the test and isolation chamber which serves as the secondary EVA airlock. Two of the four grossly fitted suits will be located in the Crew Operations Module, and two in the Power/ Subsystems Module. The suit placement provides ready access, facilitates any normal EVA, and minimizes the risk of loss of suits because of loss of any one module. IVA umbilical outlets are directly connected to the Space Station EC/LS system and are located in every pressurizable compartment. They would be used primarily when inspection or repair of an unpressurized or contaminated module is required. Additionally, IVA suits provide protection against hazards in a pressurized area.

8.4.4 Decompression

Decompression can range from an explosive decompression to a relatively slow leak. Explosive decompression could result from a massive rupture of the pressure shell (critical crack length is 25.4 cm (10 in.), blowout of a large view port, or failure of a hatch. It is highly unlikely that these events will occur because of the safety factors used in design and because the design precludes inadvertent operation of a hatch and other fail-safe features.

Loss of atmosphere from smaller holes (at a critical but not catastrophic rate) could be caused by relief valve failure, leakage at view port or hatch, or meteoroid penetration. Table 8-4 provides estimates of probabilities for accidental loss of atmosphere of a module.

Significant factors affecting the degree of safety in the event accidental decompression occurs are the crew time required to evacuate a module, the equivalent hole size, time of useful consciousness, time of unimpaired response, and the pressurized volume.

Table 8-4
DECOMPRESSION PROBABILITIES

	Probability
Loss of seal at pressure hatch	0.0005
Loss of viewport	0.0010
Dump/relief valves open	0.0016
Docking collision	0.0003
Space debris collision	0.0005
Meteoroid puncture	0.0010
Overpressurization or rupture of pressure shell (explosion)	0.0006
Structural failure of pressure shell	0.0002
Corrosion of shell	0.0005
Internal puncture	0.0010

Figure 8-9 compares the time of pressure decay from 101 kN/sq m (14.7 psia) to 59.3 kN/sq m (8.5 psia). While this pressure is too low for sustained crew operations without acclimatization, the crew would experience very little impairment in evacuating a module. Any symptoms of hypoxia can be alleviated by donning an emergency oxygen mask which is readily accessible in each module. Decompression sickness, the bends, would be no problem since a drop to approximately 360 mm Hg total pressure from 760 mm Hg can usually be tolerated safely. Figure 8-9 shows the time for the pressure to decay to 59.3 kN/sq m (8.6 psia). (No makeup from onboard atmosphere supplies is assumed.)

The top curve of Figure 8-9 (for a volume of 490 cu m) is equivalent to the ISS configuration composed of the four basic modules. This is a conservative number for the volume since RAM's also contain atmosphere referenced to the baseline modules. Note that a hole as large as 15 cm (6 in.), which is equal to complete loss of viewing port, still would provide two minutes of reaction time. The estimated times for crewmen to move the entire length of the different modules is shown below:

Module	Translation Time (sec)
GPL	23
Crew Operations	23
Logistics	11
Power/Subsystems	15

These must be considered worst-case escape times, since they assume the crewman must move to the opposite end of the module. The times represent movement at 0.6 m/sec (2 fps) which could easily be accomplished under emergency conditions. Closure of the appropriate hatch can be accomplished rapidly: an estimate of 30 sec or less is a conservative assumption. Addition of this time to the movement times still provides a worst-case 2 to 1 safety factor. For holes in the equivalent size range of 2 in. or less, so much time is available for repair that evacuation of the module might not be required. Time needed for repair is a function of the location of hole and wall accessibility.

The effect of loss of the atmosphere of a single module on the total Station atmosphere is as follows: loss of atmosphere equivalent to the 156 cu m of the GPL (without any makeup) would reduce the total pressure to 70 kN/sq m (10.2 psia). This total pressure (ppo_2 equals 110 mm Hg)

