2 (MIX)

NOVEMBER 1971

MDC G25

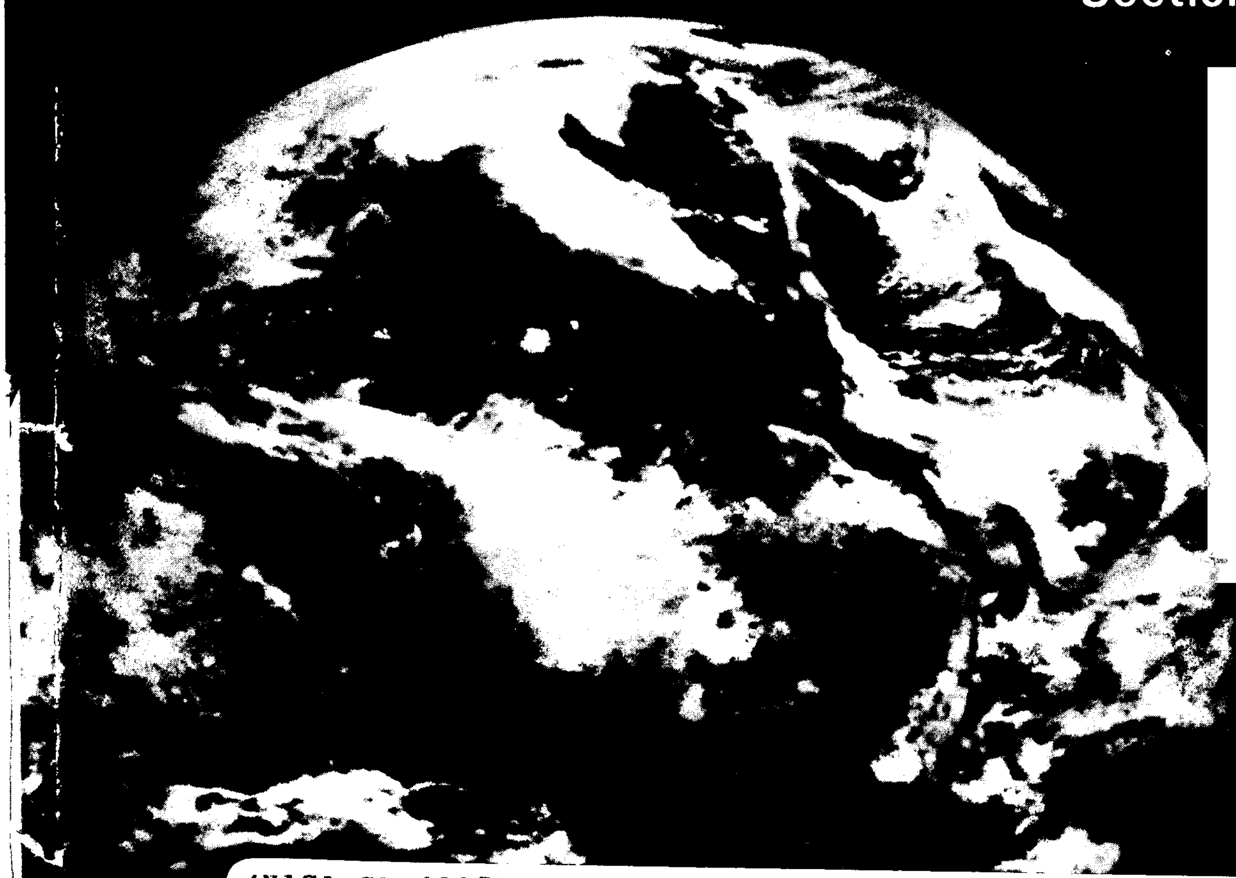
SPACE STATIO

MSFC-DPD-235/DR NO. SE-04
MODULAR SPACE STATION
DETAILED PRELIMINARY DESIGN

Volume

Sections 1 Through 4.4

CONTRACT NAS8-251



MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

MARTIN MARIETTA CORPORATION IBM International Business Machines Corporation MCDONNELL DOUGLAS CORPORATION

CAT. 31

MCDONNELL DOUGLAS

CONTRACT NAS8-25140
MSFC-DPD-235/DR NO. SE-04

MODULAR SPACE STATION DETAILED PRELIMINARY DESIGN

Volume I
Sections 1 Through 4.4

NOVEMBER 1971

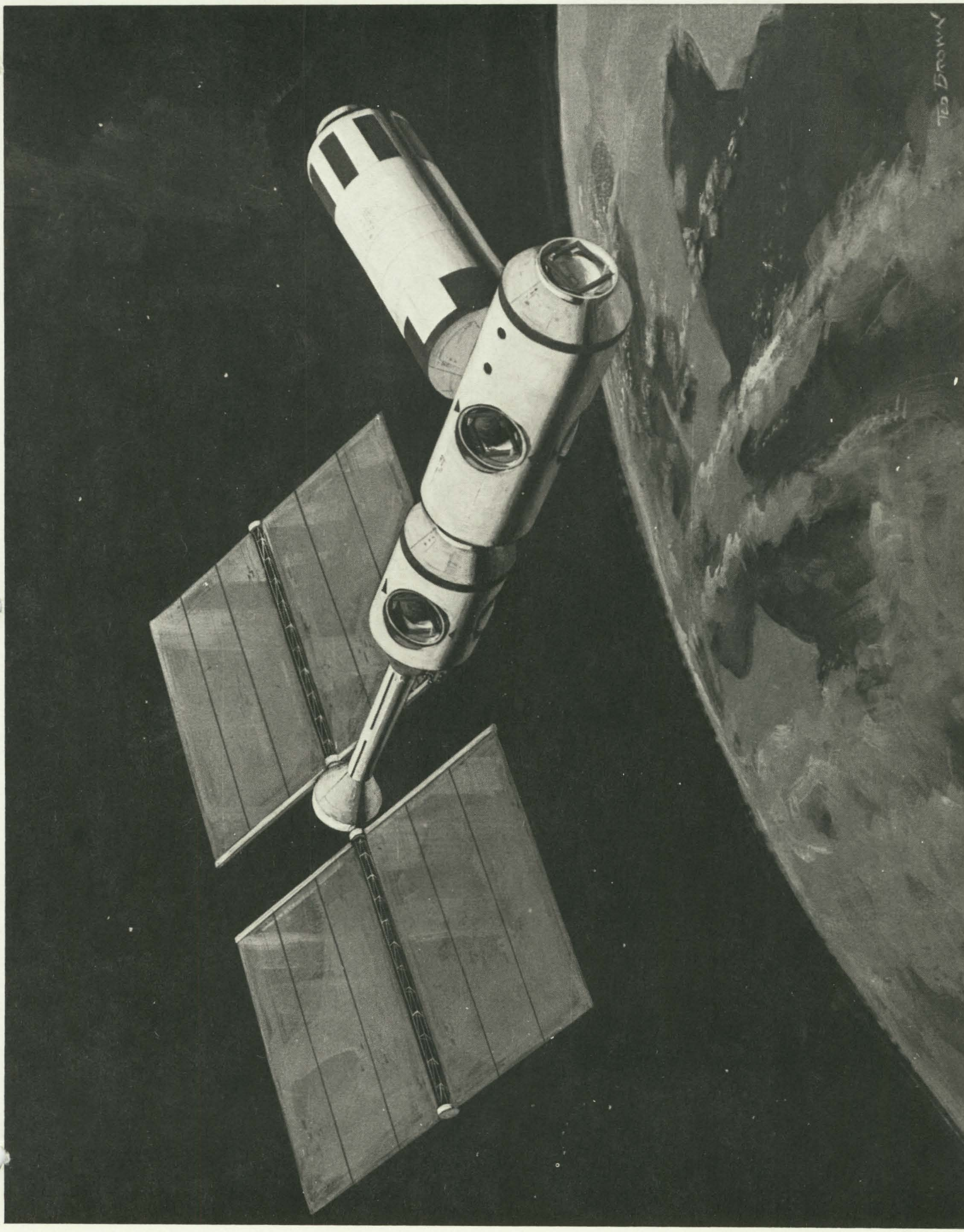
MDC G2582

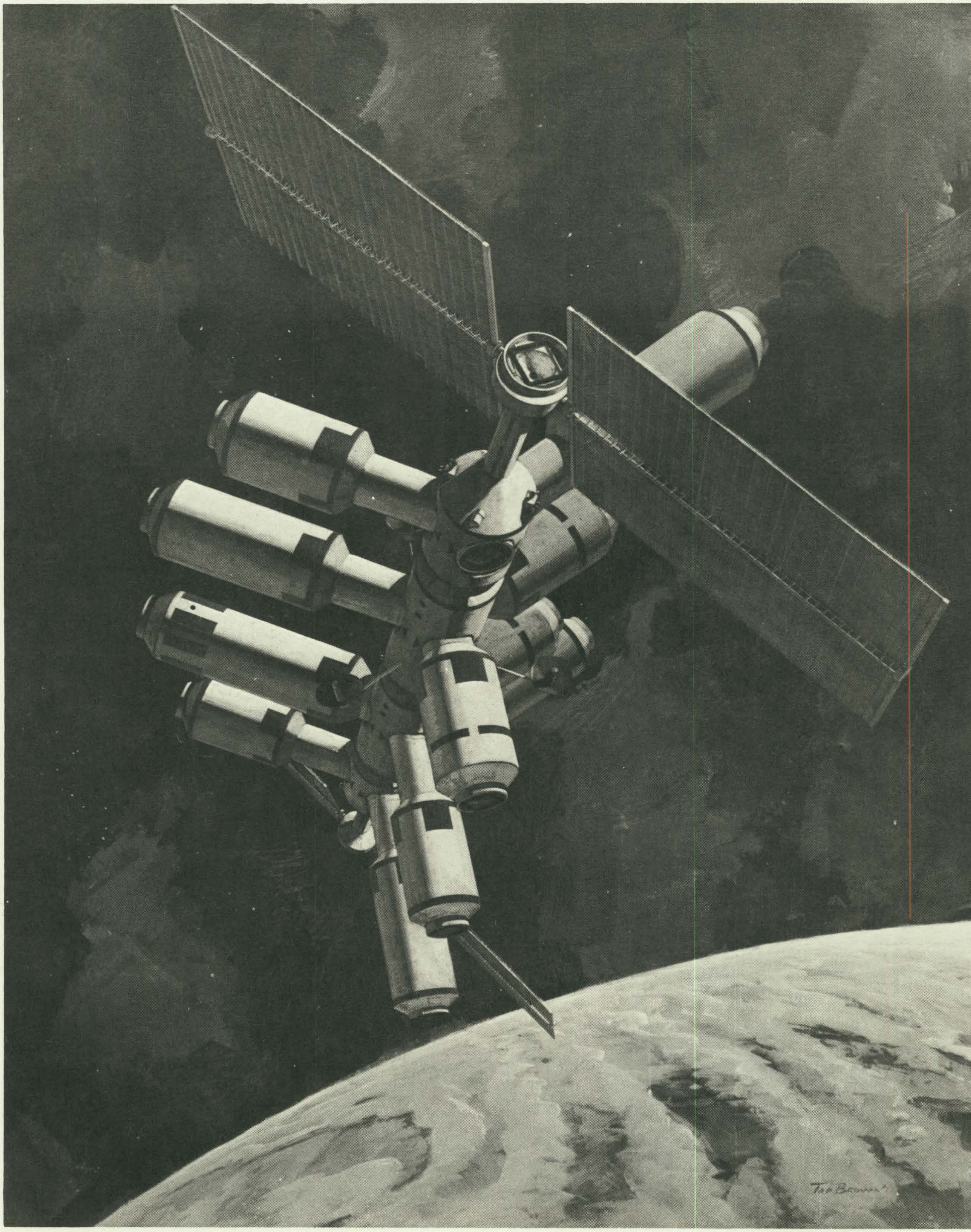
APPROVED BY:

VERN D. KIRKLAND
PROGRAM INTEGRATION/OPERATIONS DIRECTOR
SPACE STATION PROGRAM

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

5301 Bolsa Avenue, Huntington Beach, CA 92647


TED BROWN



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 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-04, Volume I; Volume II contains Sections 4.5 through 4.8; Volume III contains Sections 4.9 through 6.

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

Category	Desig- nation	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

FOLDOUT FRAME 2

SUBJECT REFERENCE MATRIX

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

	CM				MA		MF	MP			SE								
	CM-01 Space Station Program (Modular) Specification	CM-02 Space Station Project (Modular) Specification	CM-03 Modular Space Station Project Part I CEI Spec	CM-04 Interface and Support Requirement Document	MA-05 Phase C/D Program Development Plan	MA-06 Program Option Summary Report	MF-01 Space Station Program (Modular) Cost Estimates Document	MP-01 Space Station Program (Modular) Mission Analysis Document	MP-02 Space Station Program (Modular) Crew Operations Document	MP-03 Integrated Mission Management Operations Document	SE-01 Modular Space Station Concept	SE-02 Information Management System Study Results	SE-03 Technical Summary	SE-04 Modular SS Detailed Preliminary Design	SE-06 Crew/Cargo Module Definition Document	SE-07 Modular Space Station Mass Properties Document	SE-08 User's Handbook	SE-10 Supporting Research and Technology	SE-11 Alternate Bay Sizes
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						●													

PRECEDING PAGE BLANK NOT FILMED

Volume I

CONTENTS

PRECEDING PAGE BLANK NOT FILMED

Volume I

FIGURES

Volume I

TABLES

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-foot-diameter Space Station, launched by the Saturn INT-21 and supporting a complement of 12, has been completed to a Phase B level and documented in the DRL-160 series. Recently completed studies are centered around a Space Station comprised of smaller, shuttle-launched modules. These modules could ultimately be configured to provide for a crew of the same size as on the 33-foot-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-level study results are documented in the DRL-231 series. Recent Modular Space Station Phase B study results are documented in the DPD-235 series, of which this is a volume.

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 and provide a capability equivalent to the 33-foot INT-21-launched Space Station. GSS logistics support will use a Crew Cargo Module capable of transporting a crew of six.

During ISS operations, five Research Applications Modules (RAM's) will be assembled to the Space Station. Three of these will be returned prior to completion of the GSS. In the GSS configuration, 12 additional RAM's will augment the two remaining from the ISS phase. Three of the RAM's delivered to the GSS will be free-flying modules.

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

1.2 SCOPE OF THIS VOLUME

This volume contains detailed configuration and subsystems preliminary design data for the selected Modular Space Station concept. The level of definition presented is consistent with a Phase B study; i.e., at the assembly level.

In Section 2 the selected design is summarized in terms of its configuration features and subsystem capabilities. Key issues which were most influential in driving the design are highlighted. Other documents of the Phase B study final report provide additional design and capability summaries:

MA-04 Executive Summary
SE-03 Technical Summary
SE-08 Users Handbook

A detailed description of the selected Modular Space Station configuration is presented in Section 3. Each module comprising the Initial Space Station (ISS) is described in terms of its external and internal configuration, its functional responsibilities to the ISS cluster, and its orbital buildup sequence. Descriptions of the subsequent build-up to the Growth Space Station (GSS) are also presented. Pertinent issues; e.g., module commonality, docking port arrangement and functional assignment, and others, are discussed. Trade study data, however, are contained in Section 4, Subsystems. A mass properties summary is presented; a detailed mass properties analysis is contained in SE-07.

Section 4, Subsystems, presents the detailed design data of all elements comprising the selected Space Station. These elements include the following:

- Structural/Mechanical Subsystem
- Crew Habitability and Protection Subsystem
- Experiment Support Subsystem
- Electrical Power Subsystem
- Environmental Control/Life Support Subsystem
- Guidance, Navigation, and Control Subsystem
- Propulsion Subsystem
- Communications Subsystem
- Data Management Subsystem
- Onboard Checkout Subsystem

In Section 3, the Space Station subsystem characteristics and capabilities are first summarized. The analytical and design techniques, tradeoff considerations, and depth of design detail applicable to all subsystems are discussed. For each subsystem, data on the following items are presented: summary, requirements, description, interfaces, operation, Growth Space Station (GSS) considerations, design analyses, and trade studies. References are frequently made to CM-03, Part I CEI Specification, which contains detailed design and performance requirements for each subsystem. Additional data on subsystems involved in the Information Management Study (Communications, Data Management, Onboard Checkout, Packaging, Wiring and Installation) are contained in SE-02, Special Emphasis Task, Information Management. The resulting subsystem recommendations for Supporting Research and Technology (SRT) may be found in SE-10.

The purpose of Section 5, Space Station Interfaces, is to present in one location a concise summary of the interfaces between the station and other major elements of the program as a convenience to the reader of this report. Major interfaces between the Space Station and the Space Shuttle, the Logistics Module, and the Research and Application Modules (RAMs) are presented.

Finally, a concise summary of the rationale for a zero-gravity station, in lieu of one with artificial-gravity capability, is presented in Section 6.

Section 2
SUMMARY

A preliminary design has been developed for an all-Shuttle-launched Modular Space Station. The design solutions described in this report define a total Space Station concept consistent with the major guidelines and requirements specified by NASA. The following guidelines and requirements most heavily influenced the design:

A. Initial Space Station (ISS) for a six-man crew; growth to a twelve-man station (GSS) 5 years later.
B. Module design-to weight of 9,072 kilograms (20,000 pounds).
C. Maximum Shuttle launch rate of one per month.
D. No artificial-gravity capability required.
E. Minimization of initial and total program costs.
F. Solar array power system preselected for ISS.

The three-module Initial Space Station (ISS) is illustrated in Figure 2-1. It consists of a Power/Subsystems Module, a Crew/Operations Module, and a radially-docked General Purpose Laboratory Module. The payload constraints, particularly the 9,072 kg (20,000 lb) limit, determined the minimum number of modules required and greatly influenced the allocation of functions between modules. Shuttle launch rate capability set requirements for unmanned operations associated with buildup and impacted the selections of typical experiment programs and crew rotation and resupply concepts.

The absence of a requirement for artificial-gravity made possible an optimum use of space within the module. Significant reductions in required volume were achieved, when compared to previous designs [i.e., 10m (33 ft)-dia station]. The solar array power system preselection most heavily influenced the configuration and operating mode of the orbital cluster.

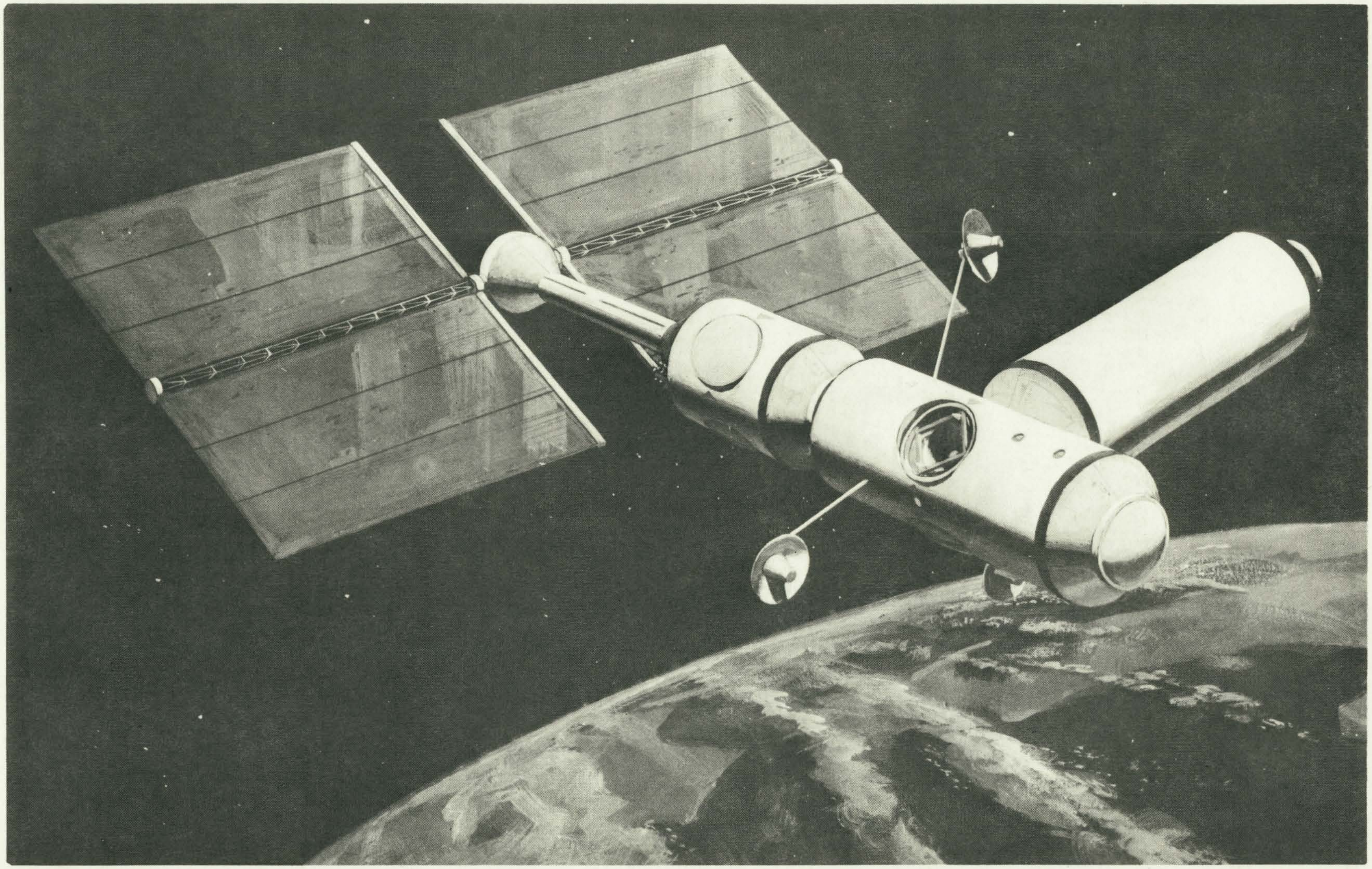


Figure 2-1. Three-Module Initial Space Station

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 for ISS, and for the growth step to GSS, use of identical modules), and long life achieved through a workable maintainability concept. Effectiveness was accomplished using modern technology which permits automation of station facilities to reduce nonproductive man hours (subsystem control, failure and warning, fault isolation, etc.). Man's involvement in the research and applications activities is maximized with the General Purpose Laboratory facility.

The first module to be launched in the buildup of the Initial Space Station is the Power/Subsystems Module (see Figure 2-2). This initial module 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, 17.7m (58 ft) long and weighs about 8,590 kg (18,930 lb). 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 portions of the high- and low-thrust systems. End docking ports permit station buildup and orbit handling.

The Crew/Operations Module (Figure 2-3) is docked to the Power/Subsystems Module one month after start of ISS buildup. The Crew/Operations Module 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, 13.7m (45 ft) long, and weighs about 7,970 kg (17,560 lb). 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

R260

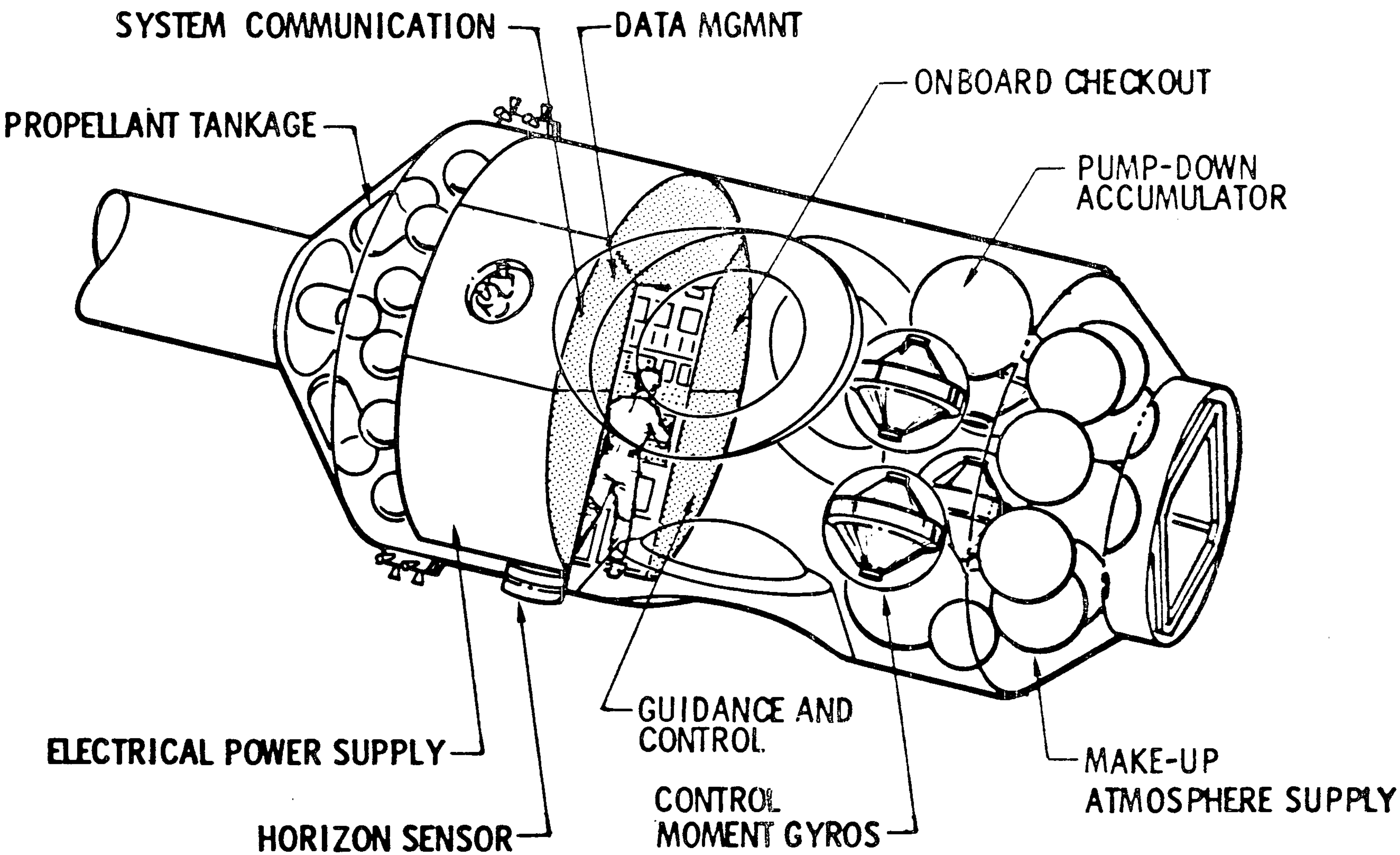


Figure 2-2. Power/Subsystems Module

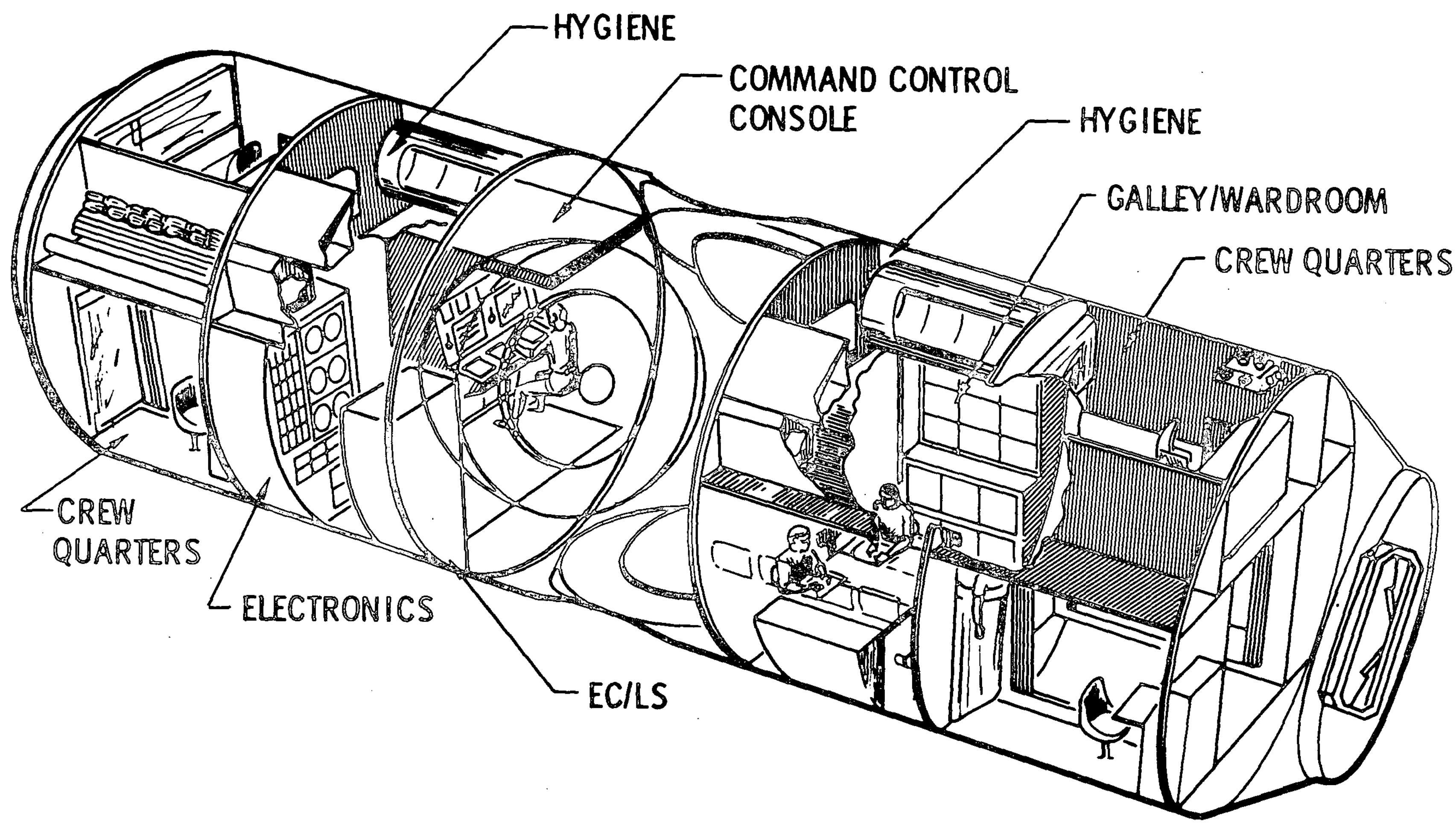


Figure 2-3. Crew/Operations Module

and female) and/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 mid-point 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).

Assembly of the ISS is completed with the arrival of the third station module, the General Purpose Laboratory (GPL), which is radially-docked to the Crew/Operations Module. The GPL, illustrated in Figure 2-4, 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 weighs about 8,340 kg (18,380 lb). The GPL also contains a zero-gravity longitudinal interior configuration with equipment arranged in functional groupings according to experiment program requirements. The module contains seven basic facilities: (1) electrical/electronics laboratory, (2) mechanical sciences laboratory, (3) optical sciences laboratory, (4) biomedical and biological sciences laboratory, (5) hard data processing facility, (6) data evaluation facility, and (7) isolation and test laboratory. The isolated experiment facility incorporates a large airlock suitable for deployment of sensors and specimens and for EVA activities. This chamber, separated from the remainder of the module by a pressure bulkhead, can be depressurized for vacuum experiments and includes a scientific airlock, glove boxes, and tankage necessary to support the experiments.

An additional experiment airlock is provided in the main laboratory section to support general experimentation. Located adjacent to this facility is the experiment control console which monitors and controls all experiment activities, including the attached Research and Application Modules (RAMs). The console 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.

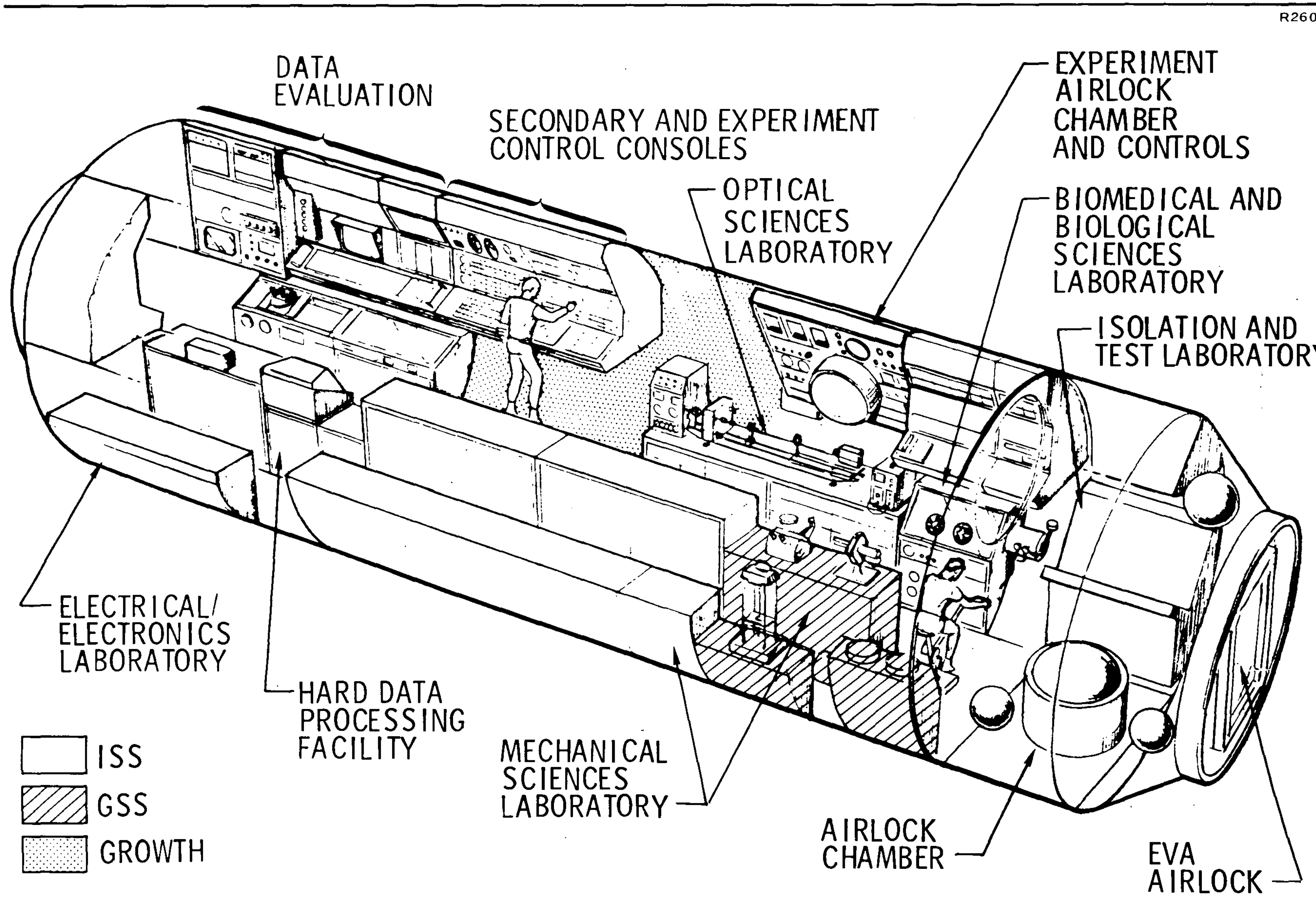


Figure 2-4. Baseline General Purpose Laboratory

The Logistics Module plays a significant role in the buildup and operation of the Modular Space Station. Because of its efficient cargo carrying capacity, about 6,350 kg (14,000 lb), it was possible to off-load nonmission critical items from the three station modules, with subsequent delivery and installation. Secondly, the Logistics 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 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 illustrated in Figure 2-5. It is 4.3m (14 ft) in diameter, 8.5m (28 ft) long and weighs about 2,720 kg (6,000 lb). It contains both pressurized and unpressurized compartments. The interior of the pressurized compartment is arranged into three basic functional spaces: (1) palletized (solid) cargo, (2) liquid/gas cargo, and (3) special cargo. The palletized cargo space is configured to support 0.6 by 0.6m (2 by 2 ft) carry-on containers. Cargo handling aids are provided for difficult cargo transfer. The liquid and gas tanks are also arranged for convenient carry-on capability. The special cargo space is sized to accept items which are planned for off-loading on the three station modules (e.g. CMG's, food freezer, trash compactor) and for experiment equipment. Egress/ingress from the orbiter requires a pressurized transfer tunnel which is also used as a two-man EVA airlock for station operations. No active subsystems are incorporated to support the Logistics Module activity; all subsystem requirements are supplied by the orbiter or the station.

To achieve the Growth Space Station (GSS) capability, two additional Space Station modules (Power/Subsystems and Crew/Operations) are added to the ISS cluster. These modules are identical in design with those deployed for the initial station. The capability of the cluster is then doubled (crew size, power, etc.) and hence, able to perform the GSS mission. As illustrated in Figure 2-6, the growth configuration is capable of accommodating seven 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

R260

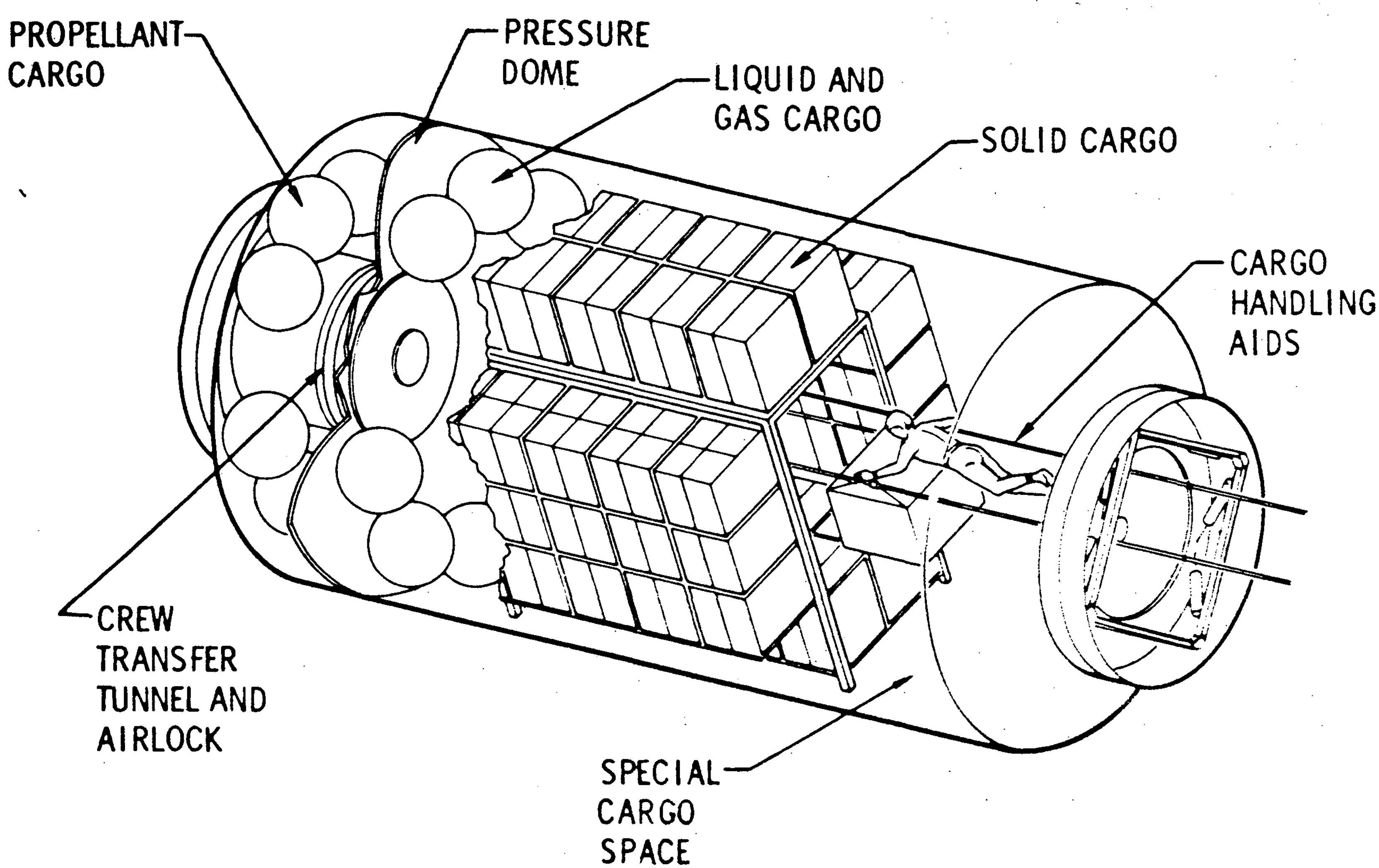


Figure 2-5. Logistics Module

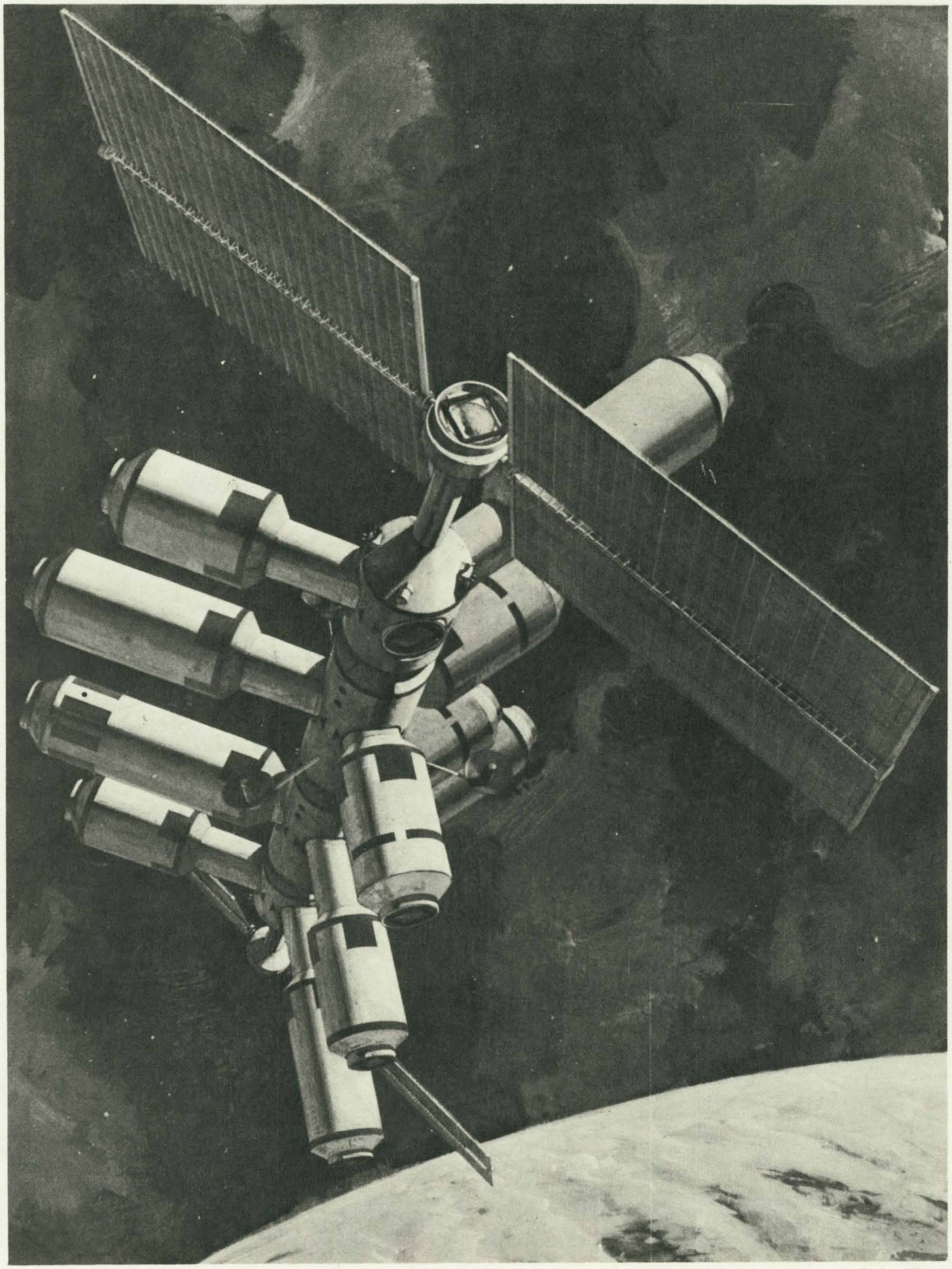


Figure 2-6. Growth Space Station

port). The sequence of launches to achieve the GSS have been arranged to permit complete assembly without dedocking operations to relocate modules.

Accomplishment of the Growth Space Station configuration permits an increase in crew size from 6 to 12. The second solar array doubles usable power; docking ports are also doubled. The GPL was sized initially to accommodate additional equipment required for GSS; hence, only one GPL is required. The GSS phase of operations introduces use of a combined Crew/Cargo Module (CCM) for delivery and return of 6 crewmen and cargo.

The criteria used to select subsystems for the Modular Space Station encompassed many quantitative and qualitative factors. Traditional trade-off factors such as weight, power, volume, and cost were supplemented and in most every case superceded by increased emphasis on minimizing initial and total program cost and the following other guidelines: (1) applicability of the solution for both ISS and GSS, (2) growth to GSS must not require new development, (3) increased emphasis on commonality and modularity, (4) consistent with operational design approach of on-orbit maintenance and replacement with low cost logistics resupply.

Figure 2-7 presents a summary of the subsystems selected for the Initial Space Station (ISS) with appropriate additions noted for GSS. The six-man module level for EC/LS was selected as most optimum. Two six-man units, one each located in the Crew/Operations and GPL Modules, support the ISS with a third 6-man unit contained in the second Crew/Operations Module, completing the GSS complement. Trade-off studies of open/closed H_2O and O_2 cycles involving the criteria noted above produced the selections as shown. 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

R260

$\boxed{\text{EC/LS}}$

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

$\boxed{\text{ELECTRICAL POWER}}$

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

$\boxed{\text{PROPULSION}}$

- N_2H_4 HI-THRUST
- CO_2 RESISTOJETS

$\boxed{\text{GUIDANCE, NAVIGATION, AND CONTROL}}$

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

$\boxed{\text{COMMUNICATIONS}}$

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

$\boxed{\text{DATA MANAGEMENT}}$

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

$\boxed{\text{ON-BOARD CHECKOUT}}$

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

$\boxed{\text{STRUCTURAL}}$

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

Figure 2-7. ISS Baseline Subsystems

Power/Subsystems Module which contains an identical array. The Lockheed (LMSC) foldout panel design concept was selected; this concept is 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 CMGs 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 N_2H_4 high-thrust (89N-20 lbf) for large disturbances, e. g., docking, and for maneuvers. Additional characteristics of the Guidance, Navigation, and Control Subsystem are summarized in Figure 2-7.

The Communications Subsystem uses the synchronous relay satellite network 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; several small computers may be required for certain experiments. The GPL multiprocessor is configured to act as a backup to the primary computer if a degraded operational mode dictates. Onboard Checkout Subsystem functions are integrated with the DMS and are automated.

The selection, sizing, and configuration of Modular Space Station subsystems were greatly influenced by considerations for on-orbit maintenance. Care was exercised to minimize crew time required for servicing while adequately substantiating maintenance estimates with detailed analysis and comparisons with previously accomplished programs.

The following sections of this report present an expanded summary of the Modular Space Station design. Major requirements, interfaces, and trade studies are highlighted. This preliminary design effort has resulted in increased confidence that:

A. A Shuttle-launched Modular Space Station is technically feasible.

B. No new technology is required.

C. Space Station design which meets NASA's requirements and program objectives which can be accomplished for low initial and total program costs.

Section 3
CONFIGURATION

The objective of the Modular Space Station configuration analysis and definition tasks has been to evaluate the basic overall configuration selected as being most responsive to the guidelines and requirements. Presented in this section are detailed descriptions of the configuration demonstrating how the requirements in the areas of habitability and safety, intermodule commonality, Shuttle compatibility, and minimum ISS cost have been met.

3.1 REQUIREMENTS

The Modular Space Station must be designed into Shuttle-transported modules which are assembled in orbit. The final assembled modules must house and support all experiments, subsystems, and the flight crew at both the Initial Space Station (ISS) and Growth Space Station (GSS) levels. The ISS provides a semiautonomous orbital base of operations and source of resources for six crewmen for an indefinite period of time with logistics resupply. The crew is expanded to 12 men for the GSS with a corresponding increase in resources.

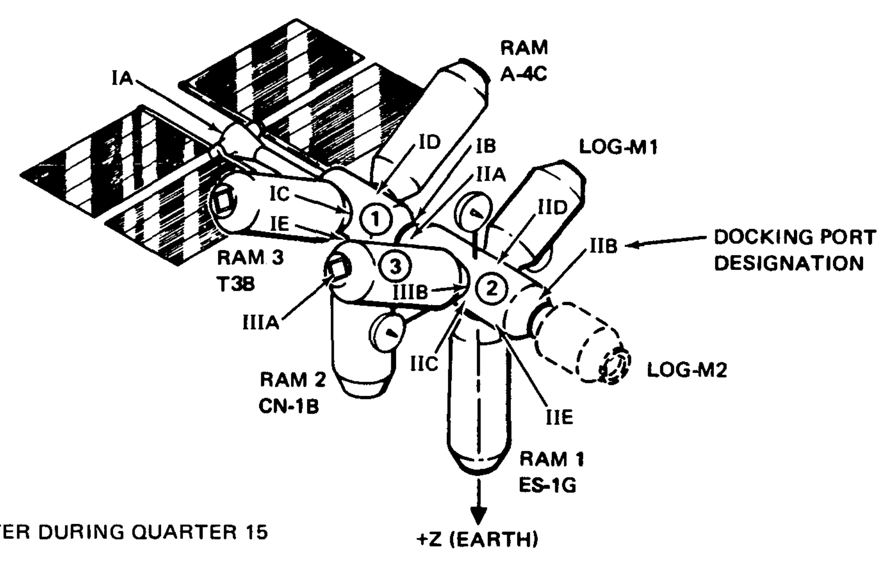
Minimum initial cost is a prime program objective. Since each module of the Space Station is essentially a different spacecraft, i.e., individual design problems, different functional elements, etc., the minimum number of modules which will provide adequate resources and also meet the launch constraints of volume and weight, must be the optimum solution.

Because of the requirements associated with orbital buildup and the limitation of a maximum launch frequency of one per month, the first module into orbit must contain all the resources and expendables to sustain itself for a period of 90 days plus 30 days reserve. Activation crews accompany each module during buildup; however, the first module will provide the necessary active subsystem functions for subsequent modules during completion of the buildup.

3.2 ASSEMBLED ARRANGEMENT

The selected ISS configuration is shown in its maximum cluster arrangements in Figure 3-1. The ISS is composed of three modules; a Power/Subsystem Module, a Crew/Operations Module, and a General Purpose Laboratory Module. It contains accommodations for six crewmen and the necessary support functions for a wide spectrum of possible experiment programs. The Station is powered by a 492 m^2 (5,300 ft^2) solar array; it contains two 6-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; four of which may be used as Research Applications Modules (RAMs). 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

R260



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

Figure 3-1. Initial Space Station (ISS)

right-hand port and the aft 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 Applications Modules. The ISS configuration was chosen from a large group of potential module arrangements which could be assembled in orbit to form a Modular Space Station.

The selected configuration satisfies the requirements of the Guidelines and Constraints and CEI Specifications for the Space Station Project. This design was found to be superior to the many other configuration candidates by comparative evaluation of important features. The major considerations in this evaluation were low initial cost, crew safety, habitability, efficient accommodations for the experiment program, adaptability to eventual growth to the 12-man Space Station, and compatibility with the Shuttle Orbiter during buildup and resupply. Other considerations include traffic flow, dual egress, docking port requirements for experiments and resupply, maintainability of modules and subsystems, and flexibility for the ever-changing requirements of the experiment program.

Perhaps the most important consideration in the choice of configuration and its development into preliminary design was low initial cost. This consideration has driven the design to the fewest number of modules which successfully meets all of the requirements for the Initial Space Station. The Crew/ Operations and General Purpose Laboratory Modules were sized to define the largest size module, 4.3 m (14-ft) diameter and 13.7 m (45-ft) long, which could accommodate all of the required functions within the "design-to" weight constraint of 9,072 kg (20,000 lb). The Power/Subsystems Module, 17.7 m (58-ft long), was sized to accommodate the solar array and the subsystem functions required for autonomy during buildup. Low initial cost is also made possible by maximizing commonality, which is accomplished by using common cylinder designs, common cylinder lengths where possible, and using a common design for all docking interfaces.

The safety requirements have greatly influenced the development of a configuration which provides multiple escape routes from all compartments of the Space Station cluster and which maximizes the safety features in the

Crew/Operations Module in which each crewman spends about 70 percent of his time on the average. An IVA 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 necessity of evacuating the adjacent module to equalize pressure. An EVA airlock is provided by the Isolation and Test Facility in the General Purpose Laboratory and a 2-man EVA airlock is provided in each Logistics Module. Figure 3-2 illustrates the relationship of functions in the assembled ISS.

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. Integral (suitcase) experiments are conducted in the GPL and in its isolation and test facility.

The selected ISS configuration then contains the following features which significantly contribute to satisfying the objective of low initial cost:

A. It contains the fewest number of modules that can meet the Initial Space Station requirements.

B. It achieves a high packaging efficiency (use of space) by taking advantage of zero-gravity. (This has made a significant contribution to achieving ISS capability in just three modules.)

C. It uses the Logistics Module transport capability to reduce Space Station launch mass. The Logistics Module becomes an integral part of the Space Station storage facility (pantry) and reduces on-orbit cargo transfer to that cargo transferred only as needed. Each Logistic Module also provides a 2-man EVA airlock in the Shuttle transfer tunnel which eliminates the need for an additional EVA airlock in any of the Space Station modules.

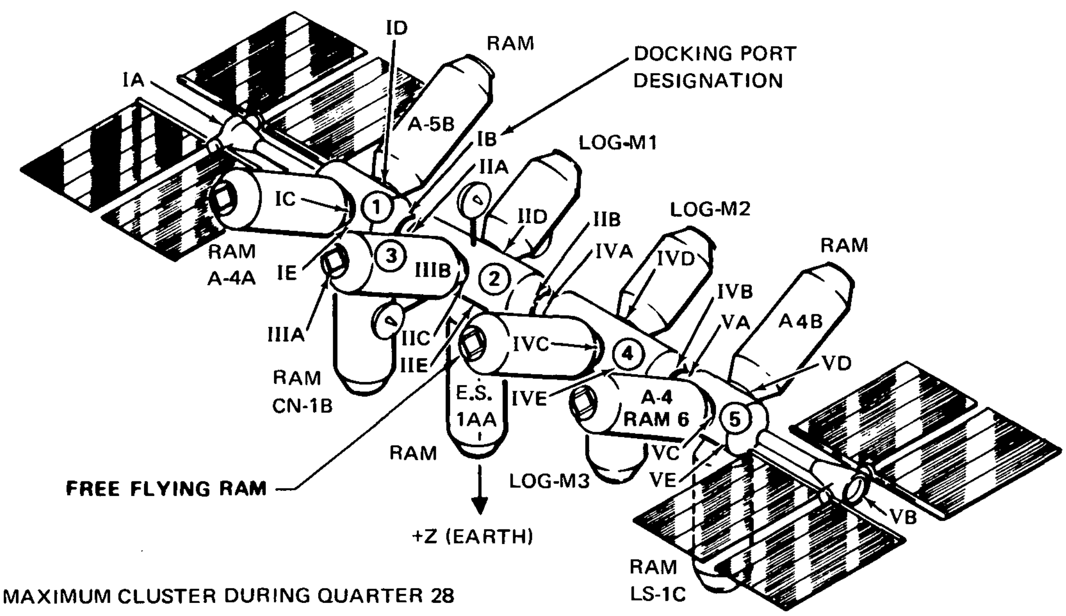
D. It provides a high degree of commonality in the structural cylinders and docking interfaces.

Further low cost program features are achieved by: (1) providing subsystems and equipment which have adequate free access (3-sided in most cases) for onboard maintenance, and (2) buildup to the GSS, which is economically accomplished by the additions of the Power/Subsystem and Crew/Operations Modules, which are of the same design as their ISS counterparts.

Expansion of the ISS into the Growth Space Station (GSS) is accomplished by the addition of one Crew/Operations Module of the same design as the original Crew/Operations Module and one Power/Subsystems Module of the same design as the original Power/Subsystems Module (The high-gain antennas are deleted in Crew/Operations Module No. 2). A net increase of five docking ports becomes available to accommodate one additional Logistics Module and four additional Research Applications Modules. The GSS configuration with its maximum cluster arrangement is illustrated in Figure 3-3.

The minimum launch weight of the three-module cluster is 24, 900 kg (54, 870 lb). At the start of operation, the on-orbit weight changes to

R260



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

Figure 3-3. Growth Space Station (GSS)

29, 850 kg (65, 809 lb) as a result of the reduction due to consumed expendables and the increase due to the resupply and equipment transported via the Logistics Module.

3.3 SPACE STATION BUILDUP

The Initial Space Station (ISS) buildup is accomplished as shown disgrammatically in Figure 3-4. The Power/Subsystems Module is the first module launched. It contains all of the expendables necessary for autonomous operation until the first logistics appointment (in 90 days), plus a 30-day reserve. An accompanying activation crew assures flight worthiness for unmanned operation and verifies readiness for the delivery of the second module.

The Crew/Operations Module is the second module launched (30 days after the Power/Subsystems Module). It is delivered to orbit and docked to the Power/Subsystems Module. The activation crew performs the necessary activities to interconnect the subsystem interfaces in addition to the verifications necessary to prepare for the arrival of the third module.

The General Purpose Laboratory module is the third module launched (30 days after the Crew/Operations Module). It is delivered to orbit and docked to the upper left-hand radial docking port (Port IIC) on the Crew/Operations Module. The activation crew interconnects the subsystems, performs verifications, and insures that the Station is ready for manned occupancy upon the arrival of the Logistics Module and the first two crewmen which will occur 30 days later.

The Logistics Module is the fourth launch, 30 days after the General Purpose Laboratory. A crew of two accompany this module to initiate manned operation of the Station. The Logistics Module contains the required additional expendables, the CMG's (for installation in the Power/Subsystems Module), crew supplies, and experiment cargo. The crew reverifies that the Station is ready for manned occupancy before departure of the Shuttle orbiter.

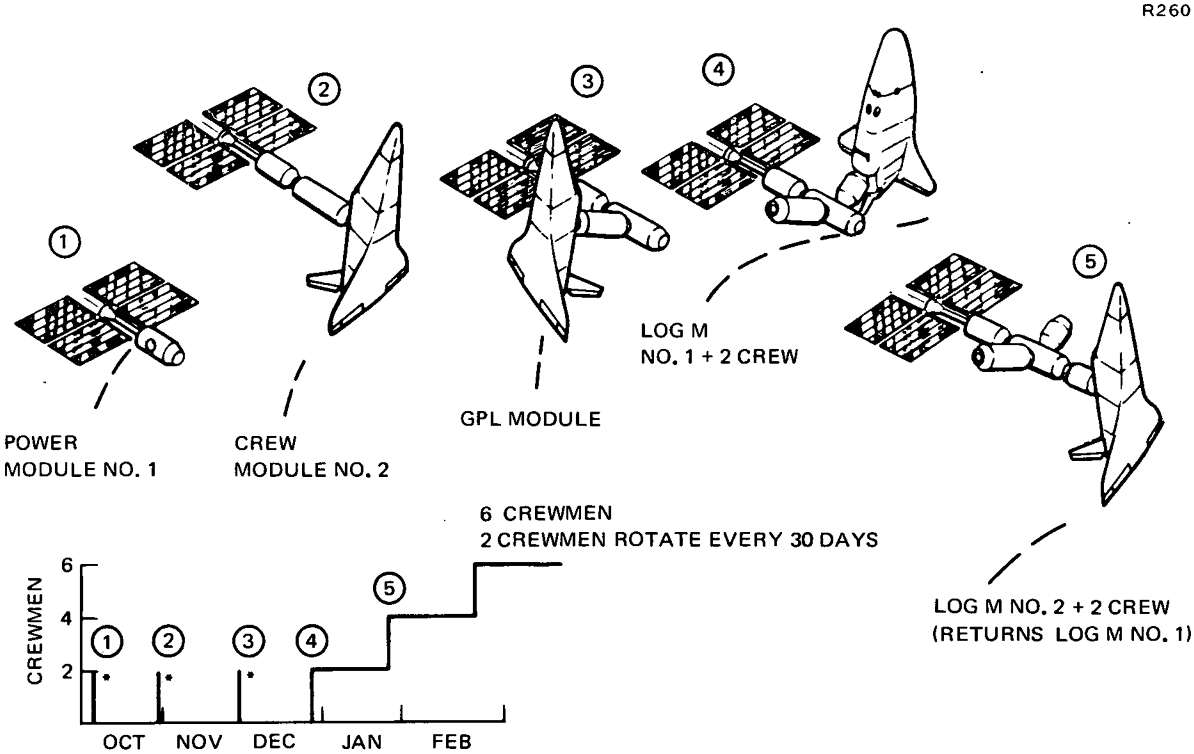


Figure 3-4. Initial Space Station Buildup

Additional launches of Logistics Modules and RAM's occur periodically throughout the life of the ISS. Expendables are resupplied, and new crews and new experiments and laboratory equipment are delivered to expand the scientific capability of the Space Station.

The Growth Space Station (GSS) is developed by adding to the capability of the ISS. This configuration needs only to have additional crew facilities for 6-men, additional power, and the additional docking ports to complete the crew and experiment accommodations necessary for the second 5 years of Station operation. The original GPL Module has the capability to incorporate the small amount of additional laboratories and facilities needed for the GSS.

The GSS buildup is accomplished by docking the Crew/Operations Module No. 2 to the aft end of the Crew/Operations Module No. 1 and by docking Power/Subsystem Module No. 2 to the aft end of Crew/Operations Module No. 2. Eleven docking ports are available in this GSS configuration. Three of these are assigned to the Logistics Modules and the remaining eight are available for attached and free-flying RAMs.

A primary consideration in establishing the configuration was to provide adequate clearance between docking ports to allow direct docking of a module by the Shuttle. Figure 3-5 illustrates the excursion and clearances for direct docking to the GSS. A post-impact gyration of ±10 degrees was used to establish clearance requirements. A minimum distance between docking ports centerlines of 10. 3 m (35. 5 ft) is maintained.

3. 4 MODULE DESIGN

The design of each module is established by the function or functions it provides the total Space Station cluster. Since all modules contain elements of all subsystems, the interfaces between modules and the internal routing of the lines and cables influences the interior arrangement of the module. Figure 3-6 illustrates in schematic form the utility runs through the three modules of the ISS. Figure 3-7 shows the established interface pattern to be 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 3-8 illustrates the details of utility run installations.

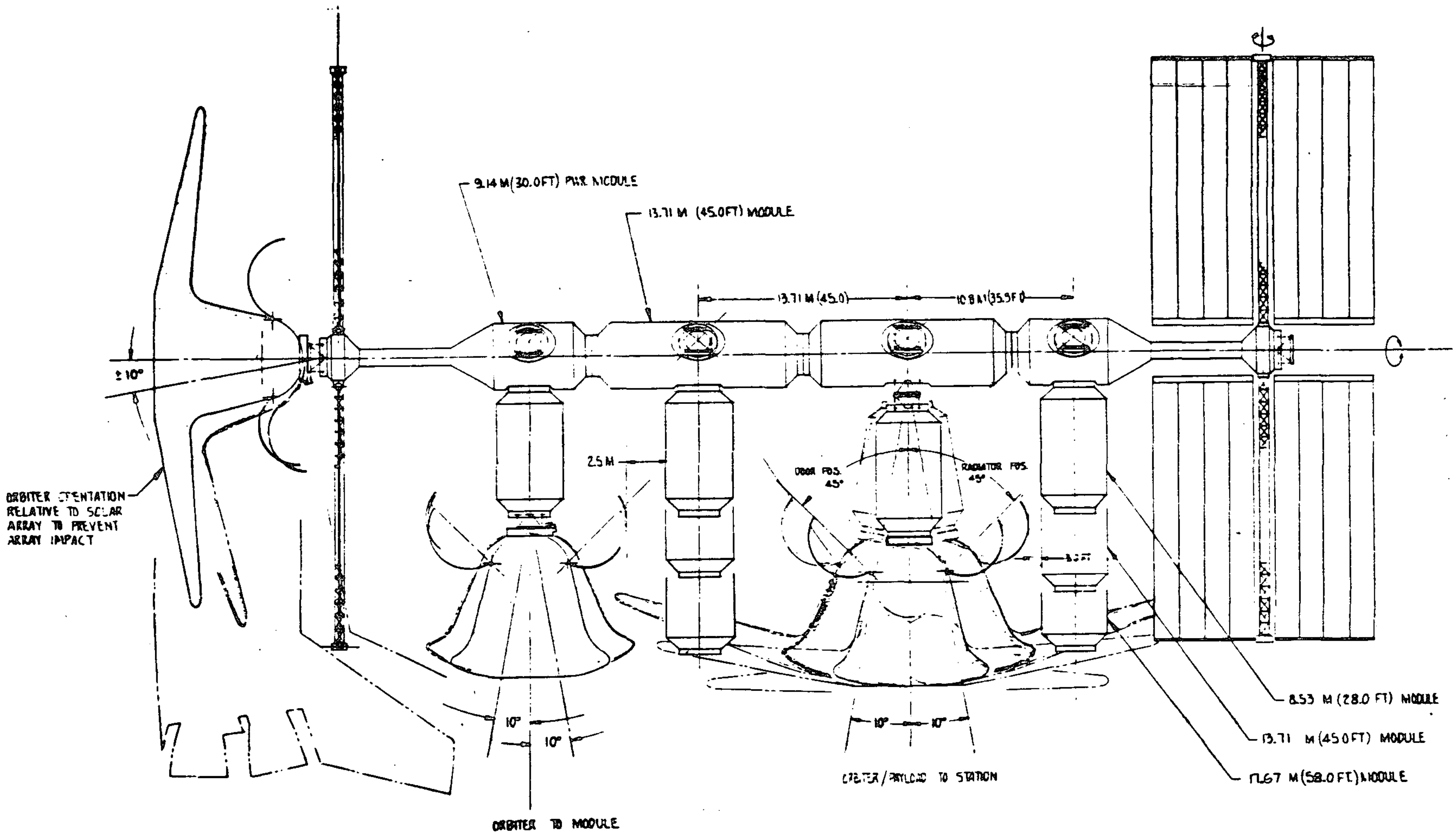


Figure 3-5. Docking Clearance

3.4.1 Power/Subsystems Module

An inboard profile of the Power/Subsystems Module is shown in Figure 3-9. This module contains capabilities for electrical power, guidance and control, propulsion, ground communcations, data management, and thermal control. The Power/Subsystem Module is 17.7 m (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 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 0.2 m (6-in.) diameter window. 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 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 0_2 tanks), cylindrical atmosphere pumpdown 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

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

R260

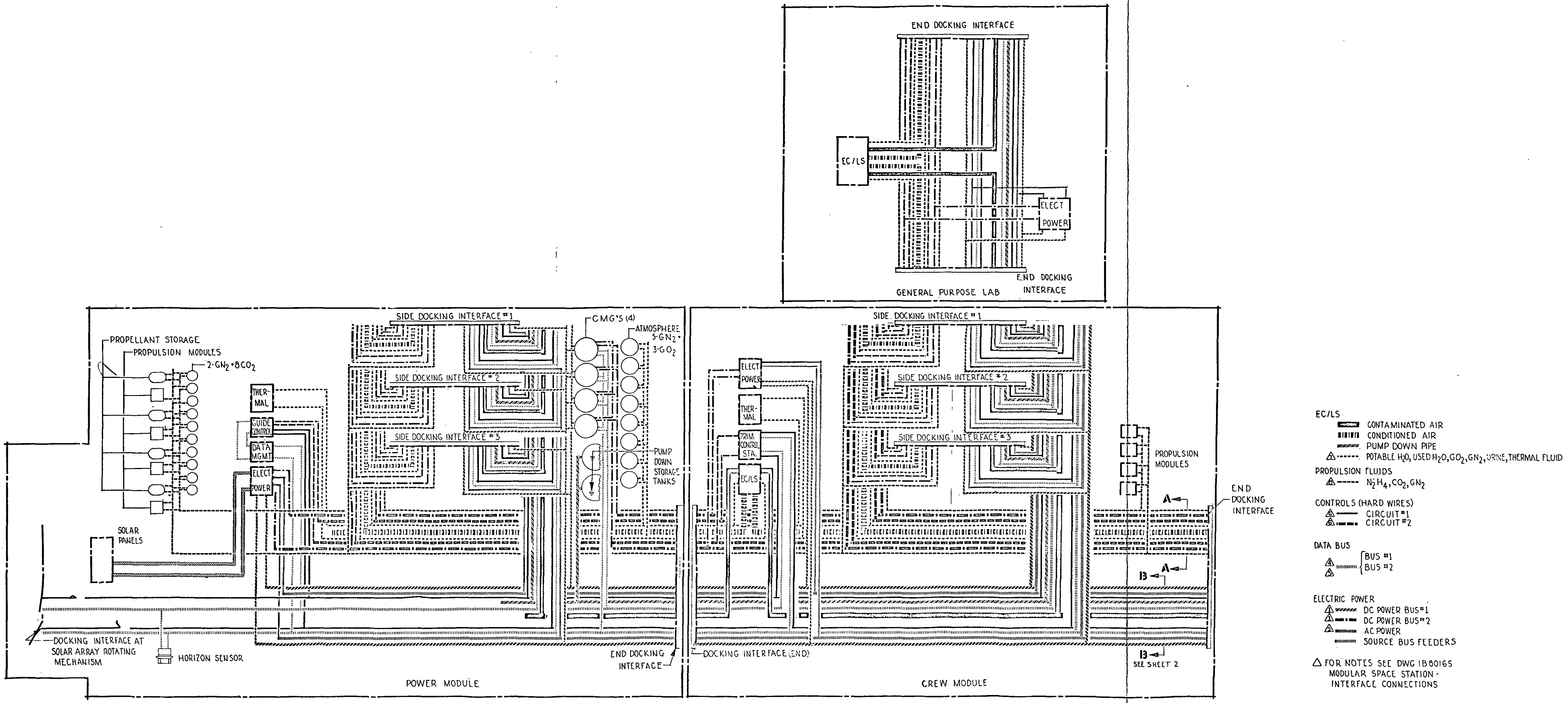


Figure 3-6. Modular Space Station Utility Runs

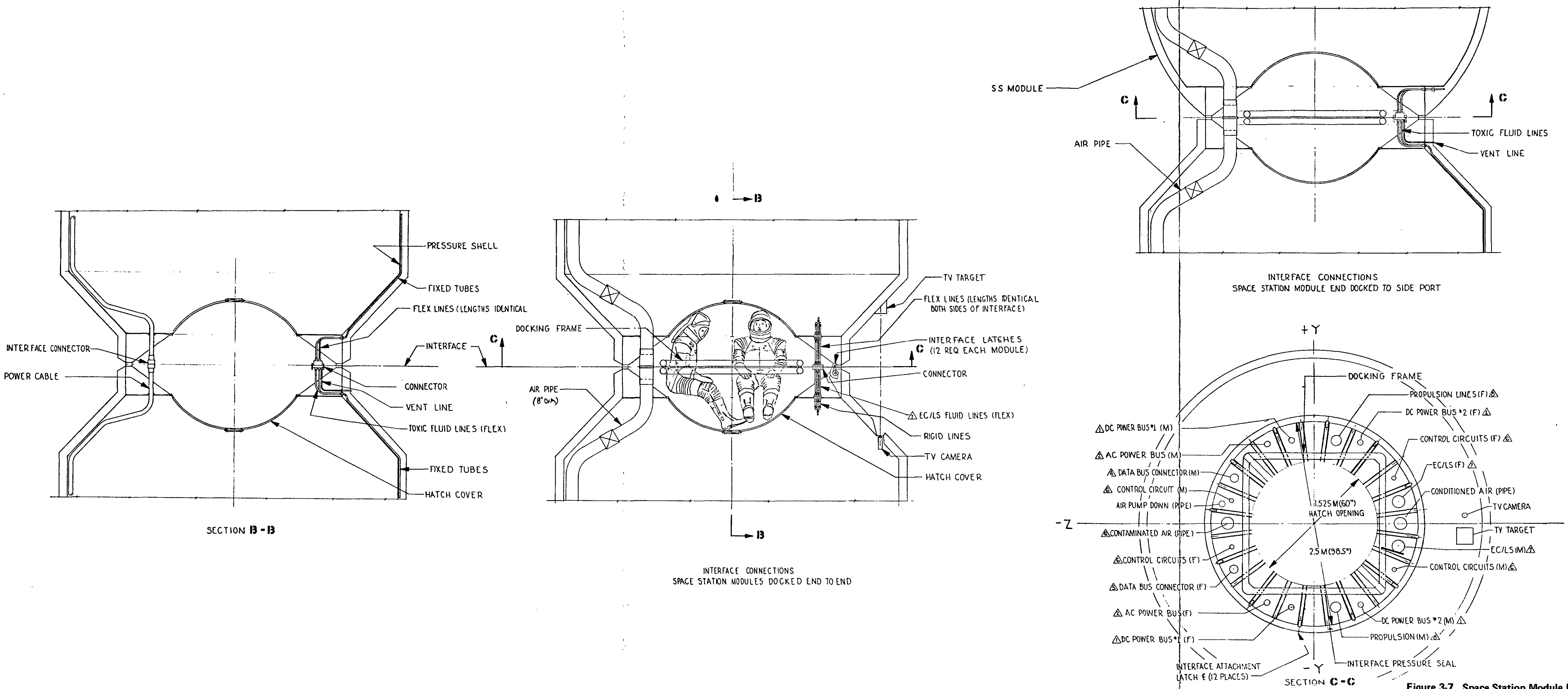


Figure 3-7. Space Station Module Interface Connections

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 1 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. This module interior has been designed for zero-g emphasis, i.e., no floors or decks; however, without penalty, its contents were 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 positior are also supported during launch at the opposite end. When deployed, the solar arrays are 492 m^2 (5,300 ft^2) in area. 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 subsequently replaced with another Power/Subsystems Module. (Note: This is not a planned replacement but a contingency capability.) The power boom can be pressurized to obtain shirtsleeve access for maintenance in the turret at the forward end of the boom to maintain, repair, and/or replace any of the 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 8,590 kg (18,930 lb). The initial on-orbit operational mass for the Power/Subsystems Module after the first Logistics Module supply is 10,621 kg (23,416 lb).

Included in this mass are expendables, pumpdown tanks, and the CMG's which are not required during buildup. These items can be transported to orbit at the completion of the ISS buildup, which is at the end of the 90-day period and when the first Logistics Module rendezvous with the Station. At that time the CMG's will be installed and the expendables for the next logistics period will either be brought aboard the Station or retained in the Logistics Module. This optional logistics cargo makes it possible to have considerable flexibility with the module design and has aided in providing a module which can be launched well within the 9,072 kg (20,000-lb) restriction.

3.4.2 The Crew/Operations Module

The Crew/Operations Module is the second module to be launched. This module is shown in Figure 3-10. The Crew/Operations Module 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. Externally 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 thrustor modules are located at 1.6 rad (90 degrees) spacing at the aft end of the module to complete the ISS Propulsion Subsystem.

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 the on-orbit zero-gravity environment that the crew will experience during the life of the Space Station. This results in a high degree of space utilization. However, for this configuration to be compatible with ground test and checkout, all of the facilities located in this module are compatible with one-g environment. The crew accommodations have been arranged so that a mixed crew (male and female) can be accommodated in this particular configuration. 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 6-man EC/LS Subsystems is also incorporated. This module contains part of the Space Station batteries and specified regions for storage of crew equipment and other Space Station equipment that is retained on-orbit. The amount of time spent in the Crew/ Operations Module by the crewmen is estimated to be about 70 percent of their total time, on the average.

Starting with the forward end of the Crew/Operations Module, there is a conic section where the 1.5 m (60-in.) hatch is stowed and where an area for miscellaneous storage is provided. 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) and contain 5.7 m^3 (200 ft^3) of space. Each of the three crew quarters contains a closet for the flight crew's personal gear, a sleep restraint, a desk, and a restraint for use at the desk. Each of the crew quarters has a window 0.3 m (12 in.) in diameter. The three crew quarters have large accordion-type doors which make it possible to open one or more of these doors to expand the spaciousness of the compartment and to make possible direct communication between the individual crew quarters if desired. 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. The aisle way between the crew quarters is 1.2 m (48-in.) wide and the overall height is 2 m (78 in.).

Adjacent to the crew quarters and "above" the control center is the first of two hygiene compartments. The hygiene compartment contains a 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 crewmen on those occasions where it may be 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 is located the associated electronics and other electrical equipment that is peculiar to the Crew/Operations Module. Immediately "aft" of the electronic equipment console is the EC/LS Subsystems equipment. When packaged, it is common with the other life support system which is located in the General Purpose Laboratory Module.

The central region of the Crew/Operations Module is a location where the three docking ports permit the attached General Purpose Laboratory, Logistics Modules, and RAMs to interface with the Crew/Operations Module. This area is reasonably large and therefore, adds considerable spaciousness to the general-purpose area used by the crewmen for recreation, for exercise, and for the general open-feeling that is desired adjacent to the dining area. The dining area is located just aft of the radial docking port interface on the right-hand side, and has a table with restraints to make it possible for the entire crew to be accommodated at one time. There are three 0.3 m (12-in.) windows in the dining area.

Across from the dining area is the galley which contains the food management and trash management equipment. It includes storage for a 30-day food supply, an oven, a freezer, and a refrigerator. Adjacent to the wardroom galley are the other three 5.7 m^2 (200 ft^3) crew quarters. The end conic section is used for storage space.

The minimum launch mass of the Crew/Operations Module is 7,970 kg (17,560 lb). The initial on-orbit operational mass of the Crew/Operations Module, after the first Logistics Module supply is 9,358 kg (20,631 lb). Included in this mass are some on-orbit expendables which are not required during buildup. These items can be transported to orbit at the end of the ISS buildup, which is at the end of the 90-day period and when the first Logistics Module rendezvous with the Station occurs. At that time the desired onboard crew equipment will be transferred from the Logistics Module into the Station. Some of this equipment will remain in the Logistics Module, which is used as a pantry during its on-orbit stay time. This optional logistics cargo makes it possible to have considerable flexibility with the module design and has aided in providing a module which can be launched well within the 9,072 kg (20,000 lb) restriction.

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.

3.4.3 General Purpose Laboratory

An inboard profile of the GPL Module is shown in Figure 3-11. 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, however, the General Purpose Laboratory does not incorporate any radial docking ports. It does incorporate docking ports on both ends. After the General Purpose Laboratory is attached to the Space Station, its unused end docking port can be used for temporary attachment of RAM's or as a berthing port during removal and replacement of RAM's and Logistics Modules, if this should become desirable. 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 into or out of the laboratory as the program may require during the life of the Space Station. The laboratory equipment is generally located in five rows of equipment consoles, one along the bottom center line, one on each side near the bottom, and one on each side near the top. This arrangement exposes the crewmen generally to the spaciousness of the full breadth and the full height of the module during the time that they spend in the laboratory. The amount of time spent in the laboratory by the crewmen is estimated to be about 12 percent of their total time, on the average.

There are seven laboratory facilities in the General Purpose Laboratory. The first of the laboratories is the Data Evaluation Facility which includes the consoles on both sides and part of the console along the bottom center line.

This particular facility can be separated from the rest of the laboratory by a curtain when it is desired to have different light levels than in the rest of the module. Other facilities include a Hard Data Processing Facility, an Electrical/Electronic Laboratory, a Mechanical Sciences Laboratory, an Optical Sciences Laboratory which includes a scientific airlock, an experiment and test isolation laboratory, and a Biomedical/Bioscience Laboratory.

There is a pressure bulkhead located near the outboard end of the General Purpose Laboratory which separates the normal laboratory functions from those tests and the equipment which requires isolation in a separate facility. This is called the Isolation and Test Facility and contains a 1.2 m (47-in.) scientific airlock, a glove box, and workbench. Gases and fluids used for experiments are stored in this area. This isolated facility can also be used for an EVA airlock. There is sufficient pumpdown equipment and storage in the Station to salvage the atmosphere, but if time is of the essence, it can simply be exhausted overboard.

It should be noted that each of the laboratory facilities, in addition to providing support for the experiment program, has those facilities and equipment that is necessary to do the onboard maintenance tasks that are required by the Space Station subsystems.

There is also subsystem equipment contained in this module. The secondary control console for the Space Station and the experiment control and display console are located in the upper right hand (facing Crew/Operations Module) console area just outboard of the Data Evaluation Facility.

The General Purpose Laboratory becomes the second separate pressurizable habitable compartment and contains the second EC/LS Subsystem, emergency food, and emergency water storage; it also contains two 3-man 96-hour emergency pallets. For convenience and also as a part of providing 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.

PRECEDING PAGE BLANK NOT FILMED

There is considerable space available in the General Purpose Laboratory for growth during the experiment program which may continue for a period of 10 years. One of the features of the General Purpose Laboratory is that it provides work area for the crewmen, so that during the progress of their experiments they have a place where they can take notes, read, relax, and communicate with other crewmen without having to leave the area of the laboratory itself.

To provide ease of inspection, maintenance, and repair of the vehicle wall, the cabinets and consoles in the General Purpose Laboratory will be designed to swing away from the walls. Maintenance for the console itself will have two-or three-sided access in the extended position. State-of-the-art, ground-based, experimental equipment can be repackaged to fit the zero-g configuration of the Initial Space Station and particularly the General Purpose Laboratory which has gained considerable usable volume by the use of zero-g orientation. In developing this design concept, it was possible to orient the equipment in the laboratory so that during manufacture, test, and checkout all of the equipment is located compatible with one-g ground operations.

The General Purpose Laboratory is most likely to require transport of large pieces of equipment during the Space Station Program; therefore, a 1.5 m (60-in.) diameter area-way has been provided throughout the length of the module. This makes it possible to transport large cargo through the hatch into the Crew/Operations Module and out of the Crew/Operations Module and into the Logistics Module or vice-versa.

Extensive storage area is provided in the inboard end conic, inside most consoles, and under the "floor." During the life of the program, the Logistics Module is used to bring additional and updated equipment to the General Purpose Laboratory and to return equipment which may need ground maintenance, or to remove equipment that is no longer needed in the program.

The minimum launch mass of the General Purpose Laboratory is 8,340 kg (18,380 lb). The on-orbit mass of this module is increased by the use of the Logistics Module which brings added equipment to the General Purpose Laboratory as the experiment program proceeds. After the first logistics flight, the on-orbit mass becomes 9,871 kg (21,762 lb). 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 for the Initial Space Station.

Section 4

SUBSYSTEMS

4.1 SUMMARY

This section presents the preliminary design for each major subsystem of the Modular Space. Subsections in this section describe the selected subsystem designs, their interfaces with other program elements (i.e., Shuttle, Logistics Modules, Research and Aplications Modules (RAM's), etc.), how they are used during normal and contingency operations, and the features incorporated in each design to facilitate transition to the Growth Space Station (GSS) level. For each subsystem, details of the design analyses and trade studies leading to their selection are presented.

Valuable assistance in this preliminary design phase has been rendered by numerous unfunded subcontractors in all technology areas. Major support has been provided by funded subcontractors in the subsystem areas noted:

Environmental Control/Life Support	- Hamilton Standard Division of United Aircraft
Guidance, Navigation, and Control	- Honeywell, Incorporated; and, Bendix, Navigation and Control Division
Communications	- Collins Radio Corporation and Radiation, Incorporated
Data Management and Onboard Checkout	- International Business Machines

This document describes the preliminary designs for the above subsystems and, in addition, the preliminary designs for the following:

Electrical Power

Propulsion

Crew Habitability and Protection

Structures/Mechanical

Experiment Support Equipment

Figure 4.1-1 is an overall schematic diagram illustrating the arrangement of major elements of each subsystem throughout the three basic Space Station Modules. For clarity, some of the redundant equipments are omitted from the illustration as noted in the associated table. Key interfaces between modules and with attached RAMs and Logistics Modules are shown. As its name implies, the Power/Subsystems Module contains the primary power source (solar array) and elements of many subsystems including GNC, communications, propulsion tanks and thrustors and the DMS subsystem computer. The hygiene, waste management, food preparation, and laundry facilities are located in the Crew/Operations Module; also, the high-gain K_u-band communications antennas, the primary display and control console, and one of the six-man EC/LS units. A second EC/LS unit is located in the GPL along with the secondary display and control console, the experiment computer, and the experiment support equipments.

4.1.1 Approach

The subsystem configurations represented in these preliminary designs are the result of a comprehensive trade study and selection process performed with the following major objectives:

A. Meet necessary requirements and performance levels as directed by guidelines and constraints or as derived through trade studies or analyses.
B. Minimize the initial program cost.
C. Minimize total program costs.
D. Maximize the effectiveness of the flight crew in support of experiment and mission operations.

These objectives have been met by application of a design selection methodology using weighted trade factors to evaluate alternate solutions. Major trades listed in Table 4.1-1 are reported in the subsystem subsections. Key (weighted) trade factors considered in these trades, as appropriate, include:

- Initial DDT&E costs to IOC.
- Total 10-year costs (including spares and expendables).
- Initial weight—factored in terms of cost/lb to orbit.
- Resupply weight—factored in terms of cost/lb to orbit.

FOLDOUT FRAME 1 FOLDOUT FRAME 2 FOLDOUT FRAME 3

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
OBCO	√	√	√	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-OBCO

- HARDWIRE
- DATA BUSES (ANALOG AND DIGITAL)

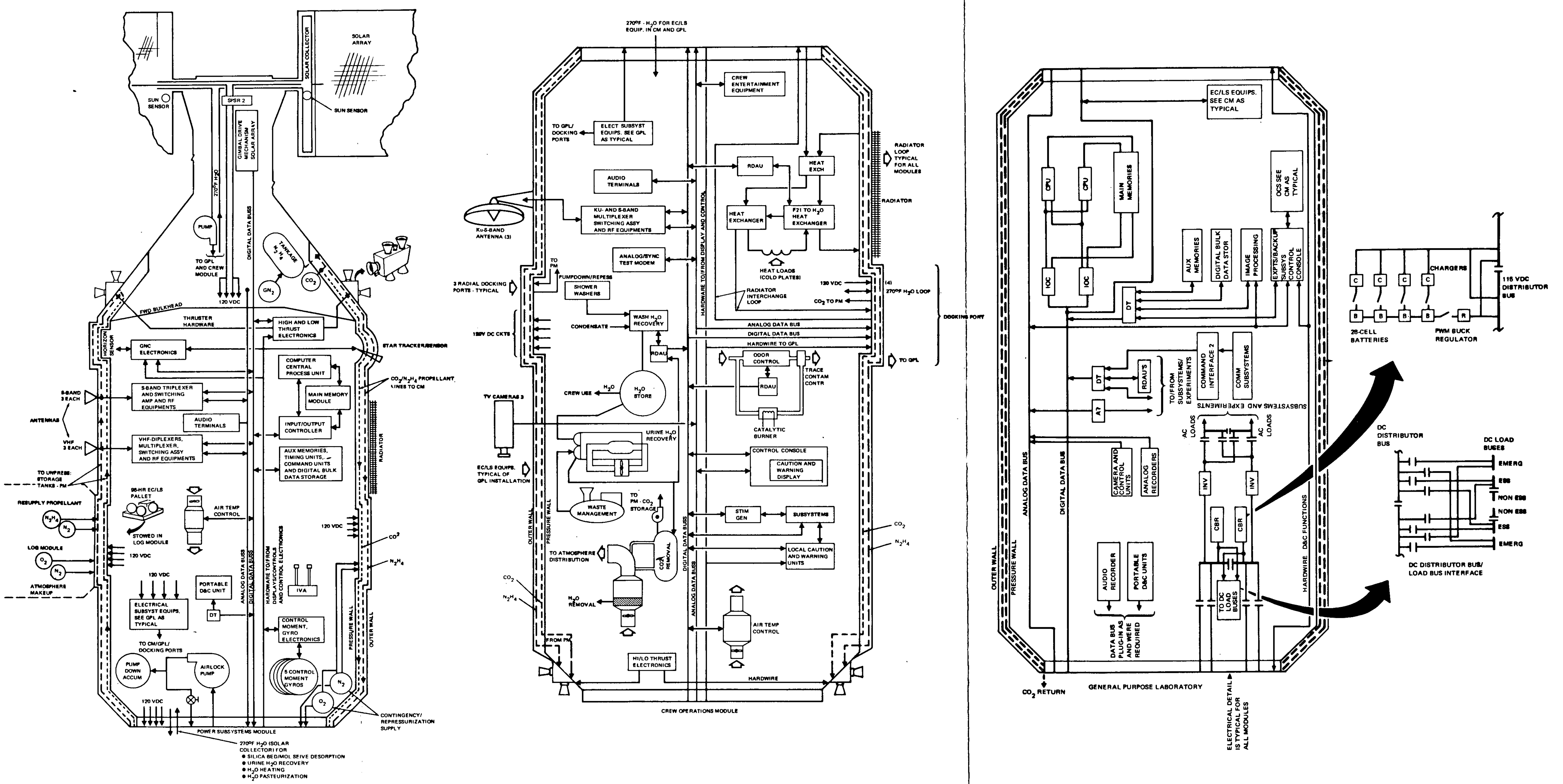


Figure 4.1-1. Schematic Arrangement of Subsystems in Three Basic Modules

Table 4.1-1 (page 1 of 2)

ENGINEERING TRADE STUDIES AND ANALYSES

COMMUNICATIONS

1. Use of DRSS.
2. Frequency allocations.

DATA MANAGEMENT

1. Onboard data processing capability determination (includes ground versus onboard allocation).
2. Computer configuration selection.

ONBOARD CHECKOUT

1. Onboard versus ground checkout.
2. Automation versus crew participation.
3. Centralized versus decentralized equipment and function distribution
4. Sizing analysis.

EC/LS

1. Degree of loop closure.
2. EC/LS module size.
3. Solar collector versus electrical heat.
4. Assembly level selections.
5. Thermal analysis.

GUIDANCE, NAVIGATION, AND CONTROL

1. Primary orientation.
2. Control actuation selection and size.
3. Pointing and experiment accommodation capability determination.

ELECTRICAL POWER

1. Solar array buildup method, size, and number of arrays.
2. Flexible versus rigid.
3. Energy storage type.
4. Transmission, conditioning, and distribution voltage and type.
5. GSS accommodation and use of nuclear power.

Table 4.1-1 (page 2 of 2)

ENGINEERING TRADE STUDIES AND ANALYSES

PROPULSION

1. Propellant selection.
2. Resistojets versus high thrust.

EXPERIMENT SUPPORT

1. Experiment mode of accommodation.
2. General purpose experiment laboratories versus individual laboratories.
3. Methods of experiment data collection and processing.

CREW HABITABILITY AND PROTECTION

1. Selection of food preparation and storage equipment.
2. Selection of trash handling techniques.
3. Washable versus reusable personal accouterments.

STRUCTURE/MECHANICAL

1. Docking port assignment.
2. 90 degrees versus 120 degrees docking-port configurations.
3. Radial and end-docking-port structure design; common versus different.

- Resupply weight—factored in terms of cost/lb to orbit.
- Crew time for operation and maintenance—in cost/hour.
- Volume—in cost/ft^3.

This type of trade methodology is most applicable to resolving selections where several alternates are available which each have adequate performance. For every selection, subjective reasoning must also be applied to resolve issues which are not quantifiable such as flexibility, growth, and risk; and, in all cases, safety and adequate performance have overriding consideration.

In general, this approach has resulted in a system design featuring:

- Use of current technology.
- No necessity for upgrading technology to achieve GSS.

- A high degree of automated operation.
- Modularized design at the replaceable unit level for ease of maintenance.

The emphasis in this design is on the use of currently available technology and technology under active development for the Space Station or related applications. No technology breakthroughs are required to implement these designs. To reduce program cost, a high degree of integration complexity and interdependency is avoided. Where interdependency is required, such as in the Data Management Subsystem, interface standardization is incorporated to reduce integration impacts. Synergistic opportunities are acknowledged, as in the use of EC/LS CO_2 for propellant, but interface simplicity is maintained and an alternate backup is available to reduce sensitivity to failures or failure propagation.

The complement of subsystems in the first Power/Subsystems Module is designed to support short-term unmanned operation and subsequent long-term manned operation. Following deployment of the two additional ISS core modules, manned operation is assumed and the advantage of crew availability is incorporated in the operational and maintenance features of the systems. To maximize the crew time available for experiment support and mission operations, routine tasks are largely automated. In the event that a major failure or operational anomaly occurs that requires deactivation (unmanning) of the Station, operation in an unmanned mode is possible with certain compromises. This unique mode of operation and the special accommodations for transition to GSS are summarized in Subsection 4.1.3.

4.1.2 ISS Subsystem Summary Descriptions

As required by this Phase B study, the preliminary design emphasizes definition of the ISS configuration. The selected designs for each subsystem are summarized in the following paragraphs.

Electrical Power

The Electrical Power Subsystem (EPS) is composed of nine major assemblies. The EPS design provides for the predicted power growth profile from 16.7 Kw at the ISS to 31.1 Kw at the GSS by replication of the initial solar-array power source. 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 source buses.

The deployment and orientation assembly provides: (1) initial array deployment from the stowed position around the power tunnel, (2) individual panel retraction for EVA replacement, (3) group panel retraction for stowage and return of the Power/Subsystem Module, and (4) two-axis gimbal orientation on a continuous basis to ensure maximum solar-energy collection for all station flight attitudes. The solar panels are "feathered" for minimum drag during eclipse periods, and are recycle before reentering the sunlight to unwind the trailing cables which transfer 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 Space 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 ISS consists of 100-amp hr, 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, (3) primary launch and ascent power for the Power/Subsystems Module, and (4) end-of-mission power when solar arrays are retracted for recovery.

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 (PWM) series buck-load 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 before 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 liner range of voltage control.

The transmission, conditioning, and distribution (TCD) assemblies constitute the power-transfer and power-processing asssemblies. These include switching and protection in the transmission and distribution assemblies, and battery charging and regulation, and dc/ac inversion in the conditioning assembly. The inverter modules operate in parallel within each Space 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 Logistic Module 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 Data Management Subsystem (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 adcordance with established priorities. These functions are performed automatically, with manual backup or override capability for all essential management functions.

Environmental Control and Life Support (EC/LS)

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 4. 1-2.

Table 4. 1-2

LIFE SUPPORT ASSEMBLY SELECTIONS

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

The cabin atmosphere is maintained at sea-level pressure and two six-man atmosphere reconditioning subsystems are provided, one in the Crew/Operations Module and one in the GPL. The Crew/Operations Module unit processes gas for the Crew/Operation, Power/Subsystems and attached Modules. Each module contains separate atmosphere-cooling provisions.

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

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/Operations 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 provide 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 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.

Crew Habitability and Protection

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 dehydration, 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.

The crew accommodations assembly consists of the following subassemblies:

A. Crew Quarters Provisions—bunk, bed roll, desk, individual light fixture, personal communications, clothing module, 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 Module—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 shall be provided insofar as practical, and shall include reading materials (microfilm and viewer, books, magazines, and journals), writing materials (paper, plus pencils), 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-radiator exposure. The equipment includes onboard and extravehicular dosimetry, which will be tied into the caution and warning systems.

Meteoroid protection outside the pressure shell is provided by a double bumper of 0.016- and 0.010-inch aluminum, separated by radiator frames. The double bumper protects the high-performance insulation as well as the pressure vessel. The remaining meteoroid protection is the pressure vessel, which in combination with the double bumper, provides a 0.9 probability of no punture in 10 years.

Fire protection is achieved largely by prevention. Sources of ignition are minimized, and use of flammable materials is reduced to the lowest possible level. Materials are selected in accordance with the flammability acceptance criteria specified in MSFC-Spec 101A, Flammability, Odor, and Toxicity Requirements and Test Procedures for Materials in Gaseous Oxygen Environments.

Guidance, Navigation, and Control

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 Stat;ion 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 geometrical X and Z axes in the orbit plane so that the bias torque on the Y-axis is zero with the X-axis near the velocity vector. 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/Subsystems Module. The star sensor and gyro triads provide the primary trimmed hroizontal reference. The horizon sensors are used to provide the acquisition of the Earth-centered reference; they are also used 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 DMS 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 effecitveness of the Modular Space Station throughout the buildup phase with varying Space Station physical characteristics while constraining the required propellant and electrical power resources to a reasonable level.

Propulsion

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 IVA or shirtsleeve mode, depending on the nature of the maintenance; i. e., most maintenance will not involve opening a Propellant 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 propulsion (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 one 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/Subssytems Module and four on the aft end of the Crew/Operations 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/Subsystem 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.

The CO_2 compression is a nearly continuous function, subject to some changes in supply pressure and quantity. The consumption 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.

Data Management

The Data Management Susbystem (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 equipments 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 a Logistics Module flight) to the Modular Space Station. The crew can also initiate program changes through the alphanumeric keyboards. The file tape transports on the equipment list provide the highest level of memory in 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), a frequency division multiplexer (FDM) technique for digital data transfer, and uses FDM techniques for analog data transfer. Control is accomplished by a computer input and output controller using standard control words which provide terminal addressing and instructions. (A terminal is defined here as any device directly sending or receiving data from a data bus.)

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 non-sampled experiment data onto analog bus subcarriers. The analog bus also carries wideband video on individual subcarriers.

Bulk data storage uses 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 before 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.

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 subsystems, and experiment program operations. A primary display and control center for subsystem operation is in the Crew/Operations Module, and an experiment operations center is in the GPL Module. 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 reproducer unit provides a source for playing stored program material.

Florescent type lighting is used to provide general overall illumination consistent with safety requirements, and supplementary light fixtures are provided at the work stations and other areas requiring brighter illumination.

Communications

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 used for communications with both the ground and the Shuttle.

Communications with the DRS's 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 in conjunction with an 8-foot-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 transmissions 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.

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 use frequencies in the 250- to 300-MHz band and will be multiplexed into the VHF antenna system used for relay satellite communications.

Onboard Checkout

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 repair and reconfiguration actions, and verifying subsystem and experiment operation following failure correction. The OBCO is used as the primary checkout and fault-isolation tool during the postmanufacturing, prelaunch, on-orbit buildup, and on-orbit operational phases of the ISS program.

The design selected for the ISS is an automatic, highly-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 used. Capabilities unique to the OBCO, however, are provided for stimulus generation, critical measurements, and checkout software. The function of monitoring life-critical warning functions is implemented independently of DMS operation. Stimulus generation, command generation, and data acquisition capabilities are distributed throughout the ISS, as dictated by check-out data-point locations.

Local caution and warning units are located in each habitable compartment, with overall status provided at both the primary and secondary ISS 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. Ancillary test equipment 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 design minimizes the need for crew participation in routine checkout functions, but it does allow for crew intervention with special capabilities of the crew are needed or requested. It also operates largely 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 check-out data. Any or all check-out data points can be selected for transmission to the ground. It is anticipated, however, that ground check-out 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 interfaces. This is particularly important since the OCS 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.

Structure/Mechanical

the design and analysis 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 Modular Space Station long-life requirements impose a life expectancy in excess of 10 years for the nonreplaceable elements and a desire for minimum maintenance of elements that are designed for replacement. Because of the hostile environments that will be encountered, a rugged, damage-resistant design that can withstand both meteoroid impact and accidental damage must be provided. The structure material must also be used to provide the thermal protection and radiation shielding.

The concepts and preliminary designs are described and shown in Section 4 of Document SE-04. The integrated primary structure is composed of a 2219 aluminim alloy, integrally milled cylinder, encapsulated within 50 layers of high-performance insulation and a 6063 aluminum alloy, double-bumper and radiator. The outer panel is a minimum of 0.016-inch thick, and the inner panel is 0.010-inch thick. They are connected with extrusions that incorporate the radiator tubes. Ring forgings are used at the docking interface. These are also integrally milled to eliminate costly buildup of numerous detail parts.

This design is a low-weight, low-cost design. It provides exceptionaly good protection against the long-life environment that will be encountered by the Modular Space Station. Other elements of the structure/mechanical subsystem are also described and shown in Section 4 of Document SE-04, including preliminary designs for the following items:

- Pressure shell structure
- Docking structure
- Radiator and meteoroid shroud
- Solar-array turret structure
- Interior equipment support structure
- Test and isolation chamber pressure bulkhead
- Docking mechanism
- Docking port covers
- Hatches and airlocks
- View ports
- Solar-array drive and orientation mechanism
- Shuttle interface support structure
- Solar-array support tunnel
- High-gain antenna deployment mechanism
- Solar-array deployment mechanism

Low weight and low cost were both emphasized in the course of the design effort. Reduced cost was achieved by using common designs where commonality was determined to be cost effective.

Experiment Support

The Experiment Support Subsystem consists of the equipments and facilities which make up the General Purpose Laboratory (GPL) and their interfaces with Space Station operational subsystems (e. g. Power, Data Management, EC/LS, etc.).

The GPL facilities are defined to include the following:

- Data Evaluation Facility
- Hard Data Processing Facility
- Electrical/Electronic Laboratory
- Optical Science Laboratory
- Experiment and Test Isolation Laboratory
- Mechanical Sciences Laboratory
- Biomedical/Bioscience Laboratory

In addition to the above facilities and the functional equipment appropriate to each, the GPL contains other major experiment support equipment, such as:

- Experiment Control Console
- Shielded Film Vault

The nature of experiment and subsystem support provided by the Experiment Support subsystem is as follows:

A. Analytical or Test

B. Checkout

C. Experiment Control

D. Assembly, disassembly

E. Contingency repair

F. Storage of parts, experiment and experiment support equipment, experiment consumables and experiment spare parts

G. Component replacement

H. Equipment calibration

I. Work areas for testing, research, repair, calibration, and other functions of a like nature

J. Physical accommodations for the performance of integral experiments

The facilities and equipments making up the Experiment Support Subsystem are provided to support both the operation and maintenance of integrally- and RAM-accommodated experiments, as well as to provide maintenance support to Space Station operational subsystems.

The facility definitions and equipment selections were the product of a commonality analysis driven by the January 1971 "Blue Book" experiment requirements, a conceptual definition of RAMs required to perform many of those experiments, and subsystem requirements for maintenance support. A detailed description of this analysis may be found in subsection 4. 4. 4 of this report.

4. 1. 3 Standby Unmanned Mode

A key requirement on the Modular Space Station is defined as follows: "All modules on orbit shall be capable of being placed into a standby manned mode and be reactivated after a period of up to one year. This capability shall be provided even when any one module has been returned to the ground for major repair."

With the selected configuration, which maximizes the efficiency of onboard operations and reduces cost through minimizing the number of modules required, key life support subsystems are located in the Crew/Operations Module and the GPL Module while necessary support services are concentrated in the Power/Subsystems Module. Since life support is not required during unmanned operations, removal of the Crew/Operations or GPL Module has a minimal impact and a standby mode essentially the same as the Initial Unmanned Mode can be conducted for an indefinite period.

If removal of the Power/Subsystems Module is necessary, a modified operational procedure is required. Since this module contains, in addition to power, the communications, attitude control, propulsion, and computing services normally used in the initial unmanned mode, the standby unmanned mode requires operation in essentially a quiescent or dormant state. If time and conditions permit, the crew will perform deactivating procedures before departure which will enhance the survivability of the subsystems and reduce the reactivation process. These procedures will include increasing orbit altitude to reduce drag, placing the remaining module cluster in a gravity-gradient stabilized orientation, and performing a final checkout sequence to assess subsequent requirements for spares and maintenance and securing all interface connections. Components susceptible to temperature extremes or other environmental effects, and those requiring ground refurbishment will be removed and stowed in the Power/Subsystems Module for Earth return. All loose equipments will be secured.

Since the remaining modules will operate without active thermal control, normal temperature extremes will be exceeded with the resulting equilibrium temperatures determined by orientation, shadowing, and the condition of the exterior surface (α / ε). Equipments, although nonoperative in this mode, must be designed for these extremes, or repair or replacement during reactivation will be necessary. Preferably, all lines and tanks will be depressurized to reduce temperature cycling stresses and the effects of micrometeoroid penetrations; and, all fluids, waste, or other nutrients for bacterial growth will be removed or sterilized before departure. The extent to which these procedures can be implemented will depend on conditions surrounding the event requiring removal of the Power/Subsystems Module. The probability of such an occurrence has been estimated at 0.02 or less for the 5-year ISS period. In all likelihood, such a requirement would only be caused by a collision, a major meteoroid puncture, a fire, or other major catastrophic event. Failures in the Power Subsystem or other subsystems in the Power/Subsystems Module are not likely to require return of the module because these elements are all redundant and repairable on-orbit. As described in subsection 4.5.3.3, the Power Subsystem itself can survive several levels of failure or degradation, including loss of 10 of the 12 solar-array panels, before it is necessary to initiate crew return operations.

A brief trade study was performed to evaluate alternate methods of treating the contingency situation that occurs if the Power/Subsystems Module must be returned prematurely from orbit. The results are summarized in Table 4.1-3.

Table 4. 1-3

POWER MODULE FAILURE OPTIONS

Option	Baseline Impacts	Description	Features	Cost
Replace Power Subsystems Module on orbit	None	Same as baseline for 10 year ISS or GSS	• Initial cost • Uses GSS Module	Highest cost
Bring up auxiliary power subsystems	Could require power communications antennas att. ref. CMG's or propellant control electronics software	Mini-power/ subsystems module installed in Logistics Module	• Long lead time • Dedicated logistic module on standby • Periodic resupply required - power and propellant • Initial cost • Cost incurred, even if not used	High cost + Shuttle launches
Built-in auxiliary power; subsystem subsystems (Assume fuel cell backup power)	Major revision relocate Power/ Subsystems Module equipment into Power/Subsystems Module and Crew/ Operation Module; Crew/Operation Module equipment into Power/ Subsystems Module	• Redistribute redundant equipments between 2 modules • Add CMG's, att. ref. antennas, and power or split power into 2 arrays	• On-Orbit system is nonredundant and unmanned for maintenance • Less efficient equipment usage • Costs incurred even if not used • Periodic resupply required • Initial cost • Weight increase	High cost + Shuttle launches

Table 4.1-3 (Cont)

POWER MODULE FAILURE OPTIONS

Option	Baseline Impacts	Description	Features	Cost
Use quiescent mode	May require • Redundant and tracking aids • Passive or active thermal • Attitude control and command for orbit boost • Periodic resupply	• Use gravity gradient orientation • Drain tanks and lines • Remove sensitive equipment • Leave inert, if possible	• Passive docking operation • Temperature effects not fully evaluated • Gravity-gradient control	Least cost
Return all modules	None	Invert buildup sequence	No design impact requires several shuttle flights	Shuttle launches only

The first option considered is a cost-effective solution if the GSS Power/Subsystems Module is available at the time the first Power/Subsystems Module must be returned. However, if the backup Power/Subsystems Module is needed at the start of ISS, a major initial cost impact results.

An alternate is to bring up a smaller auxiliary power supply and those basic subsystems needed to sustain operations equivalent to the "Initial Unmanned Mode." This option, which assumes that attitude control and communications for commands and checkout power for thermal control are required, involves the development of essentially a new module dedicated to the "standby" mode. Use of simplified baseline subsystems installed in a Logistics Module should result in lower cost than a full Power/Subsystems Module but, again, the costs occur at the start of ISS.

The third option is similar to the second option except the backup subsystems are launched with the original Crew/Operations and GPL Modules. Some equipment cost saving is possible by redistributing redundant sets of the baseline equipments (tankage, control electronics, communications) to the Crew/Operation or GPL Modules. In the extreme, the solar array could be split into two smaller arrays; one located on the Power Module and one located on the Crew Module. Because of the operational interference, this is assumed less desirable than using an alternate (e. g., fuel cell) power source. While the fuel cell source provides an additional backup during minor contingency operations, the solar-array battery system is configured to provide several levels of backup, with varying capacity as shown in subsection 4. 5, and more than adequately satisfies the power needs of contingency events other than complete loss of the Power/Subsystems Module. This option also forces a significant redistribution of equipments and added weight which may result in adding a fourth module to the basic ISS.

The fourth option is based on deactivating the remaining modules rather than attempting to maintain an equivalent of the "Initial Unmanned Mode" which requires high power consumption and operation of several subsystems. In this option, the module cluster is placed in a gravity-gradient orientation, and all functions are placed in a quiescent or dormant mode. With the stabilizing effect of gravity-gradient torques, body rates will remain within a safe range for subsequent Shuttle docking.

Further, the additional rates imposed by an aborted docking (e. g., due to misalignment) will not cause body rates that will preclude subsequent docking attempts. (See subsection 4. 7 for details.)

With the loss of active thermal control, in Option 4, module internal temperatures will exceed the normal range. Although this has not been investigated in detail, preliminary calculations indicate that resulting remperatures will not exceed typical MIL-Spec values for components.

Since with Option 4 the orbital cluster is essentially inert, greater operational risk is involved than with other options wherein the cluster is cooperative. This risk is offset by the low probability of requiring the mode and the low cost involved in implementing the quiescent mode features. Essentially, only analyses are required to verify tolerable conditions for the dormant phase and subsequent docking and reactivation operations. Some design changes that will affect initial cost may be necessary to provide adequate environmental margins and to simplify the deactivation and reactivation tasks. Since feasibility of this option is indicated, without need to compromise the baseline design and program cost, Option 4 is selected as the preferred approach for meeting the "standby mode" requirement.

A fifth option is listed which may be preferable under some conditions—especially if the on-orbit cluster contains only a few modules. Certain failures will necessitate returning the Power/Subsystem Module although sufficient power is available to support a low level of operations while the cluster is disassembled for return. Examples might include: major structural damage including loss of pressurization capability; collision causing loss of a major part of the solar array; major degradation of the array due to contamination; damage to the gimbal mechanism rendering it inoperative, etc. For these conditions, the ground repair/rebuild cycle may be lengthy and return of all modules, especially if refurbishment or upgrading of other equipments is indicated, may be more cost-effective than remaining on-orbit.

In the event it becomes necessary to return the Power/Subsystems Module, the advantages of Option 5 should be considered.

Since the Space Station is designed to operate primarily in an active, manned mode, the "standby unmanned mode" has been implemented with minimum impact on the basic design. Similarly, the emphasis on this preliminary design is the definition of the ISS although transition to a 12-man GSS has been included in the study and accommodations for this eventual growth are included in the ISS design. The provisions associated with the GSS step are summarized in subsection 4.1.4.

4.1.4 Growth Space Station Considerations

The ISS subsystems are selected with transition to GSS as a necessary requirement. No technology changes to the ISS subsystem are required to accomplish this growth step. Provisions for connecting with a second Crew/Operations Module and a second Power/Subsystems Module are included in the ISS interface designs. Data bus, power transmission, thermal control, propellant and other services are routed to the aft end of Crew/Operations Module No. 1 for subsequent interconnection with Crew/Operations Module No. 2. Subsystem assemblies are designed for eventual growth in capacity; e.g. the computers are modular and expandable, the control system can accommodate additional CMG's, display panels are designed for growth, etc.

The most significant requirement associated with the GSS step is the addition of support services for Free-Flying Experiment Modules.

Subsystem equipment additions to accommodate Free-Flying Experiment Modules are required for:

- Module checkout, monitoring, and navigation updates.
- Communications for flight control, experiment command, and tracking.
- Experiment data transfer via RF link.
- Computer and data storage services for control and experiment processing.

- Rendezvous and docking control.
- Housekeeping support while docked.
- Replenishment of subsystem consumables (e.g. propellant).

The added subsystem equipments for experiment support are listed in Table 4.1-4 and included both assembly weights and peak power requirements. The total addition for Free-Flying Module (FFM) operation is nominal, with the chief additions being needed for communications/tracking, and docking operations. The propellant required per month is reported for the peak usage and is supplied from the Logistic Module "pantry." The necessary plumbing and controls for propellant transfer exists at each docking port interface; thus, the requirement is simply one of logistic supply.

The communications subsystem will require addition of medium-gain antennas mounted on the solar-array turret drive on the second Power/Subsystems Module. From this vantage point, the tracking and communications equipments will have unobstructed view of the FFM's in their "D"-shaped flight patterns behind the GSS. A dedicated display panel will be located in the GPL and will be used to track and monitor the modules.

Rendezvous and docking operations will require addition of the laser radar, a portable display and control unit with flight controls, and a reticule telescope. The telescope will be mounted at the viewing window in the center of the docking port and, after alignment, will be used in conjunction with the portable controls to fly the modules. It is anticipated that a second crewman will support the flight operator by monitoring range and rate readouts in conjunction with external TV monitoring of the operation. It should be noted that the operations are similar to those used in the Orbiter during Orbiter/Station docking and are GSS additions since the ISS is passive during normal Orbiter docking.

The following subsections present the results of the Phase B study and preliminary design definitions for each of the ISS subsystems.

Table 4.1-4

SUBSYSTEMS EQUIPMENTS TO ACCOMMODATE FREE-FLYER EXPERIMENT MODULES—GSS

Subsystem	Description	Weight (lb)	Peak Power (w)
GNC	Docking Alignment Aids (lights)	2	8
	Rendezvous Tracker	39	4
Propulsion	Pressurant and Propellant	342/mo.	2
Communications	Medium Gain Antenna	40	20
	K_u-Band Power Amplifier	10	80
	K_u-Band Exciter	3	5
	K_u-Band Receiver	5	5
	S-Band Data Receivers	90	132
	S-Band Video Receivers	32	52
DMS/OBC	16k Digital Storage/Software	20	25
Display/Control	Portable Display and Control with Flight Control Plug-in	100	125
	Reticule Telescope (2)	10	
	Displays for Tracking/Control	50	35
EC/LS Power	None		
	Total	401*	

*Excluding propellant resupply.

4.2 STRUCTURAL/MECHANICAL SUBSYSTEM

4.2.1 Summary

The Modular Space Station structural/mechanical preliminary design has been accomplished as defined by subsections 2.3.3 and 2.5.13 of MA-01 "Space Station Phase B Extension Study Plan." The objective of these tasks is to update the subsystem definitions developed during the option period and provide design details of the modules structure and mechanical systems in sufficient depth to form the basis for a Phase C development effort. Design analysis and trade studies accompany the design descriptions and preliminary design drawings herein.

The Modular Space Station configuration analysis resulted in three basic resource module designs for the ISS consisting of a Power/Subsystems Module, a Crew/Operations Module, and a General Purpose Laboratory (GPL) Module. The GSS adds one Crew/Operations Module and one Power/Subsystem Module which are identical to those used for ISS. All of these modules use common structure/mechanical design. This section describes the results of the preliminary design accomplished for the items listed below and located schematically on the three-module ISS cluster in Figure 4.2-1.

A. Pressure Shell Structure
B. Docking Structure
C. ECLS Radiator/Meteoroid Shroud/Thermal Insulation Assembly
D. Solar Array Support Tunnel
E. Solar Array Turret Structure
F. Equipment Support Structure
G. Test and Isolation Chamber Pressure Bulkhead
H. Docking Mechanism
I. Docking Port Covers
J. Hatches/Airlocks
K. Viewports
L. Solar Array Drive and Orientation Mechanism
M. High-Gain Antenna Deployment Mechanism
N. Solar Array Deployment Mechanism

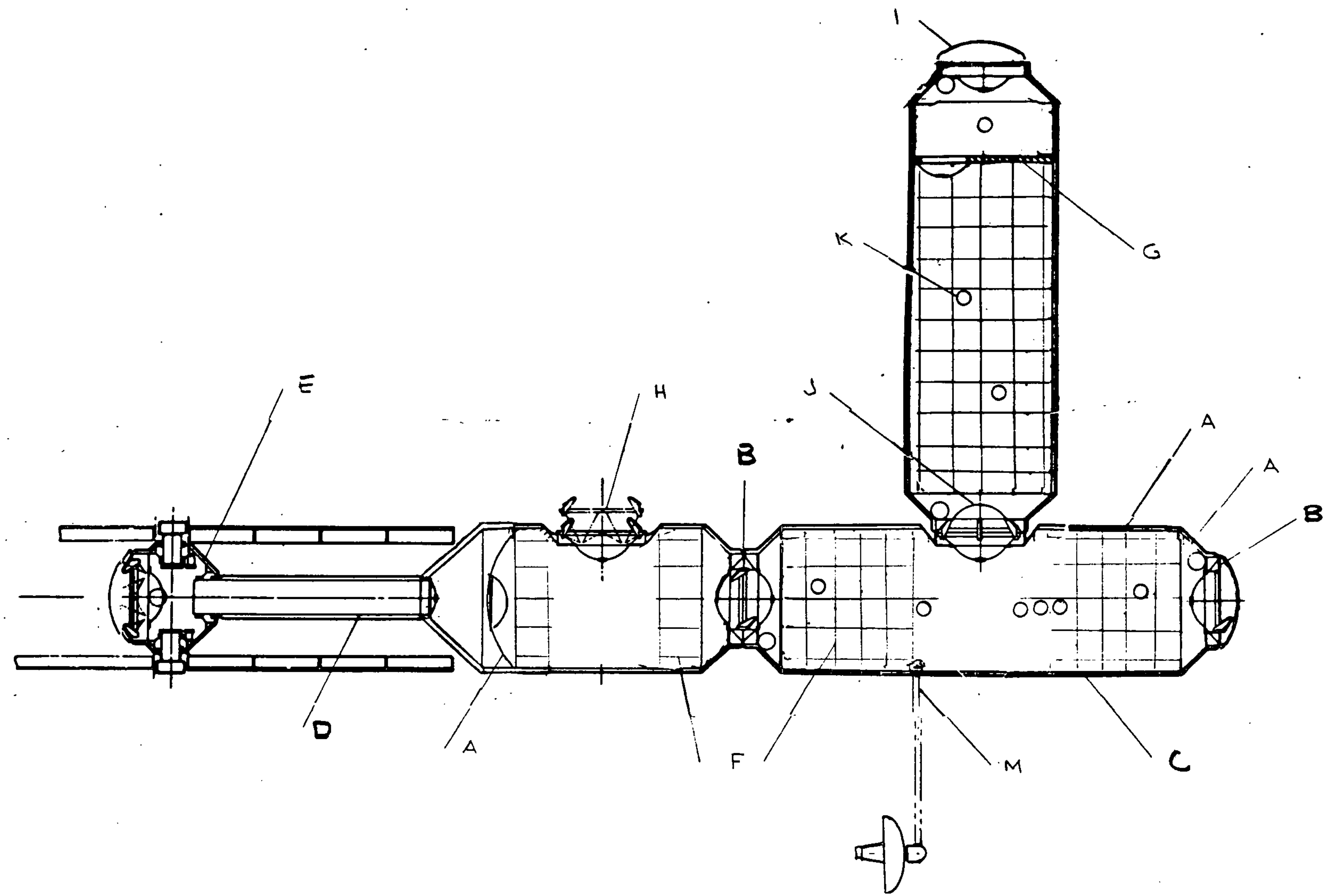


Figure 4.2-1. ISS Structural Mechanical Items

Summary descriptions of each of the structural/mechanical items, that were a product of the preliminary design study task, are presented in the following paragraphs.

The pressure shell structure for each of the three modules for the ISS used the same basic design. The 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 4.2-2 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 (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-in.) 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 Sub-System tankage.

The docking structure is a multipurpose fitting which 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. Detail design of the Power/Subsystems Module and the Crew/Operations Module is shown in Figure 4.2-26 and 4.2-39 in subsection 4.2.3.

The 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

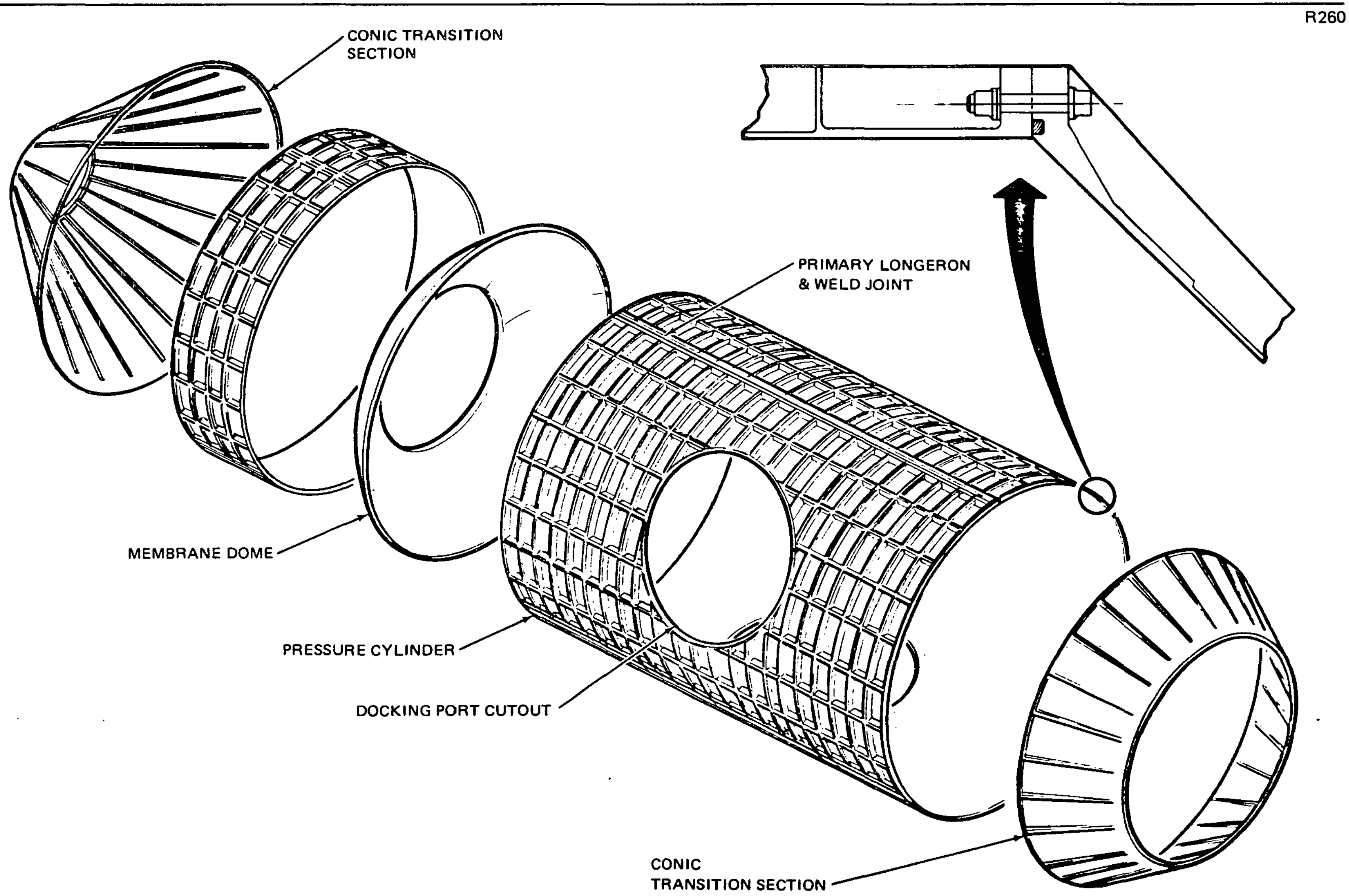


Figure 4.2-2. Power/Subsystems Module Pressure Shell

extruded sections which contain the flow passages for the EC/LS radiator fluid. A second bumper, to protect the 1.27 cm (1/2-in.) blanket of high performance insulation, is attached to the radiator extrusion forming a box section. The assembly is installed over the pressure shell and supported by fiber-glass insulators. The outside diameter of the radiator is 4.3 m (168-in.) diameter. Figure 4.2-3 illustrates a transverse section through the module wall.

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 so that with the proposed 50-percent stiffening, the $\bar{t}$ is 0.19 cm (0.075-in.). 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 for which the estimated $\bar{t}$ is 0.214 cm (0.084 in.). 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.

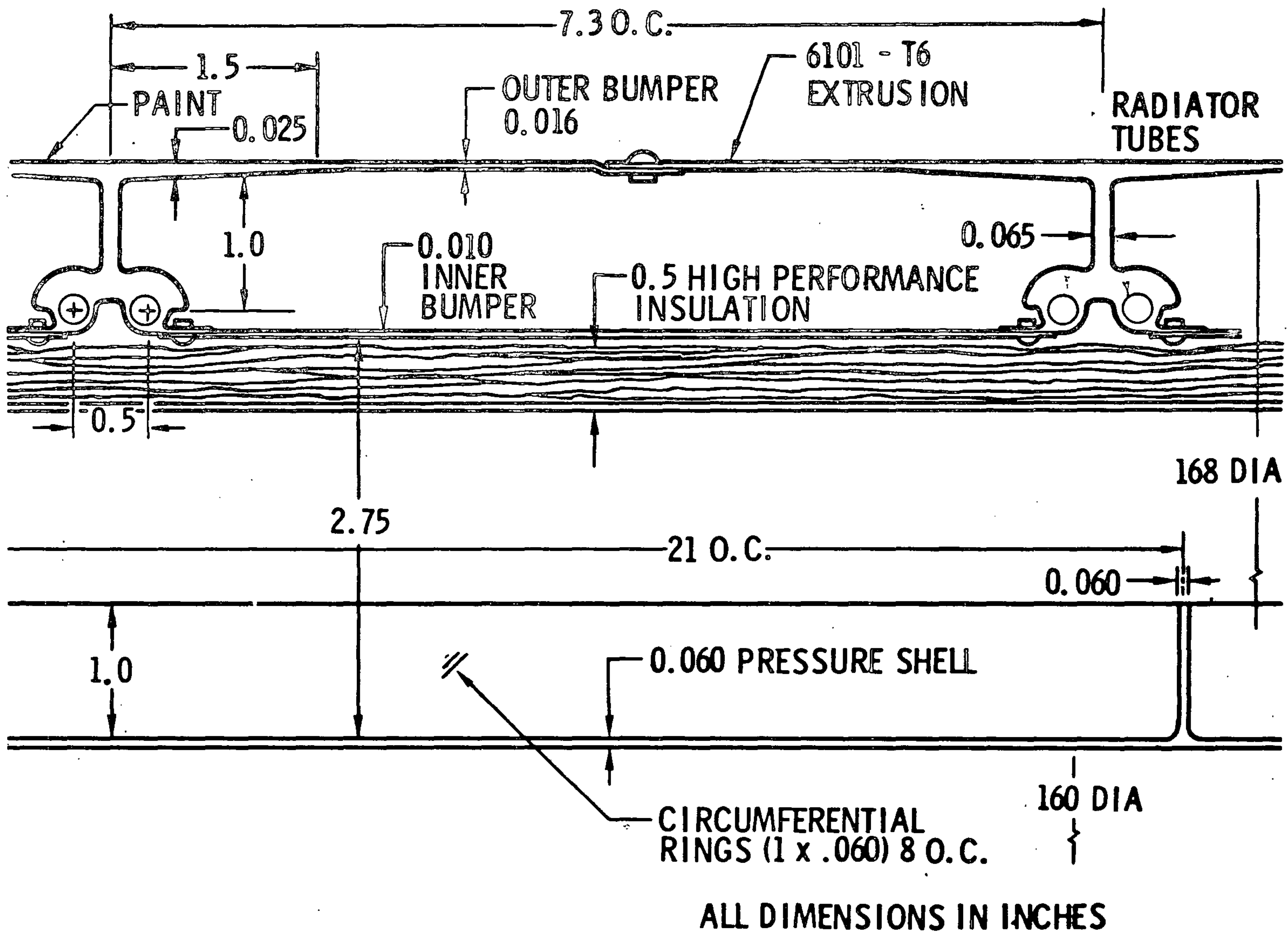


Figure 4.2-3. Typical Wall Configuration

30

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. Figure 4.2-4 illustrates the module structure concept.

The test and isolation chamber pressure bulkhead separates the GPL into two separate pressurizable compartments. The flat bulkhead is 15.2 cm (6-in.) thick and is fabricated of aluminum honeycomb sandwich. It 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.

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. Figure 4.2-5 illustrates the docking mechanism operational sequence. 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 meteroids and insulated thermally. The protective covers are electrically actuated. Since the module end-port cover must be opened 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

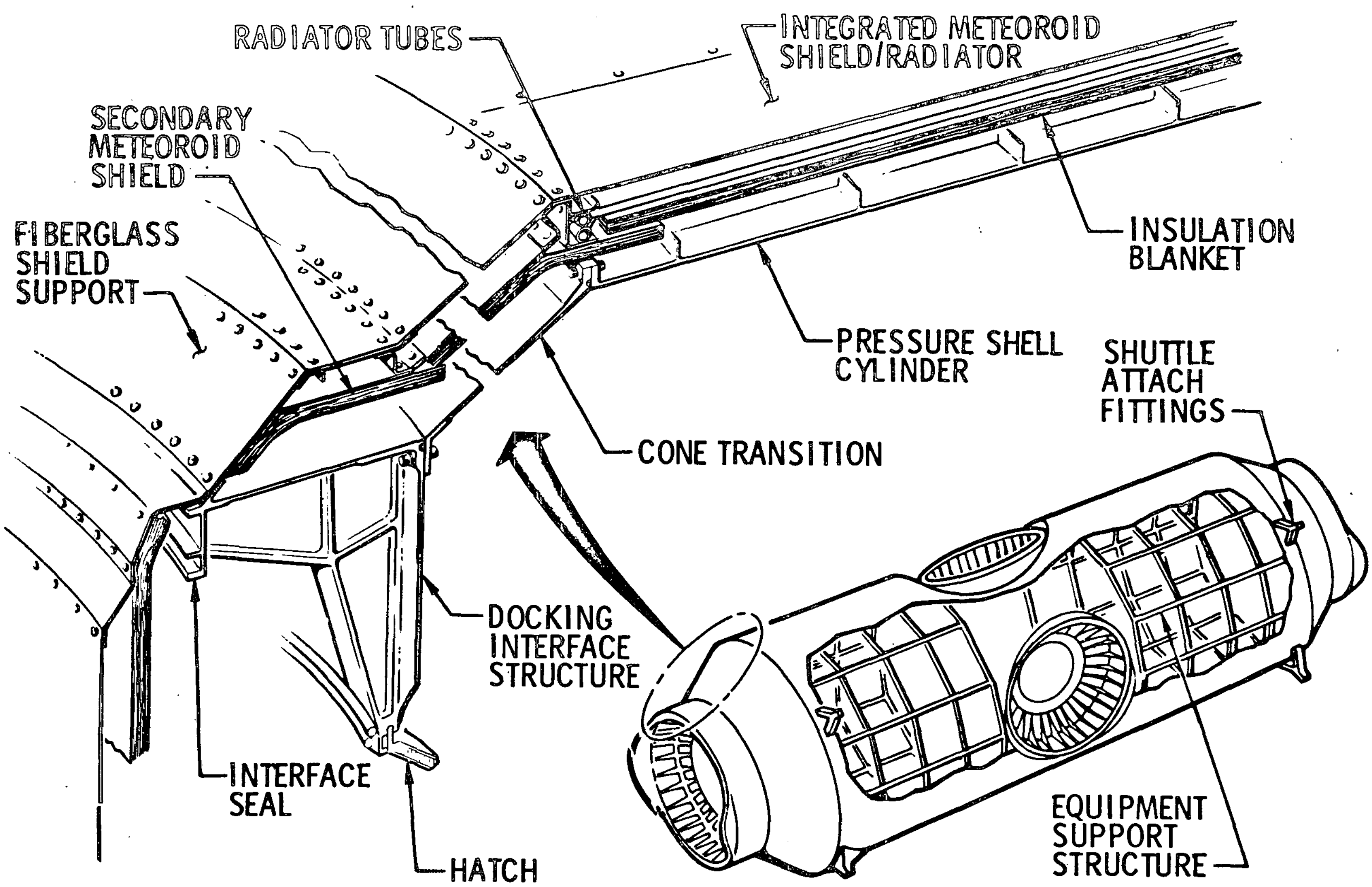


Figure 4.2-4. Structure Concept

R260

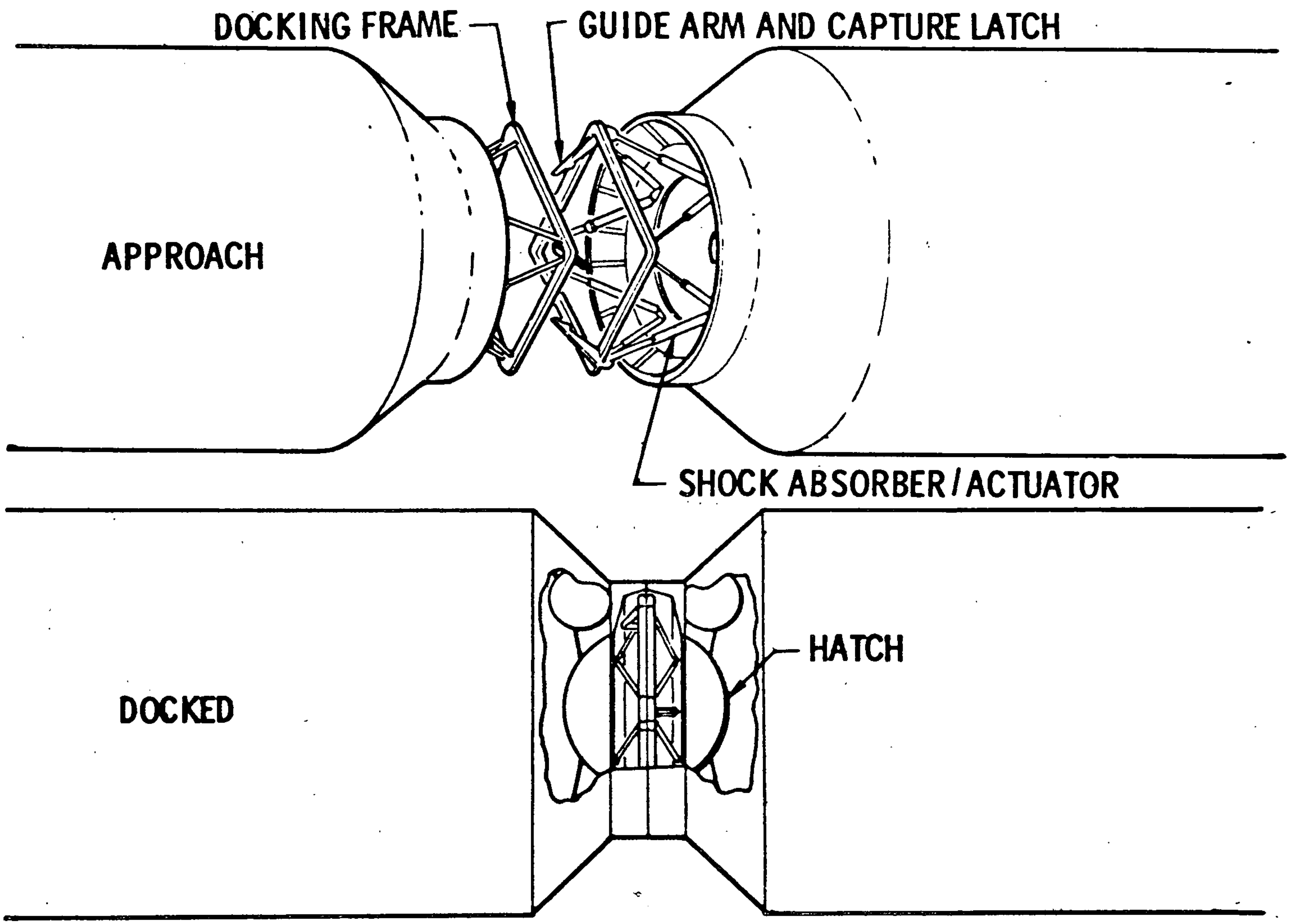


Figure 4.2-5. Docking Mechanism Operational Sequence

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. Figure 4.2-6 illustrates the docking port cover installations and operation. The covers are driven by electro-mechanical actuators and may be remotely controlled from within the Space Station or by RF links.

A common hatch design is used throughout the Space Station. All hatches are domed, spherical 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 hatches are smaller and 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 (Figure 4.2-42 in subsection 4.2.3). The selected design provides this feature with essentially no weight penalty. Figure 4.2-7 illustrates the location and intended use of each of the airlock chambers within the ISS. Each hatch contains a 15.3 cm (6-in.) diameter viewport. The viewport mounting also provides the hinge attachment to the hatch.

In addition to the hatch viewports, 30.6 cm (12-in.) diameter viewports are installed in each crewman's 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 4.2-8 illustrates schematically the solar array drive and orientation mechanism. The 492 m^2 (5,300 ft^2) gross area array is driven and positioned ±180 degrees in each of two axes. The longitudinal axis drive is located between the fixed tunnel and the turret. Two independent drives,

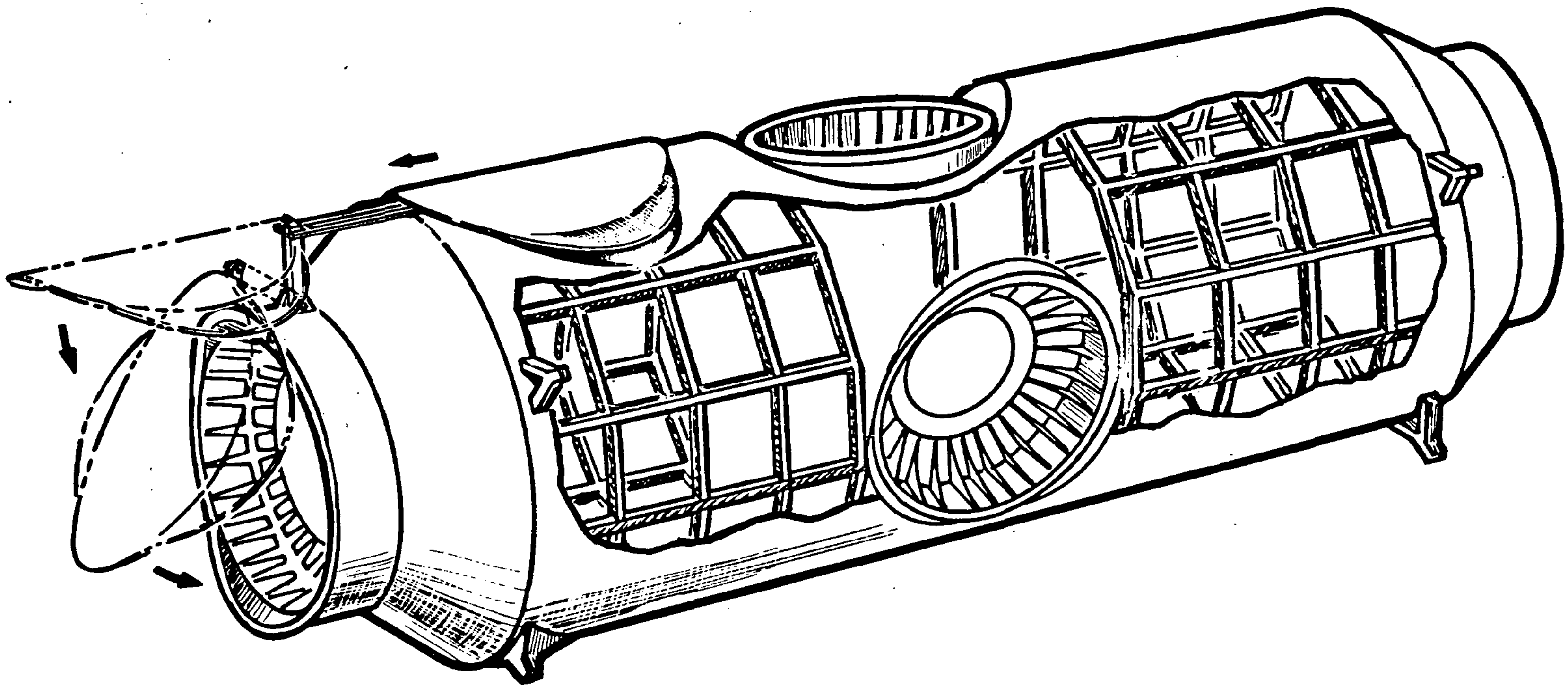


Figure 4.2-6. Docking Port Covers

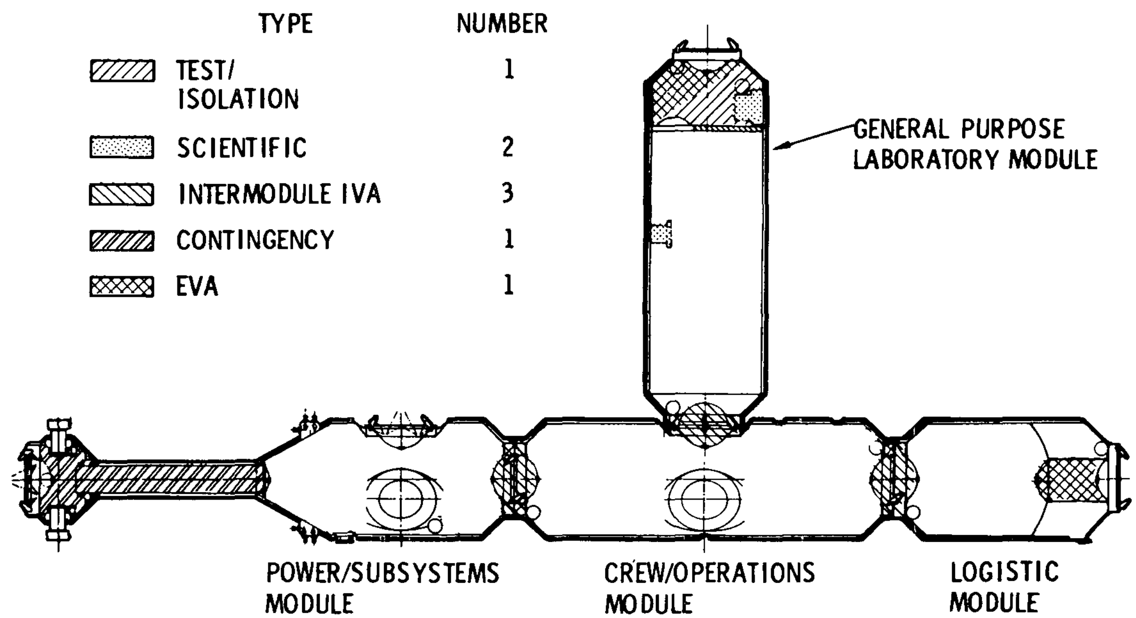


Figure 4.2-7. Integrated Space Station Airlock Summary

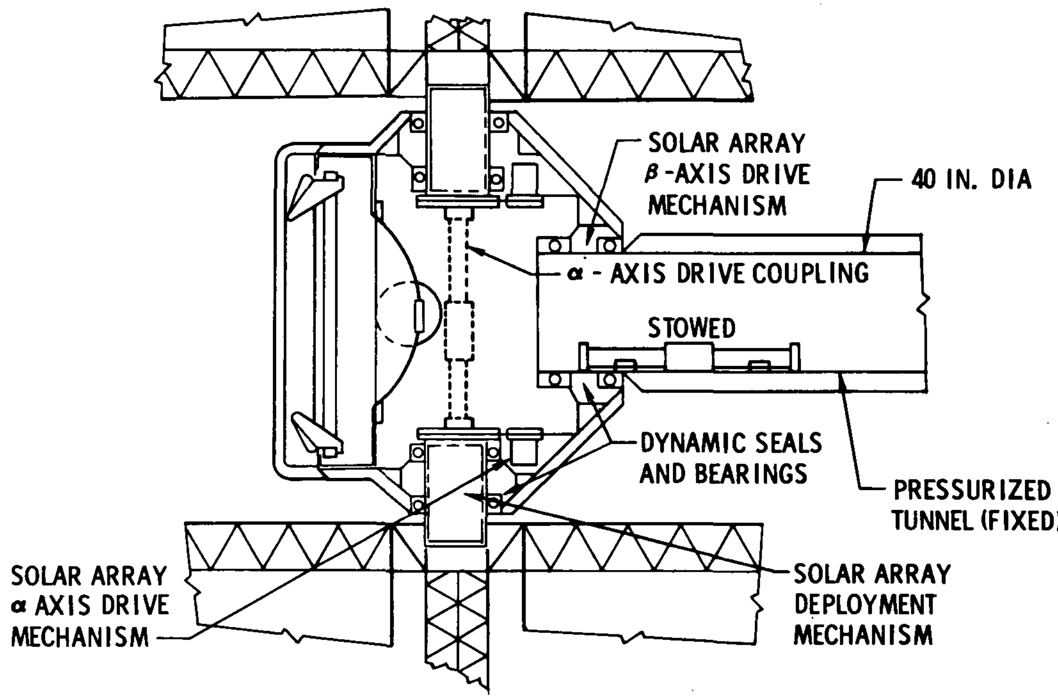


Figure 4.2-8. Solar Array Drive and Orientation Mechanism

attached to the turret, rotate the array wings in the tranverse axis. All three drive mechanisms are identical and use an electro-mechanical 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 a "friendly" environment and allowing shirtsleeve maintenance on orbit. Each drive incorporates a pressure balance arrangement to eliminate static load on the bearings.

Three 2.43 m (8-ft) diameter, high-gain communications antennas are mounted to the Crew/Operations Module. These units are stowed and latched during launch and deployed on orbit. The docking interface structural latches are used to secure the antenna in the stowed position. Deployment is accomplished by rotating the antenna mast about a structural attach point on the cylindrical pressure shell. The power is supplied by electro-mechanical actuators located inside the pressurized compartment and coupled to the antenna mast through a dynamic pressure seal. The actuator may be maintained and/or replaced in a pressurized environment. Manual operation is also possible in the event of an actuator malfunction.

The modular Space Station design used the solar array deployment concepts which have been developed by Lockheed Missiles & Space Company. The Space Station Solar Array Technology Program is being conducted under NASA contract NAS9-11039 and is administered by the Manned Spacecraft Center, Houston, Texas. The array deployment mechanism is packaged for launch within a 4.3 m (14-ft) diameter envelope. The mechanism features an extendible/retractable truss structure (Astromast) which allows partial deployment and/or retraction of the solar array so that the power subsystems module may be returned to earth via the Shuttle. Figure 4.2-9 illustrates the deployment sequence.

4.2.2 Requirements

The requirements for the structure and the mechanical systems for the Modular Space Station are derived from the Guidelines and Constraints imposed by NASA and the findings that emerged from this study. The

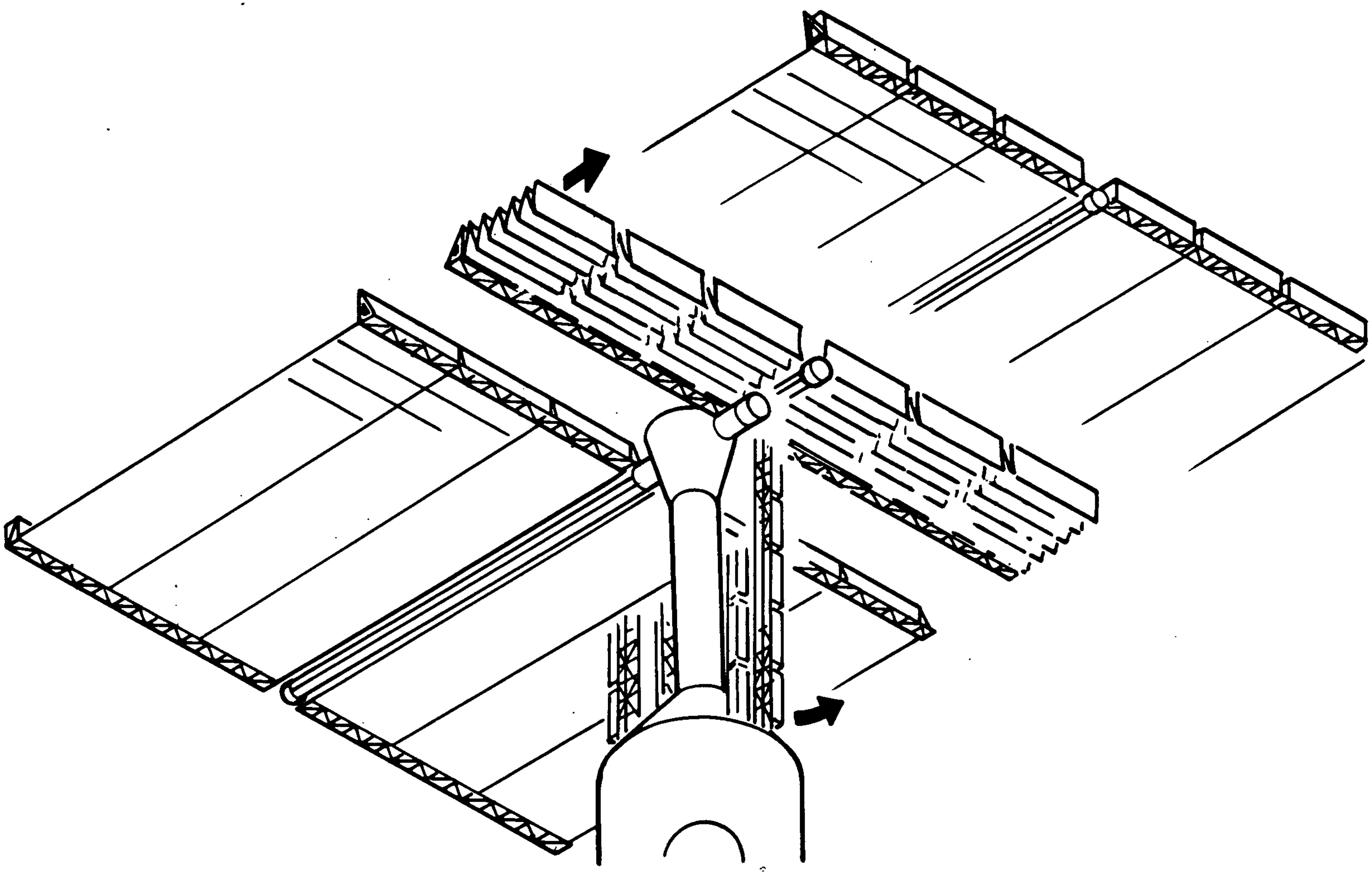


Figure 4.2-9. Solar Array Mast/Panel Deployment

program-level requirements which most significantly influenced the structural mechanical design are as follows:

A. The Space Station program (Modular) includes the design, development and operation of a semi-permanent cluster of modules each of which can be transported to and from orbit internal to the Space Shuttle (CM-01 3.1.1.1).

B. Total cost of the program is a primary consideration. Primary emphasis is on minimum cost to the IOC (CM-01 3.1.1.3).

C. 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 Reasearch and Applications Modules should be developed (CM-01 3.1.1.6).

D. The Space Station Shall provide for a hard Shuttle docking capability via the payload module (CM-01 3.2.1.5).

These four requirements are the genesis of lower level, more specific requirements applicable to each item within the Structural/Mechanical Subsystem. For example, the primary structure must be designed to withstand the environments imposed by Shuttle transport to and from orbit. The specific quantitative requirements of size limits, "g" levels, temperature, acoustic, etc. have been defined and are presented in following sections describing the structure preliminary design.

The requirement for minimum cost has led the designs to simplicity first and second to minimizing the number of items required to perform the mission through dual usage and commonality. The configuration reflects this approach because a minimum number of modules are used to assemble both the ISS and the GSS. In addition, a high degree of structural/mechanical commonality exists among all Space Station modules including the Logistics Module. The three modules of the ISS, and the Logistics Module, contain a total of 14 docking ports. All of these ports use the same structure and mechanisms requiring only one design.

The requirement for direct docking of modules by the Shuttle Orbiter requires that the docking mechanism be designed to absorb the energy generated by the momentum of two large masses impacting at a maximum of 0.31 m/sec (1 ft/sec).

4.2.3 Recommended Structural/Mechanical Designs

The structural design selected for the Modular Space Station has been influenced by several factors, some of which have been conventionally considered in previous Space Station studies, but some of which are unique for the Modular Space Station. For example, Shuttle launch of the modules has a significant impact on the structural design. Launched in the cargo bay of the Orbiter, the radiator/meteoroid shroud is protected from the buffet, aerodynamic bending moment, and unsymmetrical pressure distribution which are major design considerations for Saturn-launched Space Stations. The flight loads are substantially reduced for the Shuttle-launched module but the launch inertia forces must be reacted as point loads at a few discrete, carefully selected points to eliminate bending and torsional interaction between the Orbiter fuselage and the module.

The 9.072 kgm (20,000-lb) launch weight limit together with a clear need to minimize the number of modules in the buildup to minimize the cost, places special emphasis on high structural efficiency with developed materials and processes.

Minimizing the cost of the Structural Subsystem requires minimizing the parts count through the use of large sections with special provisions integrally machined; numerically controlled machining for easy development and minimum tooling; and standardized interchangeable structural elements common to all modules to minimize engineering and qualification costs. It is the careful attention to these considerations which leads to the structural design for the Modular Space Station described in the subsections which follow.

4.2.3.1 Pressure Shell Structure

The Space Station Module structure must transfer the launch inertia loads to the Orbiter cargo bay support points. It must contain the life support atmosphere with neglibibly small losses from leakage; and, as specified in the study Guidelines and Constraints, it must provide a 0.90 probability of no meteoroid punctures in 10 years for the orbital assembly of modules from initial launch to completion of the Growth Space Station phase.

The flight loads are carried in the integrally stiffened pressure shell of 2219-T87 aluminum, the inner surface of which is spaced four inches inside the outer bumper to provide high meteoroid shielding efficiency for the integrated wall. The module sidewall design is shown in Figures 4.2-10, 4.2-11, and 4.2-12.

Cabin Pressure

The nominal operating pressure for the Space Station module is 10.15 n/cm^2 (14.7 psi). 10.34 n/cm^2 (15.0 psi) is selected as the upper limit of the relief valve setting so that normal fluctuations in the pressure control system do not exercise the valve. The inside diameter of the pressure shell is 4.06 m (160 in.) and the minimum guaranteed tensile ultimate for 2219-T87 is 42,700 n/cm^2 (62,000 psi). With the ultimate factor of safety of 2.0 for cabin pressure (specified in the Study Guidelines and Constraints), the minimum wall thickness for the pressure shell cylinder is

$$t = \frac{S.F.\ (PR)}{f_{tu}} = \frac{2.0\ (10.34)\ (203)}{42,700} = 0.098 \text{ cm } (0.039 \text{ in.})$$

Meteoroid Shielding

The pressure shell must be sized so that with the double-sheet bumper, the NASA specified 0.90 probability of no punctures is met or exceeded with the Modular Space Station buildup selected for the 10-year mission. The exposed area, time in buildup phase, and integrated area time product for the selected buildup are shown in Table 4.2-1. The module dimensions and surface areas on which the table is based are shown in Figure 4.2-13.