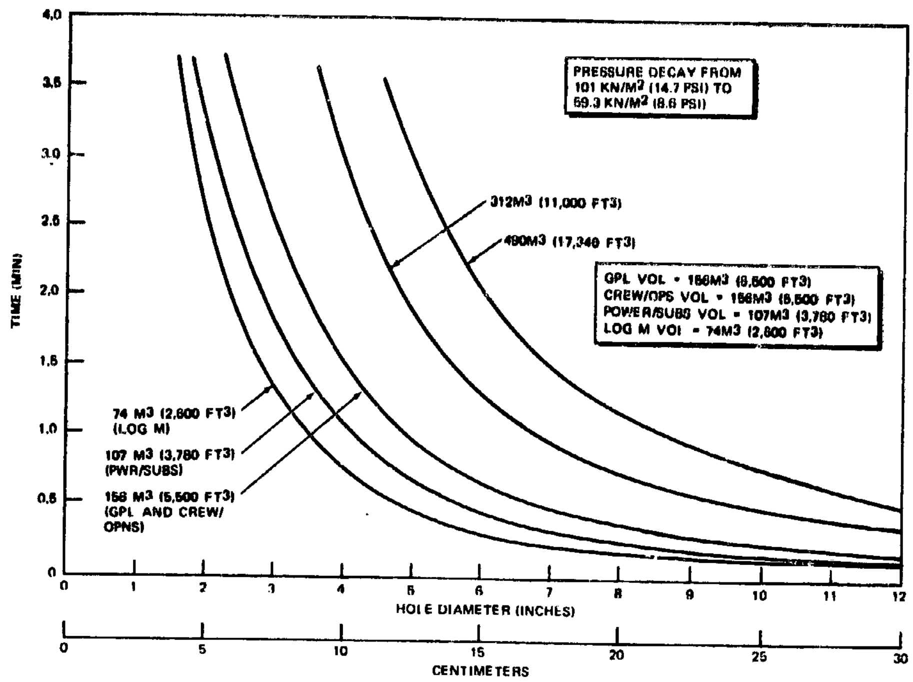


Figure 8-9. Cabin Pressure Decay

presents no particular hazard to the crew. The crew would have three options: (1) repressurizing with N_2 and O_2 to restore the atmosphere to the normal level, (2) using O_2 to slightly enrich the atmosphere (from 21 to 25 percent O_2 increases the fire hazard very slightly), or (3) operating at reduced pressure to retain onboard repressurization gas for any emergency. Repressurization supplies are onboard to provide 262 cu m (9,300 cu ft) at 760 mm Hg. This is in addition to the onboard supply for normal makeup. It is apparent that the Station could sustain substantial loss of atmosphere without approaching emergency conditions.

Section 9
SPACE SHUTTLE INTERFACES

The major interfaces between the Space Station and the Space Shuttle are summarized in this section together with a description of the Space Shuttle features which are pertinent to the preliminary design of the Space Station and a description of the Shuttle operations as they affect the Space Station design. Design requirements stemming from interfaces with the Shuttle are also summarized. Certain of these requirements were provided by NASA. Supplemental information on the Space Shuttle was utilized in this study. This information is based on the MDAC Phase B Shuttle Design performed under Contract NAS8-26016.

9.1 VEHICLE DESCRIPTION

Pertinent characteristics of the Shuttle orbiter are the vehicle configuration, payload accommodation and on-orbit propulsion and reaction control system.

The Space Shuttle orbiter vehicle is a Delta-wing configuration, as shown in Figure 9-1. This vehicle is designed to accommodate a crew of four (2 for the orbiter and 2 for the Space Station). The cargo bay is sized to accommodate a payload of up to 4.6 m (15 ft) in diameter and 18.2 m (60 ft) in length (including protuberances beyond the payload cylinder). A large door provides access to the cargo bay. This door, the Delta wing, vertical stabilizer, and radiator are potential sources of interference with the Space Station and attached Research and Application Modules during docking operations.

Structural accommodation of the payload in the orbiter is provided by a series of attach points.* These attach points are located at the forward end of the payload bay, on the cargo bay door sill, and one on the bottom centerline. Alternate support point locations are possible at any of the upper body frames for payloads less than 17.6 m (58 ft) in length.

On-orbit propulsion/reaction functions are performed by the attitude control propulsion system and the orbital maneuvering system. The attitude