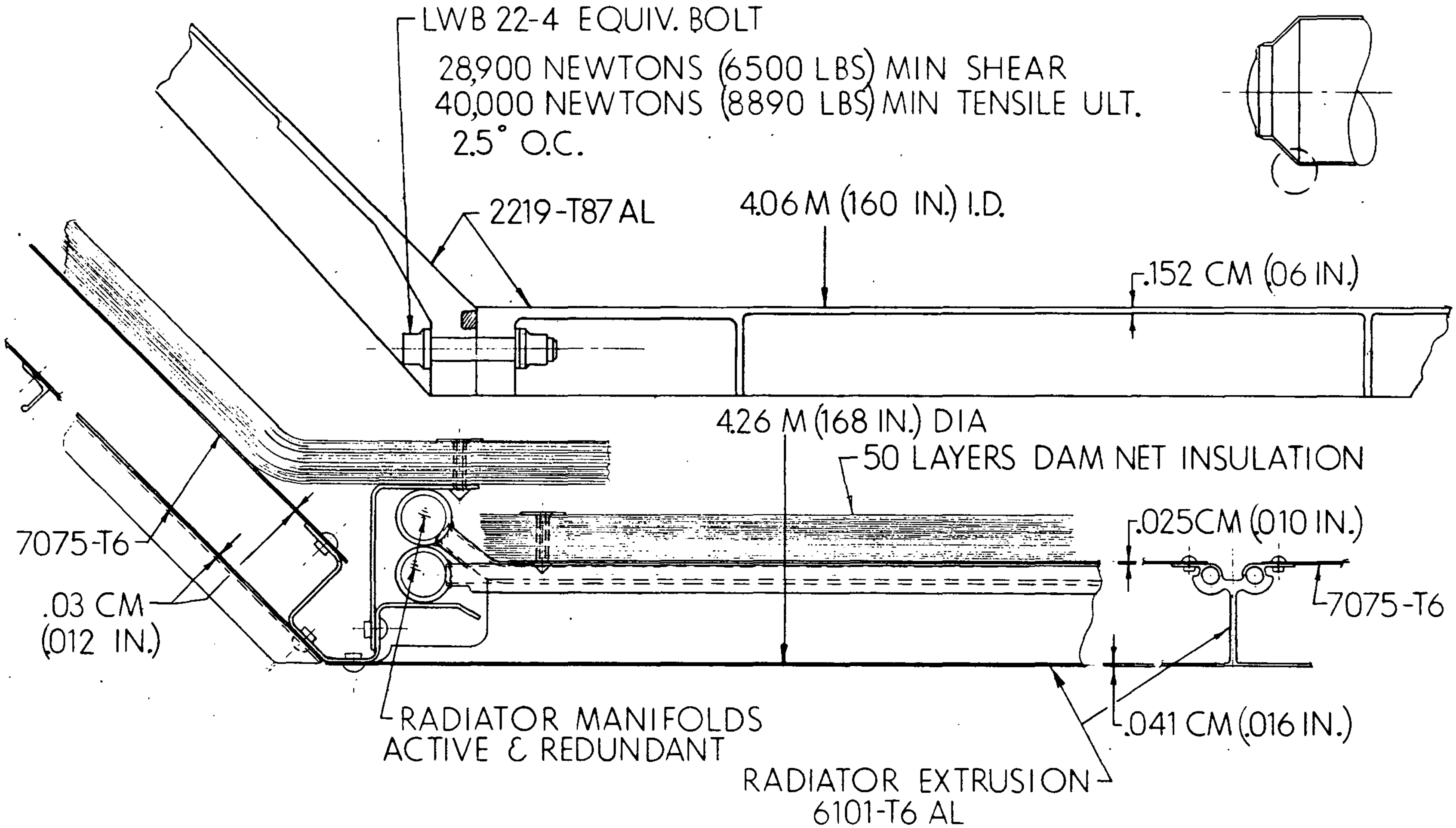


Figure 4.2-10. Space Station Module Cone/Cylinder Joint

R260

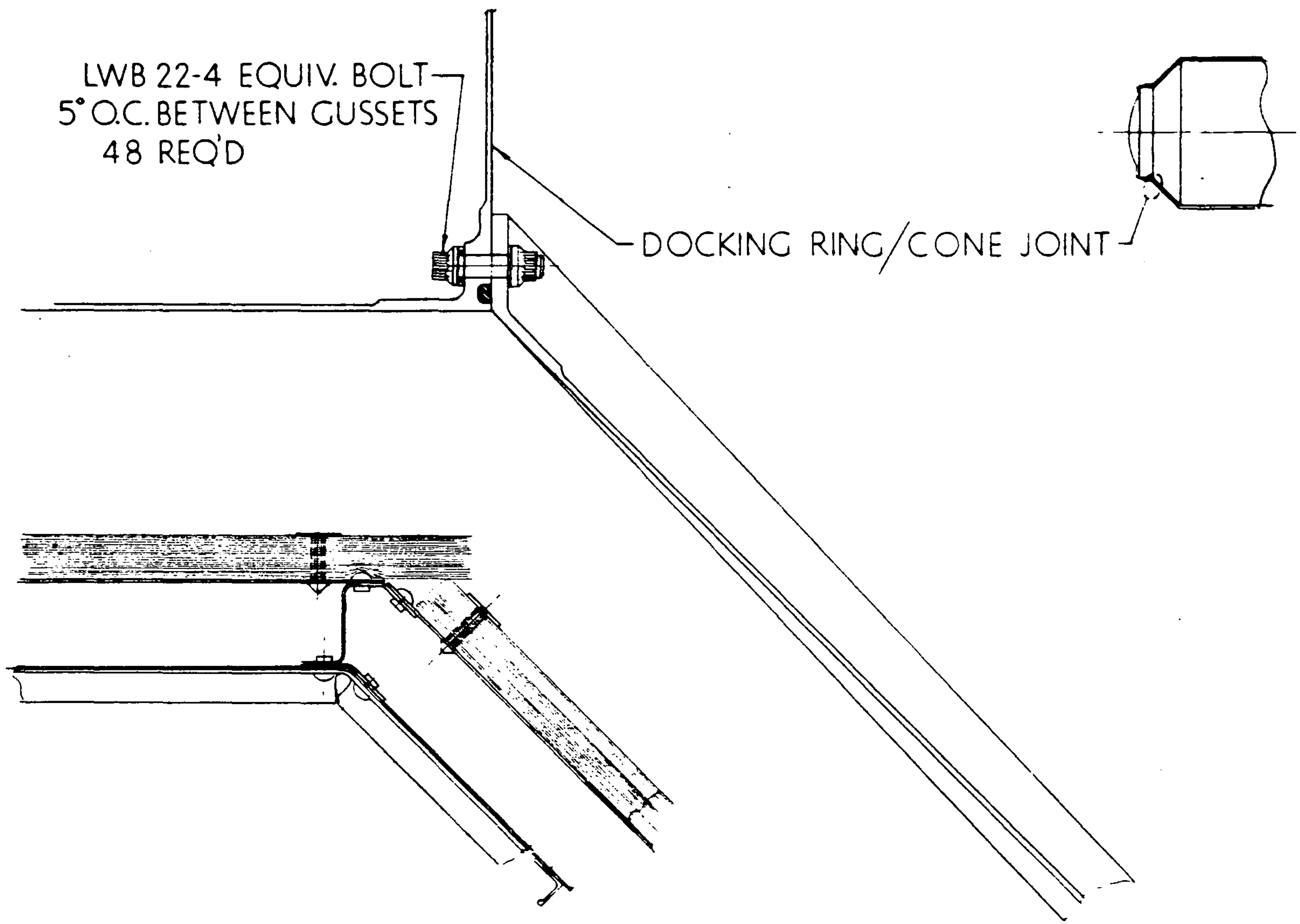


Figure 4.2-11. Docking Ring/Cone Joint

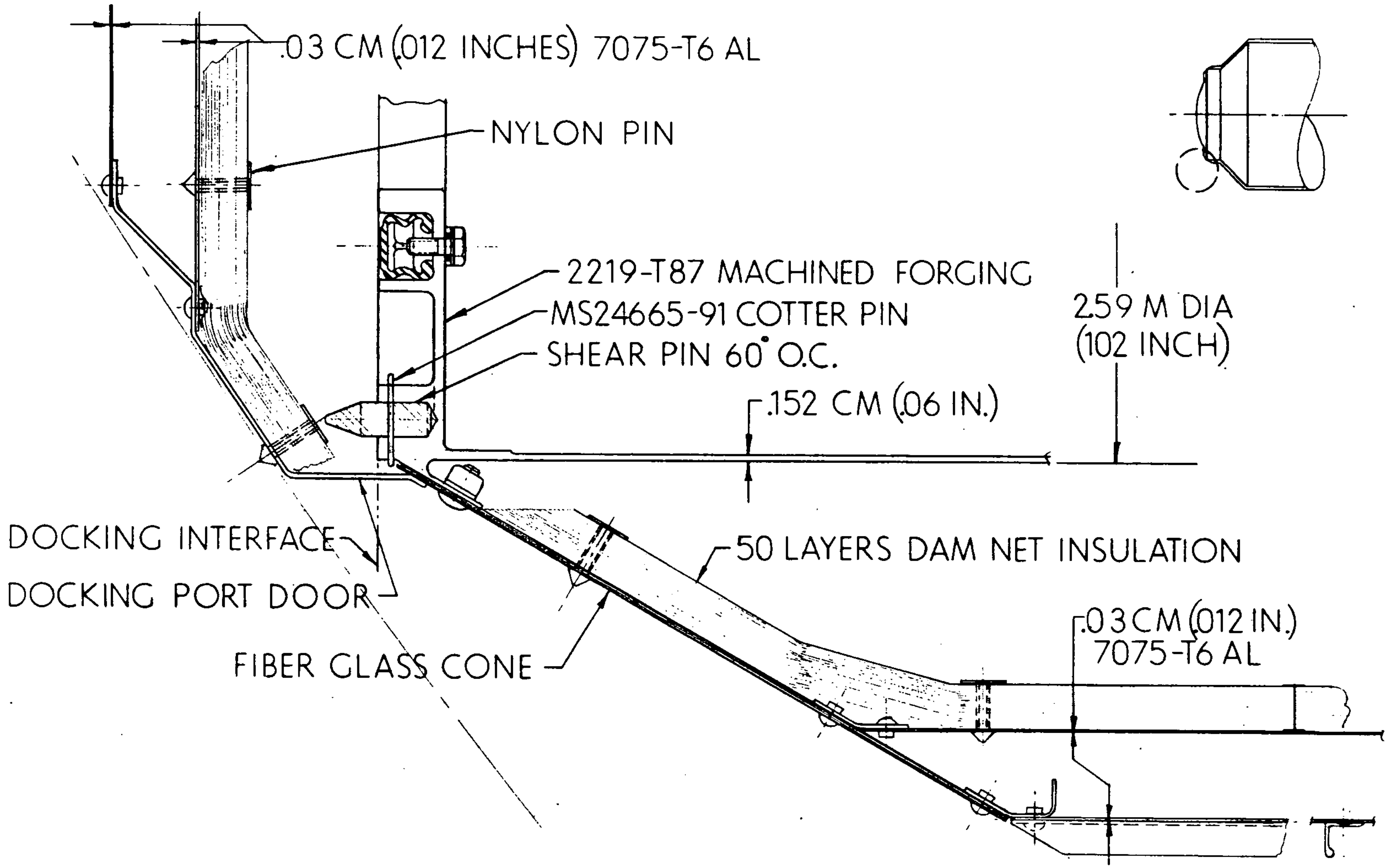


Figure 4.2-12. Docking Ring Structural Interface Details

Table 4.2-1

BUILDUP AREA TIME EXPOSURE

Buildup Phase	Exposed Area (m^2)	Time (sec)	$\Delta A. T$	Area Time m^2 sec
1st Power/Subsystems Module	178.5	2.59×10^6		4.62×10^8
1st Crew/Operations Module	362.3	2.59×10^6	9.39×10^8	14.01×10^8
1st GPL Module	551.6	2.59×10^6	14.29×10^8	28.30×10^8
1st Logistics Module	675.3	2.59×10^6	17.50×10^8	45.8×10^8
2nd Logistics Module	799	1.475×10^8	1179×10^8	1225×10^8
2nd Crew/Operations Module	982.8	2.59×10^6	26.4×10^8	1251×10^8
2nd Power/Subsystems Module	1155.8	2.59×10^6	30×10^8	1281×10^8
3rd Logistics Module	1279.5	1.525×10^8	1950×10^8	32.3×10^{10}

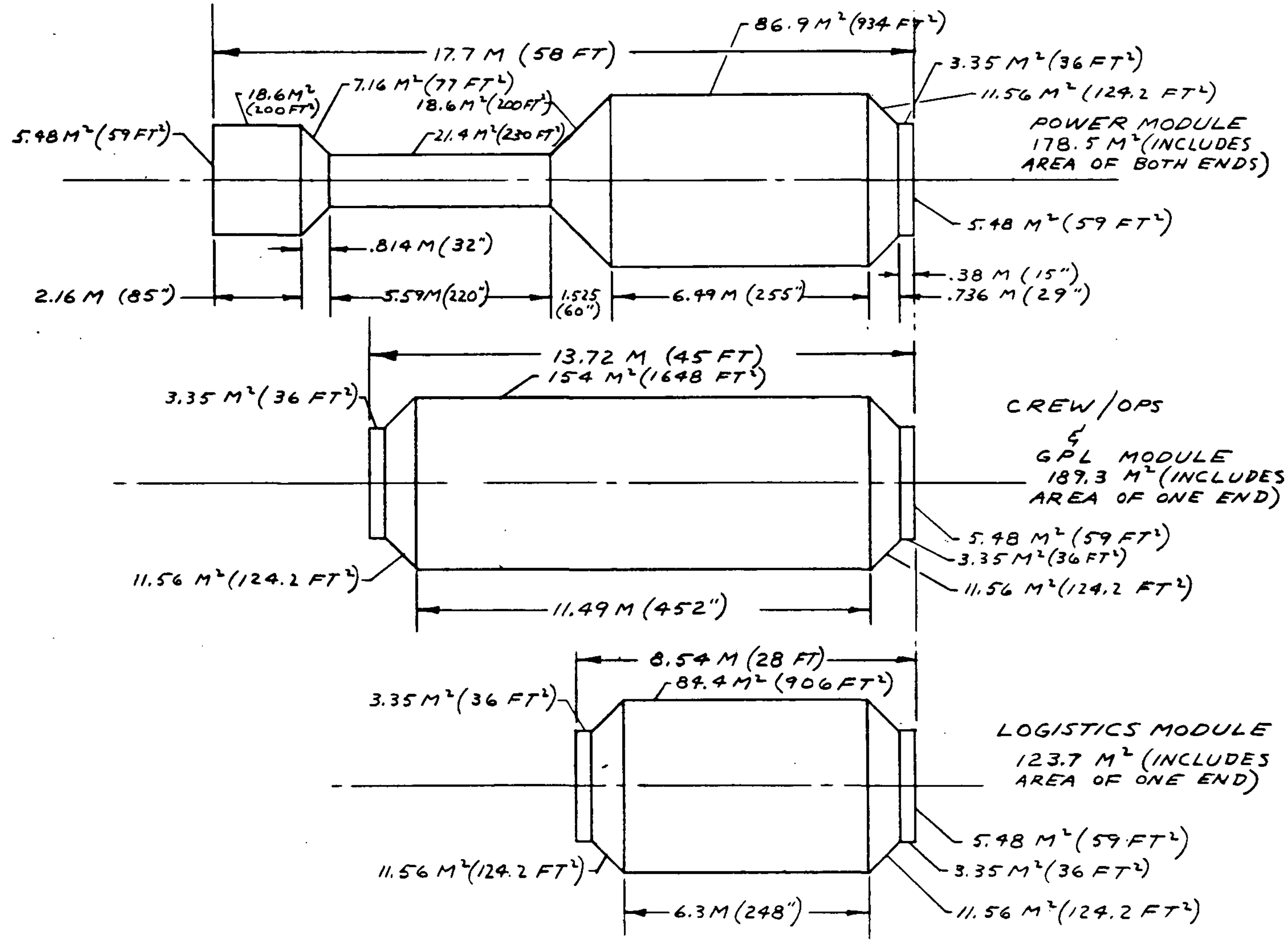


Figure 4.2-13. Exposed Surface Areas for Meteoroid Shielding Analysis

The integrated area-time product is 32.3 x 10^{10} m^2-seconds for the entire 10-year mission. The ballistic limit for the sidewall design shown in Figure 4.2-3 was determined in the MDAC light gas gun facility. This structure stopped a 0.165 gm aluminum projectile traveling 7.01 km/sec (23,000 ft/sec) without cracking or spall from the back face of the 0.060 sheet although visibly close to the ballistic limit. Using the single sheet penetration equation

$$t = K_1 \ \rho^{\frac{1}{6}} m^{0.352} \ V^{0.875} \text{ from NASA SP8013}$$

for scaling to the average meteoroid velocity and density, the equivalent mass meteoroid is

$$m_m = m_r \left(\frac{\rho_r}{\rho_m}\right)^{0.474} \left(\frac{V_r}{V_m}\right)^{2.48}$$

$$m_m = 0.165 \left(\frac{2.77}{0.5}\right)^{0.474} \left(\frac{7.01}{20}\right)^{2.48} = 0.0278 \text{ gms}$$

From the flux/mass relationship

$$\log N = -14.37 - 1.213 \log m,$$

the penetrating flux is

$$N = \frac{10^{0.063} \times 10^{-5}}{\left(m_m\right)^{1.213}} = \frac{4.26 \times 10^{-15}}{(0.0278)^{1.213}} = 3.28 \times 10^{-13}$$

penetrations per m^2/sec. The expected number of penetrations U for the 10-year mission is then

$$U = N(At)\ (S.F.) = (3.28 \times 10^{-13})(3.23 \times 10^{10})\, 0.67$$

$$U = 0.071$$

where 0.67 is the earth shielding factor at 260-miles orbit altitude.

The probability of no penetrations is

$$P_o = e^{-u} = 1 - U + \frac{U^2}{2\,!} \dots = 1 - 0.071 + 0.0025 = 0.931$$

The 0.060 pressure shell thus exceeds the thickness required to meet the NASA specified no puncture probability of 0.90.

From

$$P_o = e^{-u} = 1 - U + \frac{U^2}{2\,!} = 0.9$$

$$U^2 - 2U + 1 = 0.8$$

$$U - 1 = \pm\sqrt{0.8} = -0.895$$

$$U = 0.105 = N(At)\ (S.F.)$$

from which $N = \dfrac{0.105}{\left(32.3 \times 10^{10} \quad 0.67\right)} = 4.85 \times 10^{-13}$

using the flux mass relationship

$$\log N = -14.37 - 1.213 \log m$$

$$m^{1.213} = \frac{10^{.63} \times 10^{-15}}{4.85 \times 10^{-13}} = 0.00879$$

$$m = 0.020 \text{ gms} = \text{meteoroid mass}$$

the structure must defeat to provide a 0.90 probability of no penetrations for the 10-year mission.

Again from the single-sheet penetration equation

$$t = K_1 \rho^{\frac{1}{6}} m^{0.352} V^{0.875}$$

$$\frac{t_1}{t_2} = \left(\frac{m_1}{m_2}\right)^{0.352}$$

$$t_2 = t_1 \left(\frac{m_2}{m_1}\right)^{0.352} = t_1 \left(\frac{0.020}{0.0278}\right)^{0.352} = 0.891\, t_1$$

From the test shot in the MDAC light gas gun facility and the single sheet penetration equation

$$t_1 = K_1 \rho^{\frac{1}{6}} m^{0.352} V^{0.875}$$

$$t_1 = 0.54\,(2.77)^{\frac{1}{6}}\,(0.165)^{0.352}\,(7.01)^{0.875}$$

$$t_1 = 1.86 \text{ cm } (0.733 \text{ in.})$$

where t_1 equals the thickness of the single sheet with the same penetration resistance as the three sheet structure tested where the thickness of the outer sheet was 0.0406 cm (0.016 in.), the middle sheet 0.0254 cm (0.010 in.), and the inner sheet 0.1525 cm (0.060 in.) for a combined thickness of 0.218 cm (0.086 in.). The equivalent single sheet thickness required to meet the 0.90 probability of no penetrations is

$$t_2 = (0.891)\, t_1 = (0.891)\,(1.86) = 1.66 \text{ cm}$$

If the shielding efficiency is assumed constant, which is reasonable since the outer sheet thickness and the spacings are constant, the combined thickness of the three sheet structure required to meet the 0.90 probability of no punctures is

$$t_{eq.} = \frac{1.66}{1.86}\,(0.218) = 0.195 \text{ cm } (0.077 \text{ in.})$$

from which the minimum pressure shell thickness is 0.195 - 0.066 = 0.129 cm (0.051 in.).

Critical Crack Length

Critical crack length is a measure of the damage resistance of the pressure shell. A rupture or a through crack smaller than the critical crack length will result in a leak rather than explosive decompression. The relationship between operating stress, material properties, and critical crack length for a curved panel is

$$\frac{\sigma_h}{\sigma_u} = \frac{(1 - \ell/w)}{C_c \sqrt{1 + \frac{3\ell}{R_p}}}$$

Ref: (Christensen & Denke, ASD-TR-61-207) where ℓ = critical crack length

R = cylinder radius

w = panel width = cylinder length = 1150 cm (452 inches)

$$C_c = 1 + \frac{4.6\ l}{R}$$

R_p = plastic zone notch resistance factor = 30.5 cm (12 in.) for 2219-T87 aluminum

$$\sigma_u = 42,700 \frac{N}{cm^2} \ (62,000\ lb/in.^2)$$

$$\sigma_h = \frac{PR}{t} = \frac{(10.35)\ (203)}{t} = \frac{2100}{t} \frac{n}{cm^2}$$

$$\frac{\sigma_h}{\sigma_u} = \frac{2100}{42,700\ t}$$

$$t = \frac{0.0491}{\sigma_h/\sigma_u}$$

Critical crack length is plotted as a function of membrane thickness in Figure 4.2-14. The probability of no pressure shell penetration is also shown as well as the thickness required to provide the specified ultimate safety factor of 2.0.

The rolling direction of the sheet and the direction of the maximum tensile stress determines the direction of propagation of an unstable crack. Since the rolling direction of the sheet will be axial for the 4.06 m diameter modules and the maximum stress is the hoop stress, unstable cracks will propagate axially. The critical length for a crack oriented in the hoop direction on the 4.06 m (160-in.) diameter cylinder is 56 cm (22 in.) versus 26.2 cm (10.3 in.) for an axial crack with the selected membrane thickness. The critical length for cracks with orientations between the axial and hoop directions is not appreciably affected by the shearing stress across the ends of the crack and is roughly proportional to the tensile stress normal to the crack.

R260

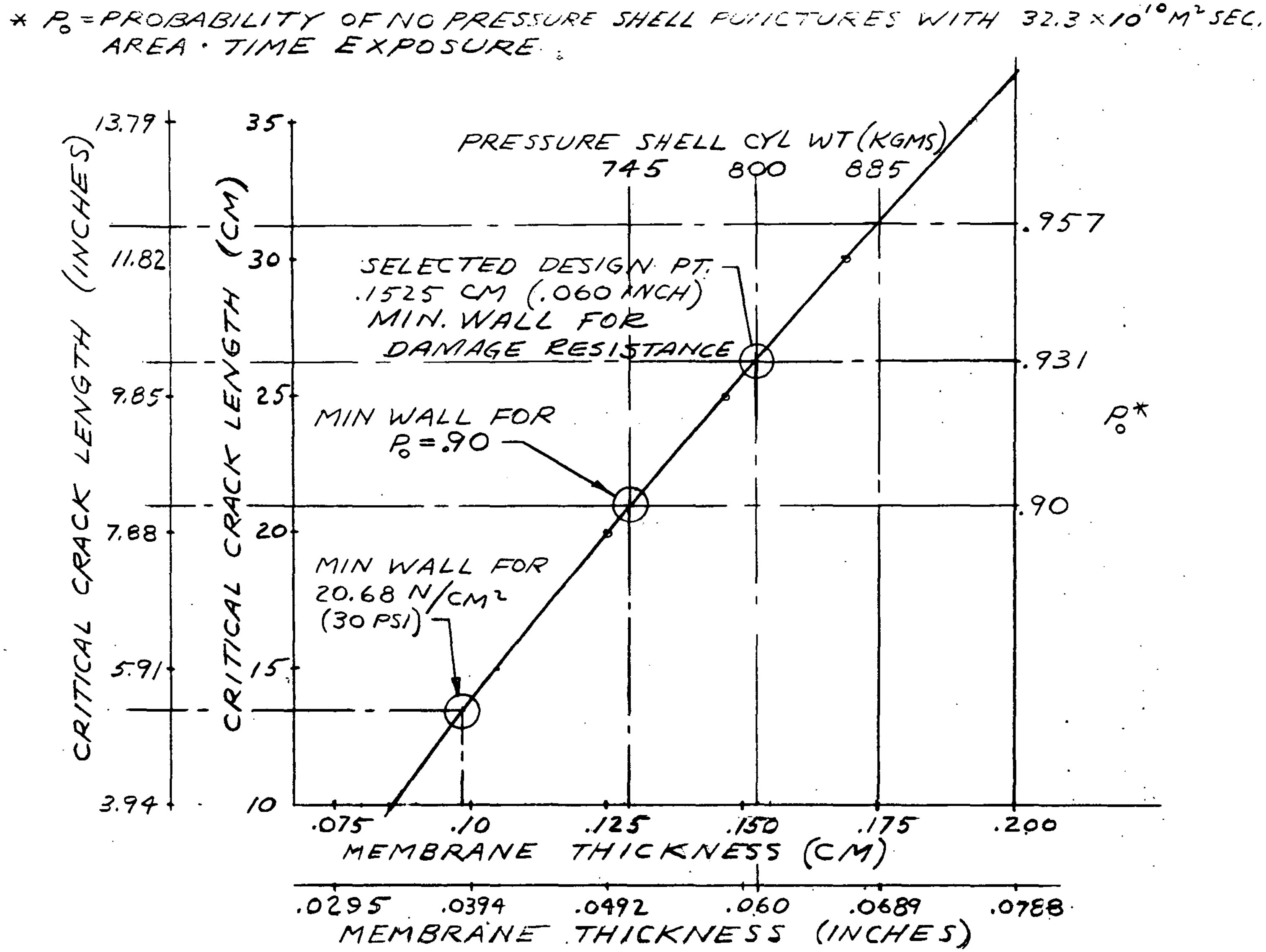


Figure 4.2-14. Membrane Thickness Selection

Rip stoppers to arrest the 26.2 cm critical axial crack must therefore be oriented as frames to be effective, and must be separate rather than integral hoop material so that they bridge the crack without being penetrated by it, since the stress concentration at the crack end is responsible for its continued propagation.

Currently available data indicates the cross-sectional area of a properly sized rip stopper may be approximated as 1/4 of the product of rip stopper spacing times the membrane thickness.

$$A_R = 0.25\ l_s\ t\ .$$

If the rip stoppers are external bands shrunk fit on the pressure shell so that no weight penalty for attachment is incurred, the increase in $\bar{t}$ is

$$\Delta\bar{t} = \frac{A_r}{l_s} = 0.25\ t, \text{ or a 25 percent}$$

increase in pressure shell cylinder weight, if the material is the same as that of the tank wall.

The growth of a crack starting at a stress concentration created by an undected defect is of real concern in the design of pressurized aircraft fuselages because of the large number of fatigue cycles the structure experiences. The possibility of fatigue cycles precipitating slow crack propagation to the critical crack length without detection provides sufficient incentive for the inclusion of rip stoppers in most pressurized fuselage designs.

The Space Station cabin will experience a very limited number of fatigue cycles and a through penetration of any magnitude will be rapidly discovered from the flight record of nitrogen use rate. Fatigue crack propagation is therefore not critical for the Space Station and the only reasonable source of a rupture of critical crack-length proportions is an onboard accident such as the failure of rotating equipment (a centrifuge, fan blade, or centrifugal pump for example).

Integral stiffeners sized for the flight loads are not effective in arresting a fast crack once initiated. They do, however, decrease the probability of fast-crack initiation by increasing the damage resistance of the pressure shell.

For design of the Space Station modules, the chosen approach has been to select a circumferential rib spacing smaller than the critical crack length with the rib heights equal to the full plate thickness to provide good inherent damage resistance, and a membrane thickness to provide a critical crack length large enough to preclude its being exceeded by any plausible onboard accident. The 20.3 cm (8-in.) circumferential rib spacing and the 26 cm (10.3-in.) critical crack length which the 0.152 cm (0.060-in.) membrane provides, should meet this design objective. Refer to section 4.2.3.15 for analysis of integral rib size and spacing.

<u>Module/Orbiter Structural Interface</u>

For design of the Space Station modules to proceed independent of definition of the Orbiter final structural design, the Module/Orbiter structural interface must be statically determinant. To eliminate bending and axial load interaction between the Orbiter fuselage and the Space Station modules (as well as accommodating temperature differentials and tolerances) the fore and aft loads must be reacted at a single station.

Several statically determinant mounting arrangement have been conceived. To accommodate a wide range of payload lengths without added structural weight on the payload or the Orbiter, the fore and aft loads should be reacted at the forward end of the payload close to the docking adapter to simplify its engagement after launch. An attractive 5-point mounting arrangement, selected for design of the Space Station modules, which eliminates torsional, bending, and axial load coupling between the Orbiter and payload, is shown with the interface fittings in the section which follows. Because of its high-strength weight ratio and low thermal conductivity, 6AL4V titanium is used for all the module support fittings which extend out beyond the insulation blanket to engage the Orbiter structure to minimize orbital heat transfer from the pressure shell through radiation from the exposed fittings. Bridging the gap between the module structure and the cargo bay structure with fittings on the module rather than the Orbiter is required to accommodate a wide range of payload lengths without modification of the cargo bay. Lateral loads are reacted at a channel shaped keel, and vertical loads at the cargo bay door jamb with the door hold-down latches.

4.2.3.2 Docking Structure

The docking interface assembly is shown in Figure 4.2-15, (also 4.2-35 and 4.2-38 in subsection 4.2.38). The outside diameter of the interface ring is 2.59 m (102 in.) and the ring depth is 38.1 cm (15 in.). The opening at the center of the ring, which must meet the requirement specified in the study guidelines for 5-feet clear opening at the docking ports, is 159 cm (62.5-in.) long, and 152.5 cm (60-in.) wide. The docking port hatch is designed to pass through the opening. The ring flat pressure bulkhead is supported by 24 pairs of equally spaced gussets, with ribs supporting the 0.152 cm (0.060-in.) membrane between the gussets.

The gussetted-ring is machined from a hand-forged, rough-machined, heat-treated, compression-stress-relieved billet of 2219 aluminum which is artifically aged from the T652 to the T87 temper after final machining.

Docking interface latches and the latch fittings they engage are mounted between alternate pairs of gussets.

4.2.3.3 EC/LS Radiator/Meteoroid Shroud/Thermal Insulation Assembly

Each of the three Space Station modules has an active and a redundant radiator system, either of which is capable of accommodating the nominal module heat load. To maximize the radiator heat-rejection capability, however, the inlet and return manifolds for the active and redundant radiators are located 90-degrees apart so that the radiator with the better orientation relative to the sun at a particular time can be selected as the active system.

The extruded radiator tubes, which are an integral part of the radiator/ meteoroid bumper to minimize the temperature drop between the radiator

R260

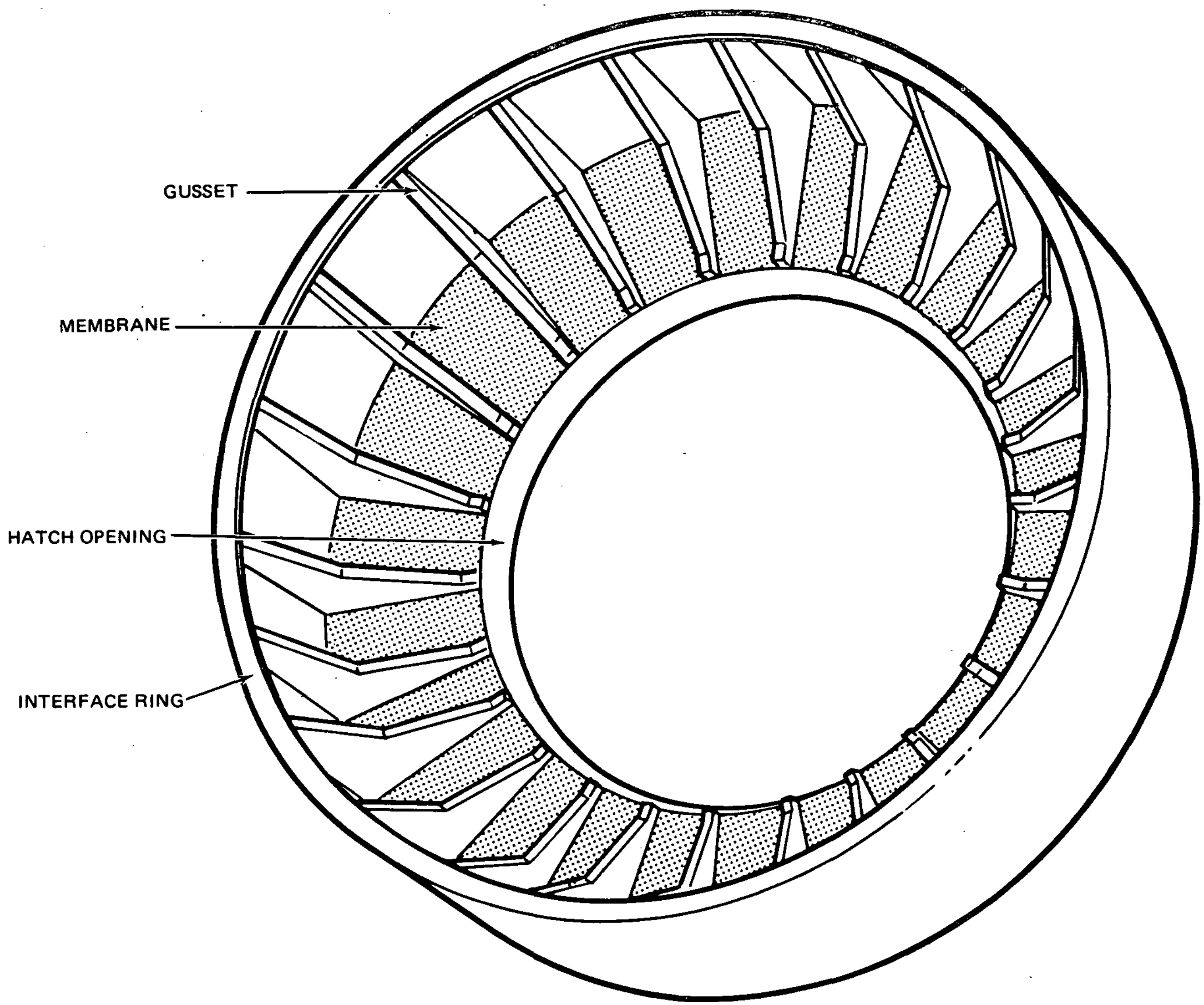


Figure 4.2-15. Docking Interface Structure

fluid (Freon 21) and the radiating surface, are longitudinally oriented and equally spaced 5 degrees apart. The manifolding is arranged so that each fluid-pass travels half way around the vehicle circumference so that the outlet is located 180 degrees away from the inlet. The number of tubes in parallel is selected so that with a tube diameter of 0.483 cm (0.190 in.), which is the smallest diameter it is practical to extrude, the flow rate gives a Reynolds number in excess of 10,000 to maximize the heat-rejection capacity. The serpentine tube arrangement with the opportunity (within 90 degrees) to select the inlet location, allows the fluid to flow in the direction of decreasing heat sink.

The radiators for each module are divided into forward and aft assemblies which are identical except as required by local cutouts. The completed forward and aft radiator/meteoroid shroud assemblies are installed by sliding over opposite ends of the module and attaching through fiberglass thermal isolation bands to the integral conical flanges on the end docking rings as shown in Figure 4.2-16. The assemblies are supported laterally by a common fiberglass frame at the module center, with sufficient separation of the assemblies to allow for thermal expansion relative to the pressure shell. Thermal expansion occurs during launch and reentry in the Orbiter cargo bay. Details of the center support and manifolds at the side docking ports are shown in Figure 4.2-17.

To provide a 0.99 reliability for the Thermal Control System on each module, meteoroid shielding for the tubing must be sized so that both the active and the redundant radiators have a 0.90 probability of sustaining no puncture or spalling of a tube in a 10-year mission. So that a common extrusion may be used for all the modules, the shielding is sized for the GPL which has the greatest length of tubing, and thus the greatest exposed area. The GPL has 72 tubes in each radiator (5-degree spacing) and the tubes cover the full length of the module cylinder. The length of the tubing for one radiator is 830 m (2,720 ft). The exposed surface area that corresponds to this length of tubing is dependent on the separation distance of the tubing from the bumper sheet. The thickness of the tubing to provide a 0.90 probability of

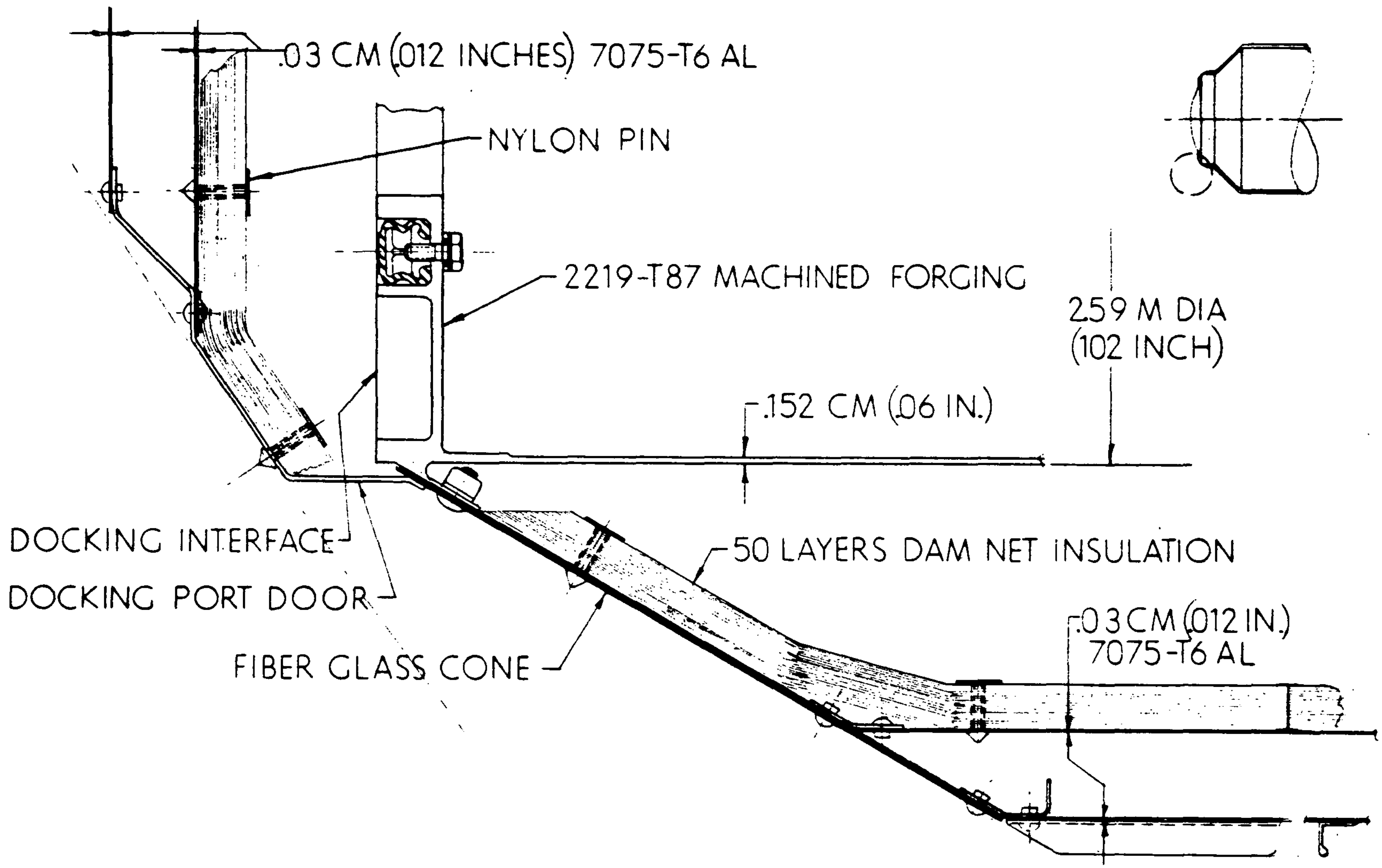


Figure 4.2-16. Radiator/Meteoroid Shroud Attach End

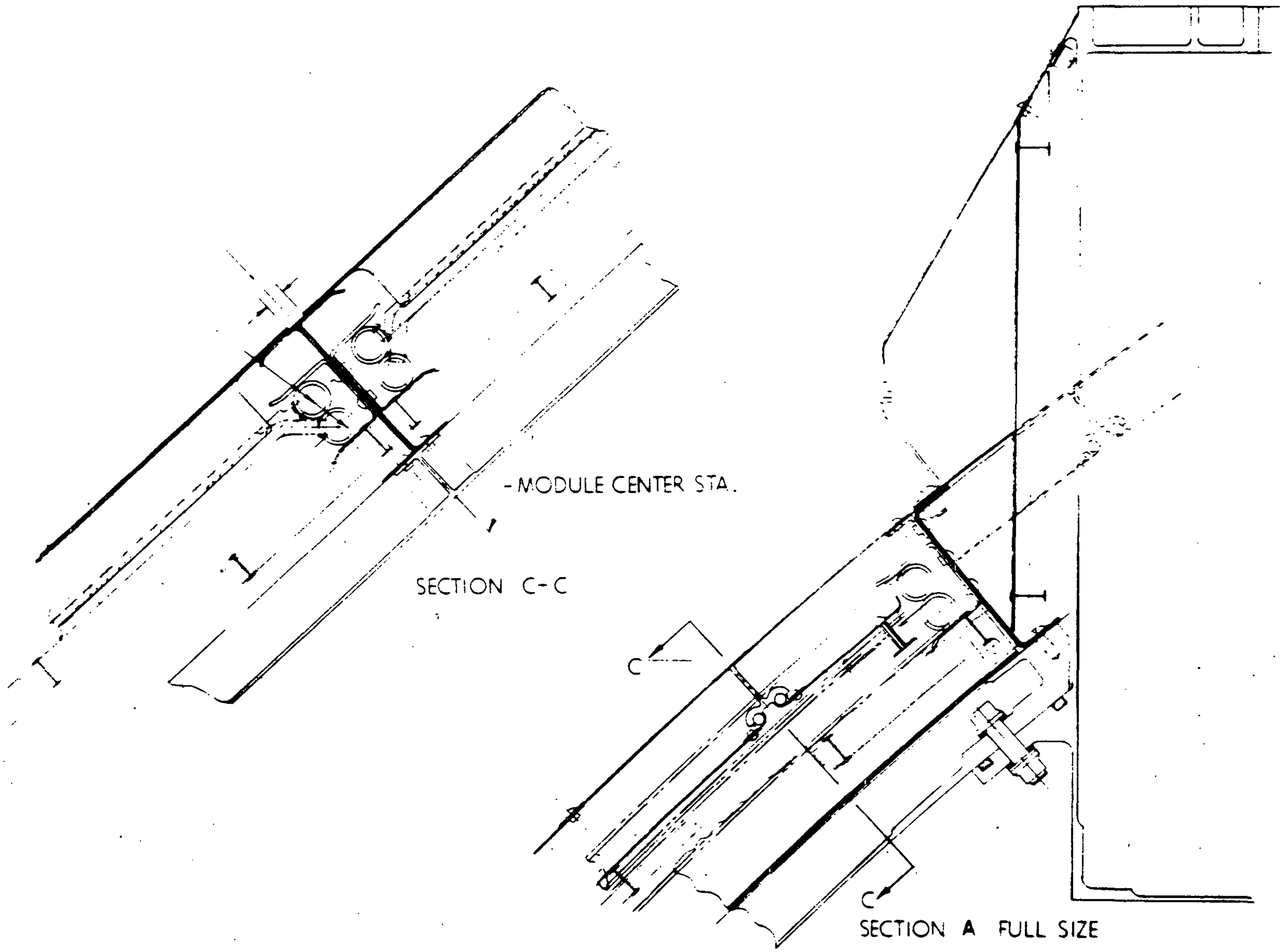


Figure 4.2-17. Radiator/Meteoroid Attachment Center

no punctures in 10 years is a function of the exposed area and the shielding efficiency which is also a function of the spacing between the tubing and the bumper. The thermal capacity of the radiator is a function of the temperature drop between the radiator fluid and the fin. This temperature drop is a function of the standoff distance and the thickness of the leg. As the standoff distance is increased, the weight of shielding required to provide the 0.99 reliability is reduced but the weight of the standoff leg increases sharply to maintain a specified temperature drop. To select the optimum (minimum weight) extrusion geometry, the width of vulnerable area for a single tube is assumed to extend from the intersection of a 45-degree tangent to the tubing outside diameter with the exterior surface of the bumper. The tubing OD is 0.635 cm (0.250 in.) and the ID is 0.483 cm (0.190 in.).

The permissible penetrating flux is calculated from $N = U/AT$ (S.F.) where $U = 1-P_o = 0.1$ = the expected number of punctures. $T = 3.15 \times 10^8$ = the number of seconds in 10 years. S.F. = 0.67 = Earth shielding factor at orbit altitude. The meteoroid mass which the shielding must defeat is given by the flux/mass relationship $\log N = -14.37-1.213 \log m$ from which $m = 1.48 \times 10^{-12}/N^{0.824}$ where m is the largest meteoroid mass in gms which will just fail to produce spall from the tubing wall and N is the flux in impacts per square meter per second as determined above.

The armor plate thickness required to defeat a meteoroid mass m is given by $t_a = K_1 \rho^{1/6} m^{0.352} V^{0.875}$ from NASA SP8013 where K_1 is dependent on the shielding material. $K_1 = 0.54$ for aluminum. ρ is the meteoroid density = 0.5 gms/cc. m is the meteoroid mass in gms. V is the average meteoroid impact velocity = 20 km/sec and t_a is the thickness of the armor shield in cm.

The thickness of the tubing shielding t_s is calculated by multiplying the armor shield thickness t_a by a shielding efficiency factor K_2. The thickness of the tubing wall t_w is t_s minus the bumper thickness of 0.041 cm (0.016 in.). The results of these calculations are summarized in Table 4.2-2 where h is the separation distance between the tubing center and the bumper.

Table 4.2-2

RADIATOR TUBE SIZING

h(cm)	N	m(gms) $\times 10^{-3}$	t_a(cm)	K_2	t_s(cm)	t_w(cm)
1.27	2.43×10^{-11}	0.817	0.544	0.80	0.435	0.394
2.54	1.58×10^{-11}	1.165	0.610	0.50	0.305	0.264
3.81	1.17×10^{-11}	1.497	0.670	0.35	0.234	0.193
5.08	0.93×10^{-11}	1.805	0.710	0.27	0.192	0.151

The average heat load of the GPL is 12,880 watts (43,936 Btu/hr). With 83,000 cm of tube length, the average heat transfer per cm is 12880/83000 = 0.155 watts/cm (1.35 Btu/hr-in.). The conductivity of the 6101-T6 extrusion is 216 watts/M^{o}K (125 Btu/hr ft^{2} ^{o}F/ft). The extrusion leg weight is shown as a function of temperature drop between the radiator fluid and fin and leg height (h) in Table 4.2-3 together with the shielding weight, assuming that it is the weight of thickness added to an 0.076 cm (0.030 in.) wall to equal t_w, and the increased thickness is added around the outer 180 degrees of tube circumference.

The data presented in Table 4.2-3 are summarized in Figure 4.2-18. The minimum weights are cross plotted in Figure 4.2-19 to show the effect of Δt on the radiator weight. The 1.11^{o}K (2^{o}F) Δt is selected as the design point because of the high ratio of required thermal capacity to available radiator area on the power module, and the desire to use a common radiator extrusion for all modules. The resulting optimized extrusion geometry is shown in Figure 4.2-20.

4.2.3.3.1 Ballistic Limit Test of the Radiator Tubing

Tubing with a wall thickness of 0.254 cm (0.1 in.) was fabricated from 6101-T6 aluminum bar stock as shown in Figure 4.2-21. Four of these 6-in.-long sections of tubing were filled with Freon and the ends plugged. The four sections were then located 2.54 cm (1 in.) in back of an 0.041 cm (0.016-in.) bumper. An aluminum projectile weighing 0.047 gms (1/8-in. diameter) and traveling 6.4 km/sec (21,000 ft/sec) impacted this target.

Table 4.2-3

RADIATOR TUBE SELECTION

			(1)	(2)	(3)	(4)	(5)
			0.555°K	1.11°K	1.66°K	2.22 K	2.78°K
h(cm)	Shielding weight		leg weights				
	(kgm)	(lb)	(kgm)				
1.27	218	(480)	47.2	24.1	16	12	9.4
2.54	112	(246)	193	96.4	64	48.1	38.6
3.81	63.1	(139)	429	217	144	108	86.6
5.08	37.7	(83)	770	386	257	193	154

The point of impact on the bumper was directly over the center of one of the tubes. There was no loss of Freon from the tube or spall inside, although the tube was bulged on the back and sides and very nearly penetrated on the front side.

From the single-sheet penetration equation $t = k_1 \rho^{1/6} m^{0.352} V^{0.875}$, the equivalent armor shield thickness is

$$t = 0.54\ (2.77)^{1/6}\ (0.047)^{0.352}\ (6.4^{0.875} = 1.11 \text{ cm } (0.437 \text{ in.})$$

The thickness of the bumper plus tubing was 0.305 cm (0.016 + 0.104 in.). The shielding efficiency factor from test is thus k = 0.305/1.11 = 0.275. The efficiency factor assumed for one-inch spacing in the analysis to size the shielding was 0.50, and therefore too conservative.

With 2.54 cm (1-in.) spacing between the tubing and bumper, and assuming a 90-degree apex angle for the debris cone, the vulnerable area of the tubing for one of the GPL radiators is 31 m^2 (32,600 in. of tubing). Using the single sheet penetration equation for scaling, the ballistic-limit-mass meteoroid is 0.0062 gms from the light-gas-gun range test. The resulting penetration rate from log N = - 14.37 - 1.213 log M is 2.03 x 10^{-12} penetrations/m^2 sec. With an Earth shielding factor of 0.67, the expected

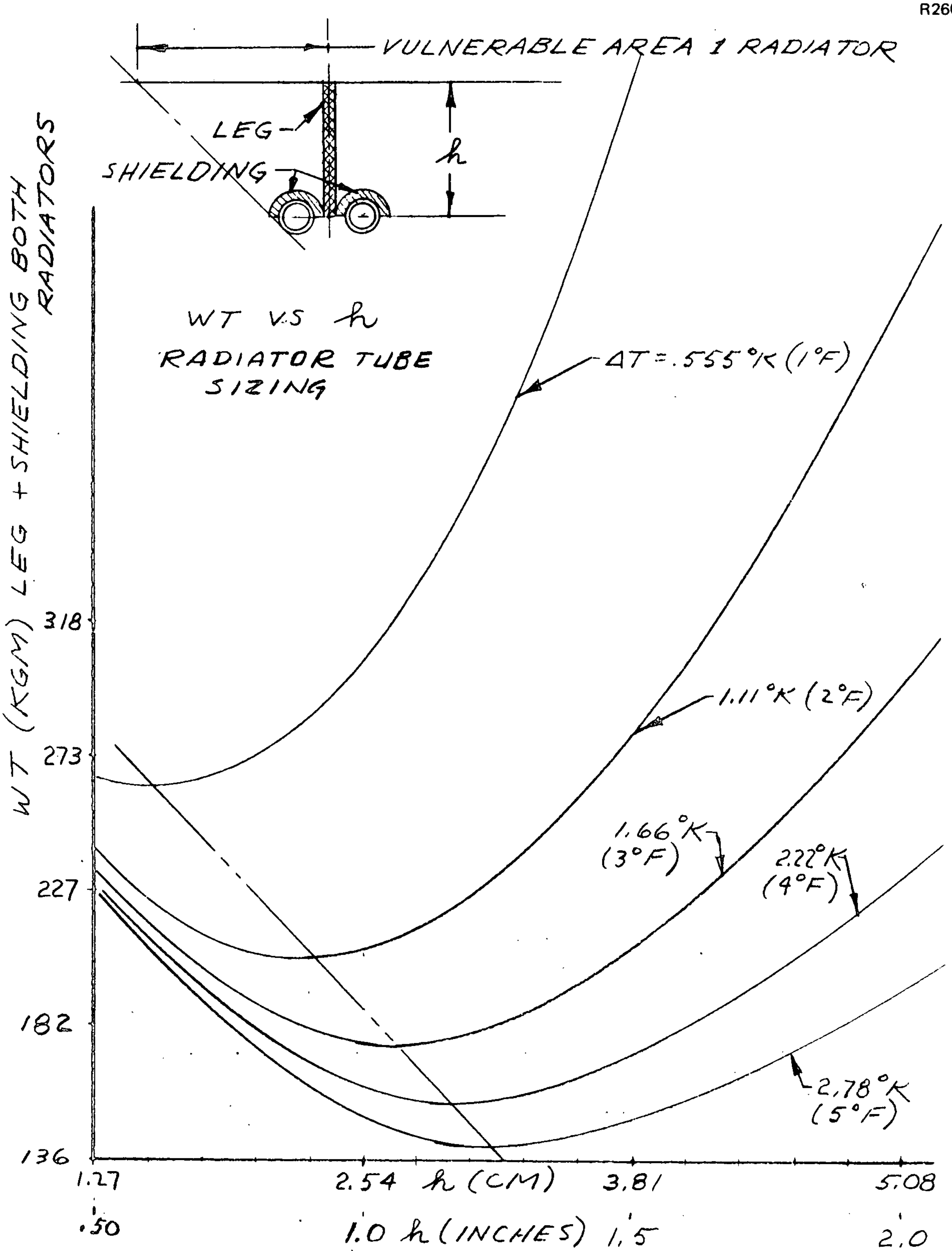


Figure 4.2-18. Radiator Tube Sizing

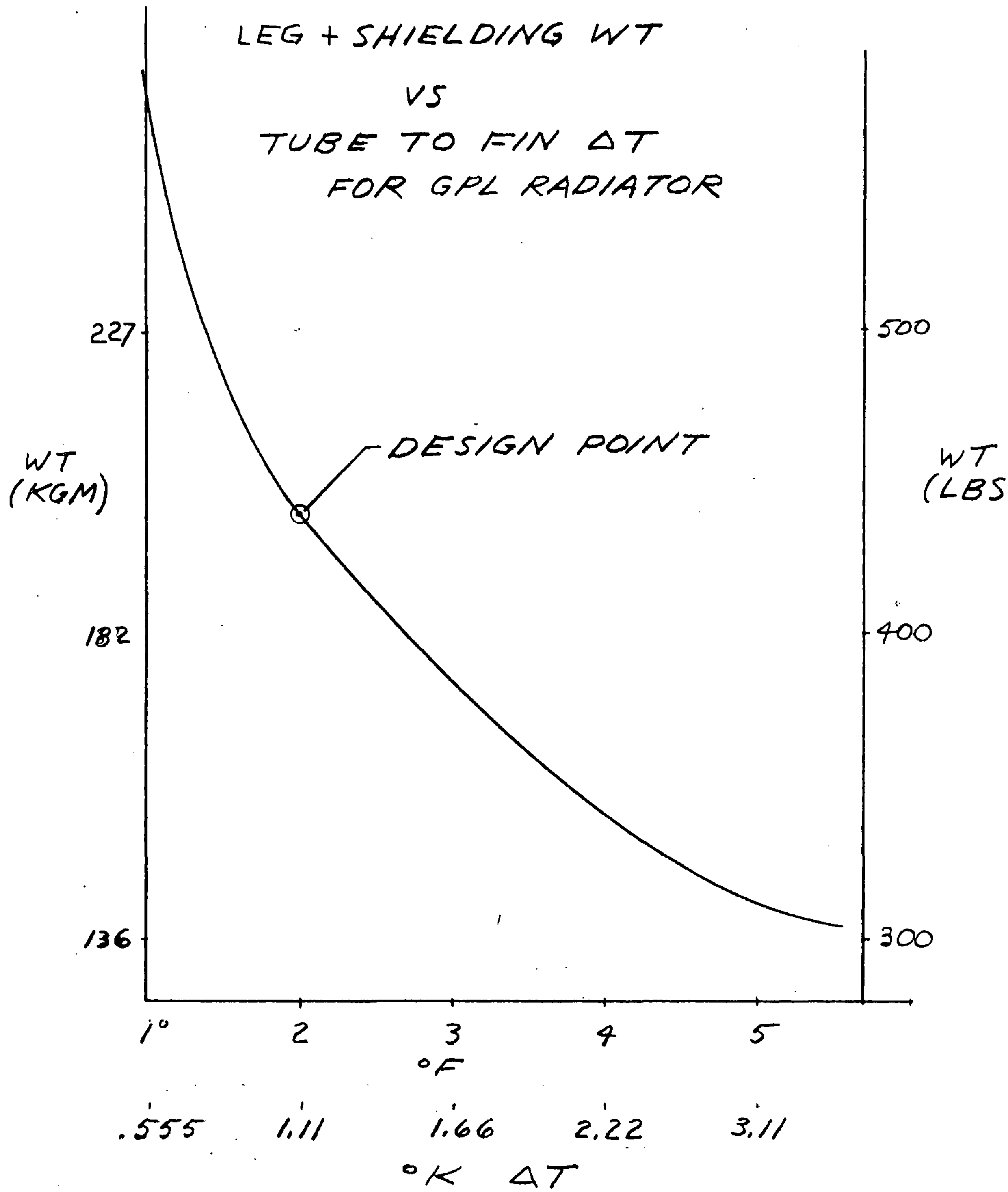


Figure 4.2-19. Radiator Tube Design Weights

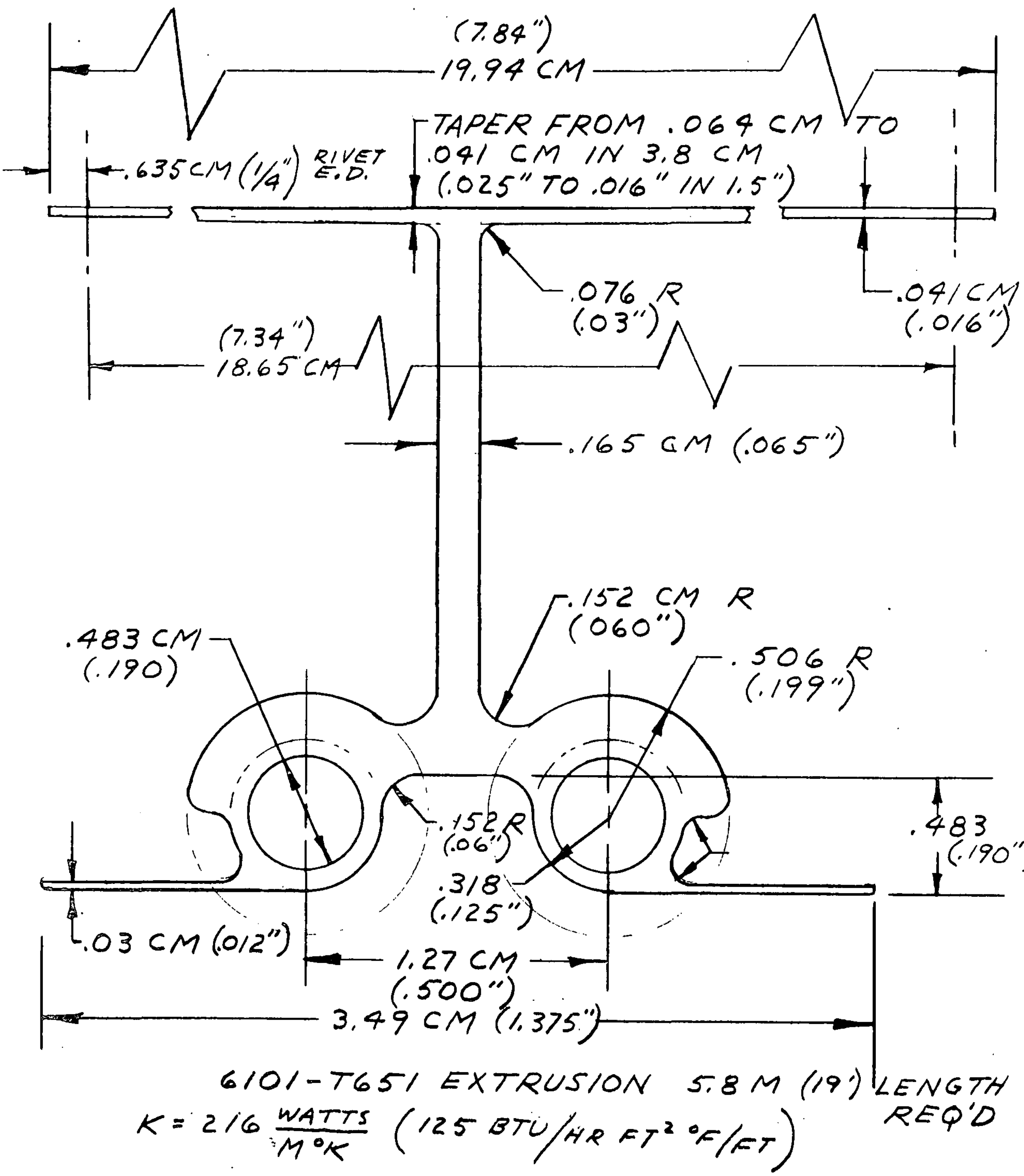


Figure 4.2-20. Radiator Extrusion

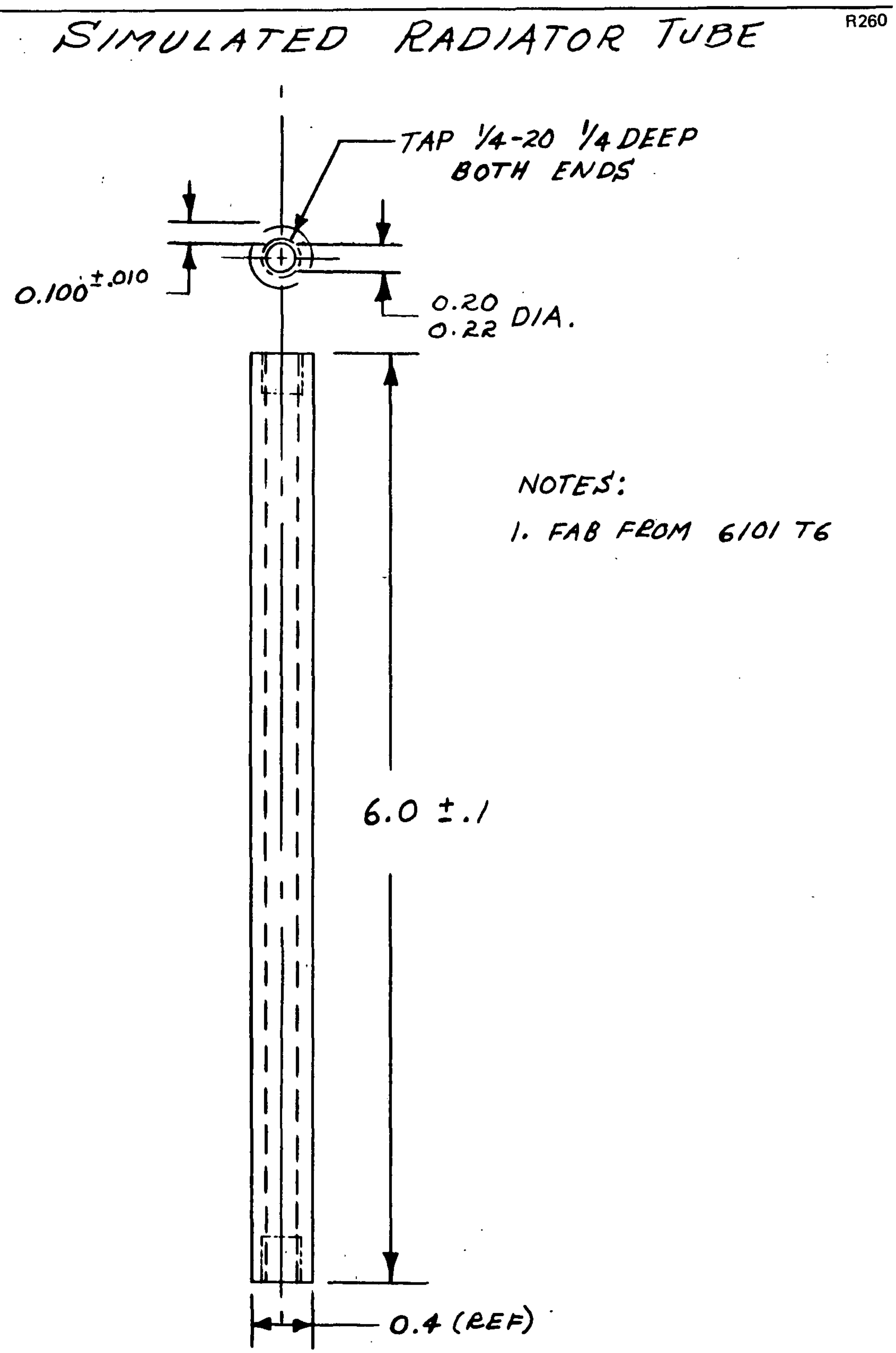


Figure 4.2-21. Radiator Tube Simulation for Test

number of penetrations on the 10-year mission is U = (S.F.) NA t = 0.0133 and the resulting probability of no penetrations for one of the GPL radiators is P_o = 0.9867. The probability that one, or the other of the GPL radiators will survive the 10-year mission without a meteoroid penetration is 0.9998, scaling from the hypervelocity ballistic limit test.

The radiator reliability selected for initial sizing of the tube shielding was 0.99. Tests show the puncture resistance of the Freon-filled tubing to be much greater than anticipated. Tubing with a wall thickness of 0.089 cm (0.035 in.) spaced 1.27 cm (0.50 in.) in back of an 0.041 cm (0.016-in.) bumper meets the selected reliability from a ballistic limit test of this configuration shown in Figure 4.2-22.

4.2.3.3.2 Sonic Fatigue Analysis

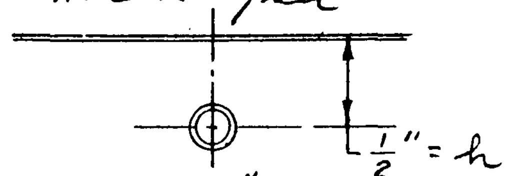
The wall section illustrated in Figure 4.2-23 is idealized for sonic fatigue analysis as a flat panel of 7.84-in. width and infinite length 0.016-in. thick.

Assuming supported edges, the fundamental frequency is 25 Hz and with clamped edges, 50 Hz. The fatigue analysis will assume a semiclamped edge resulting in a natural frequency of 40 Hz. A four-minute exposure to the environment results in approximately 10^4 fatigue cycles. The acoustic environment in the cargo compartment is given by Figure 4.2-24.

The octave-band, sound-pressure level of 138 db at 40 Hz results in a spectrum level (db_r) of 123 db. For these conditions, if no stress relief were incorporated at the supports, a panel thickness of 0.025 in. (rather than 0.016 in.) would be required; but since the extrusion process can readily achieve a decreased stress concentration at the edge through tapering (decreasing from 0.025 in. at the radiator tube to 0.016 in., 1.5 in. into the panel), the design will take advantage of this effect. Figure 4.2-25 illustrates that for a life of 10^4 cycles, db_r of 123 db, and span of 7.84 in., a mid-span minimum skin thickness of 0.014 in. is acceptable for the cargo bay acoustic environment.

5.7 mgm @ 23,000 ft/sec

7.02 Km/sec



.250" O.D.
.180" I.D.
.035 WALL
.016
.051"
.129 cm

$t = K_1 \rho^{\frac{1}{6}} m^{.352} V^{.875}$

$t = .54\,(2.77)^{\frac{1}{6}}(.0057)^{.352}(7.02)^{.875}$

$t = .54\,(1.185)(.162)(5.5)$

$t = .57$ cm

$K = \dfrac{.129}{.57} = .226$

$A = [21h + 9] = (21)\tfrac{1}{2} + 9 = 19.5\ m^2$ vulnerable area

$$m_m = m_r \left[\left(\frac{\rho_r}{\rho_m}\right)^{\frac{1}{6}} \left(\frac{V_r}{V_m}\right)^{.875}\right]^{\frac{1}{.352}} = .0057\left[\left(\frac{2.77}{.5}\right)^{\frac{1}{6}}\left(\frac{7.02}{20}\right)^{.875}\right]^{2.84}$$

$$m_m = (.0057)\left[\frac{1.326}{.53}(.4)\right]^{2.84} = (.0057)(.165) = 9.4 \times 10^{-4}$$

$\log N = -14.37 - 1.213 \log m$

$$N = \frac{4.26 \times 10^{-15}}{(.00094)^{1.213}} = \frac{(4.26 \times 10^{-15})}{.00021} = 2.03 \times 10^{-11}$$

$U = (S.F.)NAt = .67\,(2.03 \times 10^{-11})(19.5)(3.16 \times 10^{8})$

$U = .0837$

$P_0 = e^{-U} = 1 - U + \dfrac{U^2}{2!} - \dfrac{U^3}{3!}$

$P_0 = .9163$ probability of no punctures of one GPL radiator

$(.0837)^2 = .0070$

$P_0 = .993$ probability of no punctures of one or the other of the GPL radiators

Figure 4.2-22. Radiator Puncture Probability

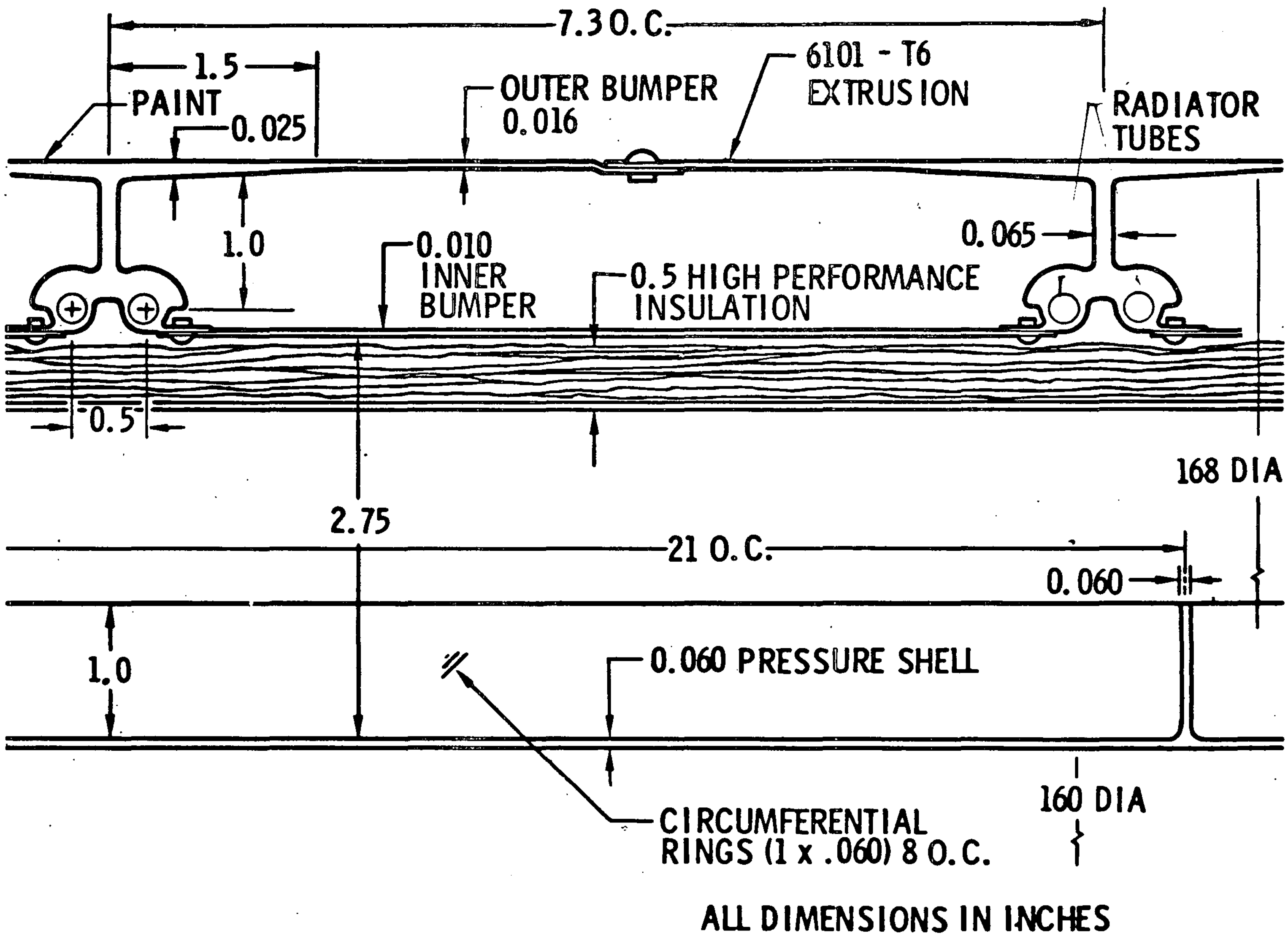


Figure 4.2-23. Typical Wall Configuration

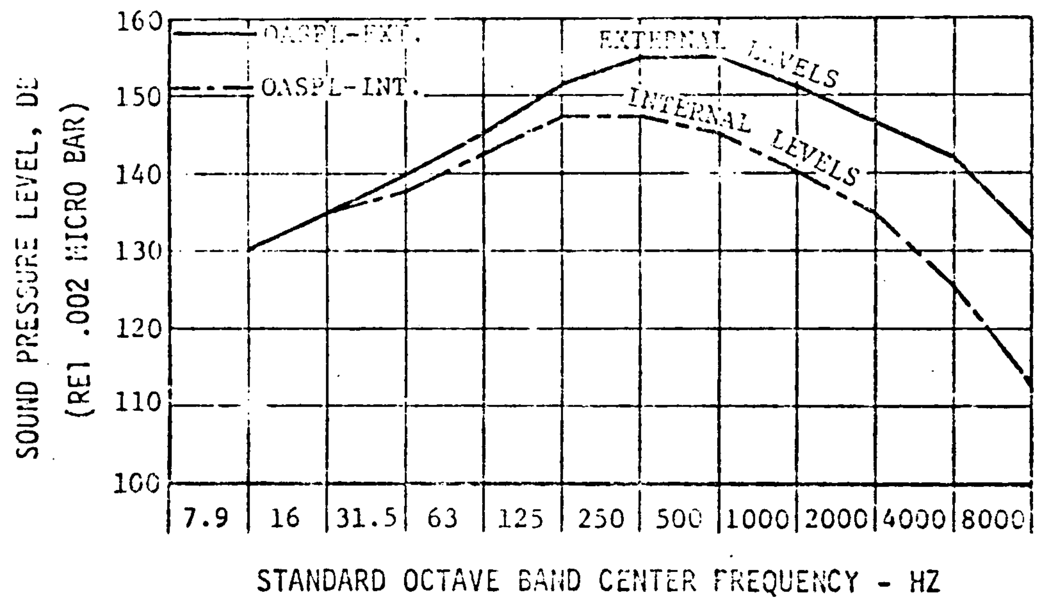


Figure 4.2-24. Frequency Spectrum

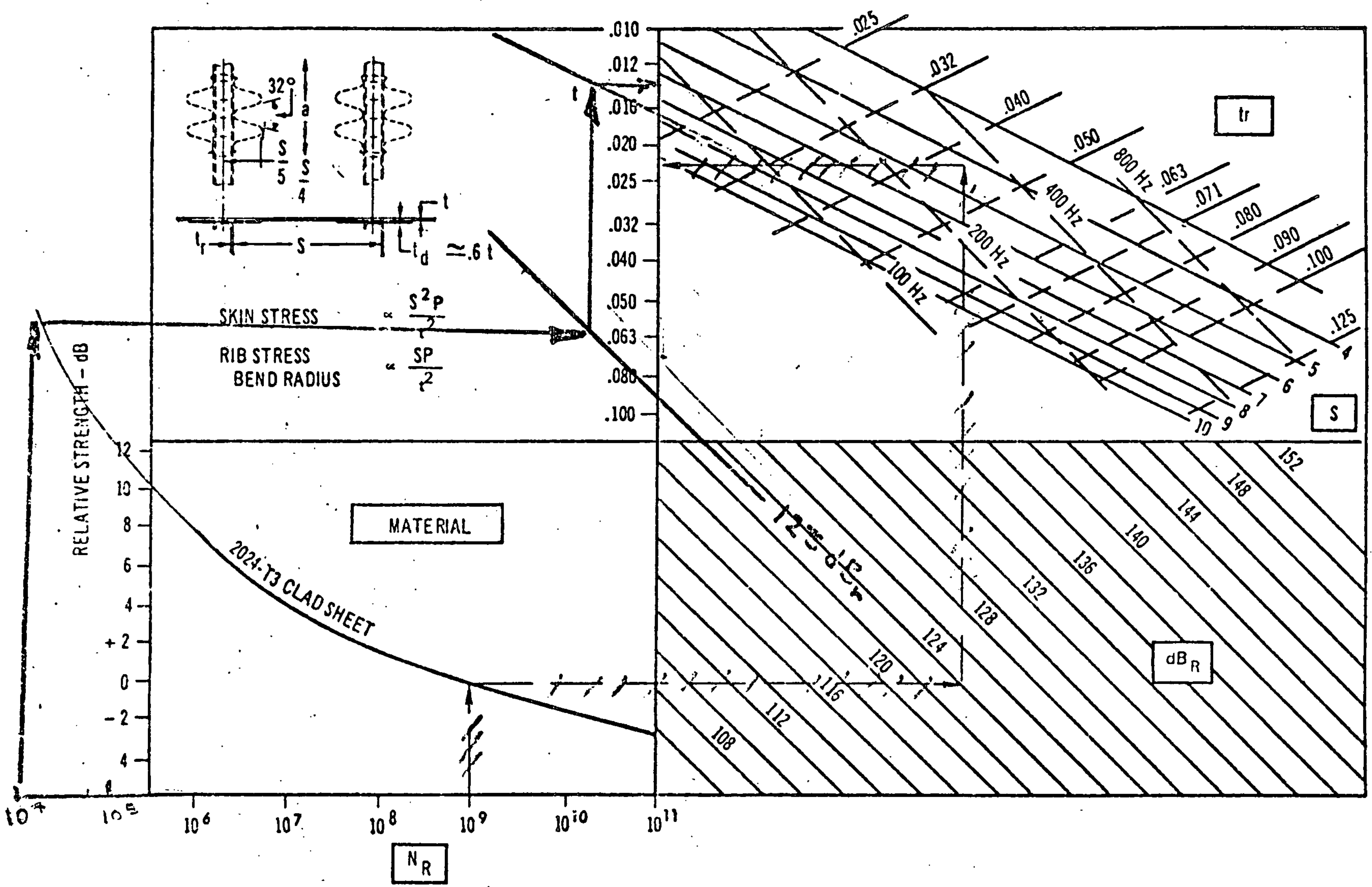


Figure 4.2-25. Acoustic Design Chart

4.2.3.3.3 Ballistic Limit Test of the Insulation Meteoroid Shield

The ballistic limit of the meteoroid shield for the insulation on the MDAC-designed 10 m (33-ft) diameter Space Station was determined in the light-gas-gun facility. The shield consisted of an outer bumper of 0.051 cm (0.020-in.) aluminum spaced 4.3 cm (1.625 in.) from an inner bumper of 0.025 cm (0.010-in.) aluminum. This shield stopped an 0.006 gm aluminum projectile traveling 7.65 km/sec (25,100 ft/sec).

The insulation shield for the Modular Space Station consists of an 0.0406 cm (0.016-in) aluminum outer bumper spaced 2.86 cm (1.125-in.) from an 0.025 cm (0.010-in.) aluminum inner bumper. Since the outer bumper is still thicker than required to vaporize the ballistic-limit-size projectile for the shield, the change from 0.020 to 0.016 in. will not affect the ballistic limit. Since the ballistic limit is roughly proportional to the square of the separation distance between bumpers, the ballistic limit for the modular space station insulation shield, from the prior test, is

$$m_r = 0.006 \left(\frac{1.125}{1.625}\right)^2 = 0.00278 \text{ gm aluminum projectile at } 7.65 \text{ km/sec}$$

Using the single sheet penetration equation $t = K_1 \; \rho^{1/6} m^{0.352} V^{0.875}$ from NASA SP8013 for scaling, the meteoroid mass the shield will just stop is

$$m_m = m_r \left(\frac{\rho_r}{\rho_m}\right)^{0.474} \left(\frac{V_r}{V_m}\right)^{2.48} = 0.00278 \left(\frac{2.77}{0.5}\right)^{0.474} \left(\frac{7.65}{20}\right)^{2.48}$$

$$= 0.000584 \text{ gms.}$$

From the flux mass relationship

$$\log N = -14.37 - 1.213 \log m$$

the penetrating flux for the insulation shield is

$$N = \frac{4.6 \times 10^{-15}}{(0.000584)^{1.213}} = 3.55 \times 10^{-11} \ \frac{\text{pen.}}{\text{m}^2 \cdot \text{sec}}$$

The integrated area times exposure time for the proposed 10-year Modular Space Station mission is (from Table 4.2-1)

$$\sum At = 32.3 \times 10^{10} \ \text{m}^2 \ \text{sec}$$

The expected number of penetrations of the insulation shield is then

$$U = NA \ t \ S.F. = (3.55 \times 10^{-11}) \ (32.3 \times 10^{10}) 0.67 = 7.69$$

If 45 degrees is assumed for the half angle of the conical debris cloud, and the cone height is the distance from the outer bumper to the center of the insulation (3.49 cm (1.375 in.)), the area of insulation anihilated per penetration is

$$A = \pi \ (3.49)^2 = 38.3 \ \text{cm}^2 \ (5.94 \ \text{in.}^2)$$

and the area anihilated in the 10-year mission is

$$A = (8) \ (38.3) \ 10^{-4} = 0.0306 \ \text{m}^2.$$

Since the total exposed area is 1,280 m^2, the percentage of insulation destroyed is (0.0306/1,280) 100 = 0.00239 percent.

4.2.3.3.4 Insulation Purge

The high-performance insulation must be protected from moisture condensation and corrosion after the panels are fabricated, through launch, and into orbit. A purge system is being used on Skylab which provides a GN_2 gas flow through the insulation blankets. The Space Station module design is such that a similar system can be used. The weight of the purge system which would have to be installed in the modules would consist primarily of a small distribution duct at each end. An allowance is made in the module structure weight to account for items of design detail which will be defined during Phase C/D.

4.2.3.4 Solar Array Support Tunnel

As shown in Figure 4.2-26, the solar array turret is supported off the forward end of the Power/Subsystems Module by a pressurized length of tunnel which provides access between the turret and the module. This tunnel is 5.85 m (230-in.) long and 1.02 m (40-in.) inside diameter. The tunnel membrane is stiffened by integral ribs in an isogrid pattern. It is machined in the flat in two sections which are then brake-formed to contour and welded. The tunnel material is 2219-T87 aluminum.

The stiffness of the tunnel must be established to preclude resonant coupling with the Space Station control frequency of 0.01 cps. The frequency of the fundamental mode of vibration of a uniform cantilever beam with a concentrated mass at the end

$$f_1 = 0.28 \sqrt{\frac{EI}{\left(m + \frac{33}{40}\mu\, l\right) l^3}}$$

where μ is the mass per unit length of tunnel, m is the mass of the turret plus solar array, and l is the distance to the cg of the turret. The insulated tunnel plus meteoroid shroud weighs 113 kgm (249 lb). The turret plus solar array weighs 1,802 kgm (3,973) lb. The cantilevered distance to the cg of the turret is 7.32 m (24 ft).

The tunnel membrane is 0.127 cm (0.050 in.) with 50-percent stiffening for the isogrid pattern of integral ribs, so that the weight equivalent monocoque thickness is 0.190 cm (0.075 in.). The EI product for the tunnel is then

$$EI = E\pi R^3 t = (6.9 \times 10^6)(3.14)(50.8)^3\,(0.190) = 54.2 \times 10^{10}\ \text{n cm}^2$$

and the fundamental frequency is

$$f = 0.28 \sqrt{\frac{54.2 \times 10^6}{[1,802 + \frac{33}{140}(113)]\,(7.32)^3}} = 2.4\ \text{cps}$$

Since a fundamental frequency 10 times the control frequency or 0.1 cps would preclude control system coupling, it is apparent that the stiffness requirement does not design the tunnel for normal operation.

The isogrid tunnel can be designed to work to a stress of 20,700 n/cm^2 (30,000 psi) in bending. The unit loading the unpressurized tunnel can be expected to carry is N_b = 20,700 (0.190) = 3,940 n/cm (2,250 lb/in.) and the ultimate bending moment is

$$M = \pi R^2 n_b = (3.14)(50.8)^2 (3,940) = 3.19 \times 10^7 \text{ n cm } (236,000 \text{ ft-lb})$$

With the tunnel pressurized to one atmosphere, which is the normal operating condition, the ultimate bending moment will be 3.62×10^7 n cm (267,000 ft-lb). Since this exceeds the bending moment the tunnel can experience from the Reaction Control System on an Orbiter docked at the end docking port of the GSS configuration, the tunnel $\bar{t}$ of 0.190 cm (0.075 inches) is considered adequate.

Attention to the dynamic effects of docking impact upon the solar array support tunnel and the solar array deployment structure should be undertaken in the near future.

4.2.3.5 Solar Array Turret Structure

The turret pressure shell is machined on an omni mill in two halves from thick walled, forged hemispheres of 2219-t87 aliuminum which are welded together. The four integral flanges on the truncated sphere are then faced in a vertical boring mill in preparation for the three drive assemblies and the conical transition structure at the docking end which bolt to them. The structural configuration is shown in Figure 4.2-27. The bolted joints are all sealed with vacuum baked, resin-cured-butyl O-rings.

The turret pressure shell must be designed for 30-psi burst pressure; for a ballistic limit comparable to that of the Space Station Module cylinder; for a stiffness that is high compared to the stiffness of the Astromast to preclude resonant coupling of the deployed array with the control system; and for the

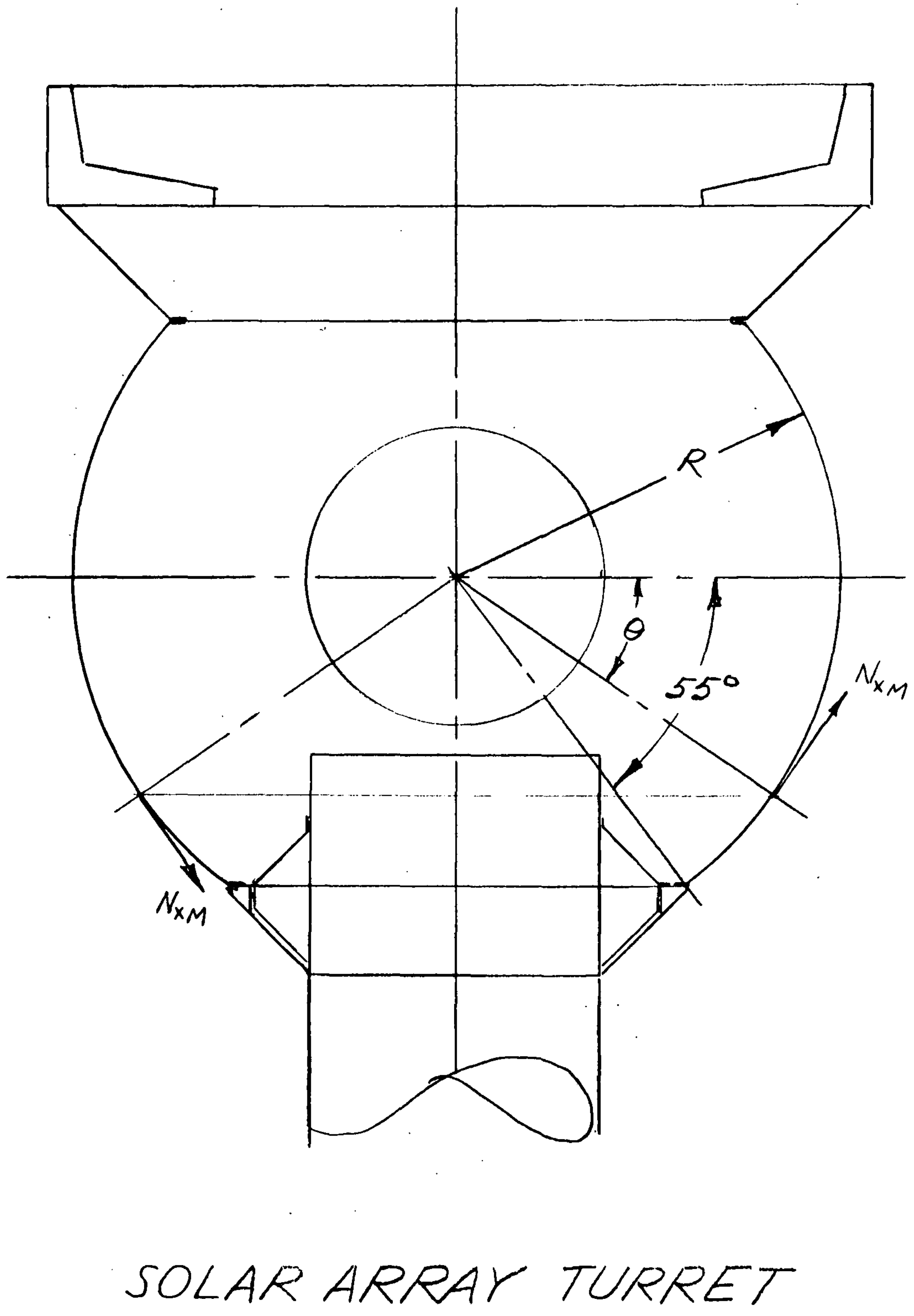


Figure 4.2-27. Solar Array Turret

loads imposed by the Reaction Control System of an Orbiter docked at the end port of the GSS configuration. Since the bending moment in the turret shell from the last requirement can be as high as 262,000 n meters (192,000 ft-lb), it is more critical than the other three. The membrane load in the shell from a bending moment M is

$$N_{X_M} = \frac{M}{\Pi R^2 \cos^3\theta}$$

where R and θ are as noted in Figure 4.2-27. With a design moment of 262,000 newton meters, and the turret radius of 1.22 meters (4 ft),

$$N_{X_M} = \frac{262,000}{\Pi(1.22)^2 \cos^3\theta} = \frac{56,000}{\cos^3\theta} \text{ n/m}$$

The membrane load is maximum when θ is maximum which is at the joint between the spherical shell and the cone where θ = 55 degrees.

$$N_{X_{M(max)}} = \frac{560}{(0.574)^3} = 2,960 \text{ n/cm } (1,690 \text{ lb/in.})$$

With an isogrid pattern of integral ribs, the shell is designed for a compressive stress of 13,900 n/cm^2 (20,000 psi). The $\bar{t}$ of the shell is then

$$\frac{N_{X_M}}{\sigma_c} = \frac{2,960}{13,900} = 0.213 \text{ cm } (0.084 \text{ in.})$$

The moment (M) is transferred to the tunnel through the double cone structure and the two drive mechanism bearings. The bearing separation is 0.51 m (20 in.). The radial load in the bearings from a 262,000 nm bending moment imposed by the docked orbiter is 262,000/0.51 = 513,000 n (115,000 lb). The bearings are 0.915 meters (36 inch) diameter. The maximum load per cm on the bearing is

$$n = \frac{2F}{\pi r} = \frac{2\ (513,000)}{\pi(91.5)} = 3,570 \text{ n/cm } (2,040 \text{ lb/in.})$$

For comparison, the listed limit radial load for a 2.3125 in. ID by 2.875 in. OD Fafnir ball bearing is 10,150 lb. The limit unit load per inch on this bearing (based on the radius at the ball center) is

$$n = \frac{2\ (10,150)}{\pi(2.59)} = 2,500 \text{ lb/in.}$$

Thus the radial load on the bearings from Orbiter Reaction Control System induced bending moment is well within the range for light, commercially available ball bearings of the selected diameter.