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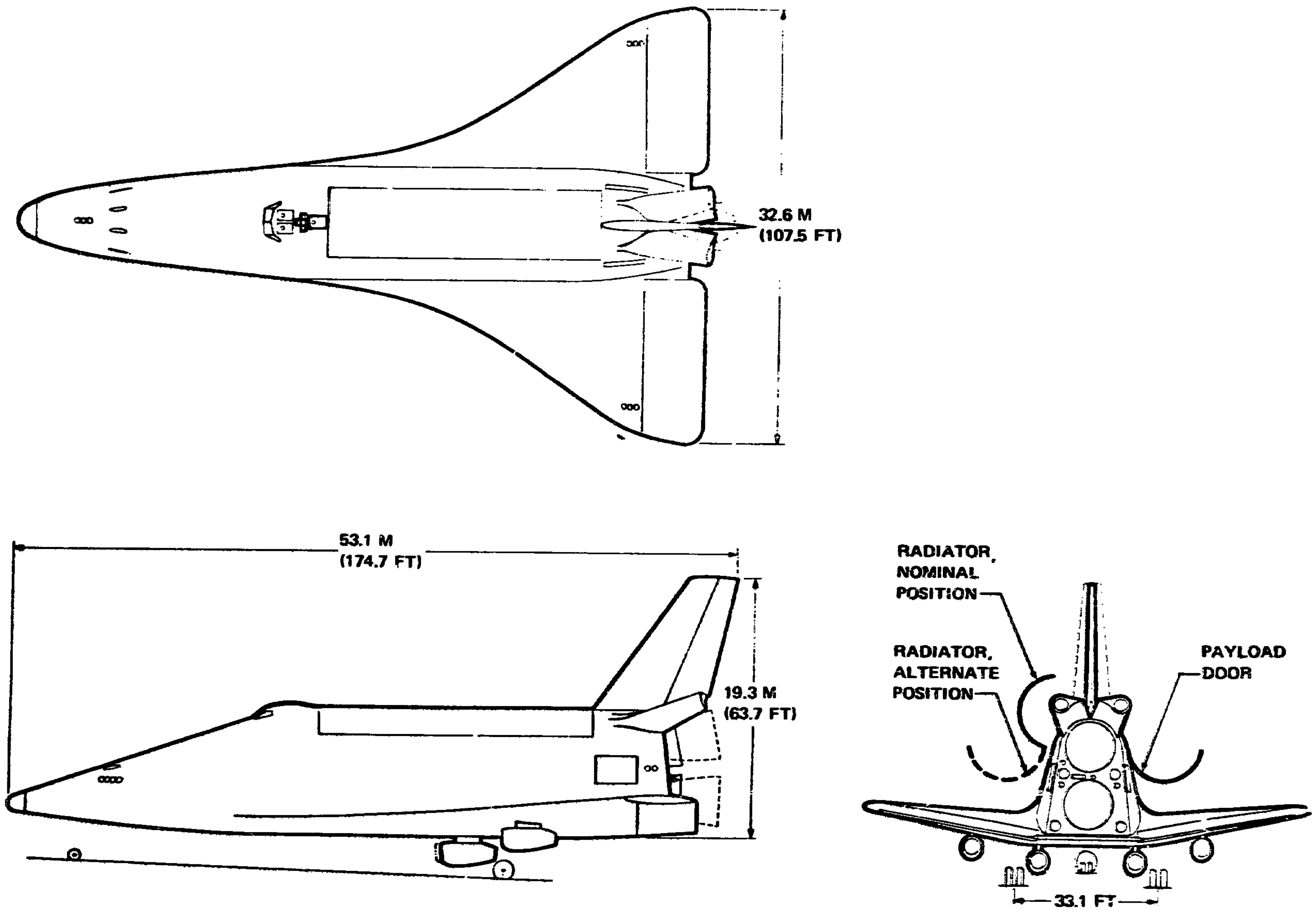

Figure 9-1. Baseline Orbiter Configuration

control propulsion system is used for attitude control and micro-translation maneuvers. Jets are located on the orbiter vehicle as indicated in Figure 9-2. Thrust magnitude of each engine is 7, 100 N (1, 600 lb) (vacuum). The attitude control propulsion system is a high-pressure GO_2/GH_2 bipropellant reaction control system. Propellants are stored in secondary tanks which also contain propellant, fuel cell, and environmental control fluids for the orbital maneuvering system.

A minimum number of thrusters are fired per axis to minimize angular accelerations; however, they are always fired in couples to minimize translational disturbances. The acceleration characteristics (orbiter vehicle only) per axis are:

	Angular Acceleration (deg/sec^2)
Pitch	1. 66 (up)
	0. 83 (down)
Yaw	0. 78
Roll	1. 74

Minimum impulse per engine is 214 N-sec (48 lb-sec) (based on minimum thruster pulse duration of 0. 03 sec).

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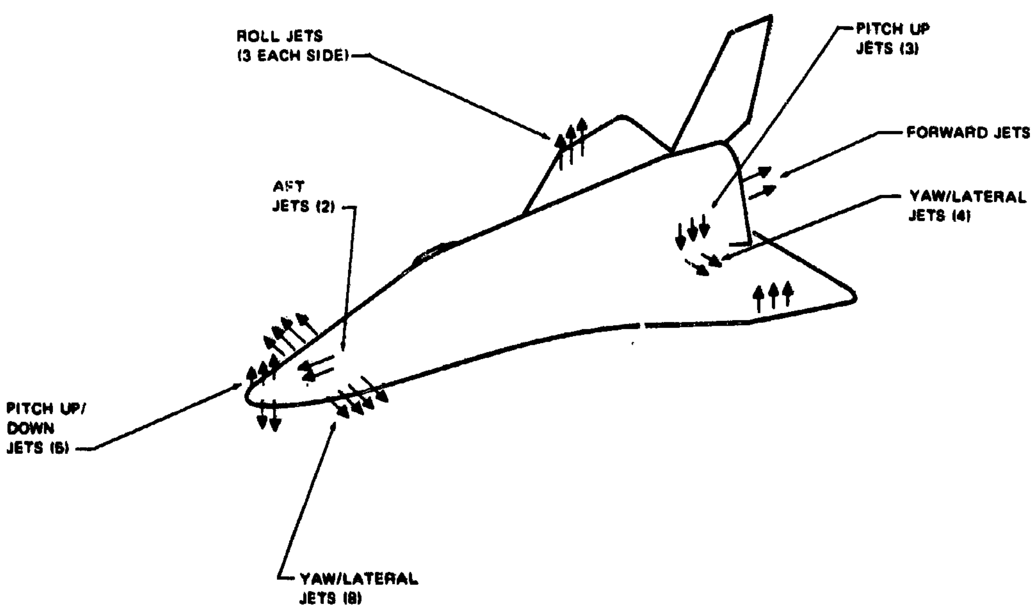

Figure 9-2. Orbiter Attitude Control Jets

The orbital maneuvering system is required to perform all major translation maneuvers during the orbital phase of the mission. The orbital maneuvering system consists of two RL 10A-3 engines mounted in the upper-aft fuselage.

Weight of the orbiter vehicle at the time of docking is 131, 000 kg (288, 000 lb) including the payload of 9, 100 kg (20, 000 lb).

9. 2 OPERATIONS

Shuttle operations which particularly impact the Space Station are those of prelaunch, docking, postdocking, and rescue. These are described in the following subsections.

9. 2. 1 Ground Operations

Figure 9-3 shows the flow of Shuttle operations from t-6 days to launch. Normally, the payload is loaded in the orbiter while it is in the horizontal position at approximately t-5 days. Access to the payload from the time of loading until launch is limited and depends on the type of Shuttle prelaunch operation in process. Figure 9-3 indicates the time periods in which access is (1) possible on a noninterference basis, (2) limited to connection of umbilicals, or (3) prevented. Due to the limited capability for access, as seen from Figure 9-3, the design of Space Station modules must result in minimal requirements for checkout, servicing, calibration, etc., during this period (postloading to launch).

9. 2. 2 Docking Operations

Docking of all modules to other modules on-orbit is performed by the orbiter vehicle. The operations of braking, docking, separation, attitude control, and station-keeping are performed by the attitude control propulsion system.

During docking operations, the Space Station is essentially passive, but retains command of the maneuver; i. e., the Station crew commands the initiation of the docking maneuver and visually monitors the operation while in voice communications with the docking pilot.

The direct docking mode, using manual control, was assessed by an evaluation of data from a man-in-the-loop docking simulation (performed under the Space Shuttle Phase B Study). These data verified the docking