The solar array is designed for a load factor of 0.5 g in the plane of the array. The mast is 20.4 m (67-ft) long and each wing weighs 730 kgm (1,630 lb). The design bending moment at the wing/turret interface is therefore (730)(10.2)(9.8).5 = 36,500 nm (27,000 ft-lb). Since the three drives are identical, the bending moment during normal operation is small compared to the design capability of 262,000 nm (192,000 ft-lb).

4.2.3.6 Equipment Support Structure

A structural assembly which can be separated from the module pressure shell as a completed unit is used for equipment mounting. This arrangement permits the equipment to be installed, complete with all interconnecting wiring, and checked out before mating with the pressure shell. While the complete accessibility for equipment installation and checkout, with an attendant reduction in assembly time and cost, is the primary reason for selection of a separate structural assembly for equipment support, the design has another notable advantage. It permits the structural interface with the pressure shell to be arranged so that pressure-induced deflections in the shell do not stress the support assembly or the equipment mounted on it. This permits any part of the assembly to be removed and reinstalled in orbit as access to the pressure shell may require.

The equipment support structure proposed for use in the Space Station Modules is shown in Figures 4.2-28 and 4.2-29. The structure contains twelve channel-shaped longitudinal members which are supported laterally at intervals down their length by machined clips which are bolted to the pressure shell at the intersection of longitudinal and circumferential integral ribs as shown in View A. A bolt through the longitudinal member at each clip is used to adjust the clearance after installation and to permit tensile as well as compressive loads in the lateral members to be reacted at the support clips. When pressurized to 10.3 n/cm^2 (15 psi), the radial expansion of the pressure shell is

$$\Delta R = \frac{PR^2}{tE}\left(1 - \frac{\mu}{2}\right) = 0.346 \text{ cm } (0.136 \text{ in.})$$

The clips accommodate this expansion without loading the support structure.

Hat section transverse members run between the longitudinal members in line with the support clips. The clearance between these straight members and the pressure shell provides for electrical, pneumatic, and hydraulic through runs. The flanges on the hat section are bolted to the longitudinal members to permit individual member removal and replacement on orbit.

The structural assembly is made up in two sections which are installed in opposite ends of the pressure shell cylinder. The lengths of the longitudinal members are adjusted to clear the docking ports at the center of the Crew/ Operations and Power/Subsystems Modules. The longitudinal members for each assembly are attached to the pressure shell at the module end through which the assembly is installed. Design details of the attachment are shown in Section B-B. The steel pin which engages the hole in the support boss in the pressure shell, is retained in the machined aluminum block by a captive bolt which is used to install and to retract the pin. The hollow steel pin is 1.27 cm (0.50 in.) OD and 0.76 cm (0.30 in.) ID so that its moment of inertia is

$$I = \frac{\pi}{64}\left[D_o^4 - D_i^4\right] = 0.111 \text{ cm}^4 \ (0.00267) \text{ in.}^4$$

PRECEDING PAGE BLANK NOT FILMED

R260

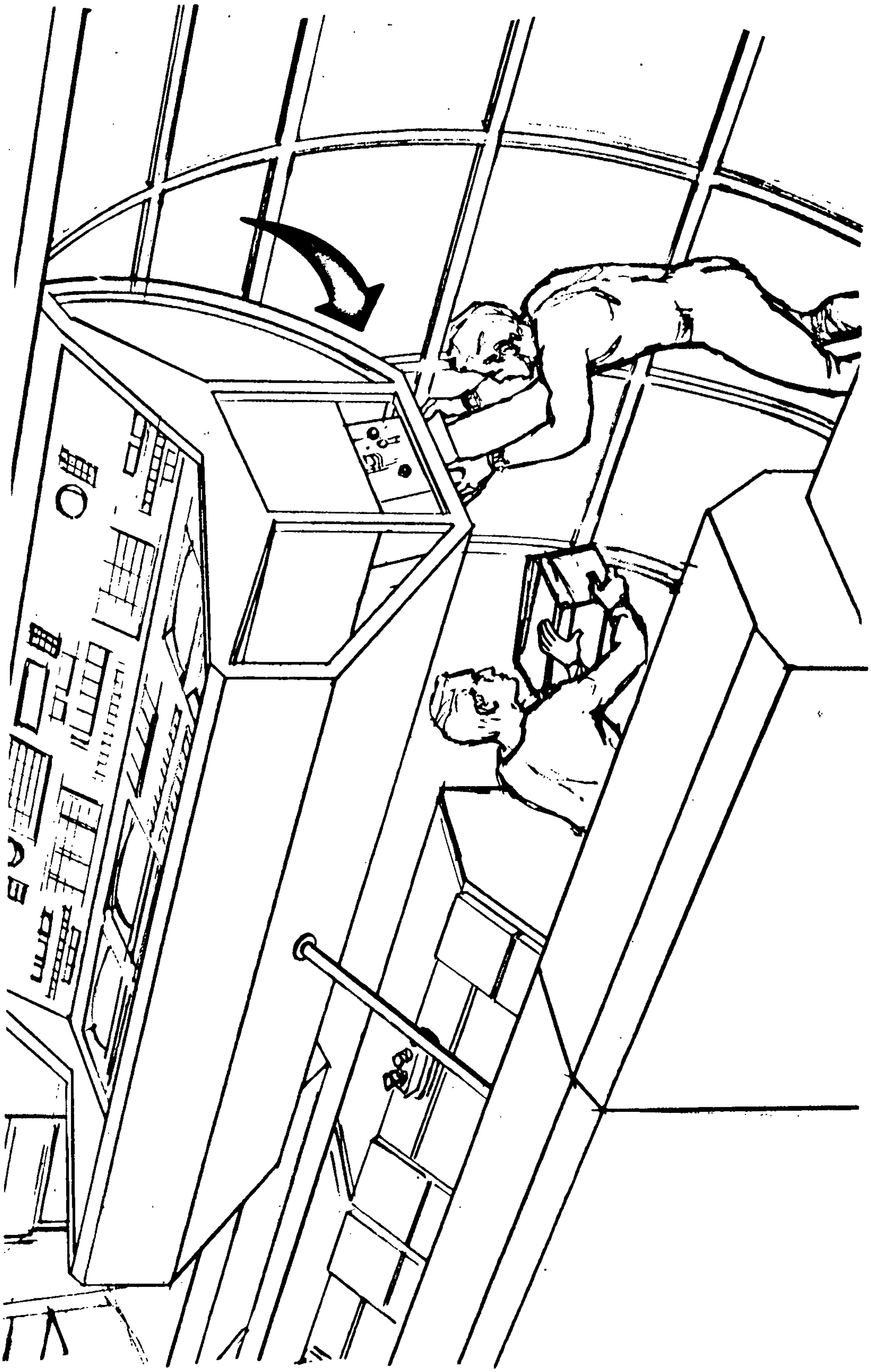


Figure 4.2-29. Equipment Support Structure

The machined aluminum block is bolted to the longeron with two 0. 475 cm (3/16-in.) diameter steel bolts. The longeron is 0. 160 cm (0. 063 in.) 7075-t6 Al.

The load on any particular longeron is dependent on the equipment arrangement and weight for the module within which it is installed. For commonality, the longeron support must be sized for the loads in the worst case. For deriving the structural loads, a module weight of 11, 350 kg (25, 000 lb) has been assumed. This allowance permits payloads to increase beyond the specified 9, 080 kgm (20, 000 lb) if the Shuttle payload capability eventually permits. An upper limit of the equipment weight could then be the payload weight less the structural weight of 2, 270 kgm (5, 000 lb) or 9, 080 kgm (20, 000 lb). The equipment inertia load is reacted at 12 points at each end. Assuming that the equipment weight were uniformly distributed on the support structure, the support pin load at booster burnout where the axial load factor is 3. 3 g would be

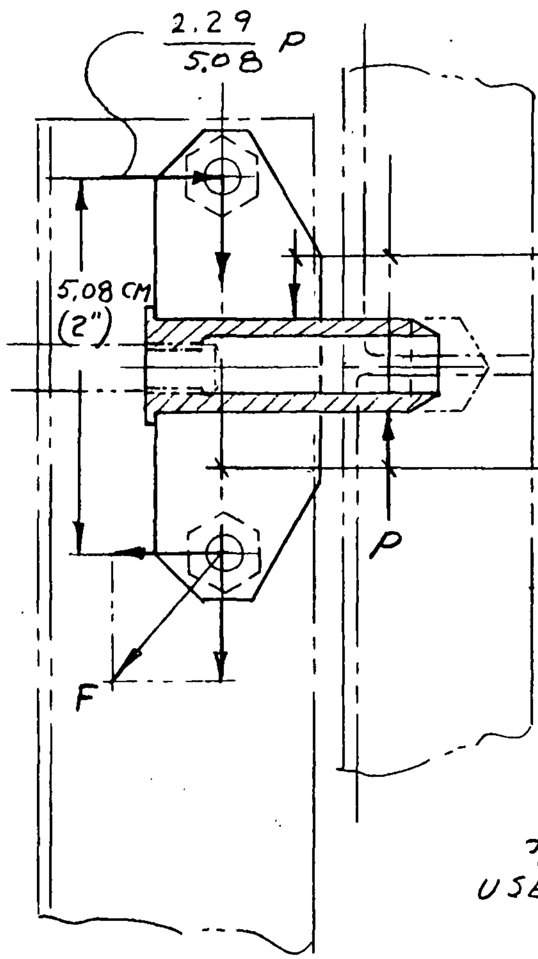
$$p = \frac{9,080\ (3.3)\ 9.8}{24} = 12,250 \text{ n } (2,770 \text{ lb})$$

To allow for unequal equipment distribution, this load is increased by 50 percent and the pin load selected for design is 18, 300 n (4, 120 lb). The stress analysis for the pin is shown in Figure 4. 2-30.

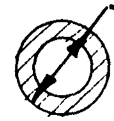
The acoustic environment inside the Shuttle bay will be attenuated by the double shroud and the pressure vessel wall. Impact on the internal support structure or the equipment mounted in the module will require further analysis. Phase C/D detail acoustic analysis and dynamic response should be conducted to determine internal structure stiffness and/or possible need for vibration isolators.

4. 2. 3. 7 Test and Isolation Chamber Bulkhead

The interior bulkhead which divides the GPL into separately pressurizable compartments, must be designed for pressure differential in either direction. To comply with the Guidelines and Constraints requirement for a



1.27 CM (.5 IN.)



1.27 CM (.5") O.D.
.762 CM (.3") I.D.
$I = .111\ CM^4$

2.29 CM (.9 IN.)

$P = 18,300\ N\ (4120\ LBS)$

$M = (1.27)18,300 = 23,200\ N\ CM$

$f_b = \frac{MC}{I}$

$f_b = \frac{(23,200)(.635)}{.111}$

$f_b = 133,000\ N/CM^2\ (193,000\ PSI)$

USE 220,000 PSI MIN H.T. PIN

BOLT SHEAR $\frac{2.29\,P}{5.08} = .45(18,300) = 8230\ N$

$F = \sqrt{(8230)^2 + (9150)^2} = 12,500\ N\ (2770\ LBS)$

DOUBLE SHEAR ALLOW AN3 BOLT = 19,000 N (4252 LBS)

BRG ALLOW IN .063" 7075T6 SHEET = 1664 LBS
.160 CM 7360 N

BRG ALLOW (2 SIDES) = 14,720 N (3328 LBS)

ATTACH PIN -
EQUIPMENT SUPPORT STRUCT

Figure 4.2-30. Equipment Support Attach Pin burst pressure two times maximum operating, this bulkhead must be designed for 20.7 n/cm^2 (30 psi). The results of a structural trade study on compartmenting bulkheads for the GPL is summarized in Figure 4.2-31. The upper curve for each pair of curves is the weight of the bulkhead plus the weight of the pressure shell, insulation, and meteoroid shielding for a length of cylinder equal to the bulkhead depth. h is the bulkhead depth (thickness in the flat bulkhead cases). For comparison, the curve for membrane bulkheads with no reverse pressure capability is added. The lower curves are all for spherical section bulkheads and include the weight of the pressure shell joint.

A flat bulkhead with machined, optimally tapered faces of 2219-T87 al alloy and an aluminum honeycomb core is the design selected because it has the least adverse impact on the GPL interior design and the weight penalty of about 100 lb over the spherical section sandwich can be accepted because of the lower cost of construction of a flat bulkhead. The core thickness is 15.2 cm (6 in.). The face thickness at the center is 0.282 cm (0.111 in.) and 0.114 cm (0.045 in.) at the outer edge. The weight of the two machine-tapered faces is 14 kgm (313 lb) versus 202 kgm (446 lb) for constant-thickness faces. The core weighs 98.5 kgm (217 lb) and the allowance for glue is 10 kgm (22 lb). The total bulkhead weight is 264 kgm (583 lb) to which must be added the weight of the pressure shell joint and seals. The selected compartmenting bulkhead design is shown in Figure 4.2-32.

4.2.3.8 Docking Mechanism

The docking mechanism is an androgynous (neuter) device which will mate with any other like mechanism. Figure 4.2-33 shows the elements of the mechanism. The assemblies which comprise the mechanism are as follows:

- Docking Frame
- Shock Absorber/Actuator
- Guide Arm/Capture Latch
- Hydraulic Assembly
- Structural Latches
- Pressure Seal

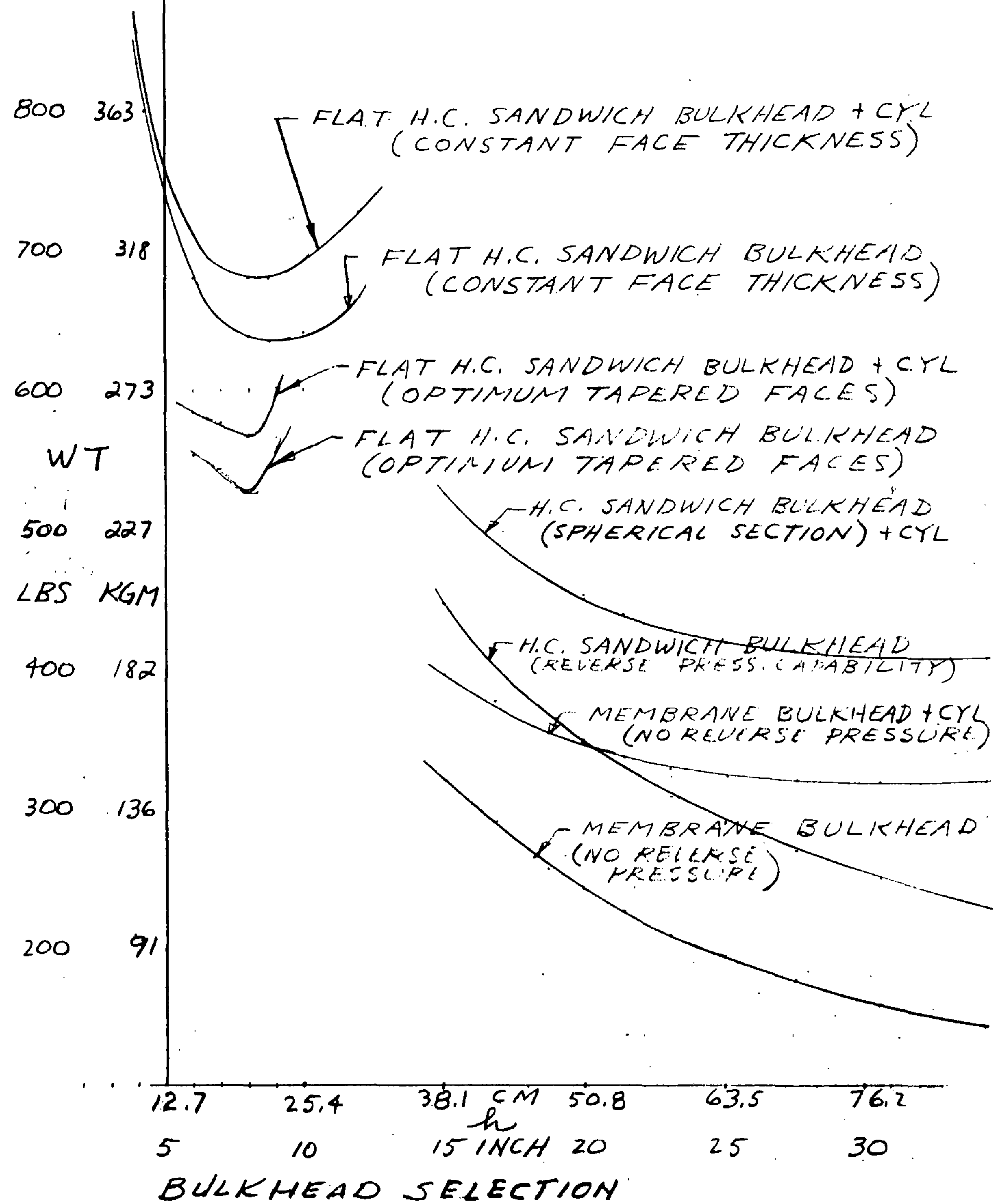


Figure 4.2-31. Test Isolation Bulkhead Selection

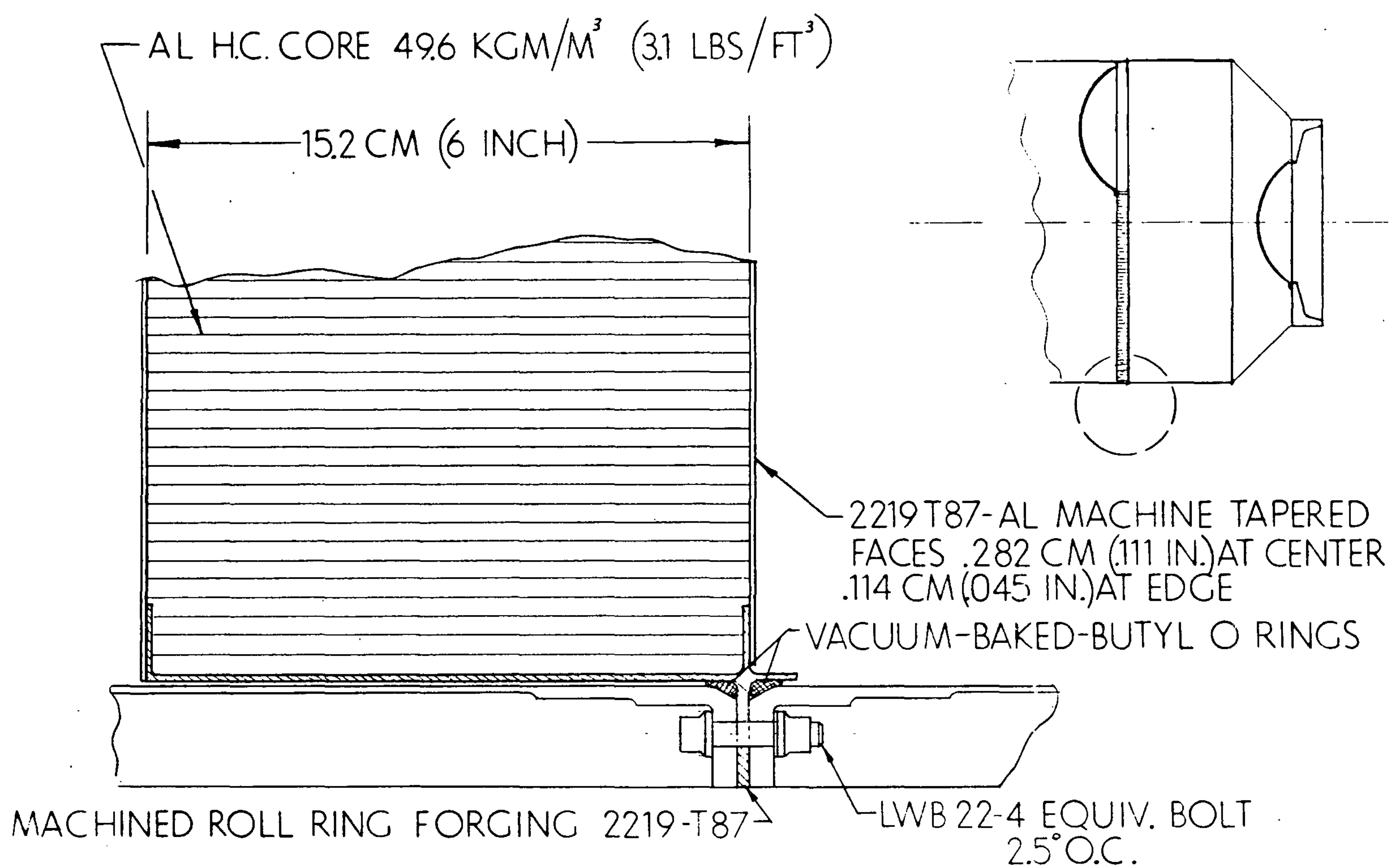


Figure 4.2-32. Test and Isolation Bulkhead Design

R260

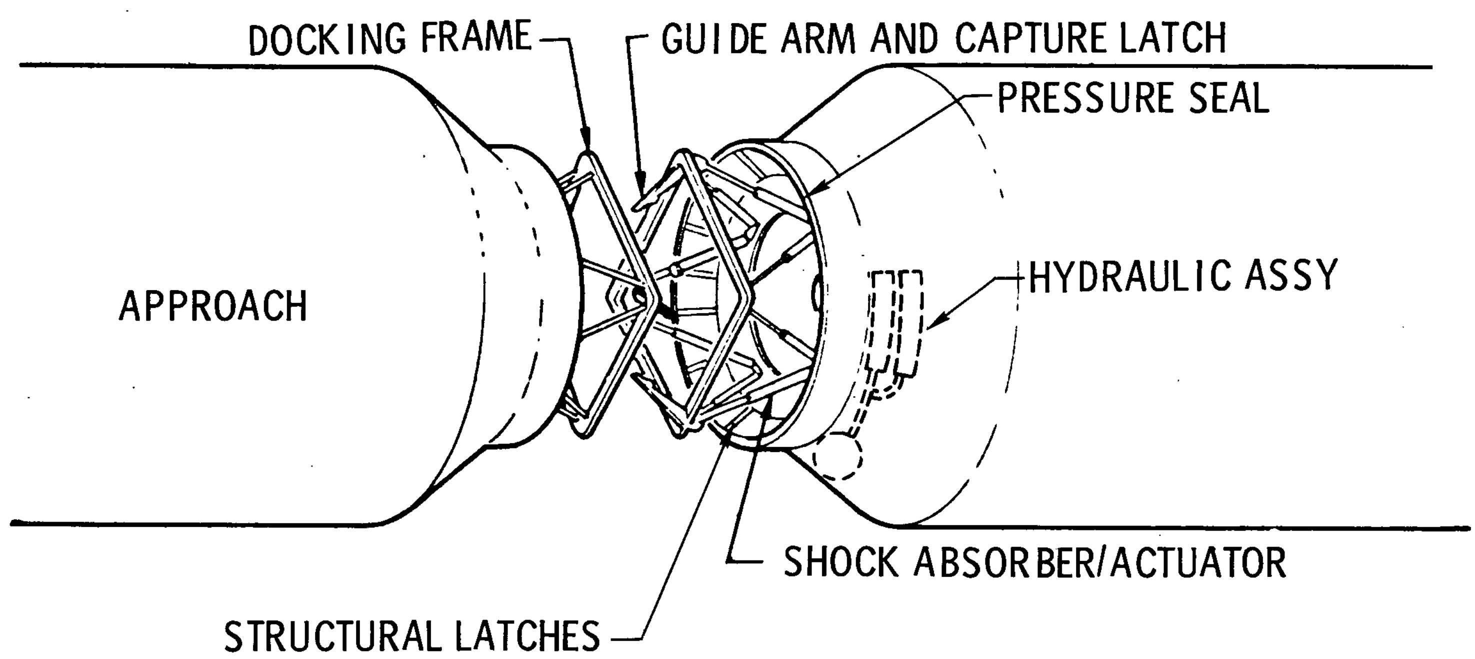


Figure 4.2-33. Docking Mechanism

The docking frame provides the initial contact interface for the guide arms and capture latches and the structural interconnect for the eight shock absorber/actuators. The square frame serves to align the modules in the roll axis because the engaging guide arms are camed into the corners of the frame. The frame is assembled from four machined corner fittings of 7079-T652 aluminum. The sides of the frame are, 7.62 cm (3.0 in.) OD, 0.211 cm (0.083 in.) wall, tubing of 7075-T6 aluminum.

The shock absorber/actuator is a conventional hydraulic cylinder with a bore area of 20.2 cm^2 (3.14 $in.^2$), a piston rod area of 9.85 cm^2 (1.54 $in.^2$) and a stroke of 61 cm (24 in.). The cylinders are fabricated from 6061-T6 aluminum alloy. Wear surfaces are hard-anodized and honed to provide the required surface finish for the dynamic O-ring seals. The cylinder rod is hollow and ported to the head end of the cylinder producing a compression ratio of approximately 2 to 1 over the active stroke. Figure 4.2-34 illustrates the design of the assembly.

The guide arm/capture latch assembly is illustrated by Figure 4.2-35. Two guide arm assemblies are attached to opposite corners of the docking frame. The arms engage the open corners of the mating frame. As the frames are aligned and approach contact, spring-loaded capture latches are initially depressed and then snap out to lock the frames together. The guide arms have folding extensions which are necessary to provide capture under the limits of the docking parameters and yet subsequently clear the 1.52 m (60-in.) diameter hatch opening. The arm extension and the capture latch are interconnected by an electro-mechanical actuator which when retracted, folds the guide arm and releases the capture latches simultaneously. The guide arms and latches are fabricated from 7079-T652 aluminum alloy hand forgings.

The energy to be absorbed from closing rate at impact from docking a 124,000 kgm (274,000 lb) Orbiter on the 145,000 kgm (320,000 lb) GSS Modular Space Station is approximately $KE = (m_1 m_2/m_1 + m_2)(V^2/2) = 3,110$ nm (2,290 ft-lb).

Page intentionally left blank

This calculation is exact only if the centers of gravity of both vehicles lie on the closing velocity vector. It does, however, permit a preliminary sizing of the Shock Absorber System since most of the energy to be absorbed comes from closing rate at impact.

The detail dynamic analysis required to determine the most adverse energy division between the eight shock absorbers is beyond the scope of this study and should be addressed at the initiation of Phase C/D. A worst-case estimate, believed conservative, is based on a total energy of 3, 260 nm (2, 400 ft-lb). Two-thirds of this is assumed absorbed by the pair of shock absorbers at one corner of the docking frame. The maximum energy per shock absorber from this assumption is 1, 090 nm (800 ft-lb).

The docking system hydraulic schematic, shown in Figure 4. 2-36, consists of a pneumatic storage bottle, eight mechanically linked 3-way valves, an air/oil accumulator, eight check valves with small bypass orifices, an air manifold, an oil manifold, and a 3-way retraction control valve. All elements of the hydraulic assembly, except the shock aborber/actuators, are located inside the pressure shell for easy maintenance.

The shock absorber detail is shown in Figure 4. 2-37. The cylinder bore is 5. 08 cm (2 inches) and the piston rod outside diameter is 3. 56 cm (1. 4 in.). The piston rod has concentric passages for the air, which pressurizes the head end of the cylinder, and the hydraulic fluid which pressurizes the rod end.

When the valves are open so that both the hydraulic fluid, through the floating piston, and the air in each shock abosrber/actuator is pressurized to the air tank pressure, the shock absorbers extend to their deployed length of 141 cm (55. 5 in.). The air valves between the shock absorbers and the air tank are then closed and the system is ready for docking.

The volume of air trapped in each fully deployed shock absorber is 1, 330 cm^3 (81 $in.^3$). If the air tank pressure is P_1, the initial stroking load is P_1A_r where A_r is the cross sectional area of the piston rod which

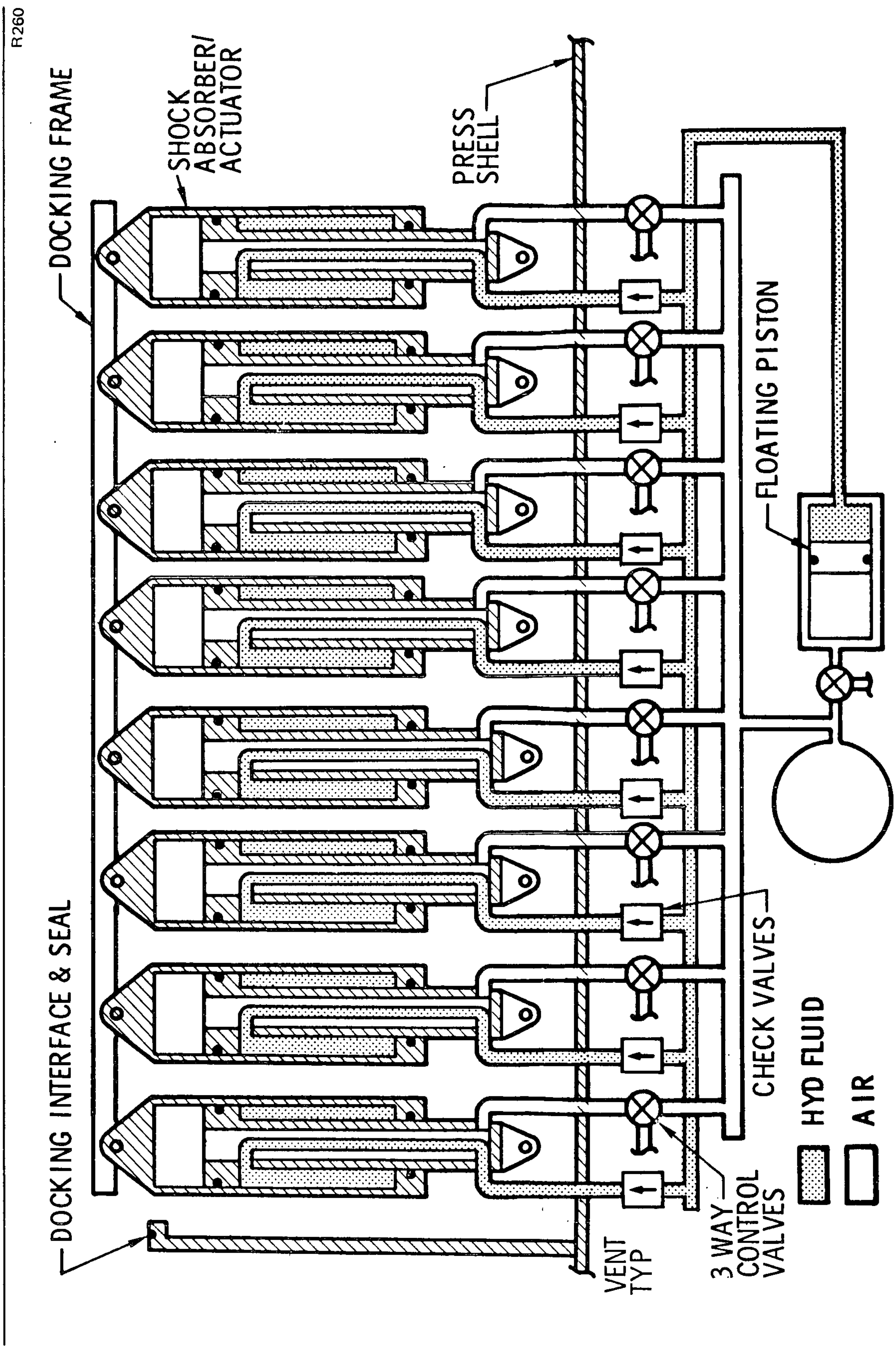


Figure 4.2-36. Docking System Hydraulic Schematic

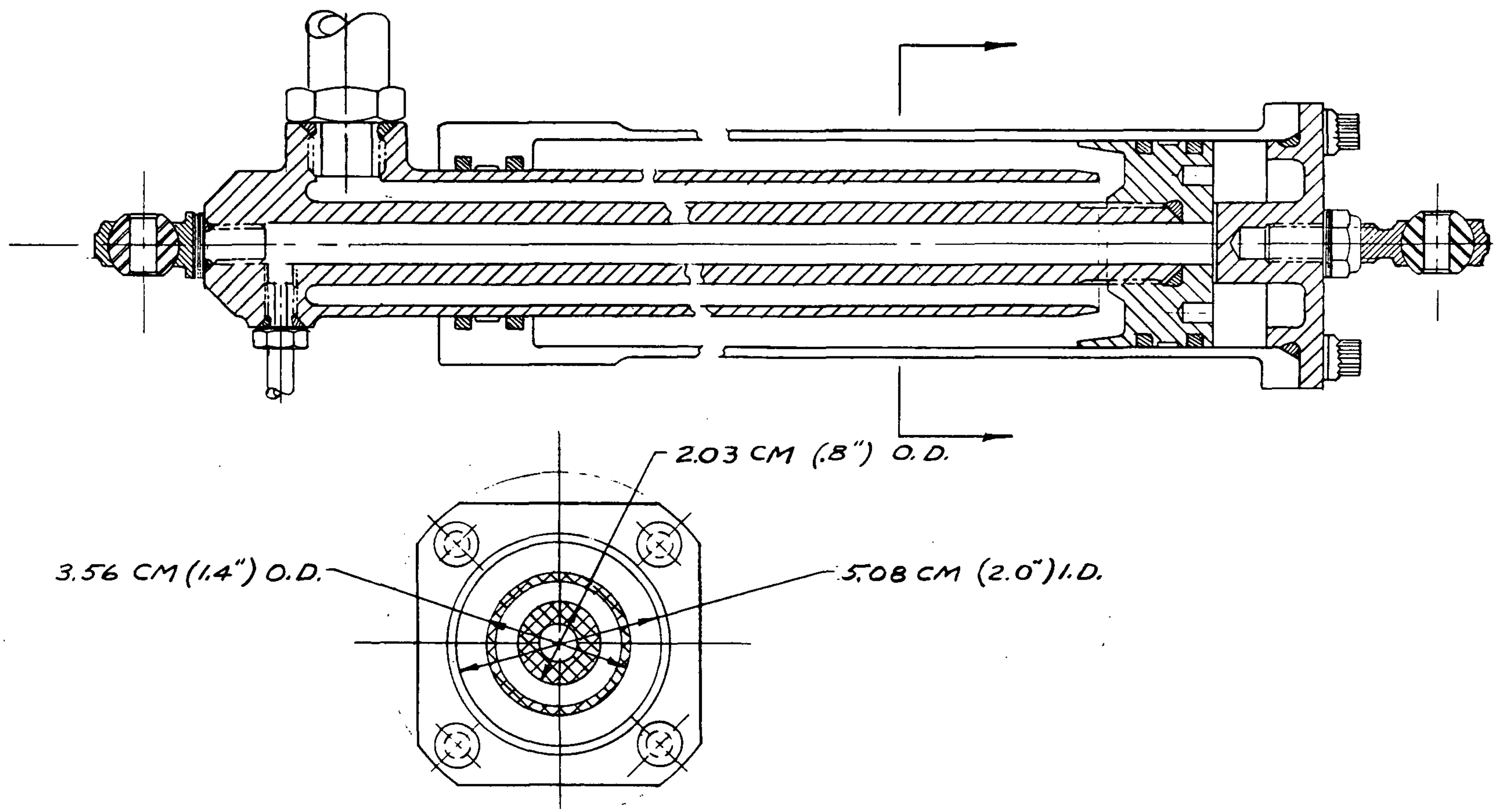


Figure 4.2-37. Docking System Shock Absorber/Actuator

equals 9.94 cm^2 (1.54 in.^{2}). The shock absorber stroke from the fully retracted to the fully deployed position is 61 cm (24 in.). The maximum stroke on docking, however, must not permit the docking frame to rotate through more than 10 degrees to insure clearance between adjacent radially docked modules and the Orbiter. If one corner of the docking frame is depressed until the plane of the frame has rotated through 10 degrees, the shock absorbers at that corner will have stroked 31.8 cm (12.5 in.). 30.5 cm (12 in.) is selected to absorb 1,090 nm (800 ft-lb) on a single shock absorber to meet this rotation constraint.

The energy absorbed from adiabatic compression of the air trapped in a shock absorber, less the work done by the hydraulic fluid pressure on the annular area between the piston rod and cylinder, must equal the energy to be absorbed by that shock strut.

$$\frac{P_2V_2 - P_1V_1}{1 - k} - P_1 (A_c - A_r) s = 1,090 \tag{1}$$

and

$$P_1V_1^k = P_2V_2^k \tag{2}$$

where P_1V_1 is the initial air volume and pressure and P_2V_2 the pressure and volume at the end of the stroke; A_c and A_r are the cylinder and piston rod cross-section areas; S is the stroke; and k is the ratio of specific heats and equals 1.4 for air or nitrogen.

With a 30.5 cm (12-in.) stroke,

$$V_2 = 714 \text{ cm}^3 \ (43.5 \text{ in.}^3)$$

$$P_2 = P_1\left(\frac{V_1}{V_2}\right)^{1.4} = 2.39 \ P_1$$

Making this substitution in equation (1) and solving gives $P_1 = 173\ n/cm^2$ (250 psi).

$$P_2 = 2.39\ P_1 = 413\ n/cm^2\ (598\ psi)$$

During stroking, hydraulic fluid flows into the annular volume between the cylinder and piston rod. For the energy calculation, pressure drop in the hydraulic line and manifold is conservatively neglected and it is assumed the hydraulic fluid flows at the air-tank pressure. At the end of the stroke, the hydraulic fluid is trapped by the check valve and prevents the compressed air from driving the shock absorber back to its extended length except at the slow controlled rate permitted by the bypass orifice. The maximum pressure on the trapped hydraulic fluid to prevent springback is

$$P_3 = \frac{P_2 A_C}{A_C - A_r} = 1.96\ (413) = 810\ n/cm^2\ (1,175\ psi)$$

The initial compressive load on the shock absorber is 1,710 n (385 lb) and the compressive load at the end of the 30.5 cm (12-in.) stroke is 6,650 n (1,495 lb), again assuming the hydraulic fluid is at the initial air tank pressure throughout the stroke.

The foregoing analysis is based on the assumed maximum energy case. The docking system, as currently sized, will however, tolerate considerably higher energy requirements without overstressing any of the structural/mechanical elements, by simply increasing the initial tank pressure. The tank can be pressurized with a handpump from the cabin air supply, or from the high-pressure nitrogen source. Where the docking energy requirement is lower, as it will be for most dockings up to GSS, the tank pressure can be reduced to minimize the docking disturbance.

The structural latch is shown in Figure 4.2-38. Each latch is mounted on a clevis on the circular spline of a harmonic drive. The circular spline is supported by a plain bearing in the gusset at one end and by a flange on the flex spline at the other end. This detail is shown in Section C-C of Figure 4.2-38. The sequence of assembly is:

A. The plain bearing is installed in the gusset.

B. The harmonic drive assembly is installed from the left side of Section C-C with the clevis on the circular spline passing through the cutout in the gusset and is bolted in place with the three hex-head bolts and one flush-head screw shown in Section B-B.

C. The latch is positioned in the clevis with the torsion spring in place and the 0.8 cm (5/16 in.) diameter cross pin is installed through a hole in the flex spline mounting flange. The cross pin is retained with a spring pin on the inner end. The latch may be rotated past the full-open position before installation of the stop pin to facilitate installation of the spring.

The circular spline has 320 teeth and the flex spline has 318 to match the geometry of harmonic drives manufactured by the American Shoe Machinery Corporation. One clockwise revolution of the wave generator causes the circular spline to rotate counter clockwise 2 teeth so that the reduction is 160:1. The rollers on the planetary wave generator are 1.59 cm (0.625 in.) diameter and the shaft is 1.27 cm (0.5 in.) diameter so the reduction due to the wave generator is $2\,(r_1 + r_2)/r_1 = 4.5$. The total reduction is then 160 (4.5) = 720:1. The circular spline rotates 75 degrees to move the latch from the full open to the closed position so the wave generator shaft must be rotated 75/360 (720) = 150 revolutions.

A single double-ended drive motor is used to actuate all 12 latches. The wave-generator shafts for each of the six latches on either side of the motor are coupled through universal joints by short sections of torque tube. A separate splined fitting on one end of the wave generator shaft allows for generous tolerance on the dimension between latches.

A master gage is used to adjust the closed position preload for each latch. A latch position can be adjusted by uncoupling it from the other six latches by pulling the three pins in its two universal joints and rotating its wave-generator shaft independently. The preload with the master gage is adjusted with the laminated shims under the bolt-on latch cross-pin. The position of each latch mating fitting is similarly adjusted with a go-no go master gage so that any docking interface can be mated with any other and every latch preload will fall between preset limits.

All of the torque tubes are fabricated from aluminum tubing except one between the first and second latches on one side of the motor. This torque tube is steel and an external thread (0.875-20 UNEF-24) is machined along its length. A nut, which is restrained from rotating by a track, travels along this thread between limit switches which stop the drive motor in the latch-open and latch-closed positions. The nut travel between these positions is approximately 7.5 in. (150 revolutions), and one minute (150 rpm) is the estimated time for latch actuation.

The docking interface is sealed after latching by inflating the vacuum-baked, resin-cured-butyl seal on either side of the interface. An aluminum insert, machined on a boring mill from a 2.5 m (98 in.) OD ring forging, is installed inside the inflatable seal and permits one, or the other, or both of the mating inflatable seals to be pressurized and the interface effectively sealed so that the interface sealing is redundant.

On separation, the torsion spring on each latch holds the latch in contact with the mating latch fitting until the interfaces are separated about 15 cm (0.6 in.) at which time the latch stop pin is contacted and the latch rotated to the full-open position. The latches are thus used to guarantee separation of the interface seals as well as providing a preload between docked modules.

The diameter at the seal ℄ is 2.47 m (97.25 in.). The design load on the interface latches from cabin pressure is

$$p\pi r^2 \text{ (SF)} = (10.35)(3.14)\left(\frac{247}{2}\right)^2 2 = 9.9 \times 10^5 \text{ n}$$

Twelve latches on each side of the interface, or 24 latches total, carry this load. But for redundancy, guaranteeing the pressure integrity of the joint by activating the latches on one side only was selected as a design requirement. The design load per latch is $9.9 \times 10^5/12 = 82,500$ n from cabin pressure plus 2,800 n from seal pressurization or 85,300 n (19,200 lb).

With all 24 latches engaged, the design load per latch from combined bending and pressure is

$$P = \left[\frac{p\pi r^2}{24} + \frac{M}{\pi r^2}\left(\frac{2\pi r}{24}\right)\right] SF$$

For a safety factor of 1.4, and $p = 11$ n/cm^2 (16 psi) to account for cabin pressure plus sealing pressurization, the limit bending moment for the docking interface is

$$M = 12r\left[\frac{P}{1.4} - \frac{p\pi r^2}{24}\right] = 12\left(\frac{2.47}{2}\right)\left[\frac{85,300}{1.4} - \frac{11\ (3.14)\left(\frac{247}{2}\right)^2}{24}\right]$$

from which M = 577,000 newton meters (426,000 ft-lb). With only the latches on one side of the interface engaged, the limit bending moment from the latch sizing is

$$M = 6r\left[\frac{P}{1.4} - \frac{p\pi r^2}{12}\right] = 126,000 \text{ nm } (92,900 \text{ ft-lb})$$

The maximum moments which the docking interface can experience come from firing of the reaction control system thrustors on the orbiter. These are summarized in Table 4.2-4 below for a side docking port.

Thus, designing the latches for an ultimate pressure of 20.7 n/cm^2 (30 psi), the docking interface is good for all the loads the Orbiter can impose through GSS if the latches on either side of the interface are engaged.

Table 4.2-4

ORBITER CONTROL SYSTEM IMPACT ON SPACE STATION

	Orbiter Pitch	Orbiter Roll	Orbiter Yaw
ISS Side Docking Port*	35,300 nm (26,000 ft lb) bending	26,500 nm (17,000 ft lb) bending	99,500 nm (73,000 ft lb) torsion 18,750 nm (13,800 ft lb) bending
GSS Side Docking Port*	78,000 nm (57,500 ft lb) bending	35,700 nm (26,300 ft lb) bending	144,000 nm (106,000 ft lb) torsion 119,000 nm (87,500 ft lb) bending

*Simultaneous firing of two 1,600 lb thrusters.

With the 12 tapered alignment pins (6 on each side of the interface) shown in Figure 4.2-38, the maximum shear load per pin from torsion across the interface at GSS is

$$P_s = \frac{288,000}{2.47(6)} = 19,400 \text{ n } (4,360 \text{ lb}).$$

Details of the shear pin are shown in Figure 4.2-12 of subsection 4.2.3.1.

4.2.3.9 Docking Port Meteoroid Doors

The docking ports must be shielded from the meteoroid environment and insulated during the periods when no docked module is present. An insulated meteoroid door, common to both end and side ports, is provided for this purpose. The meteoroid door is shown on the structural assembly drawings of the Crew/Operations Module, Figure 4.2-39, and the Power/Subsystems Module, Figure 4.2-26.

The end port which mates with the Oribter docking adapter during launch is exposed after separation from the Orbiter. A docking-port door, which stows within the 15-foot-diameter clearance envelope in the open position, must be provided at this end.

The center section of the meteoroid door is cylindrical with a 2.14 m (84-in) radius of curvature to match the radiator/meteoroid shroud curvature. The outer sections are flat paralleling the docking interface. The door curvature provides clearance for the guide arms which extend out beyond the interface with the docking frame fully retracted.

The door has inner and outer sheets of 0.030 cm (0.012-in) 7075-T6 aluminum spaced 2.54 cm (1 in.) apart. Both sheets are beaded to withstand the launch acoustic environment. An insulation blanket of 50 layers of doubly aluminized mylar interspersed between layers of dacron net is attached to the inner sheet with nylon pins. Stretch-formed, zee-section frames of 0.051 cm (0.020-in.) 7075-T6 aluminum are riveted between the face sheets. The stiffening beads run 90 degrees from the frames.

An aluminum extrusion with two tracks and a mounting pad for a rack, runs across the center of the door (Figure 4.2-40). The tracks engage four cam followers mounted on the end of the door hinge arm. A torque-motor-driven pinion is also mounted on the hinge arm and engages the rach on the door. This arrangement permits the door to be moved fore and aft so that it is within the 15-foot clearance diameter in the open position on eht end docking port, and yet clear of the docking interface. This feature also permits the door to be centered in the interstage area between end docked modules to minimize the radiator area obstructed.

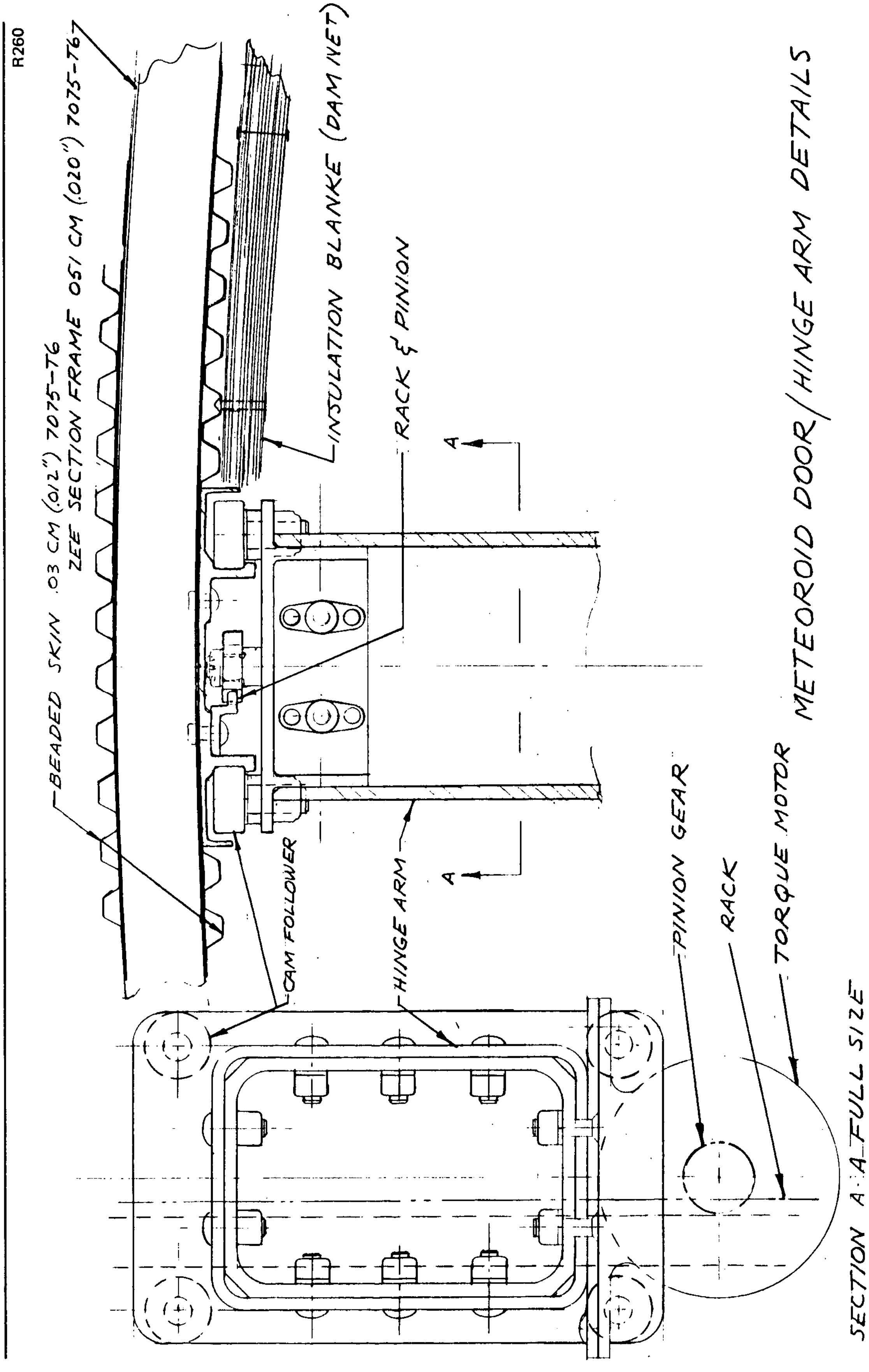


Figure 4.2-40. Docking Port Cover Drive

On the side docking port, the door is hinged open so that its curvature matches the curvature of a side docked module. The hinge point is in line with the side of the docked module, 2.14 m (84 in.) from the docking-port center. The hinge arm lies in a channel-shaped fitting in the meteoroid shroud. The rack and pinion are used to move the edge of the door to the hinge point (33 in.) to minimize the radiator area obstructed on the side docked module. The hinge arm is rotated 135 degrees before docking so that the door is well clear of the approach to the side port. After docking, the hinge arm is rotated back to bring the door into contact with the docked module.

4.2.3.10 Hatches and Airlocks

The three basic resource modules of the ISS plus an attached Logistics Module contain a total of 14 1.52 m (5-ft) diameter hatches and 4 1.02 m (40-in.) diameter hatches. Figure 4.2-41 illustrates the Space Station with a radially attached Logistics Module. All hatches are illustrated in the open and closed position showing the volume swept through by hatch operation and stowage in the open position.

The primary EVA airlock is located in the outboard end of the Logistics Module. It is 1.52 m (5 ft) diameter and approximately 1.83 m (6-ft) long. The inside hatch is hinged inboard and the outside hatch is hinged outward allowing unobstructed use of the airlock's internal volume. The volume is sufficient for simultaneous occupancy by two crewmen wearing suits. Since through access is required in the Logistics Module, a tunnel must be provided through the unpressurized section of the module. By adding a hatch to the inside end of the tunnel, the EVA airlock was formed without an appreciable increase in structural weight. The volume of this compartment is approximately 3.43 m^3 (118 ft^3) and can be pumped down to a pressure of 0.345 n/cm^2 (0.5 psi) in 20 minutes by the pumping system installed in the Space Station. A second EVA airlock is provided by the test and isolation chamber in the outboard end of the GPL module. This chamber provides all systems necessary to act as an EVA airlock for two or more crewmen, however, its large volume would require that the atmosphere be dumped to provide a reasonable crew transfer time. The Power/Subsystem Module, solar

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

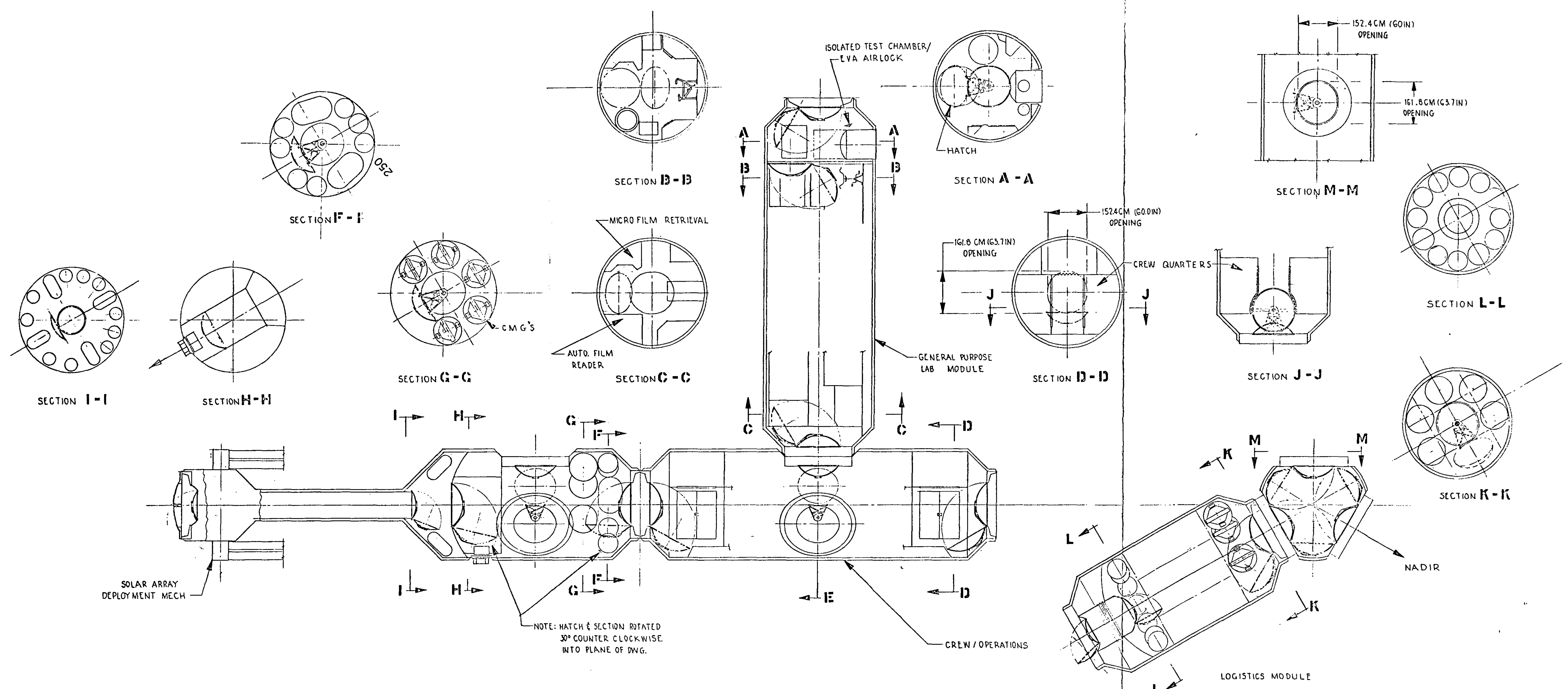


Figure 4.2-41. Hatch Operation

array support tunnel and turret may also be used as an external access airlock.

The domed hatch at each docking port forms a compartment between modules which is used as an IVA airlock. Figure 4.2-42 illustrates the use of the compartment as an IVA airlock.

Figure 4.2-43 illustrates the docking-port hatch design and installations. The hatch opening is a 1.52 m (60-in.) diameter elongated circle. The opening is elongated 9.4 cm (3.7 in.) along one axis to allow the hatch to pass through the opening. The hatch is a dome formed by spherical segments and elongated by a 9.4 cm (3.7 in.) cylindrical segment. The radius of the dome is 100.33 cm (39.4 in.) and the height is 42.67 cm (16.8 in.). The hatch is fabricated from 1.27 cm (0.5-in.) thick aluminum honeycomb with 0.041 cm (0.016 in.) 2219-T87 aluminum faces.

An A-shaped frame, hinged from the docking port flat-plate structure supports and locates the hatch in both the open and closed position. The hatch is supported from the A-frame by a 25.4 cm (10-in.) diameter "Kaydon Reali-Slim" ball bearing, which permits rotation of the hatch in the plane of the opening. Stops and detents are provided to hold the hatch in the proper relation to the open and closed position. After the hatch is closed it is held in a closed position in the docking frame structure by using a breech block action at the sealing interface. The hatch sealing surface is a flat face 3.18 cm (1-1/4-in.) wide with a cantilever lip, cut for the breech-block action, extending 0.89 cm (0.35 in.) past the face. The mating portion of the breech block is machined into the docking-frame structure and incorporates two seals. One seal is of the inflatable type and the other is a solid O-ring.

Starting with the hatch in the open position, the closing operation is as follows: first, the hatch and A-frame is swung until the hatch is closed and the hatch lip is mated with the structure; second, the hatch handles are rotated which engages the breech blocks. The detent previously mentioned holds the

R260

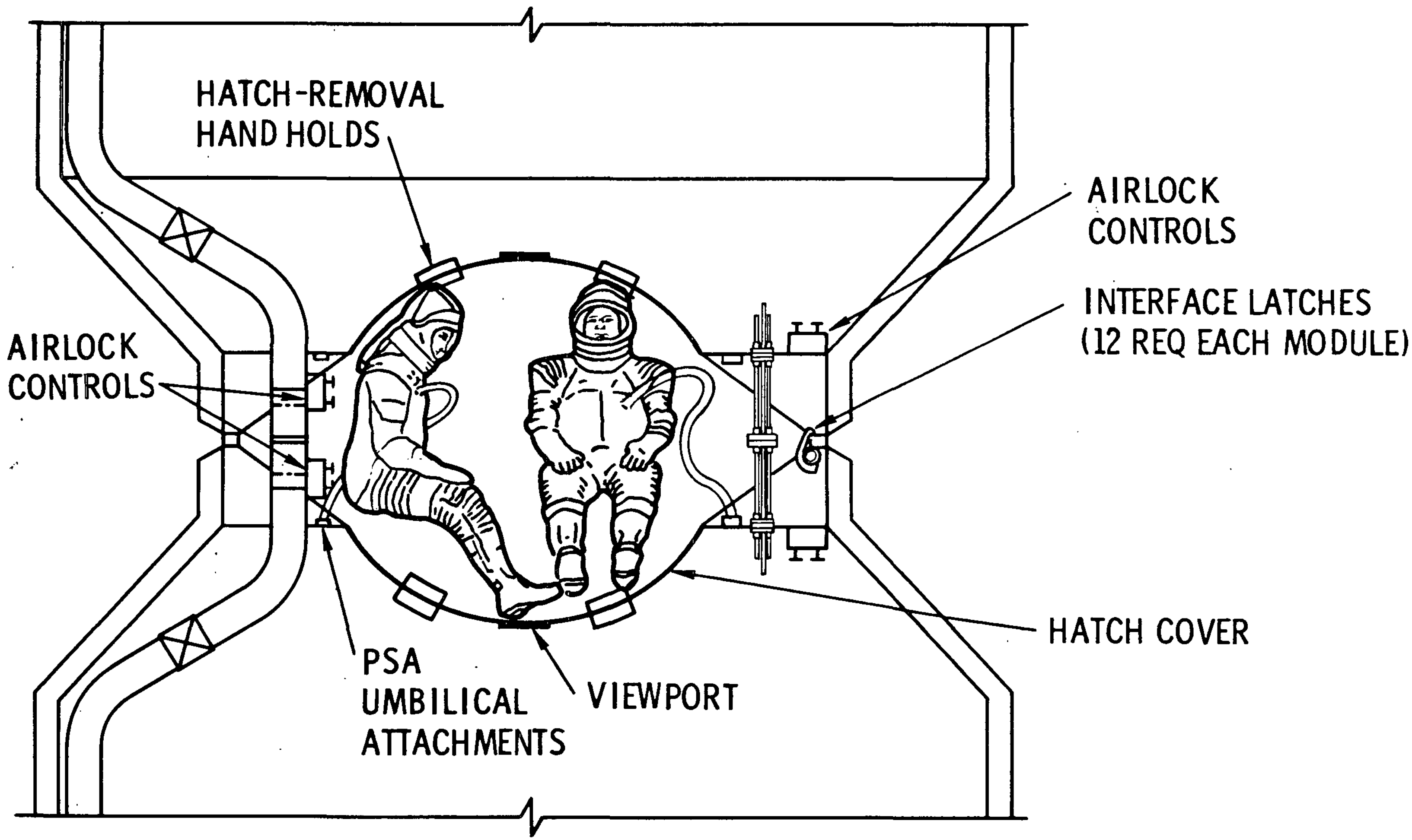


Figure 4.2-42. IVA Airlock

hatch in the closed-breech block position. At this point the inflatable seal is pressurized, which pushes the hatch lip against the structure face, away from the solid O-ring and provides a positive locking action.

When the module compartment is pressurized and reaches an internal pressure of 10.2 n/cm^2 (14.7 psi) a force of 185,000 n (41,600 lb) is pushing against the hatch, which in turn forces the hatch to compress the inflatable seal and press against the solid O-ring. When the volume between two modules is pressurized and the module interior is at a low pressure or a vacuum, the O-ring is not active and the seal across the interface is being performed by the inflatable seal.

To pressurize and equalize the pressure between the compartments, valves are provided in the docking port structure bulkheads.

4.2.3.11 Viewports

The Modular Space Station specifications requires that adequate windows be provided and arranged to allow viewing of the docking maneuvers, the Earth, and the celestial sphere. Windows of high optical quality are provided for experiments in addition to windows for general viewing and operations.

Figure 4.2-44 shows in flat-pattern the pressure shell penetrations of the three ISS modules including all viewports. Each hatch has a 15.24 cm (6-in.) diameter view port located in the center of the hatch. Each of the six individual crew quarters has a 30 cm (11.8-in.) diameter view port. In addition, three ports are provided in the wardroom and one adjacent to each of the two command and control stations. Optical quality viewports are installed adjacent to each of two scientific airlocks in the GPL module.

The visual quality viewports (1) provide optimum visibility under flight conditions and after solar flares, (2) have low reflectance and glare, (3) do not transmit ultraviolet radiation, (4) reflect thermal energy from solar radiation, (5) will not fog or ice from moisture, (6) provide structural strength for internal pressure, and (7) absorb energy from impact of micrometeoroids. The window system shall have minimum leakage, be fireproof, and have low permeability and outgassing.

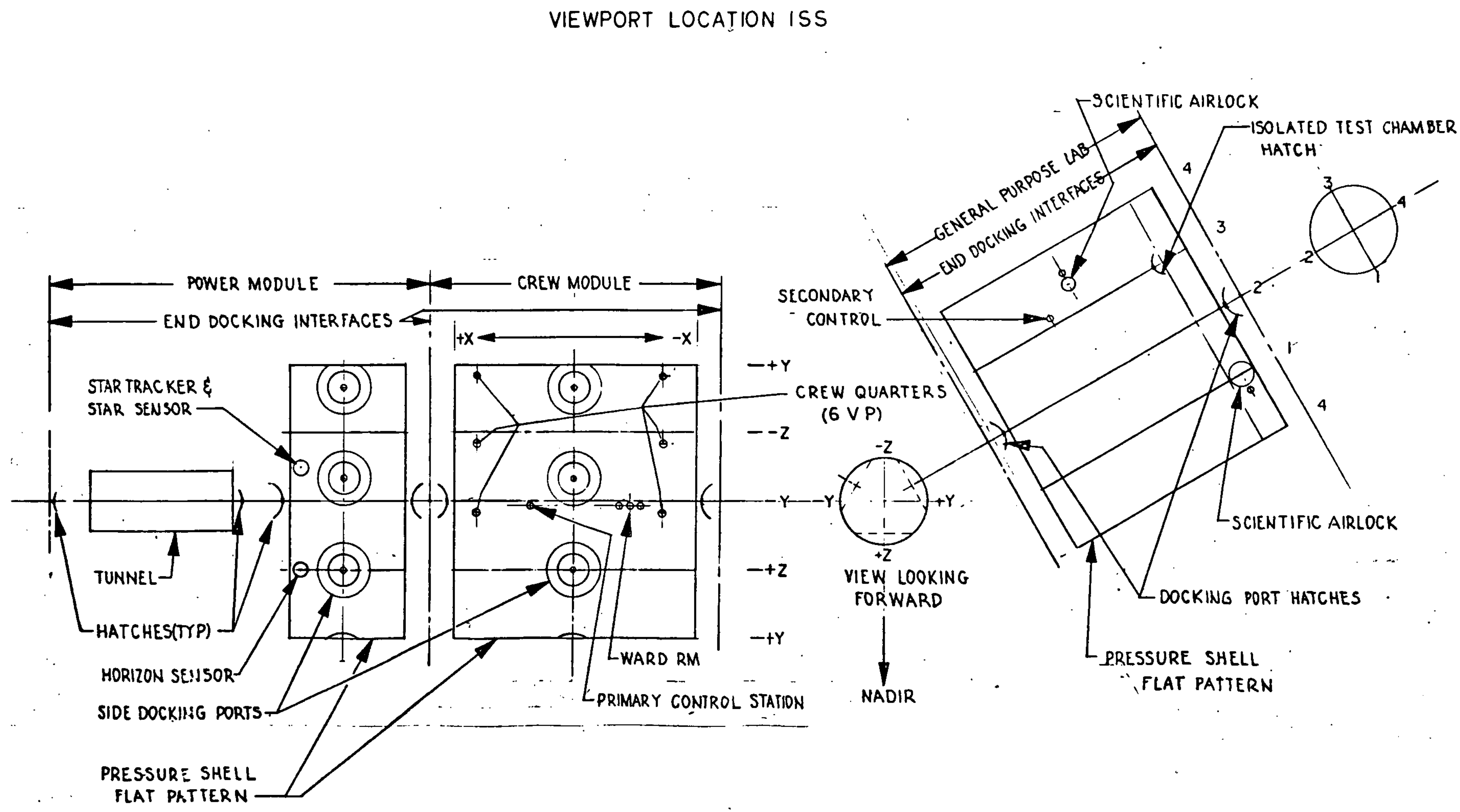


Figure 4.2-44. ISS Viewport Location

The optical quality windows are protected against micrometeoroid damage, they are 99.97 percent fused silica glass, ground and polished optical glazing quality of ultraviolet grade. The unit surfaces must be flat and parallel within 0.1 of a wavelength in the visual region with full differential pressure across glass.

Figure 4.2-45 shows the viewport installation in the pressure shell. The dual pane window is sealed and cushioned using O-rings and a face gasket to allow structural deflections without glass strain.

Manually-operated external viewport covers are provided for the two optical quality windows, as well as transparent protective covers inside the module. These covers are for protection of the optical qualities. The visual quality ports are designed so that covers are not necessary. The window consists of a double, fused-silica pane which will meet the meteoroid design criteria of the basic pressure shell. The Thermal Control System will compensate for thermal properties and prevent condensation. Damage repair, cleaning, or replacement will be accomplished using a portable seal box which can be attached to the inside of the pressure shell for unit replacement. Figure 4.2-46 is a preliminary layout of the viewport replacement mechanism. Following are the steps in replacing a viewport assembly:

A. Remove viewport hold-down bolts.
B. Place rotation arm assembly over window assembly to be replaced.
C. Attach arm to window assembly with four flush screws.
D. Place new window over old window and position on two rounded dowels.
E. Check to see that arm rotates freely.
F. Place portable-seal bell jar over arm assembly and seat bottom seal on Space Station pressure shell.
G. Attach handwheel to rotation arm assembly.
H. Evacuate bell jar (note: method to evacuate jar not shown).
I. Pull on handwheel (this will pull window loose from Space Station pressure shell) until arm assembly is near top of bell jar.
J. Rotation of handwheel 180 degrees will rotate window assembly 180 degrees.

58

K. By pushing handwheel down towards bell jar, replacement window will go into position.

L. Attention should be given to insure that rounded dowels go into bolt holes.

M. Bell jar is now pressurized.

N. Bell jar, arm assembly, and old window is now lifted off.

O. Hold-down bolts are not replaced to secure replacement window.

4.2.3.12 Solar Array Drive and Orientation Mechanism

The turret for solar array orientation is mounted on the end of a fixed tunnel on the forward end of the Power/Subsystems Module. The turret pressure shell is machined in two sections from thick-walled forged hemispheres of 2219-T87 aluminum on an omni-mill. The machined hemispheres are welded together and the end flanges faced in a vertical boring mill. Three identical harmonic drive assemblies are bolted to O-ring-sealed machined flanges on the truncated spherical shell. The Power/Subsystems Module tunnel is bolted to one of these assemblies. A boom canister containing the solar array Astromast is bolted to each of the other two. The overall assembly is shown on the Power/Subsystems Module structural assembly, Figure 4.2-26 and 4.2-47. The gimble design is illustrated schematically in Figure 4.2-48. The harmonic drive assembly is shown in Figure 4.2-49. Seven separate machined details comprise the drive assembly. These are:

(1) A 13 cm (5-1/8-in.) long, 91.5 cm (36-in.) diameter, double-flanged cylinder containing two dynamic seals, the outboard bearing, a static seal, and a segmented locking flange. The outer, O-ring-sealed flange mates with either the Astromast canister or the fixed tunnel.

This section of cylinder permits shirtsleeve replacement of the dynamic seals or the bearing. The outer surface is teflon coated to prevent scoring the mating sealing surface during retraction. Slots in the outer flange engage tapered guide pins during retraction to facilitate indexing the segmented locking flanges for seal or bearing replacement. This part is machined from a roll-ring forging of 2219-T87 aluminum.

Page intentionally left blank

R260

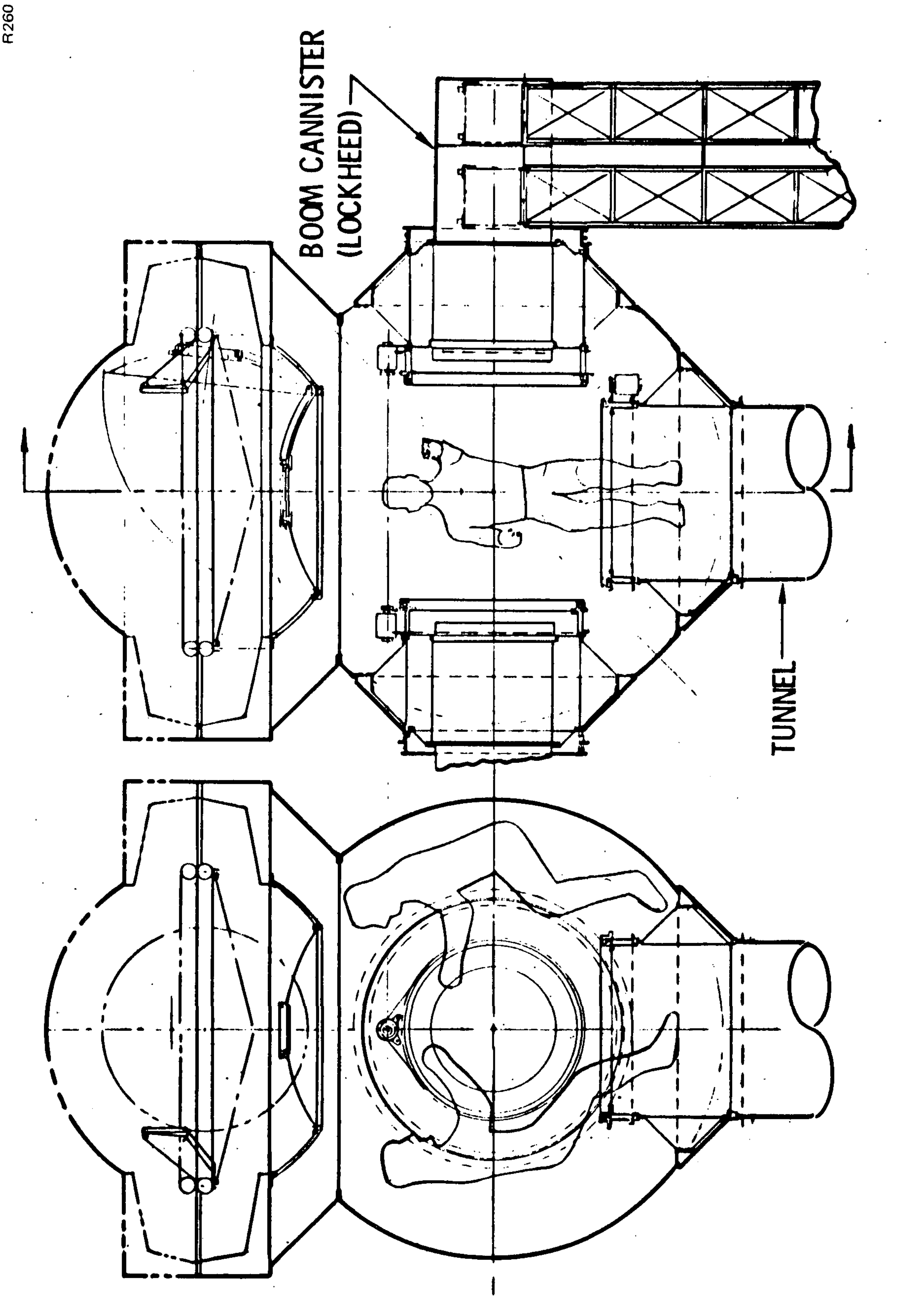


Figure 4.2-47. Solar Array and Orientation Mechanism

R260

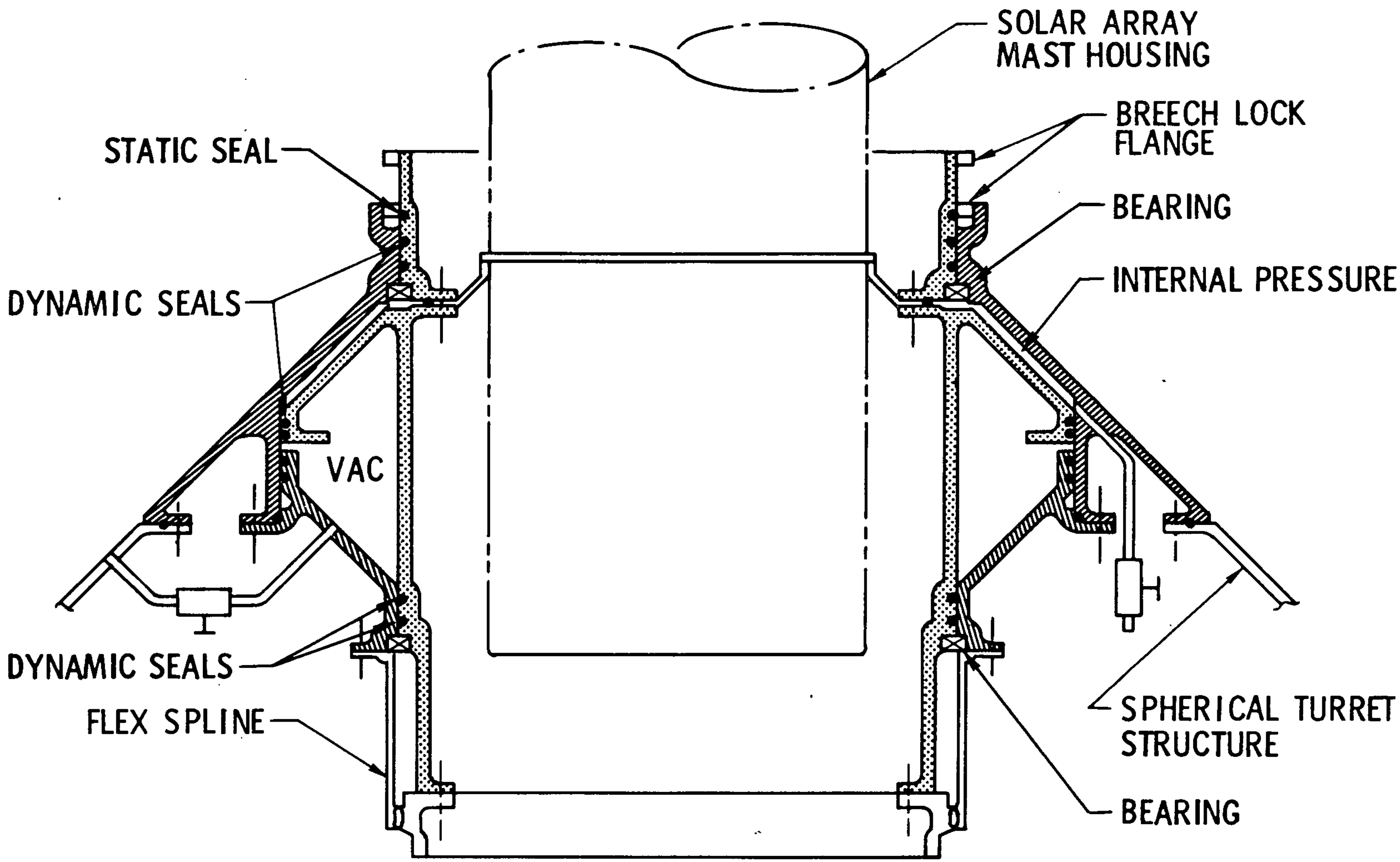


Figure 4.2-48. Solar Array Gimbal

(2) An outer truncated cone which is bolted to an O-ring-sealed flange on the spherical turret pressure shell. The outer end of this cone engages the bearing and dynamic seals on the short cylinder and contains a segmented locking flange which mates with that on the cylinder for bearing or seal replacement. The length of the inner cylindrical surface on this cone is established to permit removal of the bolts which mount the inner cone. This cone is machined from spin forged aluminum which is heat treated, compression stress relieved, and aged to the T87 temper.

(3) A 66 cm (26-in.) long, 91.5 cm (36-in.) diameter inner cylinder containing the two inner dynamic seals and bearing, and an integral load balancing cone which also contains two dynamic seals. The diameter of the sealing cylinder on the load balancing cone is the $\sqrt{2}$ times the diameter of the inner cylinder so that with the inboard side of the cone vented to vacuum and the outboard side to the turret pressure, there is no static end load on the bearings. Increasing the pressure between the load balancing cone and the outer cone after removal of the bolts retaining the inner cone and installing guide pins to prevent its rotation during retraction, is the procedure employed to engage the segmented locking flanges with the drive motor providing the relative rotation to interlock them. With the segment flanges interlocked, the dynamic seals and bearing on the outer cylinder are exposed and the whole drive assembly can be disassembled for servicing. The inner cylinder and load balancing cone are machined from spin forged 2219-T87 aluminum.

(4) An inner cone which forms the back bulkhead for the vacuum chamber behind the load-balancing cone and engages the inner dynamic seals and bearing on the cylinder, bolts to the outer cone, and transmits torsion and bending loads to the turret pressure shell. The inner cone contains a flange for mounting the flex spline and mounting points for the drive motor. It also is machined from spin forged 2219-T87 aluminum.

(5) A flex spline with a pitch diameter of approximately 92 cm (36.25 in.) and 462 teeth.

(6) A circular spline which mounts on the inner cylinder and which contains a bearing for mounting the wave generator. The circular spline contains 460 teeth.

(7) A wave generator which is driven through a chain from a sprocket on a variable speed drive motor. Rollers on the elliptical surface of the wave generator force the teeth on the flex spline into engagement with those on the circular spline. One clockwise revolution of the wave generator causes the circular spline to move two teeth counterclockwise, so that the reduction between the wave generator and the circular spline is 230:1. The pitch diameter of the chain sprocket on the wave generator is 99 cm (39 in.) and that of the drive sprocket is 8.9 cm (3.5 in.) for a reduction of 12:1. The overall reduction is then

$$230 \times 12 = 2760:1$$

so that when the relative rotation between cylinder and cone is the orbital rate (1 revolution in 90 minutes), the drive motor is rotating at about 30 rpm.

The flex spline, circular spline, and wave generator comprise the harmonic drive which is selected here for its high torsional stiffness and low backlash and tooth load, as well as its high single-step reduction. The harmonic drive is a proprietary development of the American Shoe Machinery Corporation.

4.2.3.13 High-Gain Antenna Deployment Mechanism

The Space Station communications subsystem requires that three 2.43 m (8-ft) diameter antennas be mounted on the Crew/Operations Module. These antenna are mounted on 6.1 m (20-ft) long support booms and extended radially from the cylindrical surface of the module. They are equally spaced 120 degrees apart and interdigitated with the radial docking ports of the module. The antennas must be stowed within a 4.5 m (15-ft) diameter during Shuttle transport of the module. Figure 4.2-50 illustrates the geometry of the antenna in the stowed and the deployed position. The deployment actuation system must be reversable to allow return to Earth of the module via the Shuttle Cargo bay.

Figure 4.2-51 illustrates the mechanical design of the antenna deployment system. During launch, each antenna is stowed with the boom supported at the powered hinge point and within a block attached to the module end-ring structure. The horn of the antenna is equipped with a fitting which allows three of the end-docking port structural latches to be used to secure the antennas during launch. An electro-mechanical actuator is mounted on a fitting which protrudes into the cylindrical pressure shell allowing the actuator to operate in a pressurized environment as well as providing the feature of pressurized access by the crew.

The drive for the antenna boom consists of an electric motor, a gear train, and a harmonic drive that is coupled to the boom through a dynamic seal. The dynamic seal uses a double plate design allowing the seal and/or the actuator to be replaced without creating a leak.

The slot penetration of the meteoroid/thermal shroud caused by the boom articulation is covered by a spring-loaded sliding panel which is actuated by the boom motion.

The antenna assembly mounted at the outer end of the boom has a mass of 107 kg (235 lb). It is gimballed in two axis with servo drives to provide pointing and tracking. A 12.7 cm (5-in.) diameter aluminum alloy or a 10.2 cm (4-in.) diameter Boron epoxy composite boom will provide sufficient stiffness to preclude dynamic coupling with the control system.

4.2.3-14 Solar Array Deployment Mechanism

The array support structure provides for packaging the array blankets and releasing them for deployment. It provides the structure and mechanisms to deploy and tension the arrays, and to retract the arrays or individual strips. Figures 4.2-52 and 4.2-53 illustrate the deployment mechanisms. The array structure component designs are discussed below.

The extendible mast deploys and supports the entire flexible-array system. The mast and canister assembly provides support at partial deployment and also has full retraction capability for array wing replacement. The mast is lightweight and has the strength and stiffness to withstand compression loads for tensioning the array strips and withstanding bending loads. In the design study for the Space Station Solar Array Technology Evaluation Program, NAS-11039, many other candidate deployment booms were evaluated for application to the Space Station solar array.

An open lattice structure has an insignificant thermal bending characteristic. The Astromast-articulated triangular lattice proved to be the most efficient structure investigated in terms of stiffness, weight, and material economy and is being fabricated for test and evaluation under the above reference contract. The Astromast has been selected for the Modular Space Station for the above reasons.

Inboard and Outboard Assemblies

The inboard and outboard assemblies support the packaged array strips during launch. The deployed array strips are attached at one end to the inboard support assembly (ISA) and at the other end to the outboard support assembly (OSA). Each array quadrant has one set of an ISA and an OSA.

PRECEDING PAGE BLANK NOT FILMED

R260

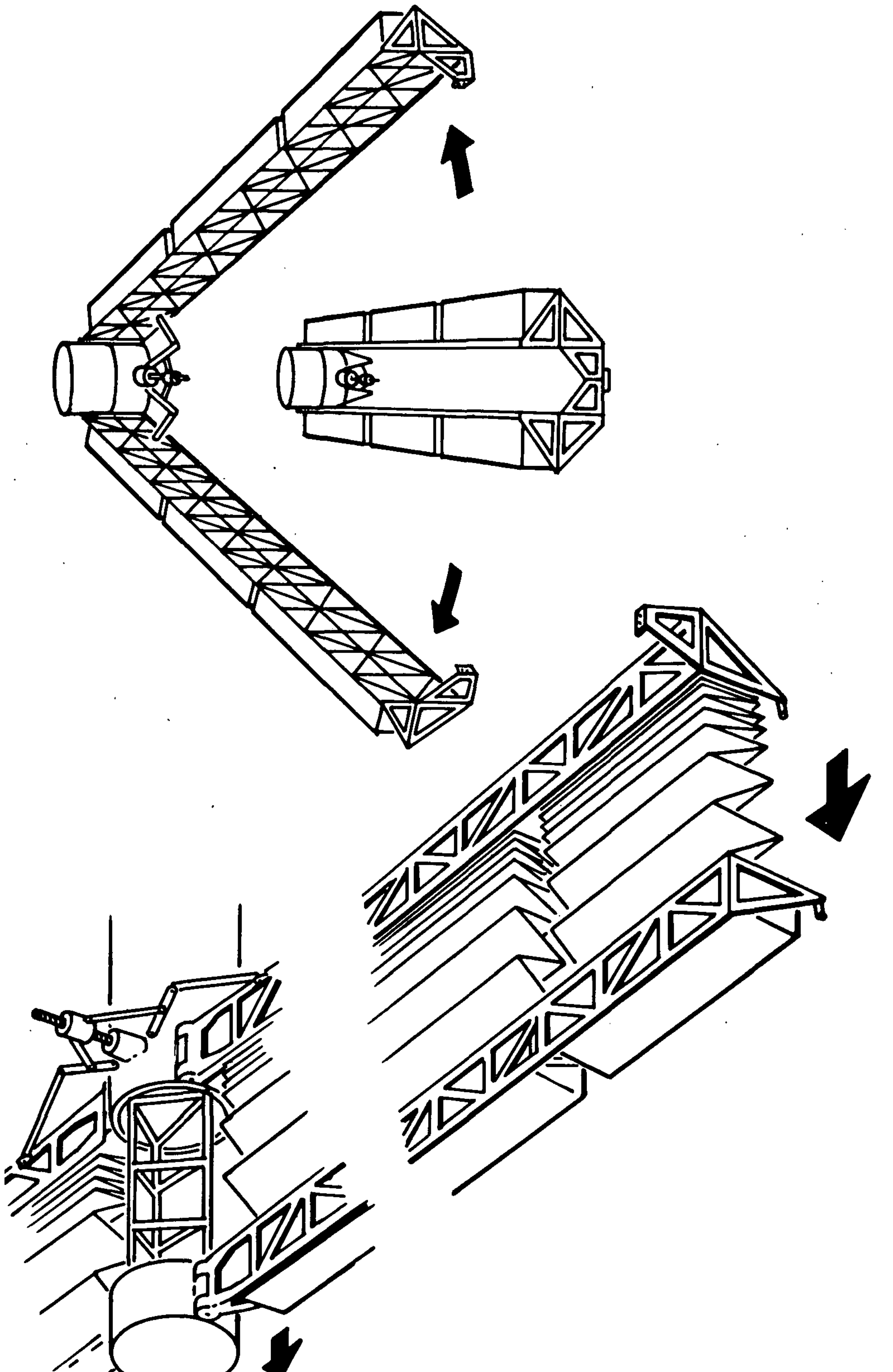


Figure 4.2-52. Solar Array Support Structure

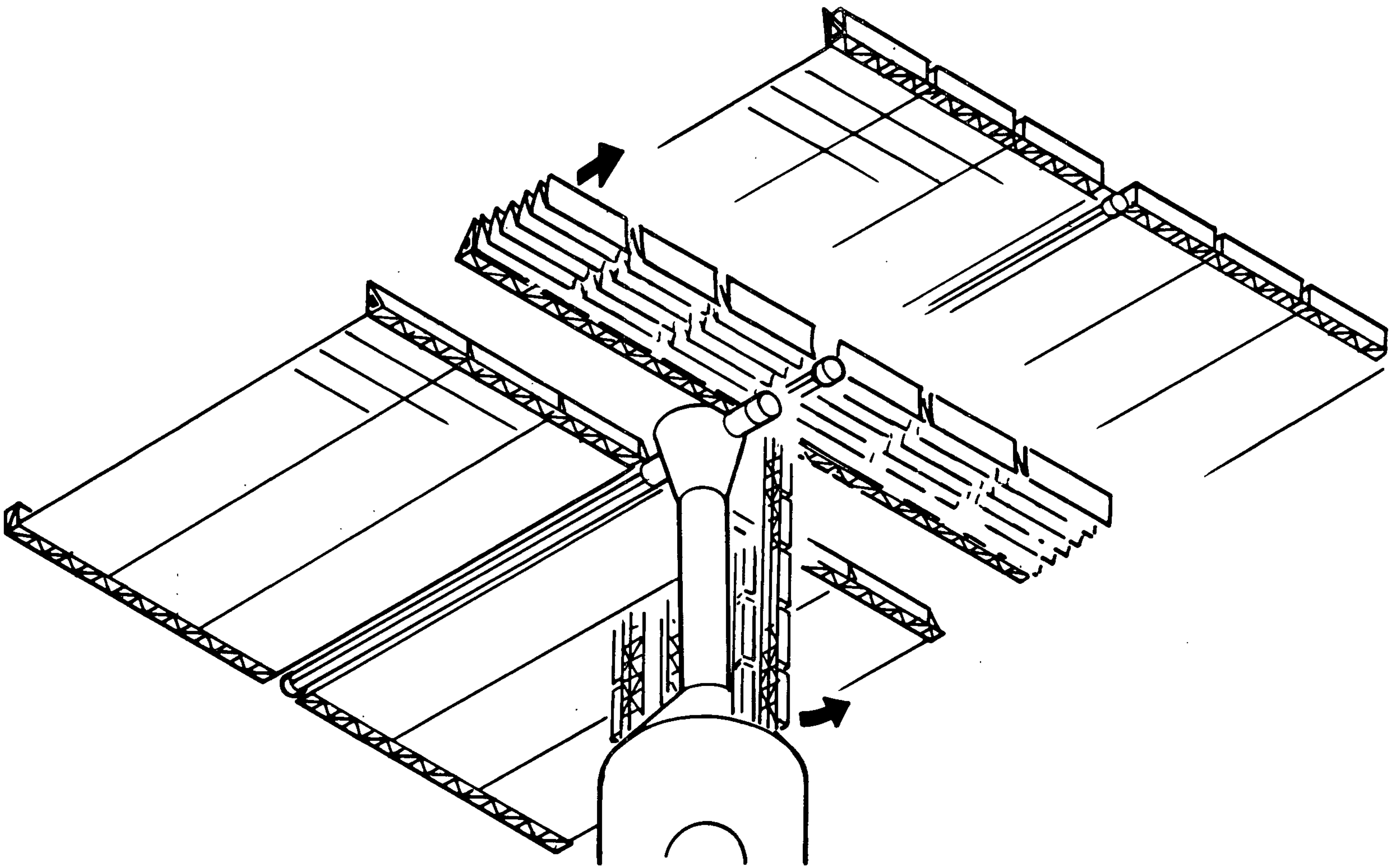


Figure 4.2-53. Solar Array Mast/Panel Deployment

The functions of an ISA are:

A. Support the flatfold array strips in their containment packages.

B. Anchor the strip deployment/retraction guide wires and their tensioning negators.

C. Anchor the extendible-truss mast guy wire (tape) and its reel-motor at the outer end.

D. Mate and lock with the OSA so that both bodies can swivel into operational position from ascent-stowed position by means of the positioning-mechanism lever arm attached to the inner end of the two assemblies.

E. Mate with the extendible mast canister to support the array quadrant.

The functions of the OSA are:

A. Deploy the array strips when the OSA is separated from the ISA.

B. Anchor the guide wires for all strips of the quadrant.

C. Mate and lock with ISA for stow condition and for positioning before strip deployment.

D. Support the mechanism by which the strip container compression cover and the array strip can be retracted back to the inboard support assembly and a new array strip hauled out.

The inboard support assembly (one per quadrant) is a triangular truss beam constructed of aluminum tubing and divided into sections, each of which supports one packaged (flat-folded) array strip and its guides for deployment and retraction. The base plate of each of the strip packages is secured to the upper rectangular truss section. The multiple-negator motor for tensioning of the guides is mounted on the under side and at the front edge of the base plate. The takeup reel for the guides is mounted to the multiple negator motor.

The outboard support assembly (one per quadrant) is structurally a mirror image of the ISA (aluminum tubular truss). It is divided into compartments, each with space provided for housing a strip compression cover with stiffeners which provide protection for the array strips from prelaunch, ascent, and orbit environments before deployment. The strip covers go out with the OSA when the extendible mast is deployed but are released by a motor-reel system to allow strip retraction and replacement. The central-truss beam cap, to which the OSA pivot support is jointed, also provides a locking mechanism to prevent further motion about the pivot axis of the OSA after deployment.

The triangular tubular truss form for these support assemblies was selected for the following reasons:

- This structural form has the lowest weight-to-stiffness ratio for the required torsion and bending loads in this application.
- Fabrication and assembly costs are reduced 20 to 30 percent over other forms.
- Easy access is provided for installation of guide wires and deployment mechanism for strips and compresssion covers used in array deployment retraction and replacement.

Guy-Wire Assembly

The guy-wire runs from the tip of the extendible mast to the ends of the inboard support assembly that are away from the base of the mast. These wires serve to limit tip deflection of the extendible mast in the plane of the array. By limiting tip deflection, significant warping of array strips is avoided as is the interference of array strips with each other and with the extendible mast. The mast tip tends to deflect with unbalanced strip tensioning loads and with docking loads. Each guy-wire assembly (two per array wing) consists of two elements, a winding tape and a reel and motor for stowage and release of the tape. As the extendible mast is deployed, the tapes unreel until a fixed position of the array wing is reached.

Stainless steel tapes were chosen for this central truss beam support function (docking "g" loads) rather than braided cable for three basic reasons:

A. Minimal stretch quality avoiding twist and sag.
B. Reels out and in without misalignment.
C. Lighter weight for a given stress level.

4.2.3.15 Flight Loads and Module/Shuttle Orbiter Interface Fittings

The selected mounting arrangement is shown in Figure 4.2-54. All the fore and aft loads are reacted at a single point on the keel of the cargo bay at the forward joint between the cone and cylinder of the module pressure shell. A titanium fitting on the module engages a clevis pin which is mounted in the cargo bay keel so that it is free to rotate and move in or out along its axis to accommodate tolerances. This pin thus reacts only axial and lateral loads and does not restrain the module vertically or in pitch. The details of this design are shown in Figure 4.2-55. The axial and lateral reactions at this pin are designated R_1 and R_2 respectively.

A titanium fitting on the module at the aft cone/cylinder joint engages the slot in the cargo-bay keel. Thus, this fitting reacts only lateral load and does not restrain the module axially, vertically, or in pitch or roll, but, with the forward keel fitting, provides yaw positioning. The lateral reaction at this fitting is R_3.

The vertical loads are reacted by a single fitting at the aft cone/cylinder joint and an identical pair of fittings at the forward cone/cylinder joint. These titanium fittings do not restrain the module axially or laterally (or thus in yaw), but position it in roll and pitch. The aft and two forward vertical reactions are designated R_4, R_5, and R_6 respectively.

During orbital operation it may be desirable to reverse the Crew/Operations Modules in the Shuttle cargo bay during return to Earth. This is feasible with a design change by duplicating the forward fitting on the aft end of the module bottom centerline. During return, the module would be attached to the Orbiter keel at the forward end (in the Orbiter) where horizontal and side loads would be taken. The other bottom fitting would take side load only at the Orbiter keel. Vertical loads would be taken by the Orbiter door rails at the one forward side fitting and the two aft side fittings—just the opposite of the original launch. The weight penalty to incorporate this change would be approximately 30 lb.

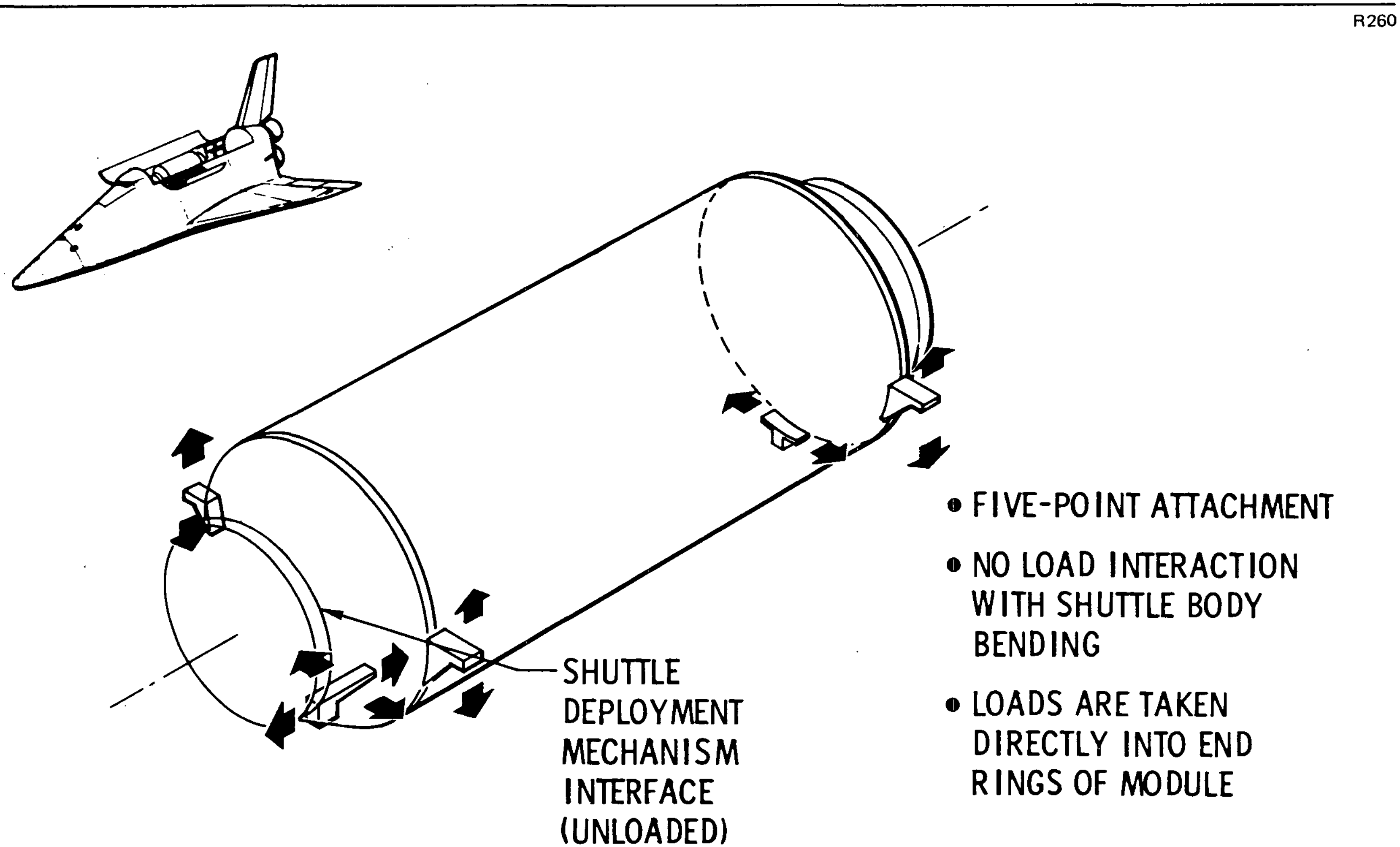


Figure 4.2-54. Support in Shuttle Cargo Bay

From inspection of Figure 4.2-56:

$$R_1 = P_x = N_x (S.F.) W = N_x (S.F.) (11,350)\ 9.8\ n$$

$$R_2 = R_3 = 0.5\ P_y = 0.5\ N_y (S.F.) W = 55,600\ N_y (SF)\ n$$

$$R_4 = \frac{5.75\ P_z - 2.16\ R_1}{11.5} = 0.5\ P_z - 0.188\ R_1$$

$$R_6 = \frac{2.44\ P_z \pm 2.16\ (R_2 + R_3)}{4.88} = 0.5\ P_z \pm 0.442\ P_y$$

$$R_5 = P_z - (R_4 + R_6)$$

The applied loads and resultant reactions are summarized in the table of Figure 4.2-56 for each mission phase. The emergency landing is the critical condition for the design of all three support fittings since, for commonality, the same fitting design is used at R_4, R_5, and R_6. The critical reactions are used for sizing the attachment of the fittings as well as the local shear strength of the module pressure shell to preclude tear out at the emergency landing condition.

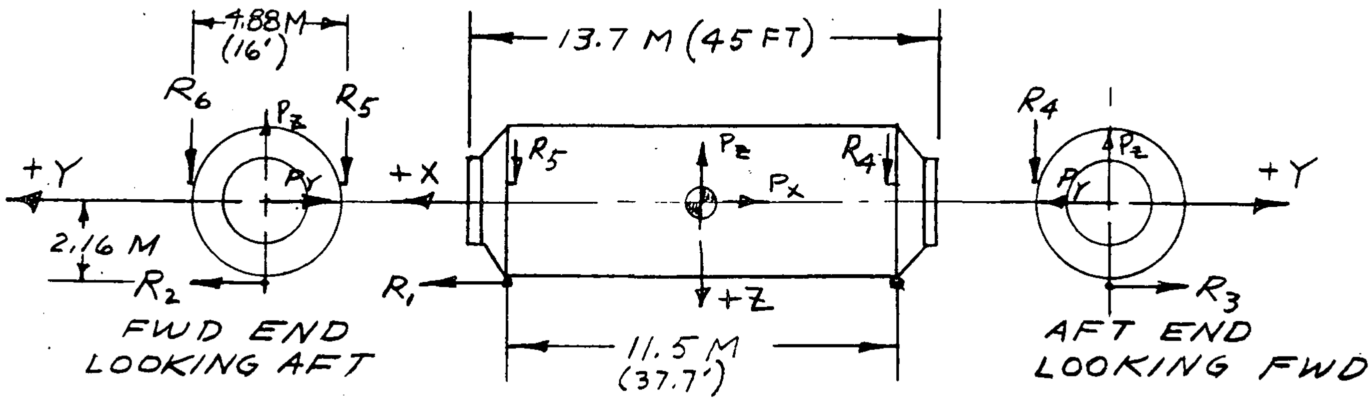
Again from inspection of Figure 4.2-56 a conservative approximation of the module bending moment is

$$M_y = 2.16\ P_x - \frac{11.5\ P_z}{8} = 2.16\ P_x - 1.438\ P_z$$

If it is assumed that the load factors specified along all three axis act simultaneously, the maximum bending moment occurs at Orbiter burnout and is

$$M = 2.16\ (514,000) + 1.438\ (78,000)$$

$$M = 1.22 \times 10^6\ \text{nm}\ (10.8 \times 10^6\ \text{in. lbs})$$



REACTIONS SHOWN POSITIVE - SHUTTLE COORDINATE AXES

MISSION PHASE	LIMIT LOAD FACTORS n_X	n_Y	n_Z	SAFETY FACTOR	APPLIED LOAD NEWTONS x 10⁻³ P_X	P_Y	P_Z	REACTIONS - NEWTONS x 10⁻³ R_1	R_2	R_3	R_4	R_5	R_6
LAUNCH	3.0	±1.0	1.0	1.4	467	±156	156	467	±78	±78	-10	19 / 157	147 / 9
HIGH Q	1.9	1.0	1.0		296	156	156	296	78	78	22	-13 / 125	147 / 9
HIGH Q	1.9	1.0	-1.0		296	156	-156	296	78	78	-134	13 / 125	-9 / -147
END BOOSTER	3.3	2.0	2.0		514	311	311	514	156	156	60	-42 / 234	294 / 18
END ORBITER	3.3	0.5	-0.5		514	78	-78	514	39	39	-136	62 / 132	-4 / -74
ENTRY	-0.5	1.0	-2.0		-78	156	-311	-78	78	78	-141	-84 / 54	-87 / -225
FLYBACK	-0.5	1.0	1.0		-78	156	156	-78	78	78	93	-84 / 54	147 / 7
FLYBACK	-0.5	1.0	-2.5		-77.9	156	-389	-78	78	78	-180	16 / 54	-126 / -264
LANDING	-1.3	0.5	-2.7		-202	78	-420	-202	39	39	-172	-73 / -3	-175 / -245
EMERGENCY LAND.	-8.0	1.5	-4.5	1.0	-890	167	-500	-890	84	84	-83	-239 / -95	-178 / -322
EMERGENCY LAND.	+1.5	—	+2.0	1.0	167	—	222	167	—	—	80	142	111

11,350 KGM (25000 LB) MODULE WT ASSUMED FOR LOADS ANALYSIS

5 POINT STATICALLY DETERMINANT MOUNT

4.448 NEWTONS = 1 LB

Figure 4.2-56. Module Reactions

and the unit load from bending is

$$N_b = \frac{M}{\Pi R^2} = \frac{1.22 \times 10^6}{\Pi (2.03)^2} = 9.36 \times 10^4 \frac{n}{m}$$

$$N_b = \frac{(10.8 \times 10^6)}{\Pi (80)^2} = (537 \text{ lb/in.})$$

At the end of Orbiter burn, the cargo bay will have vented to vacuum and the pressure differential across the Space Station Module pressure shell will be 1.01×10^5 N/m^2 (14.7 psi). The unit axial load from pressure is then

$$N_p = \frac{PR}{2} = \frac{(1.01 \times 10^5)(2.03)}{2} = 10.3 \times 10^4 \frac{n}{m}$$

Thus, there is no net axial compression from combined pressure and bending at Orbiter burnout.

At launch, during flyback, and at landing there will be no pressure differential across the module pressure shell to act in combination with the bending moment. The torque and bending moments on the pressure for each mission phase are summarized in Table 4.2-5.

The highest bending moment with no stabilizing pressure differential occurs during emergency landing. This is considered the design condition for the mounting fittings, but since the Space Station Module pressure-shell buckling on emergency landing will not endanger the Orbiter crew, it is not considered a design condition for the pressure shell other than to establish the local shear strength of the shell at each mounting point to preclude tear out. The critical bending condition thus occurs during launch and the design unit loading from bending is

$$N_b = \frac{M_y}{\Pi R^2} = \frac{786,000}{\Pi(2.03)^2} = 60,800 \frac{n}{m} \text{ (350 lb/in.)}$$

Table 4.2-5

TORQUE AND BENDING MOMENTS

$M_x = 2.16\ P_y$ $M_y = 2.16\ P_x - 1.44\ P_z$ $M_z = \frac{11.5\ P_y}{8} = 1.44\ P_y$

Mission Phase	Ultimate Load Factors			Applied Loads n x 10^{-3}			Module Moments* nm x 10^{-3}		
	N_x	N_y	N_z	P_x	P_y	P_z	M_x	M_y	M_z
Launch	4.2	±1.4	1.4	467	±156	156	337	786	225
High Q	2.66	±1.4	-1.4	296	±156	-156	337	865	225
End Booster	4.62	±2.8	2.8	514	±311	311	672	661	449
End Orbiter	4.62	±0.7	-0.7	514	±78	-78	168	1223	112
Entry	-0.7	±1.4	-2.8	-78	±156	-311	337	281	225
Flyback	-0.7	±1.4	1.4	-78	±156	156	337	-393	225
Flyback	-0.7	±1.4	3.5	-78	±156	-389	337	393	225
Landing	-1.82	±0.7	3.78	-202	±78	-420	168	169	112
Emergency Landing	8.0	±1.5	-4.5	-890	±167	-500	360	-1200	240
Emergency Landing	1.5	-	2.0	167	-	222	-	41	-

*Assumes load factors at each mission phase act simultaneously.

The maximum torque on the pressure shell occurs at Booster burnout and the maximum unit shear flow from torsion is

$$q = \frac{M_x}{2\Pi R^2} = \frac{672,000}{2\Pi\ (2.03)^2} = 26,200\ \frac{n}{m}\ (150\ \text{lb/in.})$$

4.2.3.16 Integral Stiffener Sizing

From consideration of meteoroid shielding, critical crack length, and damage resistance, as described earlier, 0.152 cm (0.060 in.) was selected as the minimum pressure shell thickness satisfying the requirement for manned safety. The circumferential rib spacing, selected to be smaller than the critical crack length, is 20.3 cm (8 in.). The buckling stress from axial compression of the pressure shell membrane is then

$$\frac{F_{cr}}{E} = 9\left(\frac{t}{R}\right)^{1.6} + 0.16\left(\frac{t}{L}\right)^{1.3} \quad \text{(Kanemitsu and Nojima)}$$

from which F_{cr} = 2540 n/cm^2 (3,680 psi). The ring stiffened pressure shell will thus carry (2,540) (0.152) = 386 n/cm (221 lb/in.). The longitudinal ribs must then be sized for 608-386 = 222 n/cm (127 lb/in.). Spaced to align with the docking interface latches and the equipment support structure attach points, the longitudinal ribs are 15-degrees apart. The maximum compressive loading at launch occurs on the rib at the top ℄ and is

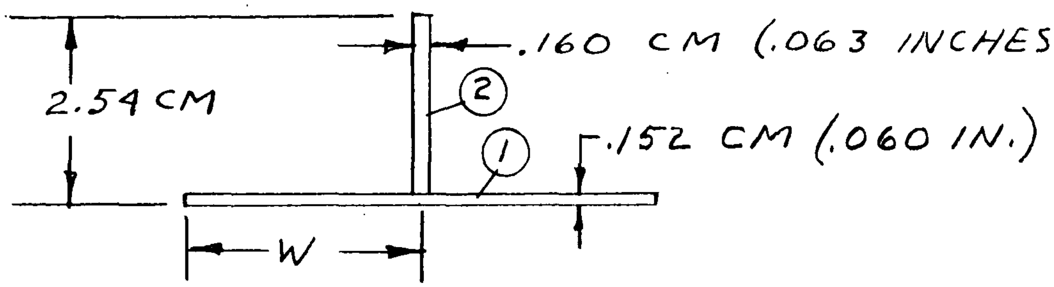
$$N_R = \frac{\Pi\ (406)\ (222)}{24} + 6.1\ (386) = 14,160\ n\ (3,180\ \text{lb})$$

The moment of inertia required for this rib to prevent column buckling between frames is

$$I = \frac{P_{cr} L^2}{\Pi^2\ E}$$

The moment of inertia of the selected longitudinal rib with an effective width of skin W = $0.85t\ \sqrt{E/F_c}$, is calculated in Figure 4.2-57.

LONGITUDINAL RIB



$$W = .85t\sqrt{\frac{E}{F_c}} = .85t\sqrt{\frac{EA}{P}}$$

$$A = .304W + .382$$

$$W = (.85)(.152)\sqrt{\frac{6.9\times10^6(.304W + .382)}{14550}}$$

$$W = 3.38 \text{ CM}$$

ITEM	AREA	Y	AY	AY^2	$bh^3/12$
1	1.028	.076	.0781	.0059	
2	.382	1.346	.514	.692	.184
	1.41		.592	.6979	
				.184	
				.882	
				.249	
				.633	

$$\frac{.592}{1.41} = .42$$

$$(.42)^2 1.41 = .249$$

$$I = .633 \text{ CM}^4$$

$$F_c = \frac{14{,}550}{1.41} = 10{,}300 \frac{\text{NEWTONS}}{\text{CM}^2} = 15{,}000 \text{ PSI}$$

Figure 4.2-57. Longitudinal Rib Design

The moment of inertia of the circumferential ribs that is required to preclude general instability buckling at the design bending moment can be approximated by using the empirically-derived frame coefficient proposed by F.R. Shanley

$$C_f = \frac{(EI)_f L}{MD^2} = \frac{1}{16,000}$$

where

$$L = \Pi \sqrt{\frac{E I_s}{P}} = 3.14 \sqrt{\frac{6.9 \times 10^6 (0.633)}{14,160}} = 55.0 \text{ cm}$$

$$M = 78.6 \times 10^6 \text{ n cm } (6.95 \times 10^6 \text{ in. lb})$$

$$D = 406 \text{ cm } (160 \text{ inches})$$

$$I_f = \frac{MD^2}{16,000 \text{ EL}} = \frac{78.6 \times 10^6 (406)^2}{(16,000)(6.9 \times 10^6) 54.4} = 2.17 \text{ cm}^4$$

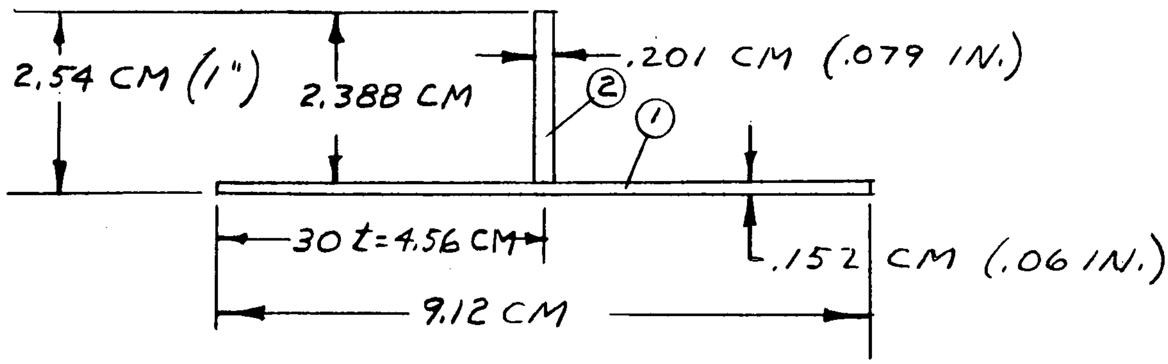
$$I \text{ (per in.)} = \frac{2.17}{55.0} = 0.0395$$

$$I_{rib} = 20.3 (0.0398) = 0.802 \text{ in.}^4$$

The circumferential rib is shown in Figure 4.2-58. The thickness of a monocoque cylinder with the same weight per unit area as the waffled cylinder (t) is 0.183 cm (0.072 in.).

In addition to the flight loads, the integral ribs must be designed to give the pressure shell enough longitudinal and circumferential bending stiffness at the radial docking ports to prevent resonance of a docked module with the Modular Space Station control frequency. To preclude resonance with the selected control frequency of 0.01 cps, it is desirable to establish the docking

CIRCUMFERENTIAL RIB



ITEM	AREA	Y	AY	AY²	bh³/12
1	1.386	.076	.1052	.008	
2	.480	1.346	.646	.870	.232
	1.866		.751	.878	
				.232	
				1.110	
				.302	
				.808	

$$\bar{Y} = \frac{AY}{A} = \frac{.751}{1.866} = .402$$

$$(.402)^2(1.866) = .302$$

$$I = .808 \text{ CM}^4$$

$$\bar{t}_{FRAMES} = \frac{(2.388)(.201)}{20.3} = .0237 \text{ CM } (.0093 \text{ IN.})$$

$$\bar{t}_{LONG.} = \frac{(2.388)(.160)}{53.2} = .0072 \text{ CM } (.00283 \text{ IN.})$$

$$\bar{t}_{PRESS.\ SHELL} = .152 + .031 = .183 \text{ CM } (.072 \text{ IN.})$$

Figure 4.2-58. Circumferential Rib Design port stiffness to provide a fundamental frequency 10 times the control frequency, or 0.1 cps, for a docked module 4.26 m (14-ft) diameter, 13.7 m (45-ft) long, and weighing 9,060 kgms (20,000 lb). The moment of inertia of the docked module is approximately

$$I = m\left[\frac{l^2}{3} + \frac{r^2}{4}\right] = 5.8 \times 10^5 \text{ kgm m}^2 \ (4.26 \times 10^5 \text{ slug ft}^2)$$

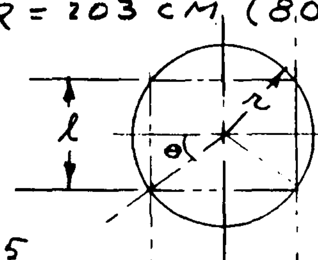
The integral frames at the radial docking ports must also be sized to carry the bending moments imposed by the Reaction Control System (RCS) of a docked Orbiter. With two 7,120 n (1,600-lb) thrusters firing, the Orbiter roll control torque from the MDAC Phase B study is 142,500 nm (105,000 ft lb) and the pitch control torque is 258,000 nm (190,000 ft lb). The roll control torque results in a longitudinal bending moment, and the pitch control torque in a circumferential bending moment at the radial docking port. The bending moment is $M = T\, I_S/I_T$ where T is the control torque, I_S the roll or pitch moment of the Space Station about the docking port, and I_T the total moment of inertia (Orbiter plus Space Station) about the cg. The maximum bending moments occur at the GSS phase of the buildup where the Space Station moments of inertia are maximum. The maximum circumferential bending moment is 64,600 nm (47,600 ft lb) and the maximum longitudinal bending moment at the radial docking port is 35,700 nm (26,300 ft lb).

Orbiter RCS which imposes these moments is sized for the reentry condition and appears unreasonably large for orbital operations. The ignitors for the large RCS engines, with about 220 n (50 lb) thrust, have been proposed for orbital operations and may be a more reasonable solution. The 7.120 n (1600 lb) thrustors with the moments they generate, have been used however, for sizing the frames in the vicinity of the radial docking ports.

If the shell is pressurized, the circumferential bending moment can be carried by a realignment of the membrane forces along the sides of the port as shown in Figure 4.2-59. The calculation shows the realignment of the membrane forces from a 68,000 nm (50,000 ft lb) circumferential bending

$$P = 2\int_0^{\frac{\pi}{2}} \frac{M \cos\theta \, r \, d\theta}{\pi r^2}$$

$r = 129.5$ CM ($51''$)
$R = 203$ CM ($80''$)



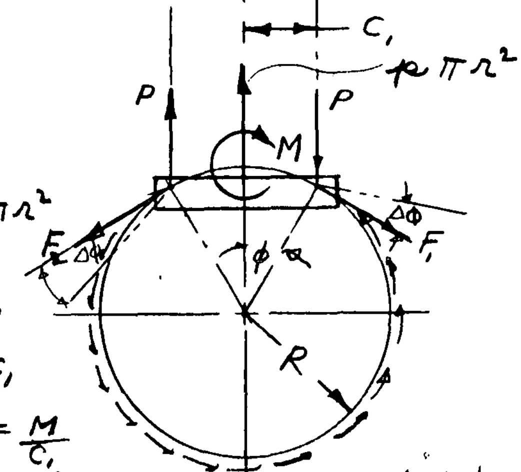
$$P = \frac{2M}{\pi r} \qquad 2c_1 P = M$$

$$c_1 = \frac{M}{2P} = \frac{\pi r}{4}$$

$\cos\theta = \frac{40}{51} = .785$
$\theta = 38.3°$
$\sin\theta = .62$
$r \sin\theta = 31.6$
$l = 63.2''$

$$\sin\phi = \frac{c_1}{R} = \frac{\pi r}{4R} = \frac{3.14(51)}{(160)2} = .5$$

$$\phi = 30° \qquad c_1 = 40''$$



① $F_1 \cos(\phi - \Delta\phi) = F_2 \cos(\phi + \Delta\phi)$

② $F_1 \sin(\phi - \Delta\phi) + F_2 \sin(\phi + \Delta\phi) = p\pi r^2$

$$P = \frac{p\pi r^2}{2} - F_1 \sin(\phi - \Delta\phi) = M/2c_1$$

$$P = F_2 \sin(\phi + \Delta\phi) - \frac{p\pi r^2}{2} = M/2c_1$$

③ $F_2 \sin(\phi + \Delta\phi) - F_1 \sin(\phi - \Delta\phi) = \frac{M}{c_1}$

solving ①, ② & ③ simultaneously for F_1 F_2 and $\Delta\phi$
where $\Delta\phi$ = rotation of tangents to membrane from M.

add ② & ③

$$2F_2 \sin(\phi + \Delta\phi) = p\pi r^2 + \frac{M}{c_1} \qquad F_2 = \frac{p\pi r^2 + M/c_1}{2\sin(\phi + \Delta\phi)}$$

subtract ③ from ②

$$2F_1 \sin(\phi - \Delta\phi) = p\pi r^2 - \frac{M}{c_1} \qquad F_1 = \frac{p\pi r^2 - M/c_1}{2\sin(\phi - \Delta\phi)}$$

substitute in ① and solve for $\Delta\phi$

$$\frac{(p\pi r^2 - M/c_1)\cos(\phi - \Delta\phi)}{2\sin(\phi - \Delta\phi)} = \frac{(p\pi r^2 + M/c_1)\cos(\phi + \Delta\phi)}{2\sin(\phi + \Delta\phi)}$$

$$\frac{\sin(\phi + \Delta\phi)\cos(\phi - \Delta\phi)}{\sin(\phi - \Delta\phi)\cos(\phi + \Delta\phi)} = \frac{p\pi r^2 + M/c_1}{p\pi r^2 - M/c_1}$$

$$\frac{(\sin\phi\cos\Delta\phi + \cos\phi\sin\Delta\phi)(\cos\phi\cos\Delta\phi + \sin\phi\sin\Delta\phi)}{(\sin\phi\cos\Delta\phi - \cos\phi\sin\Delta\phi)(\cos\phi\cos\Delta\phi - \sin\phi\sin\Delta\phi)} = \frac{p\pi r^2 + M/c_1}{p\pi r^2 - M/c_1}$$

$$\frac{\sin\phi\cos\phi + \sin\Delta\phi\cos\Delta\phi}{\sin\phi\cos\phi - \sin\Delta\phi\cos\Delta\phi} = \frac{p\pi r^2 + M/c_1}{p\pi r^2 - M/c_1}$$

Figure 4.2-59. Radial Docking Deflections moment at the port to be small. The 0.152 cm (0.06 in.) membrane will, when pressurized, carry the circumferential bending moment without frames. The frames must be sized to carry the longitudinal bending moment. They must also carry the circumferential moment when the shell is unpressurized.

A conservative approximation of the unpressurized circumferential bending stiffness of the radial docking port, and the frame stresses from a circumferential bending moment, can be derived using Wise's coefficients. To facilitate this calculation, the stiffness of the clamped joints between the machined docking-ring flange and the pressure-shell frames are assumed to match the stiffness of the frames so that they can be treated as continuous. The load

$$p = 2 \int_{o}^{\pi 2} \frac{M \cos\theta \; r \, d\theta}{\pi r^2} = \frac{2M}{\pi r}$$

where r is the docking port radius and M the applied circumferential moment, is assumed shared equally by five frames on each side of the docking port centerline. The frame, the loading schematic, and calculations for frame stress and docking port stiffness are shown in Figures 4.2-60 and 4.2-61.

Wise's deflection coefficients have also been used to derive a conservative approximation of the radial docking port longitudinal bending stiffness, and the maximum frame stresses from a longitudinal bending moment. For this calculation the docking ring is assumed stiff compared to the pressure shell so that the plane of the docking interface remains plane (rotates without bending). The stiffness of the clamped joints between the frames and the docking-ring flange is again assumed to match the stiffness of the frames so they can be treated as continuous.

The longitudinal moment is carried by the eight frames on each side of the docking-port centerline. The loading schematic, deflections, and frame stresses from a longitudinal moment of 35,700 nm (26,300 ft lbs) are shown in Figures 4.2-62, 4.2-63, and 4.2-64.

$$\frac{\left(\frac{1}{2}\right)\frac{\sqrt{3}}{2} + \sin\Delta\phi\cos\Delta\phi}{\left(\frac{1}{2}\right)\frac{\sqrt{3}}{2} - \sin\Delta\phi\cos\Delta\phi} = \frac{p\pi r^2 + M/c_1}{p\pi r^2 - M/c_1}$$

$$\frac{.433 + \sin\Delta\phi\cos\Delta\phi}{.433 - \sin\Delta\phi\cos\Delta\phi} = \frac{p\pi r^2 + M/c_1}{p\pi r^2 - M/c_1}$$

$p\pi r^2 = 14.7(3.14)(51)^2 = 120{,}000$ lbs (534,000 N)

$M = 50{,}000$ ft lbs $= 600{,}000$ in. lbs. $\quad c_1 = 40''$

$$\frac{.433 + \sin\Delta\phi\cos\Delta\phi}{.433 - \sin\Delta\phi\cos\Delta\phi} = \frac{120{,}000 + 15000}{120{,}000 - 15000} = \frac{135}{105} = 1.286$$

$$.433 + \sin\Delta\phi\cos\Delta\phi = .556 - 1.286\sin\Delta\phi\cos\Delta\phi$$

$$\sin\Delta\phi\cos\Delta\phi = \frac{.556 - .433}{2.286} = .0538$$

$\sin\Delta\phi = .054 \qquad \cos\Delta\phi = .9985$

$\Delta\phi = 3°\ 6'$

$$\frac{M}{\Delta\phi} = \frac{600{,}000 \text{ in. lbs}}{.054 \text{ rad}} = 11.1\times10^6 \frac{\text{inch lbs}}{\text{radian}}$$

$$F_2 = \frac{p\pi r^2 + M/c_1}{2\sin(\phi+\Delta\phi)} = \frac{135{,}000}{2\sin 33°6'} = 124{,}000$$

$\sin 33°6' = .546$

$$\frac{124{,}000}{63.2} = 1960 \text{ lbs/inch}$$

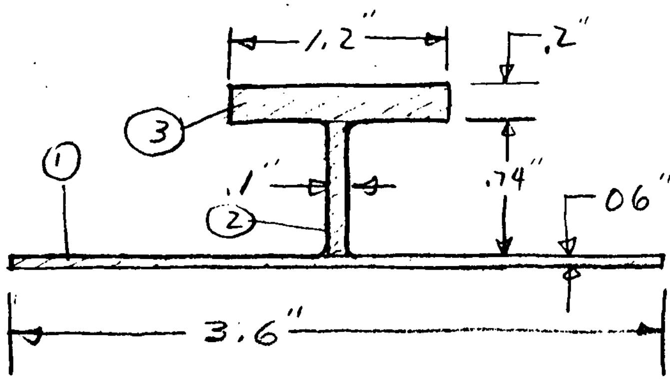
$$F_1 = \frac{105{,}000}{2\sin 26°54'} = 116{,}000$$

$\sin 26°54' = .4524$

$$\frac{116{,}000}{63.2} = 1835 \text{ lbs/inch}$$

$\frac{1960}{.060} = 32{,}700$ psi max membrane stress from combined cabin pressure and 50,000 ft lbs circumferential bending moment @ docking port from orbiter RCS

Figure 4.2-60. Analysis



ITEM		AREA	Y	AY	AY^2	$bh^3/12$
1	3.6 × .06 =	.216	.03	.00648	.00019	
2	.1 × .74 =	.074	.43	.0318	.0137	.0034
3	1.2 × .2 =	.240	.90	.216	.1945	
		.530		.25428	.2084	
					.0034	
					.2118	
					.1216	

$Y_0 = \frac{.254}{.530} = .479$

$1.000 - .479 = C = .521$

$(.479)^2(.530) = .1216$ $\quad I = .090 \text{ in}^4 \; (3.74 \text{ CM}^4)$

$M = (47{,}600 \text{ ft lbs}) \; 64{,}600 \text{ NM}$

$P = \frac{2M}{\pi R} = \frac{2(64{,}600)}{\pi(1.02)} = 40{,}300 \text{ N}$

$m = .266 \, PR = .266(40{,}300)(2.03) = 21{,}800 \text{ NM}$

$m = 2.18 \times 10^6 \text{ N CM}$

$\frac{mc}{I} = f_b \qquad I = \frac{mc}{f_b}$ $\qquad f_b = 44{,}100 \frac{N}{CM^2}$ (64000 PSI ult.) $\quad f_b = 45{,}700$ limit allow

$I = \frac{(2.18 \times 10^6)(1.4)(.521)}{44{,}100} = 36 \text{ CM}^4$

$\frac{36 \text{ CM}^4}{3.74} = 9.64$ $\qquad$ use 10 frames 18.1 CM O.C.

$\frac{32}{4.5} = 7.11'' \text{ O.C.}$

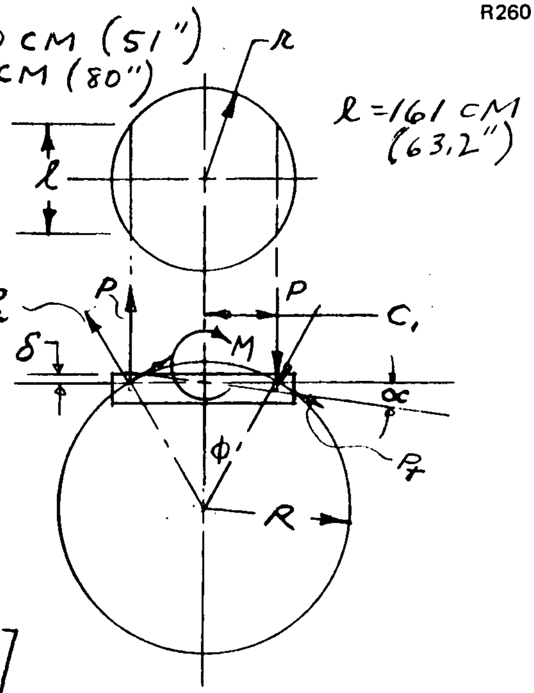
$f_b = \frac{mc}{I} = \frac{2.18 \times 10^6 (.521)}{37.4} = 30{,}400 \text{ N/CM}^2$ (44,100 fail limit)

from 64,600 NM (47,600 ft lbs) circumferential bending moment

Figure 4.2-61. Circumferential Rings at Radial Docking Ports

$$P = 2\int_0^{\pi/2} \frac{M \cos\theta}{\pi r^2}\, r\, d\theta$$

$r = 130$ CM (51")
$R = 203$ CM (80")



$$P = \frac{2M}{\pi r}$$

$$C_1 = \frac{M}{2P} = \frac{\pi r}{4} = 102 \text{ CM } (40")$$

$$\sin\phi = \frac{C_1}{R} = \frac{\pi r}{4R} = .50$$

$$\phi = 30°$$

$$P_r = P\cos\phi \qquad P_t = P\sin\phi$$

$$\delta = \delta_r \cos\phi \qquad \alpha = \frac{\delta}{C_1}$$

from Wise's deflection coeff.

$$\delta_r = \frac{R^3}{EI}\left[P_r(.043 + .023) - P_t(.0148)\right]$$

$$\delta_r = \frac{PR^3}{EI}\left[.066\cos\phi - .0148\sin\phi\right] = \frac{.0498\, PR^3}{EI}$$

$$\delta = \delta_r \cos\phi = \frac{.043\, PR^3}{EI} \qquad \alpha = \frac{.043\, PR^3}{C_1\, EI}$$

$$k = \frac{M}{\alpha} = \frac{\pi r P}{2\left[\dfrac{.041\, PR^3}{EI\,\frac{\pi r}{4}}\right]} = \frac{(\pi r)^2 EI}{.328\, R^3} = \frac{r^2 EI}{.0319 R^3}$$

$$E = 6.9 \times 10^6 \frac{N}{CM^2} \quad (10^7 \text{ psi})$$

$$I = 36 \text{ CM}^4$$

$$k = \frac{(130)^2 (6.9\times10^6)(36)}{(.0319)(203)^3} = 1.57\times10^7 \frac{N\ CM}{radian}$$

$(1.16 \times 10^5$ ft lbs$)$

$$k = 1.57\times10^5 \frac{NM}{rad}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{I_m}} = \frac{1}{6.28}\sqrt{\frac{1.57\times10^5}{5.8\times10^5}} = .083 \text{ cps}$$

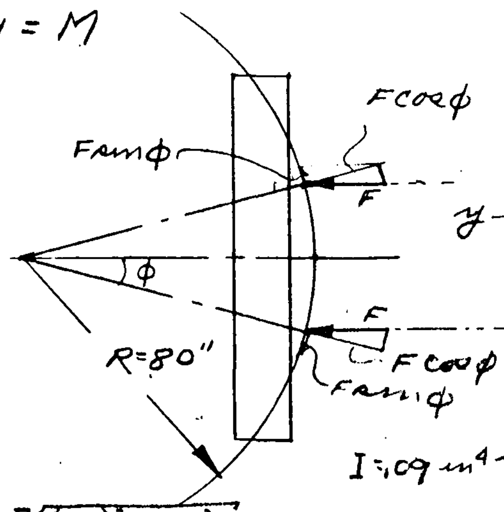
control freq = .01

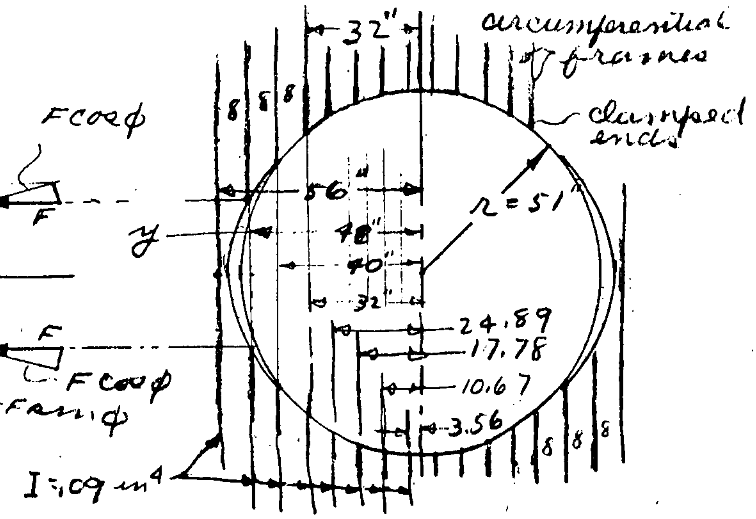
radially docked module freq ≈ 8 × control freq.

roll excited

Figure 4.2-62. Cylinder Deflections at Radial Docking Ring

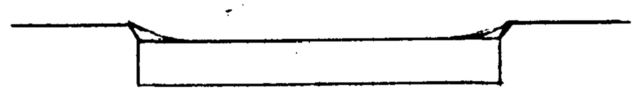
$4\sum Fy = M$





$\sin\phi = \dfrac{\sqrt{(51)^2 - y^2}}{80}$

$(51)^2 = 2600$

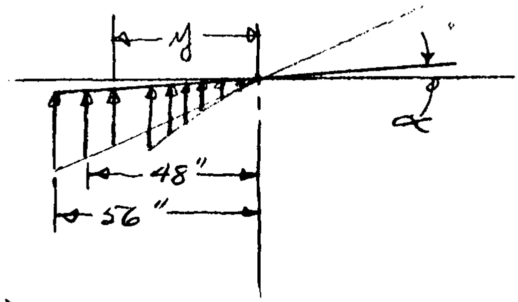


$$y\alpha = \left[\frac{F\cos\phi\, R^3 D_r}{EI} + \frac{F\sin\phi\, R^3 D_t}{EI}\right]\cos\phi = \frac{FR^3}{EI}\left(D_r\cos\phi + D_t\sin\phi\right)\cos\phi$$

$$F = \frac{EI\,y\alpha}{R^3\left(D_r\cos\phi + D_t\sin\phi\right)\cos\phi}$$

$$4\sum Fy = M$$

$$\frac{F}{\alpha} = \frac{EI\,y}{R^3\left(D_r\cos\phi + D_t\sin\phi\right)\cos\phi}$$



y (inches)	$\cos\phi$	$\frac{y}{\cos\phi}$	$\frac{EIy}{R^3\cos\phi}$ (lbs)
56	1	56	98.5
48	.976	49.11	86.5
40	.919	43.6	76.7
32	.868	36.8	64.8
24.9	.831	30	52.8
17.8	.801	22.2	39.1
10.7	.781	13.7	24.1
3.6	.771	4.66	8.2

$$\frac{EI}{R^3} = \frac{10^7(.09)}{(80)^3} = 1.76 \text{ in}^4$$

Figure 4.2-63. Circumferential Ring Spacing at Radial Docking

y	y^2	(51^2-y^2)	$\sin\phi$	$\phi°$	ΣD_n *	D_r *	$\cos\phi$	$D_n\cos\phi$	$D_r\sin\phi$	$(D_n\cos\phi+D_r\sin\phi)$	F/α	$\frac{Fy}{\alpha}\times10^{-3}$
56			0	0°	.043	0	1	.043	0	.043	2290	128.6
48	2300	300	.216	$12\frac{1}{2}$	.066	.0155	.976	.0645	.00334	.0678	1275	61.2
40	1600	1000	.395	$23\frac{1}{4}$	.037	.0186	.919	.034	.00734	.0413	1860	73.3
32	1024	1576	.496	$29\frac{3}{4}$	.021	.015	.868	.0182	.00745	.0257	2520	80.5
24.9	620	1980	.557	33.9	.014	.0114	.831	.0116	.00635	.018	2940	73.3
17.8	316	2284	.598	36.6	.011	.0083	.801	.0081	.00996	.0131	2980	53.1
10.7	113	2487	.624	38.5	.0094	.0062	.781	.00735	.00386	.0112	2170	23.2
3.6	13	2587	.637	39.5	.009	.005	.771	.00694	.00319	.0101	812	2.9
												496.1

$$4\Sigma Fy = M \qquad \Sigma\frac{Fy}{\alpha} = 4.96\times10^5$$

* Wise's radial deflection coefficients

$$\alpha = \frac{M}{4\Sigma\frac{Fy}{\alpha}}$$

$$K = \frac{M}{\alpha} = 4\Sigma\frac{Fy}{\alpha} = 1.98\times10^6\ \underline{\text{inch lbs}}\ \left(1.65\times10^5\ \frac{\text{ft lbs}}{\text{rad.}}\right)\ \text{radian}$$

$$m = FR(W_R\cos\phi + W_T\sin\phi)$$

$$\frac{c}{I} = \frac{.521}{.09} = 5.79$$

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{I_m}} = \frac{1}{6.28}\sqrt{\frac{1.65\times10^5}{4.26\times10^5}} = \frac{1}{6.28}\sqrt{.387} = .099\ \text{cps}$$

for $M = 26{,}300$ ft lbs
304,000 inch lbs.

f = 9.9 times the control frequency pitch excited

$$\alpha = \frac{M}{K} = \frac{304{,}000}{1.98\times10^6} = .153$$

y	F/α	F	W_R **	W_T **	(6) $W_R\cos\phi$	(7) $W_T\sin\phi$	(6)+(7)	m	$f_b = \frac{mc}{I}$ Δ	f_D
56	2290	352	.24	0	.234	0	.234	6600	38,100 psi	26,300 $\frac{N}{cm^2}$
48	1275	196	.29	.06	.283	.013	.296	4640	26,900	18,500
40	1860	286	.185	.055	.170	.0217	.192	4390	25,400	17,500
32	2520	386	.15	.04	.130	.0198	.15	4620	26,800	18,500
24.9	2940	451	.14	.026	.116	.0195	.131	4720	27,400	18,900
17.8	2980	457	.14	.019	.112	.0114	.123	4500	26,000	17,900
10.7	2170	333	.14	.012	.109	.007	.116	3090	17,900	12,300
3.6	812	125	.14	.009	.108	.006	.114	1140	6,600	4,550

**Wise's coeff

Δ max frame stresses from 26,300 ft lbs longitudinal bending moment.

Figure 4.2-64. Analysis

The fundamental frequencies in the circumferential and longitudinal directions are 8 and 9.9 times the control frequency respectively, with a docked module moment of inertia of 5.8×10^5 kgm M^2 (4.26×10^5 slug ft^2) and the shell unpressurized. The circumferential bending stiffness and resultant docked module frequency is much higher with the shell pressurized. The side docking port structural details are shown in Figure 4.2-65.

The maximum shear flow from torsion in the pressure shell is 262 n/cm (150 lb/in.) and occurs at Booster burnout (Table 4.2-5). The resulting shear stress is 262/0.152 = 1725 n/cm^2 (150/0.06 = 2,500 psi). The elastic buckling stress for thin rectangular plates in shear is given by

$$f_{s_{cr}} = KE\left(\frac{t}{b}\right)^2$$

The ratio of panel width to length with the selected rib spacing is 2.6 and, if the panel is assumed simply supported at the ribs, K = 5.5 so that

$$f_{s_{cr}} = (5.5)\ 6.9 \times 10^6 \left(\frac{0.152}{20.3}\right)^2 = 2130 \frac{n}{cm^2}$$

$$\left(f_{s_{cr}} = 3,100 \text{ psi}\right)$$

and the 20.3 cm (8-in.) rib spacing makes the shell shear resistant even with the conservative assumptions of simple support at the ribs and neglect of panel curvature.

The pressure shell thickness is increased at the mounting fittings to distribute the concentrated flight loads.

6 ④

4.3 CREW HABITABILITY AND PROTECTION SUBSYSTEM

4.3.1 Summary

The Crew Habitability and Protection Subsystem encompasses all of the equipment facilities and design characteristics of the Space Station which provide for the physical, physiological and psychological requirements and the effective performance of the crew. It is not limited to the "living quarters" of the Station, but it includes the habitability/usability characteristics of all of the Space Station modules, i.e., the General Purpose Laboratory Module(s), the Power/Subsystems Module(s), the Logistics Module(s), and the Research and Applications Module(s), as well as the Crew/Operations Module(s). Specifically, the Crew Habitability and Protection Subsystem includes the Space Station design characteristics associated with the following:

A. Interior configuration and arrangement
B. Work stations size, layout, and arrangement
C. Crew quarters size, location, and equipment design
D. Galley/wardroom size, arrangement, and equipment design
E. Hygiene facilities size, design, and arrangement
F. Food and food management
G. Housekeeping and trash management equipment and procedures
H. IVA-EVA support
I. Radiation, meteoroid and fire protection

For the Modular Space Station Study, the major issues of concern in the definition and preliminary design of the Crew Habitability and Protection Subsystem were:

A. Interior orientation and configuration for optimum zero g operations without unduly compromising ground installation, checkout, and evaluation.
B. Volume requirements for extended duration operations by multiple crews in a zero g environment.
C. Location and arrangements of facilities within modules and equipment within facilities to insure effective crew performance, continuous high level motivation, and morale.

The general interior orientation and configuration that was selected are essentially the same for all modules, although they vary in detail according to the specific requirements of each module. The selected orientation and configuration can be described as a longitudinal orientation, using a minimum of separating walls or decks, but with equipment and facilities arrangement for two levels of operation where possible. Figure 4.3-1, which is a picture of the interior of a 1/20th-scale model of an early version of the General Purpose Laboratory, best illustrates this concept. Figures 4.3-2 and 4.3-3 are pictures of full-scale mockups showing the interior, orientation, and configuration of the Crew/Operations Module and the General Purpose Laboratory module, respectively.

Each facility/work station has been sized (shape and volume) to provide sufficient free space to insure optimum task performance/need satisfaction, minimum interference from other crew members or equipment, and multiple use of facilities without routine scheduling; and to provide a maximum number of alternatives areas for accomplishing specific job requirements (e.g. study, report preparation) or meeting personal needs (e.g. social activities, privacy). The location and arrangement of facilities and equipment further facilitate the above capability, and in addition, they minimize the "total" Space Station volume requirements; maximize the appearance of "spaciousness"; maximize the common use of free space; and facilitate the accommodation of mixed crews (male/female, scientist/astronaut) and dual shift operations.

The Crew/Operations Module contains all of the normal "living" facilities required to sustain the crew while on orbit. That is, it contains the facilities for eating, sleeping, recreation, personal activities, and hygienic needs. In addition, the Crew/Operations Module houses the primary control center and incorporates five docking ports—one at either end and three at the mid-point of the module, located at 120-degree intervals around the periphery.

The crew quarters (each approximately 7 by 7 by 4 feet with a volume of 200 cu ft) are located at the two ends of the module—three at each end—to facilitate dual-shift operations and to better accommodate mixed crews.

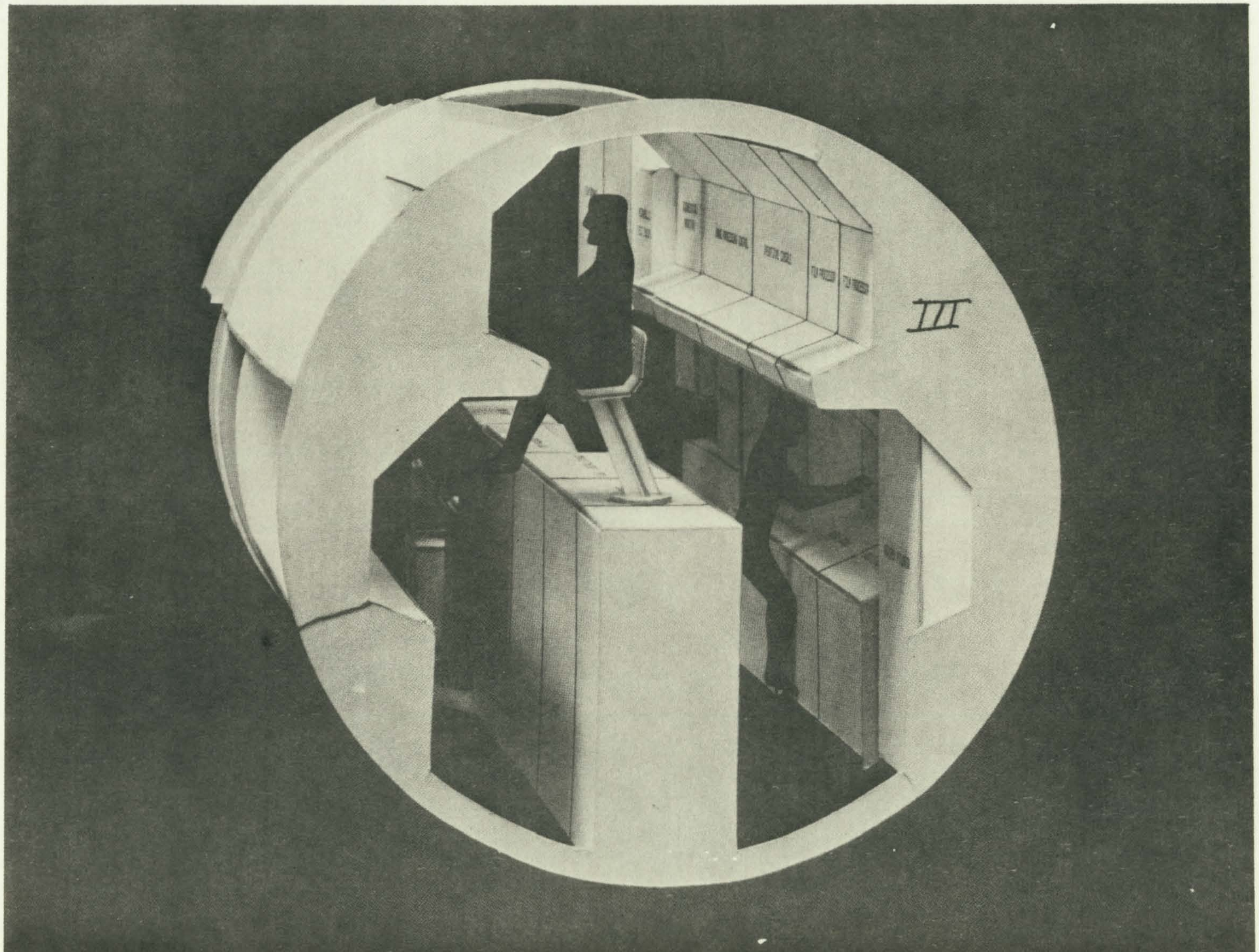


Figure 4.3-1. General Purpose Laboratory - 1/20 Scale Model

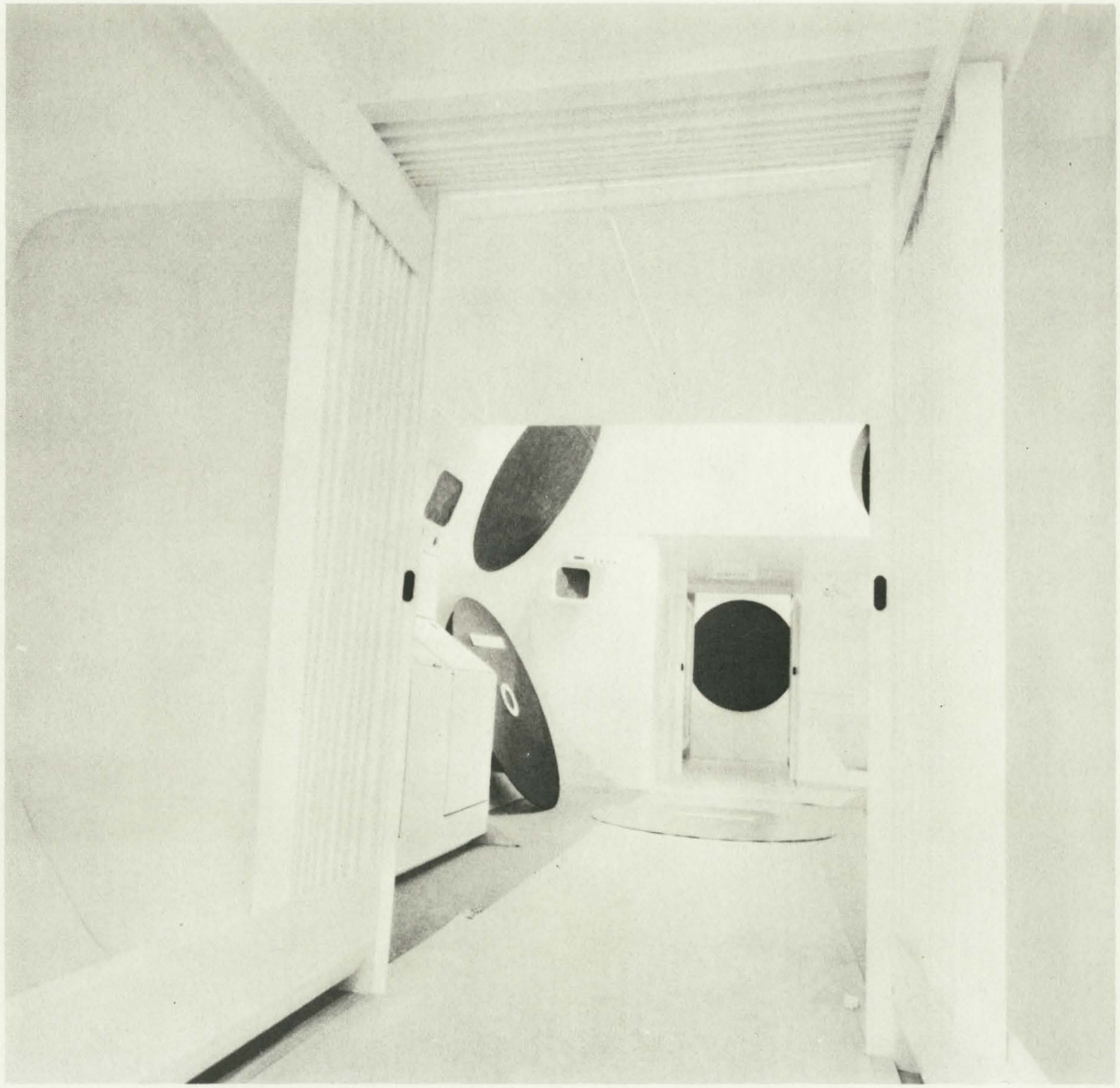


Figure 4.3-2. Crew/Operations Module - Full-Scale Mockup

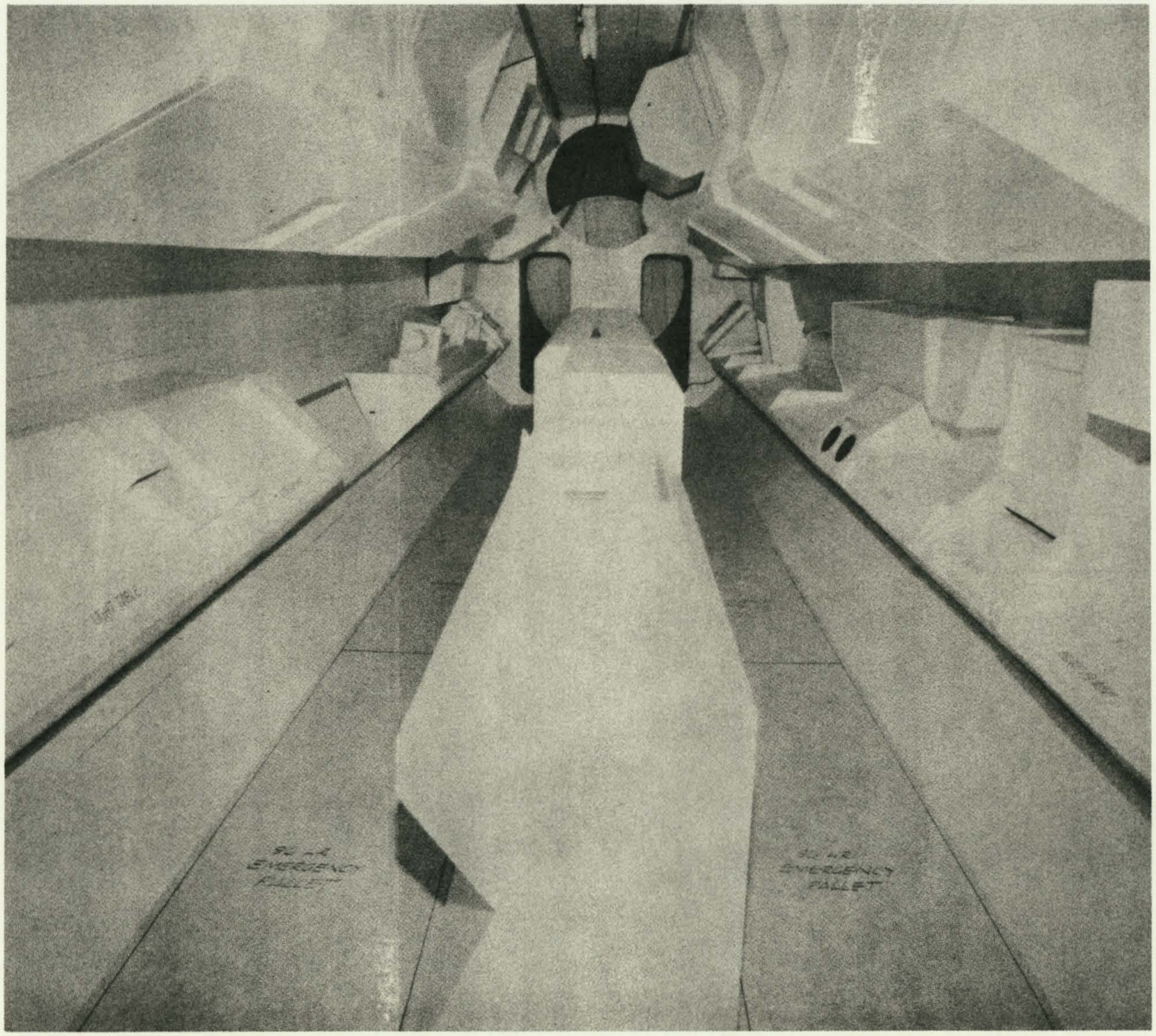


Figure 4.3-3. Crew Habitability - General Purpose Laboratory

Each of the quarters have folding doors across one wall that can be opened to a center aisle which is equivalent in size to each quarter, thereby converting the three into one single large (800 ft^3) stateroom. Separate hygienic facilities are provided for each set of three quarters.

The Galley/Wardroom which will accommodate up to six men simultaneously for purpose of food preparation, eating, and/or rest and relaxation is located adjacent to one set of quarters. One hygiene facility, accessed from the docking port area, is located above the Galley/Wardroom. The second hygiene facility occupies a simpler location above the control center at the opposite end of the module. Each hygiene facility contains a shower, laundry, waste management, handwash, and a urinal.

The Primary Command Control Center occupies a location similar to the Galley/Wardroom adjacent to the other set of quarters. The Control Center is designed for nominal one-man operation but will accommodate two men on a limited basis. The control center has all of the display and control equipment required to monitor the status of and/or control all of the station, and subsystems (excluding experiments) operations. The docking port area (for the three center docking ports), 10 ft in length, separates the Galley/Wardroom from the Control Center. The docking port area, with a volume of approximately 980 cu ft, normally unoccupied, is used to augment the primary area assigned to the Galley/Wardroom for crew rest, relaxation, exercise and active group sports (volley ball).

The General Purpose Laboratory Module (GPL), which houses all of the laboratories and associated support equipment essential to the primary mission of the station, is the primary work area for most of the crew and is the module in which all of the crew members will spend a major portion of their duty time. Hence, it has been designed not only to provide adequate support to all experiment activities, but also for maximum habitability/usability so as to be conducive to continued high-level performance and the maintenance of motivation and morale. In fact, during this study it has been considered as having priority No. 1 for achieving habitability/usability in design, layout, and arrangement.

The basic interior configuration and arrangement is shown in Figure 4.3-3. The "open" longitudinal configuration with two "operational levels" enhances the appearance of spaciousness and at the same time maximizes the amount of usable free space available to the crew. Also easy access to all equipment for group checkout, replacement and evaluation is possible with a minimum of specialized ground support equipment. With a temporary floor over the center consoles, all equipment can be accessed on the ground from a normal upright position.

Equipment in the GPL is separated functionally into six laboratories, a control center, and an isolation chamber. There is a Hand Data Processing Laboratory, an Electrical/Electronics Laboratory, a Mechanical Laboratory, a Bioscience Laboratory, an Optical Laboratory, and a Data Evaluation Laboratory. A secondary control console which essentially duplicates the primary control console in the Crew/Operations Module and an experiment control console are integrated into a single two-man control center from which all Station and experiment operations can be controlled and/or monitored. An isolation chamber, separated from the rest of the laboratory by a pressure bulkhead, houses hazardous supplies and materials, provides a capability for conducting potentially dangerous experiments without endangering other areas of the Station, and also serves as an air lock for EVA activities.

Each functional area/laboratory of the GPL has been sized and arranged so as to accommodate up to three crewmen working/studying/socializing. Aisles and work areas permit "other" crewmen to pass without interfering with operators/experimenters. No primary work station is located directly above or below another, thereby avoiding the requirements (except for occasional access or maintenance) for simultaneous "head-to-foot" operations.

Figure 4.3-4 shows a 1/20th-scale model of the Power/Subsystems Module. This module, which houses atmosphere supply tanks, CMG's, power generation equipment, and electronic equipment for much of the station's subsystems, is nominally not inhabitated. However, crew members will be

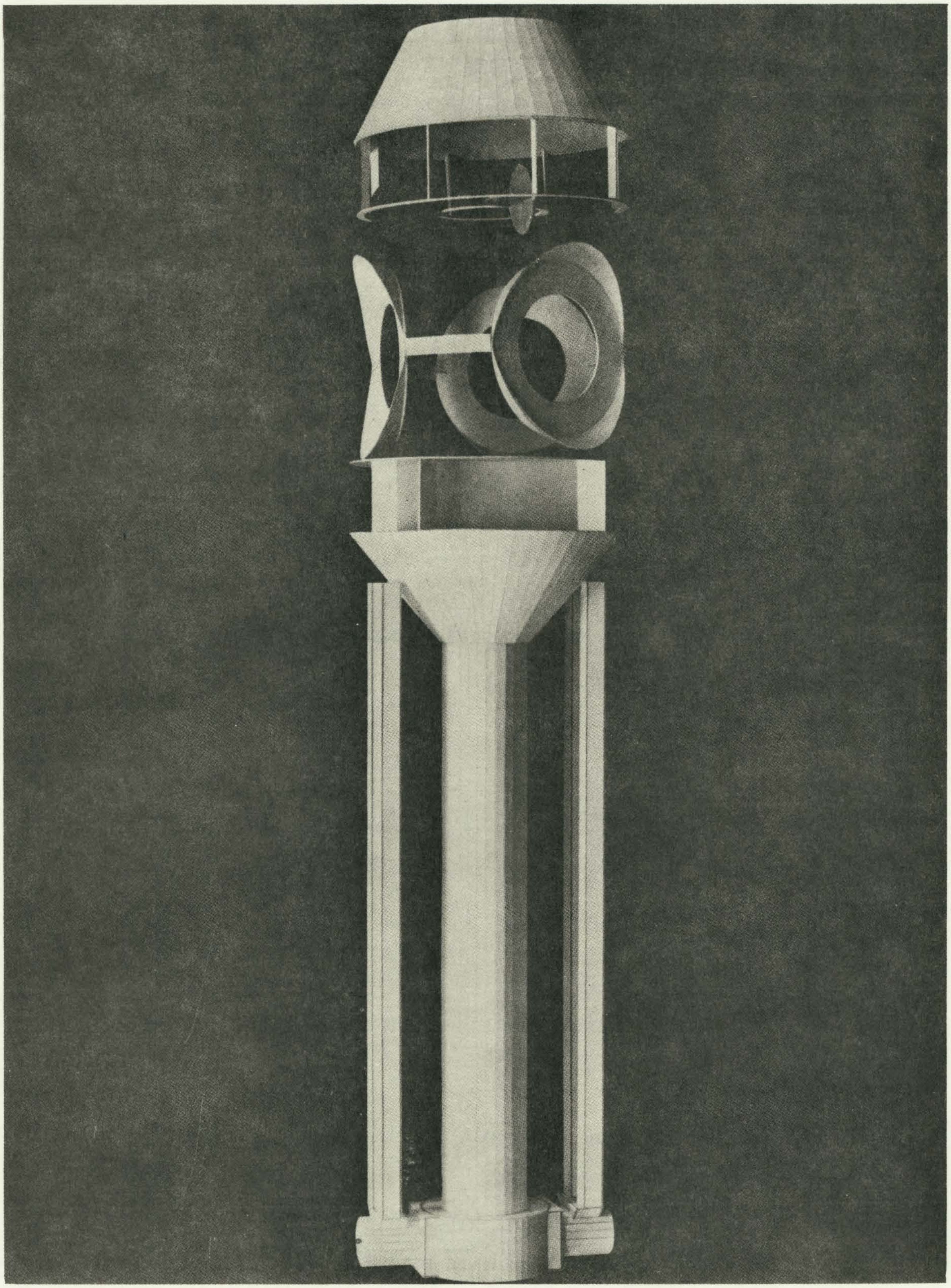


Figure 4.3-4. Power Subsystems Module - 1/20 Scale Model

required to enter the module to install and/or perform maintenance on equipment therein. Hence, the interior is sized and arranged so these tasks can be accomplished efficiently.