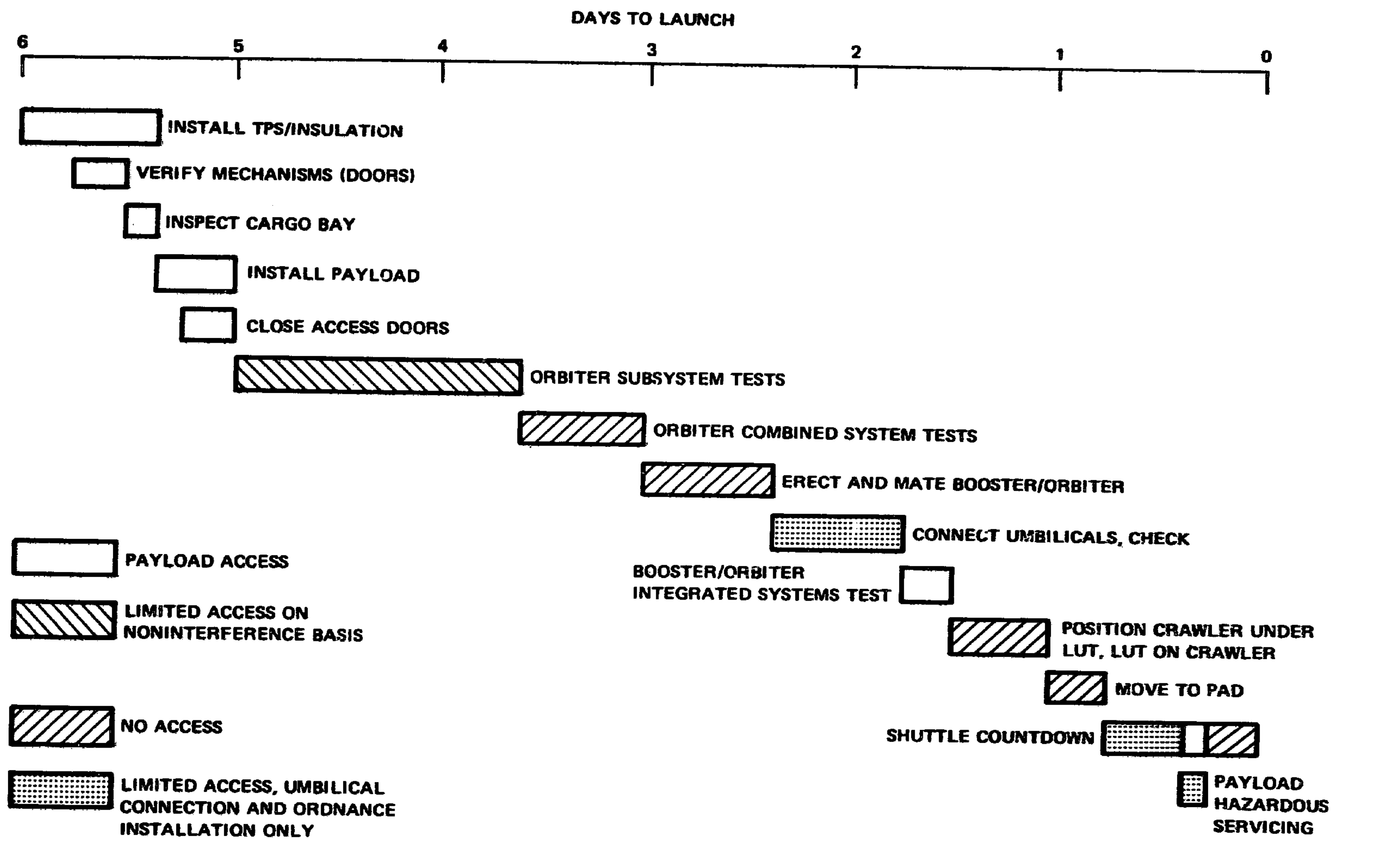

Figure 9-3. Payload Interface with Shuttle Operations

design criteria and the capability of orbiter control within translational and attitude limits. The simulation employed six degrees of freedom. Target alignment aids were similar to those defined in Section 7. Onboard docking displays provided range-to-docking, relative range rate, and attitude rate.

In the simulation, the payload module was mounted with the centerline parallel to the orbiter centerline in contrast to the current design which the module centerline is perpendicular to the orbiter centerline when erected. Results of the simulation are nevertheless considered representative. In both cases, there is a large distance between the pilot and the docking interface and rotation about the orbiter center-of-gravity results in significant translation of the pilot and the docking interface.

Figure 9-4 shows the docking precontract conditions (mean and worst case) in comparison with the values used for the Space Station design. The results shown include data from all 34 simulations and they are within the specified design criteria values.

Another objective of the simulation was to determine the accuracy of the Shuttle position and attitude control relative to a target. The results are applicable to the determination of position and attitude control during approach to the Station in a docking operation. These results are shown in Figure 9-5. This figure shows the longitudinal, lateral, roll, and yaw error distributions. The pilot's objective was to nullify these errors and maintain a fixed position and attitude relative to the target. As indicated in the figure, displacement errors are generally less than 0. 305 to 0. 456 m (1. 0 to 1. 5 ft) and angular errors are less than 3 deg.

9. 2. 3 Rescue Operations

The Space Station program included a guideline that the Space Station design have provisions and habitable facilities adequate to sustain the entire crew for a minimum of 96 hr during an emergency situation requiring Shuttle rescue. An analysis was performed to determine the Shuttle reaction capability to verify the adequacy of 96 hr as a design requirement. Table 9-1 indicates the reaction time or time from emergency to rescue. The total reaction time shown is the maximum that would be required. This time is 58 hr during the period the Shuttle launch rate is less than 50 per year. In the high launch-rate phase of the Shuttle program, the maximum reaction time is 90 hr (reaction time is less than 58 hr, 60 percent of the time).