A minimum of 54 ft^3 (6 by 3 by 3 ft) of free volume is proved in any/all areas where a crewman may be required to perform scheduled or unscheduled maintenance. A clearance of at least 6 in. is maintained between items such as atmosphere bottles and CMG's requiring on-orbit installation or change, and access of 5-ft diameter is provided to all areas.

The habitability/usability features of the Logistics Module is covered in SE 06. Preliminary design of the Research and Application Modules was not a part of this study, but is discussed briefly in Section 4.4 of this report.

The significant trade studies for crew habitability conducted during the Modular Space Station Study all involved either interior configuration and/or orientation or the location and/or arrangement of equipment within the modules. In contrast to analytical techniques used for the conduct of trade studies for other subsystems, the techniques employed for performing trade studies for crew habitability involved the development and evaluation of 3-dimensional 1/20th scale models and full-scale soft mockup of the alternate configuration and arrangement. The approach, procedures, and evaluation criteria used in these studies are shown in Table 4.3-1. The key trade studies and resulting selections are listed below.

Trade Study	Selection
Longitudinal vs Radial Orientation (Crew/Operations Module)	Longitudinal
Longitudinal vs Radial Orientation (GPL)	Longitudinal
Crew Quarters Orientation (One-G vs Zero-G)	Zero-G
Interior Arrangement for Single vs Dual Docking Port Location	Single
Crew Quarter Location - Single vs Dual	Dual
Hygiene Facility Access Docking Port Area vs Crew Quarters	Docking Port Area

4.3.2 Requirements

The major program requirements specified by NASA and included in the Program Requirements Document effecting the Crew Habitability and Protection Subsystem are listed below. Each of these requirements has been met or exceeded in the design of the Modular Space Station.

A. No artificial G
B. Dual, independent pressure volumes
C. Provide equivalent provisions as 33-ft Station
D. Private staterooms
E. Provide for easy maintenance accessibility
F. Provide alternate escape routes
G. 48 hr emergency habitability provisions (96-hr Capability)
H. Provide emergency EVA/IVA suit station
I. Consistent with "good architectural design"

To augment and further clarify the intent of these program requirements, the following general requirements or design goals were generated by MDAC through design analyses to guide the preliminary design effort:

A. All compartments designed for maximum habitability.
B. Interiors shall be optimized for zero g with due consideration to ground checkout and evaluation requirements and constraints.
C. Volume allocation, equipment location, and interior arrangement shall be designed to minimize "casual" interference, i.e., to avoid any interruption to crewmen performing tasks.
D. The opportunity for freedom of choice in facility usage shall be maximized.
E. The common use of free space shall be applied where appropriate.

In addition to those general requirements, specific crew habitability requirements and design goals for each facility of the station were also generated. They are as follows:

4.3.2.1 Private Quarters

The requirements for private quarters are aimed at providing an alternative to the wardroom for social and work/study activities and still provide maximum privacy when needed for sleep and other personal activities. The specific requirements are:

A. 50 ft^2 equivalent - 200 ft^3 free volume.

B. Freedom for maneuverability in two planes.
   6.5 by 6.5 by 3.5 = 148 ft^3.

C. Furnishing (in place) and personal equipment — -33 ft^3.

D. Capability for dual occupancy - 5 ft separation — -7 ft total.

E. Recommended size - 7 by 7 by 4 = ft^3.

F. Capability for easy conversion to 2 ro 3 man staterooms.

G. Sight/sound isolation.

H. Accommodation for male/female crew members.

4.3.2.2 Galley/Wardroom Gymnasium

The driving requirement for the wardroom, galley, and gymnasium area is multiple usage for a variety of simultaneous on- and off-duty activities without interference. The wardroom, galley, and gymnasium requirements shall be as follows:

A. Simultaneous use by six men for same or different activities.

B. Common use of free space for non-interfering activities.

C. One-to-six-man food preparation and consumption.

D. Total volume = largest single free space requirement plus volume for equipment or competitive activities
   Gymnasium - 14 by 10 by 8 = 1,120 ft^3
   Equipment 594 ft^3

4.3.2.3 Hygiene Facilities

Hygiene facilities that only meet the basic requirements for cleanliness sufficient for the maintaining of the crew's health are not considered adequate for extended-duration missions. The maintenance of high morale on such missions is dependent upon the satisfaction of certain "psychological" needs for cleanliness that exist in a high percentage of the potential crew population. Hence, the requirement established for hygiene facilities are intended to satisfy these psychological needs as well as the basic physical needs.

A. Two complete facilities.

B. Accommodations for male/female crew members.

C. Adjacent to private quarters.

D. Easy access from other modules.

E. Volume requirements.

Shower	60 ft^3
Waste management	65 ft^3
Hand wash/laundry urinal	50 ft^3
Free space (Inclosed facility)	65 ft^3

4.3.2.4 Primary-Command Control Center

The command-control center shall be located adjacent to the wardroom/docking port area. This location will allow an off-duty crewman to respond quickly to any warning signals from the center. It also allows the command-control operator to view docking operations while monitoring all other functions.

Specific requirements for the control center are as follows:

A. Adjacent to but separable from wardroom.

B. Capable of temporary sight/sound isolation.

C. Front and back equipment access for maintenance.

D. 1- or 2-Man operation

E. Volume requirements

Equipment	110 cu ft
Operation space	105 cu ft
Maintenance access	0 cu ft
(Shared with other activities)	

4.3.2.5 EC/LS and Power

The Crew/Operations Module is intended as one of two self-sustaining "habitable" environments. Hence, it is provided with an EC/LS system and a secondary source of power. The essential requirements for these subsystems are:

- EC/LS

Volume	200 ft^3
Minimum dimensions	20 in.
Easy access for service and maintenance	

- Power

Volume	25 ft^3
Minimum dimensions	12 in.
Easy access for replacement	

4.3.2.6 General Purpose Laboratory

As the primary work area for most of the crew and the area where all of the crew will spend a major portion of their time, the GPL shall be designed for maximum habitability/usability. The specific habitability requirements for the GPL are as follows:

A. Functional separation of different laboratory areas
B. Study/relaxation area available to each lab
C. Light isolation capability for optics lab and data processing facilities
D. Layout, arrangement, and installation facilitates equipment removal and modification required by progressive experiment program
E. Prime work stations located to eliminate interference
F. Volume and size criteria - minimums

Aisles	24 by 78 in.
Prime work areas	33 by 78 in.
Access for maintenance	30 by 78 in.
Study/relaxation area	200-ft^3 Free Volume

Accommodate experiment equipment size and shape as dictated by changing experiments requirements.

4.3.2.7 Power/Subsystems Module

The Power/Subsystem Module is normally manned on an intermittant basis only. However, the pressurized compartment shall be capable of providing a retreat from environmental hazards. Therefore, two EVA suits and two PLSS's, three oxygen masks, and a 96-hour emergency pallet shall be stored in the compartment.

Provisions shall be provided in the Power Subsystems Module to meet the following requirements:

A. Access to all equipment for installation and unscheduled maintenance

B. IVA access to solar array assemblies

C. On-orbit installation of CMG's and atmosphere storage containers

D. Volume and space constraints

Electronics equipment	510 cu ft
CMG's and atmosphere supply storage	210 cu ft
Docking ports	1,400 cu ft
Work area adjacent to all equipment*	54 cu ft
Access to CMG's and atmosphere storage area from docking ports	5 ft (diameter)

(*May be Shared)

4.3.3 Selected Systems Design

4.3.3.1 Description

The Crew Habitability and Protection Subsystem encompasses all of the equipment and design characteristics which have been included therein to provide for the health, safety, and effective performance of the crew for 90 days (nominal). This section describes this subsystem in terms of the facilities and equipment included in each of the three primary modules of the six-man Station, the Crew Operations Module, the General Purpose Laboratory Module, and the Power/Subsystems Module. Habitability features of the Logistics Modules are described in SE 06. Preliminary design of the Research and Application Modules were not included in this study but some of the requirements for their design are discussed in Section 4.4 of this book.

4.3.3.1.1 Crew/Operations Module

The Crew/Operations Module contains all of the necessary "living" provisions for a six-man crew. Figure 4.3-5 shows the location of the various

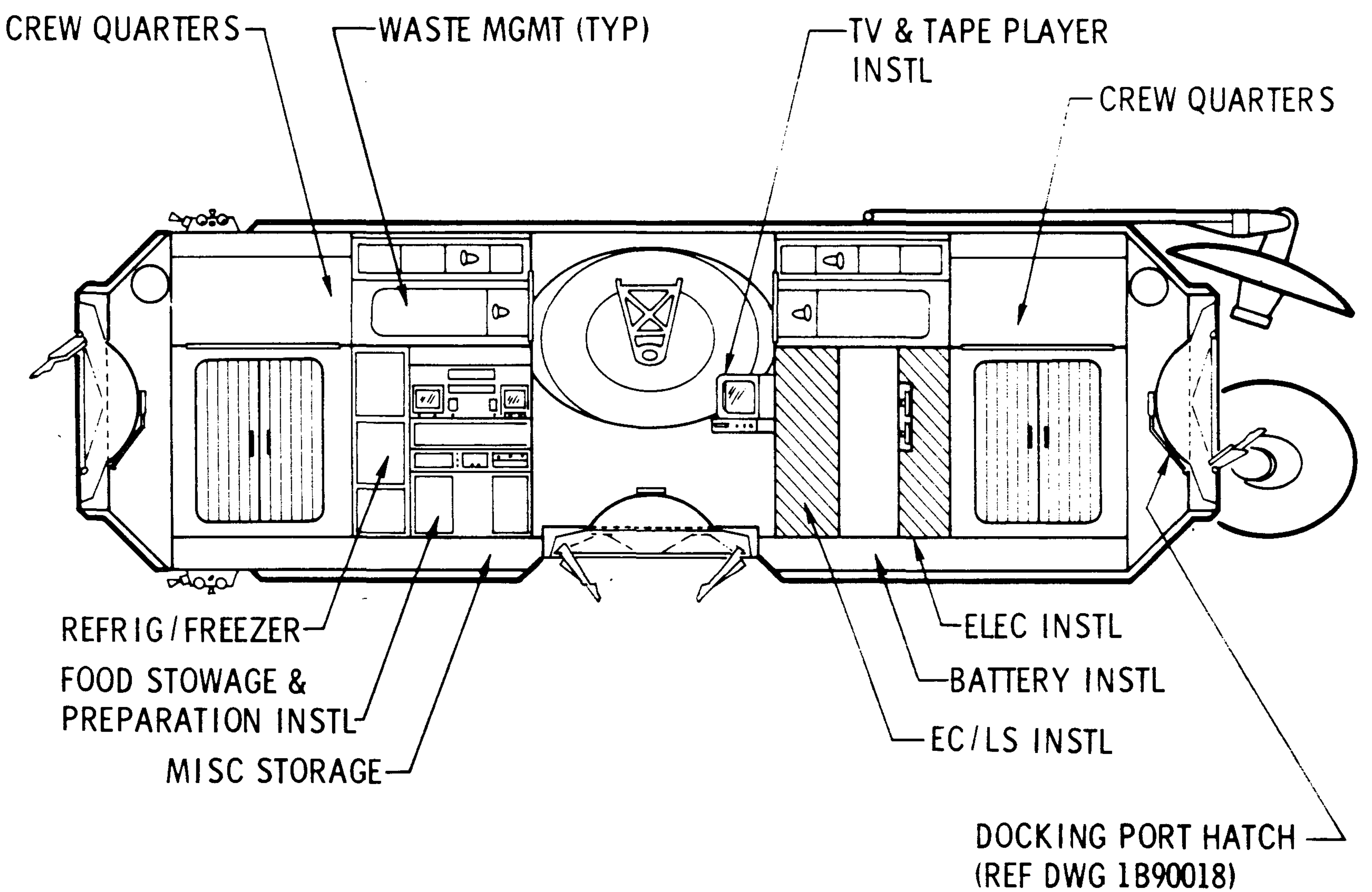


Figure 4.3-5. Modular Space Station Crew/Operations Module

facilities within that module. The full-scale mockup was shown in Figure 4.3-2.

Crew Quarters

Three crew quarters are located at either end of the module. Each crew quarters is approximately 7 by 7 by 4 ft, with a total volume of 200 ft^3. The three crew quarters "surround" a common aisleway of the same dimensions. The quarters have large folding doors opening to the common aisle and can be opened to form a large (800 ft^3) stateroom which can be used (if desired) as an alternative to the primary wardroom. Figure 4.3-6 depicts this arrangement. Each of the quarters contains the following equipment:

A sleep restraint, or bunk, accommodating an individual bed roll which is either washable or disposable. The sleep restraint shall be designed/ located so as not to interfere with other activities when not in use.

A desk, with a writing surface, storage facilities, adequate lighting and restraints. Storage of a personal clothing module and an area for soiled clothing is provided. The clothing module is sized for one crewman for 30 days. An emergency oxygen mask with a portable, rechargeable oxygen bottle is stored in the private quarters. Restraints and locomotion aids are strategically located to permit efficient use of the quarters area.

A communication system is provided in each of the crew quarters to allow inter-communications with other crewmen throughout the station.

Stereo equipment, a television receiver, and a 12-ft window are also provided. Figure 4.3-7 shows the interior of a single crew quarters.

Galley/Wardroom

Adjacent to one set of three quarters is the Galley/Wardroom. The Galley is shown in Figure 4.3-8. The Galley/Wardroom provides the following capabilities and equipments:

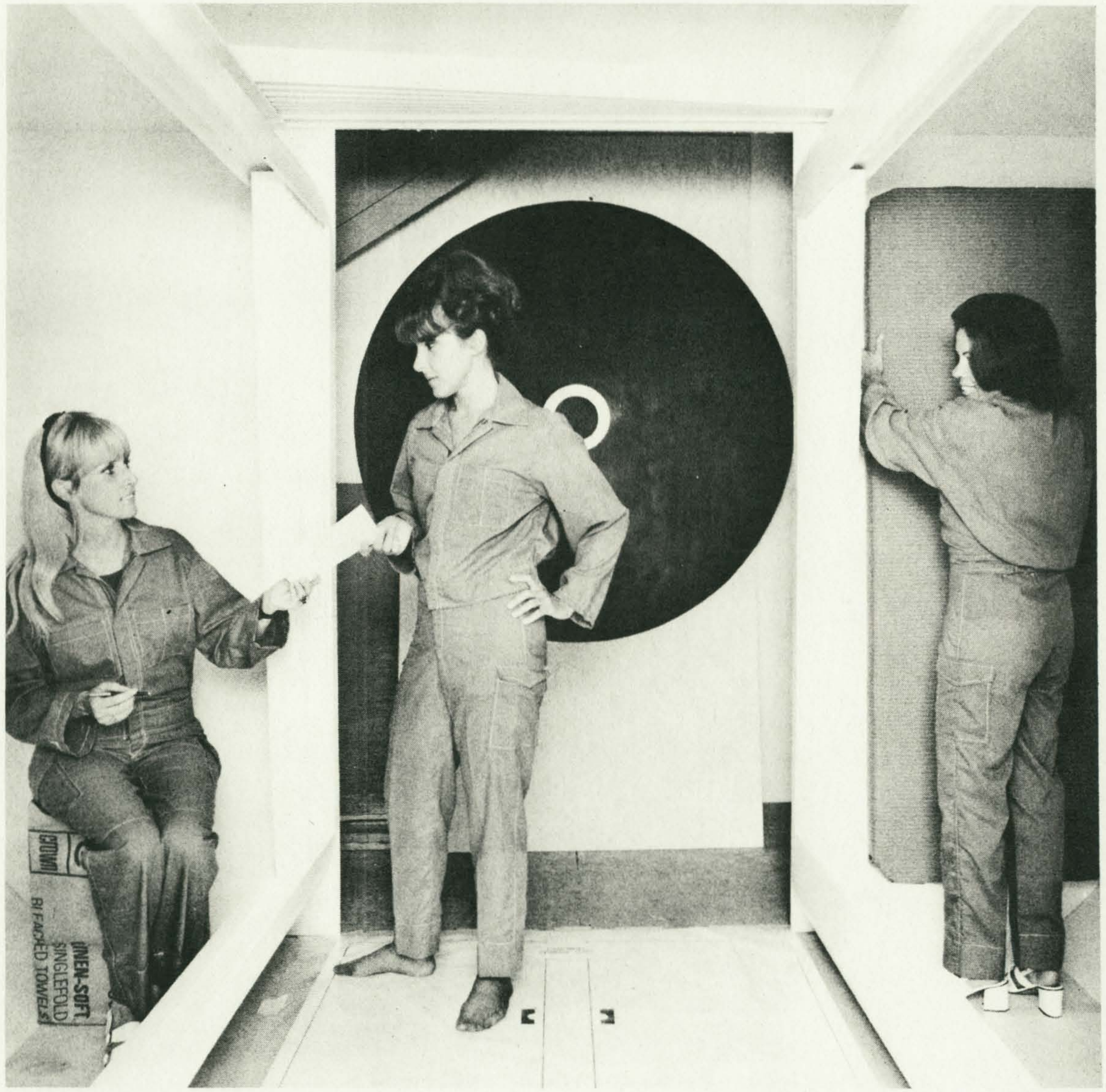


Figure 4.3-6. Crew Quarters

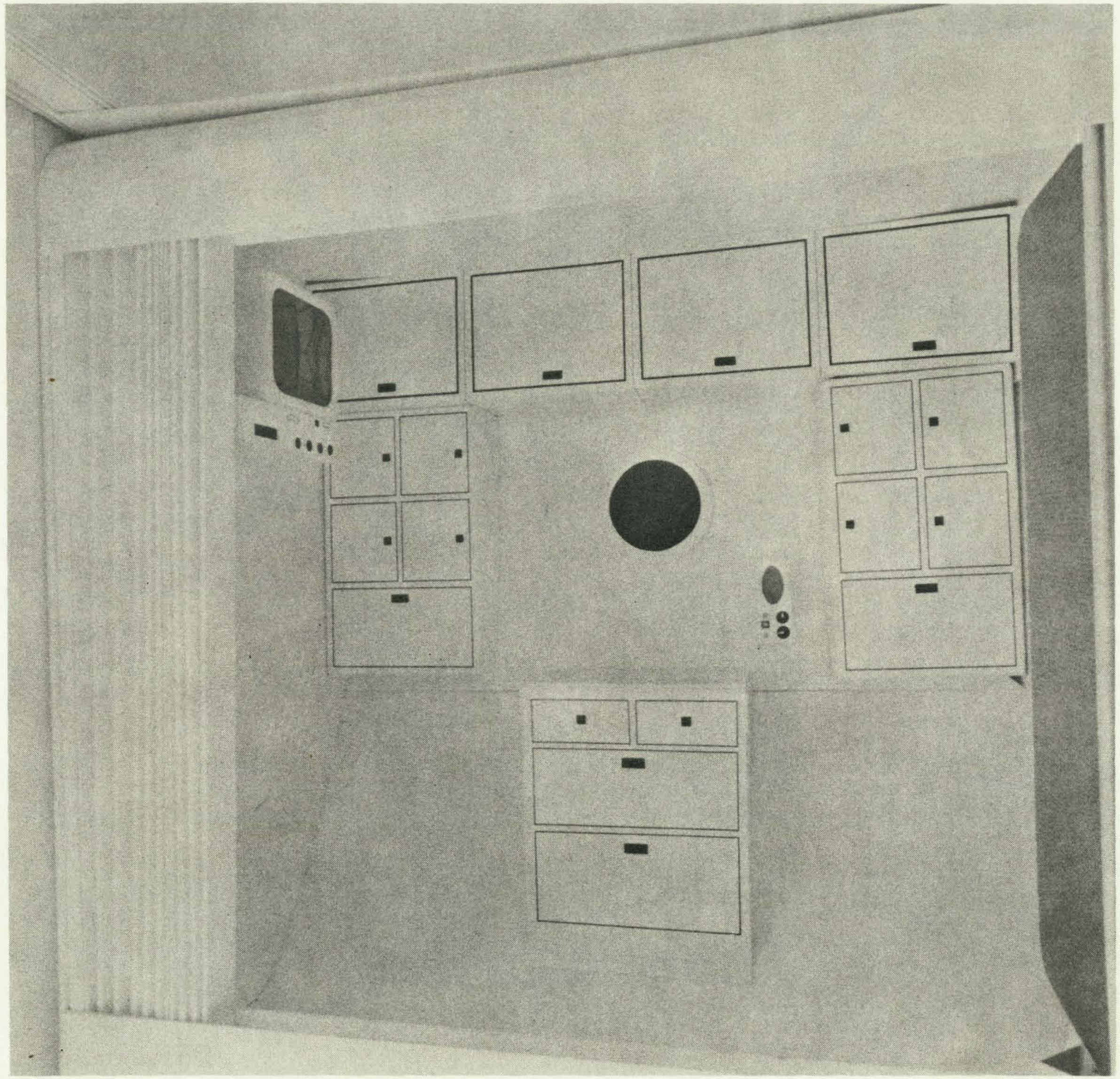


Figure 4.3-7. Interior of a Single Crew Quarter

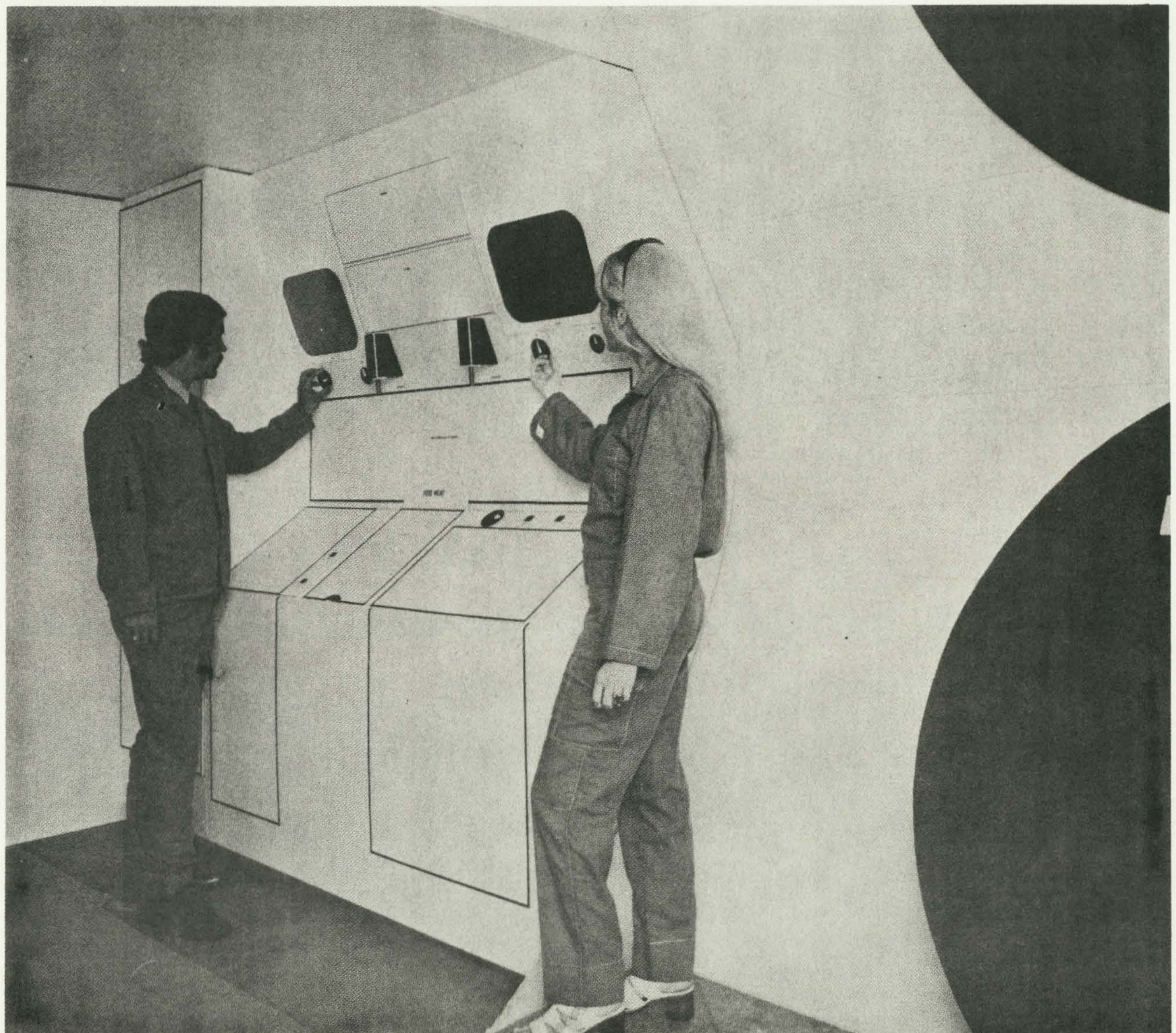


Figure 4.3-8 Crew Habitability - Galley

Food Management—The food management assembly provides the food stores (both ambient and controlled temperatures), equipment, facilities, and supplies required for the storage, preservation, preparation, service and consumption for six crewmen for 30 days. Onboard storage provisions are for a six-man/30-day supply plus a six-man/30-day contingency supply. The remainder of food is stored in the Log Modules. Each crewman shall be provided with three meals and an optional snack for each 24-hour period. The diet shall be designed to provide an average of 2,800 Kcal per man per day. A food preparation and cleanup center is provided as well as an area designed for consumption of meals.

The food management assembly includes equipment and provisions for hot and cold rehydration, cooking, and warming of foods. Zero-g restraints are provided where needed. Utensils for serving and eating, as well as house-keeping and trash disposal devices are included. Packaging design shall facilitate the identification and instructions for preparation, inventory control, and disposal of food waste products.

The food stores include dried, freeze-dried, dehydro-frozen, wet pack, and perishable foods. The diet provides adequate quantities of proteins, fats, carbohydrates, minerals, and vitamins based upon anticipated crew body weight, age, height, and activity levels. A 30-day supply of food for six crewmen is estimated to weigh 530 lb and occupy a volume of 17.8 ft^3. Water requirements for a 2,800 Kcal diet are 6.17 lb/man/day based upon 1.0 ml for each Kcal of food.

Oven—A combination resistance and microwave oven is provided for the cooking or heating of fresh and dehydrofrozen, and reconstituted foods. The oven is capable of heating foods to a specified internal temperature and holding food at specified lower temperatures. The oven can accommodate a six-man meal or prepare individual snack items with maximum efficiency and minimum crew time. Automatic controls, timers, and situation lights are provided. The interior configuration of the oven is designed to avoid entrainment of food particles and permit ease of cleaning. Major operating elements of the oven are located to allow effective maintenance and repair procedures.

The oven is capable of raising the temperature of six-man meals or snack items from a frozen state to 160°F (center temperature) in 10 to 15 minutes. It is also capable of holding food at 150°F to compensate for delays in the serving schedule. The interior volume of the oven is approximately 0.15 cu ft and weighs 24 lb. It requires about three 160 watts of peak power. The duty cycle will be from 10 to 15 minutes, yielding 526 watt-hours or 737 watt-hours, respectively, depending on type of food being prepared. The oven size is approximately 17.5 in. long, 11 in. high, and 11.75 in. wide when installed on the vehicle; the exterior volume is approximately 1.3 cu. ft.

Food preparation, eating and cleanup utensils are compatible with zero-g operations and with other related food management assemblies such as the dishwasher, dining facilities, and general galley design. Candidate reusable utensils include hot food handling tongs, mechanical kneading device, clam-shell type handling device, scoop, mixer/blender (manual), spatula, controlled spillage module, food waste restraint, net type bag, serving trays (recessed), eating tray (recessed), and eating utensils. Total utensil equipment characteristics are estimated as follows: weight - 19 lb or less, volume - 1.7 ft^3 or less, dimensions - 5.9 by 4.1 by 14.2 in.

Freezer—The freezer is designed to store fresh and dehydrofrozen foods at a temperature of -10°F to +5°F. The freezer is designed for effective utilization of super-insulation to reduce heat loss to a minimum. The freezer is of rectangular geometry with doors mounted vertically. The front-to-back interior dimensions do exceed the 95th percentile of functional arm reach. An automatic audio-visual warning system is incorporated to indicate system failure or a temperature rise above allowable limits; alternatively, the freezer system shall interface with the master caution-alarm system.

The freezer interior shall be moisture-free. The doors allow for thermal sealing to reduce door seal losses as the freezer contents are consumed. When the food in one compartment has been consumed, that door is sealed mechanically to reduce losses. The freezer has compartments capable of storing 3.5 cu ft of food. In addition to the insulated compartments, it includes the following components—compressor, unloader, condenser, evaporator/separator, sensors and controls.

Refrigerator—A refrigerator is provided for storing food requiring controlled temperature. It serves as a storage compartment for use in defrosting frozen foods, storing unconsumed prepared foods, and a maximum of a two-week supply of perishable food.

The refrigerator unit will be integral with the freezer with an automatic warning system common to that of the freezer.

The refrigerator will maintain stored food at temperatures ranging from 40°F - 50°F with an interior volume of 10 ft^3. The refrigerator assembly consists of four insulated compartments at preselected temperature levels. The refrigerator assembly is estimated to weigh a maximum of 150 lb (installed) with dimensions not to exceed 70 in. high, 24 in. long, and 24 in. wide. Power consumption shall not exceed 50 w.

Dishwasher—A dishwasher is provided for the automatic washing and drying of food preparation, serving, and eating devices. The duty cycle shall consist of an automatic washing and drying sequence suitable for zero-g. Any cleaning agent, disinfectant, or drying agent required shall be metered automatically, and non-toxic agents will be used.

A positive method of solvent injection and recovery are provided and a trap to collect particulate matter is incorporated. The system provides water at 170°F to clean and sterilize utensils for one six-man meal. The forward part of the unit contains an ultrasonic transducer and the cavity in which the items to be cleaned are placed. A water pump, motor, liquid-gas separator and filter unit is located in the aft section. Operating controls are placed on the front console. An integral water heater capable of raising and holding the water temperature at 170°F is included. The dishwasher and dryer shall weigh approximately 50 lb (installed), consume an average of no more than 100 w of power, have an internal volume of no more than 50 cu ft (installed), and the unit shall be approximately 24 in. long, 18 in. high, and 20 in. wide. Cleaning agent resupply requirements shall be no more than 4 lb per 90 days. It requires 100 w for six 26-minute cycles per day.

Water Dispensers—Hot (160°F) and cold (40-50°F) water dispensers for the reconstitution of food and beverages and for drinking water purposes are provided. For reconstitution of dry foods, the dispenser has a capacity of 5 oz and 1 oz for hot and cold water, respectively.

Housekeeping and Trash Handling—The housekeeping and trash handling assembly is provided for (1) collection containment, decontamination, and transport of all forms of loose debris, trash and particulate material generated by the crew and equipment throughout the Station and other attached modules; (2) cleaning and disinfection of all microbiological contamination of equipment and surface exposed to the crewmen; (3) collection, temporary storage, and pretreatment of all trash and waste discarded in various compartments throughout the station; (4) deactivation of all bacteria in the collected trash and debris; (5) reduction of the volume of processed and unprocessed trash prior to stowage; (6) stowage of processed trash that ensures deactivated bacteria remains in the deactivation state.

Color-coded trash receptacles with removable liners and pretreated self-contained trash bags will be provided for the temporary collection and storage of trash. Storage provisions for trash liners and bags are available in appropriate compartments throughout the Station.

A trash compactor is provided to reduce the volume of collected trash. The compactor collects trash bags in a collection hopper. The compactor provides a ram for feeding the compaction chamber and a compacting ram for compressing trash to 25 percent or less of the uncompacted volume. The compacted slug measures approximately 15 by 15 by 12 in. Trash is stored and sealed in containers which have two pneumatic ports - one for withdrawing the container air to remove the oxygen and water vapor through the cabin vacuum facility, and the second for presurizing the container with 15 psi of gaseous nitrogen to provide a dry inert atmosphere surrounding the trash. Sufficient containers are provided to handle approximately 120 cu ft (uncompacted) of trash every 30 days.

Wardroom—The wardroom, which is shown in Figure 4.3-9, contains a removable table and seating/restraints to accommodate up to six crewmen simultaneously in similar or different activities (e.g., eating, relaxation/entertainment, exercise). Three 12 in. side-by-side windows are provided for external viewing. Television receivers and stereo equipment are also located in the wardroom. The docking port area, located at the midpoint of the modules, and containing three docking ports 120 degrees apart, provides approximately 800 ft^3 of normally unoccupied volume to augment the wardroom capability. This area, as depicted in Figure 4.3-10, would be used primarily for exercise and gymnastic purposes. With this additional area approximately 1,920 ft^3 is available for use as a wardroom/galley/gymnasium.

Hygiene Facilities

Duplicate hygiene facilities are provided to reduce interference during period of high usage (e.g., upon awakening) to provide more suitable accommodation for mixed crews, and to better accommodate dual shift operations. These facilities are located adjacent to each set of crew quarters, one above the Galley/Wardroom, and the other above the Control Center at the opposite end of the module. The location of the latter is shown in Figure 4.3-11. Primary access is from the docking port area to provide easy access from other modules, but a secondary access route is provied from one of the crew quarters. Full-scale mockups of the interior of the hygiene facilities are shown in Figures 4.3-12 and 4.3-13. Each facility contains the following:

Shower—The shower provides a whole-body wash capability. It consists of a cylindrical enclosure equipped with the provisions for wetting, washing,

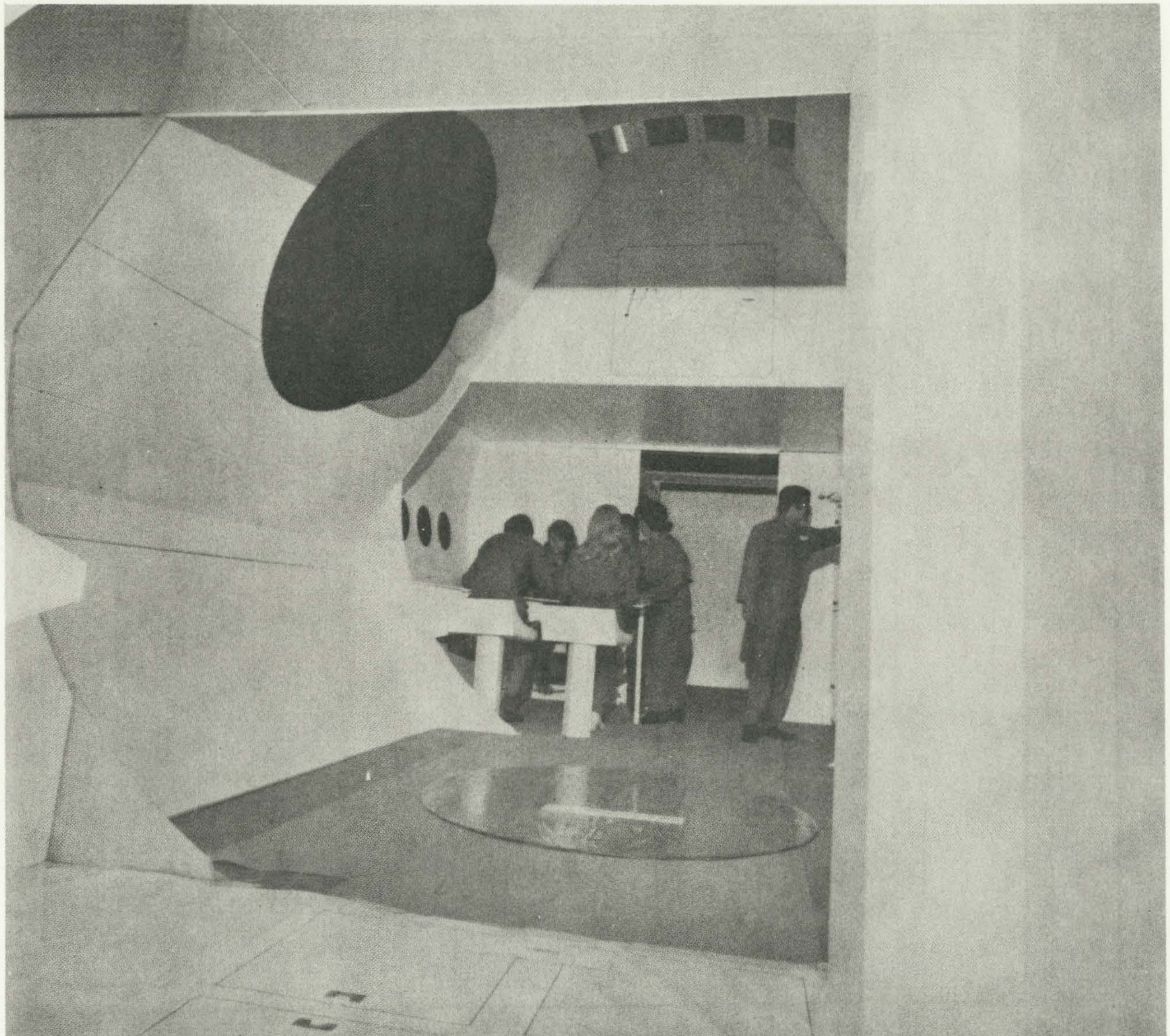


Figure 4.3-9. Ward Room

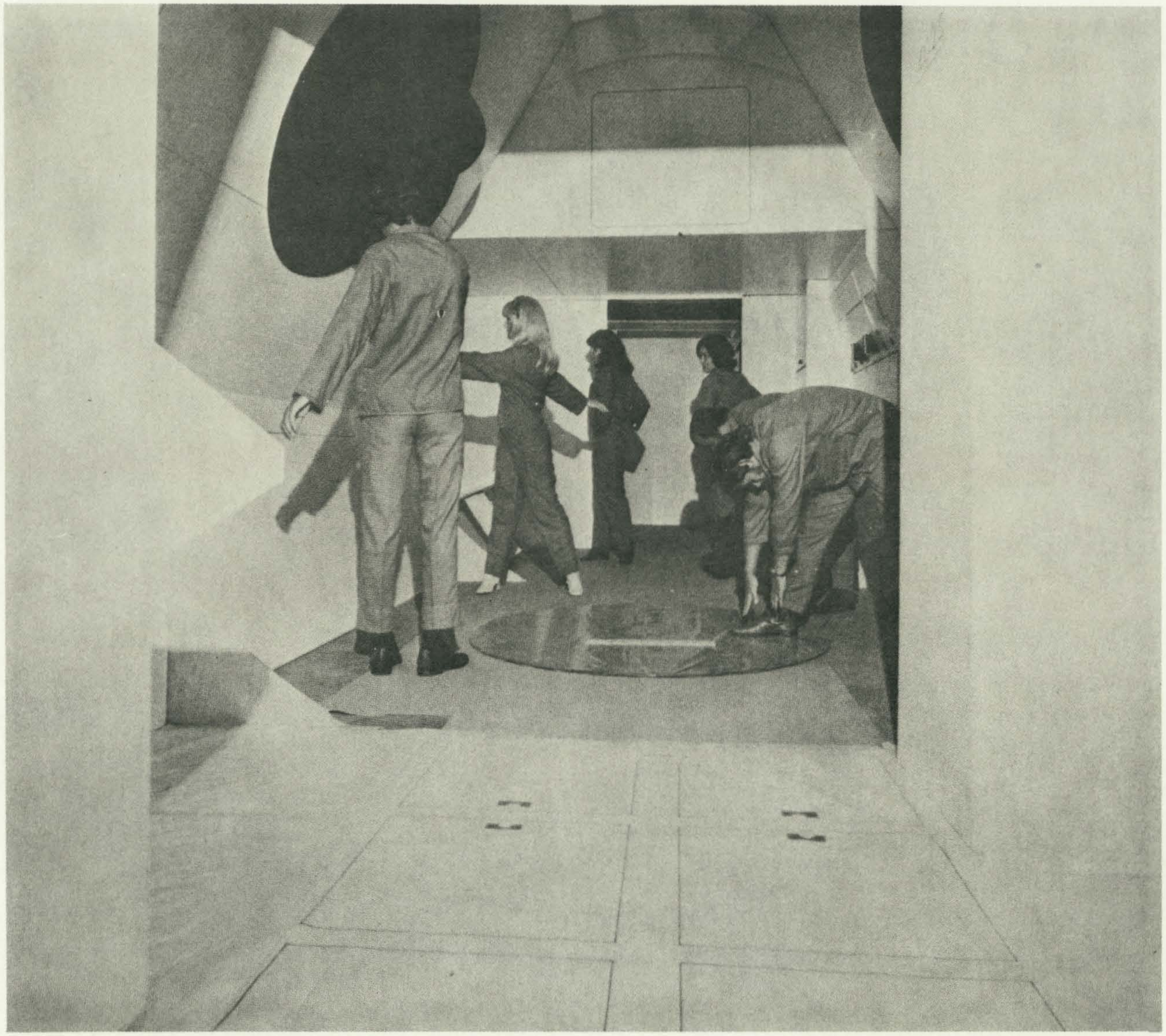


Figure 4.3-10. Docking Port Area (Ward Room Augmentation)

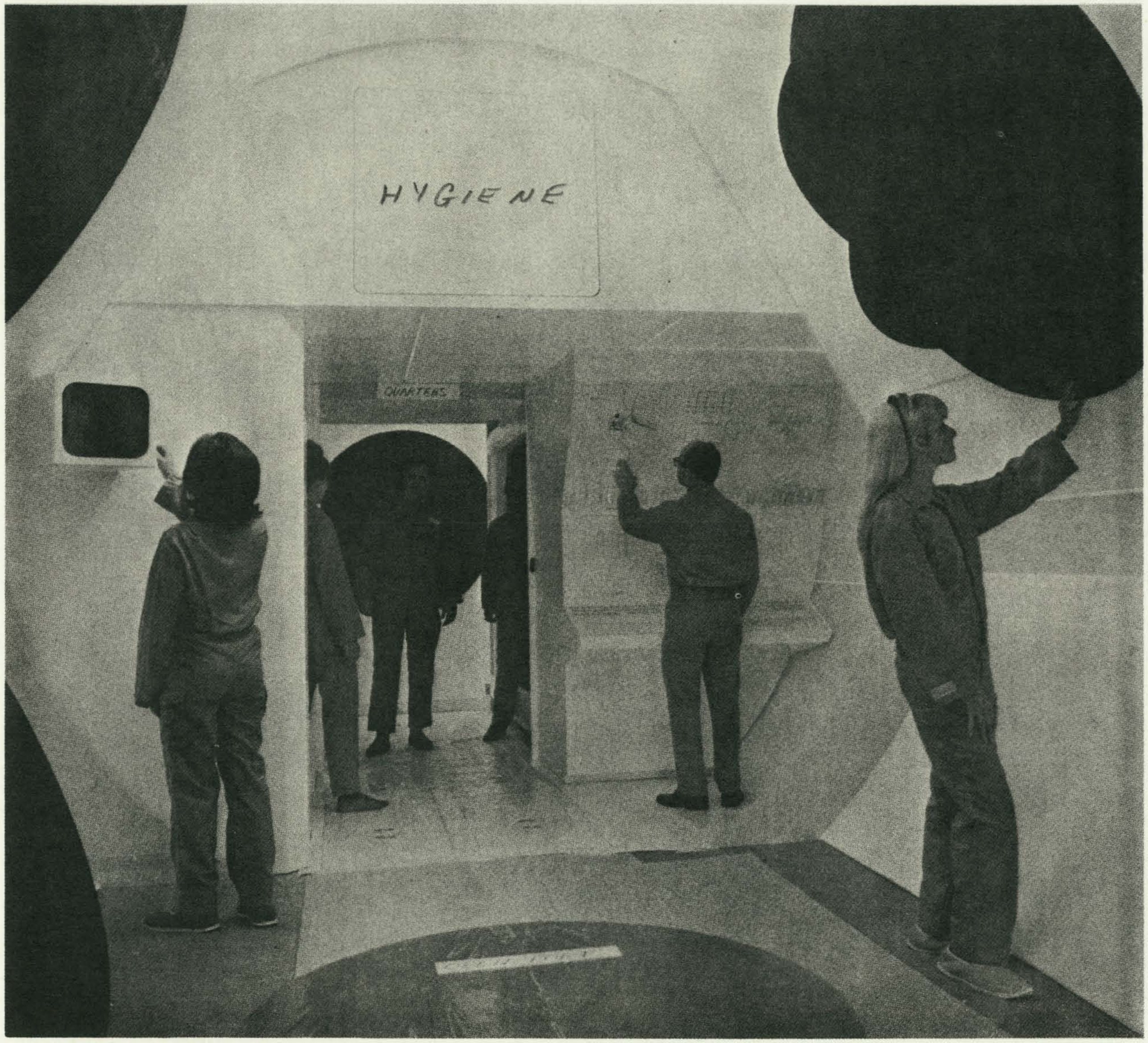


Figure 4.3-11. Hygiene Facility Location

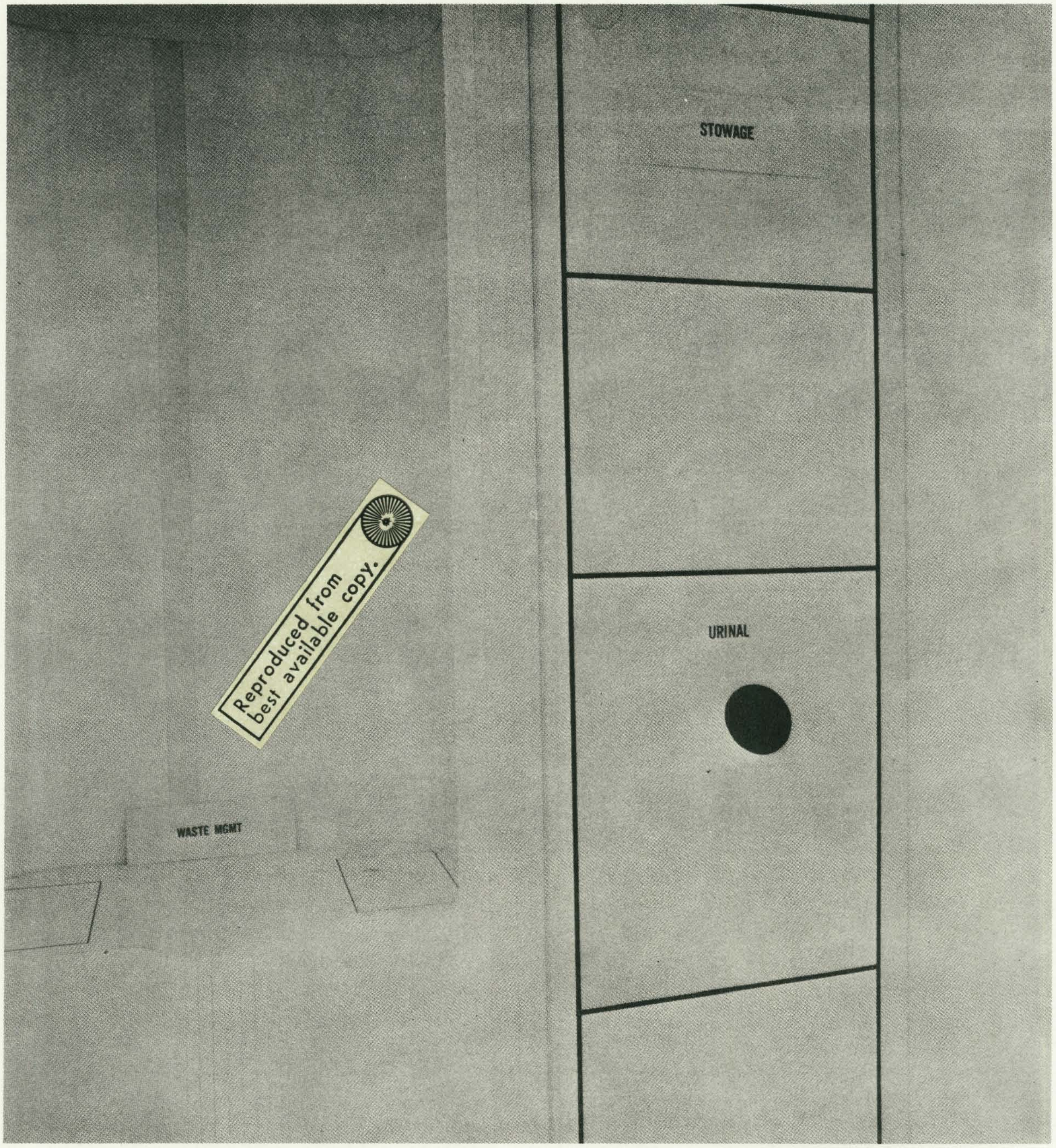


Figure 4.3-12. Hygiene Facility

R260

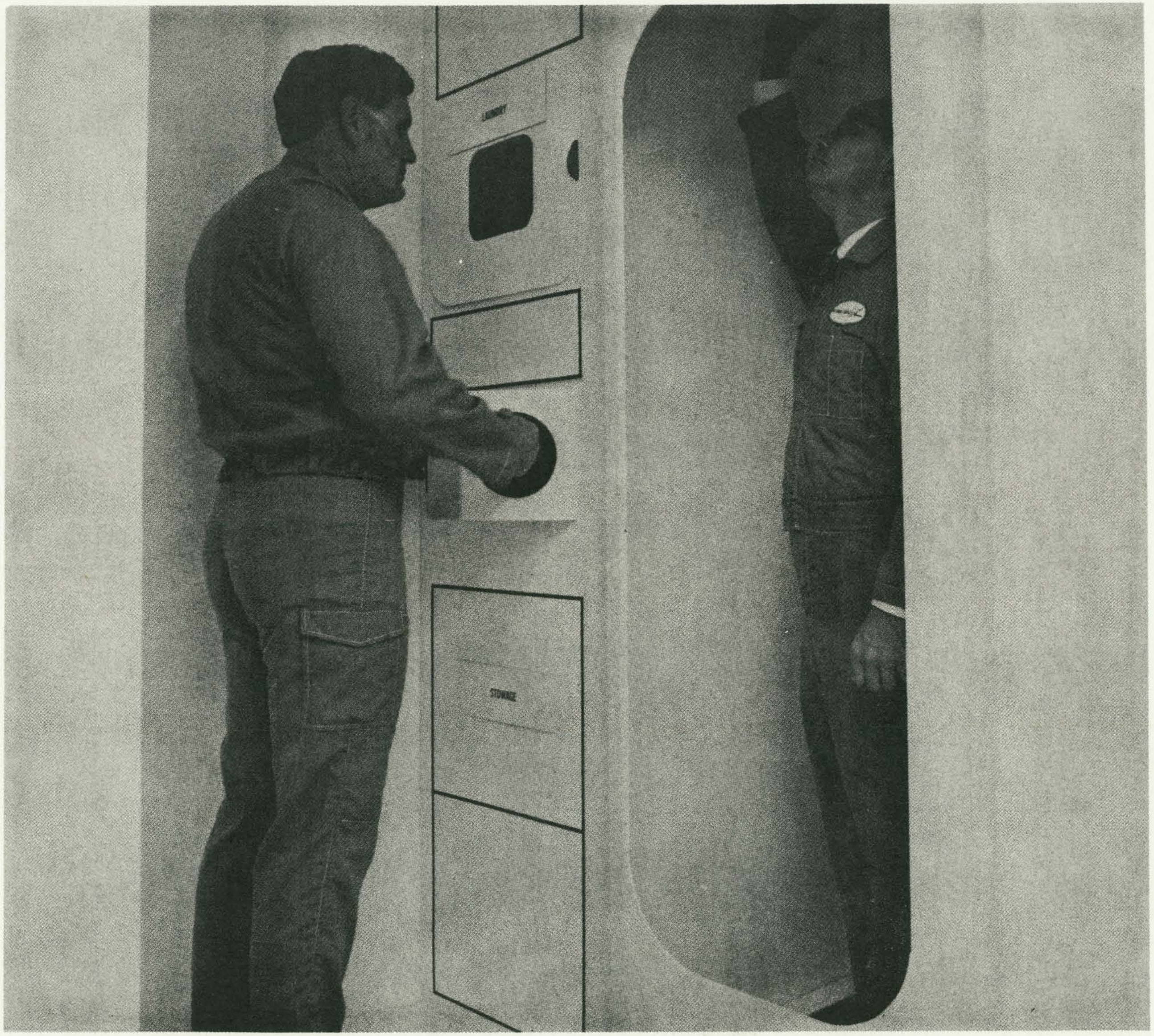


Figure 4.3-13. Hygiene Facility

rinsing and drying the body. A mixture of warm air and water impinge upon the body from a fixed or hand-held shower head. The spray is carried laterally along the axis and out the end of the air stream. A water collection and blower is used to remove the local accumulations of water to aid in drying. Temperature and flow rate is controllable by the crewman. Towels may be required to complete drying.

The shower dispenses water at the rate of 0.03 ml of water/1 sq cm of skin area (approximately 0.6 liters/man shower) for initial wetting of the body and 0.1 ml of water/1 sq cm (approximately 2 liters/man/shower) of skin area for rinsing. The volume of the shower is approximately 60 ft^3. The usable area is a cylinder 6.5 ft high and 3 ft in diameter.

Power requirements are approximately 200 w and heat rejection approximately 170 Btu/shower (25 min or less) and 17 lb water/shower delivered at 30 psi, consisting of 165°F and 72°F mixture.

Chamber Sink—Provisions for hand and face wash is provided by an enclosed chamber sink similar to a glove box. A mixture of hot and ambient temperature water is provided along with metered dispensing of the cleaning agent. The sink is compatible with oral hygiene provisions (pressurized water cleaning device, brush and dentrifrice).

Personal Hygiene Kit—Each crewman will be supplied with a personal hygiene kit containing the small equipment items and supplies needed for routine personal hygiene and grooming. The kit contains such items as an electric razor, comb, hair brush, nail clipper, toothbrush, dentrifice, deodorant, after shave lotion. These items shall be selected on an individual crewman basis to assure that personal requirements are met and that unnecessary items are deleted.

The electric razor shall require no more than 10 min to accomplish and shall use less than 20 w of power. It shall be available for daily use. Entrapped hair shall be removed periodically by the crewman.

Laundry—The laundry provides washing action through mechanical agitation and semi-drying through centrifugal force. Water is introduced into the spinning tub through the inlet pitot and the air passes through the phase separator and is discharged through the vent. When the tub is filled, the spinning action stops and agitation commences, providing the washing action. At completion of the wash cycle, agitation ceases and the tub is spun to provide positive head for water discharge. Then, this water is passed through the filter and returned to the tub to provide clear water for the rinse cycle. At completion of the rinse cycle, the tub is spun again, but in a reverse direction to provide discharge through the inlet pitot and back flushing of the filter before dumping. Additional spinning will provide the force necessary for semi-drying.

Once washed and semi-dried, clothing is dried further by vacuum evaporation prior to storage or use. Vacuum drying reduces the overall volume of the laundry as well as the drying time. The laundry is capable of handling a minimum of 10 lb of dry clothing per cycle. Both wash and dry cycles can be completed in 30 min or less at an average of 8 w. Wash cycle require approximately 200 lb of water and a peak power requirement of less than 250 w.

Waste Management Compartment—The waste management compartment (within the total hygiene compartment) contains a urine collector, fecal collector and appropriate expendables. It is provided with appropriate odor, liquids and contamination control. A second urinal is provided outside the waste management system compartment. It shares "console" space with a handwash.

Control Center

The Control Center occupies a section similar to the Galley/Wardroom at the opposite end of the module. Its location permits observation of caution/warning indicators by off-duty crewmen in the Galley/Wardroom/docking port area. Its location and general layout of the primary control console is shown in Figure 4.3-14. Electronic support equipment is shown

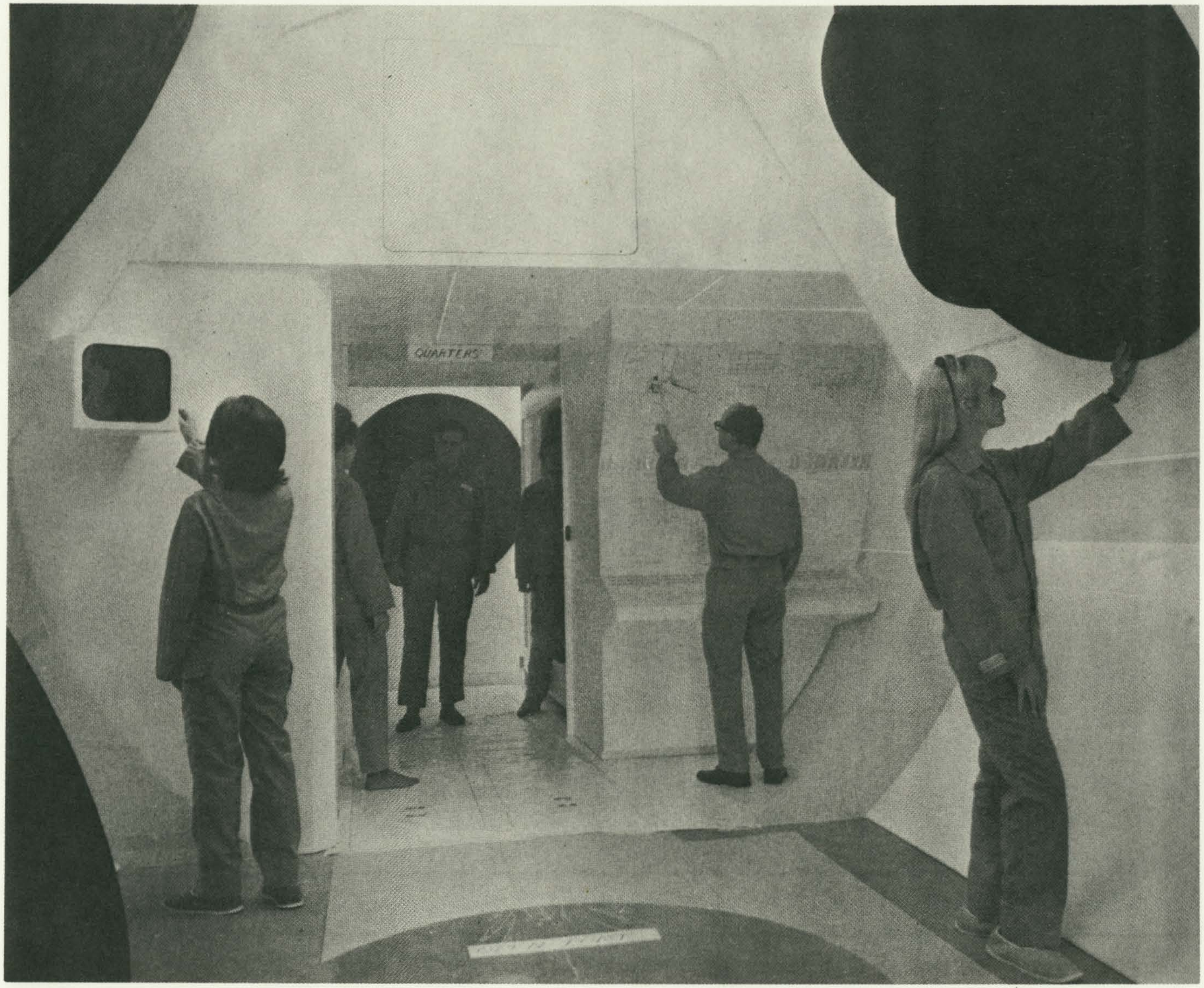


Figure 4.3-14. Primary Control Center

in Figure 4.3-15. The Control Console is designed to be operated normally by a single man, but permits use by a second man in certain checkout operations.

The detailed design characteristic of the Control Center is discussed in Section 4.10, but it has the following general characteristics: all Station operations, excluding experiment operations, can be monitored and/or controlled from the Control Console. A secondary console located in the GPL provides a redundant capability. Windows are provided to allow direct viewing of docking operations and to allow for gross assessment and control of Space Station attitude and orientation. The Control Center was designed to support all known subsystems and Station requirement, and to provide for growth and/or modification to those subsystems. In defining the requirements for the design of the Control Center, all subsystems requirements were collected and analyzed. To these requirements were added those that might be generated by other potential candidates for inclusion in the Station. These requirements were then integrated and synthesized to determine all of the potential requirements for displays and control that such a Station might require in its 10 year-life. General purpose/integrated display and control equipment was then defined to have the generalized capability to meet these requirements. However, a number of dedicated displays are included, where sharing of use was deemed inefficient. The Control Center also contains the capability for the continuous display of selected high use information. Both visual and auditory warning of emergency information is provided. Light and sound isolation of the entire Center or the primary control console is provided by an adjustable curtain. All of the equipment in the Control Center can be accessed from four sides.

Table 4.3-2 shows a summary of volume requirements versus volume allocated to each of the facilities in Crew/Operations module.

In addition to the specific facilities noted above the crew habitability and protection subsystems include the following general capabilities.

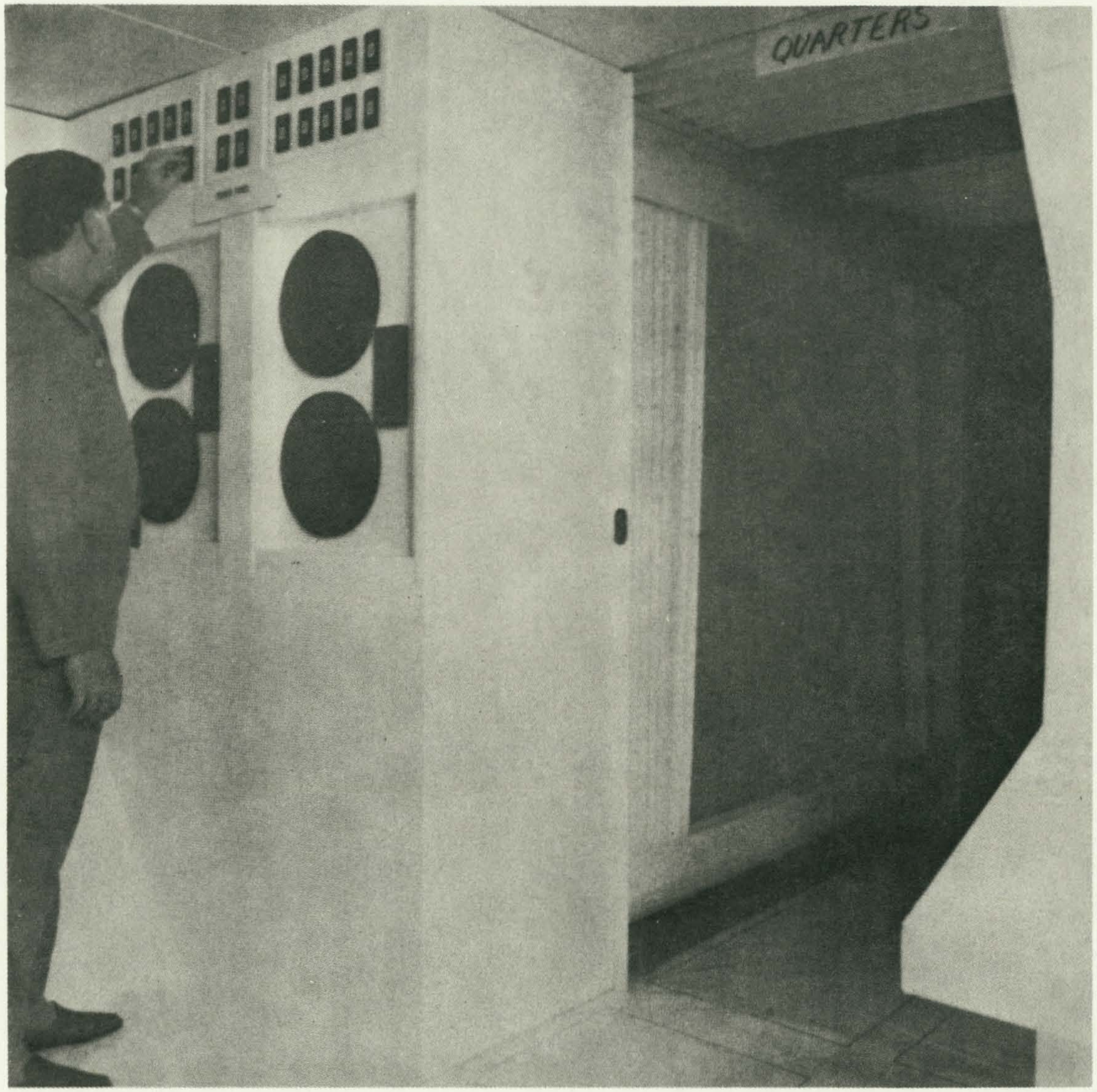


Figure 4.3-15. Primary Control Center Support Equipment

Table 4. 3-2

CREW/OPERATIONS MODULE VOLUME REQUIREMENTS VERSUS CAPABILITY SUMMARY

	Required	Allocated	Available
Total	4, 520 ft^3	5, 280 ft^3	5, 620 ft^3
Private Quarters	1, 200 ft^3	1, 200 ft^3 + 400 ft^3	Common space
Galley/Wardroom/Gym	1, 720 ft^3	1, 920 ft^3	
Hygiene	480 ft^3	505 ft^3	
Control Center	215 ft^3	285 ft^3	
ECLS and Power	225 ft^5	280 ft^3*	

*Non-Allocated Storage 340 ft^3

Crew Aids

Restraints and locomotion aids are provided throughout the Station to assure safe and convenient crew operations. Fixed restraints and locomotion aids are provided at specific locations as required by the tasks to be performed at that location. Portable restraints and locomotion aids are provided as required for infrequent or unplanned tasks. Fixed restraints are provided in the galley at the food preparation console. These restraints are suitable for the standing position and are adequate for single or two-man operations. Fixed (seat) restraints for six men are provided at the dining table. Seat restraints are stowable as will the table to provide an open area as required for other activities. Fixed foot restraints are provided at each console (or unit such as urinal, laundry, handwash, WMS). Fixed restraints are provided in the wardroom as required for exercise and recreation equipment. These restraints are stowable. Fixed foot restraints are provided also at each work station in the GPL. Fixed foot restraints are provided at the Command-Control Console for two operators working concurrently or separately.

Portable foot restraints are provided throughout the Station as required for infrequent or unplanned tasks. These restraints are similar in design as those developed for Skylab, i.e., portable foot restraint assembly and portable pressure suit foot restraint assembly. Tool kits, containing standard and a limited quantity of special tools, are provided for spares replacement and general maintenance. These tools are applicable also for minor emergency and repair operations. It is similar to the Orbital Workshop Tool Kit. It contains a variety of screw drivers, Allen wrenches, Torque wrenches, pliers, tethers, etc., as required. Specialized items such as leak detectors, meteoroid damage repair materials, are provided in separate kits. Additional aids include portable lighting (flash light), portable fan (to provide air circulation in remote work areas), and portable (high-intensity) lighting for use in remote work areas.

Mechanical aids are provided to assist the crewmen in handling large objects such as offloaded equipment, supplies, spares, etc. Although the majority of the items can be safely handled and transferred by the crew from the Log Module to the power, crew/operations, or GPL without the use of a cargo handling system, the characteristics of a few items exceed the capability of a crewman to safely control the movement. These characteristics include size or shape, moment of inertia and safety precautions. Some of the items requiring installation for ISS activation are resupplied periodically throughout the ISS and GSS operations and will require transfer from the Log Module to the Station modules. The experiments will also require the periodic delivery and transfer of cargo exceeding crew capability. Since the usage rate of the transfer system is periodic rather than routine, a simple system that can be easily installed and removed for storage is indicated. Thus, a dual cable cargo handling system is provided. The system consists of two nylon cables attached to fixtures located in the passage ways of each Station module and the Log Module. Separate cables are attached on each side of the passageway to provide directional control of the cargo transfer. The cables are anchored at convenient intervals and no fittings are required on the cable. Removable cable trackers are easily and quickly installed and a deadman brake is provided on the cables. The system shall require minimum storage and minimum new time for crew installation or removal.

IVA-EVA Support

The Intravehicular Activities (IVA) and the Extravehicle Activities (EVA) support assembly provides protective garments, emergency oxygen masks and portable oxygen supply, maintenance devices, communications, tethers, and restraints for all emergency and any planned hazardous operations requiring special support equipment. In addition to the protective items and work aids mentioned above, the assembly provides for special lighting as required to assure safe and efficient operation during IVA and EVA. Finally, crew status monitoring is provided at the Command-Control Center and at the EVA hatch. The following list describes the essential features of the EVA support equipment.

A. EVA support equipment is designed so that a minimum of two crewmen can participate in all activities. The two crewmen shall be suited and pressurized so that one can assist the other as required.

B. It will support a two-man EVA operation for at least 3 hrs.

C. Tethers are provided so that both crewmen can be tethered to the spacecraft.

D. Crewmen shall remain within visual range of each other at all times.

E. Life support is provided through portable units, not umbilicals.

F. Continuous monitoring of EVA crewmen is maintained onboard through direct or TV surveillance, voice communication and telemetry readouts of critical life support and physiological functions.

G. PSA's (pressure suit assemblies) and PLSS's (portable life support systems) are stored in or adjacent to the airlock.

H. EVA hatches are designed for one-man operation.

I. Facilities are provided for prebreathing of exygen for at least 3 hrs. prior to EVA.

J. Radiation monitors are provided for EVA crewmen.

K. Emergency lighting is provided to assist in rescue operations if EVA is required during the dark part of the orbit.

L. EVA air locks are sized to accommodate two suited crewmen.

M. Handholds and guard rails are provided to assist in scheduled EVA.

N. Four EVA suits are provided. Two individually fitted suits are located in the GPL where all planned EVA egress/ingress shall take place. Two backup suits (not individually fitted) are located in the Power Subsystems Module.

The following list describes the essential features of the IVA support equipment.

A. Umbilical connectors for IVA suits are located in every pressurizable compartment.

B. An IVA suit is available for each crewman and located in a readily accessible area.

C. The capability for continuous communication between IVA crewmen and the Command-Control Center is provided.

D. Four IVA suits are provided. Two suits are located in the Power Subsystems Module and two in the GPL.

E. Egress/ingress is possible at any docking interface.

Emergency Oxygen Supply

Emergency oxygen is provided throughout the station to protect the crew against environmental hazards as fire and toxicity. The oxygen supply is available through portable bottles or the 96-hour emergency pallet. Six masks and portable supply bottles are located in private quarters (Crew/ Operations Module). Three masks are located in each of the following modules — Logistics, Power, and attached RAM. In the latter case, metabolic oxygen is available from the 96-hour emergency pallet. Similarly, six masks are located in the GPL with supply for the two pallets located in that module. The portable bottles provide an average of 15 min supply and the emergency pallets an average of 96 hours.

EVA Tethers and Lighting

Specially designed handholds and restraints shall be provided as required for specific EVA tasks. They will be compatible with two-man operations (suited and pressurized), and with the special tools and work aids to be used. Additionally, special lighting (high intensity, where necessary, will be provided to assure safe and efficient crew performance and to permit close observation of the EVA from the Station.

Radiation Protection

The Radiation Protection assembly provide the crew with protection against adverse radiation exposure. The solar-flare environment is the major contributor to the dose. The primary protective measure is the spacecraft structure along with onboard equipment. The structure design concept which affords the primary shielding is discussed in detail in section 4. 2.

The Radiation Detection system will monitor and measure the extent and kind of radiation to which the crew is exposed, keep cumulative records of that exposure and predicts time/area limits to assure crew safety. Onboard and extravehicular dosimetry are tied into the caution and warning systems.

Meteoroid Protection

The Meteoroid Protection assembly is described in detail in Section 4. 2, but a brief description is presented here. The assembly assures the probability of no puncture in 10 years of operations and a 0. 99 probability of no unrepairable damage in 1 year of operation. Module size and number of modules, including the logistic module, and the time on-orbit were considered in the design of the Meteoroid Protection assembly.

As a part of the MDAC research program, tests were conducted in a Light Gas Gun Facility to substantiate the integrity of proposed pressure vessel structures. The results showed that a minimum wall thickness of 0. 049 in. is required to provide the 0. 90 no-puncture probability requirement. The integrated design selected for other considerations (0. 060-in. wall thickness) provides a 0. 936 no-puncture probability.

The final structure concept is the result of the integrated design requirements for cabin pressure, meteoroid protection, thermal protection, radiation protection, launch load survival, damage resistance and long life. The meteoroid protection outside and pressure shell consists of a double bumper of 0. 016-and 0. 011-in. aluminum separated by radiator frames. The double bumper protects the high-performance insulation as well as protecting the pressure vessel. The remaining meteoroid protection is the pressure vessel, which in combination with the double bumper, provides the 0. 9 probability of no puncture in 10 years.

Detection and Location of Meteoroid Damage

Although the probability of meteoroid penetration is estimated to be quite low, provisions for detection and location in the event a penetration does occur is extremely important. Several techniques have been recommended and are under investigation. The exact technique to be employed on the Modular Space Station have not yet been determined. However, some likely candidates for detection and repair are as follows:

Dimple: detected by acoustic wall sensor. May yield characteristic signature. Crew should routinely examine wall for stress cracks and watch for progressive failure.

Spall: Detected by acoustic wall sensor. May yield characteristic signature. Crew should routinely examine spall eara for cracks and apply sealer and patch, as required. Damage should be routinely monitored for progressive failure.

Leaks (very small hole or perforation/seal defect): Detected by an acoustic wall sensor or perhaps a gas controller indicator. Crew should examine slow leaks with a portable leak detector and apply sealing compound as required. Larger holes would be repaired with a flat or blister patch, as needed. A critical leak or large perforation could be sensed by a gas controller which stimulates the alarm system. The crew would abandon the compartment. Later, the operations crew would enter the area in protective garments and repair the damage if possible; if not, the area would be sealed-off from further use.

Leak detection sensors are required at strategic locations throughout the modules to alert the crew of a hazardous condition. Sensor outputs shall be relayed to the Master Warning and Alarm System.

Fire Protection

Fire protection will be achieved largely by prevention. Every known precaution within reason will be taken to reduce fire hazards since no detection/extinguishment/suppressant system avoids all risks to the crew. Sources of ignition will be minimized and use of flammable material will be reduced to the least quantity possible. Materials will be selected in accordance with the flammability acceptance criteria specified in MSFC-Spec-101A, Flammability, Odor, and Toxicity Requirements and Test Procedures for Materials in Gaseous Oxygen Environments. Egress hatches between modules provide the crew with a means of immediate egress to a safe compartment. The basic design of the electrical system incorporates fire prevention provisions, i. e., emergency lighting, caution and warning, etc. An automatic fire detection and location system has been studies, but no design firmed up to the crew of fire hazards. The OCS would continually monitor critical areas and sound an alarm when a fire hazard arose. At the present time, however, direct olfactory sensing by crewman is superior to known mechanical devices. Dependance on crew sensing however is not completely satisfactory since crewman will not always be near the source of the fire or "attending" to its existence.

Apollo-type fire extinguishers are located throughout the Station to suppress any fire preferrably after it has been isolated. Emergency oxygen masks and protective clothing are provided to protect the crew against related hazards.

An automatic (heat sense) extinguishing system is located in areas where a fire hazard (though remote) exists. The detailed design of these has not been determined. Several agents have been considered as suppressant including water spray, a gueons foam, dry sodium ciocarbonate powder, carbon dioxide, inert gas, and volatile organic halides.

The General Purpose Laboratory Module

The GPL represents the "Center of Operations" for the conduct of the Stations primary mission. It contains the experimental equipment for the early experimental program (i. e., prior to the arrival of RAMS) and much of the experimental equipment for the continuing program, all of the experiment support equipment (excluding the primary power source, and oxygen supply in the Power/Subsystem Module), and the control center from which the entire experiment program is monitored and controlled. (This includes the capability for control of free-flying RAMS). Since it also contains the Secondary Control Center for the Station, it has the capability for control of the "total" mission.

The GPL represents one of the two "habitable volumes" required in the Station with a capability for extended duration operations. It has its own independent EC/LS system (less the oxygen supply in the Power/Subsystem Module) houses the 30-day emergency food supply, has a water dispenser unit for reconstituting freeze-dried food, urine and fecal collection equipment and a hand wash with associated wipes, towels, etc., for total body cleansing. It was configured with sufficient free volume to accommodate six sleeping crewmen comfortably, and with its capability for "light isolation" of certain laboratory areas and the inclusion of the Isolation Chamber, it can even accommodate dual shift operations on a somewhat limited basis. The Isolation Chamber also serves as an EVA airlock and stores two EVA pressure suits so that EVA operations can be conducted and controlled from the GPL. A 96-hour emergency pallet (for power and atmosphere) is stored in the GPL thereby providing the capability for self sustaining operations for that period of time in complete isolation from the rest of the station.

As noted in section 4.3.1, for the Modular Space Station Study, the GPL was considered to have first priority in the achievement of Crew Habitability/ Useability. Hence a significant amount of the habitability oriented effort of this study was directed to the analysis and development of requirements for habitability and the construction and evaluation of 1/20th scale models and full-scale soft mock-up of alternate configurations to achieve these requirements. The ultimate objective of that effort was to achieve a design that would be functionally efficient and at the same time represent a desirable place to work, conductive to continued high-level scientific endeavors.

Figure 4.3-16 shows the final interior configuration selected for the GPL. It is an "open" longitudinal arrangement, utilizing two operational levels, but, with the exception of the isolation chamber, has no permanent separating walls or floors, thereby achieving a high degree of spaciousness. Equipment are grouped functionally into laboratories or specialized facilities. Each

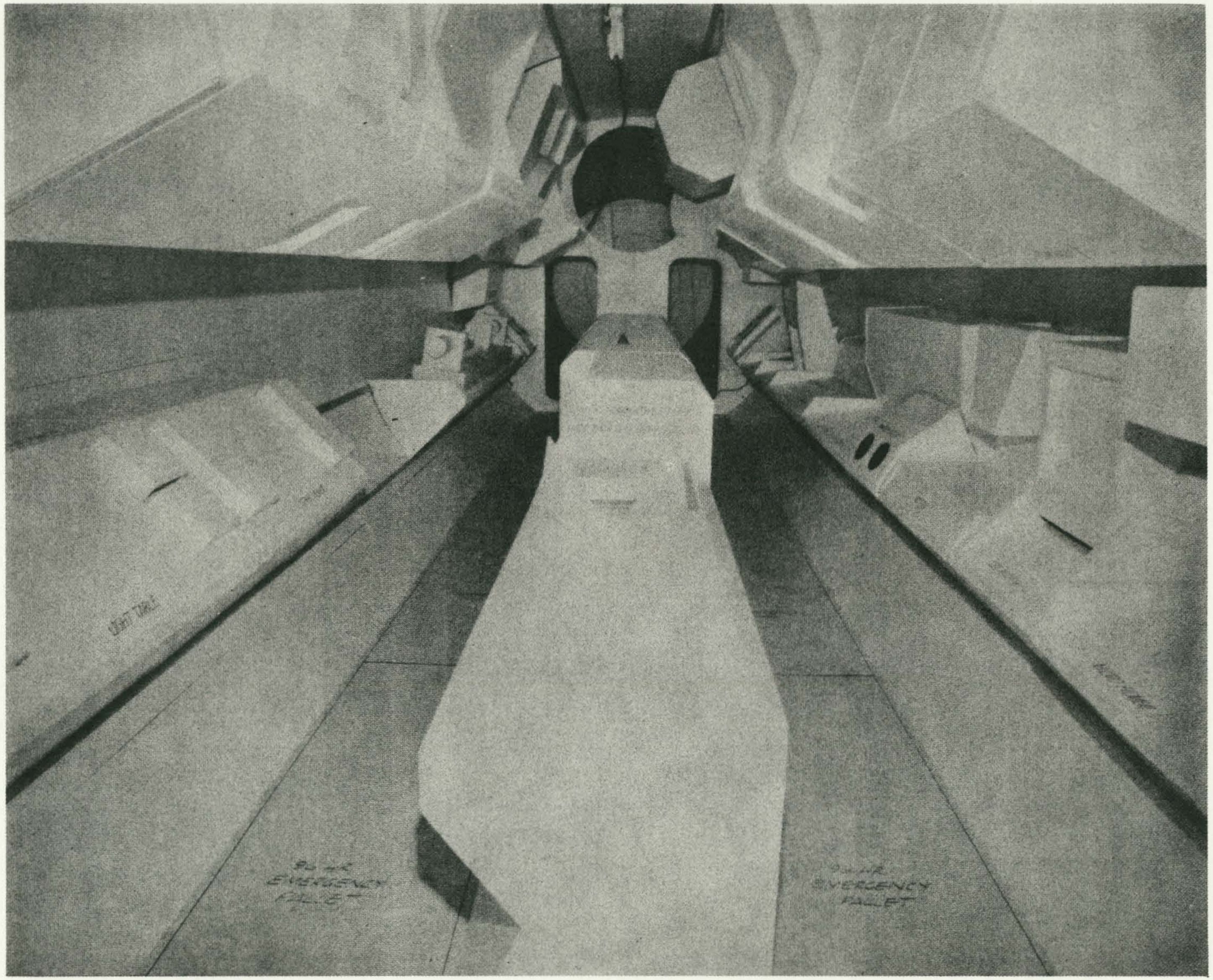


Figure 4.3-16. General Purpose Laboratory

laboratory/facility has been sized to allow up to three crewmen to work at one time. Also, there is sufficient free volume associated with each laboratory to permit up to three crewmen to confer, study, relax or socialize, thereby eliminating the need to always return to the wardroom or private quarters for such activities. Aisles and laboratories were also sized and/or arranged to allow crewmen to pass other crewmen at work without causing any interruption or interference with their activities. Equipment in the GPL has been located and arranged to eliminate any requirements for routine "foot to head" operations (i. e., one crewman working directly above another).

Figure 4. 3-17 shows the arrangement of equipment in the GPL. There are six support facilities or laboratories, an isolation chamber and the Experiment/Secondary Control Center. The facilities and laboratories provide for Hand Data Processing, Electrical/Electronic, Mechanical, Bioscience/Biomedical, Optical, Test and Isolation and Data Evaluation. Figures 4. 3-18 through 4. 3-31 shows the location in the module and the essential characteristics of each of these facilities. Each of these facilities is described in detail in Section 4. 4. The Experiment/Secondary Control Center is also described in Section 4. 10. Therefore except for the Bioscience/Biomedical Laboratory which does double duty as dispensary during ISS, only some general features of these facilities will be described here. Equipment requiring frequent access for servicing and maintenance have been located in the center consoles. Other equipments located around the periphery of the Station are hinged so they can be swung out for maintenance or access to the module walls. Hand holds and foot restraints are strategically located throughout the GPL. In addition a movable, adjustable pelvic/foot restraint, shown in Figure 4. 3-32 is provided for operation/maintenance of upper-level equipment. Two handrails, one on either side of the module, extends the length of the modules in front of the upper consoles. Several pelvic/foot restraints are attached to these handrails. They can be moved to any position along the rail and locked in place and at any angle desired, including the relative angle between foot and pelvic restraint.

As noted above, the Bioscience/Biomedical Laboratory serves also as a dispensary. The following medical support capability is included in that laboratory.

R260

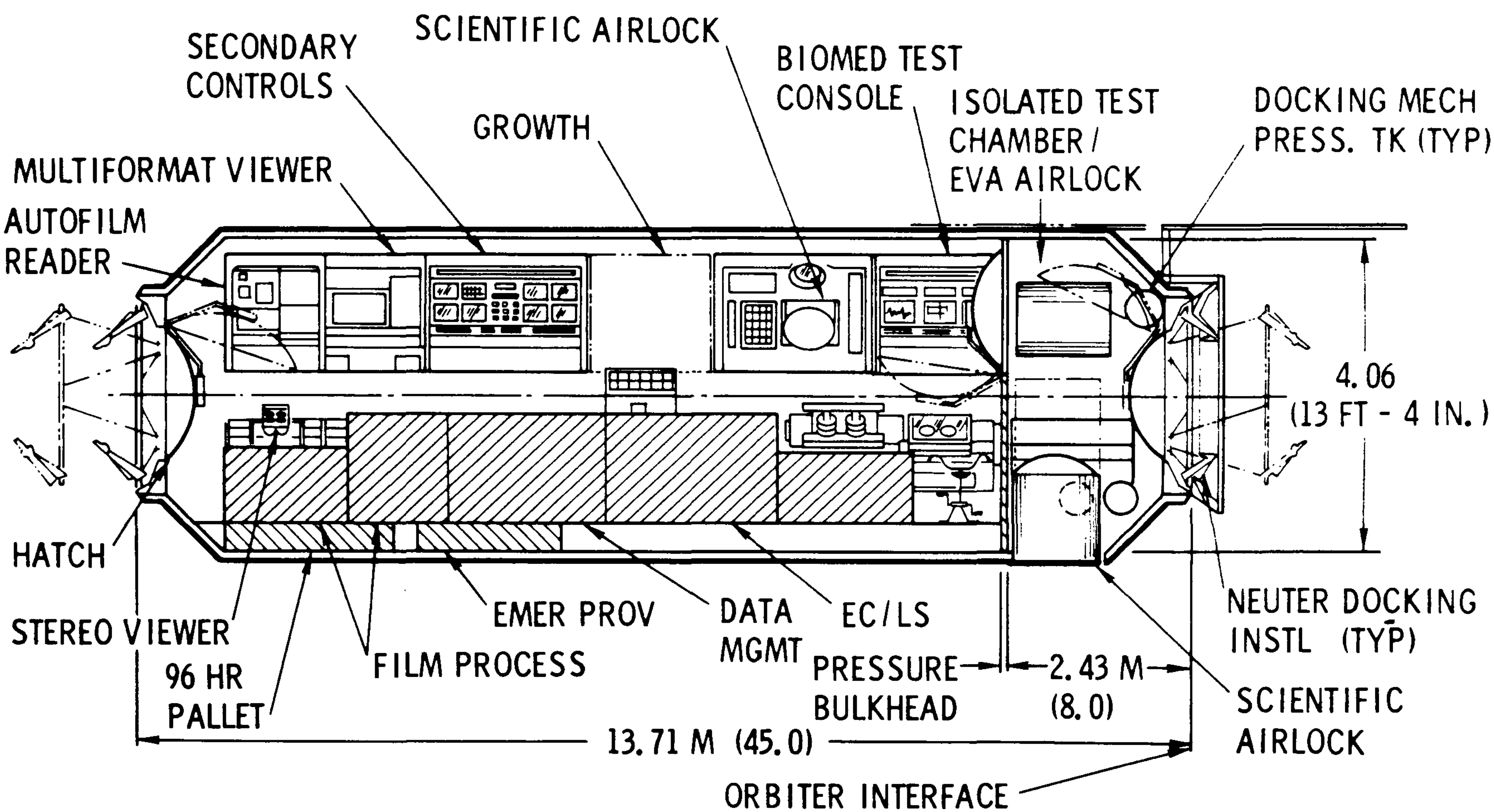


Figure 4.3-17. Modular Space Station General Purpose Laboratory

R260

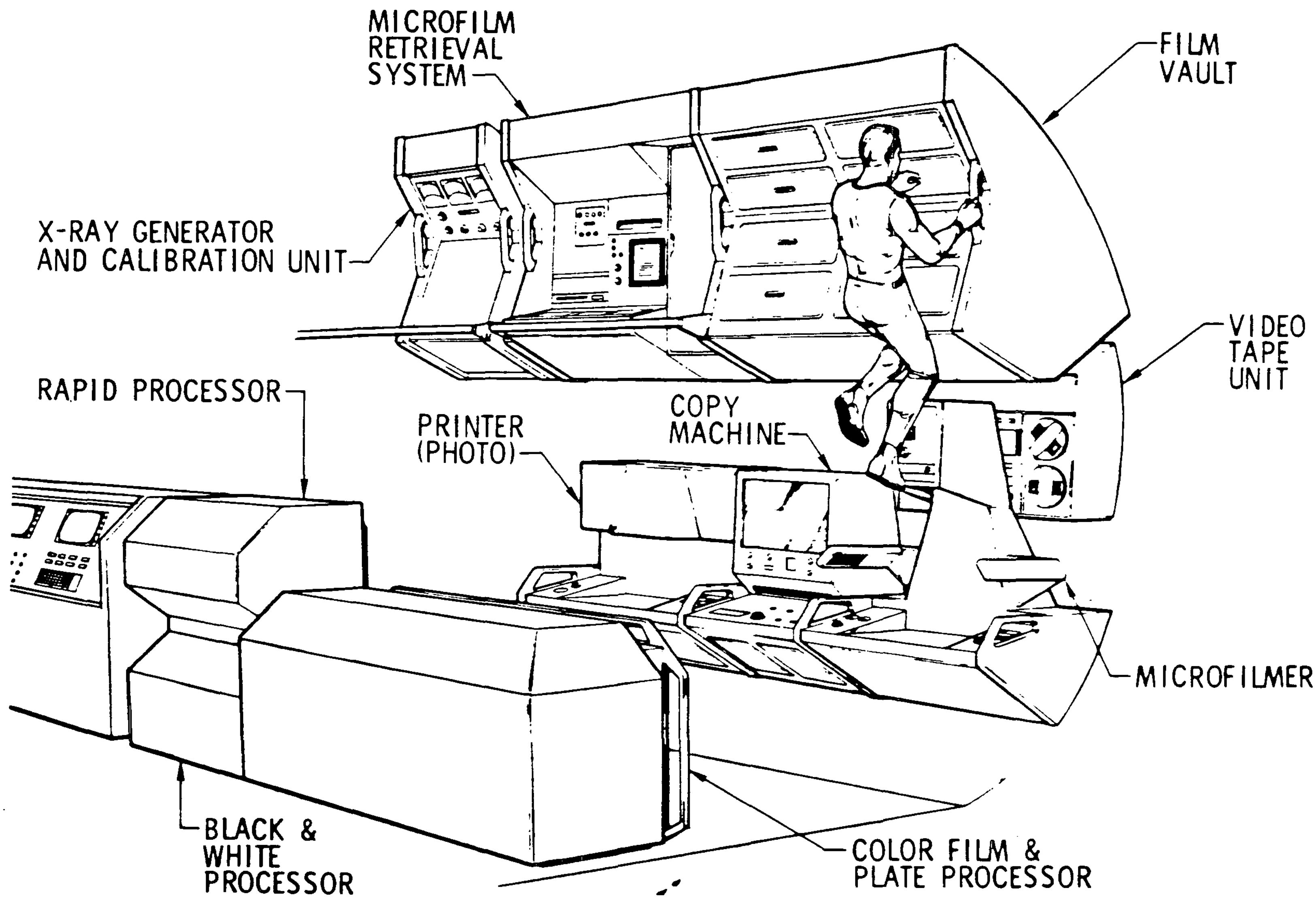


Figure 4.3-18. Hard Data Processing Facility

Figure 4.3-19. Hard Data Processing Facility

R260

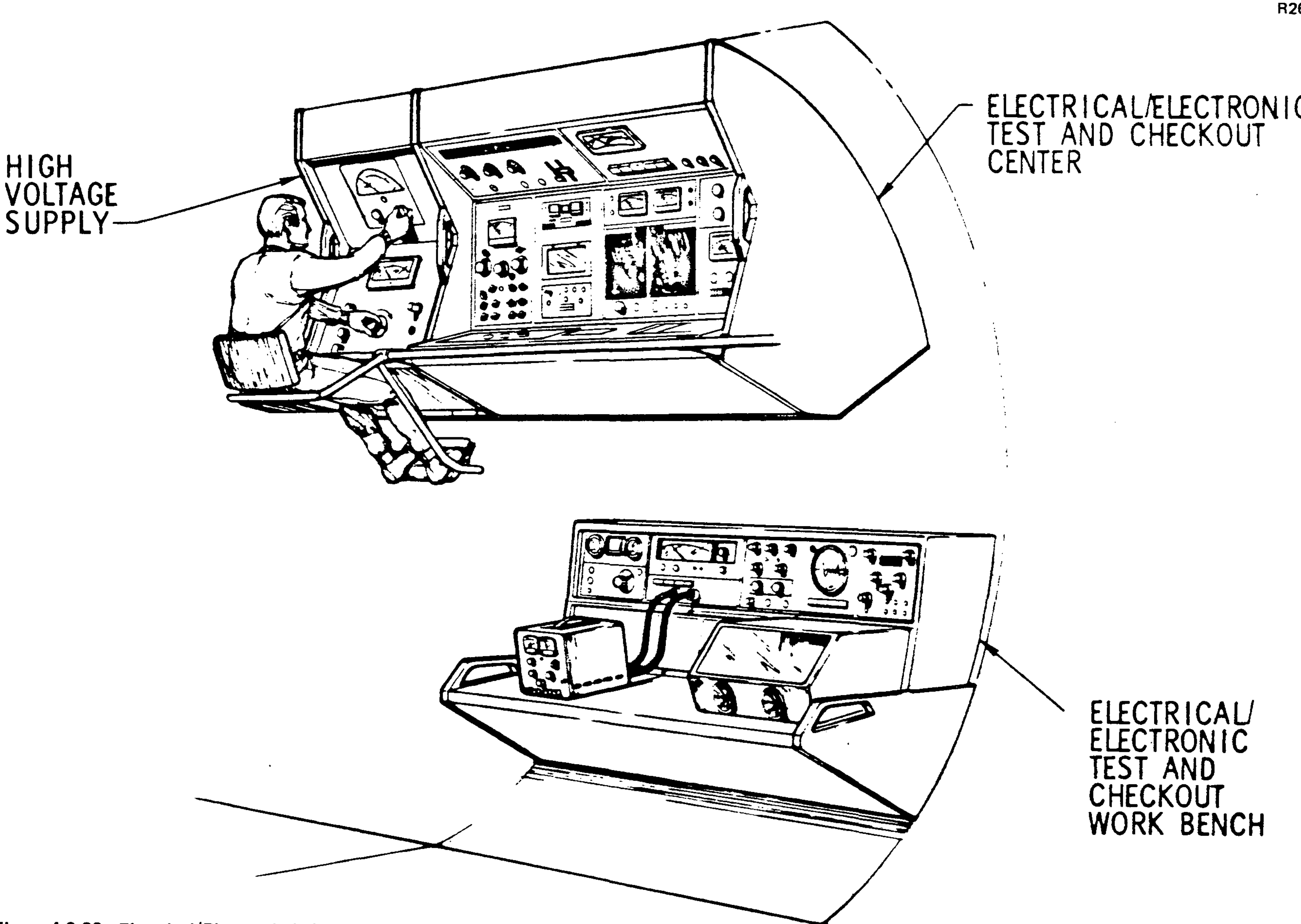


Figure 4.3-20. Electrical/Electronic Laboratory

70

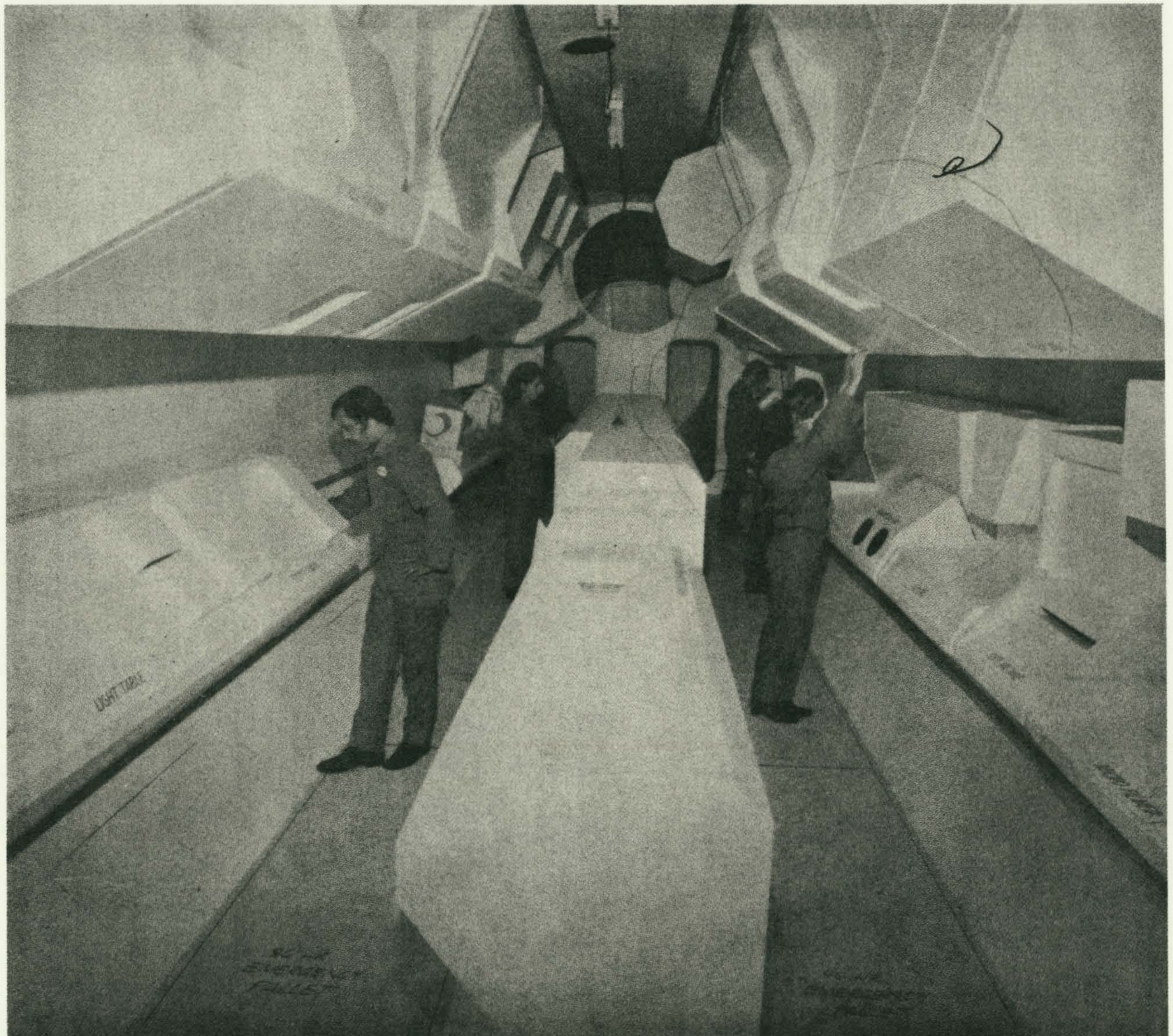


Figure 4.3-21. Electrical/Electronic Laboratory - Full-Scale Mockup

R260

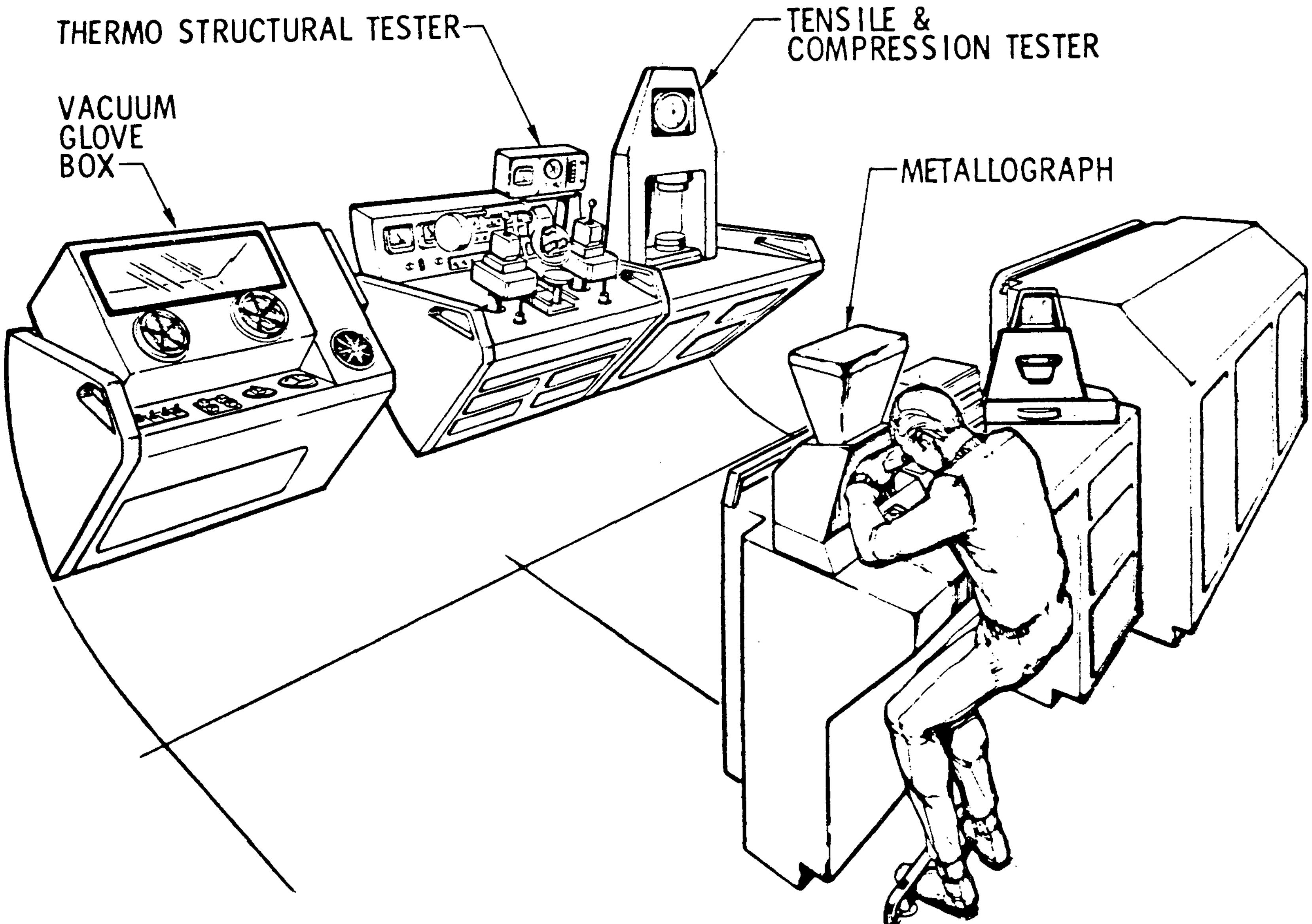


Figure 4.3-22. Mechanical Laboratory

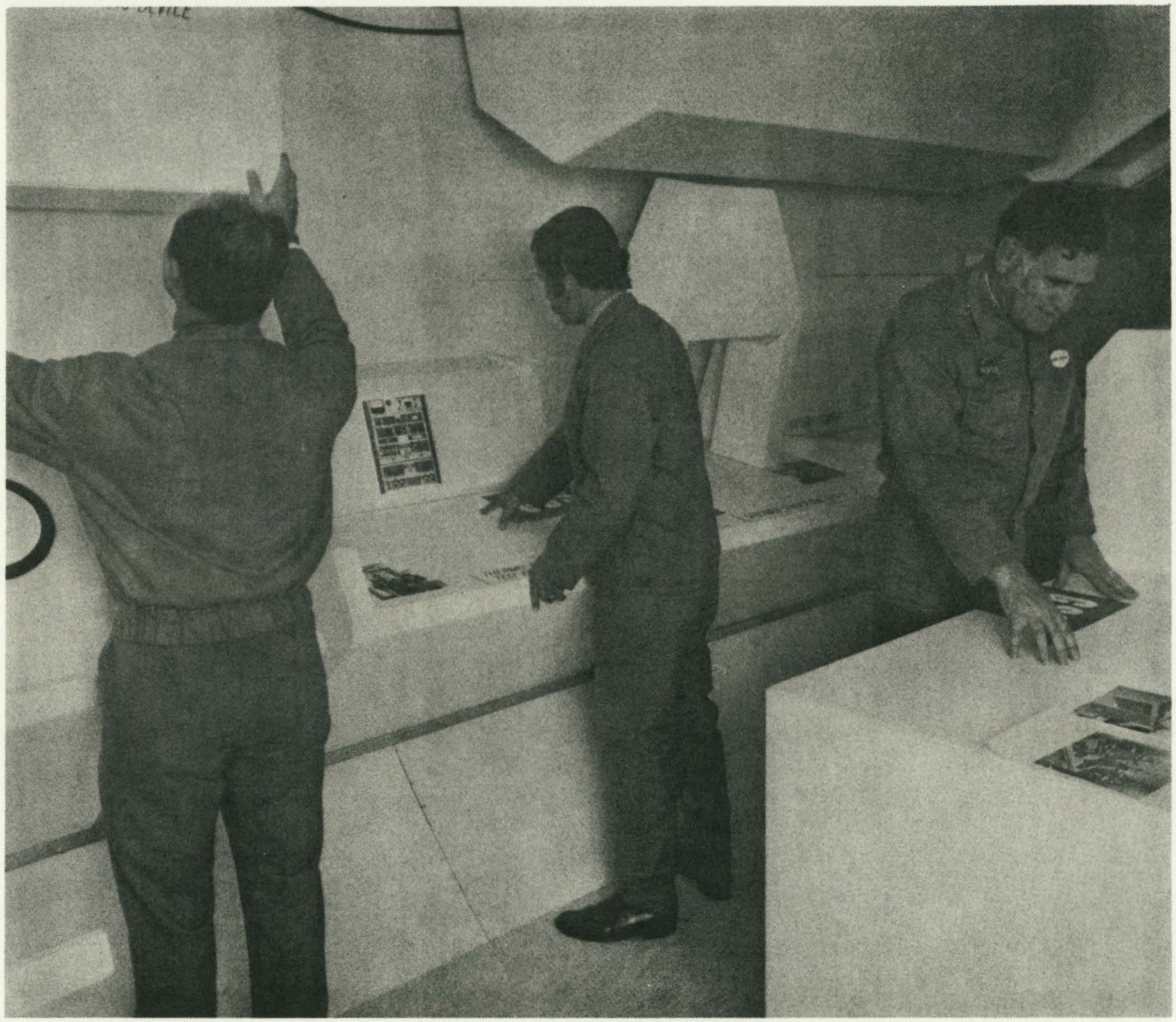


Figure 4.3-23. Mechanical Laboratory - Full-Scale Mockup

R260

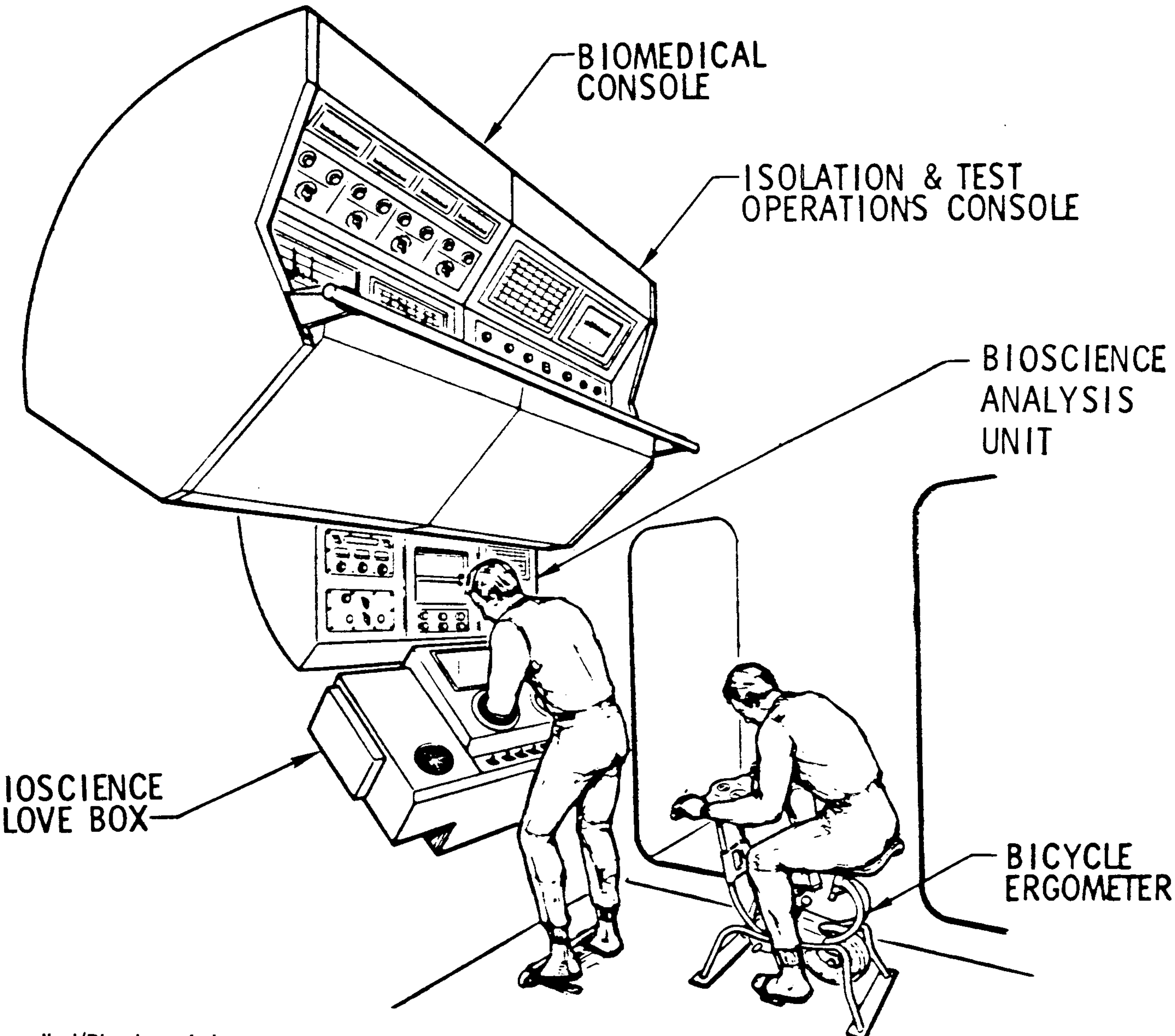


Figure 4.3-24. Biomedical/Bioscience Laboratory

Figure 4.3-25. Biomedical/Bioscience Laboratory

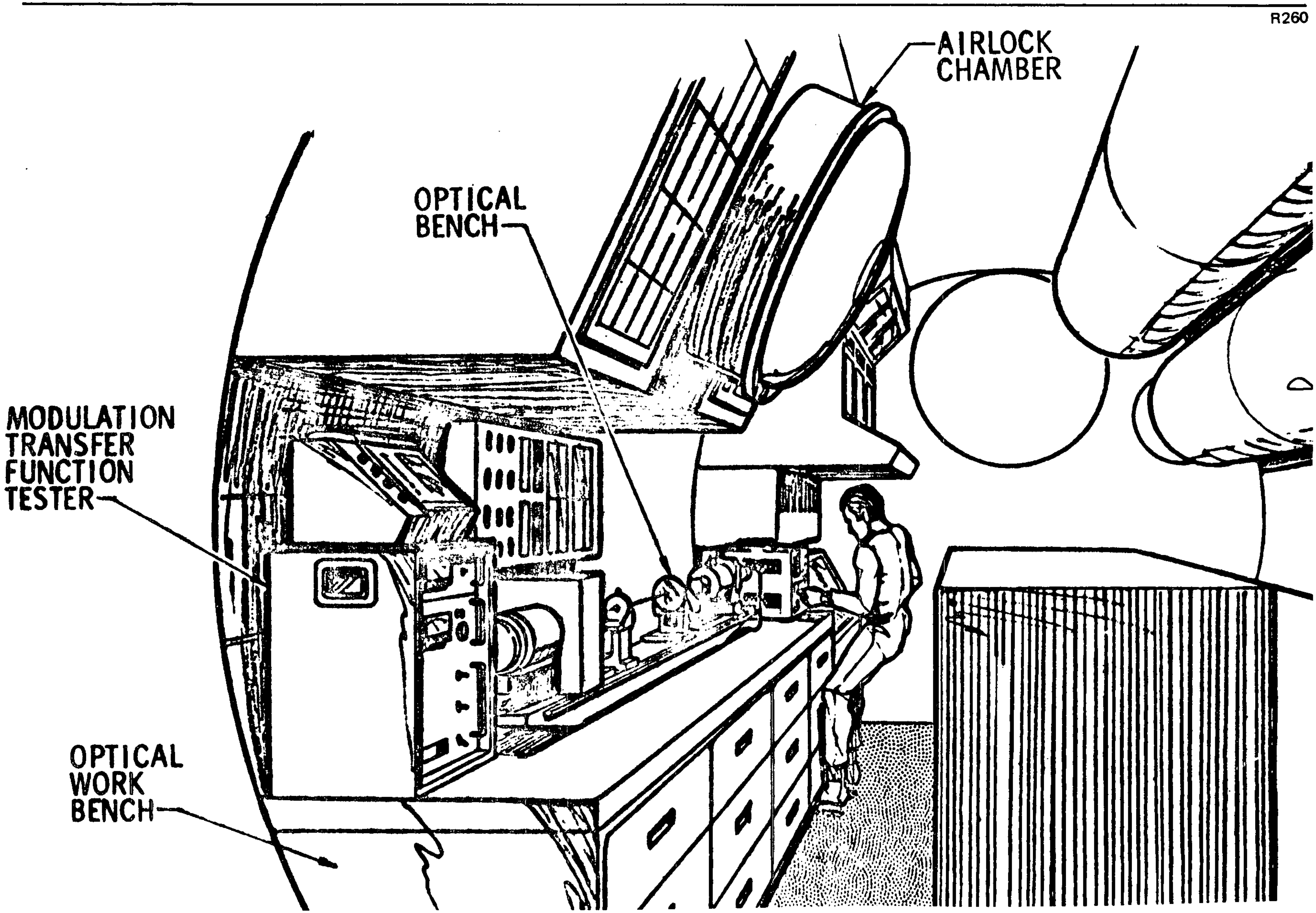


Figure 4.3-26. Optical Sciences Laboratory

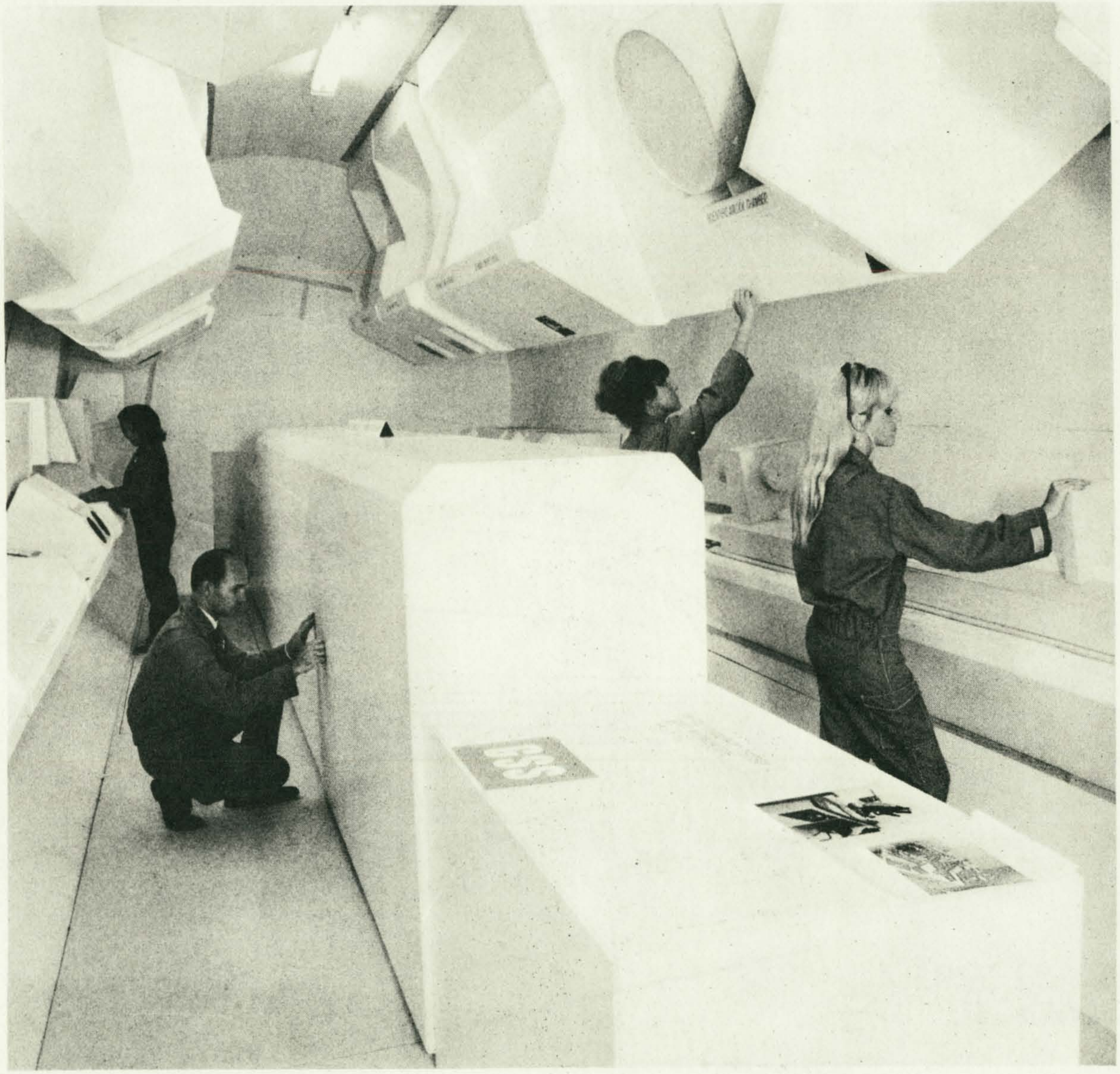


Figure 4.3-27. Optical Sciences Laboratory - Full-Scale Mockup

R260

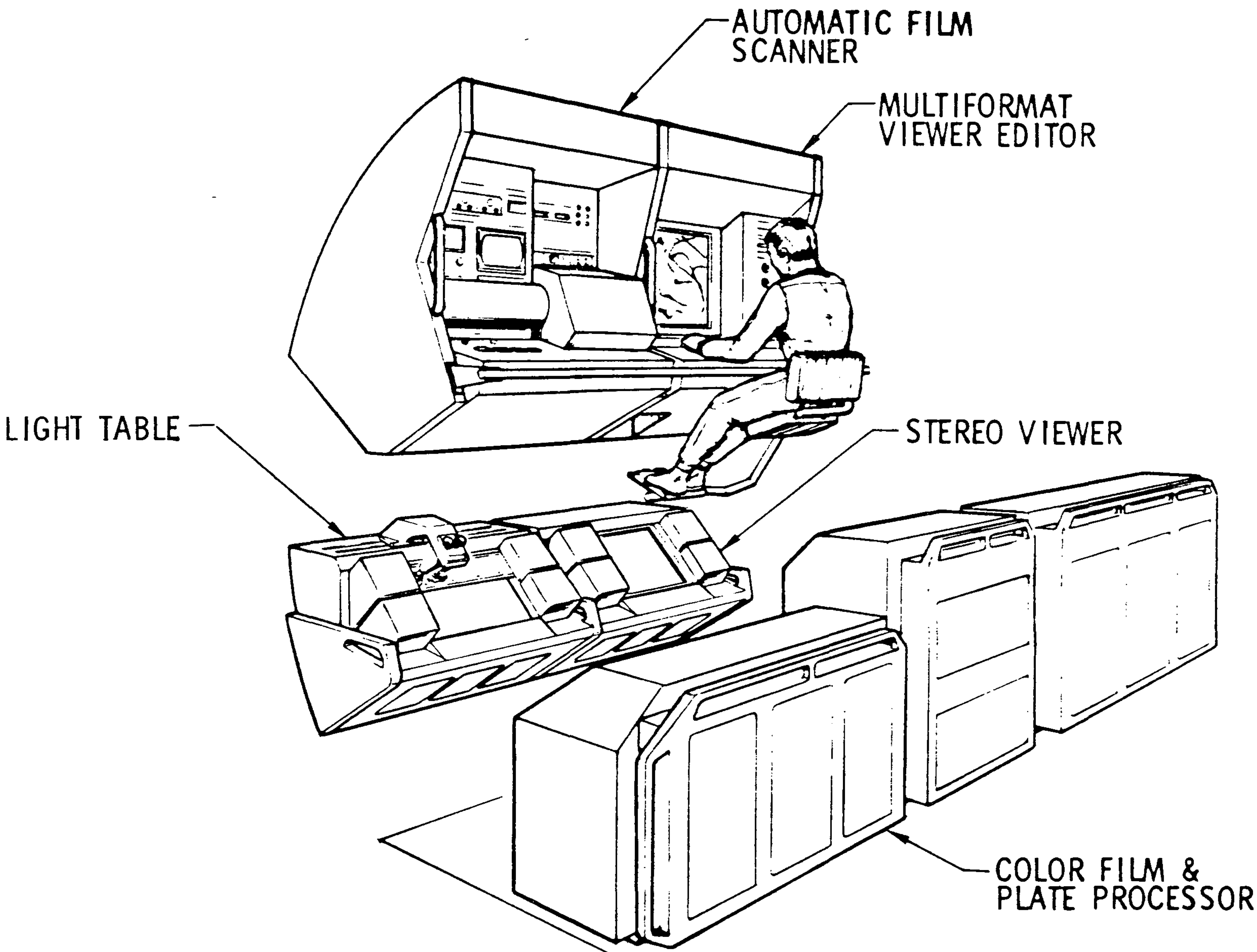


Figure 4.3-28. Data Evaluation Facility

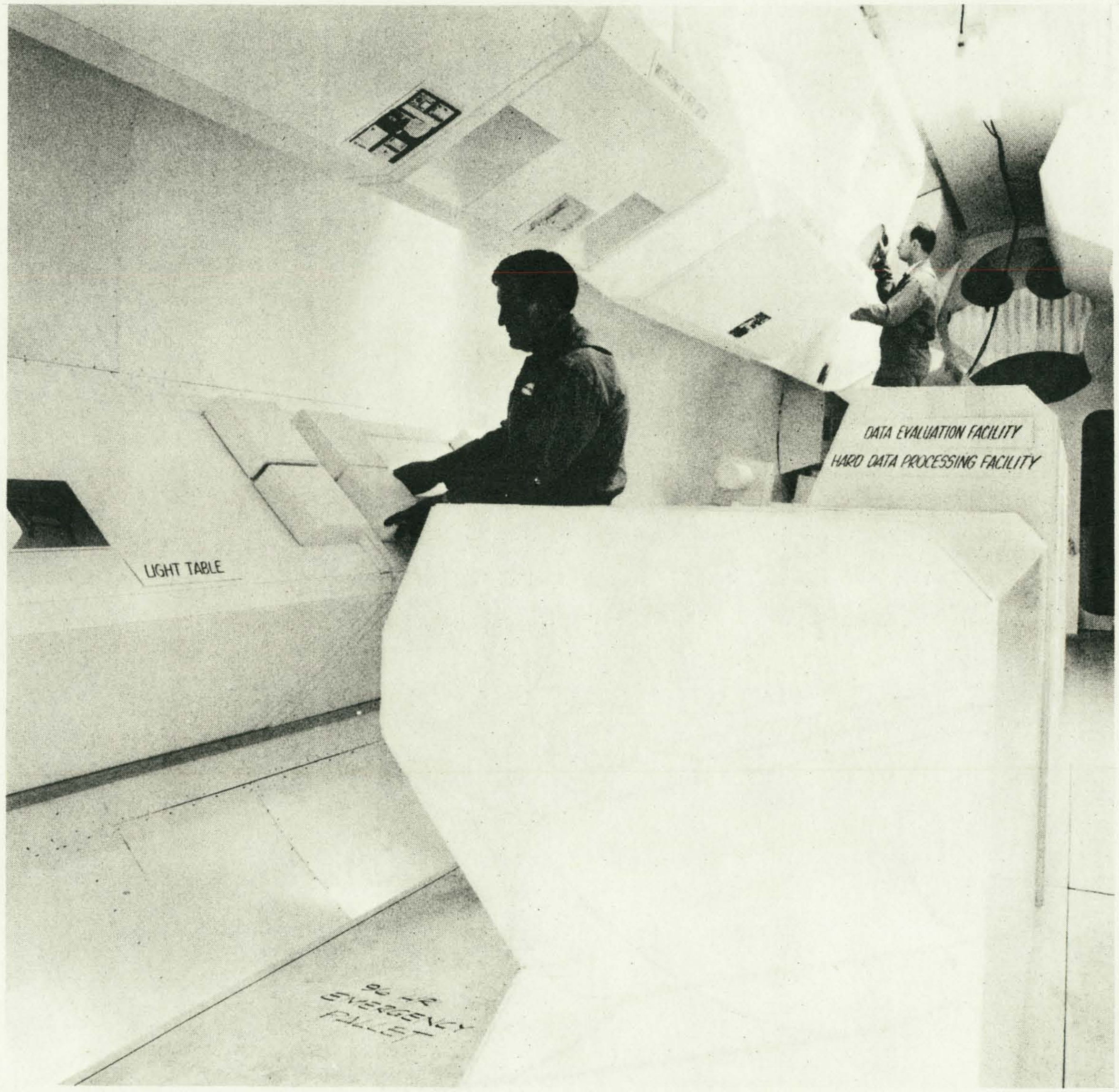


Figure 4.3-29. Data Evaluation Facility - Full-Scale Mockup

R260

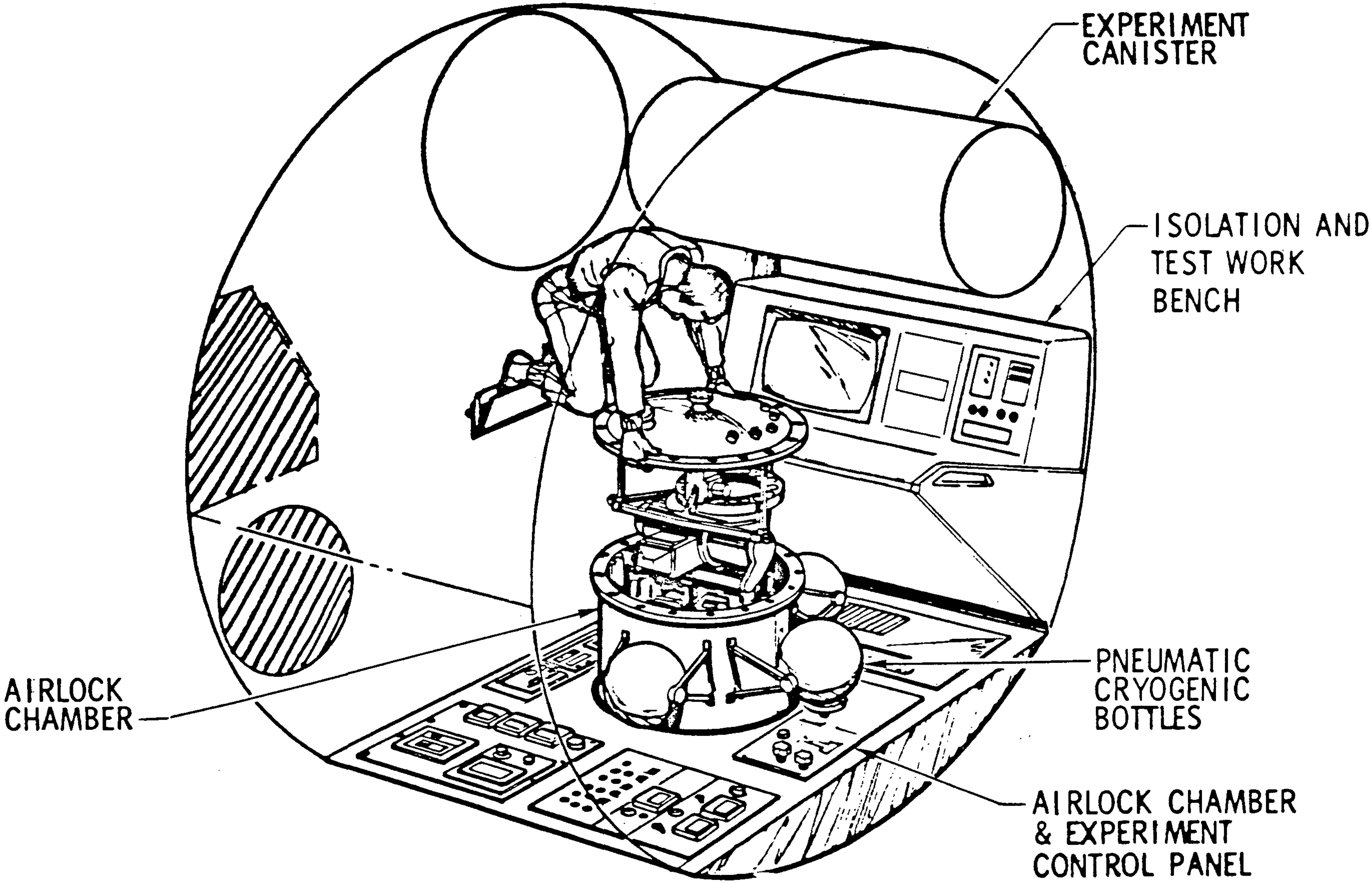


Figure 4.3-30. Experiment and Test Isolation Laboratory

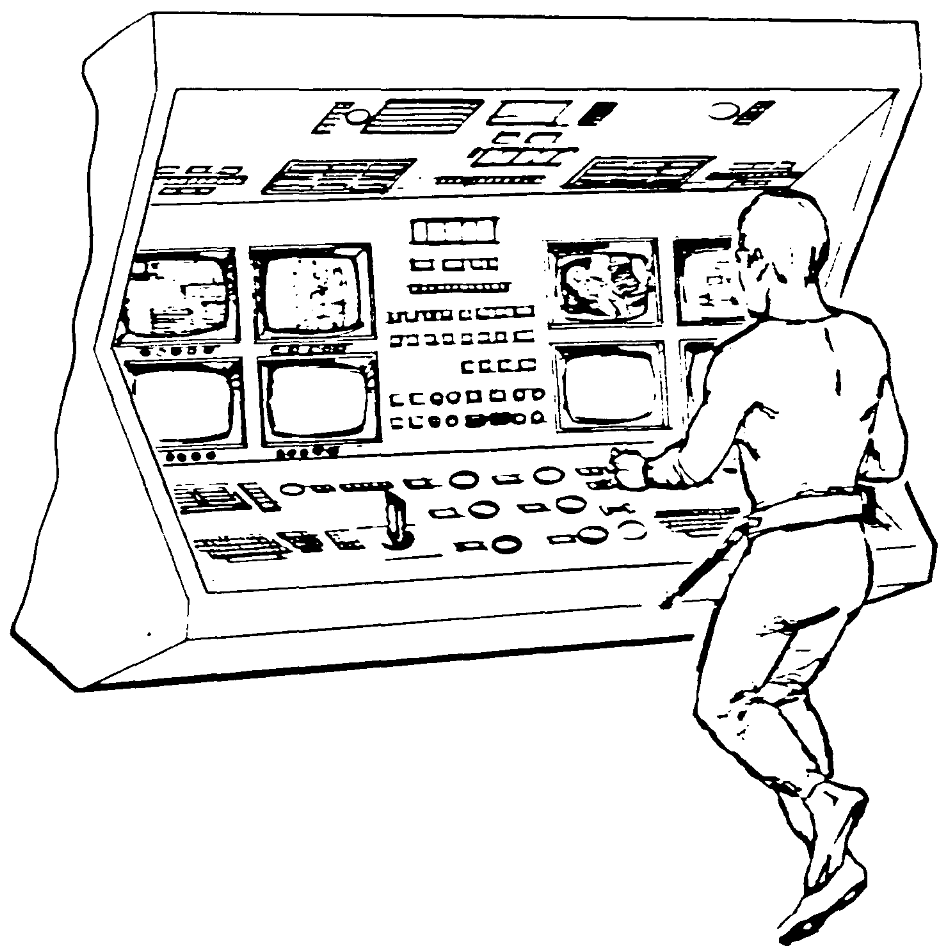


Figure 4.3-31. Experiment/Secondary Control Center

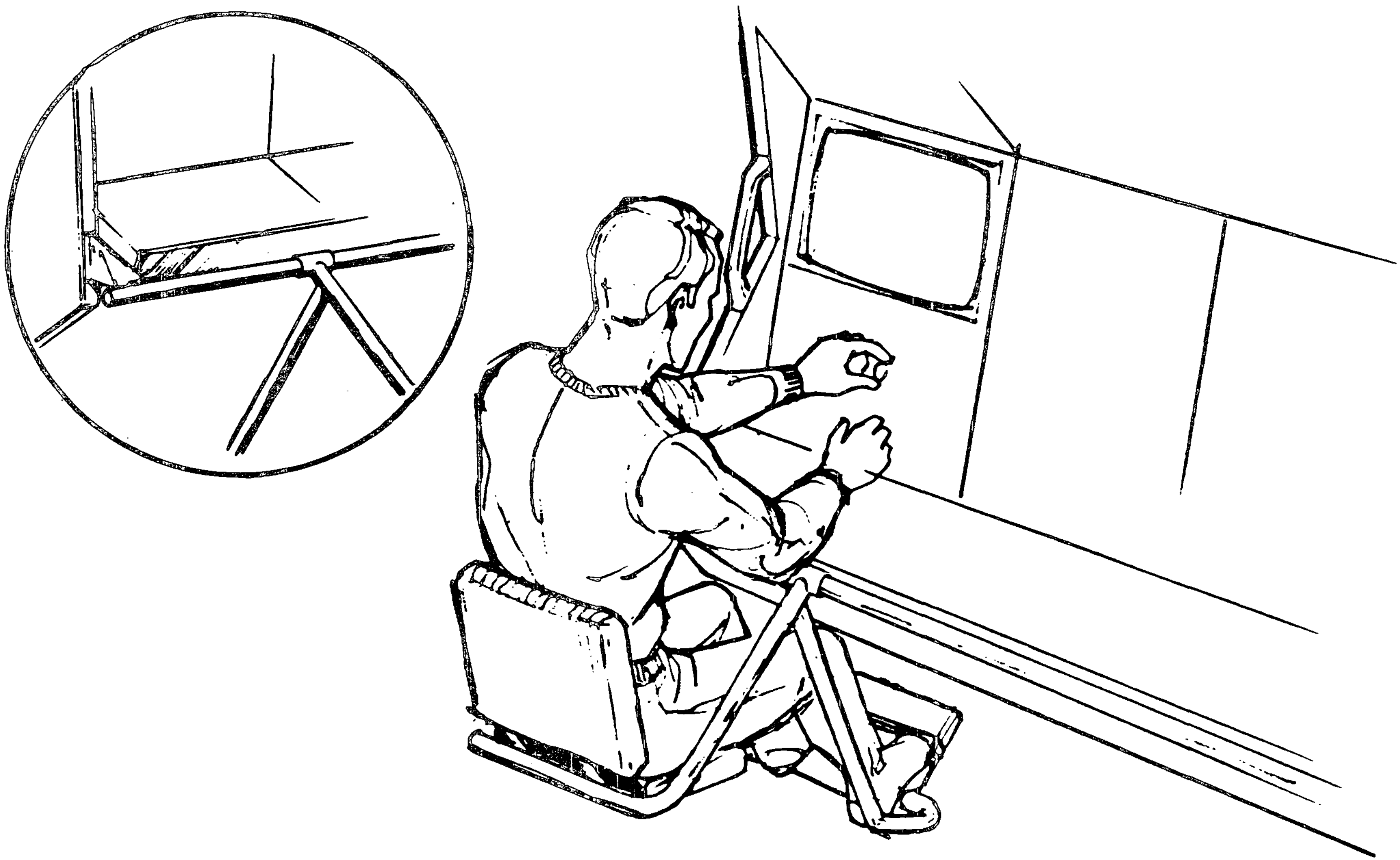


Figure 4.3-32. Crew Restraint

The onboard medical support assembly provides first aid, resuscitation, and supportive measures for Earth-return of crewmen in the event of illness or injury. The medical support assembly includes equipment for diagnosis, therapeutics, urinalysis, hematology and microbiology. The equipment is designed for operation by a specially trained astronaut and does not require a physician.

The equipment is designed for stowage in standard modules for ease of installation and inflight use. Medical kits shall be designed to house related supplies and instruments. As a minimum, four standard lockers are provided for stowage; (1) drugs, (2) in-use drugs, (3) laboratory equipment, and (4) kit stowage. Additional containers are provided for stowing perishables and for returning samples to the ground. Diagnostic equipment is provided for the routine evaluation of crew health status and in the event of illness or injury. Diagnostic equipment includes the following items: thermometer, stethoscope, ophthalmoscope/otoscope set, aneroid sphygmomanometer, light source (head mounted), nasal speculum, binocular magnifying glasses, neurological examination kit, tongue depressors (metal), politzer bag and batteries. The above items are available off-the-shelf from vendors. Therapeutic equipment is provided for the treatment of illness or injury. It includes the following items: catherization kit, emergency kit, dental kit, minor surgery kit, bandage set, and drugs. Laboratory equipment is provided for onboard urinalysis, hematology and microbiology. The urinalysis equipment includes a microscope, reagent strips, and a specific gravity meter. The hematology equipment includes a hemocytometer, unipettes, hemoglobinometer, lances, and pipettes. The microbiology equipment includes swabs, needles, and loops; incubator, slide staining kits, plates and tubes of media and antibiotic discs and strips.

Power/Subsystems Module

The equipment located in the Power/Subsystems Module does not require crew involvement during normal operations. However, access to and work space for installation, replacement and emergency maintenance and repair is provided. In addition, during the initial buildup, when the Power/Subsystems Module alone is in orbit, provision for a work station with checkout controls and displays to insure the capability of all equipments in the modules is included. These equipments include data management, communications, onboard checkout, guidance and control, and power. All equipments are located and arranged to meet or exceed the following requirements:

A. 54 ft^3 free volume access to all component (common use of space)

B. 5 ft diameter access to CMG, atmosphere storage

C. 6-in. clearance between CMGs, atmosphere bottles

4.3.3.2 Interfaces

Interfaces between the crew habitability and protection subsystem and other subsystems such as EC/LS, Power and Data Management are discussed under those subsystems. There is, however, one significant interface between modules resulting from the design of crew habitability and Protection Subsystem. This involves the food management systems which presents an interface between the Crew/Operations Modules and the Logistics Modules, and between the Crew/Operations Module and the General Purpose Laboratory. The present operational concept for the station involves a "pantry" concept for use of the Logistic Module. Expendables, including food, are stored in the Logistics Module until required. In the case of the food management systems, the Galley has storage space for a 30-day supply of food. The remaining food (60-day supply initially, excluding the 30-day contingency supply stored in the GPL) is retained in the Logistic Module. When the first Logistics Modules arrive on orbit, a 30-day supply of food is transferred to the Galley of Crew/Operation Modules. Approximately once a week thereafter the food supply used from the galley is replaced from the Logistics Module to maintain that supply near the 30-day limit. This is done to ensure an adequate supply (approximately 30 days) of food in the Crew/Operations Module in case of an emergency requiring the denial of access between the two modules. Any food remaining in the Logistics Module when it is replaced by another module would be transferred to the station or the newly-arrived Logistics Module.

The 30-day contingency supply of food (consisting of freeze-dried food only) is stored in the General Purpose Laboratory. It is stored there to partially satisfy the requirement to make the General Purpose Laboratory the second self-sustaining habitable environment. Two different emergency conditions could engender the need to use this food. First, a logistics resupply mission could be delayed. In this case all or a part of that food, depending upon the nature of the delay and its anticipated duration, would be transferred to the galley of the Crew Operations Module and used in the normal manner.

In the second case, an emergency could occur which would make the Crew/Operations Module and the Logistics Module uninhabitable or deny crew access thereto. In this case the GPL would become the living quarters as well as the work area for the Station, and food would be consumed as required in that facility. The GPL contains a water dispenser, preparations and eating utensils, and cleansing facilities that are required for this purpose.

4.3.3.3 Operations

Due to the unique nature and content of the crew habitability and protection subsystem, it was deemed most appropriate and more understandable to describe its operation along with its design. Hence, all pertinent aspects of its operation was discussed as an integral part of Section 4.3.3.1. Additional details are presented in a separate document MP-02, Crew Operations.

4.3.3.4 Growth Space Station (GSS) Considerations

For GSS the crew habitability and protection subsystem provided for ISS are duplicated in additional modules.

4.3.4 Design Analyses and Trade Studies

As noted in Section 4.3.1 the significant crew habitability trade studies conducted during the Modular Space Station Study all involved interior configuration and arrangement. The techniques used for conducting these trade studies involved the construction and evaluation of 3-dimensional, 1/20th-scale models and full-scale soft mockup. These trade studies are described in the following paragraphs.

laboratory/facility has been sized to allow up to three crewmen to work at one time. Also, there is sufficient free volume associated with each laboratory to permit up to three crewmen to confer, study, relax or socialize, thereby eliminating the need to always return to the wardroom or private quarters for such activities. Aisles and laboratories were also sized and/or arranged to allow crewmen to pass other crewmen at work without causing any interruption or interference with their activities. Equipment in the GPL has been located and arranged to eliminate any requirements for routine "foot to head" operations (i.e., one crewman working directly above another).

Figure 4.3-17 shows the arrangement of equipment in the GPL. There are six support facilities or laboratories, an isolation chamber and the Experiment/Secondary Control Center. The facilities and laboratories provide for Hand Data Processing, Electrical/Electronic, Mechanical, Bioscience/Biomedical, Optical, Test and Isolation and Data Evaluation. Figures 4.3-18 through 4.3-31 shows the location in the module and the essential characteristics of each of these facilities. Each of these facilities is described in detail in Section 4.4. The Experiment/Secondary Control Center is also described in Section 4.10. Therefore except for the Bioscience/Biomedical Laboratory which does double duty as dispensary during ISS, only some general features of these facilities will be described here. Equipment requiring frequent access for servicing and maintenance have been located in the center consoles. Other equipments located around the periphery of the Station are hinged so they can be swung out for maintenance or access to the module walls. Hand holds and foot restraints are strategically located throughout the GPL. In addition a movable, adjustable pelvic/foot restraint, shown in Figure 4.3-32 is provided for operation/maintenance of upper-level equipment. Two handrails, one on either side of the module, extends the length of the modules in front of the upper consoles. Several pelvic/foot restraints are attached to these handrails. They can be moved to any position along the rail and locked in place and at any angle desired, including the relative angle between foot and pelvic restraint.

As noted above, the Bioscience/Biomedical Laboratory serves also as a dispensary. The following medical support capability is included in that laboratory.

4.3.4.1 Longitudinal vs Radial Orientation (Crew/Operations Module)
The purpose of this trade study was to determine the optimum orientation for the Crew/Operations Module, that would operate entirely in a zero-g environment, but require checkout and evaluation on the ground.

Figure 4.3-33 and 4.3-34 show one, among many versions, studied, of 1/20th-scale models of longitudinally and radially oriented crew modules used for the trade study. These models represent three-man versions of the Space Station, which was the baseline concept at the time that this trade study was conducted. In the case of this study the advantage of the longitudinal orientation was so apparent from evaluation of the 1/20th-scale models alone that the development of full-scale mock-up of both concepts was not deemed to be warranted. Hence, a full-scale mock-up of the longitudinal version only was constructed for verification of the results of the evaluation of the models. This is shown in Figure 4.3-35. The major and deciding advantage of the longitudinal arrangement was its more efficient utilization of space. This results from the fact that in such a configuration the same free volume can be shared without interference, by a number of different activities and functions. The same degree of sharing is not possible with a radial configuration, especially if it is separated by floors. A second significant advantage of the selected configuration was the enhanced appearance of spaciousness. This is considered of major importance for the maintenance of crew motivation and morale in extended duration missions. Moreover, it was found that with adequate attention to the location and arrangement of equipment such a configuration could be optimized for zero-g operations and at the same time be amenable to ground installation, checkout, and evaluation with a minimum of specialized ground-support equipment.

4.3.4.2 Longitudinal Versus Radial Orientation (General Purpose Laboratory)
The purpose of this trade study was identical to the previous one except that it involved the General Purpose Laboratory—the determination of the optimum orientation for all "zero-g" operations, with due consideration for ground checkout and evaluation.

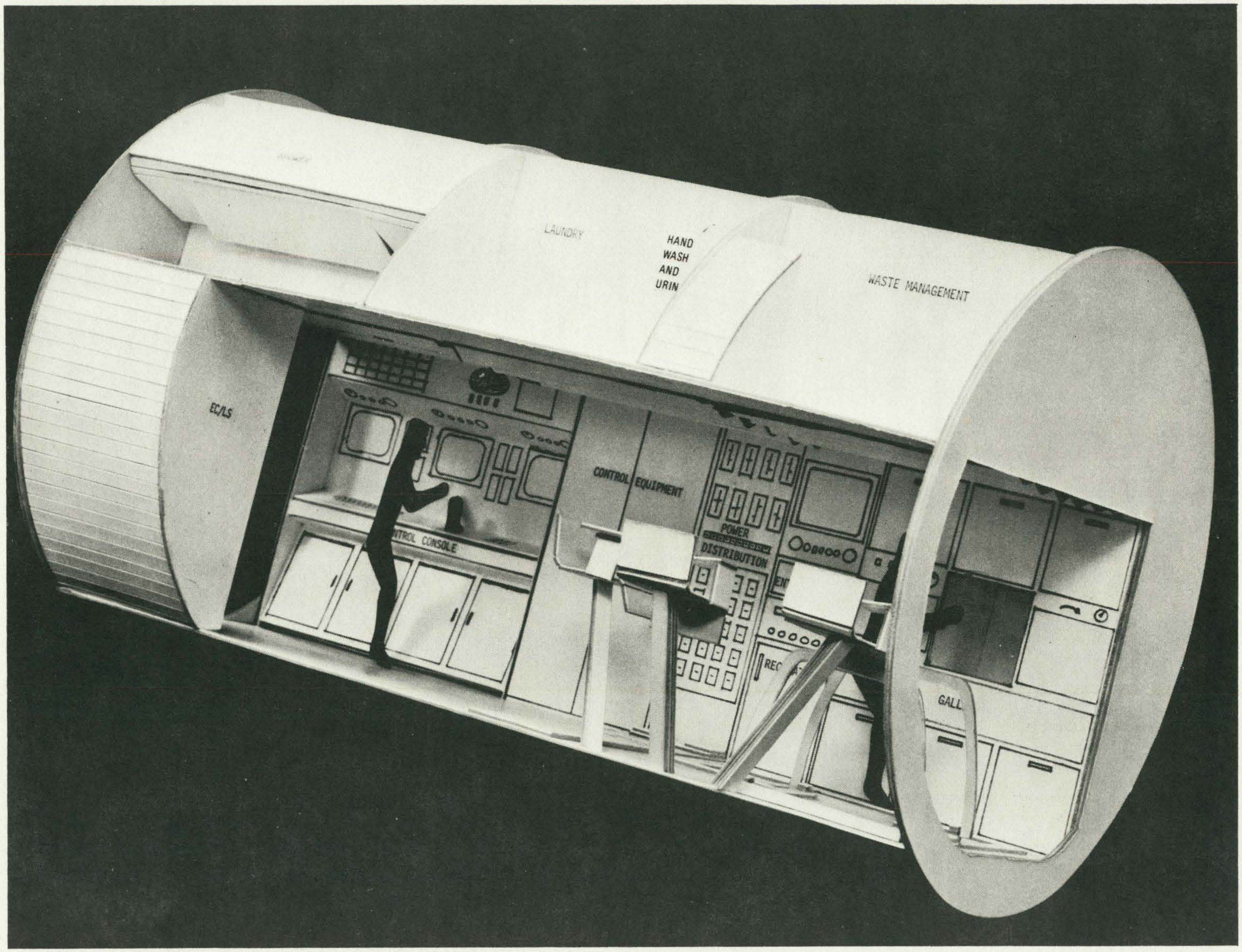


Figure 4.3-33. Crew - Longitudinal Orientation - 1/20 Scale Model

R260

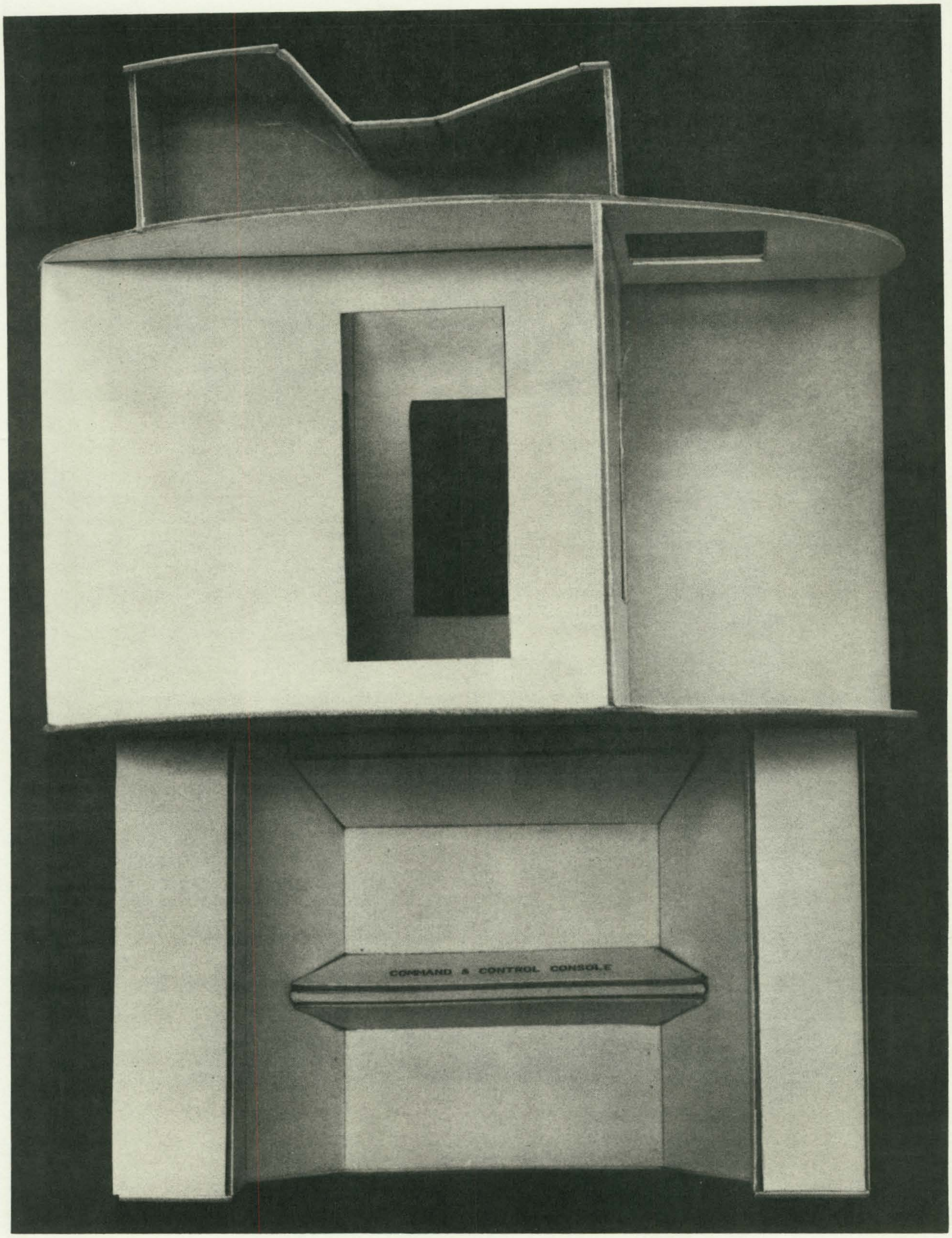


Figure 4.3-34. Crew/Operations Module - Radial Orientation - 1/20 Scale Model

Figure 4.3-35. Crew/Operations Module - Full Scale Mockup

Figures 4. 3-36 and 4. 3-37 show 1/20th-scale models of one version among many studied, of each concept. These models also represent three-man versions of the Space Station, since this was the baseline concept at that time.

Figure 4. 3-38 shows the various "Volumetric Packaging" concepts that were analyzed and modeled for this trade study. The primary aim here was to maximize the amount of usable full volume available for crew activities while accommodating all of the designated GPL equipments so they could be operated and/or maintained efficiently. Concepts B and F, represented by the models shown in Figures 4. 3-36 and 4. 3-37, were selected as providing the most effective volume utilization for the radial and longitudinal configurations, respectively. Concept A was equivalent to Concept F in volume utilization, but was discarded in favor of Concept F because of the latter's much greater amenability to ground installation, checkout, and evaluation.

As in the case of the previous trade study involving the Crew/Operations Modules, it was possible to establish the superiority of the longitudinal configuration over the radial configuration through quantitative analysis and evaluation of the 1/20th-scale models. Hence only that configuration was mocked up in full scale for verification. This is shown in Figure 4. 3-39. The major advantages of the selected configuration were:

A. More effective volume utilization.
B. Enhanced appearance of spaciousness essential to crew morale.
C. Amenability to ground checkout and evaluation.

4. 3. 4. 3 Crew Quarters Orientation - One "G" vs Zero-"G"

The purpose of this trade study was to determine the optimum orientation of crew quarters for all zero-g operations without unduly compromsing ground checkout and evaluation. This trade study was also conducted for the three-man version of the Station as baseline.

Figures 4. 3-40 and 4. 3-41 show the 1/20th-scale models of the one-g and zero-g configurations respectively used for this study. Full scale mock-ups

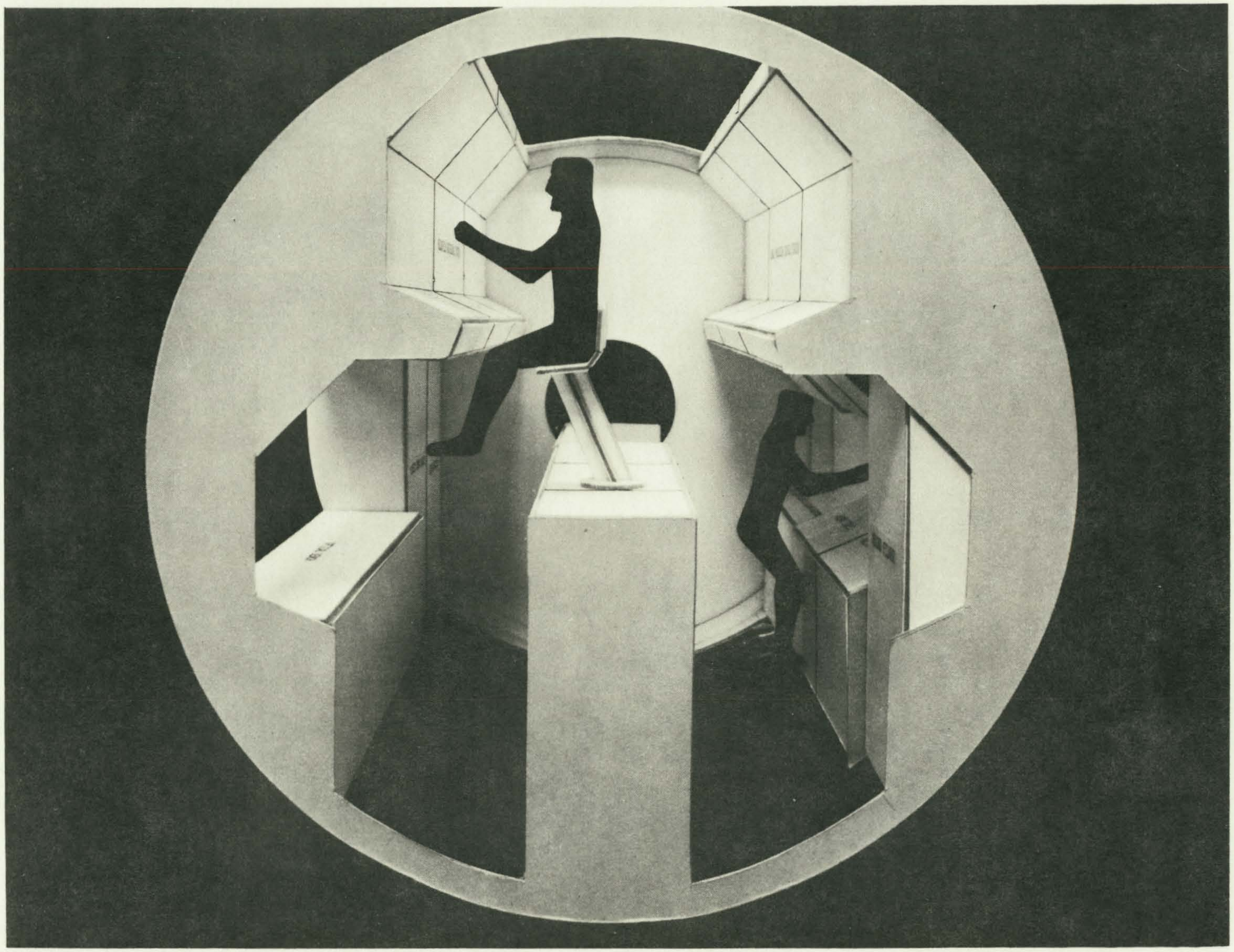


Figure 4.3-36. General Purpose Laboratory - 1/20 Scale Model

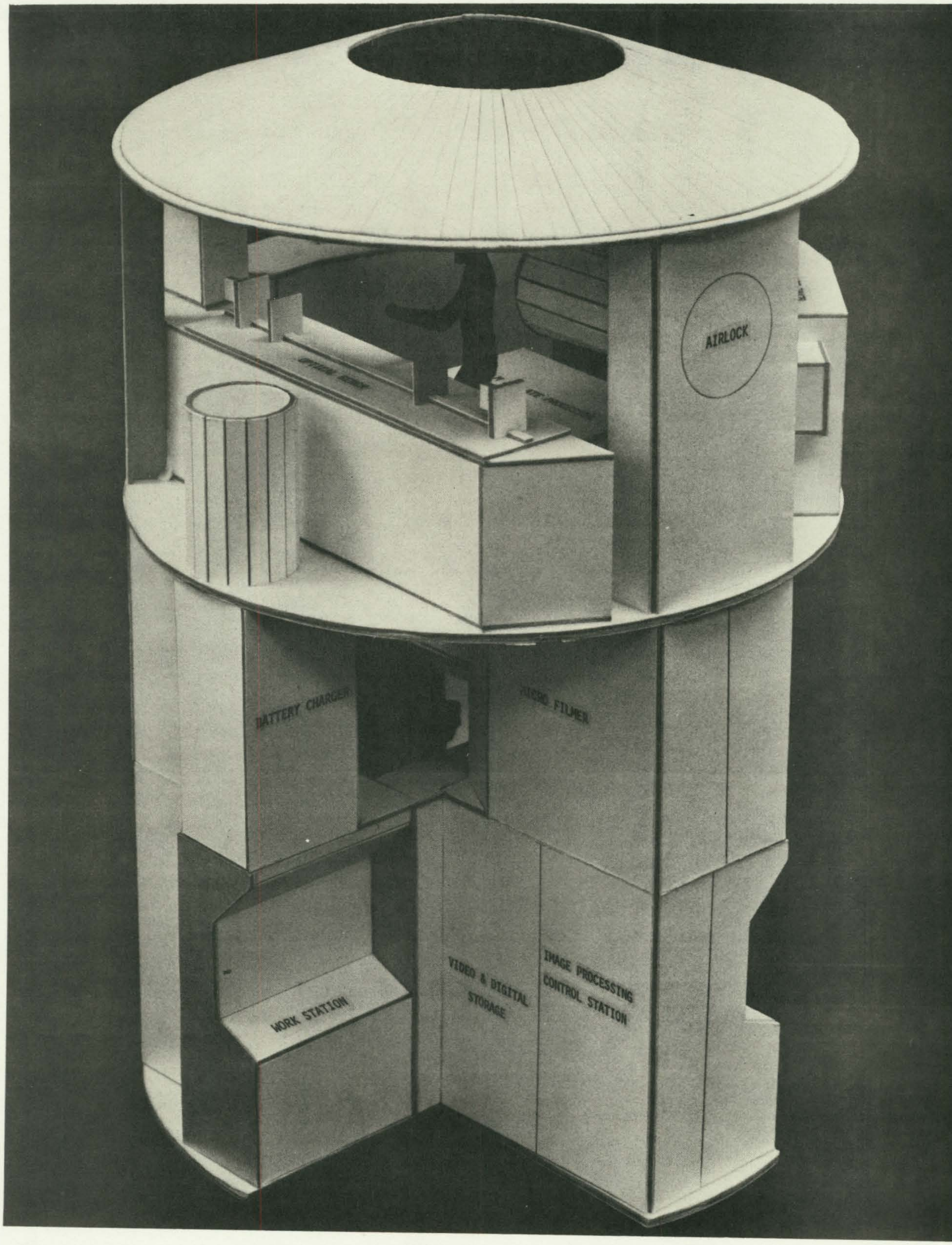


Figure 4.3-37. General Purpose Laboratory - 1/20 Scale Model

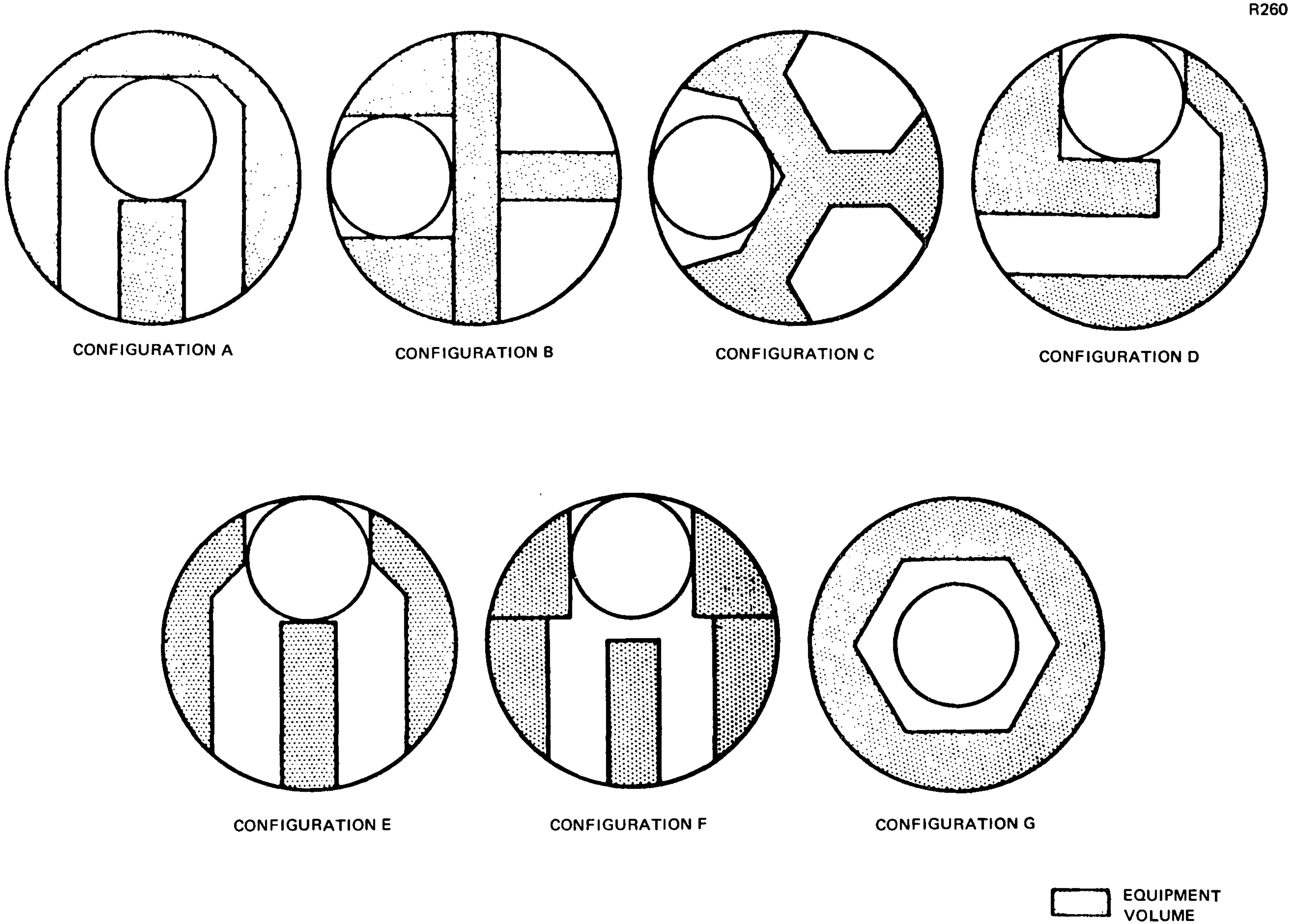


Figure 4.3-38. Volumetric Packaging Concepts

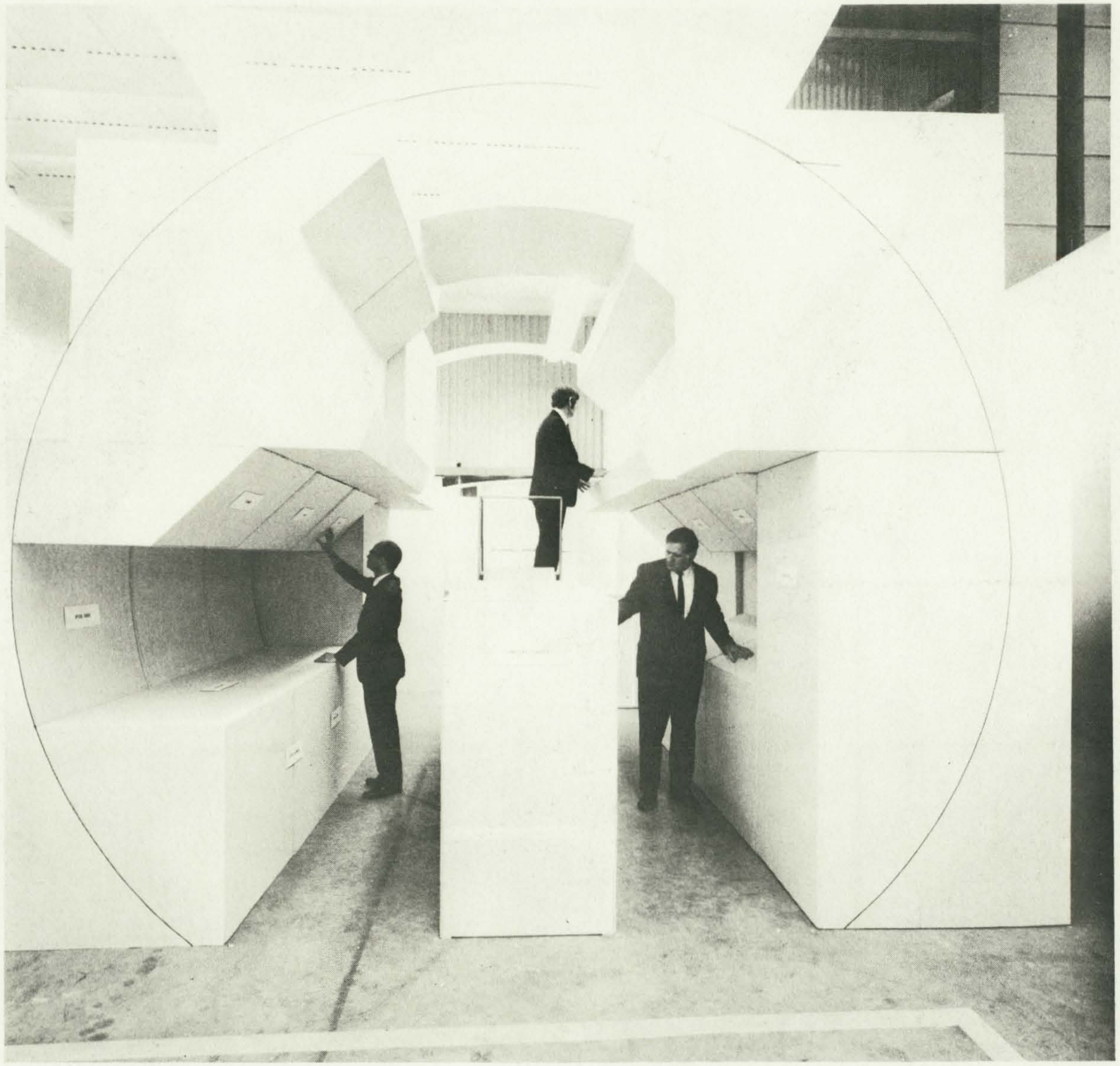


Figure 4.3-39. General Purpose Laboratory - Full-Scale Mockup

Figure 4.3-40. One-g Configuration - 1/20 Scale Model

R260

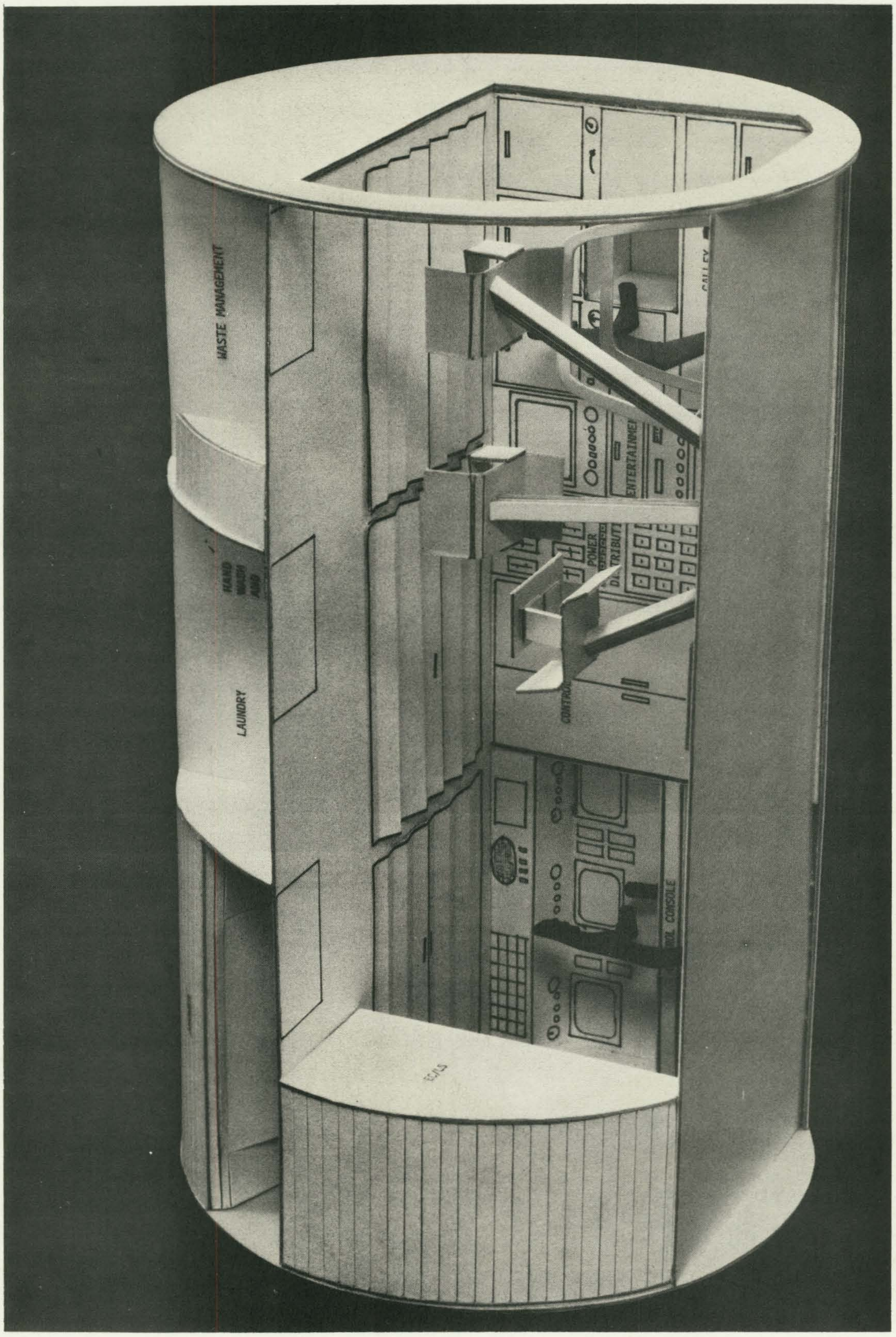


Figure 4.3-41. Zero-g Configuration - 1/20 Scale Model

of both of these configurations shown in Figures 4. 3-42 and 4. 3-43 were constructed to complete this evaluation since the results of the evaluation using 1/20th-scale models alone were not conclusive. This evaluation resulted in the selection of the zero-g configuration (Figure 4. 3-43) for the following reasons:

A. More effective utilization of volume.
B. Amenability to sharing specific volumes for different activities.
C. Enhanced spaciousness.
D. Compromise to ground checkout and evaluation, while greater than the one-g orientation, was not deemed significant, due to the nature of the equipment involved.