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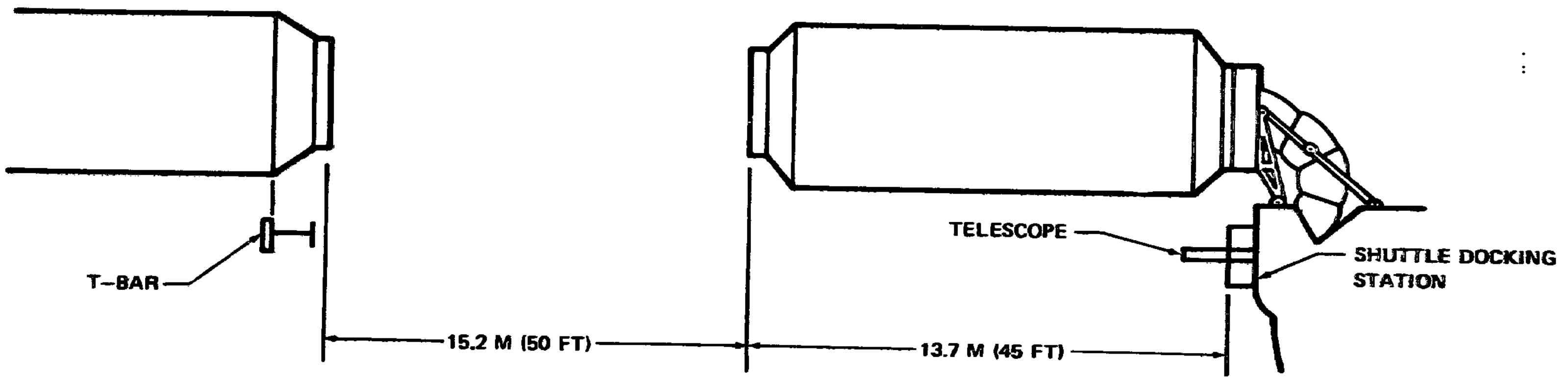
SIMULATION GEOMETRY



RESULTS (34 RUNS)

	MEAN	WORST CASE	DESIGN CRITERIA
MISS DISTANCE, M (FT)	0.152 (0.5)	0.274 (0.9)	0.305 (1.0)
LONGITUDINAL VELOCITY, MPS (FPS)	0.037 (0.12)	0.07 (0.23)	0.305 (1.0)
LATERAL VELOCITY, MPS (FPS)	0.021 (0.07)	0.033 (0.11)	0.076 (0.25)
MISS ANGLE (DEG)	0.9	1.7	5.0
ANGULAR RATE (DEG/SEC)	0.1	0.15	0.5
ROLL ANGLE (DEG)	1.5	3.5	5.0
ROLL ANGULAR VELOCITY (DEG/SEC)	0.1	0.17	0.5

Figure 9-4. Docking Simulation

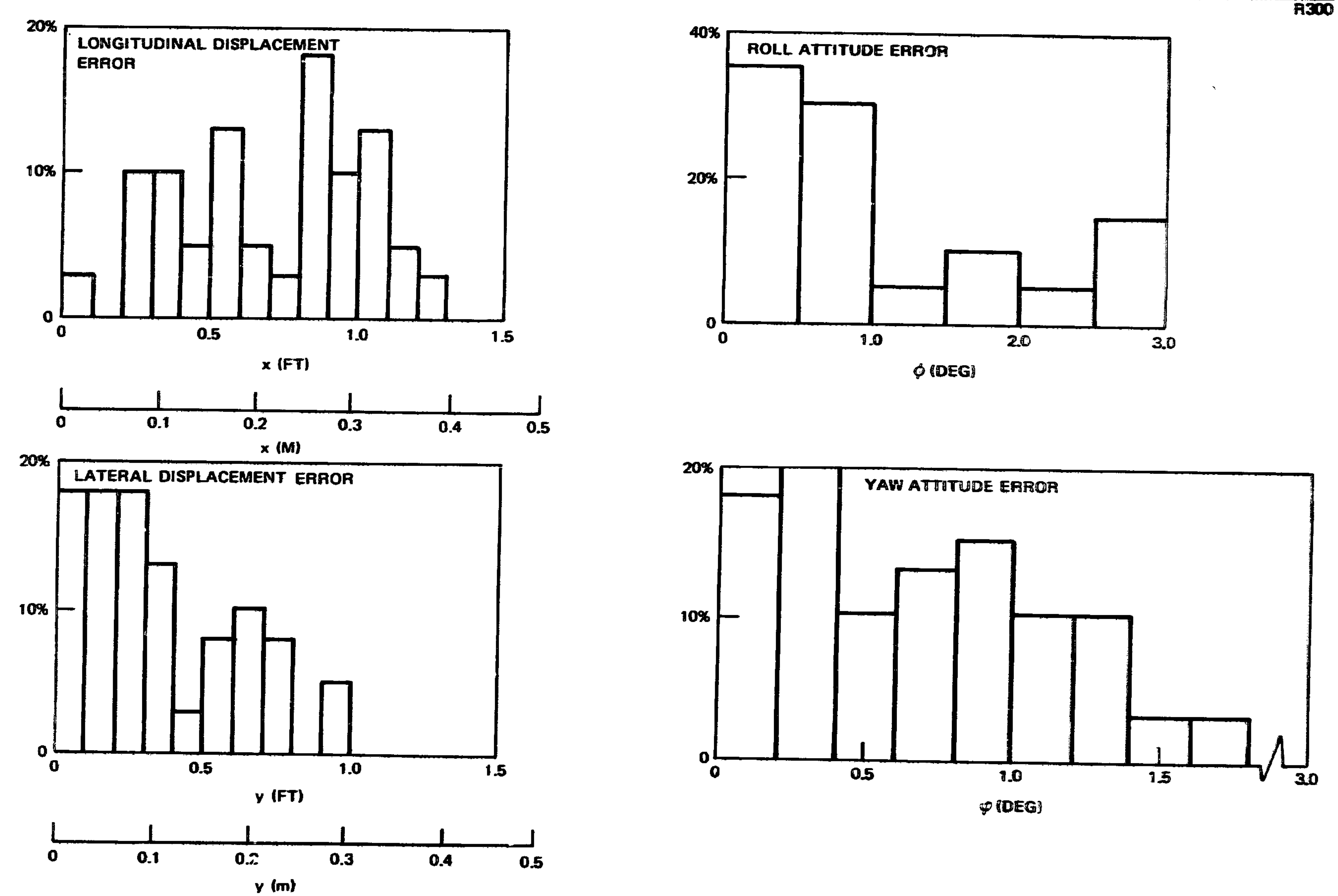


Figure 9-5. Distribution of Orbiter Control Errors

Table 9-1

SHUTTLE RESCUE CAPABILITY (WORST CASE)

	Low and Medium Launch Rate (<50/hr) (hr)	High Launch Rate (75/hr) (hr)
Launch preparation	24	56
Ground hold for window	15	15
Rendezvous	16	16
Rescue operations	3	3
Total	58	90

Notes: Four orbiters and three boosters available. Maximum ground hold for launch opportunity. Vehicle maintained at t-24 hr status for low- and medium-rate case.

The reaction times shown do not require a Shuttle vehicle dedicated to a Space Station rescue mission, nor do the attainment of these reaction times create a significant impact on the Shuttle prelaunch operations.

9.3 INTERFACE REQUIREMENTS

This section contains a brief summary of Space Station design requirements which arise as a result of operations with the Space Shuttle.

9.3.1 Payload Launch Weight

Maximum weight of Space Station modules was directed by NASA as follows: "The design-to weight of Shuttle-transported modules shall not exceed 20,000 lb." This guideline was interpreted by NASA to apply to descent missions as well as ascent missions.

9.3.2 Payload Size

Maximum size of Space Station modules was directed by NASA as follows: "The maximum external dimensions of the modules shall be 14 ft in diameter and 58 ft in length. Mechanisms that are external but attached to the module, such as handling rings, attachment for deployment, docking mechanisms, storage fittings, thrusters, etc., shall be contained at launch within an envelope 15 ft in diameter and 60 ft in length."

9.3.3 Center-of-Gravity Location

The allowable payload center-of-gravity envelope is based on the MDAC Phase B Shuttle Design. The allowable longitudinal center-of-gravity envelope is shown in Figure 9-6. Lateral and vertical center-of-gravity axis limits are ±0.30 m (12 in.).

9.3.4 Load Factors

Design load factors are listed in Table 9-2.

9.3.5 Orbiter Support Functions

The design of the Space Station and Logistics Modules is based on using selected services from the Shuttle during buildup operations and logistics missions. These services include electrical power; limited use of the orbiter caution, warning, and onboard checkout capability; limited use of orbiter data management system for module command and control functions; and a supply of conditioned air.

9.3.6 GSS Considerations

The primary difference between ISS and GSS operations is that six crewmen are transported in a Crew/Cargo Module for the GSS rather than two crewmen in the orbiter crew cabin for the ISS. However, docking of the Crew/Cargo Module to the Station is performed in the same manner as docking of the Logistics Module. Docked operations in the GSS phase differ from the ISS in that attitude control of the Station-orbiter cluster is performed by the Station rather than the orbiter.

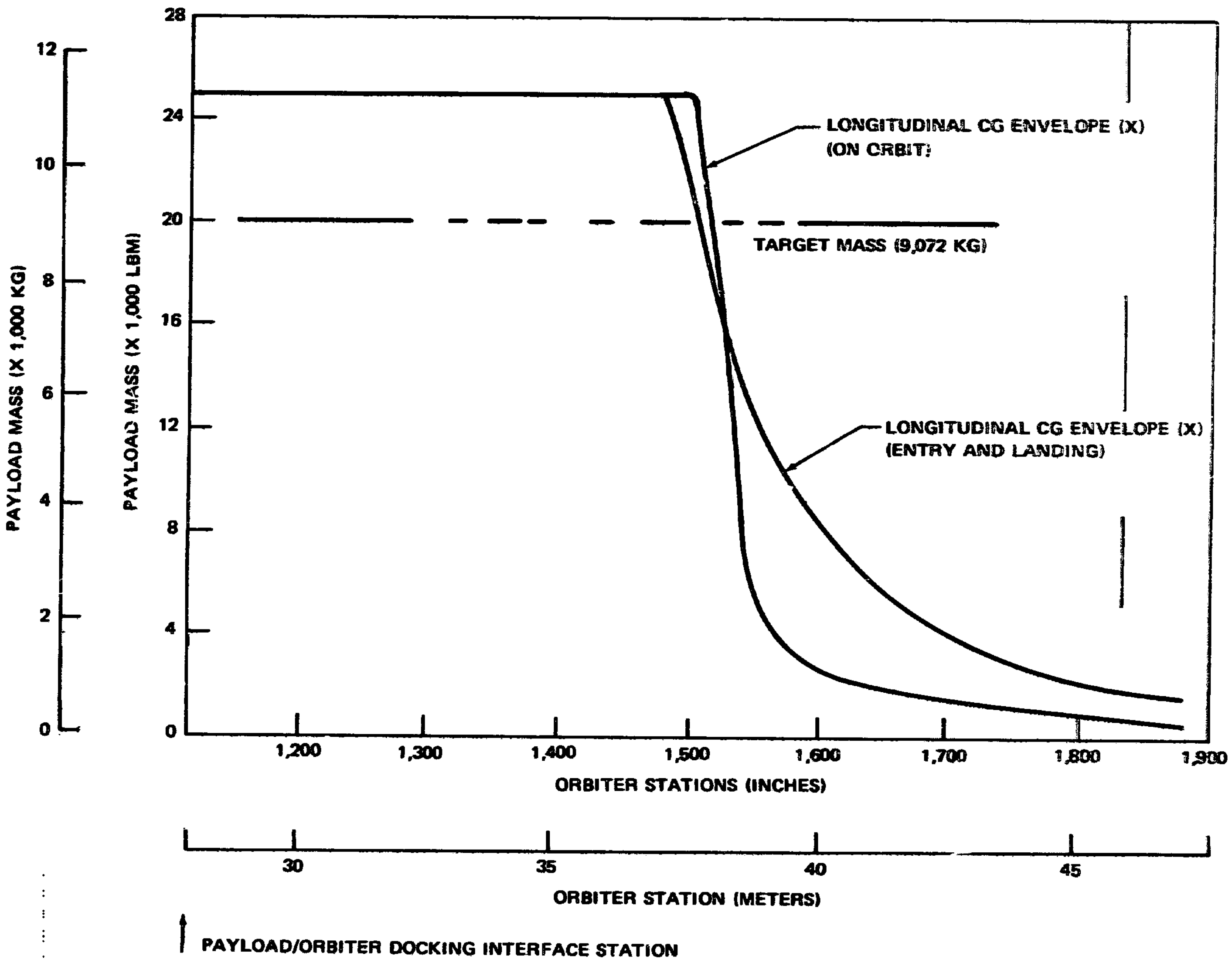


Figure 9-6. Longitudinal cg Limitation

Table 9-2

LOAD FACTORS*

	Axial (n_x)	Lateral ($\pm n_y$)	Vertical (n_z)
Launch	1.5	0.5	0.5
High Q	1.9	1.0	±1.0
End Boost (Booster)	3.3	0.6	-0.6
End Boost (Orbiter)	3.3	0.5	-0.5
Entry	-0.5	1.0	-2.0
Flyback	-0.5	1.0	+1.0
			-2.5
Landing	-1.3	0.5	-2.7
Emergency Landing	-8.0	1.5	-4.5
	+1.5		+2.0

*Load factors are in the direction of the acceleration (n_x positive forward; n_z positive down), the load factors for each condition can act simultaneously.