Interior Arrangements for Single vs Dual Docking Port Locations

The purpose of this trade study was to assess the advantages and disadvantages, from a crew habitability standpoint, of a single docking port area accommodating three docking ports 120 degrees apart vs two separated areas each accommodating two docking ports at 180 degrees. This study was accomplished to provide data for use along with other subsystems data relative to the same problem in the final decision on docking port locations.

Figures 4. 3-44 and 4. 3-45 show models of the configurations used for this study. The results of the evaluation of these concepts indicated that the single docking port area concept provided significant advantages. These were:

A. More efficient utilization of volume
B. Capability to share available volume for different activities (Dual docking area concept required greater spatial separation of facilities.)
C. Greatly enhanced appearance of spaciousness.

Crew Quarters Location - Single vs Dual Location

The purpose of this trade study was to assess the advantages and disadvantages of locating the six crew quarters in a single location as opposed to locating three each at either end of the crew module.

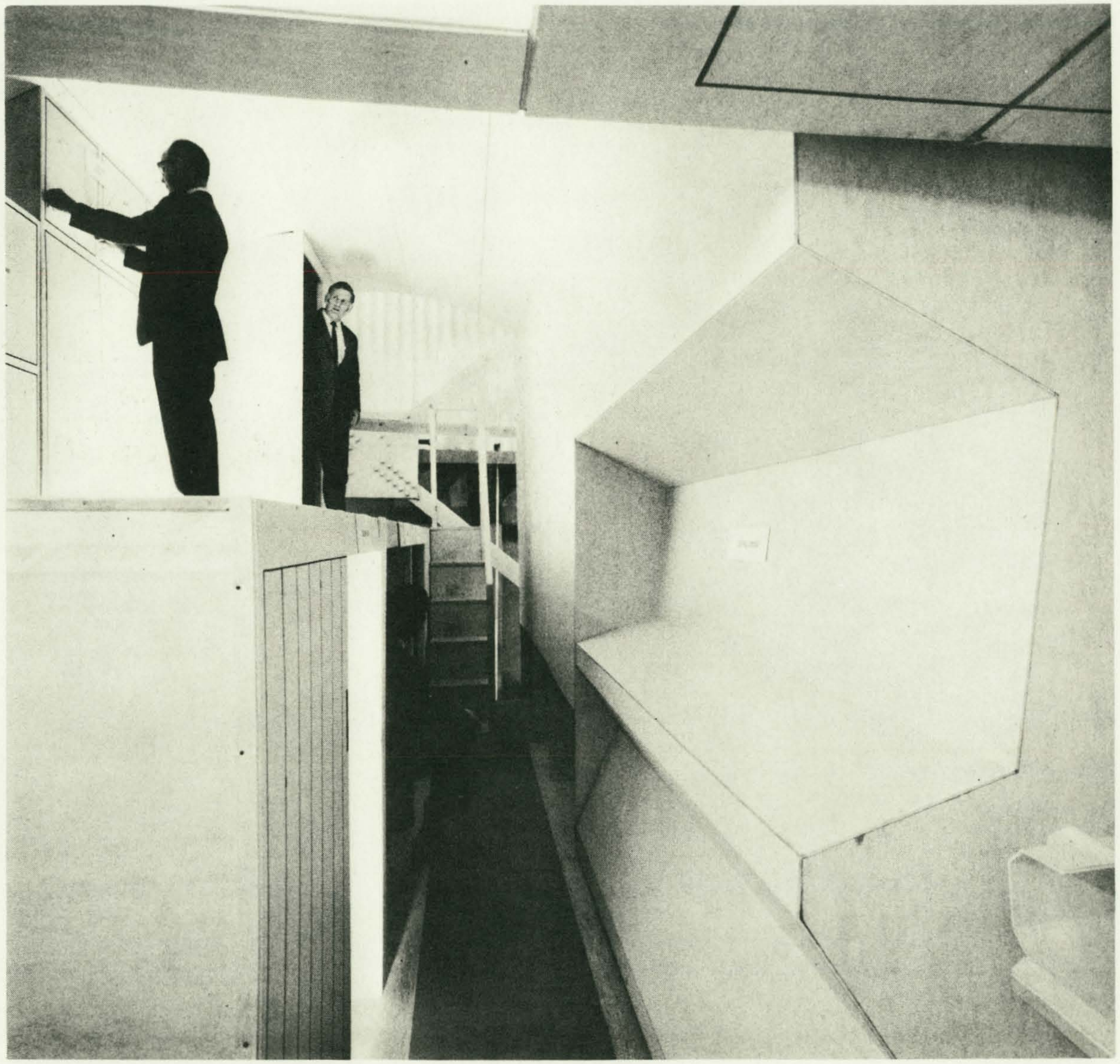


Figure 4.3-42. One-g Configuration - Full-Scale Mockup

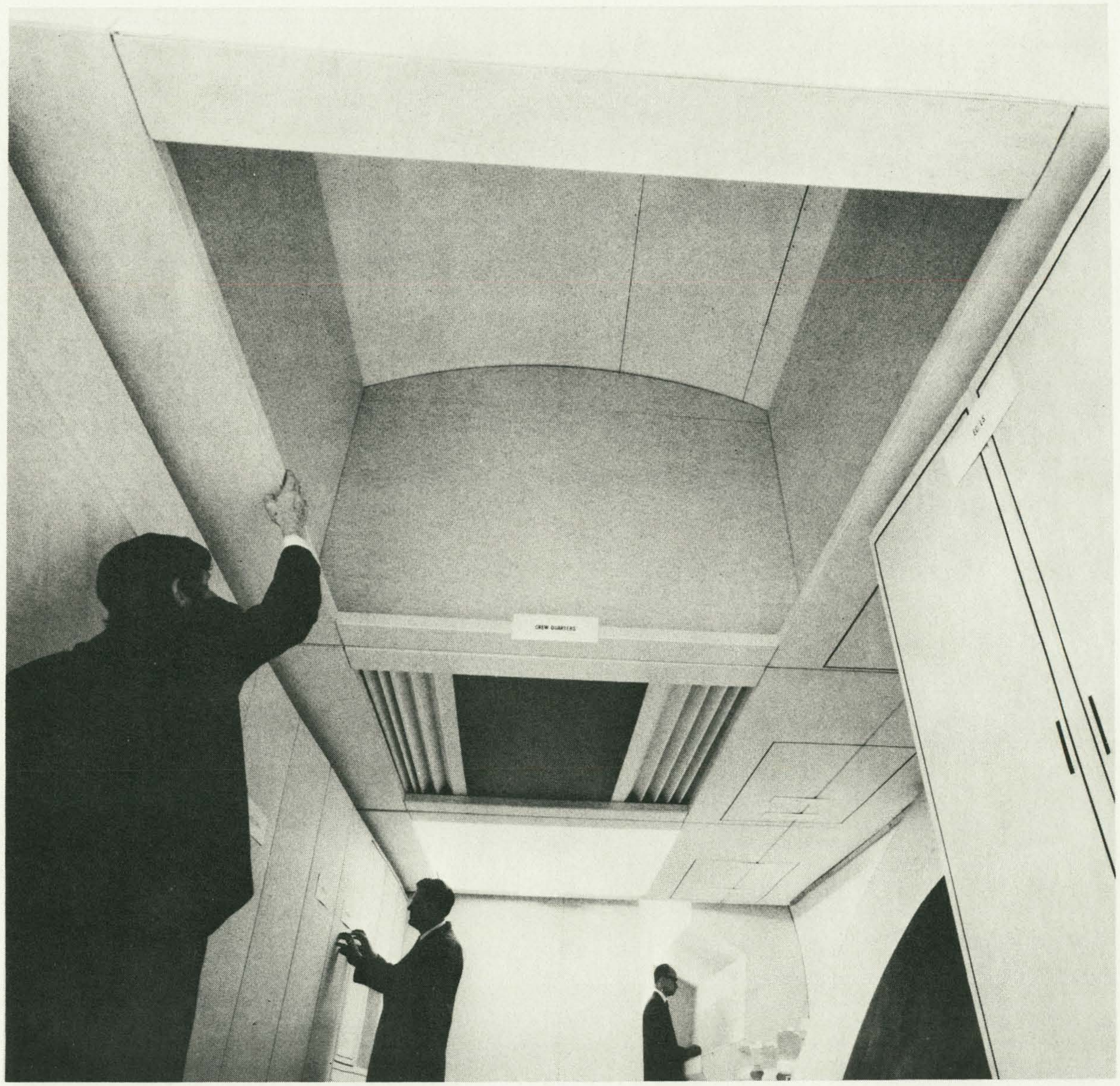


Figure 4.3-43. Zero-g Configuration - Full-Scale Mockup

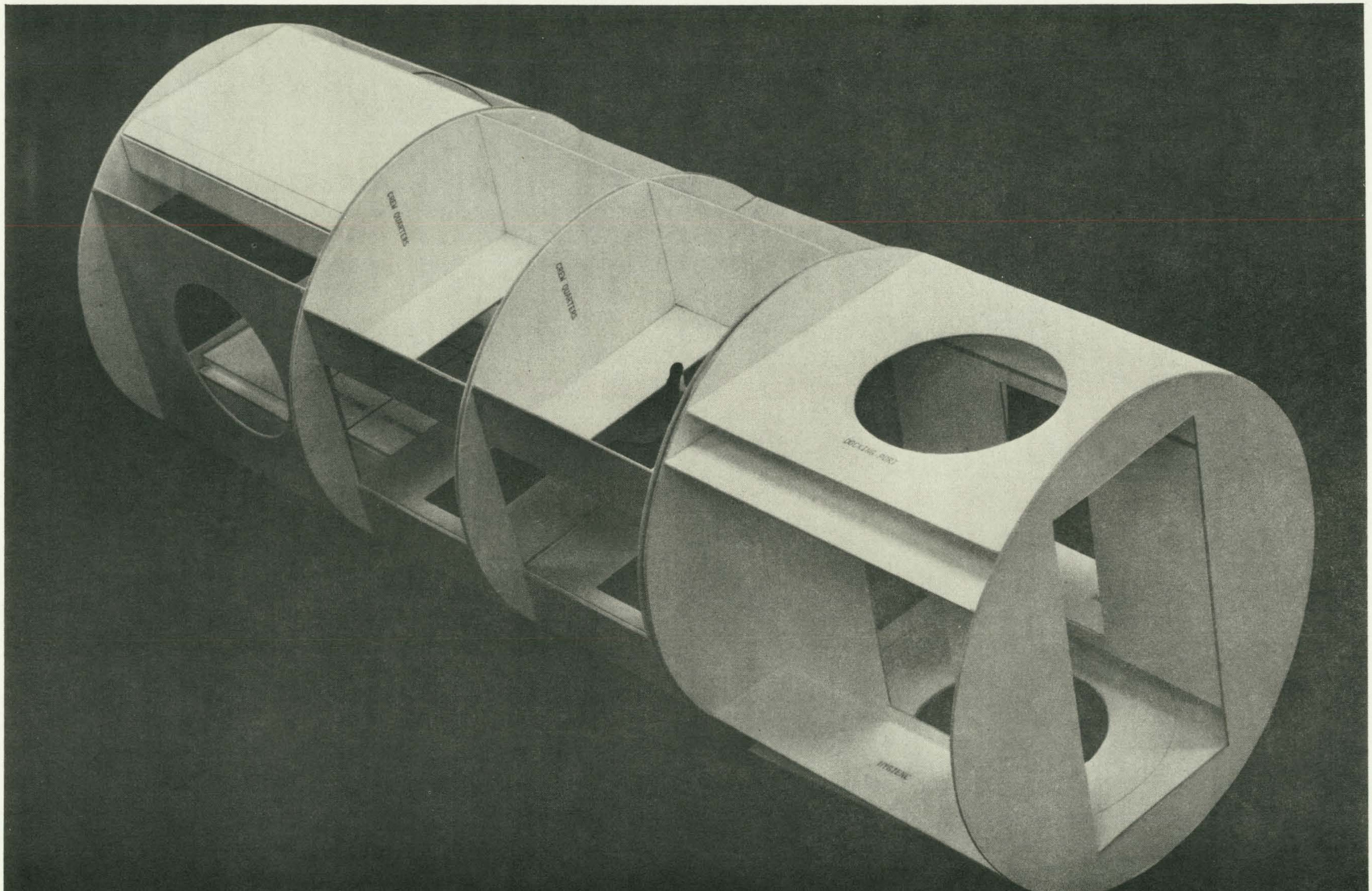


Figure 4.3-44. Crew/Operation Module - Dual 180 Degree Docking Ports - 1/20 Scale Model

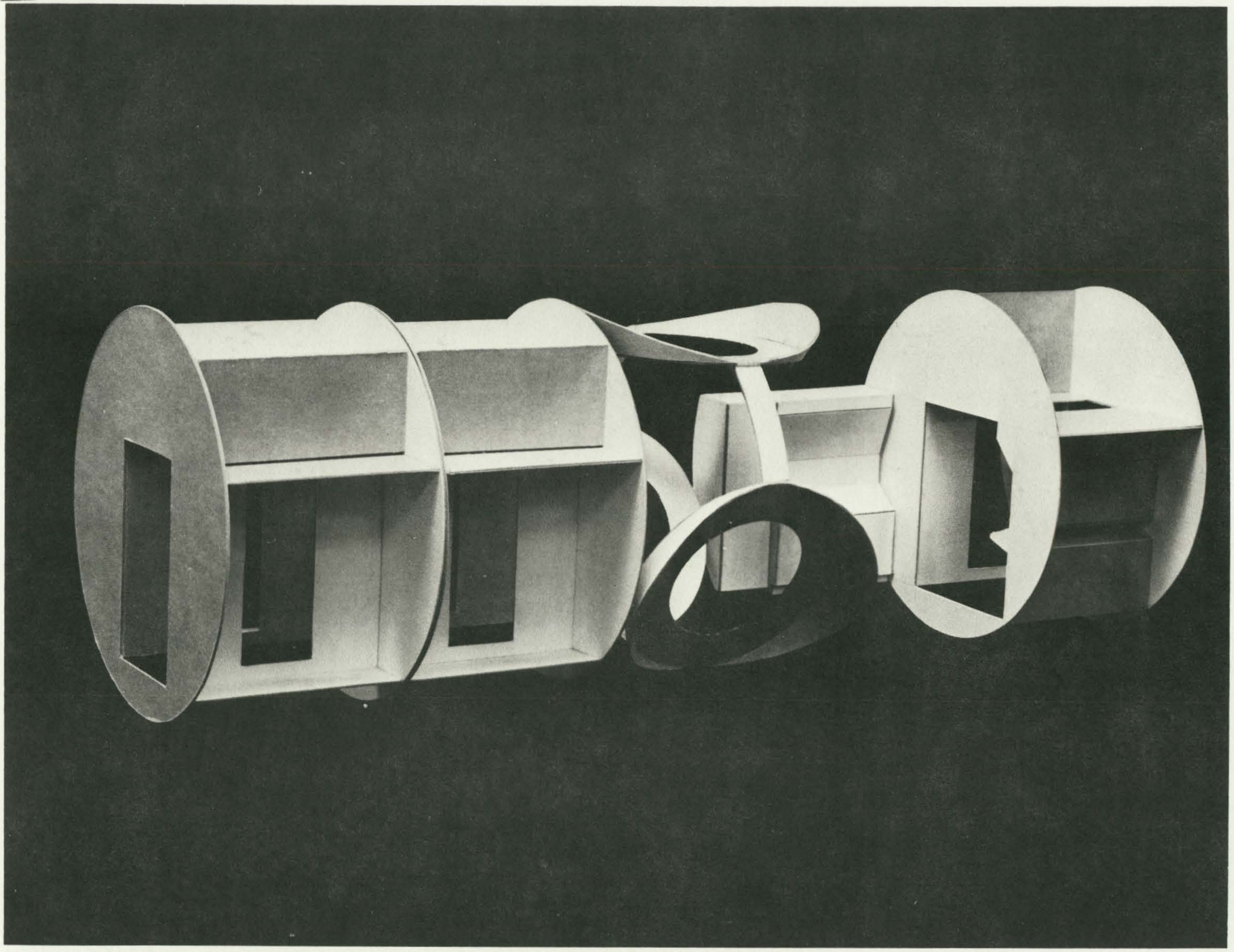


Figure 4.3-45. Radial Docking Ports at 120 Degrees - 1/20 Scale Model

Figures 4.3-46 and 4.3-47 show 1/20th-scale models of the two configurations used in this study. The results of this evaluation using the models alone were sufficiently conclusive in favor of the dual location concept that only a full-scale mockup of that concept was developed. It is shown in Figure 4.3-48. The major advantages of the dual concept are:

A. More effective utilization of volume.

B. More free volume available as a unit for recreation, exercise, and group sports.

C. Enhanced spaciousness.

D. Better accommodation for mixed crews.

E. Better accommodation for dual shift operations.

4.3.4.4 Hygiene Facility Access - Docking Port Area Versus Crew Quarters

The purpose of this trade study was to determine the optimum location for primary access to the hygiene facility.

Figure 4.3-49 shows the location of one of the two hygiene facilities in the final baseline configuration. The second hygiene facility occupies a similar location at the opposite end of the module. Primary access to both facilities is from the docking port area. Secondary access is provided through one of the crew quarters. There is a requirement for ease of access to the hygiene from other modules, but it would also be desirable from a "privacy" standpoint to have access from the crew quarters area, but without the need to pass through a single crewman's quarter. With the present internal configuration and location of the hygiene facilities, the two requirements are incompatible. Hence, two possibilities for relocating these facilities were assessed. These along with their associated advantages and disadvantages were:

First: Exchange the location of the hygiene facilities with one of the crew quarters.

This possibility does have the advantage of providing the desired access from the crew quarters area. However, it results in degraded access from other modules, where the greater access requirements exist. In addition it

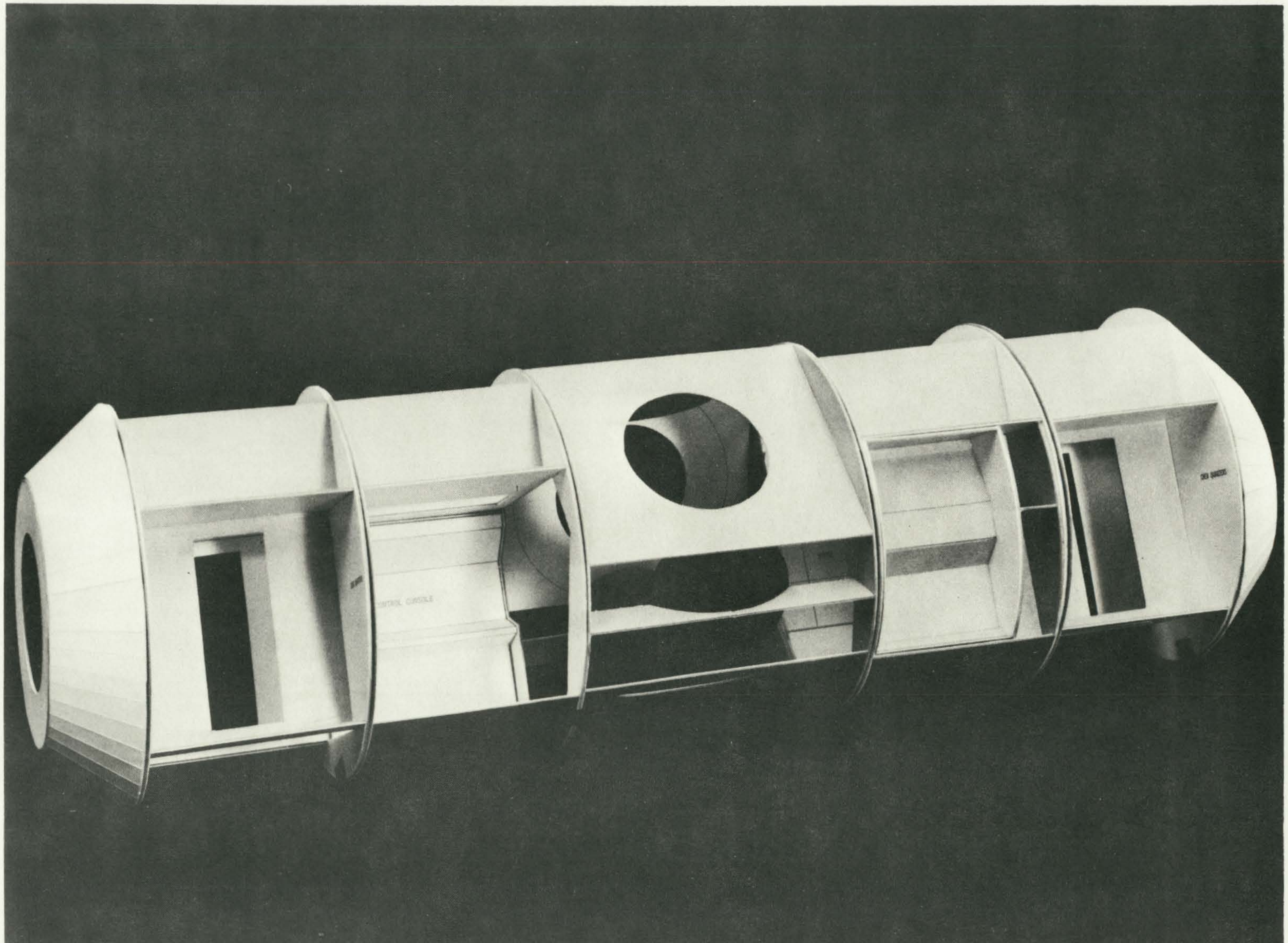


Figure 4.3-46. Crew/Operations Module - Baseline Model

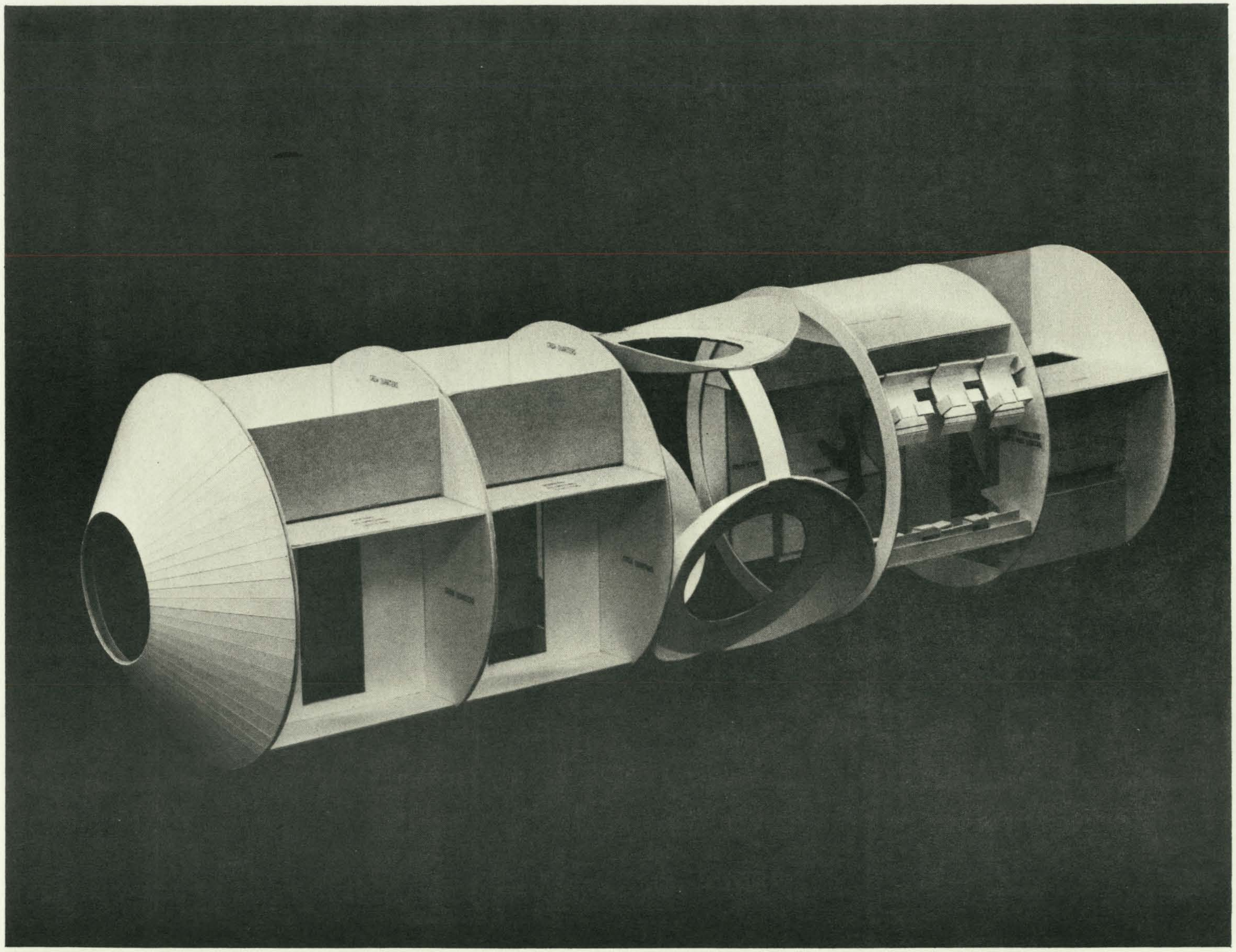


Figure 4.3-47. Baseline Crew/Operations Module - 1/20 Scale Model

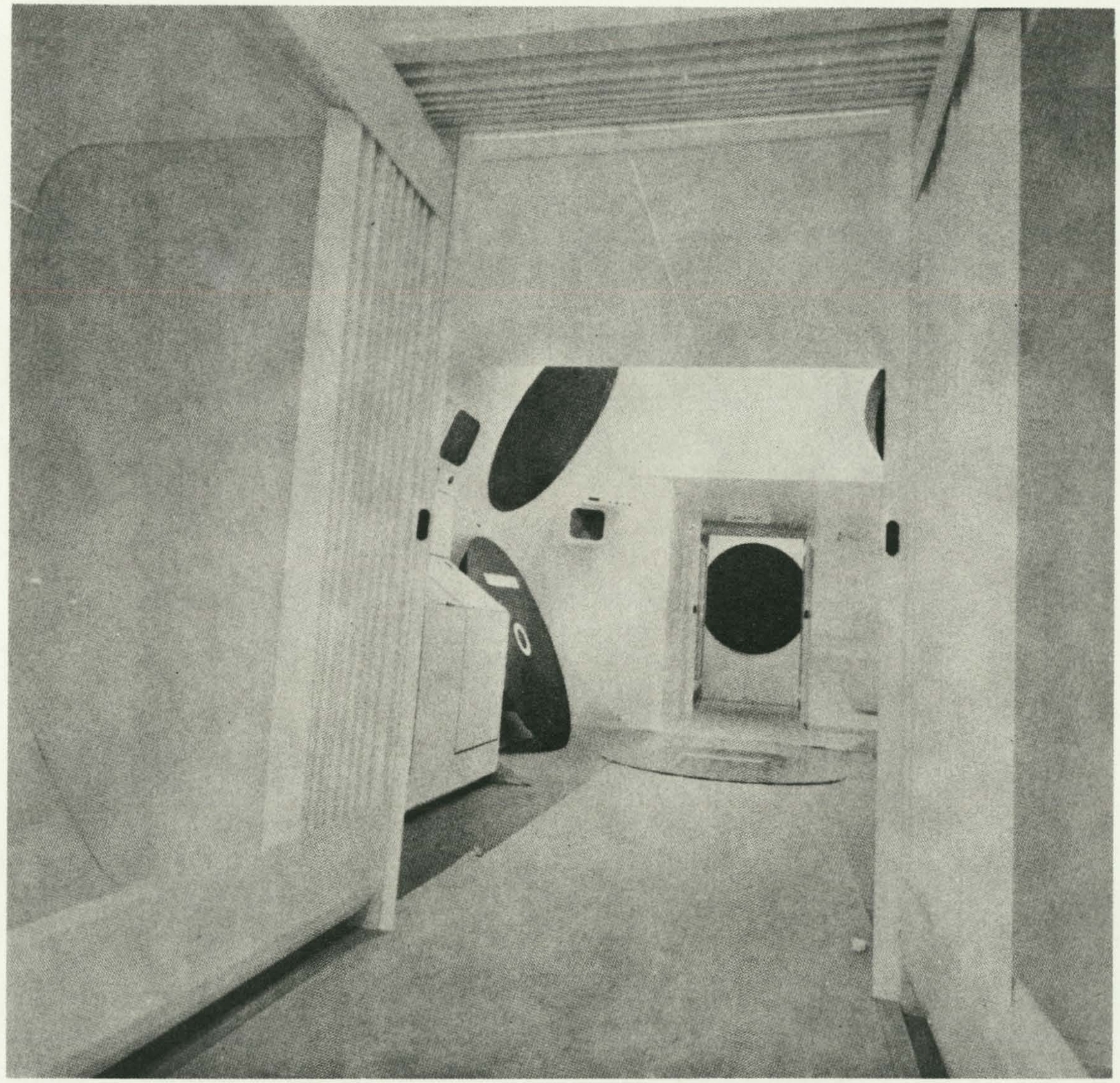


Figure 4.3-48. Crew Quarter Location

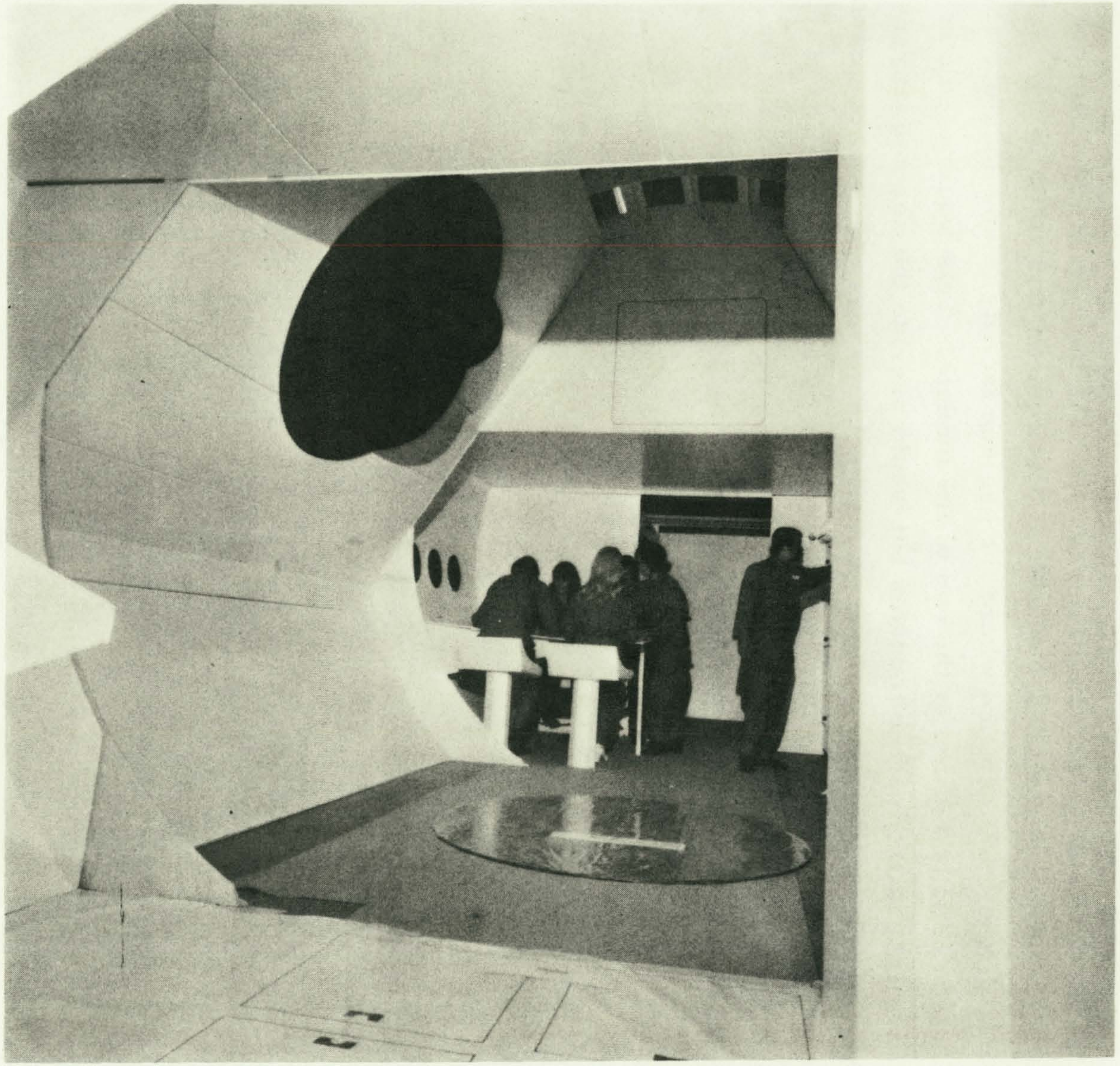


Figure 4.3-49. Hygiene Facility Location

results in the loss of the capability to convert the three individual quarters and adjoining aisle into a large (800 ft^3) stateroom.

Second: Exchange the location of each facility with some subsystem or equipment.

This possible exchange could be accomplished for the hygiene facility located above the control center area. The EC/LS equipment and some of the support electronics could be installed where the hygiene facility is now located, and the hygiene facility located at the end of the module. This would result in degraded access from other modules but would provide the desired privacy. For the other hygiene facility however, no exchange was deemed acceptable. Hence, this trade study resulted in the decision to retain the location of the hygiene facilities as shown in Figure 4.3-49, above the wardroom and the control center with primary access from the docking port area.

4.4 EXPERIMENT SUPPORT SUBSYSTEM

4.4.1 Summary

The Space Station Experiment Support Subsystem consists primarily of the General-Purpose Laboratory (GPL). The General Purpose Laboratory, as defined from the experiment program requirements and Space Station support requirements, provides the capability to perform and support experiments as well as support operation and maintenance of Space Station subsystems. It also contains equipment and facilities required to support, service, and maintain RAMs and experiments in the RAMs. The General-Purpose Laboratory concept is derived from the work statement requirements that the modular Space Station have the capability to support and conduct a broad range of experimentation and operational functions that to date, are undefined in detail. An analogy of the General Purpose Laboratory in the Space Station are the shops and laboratories of the oceanographic research vessel. Individual laboratories support scientific research and applications and and other shops and laboratories support the operational seaworthiness and mission of the vessel. The Space Station facilities are arranged in much the same manner. The General Purpose Laboratory is intended to be a dynamic entity which embodies the concept allowing full support of a wide range of experimentation and operations without limiting the type or breadth of the program. The General Purpose Laboratory, as its name implies, is flexible and can be responsive to program changes on the ground, in the fabrication phase, or while operating in orbit. Primary functions of the GPL have been specified as functional laboratories and facilities based on the requirements of technological disciplines and Space Station operations. These disciplines and operations encompass the wide range of experimentation and operations which are candidates for space flight throughout the research and applications community and space operational organizations.

The experiment program which was used as a prototype for the design of the GPL was derived from the NASA experiment "Blue Book" (officially entitled "Reference Earth Orbital Research and Applications Investigation," Document Number NHB7150.1, dated January 15, 1971). In addition to the typical experiment program used to determine Space Station capability, a responsiveness analysis has been performed to determine whether the Space Station, as designed, can support the total Blue Book requirements. From this analysis, it has been determined that the Space Station design including the GPL can support any experiment in the Blue Book, although not all at the same time. The approach and conclusions of the responsiveness analysis above noted is documented in MP-01, "Experiment Support Requirements". The selected Space Station subsystems, as defined in other sections of this report, have been analysed to determine the amount of maintenance and repair support required from the GPL; all of these facilities, equipment, tools, maintenance, and repair items are encompassed in the GPL. Detailed documentation of these requirements and the facilities needed to meet them are covered in subsequent sections of this report.

The nature of the support for experiments and subsystems provided by the GPL includes: 1) analytical and tests, 2) disassembly – assembly, and repair, 3) storage of parts (in-flight spares, operational equipment, etc.), 4) capability for replacement of parts from onboard spares, 5) calibration of experiments and operational equipment, 6) facilities to contain all of the above equipment and to perform the above functions, 7) physical accommodation for the performance of experiments, 8) equipment for the performance of experiments.

A summary of the major functions performed by the GPL are shown in Table 4.4-1. As the table indicates, the GPL is divided functionally and physically into laboratories and facilities combining related activities. Facilities are permanent throughout the operational mission life but the test calibration alignment, etc. equipment contained can be reconfigured as required when the experiment program evolves and changes. The basic equipment provided in the facilities and laboratories (such as microfilm system, workbenches, storage facilities, operational control consoles) are expected to remain throughout the whole mission. Replacement parts and components and consumables are stored on board the Space Station and the logistics Cargo Module and are resupplied by logistic delivery. Figure 4.4-1 is a view of the GPL module; the facilities and laboratories are indicated and show the relative placement of each. Laboratories and facilities in the GPL

Table 4.4-1

GENERAL PURPOSE LABORATORY

Area	Function
Hard Data Process Facility	• Process and calibrate film to support experiments and operations
Data Evaluation Facility	• Evaluate, prepare, and condition experiment data
Optical Sciences Laboratory	• Calibrate, set up, and perform experiments and operations requiring optical facility • Scientific airlock chamber and viewport with optical support
Electronics/Electrical Laboratory	• Perform bench calibration and repair of electronics and electrical equipment • Support and performance of experiments
Mechanical Sciences Laboratory	• Perform mechanical assembly and disassembly • Perform mechanical tests and experiments • Perform physical metallurgical testing, set up experiments requiring mechanical support • Provide laminar flow glove boxes in central location for maintenance and experiment performance support
Experiment and Test Isolation Laboratory	• Support experiment and operations requiring isolation • Isolate toxic liquids, gases, molten metals, and high pressures • Scientific airlock, environmental chamber, and heat exchanger for high-temperature chamber experiments • Remote operation of experiments • Perform and support chemistry and physics
Biomedical and Bioscience Laboratory	• Perform and analyze astronaut well being experiments • Perform and analyze bioscience experiments

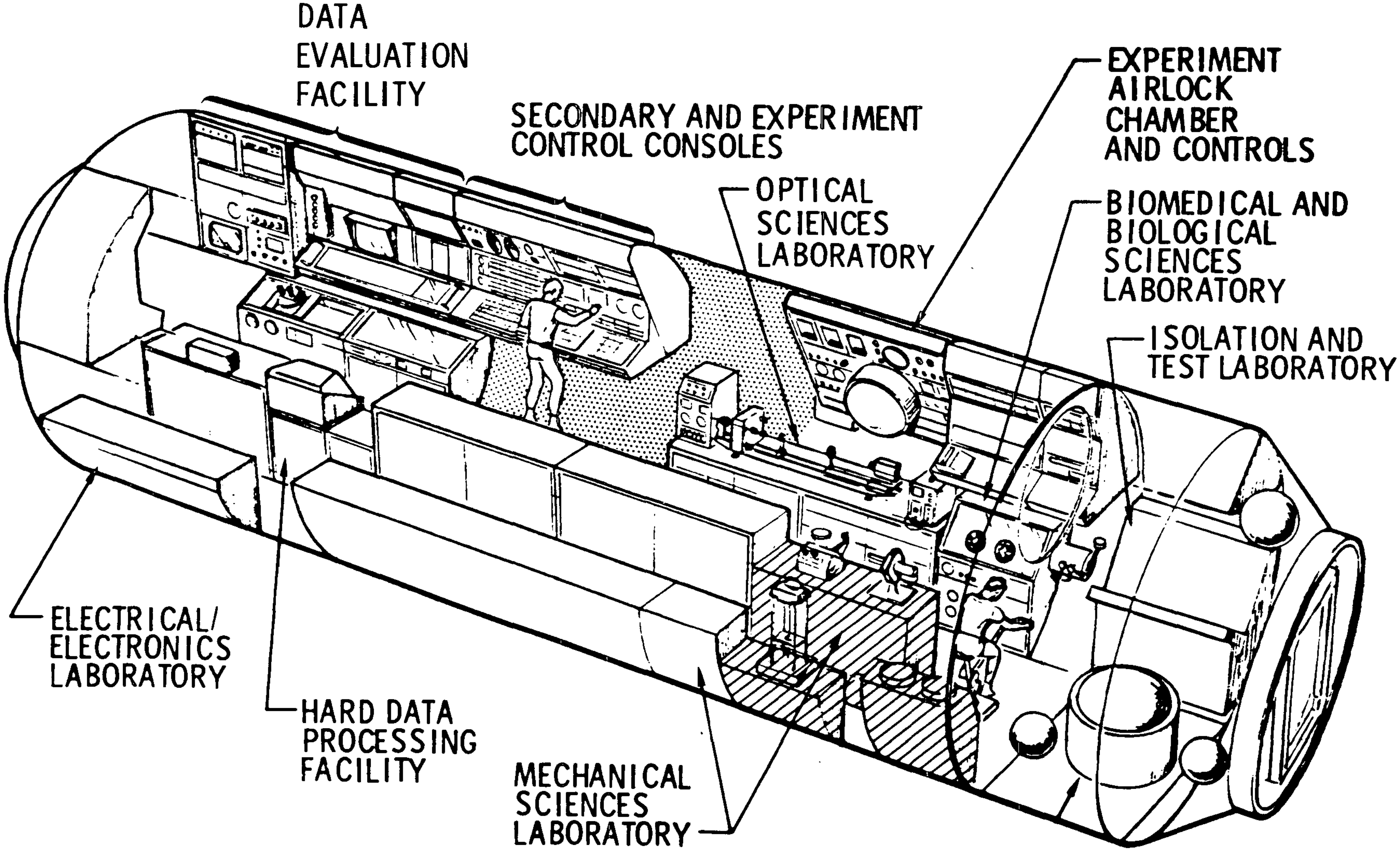


Figure 4.4-1. General Purpose Laboratory

are as shown in the perspectives are 1) ElectricalElectronic Laboratory 2) Mechanical-Sciences Laboratory, 3) Experiment and Test Isolation Laboratory, 4) Hard-Data Processing Laboratory, 5) Data-Evaluation Facility, 6) Optical-Sciences Laboratory, 7) Biomedical and Bioscience Laboratory.

4.4.1.1 General-Purpose Laboratory and Facility Functional Summary Descriptions Data-Evaluation Facility

The Data Evaluation Facility contains equipment to analyze, reconstruct, mensurate, store, and retrieve experimental and operational data. The data evaluation facility works in conjunction with Space Station Data Management System to provide a complete complement of hardware and software for Space Station data handling capability. Significant portions of the Data Management System are located physically in the Data Evaluation Facility.

Optical-Sciences Laboratory

The Optical Sciences Laboratory contains optical test, calibration and alignment equipment. This equipment supports a wide range of experiments and experiment and operational equipment, such as contamination sensors, telescopes, cameras, scanners, navigation equipment, stabilization equipment, electronic imagers, rendezvous and tracking equipment, and any other gear and experiment that requires optical or spectral alignment calibration, troubleshooting, or setup.

Electronic/Electrical Laboratory

The Electronic/Electrical Laboratory supports both experimental and operational subsystems. The main service facility in the Electronic/Electrical Laboratory is the multi-instrument test bench. This test bench and console provides the capability for bench checkout, calibration, and diagnostic checks on all electronic and electrical equipment. Also, the instruments in the multi-instrument test bench can be unplugged and utilized in remote locations as portable test equipment. In addition to the multi-instrument test bench there is an electronic/electrical work bench in the Laboratory. This work bench provides the capability for contingency repair, checkout, and diagnostic analysis of malfunctions at the black-box level for experiment apparatus. It also allows assembly setup and disassembly of electronic equipment for experiment purposes or as required for operational equipment. Built into the workbench is a miniature laminar flow glove box for requirements which include cleaning, assemblying, disassemblying, lubrication, soldering, spot welding, and any other servicing of electronic equipment requiring isolation from the Space Station environment for safety or other purposes. The workbench also contains storage for hand tools required for contingency bench level work on electronic equipment and for hand tools required for working on Experiment or Space Station equipment.

Experiment and Test Isolation Laboratory

The Experiment and Test Isolation Laboratory provides the capability to perform experiments isolated from the Space Station environment. It permits isolation of toxic fluids, gases, molten materials, and high pressures from the normal habitable environment of the GPL. An airlock chamber is provided in the laboratory for experiments involving exposure to environments other than that of the Space Station proper. The isolation facility is utilized for safety; experiments are set up in the isolation laboratory but operated remotely from a control console immediately outside of the facility. A chemistry and physics glove box and a storage and analysis console is located in the Isolation Laboratory to provide enclosed work stations for experiments and operations involving chemical handling and other similar functions. A heat exchanger connected to the Space Station radiator is provided as part of the airlock chamber when it is being used for high-temperature experiments. Temporary storage and utilization capability is provided for high-pressure gases, cryogenics, toxic fluids and similar materials used during experiments.

Hard Data Processing Facility

The Hard-Data-Processing Facility includes the capabilities and all the equipment related to film handling and processing, preliminary film calibration, and quick-look film data evaluation. The Hard-Data-Processing facility supports all services and experiments utilizing film. Each piece of equipment in the facility which has the potential of emitting toxic fluids or gases will be of double-barrier cabinet design. Waste products from the equipment will be collected in reservoirs associated with each unit of equipment. (Depending on the waste product generation rate) these reservoirs will be returned to Earth and resupplied by the logistics system. Film storage is also in the data processing facility. The film storage cabinet provides radiation protection as well as temperature stabilization.

Mechanical Science Laboratory

The Mechanical Sciences Laboratory supports a wide range of operational and experimental functions. Many types of mechanical, electromechanical, and chemical functions are to be accommodated by equipment in this laboratory. The Mechanical Sciences Laboratory feature a vacuum and laminar flow glove box for chemical and gas operations in mechanical sciences. The glove box is utilized to assemble, disassemble, repair, replace, purge, clean, lubricate, and calibrate items up to subassembly size. This glove box also provides a zero-g hold down for items subject to disassembly as well as the removal of elements and their replacement; it is also used for spaces and consumables requiring clean room conditions necessary for the protection of flight crews and reliability of items receiving maintenance attention. A work bench provides stowage for hand tools and and maintenance consumables used frequently. The glove box provides laminar flow vacuum removal of contaminants which are collected and returned to Earth on the logistics vehicle.

Biomedical/Bioscience Laboratory

The Biomedical/Bioscience Laboratory provides the capability for monitoring astronaut well-being, microbiological research, and invertebrate and plant research. The Biomedical equipment has the capability of measuring such things as heart function (utilizing an electrocardiogram and vector cardiogram in conjunction with a Bicycle ergometer) and body mass with a Body Mass Measurement Device, a lower Body Negative Pressure Device is provided as an anti-deconditioning device, either in a continuing development application or an operational application. Equipment is available in the Biophysical and Biochemical Analysis Unit for zero-g blood and urine analysis. A Biological Glove Box is provided for biological work requiring isolation and separation from the Space Station environment, due either to toxicity or particulate or odor contamination. An incubation unit for microbiological research, plant physiology, and plant research is provided in the laboratory as well as a microscope facility and a microtome for preparation of microscope specimens. Also contained in the bioscience console is an autoclave and a freezer (Typholization unit) for preparing specimens for return to Earth on the logistics vehicle. Micrography and photomicrography capability is provided on a microscope for photographing specimens as well as the capability for time-lapse photography of plants, cultures, etc. Figure 4.4-2 is a perspective showing each of the laboratories as they would appear in the Space Station when in use.

4.4.1.2 Approach to Design of the Experiment Support Subsystem

The Experiment Support Subsystem (GPL) was developed from a logical approach to the design of a facility that would support the Space Station experiments and subsystems. Figure 4.4-3 is a flow diagram showing the design evolution of the GPL as it was derived and designed during the modular Space Station study. As shown in the flow, the Blue Book experiment description and the Green Book Resource Requirements developed during the study were analyzed for each FPE and FPE subgroup and experiment for identification of all experiments and support equipment necessary to perform the experiments. After this was accomplished, accommodation data sheets were prepared which indicated all critical functions necessary for equipment accommodations in the Space Station. An experiment and experiment support equipment matrix was prepared from the accommodation data sheets and the equipment lists. From this matrix, unique and common equipment were identified and separated. The common equipments were based on the criteria of equipments having common application to a number of experiments and FPE's and equipments that would be required normally in a multicapability laboratory. Unique equipments that type of equipment necessary for a single experiment or that can only be used for a short time. This type of equipment is not considered to be general-purpose equipment, and consequently, was not utilized for permanent installation in the GPL.

In parallel with this, the equipment necessary to support Space Station subsystems was defined and this equipment then was added to the common equipment grouping. When unique equipment (as defined above) was identified,

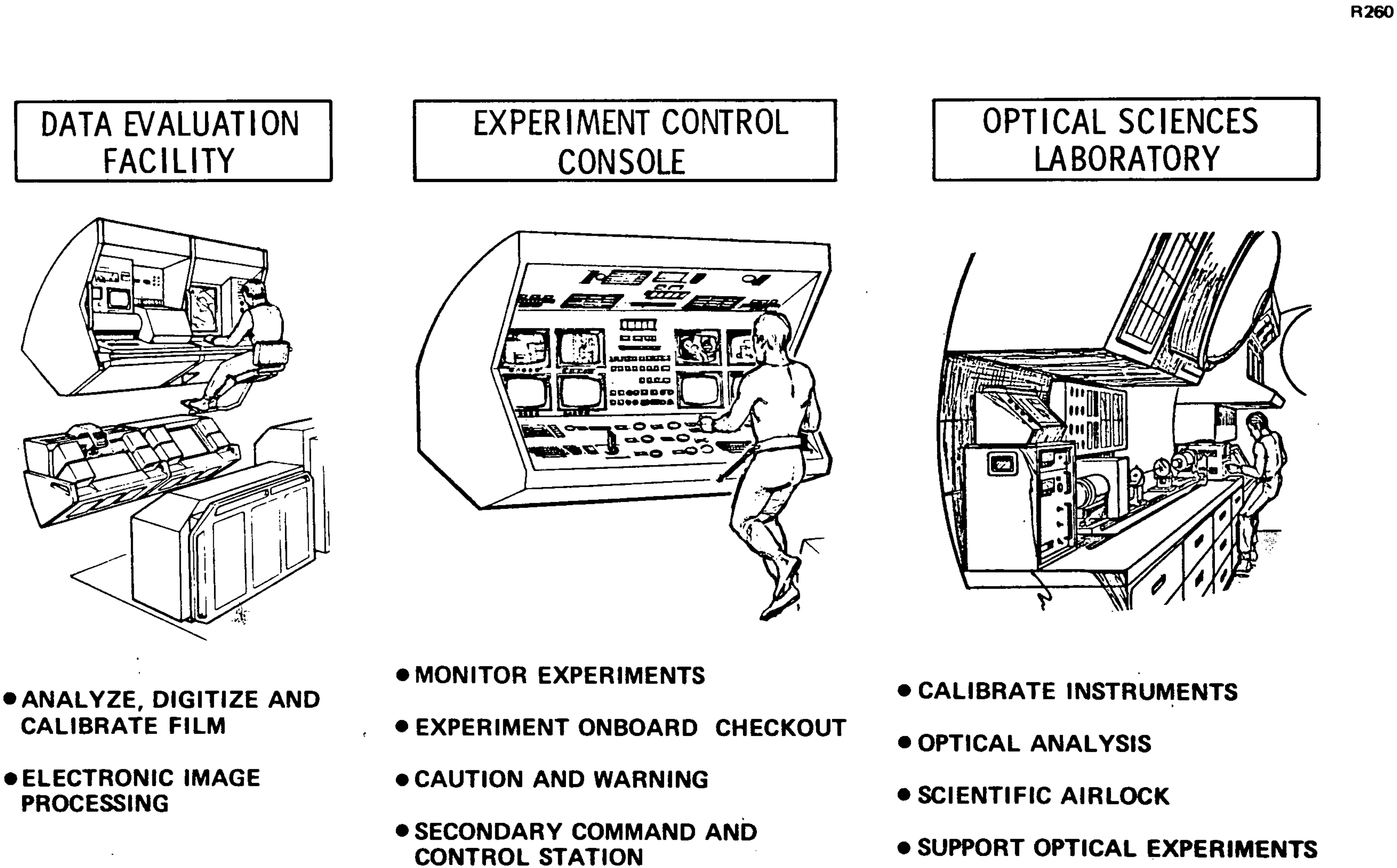
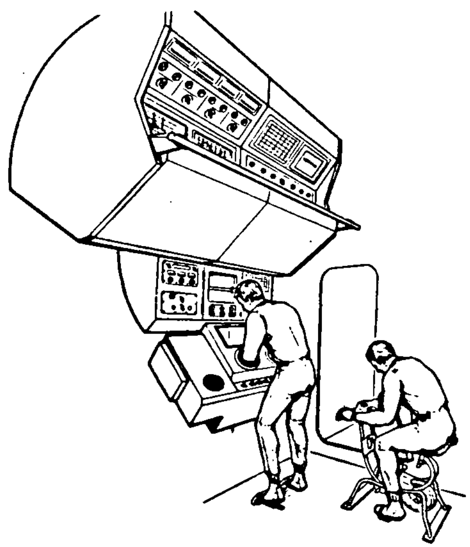


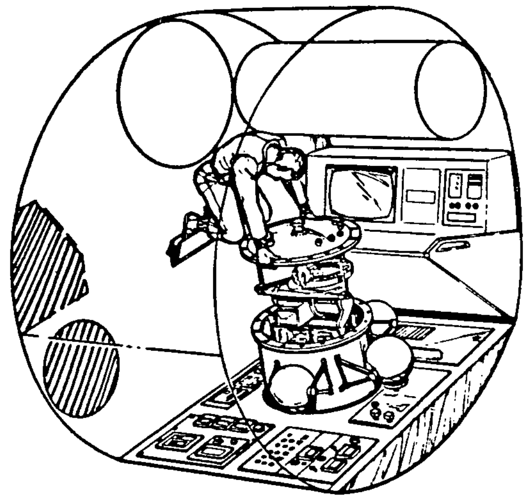
Figure 4.4-2. General Purpose Laboratories and Facilities

BIOMEDICAL/BIOSCIENCE LABORATORY



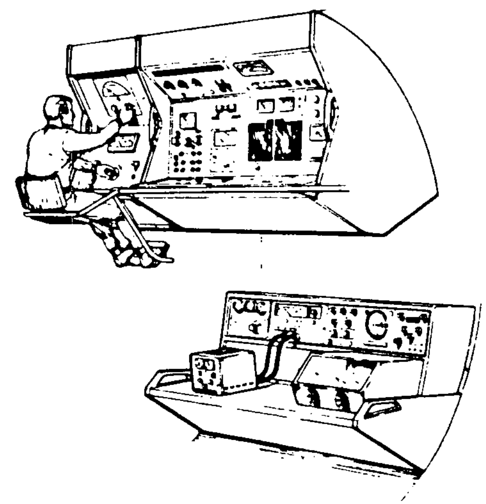
- FLIGHT CREW WELL–BEING
- BIOSCIENCE RESEARCH
- SPECIMEN PREPARATION
- FLUID ANALYSIS

EXPERIMENT AND TEST ISOLATION LABORATORY



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

ELECTRONIC/ELECTRICAL LABORATORY

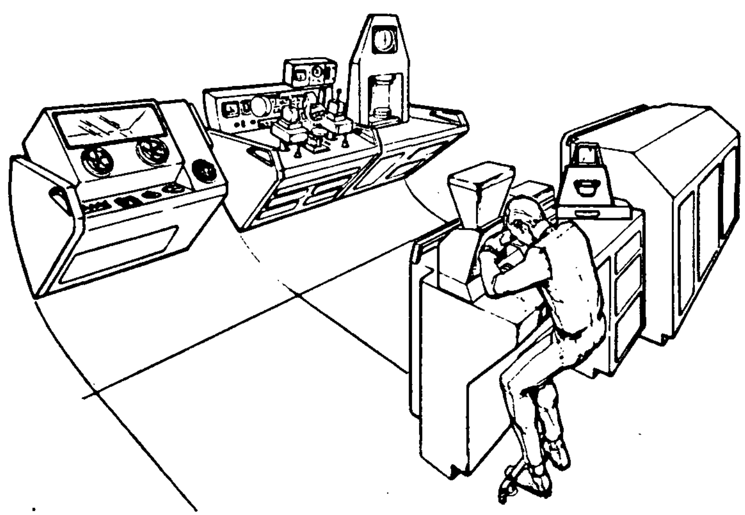


- ELECTRONIC CALIBRATION
- CHECKOUT AND DIAGNOSTIC STIMULI
- MULTI–INSTRUMENT TEST STATION
- ELECTRONIC WORK BENCH

Figure 4.4-2. General Purpose Laboratories and Facilities (cont)

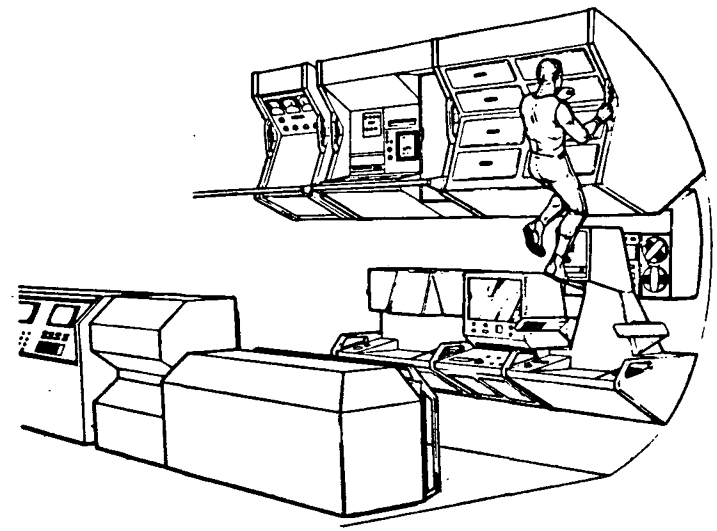
R260

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

Figure 4.4-2. General Purpose Laboratories and Facilities (cont)

R260

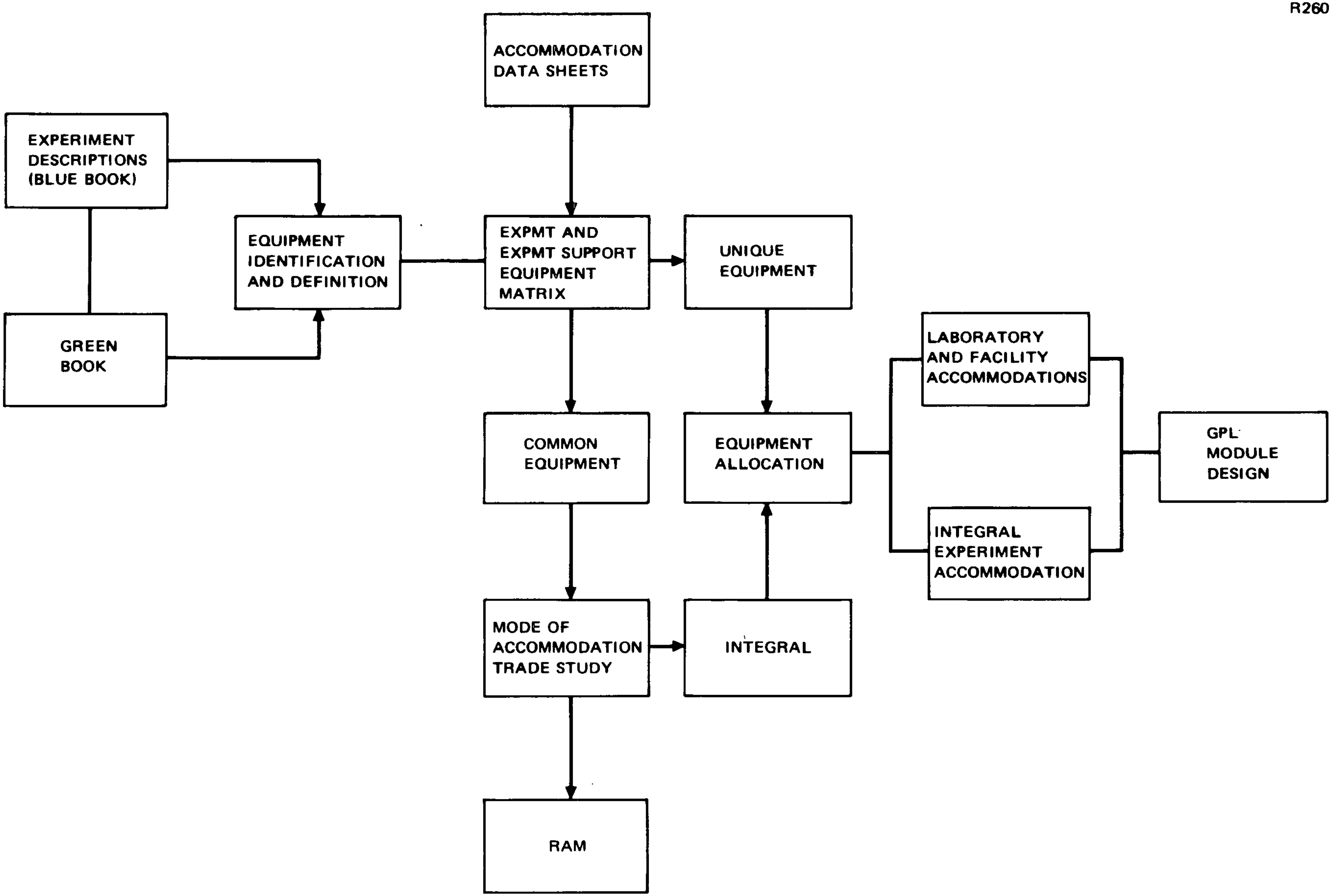


Figure 4.4-3. GPL Design Flow

the mode of accommodation trade study, which is documented in MP-01, "Mission Analysis", was utilized for allocating of this experiment-unique or support equipment to a RAM or to the Space Station as an integral experiment. When this assignment was accomplished, the integral experiment equipment and the common general-purpose equipment were analyzed for allocation of the equipment to laboratories and facilities in the Space Station. The laboratory and facility allocation and interface requirements were documented on laboratory and facility assembly data sheets. From these assembly data sheets and equipment identification lists, laboratory equipment to perform the functions required were selected and defined. This was accomplished by surveying literature on ground laboratory equipment to select equipments that met the requirements for the Space Station program versatility and could be modified and feasibly reconfigured for installation in the Space Station. From the literature search candidates, equipments were selected and various methods of laying out the equipment functionally within the GPL were studied; crew systems aspects, accommodation aspects, utility of equipment usage, and functional arrangement of equipment were taken into consideration. From these layout studies, a configuration was selected which best met the overall Space Station program requirements.

Figure 4.4-1 shows the selected GPL derived from the foregoing analysis. The basic methodology utilized for the modular Space Station and GPL design was essentially the same as that utilized in the previous 33-ft diameter Space Station study. However, there were some noteable exceptions. These exceptions are 1) the requirements for the GPL to be in a module which was one module of those that made up the Space Station; 2) much learned in the design of the 33-ft diameter GPL did not have to be repeated; the equipment selection and design analysis of previous work allowed more study to go into use of the equipment and selection of the proper type of equipment to meet requirements; 3) while the 33-ft diameter GPL was derived from Experiment and Blue Book Requirements, the new Blue Book completely espoused the laboratory and facility concept; consequently the study was able to obtain a better grasp of the experimenter's view of how a space experiment laboratory facility would be used.

The 33-ft diameter Space Station GPL was designed to a 1-"g" arrangement to facilitate artifical gravity operations. The Modular Space Station GPL interior arrangement was optimized for zero-"g" operations allowing a significant improvement in volume utilization. Consequently, the modular Space Station evolved to a more compact, more efficient facility capable of accomplishing a very broad range of experimentation and subsystems support, — the GPL was designed as a low-cost facility for performing a wide variety of applications.

4.4.2 Requirements

4.4.2.1 Experiment Support Requirements

The experiment support equipment requirements by FPE are shown in a matrix format in Table 4.4-2. These requirements were derived by analysis of the experiments of the Reference Earth Orbital Research and Applications Investigations (Blue Book). A study of the matrix reveals that a large number of equipments have commonality in many FPE's and sub FPE's and, therefore, pass the first screen for common usage equipment in the GPL. The objective of this task was to define common use experiment support equipment which is required to conduct, maintain, or repair experiments and experiment equipment. Support equipments shown in Table 4.4-2 are either called out specifically in the Blue Book or are implied in the Blue Book with further definition of the particular experiment dictating a need for the equipment shown.

Note that the equipments listed were not postulated without specific requirements necessary to carry out the intent of the experiments as defined in the NASA Blue Book. Some of the equipment that is not defined in the Blue Book had to be identified, analyzed, and characteristic size and configuration determined. An example of this type of equipment is for film storage and film processing. For the film storage, the amount and type of film to be used had to be determined. The use to which the film is to be put also must be determined, comparing it with a natural radiation environment existing in

Page intentionally left blank

Page intentionally left blank

Page intentionally left blank

the Space Station. Further the frequency of logistic flights and the amount and type of film storage must be specified as well as the weight of radiation shielding required. Another item of equipment in the same vein as the film vault is the film processor. For example, all of the following must be determined: the type of film used; the amount of film to be processed; the requirements for analysis onboard, such as quick-look analysis or detail analysis; data processing resolution required; and the requirement for transmission of data to the ground. All of these items must be taken into account in selecting the capabilities and type of film processes to be selected.

Some common equipment is already specified in each FPE and experiment description in the Blue Book. This equipment may be called out in a number of FPE's. These equipments are then posted for each FPE on a matrix and thus, become candidates for GPL equipment. Some of these equipments may not be called out as support equipment, but are specified as part of the FPE experiment equipment. However, if these equipments are used for a number of experiments, then that item becomes general purpose equipment and a candidate for the GPL as opposed to being specified as part of FPE. This presents a bookkeeping problem, for weight, volume, resources, etc., which must then be transferred to the GPL and taken from the FPE.

The mode of accommodation analysis covered in Section 4. 4. 2. 6 of this report may also affect FPE or support equipment and its candidacy for the GPL. For example, FPE's that are Free-Flying Modules may require automated support equipment in the module if this support must be accomplished in free flight; i. e., changing filters, changing types of film, film storage, and shielding fall into this grouping.

In the case of attached modules, support equipment is required to check out, service, and get the module ready for flight on the ground. The support equipment should be the same equipment as utilized for checkout and servicing of the equipment prior to launch. In many cases, this equipment may be in a subsystem chamber of the attached module and brought up with the RAM; that is, docked to the station and remain in the subsystem chamber of the RAM. In addition, there may be calibration and alignment functions on the

RAMS that would require a very complex interface with the GPL module, such as many wire umbilicals, rigid optical paths, etc. Therefore, these equipments, while normally general-purpose if the FPE were integral, would become unique equipment to the RAM and be part of the RAM.

Another situation where a module may effect equipment candidacy for the GPL is in dual usage of heavily used equipment. For example, in the Communication/Navigation Module, most of the electronic checkout and support equipment utilized for the communication navigation experiments is required for maintenance and operation of the communication and navigation operational subsystems of the Space Station. However, this equipment must be available at all times for the operational subsystems. Consequently, though it is the same equipment, a duplicate set of equipment must be provided in the module for the experiments. The Space Station subsystem equipment can also be used for the communication navigation experiments, in a backup-mode situation.

Another type of equipment is that equipment which is not called out in the Blue Book as FPE equipment which is required for an FPE or a single experiment within an FPE. When this equipment is identified from the matrix, an accommodation will be provided for it either in the GPL or in the FPE equipment. This equipment will not be shown as part of the permanent installation within the GPL. It is recommended that this type of equipment normally be supplied with the FPE as something that is unique to one experiment and should stay identified with the particular experiment. Looking at the matrix, it is apparent that there are very few types of equipment that fall into the category of unique equipment. However, an example of this type of equipment is a photoelectric polarimeter; the matrix shows only two FPE subgroups which require the photoelectric polarimeter. It is to be expected that a unique photoelectric polarimeter will be supplied for each type of experiment.

The Experiments Support Equipment, the Experiment FPE equipment, and the Space Station resources should be all that is necessary to perform the experiments specified. Each piece of equipment specified is required to do the experiments as defined in the Blue Book and the equipment listed in the matrix is based on this criteria. The equipment matrix is also based on the assumption that all ISS Space Station resources are available to perform the experiments. That is, those resources that have been allocated to and shown to be required for experiments during the ISS phase are available for the performance of experiments. The heart of the task of determining experiment support requirements is complete identification of everything necessary to perform the experiment program.

Table 4.4-3 is an example page of a table of all the equipments identified to perform each FPE. Each FPE subgroup is noted with FPE equipment identified and support equipment identified for the total Blue Book experiment program. The support equipment shown on the matrix of Table 4.4-2 was derived from this equipment requirements list.

4.4.2.2 Experiment Facility Requirements

From the list of FPE and support equipment and equipment commonality matrix in subsection 4.4.2.1, an allocation of equipments to facilities was accomplished. Figure 4.4-4 shows the design task flow utilized in facility identification allocation and design. The tasks involved in allocating equipment to facilities and configuring those facilities shows a logical flow from the FPE detail derived from the Blue Book, further analysis during the Space Station study support requirements, and from the Blue Book study analysis to specific support equipments from the Blue Book as analyzed in Document DRL MP-01. Then, the flow continues to equipment identification shown in Table 4.4-3 and, thence, to the task of apportionment of equipment to facilities and facility identification.

As noted in previous sections of this report, it is required that the Modular Space Stations have flexible support facilities because of the dynamic nature of the program. The Space Station must be designed to support not only candidate experiment programs but also to support those experiments and operations that will evolve as the scientific and operational program objectives of the space program are further defined. To accomplish this, the experiments and the support equipment have been defined in sufficient detail to establish the common equipment and facilities required aboard the Space Station.

For the GPL, the commonality of facility functions is based on the premise that FPEs, experiments, and operations displaying similar requirements and needing similar equipment are sufficiently flexible to allow the use of common facilities. Common usage is defined as existing when a laboratory facility satisfies the requirements of more than one FPE or parts of a single FPE or experiment, and this laboratory may also support Space Station subsystems. From the matrix of Table 4.4-2 a set of candidate facilities were derived. These candidate facilities were shown in Table 4.4-2. These facilities were then tested against the requirements of the experiments, subsystem maintenance requirements, support requirements of modules, and support for a total program to determine the ability of the candidate facilities to support all program requirements. Section 4.4.2.4 of this report shows how these facilities support the requirements of Space Station subsystems.

The extent of resupply, consummables, operational subsystems support, and Space Station logistics and storage requirements will be defined in subsequent sections of this report, for implementation in the design of the Space Station GPL.

4.4.2.2.1 Facility Equipment Accommodation Requirements

After the support equipment required by the Space Station experiment program was defined, the equipment was allotted to Space Station functional areas as indicated in Subsection 4.4.2.2. In most cases, the allocation of equipment and facilities to functional areas of the Space Station was relatively simple to assign as equipments usually have a specific function that fall into a defined laboratory or facility area. However, in some cases, the choice of equipment location had to be based on other things such as center of gravity. For example, the film vault is very heavy and, therefore, placing it at the shortest moment to the centroid of the Space Station will make for a

Table 4.4-3

FPE EQUIPMENT LIST

EXAMPLE

REVISION 7-1-71

FPE NO. P-2 TITLE PLASMA PHYSICS AND ENVIRONMENTAL PERTURBATION LABORATORY SHEET 1 OF 5

Item	Weight K Grams	Weight lb	Volume Cu M	Volume Cu Ft	Remarks
FPE EQUIPMENT P-2A					
Planar Electron Traps (4)	24.0	52.0	0.006	0.21	On Station or module surface.
Planar Ion Traps (4)	24.0	52.0	0.006	0.21	
Quadrupole Mass Spectrometer (2)	16.0	35.4	0.002	0.057	
Cylindrical Electrostatic Probes (2)	3.0	6.6			
Spherical Ion Probe	2.0	4.4			
AC Electric Field Meter	15.0	33.0	2 sensor pkgs each		Sensors packaged within boom cannister.
DC Electric Field Meter	30.0	66.0	0.175	6.16	
Fluxgate Magnetrometer	1.5	3.3			
Retarding Potential Analyzer	1.5	3.3			
TOTAL P-2A	117.0	256.0	0.189	6.637	
SUPPORT EQUIPMENT					
Airlock Deployable Booms & Servo Platforms (2)	45.4	100	0.5 each	17.65	
Airlocks 0.5 x 0.5M (2)	(part of station structure or possibly mounted on a platform)				
Class 1000 laminar flow bench	127.0	280.0	1.02	36.0	
General Purpose Volt/Ohm/Amp Meter	2.3	5.0	0.007	0.25	(Use OCS)
Spot Welder (capacitor discharge)	10.0	22.0	0.05	1.8	
TOTAL SUPPORT EQUIPMENT	184.7	407.0	2.077	55.7	
SPECIAL EQUIPMENT					
Control & Display (with 2 oscilloscopes)	61.0	134.0	0.1	3.5	
Oscilloscope Camera	5.0	10.0	0.024	0.84	
TOTAL SPECIAL EQUIPMENT	66.0	144.0	0.124	4.34	
GRAND TOTAL	367.7	807.0	2.39	66.677	

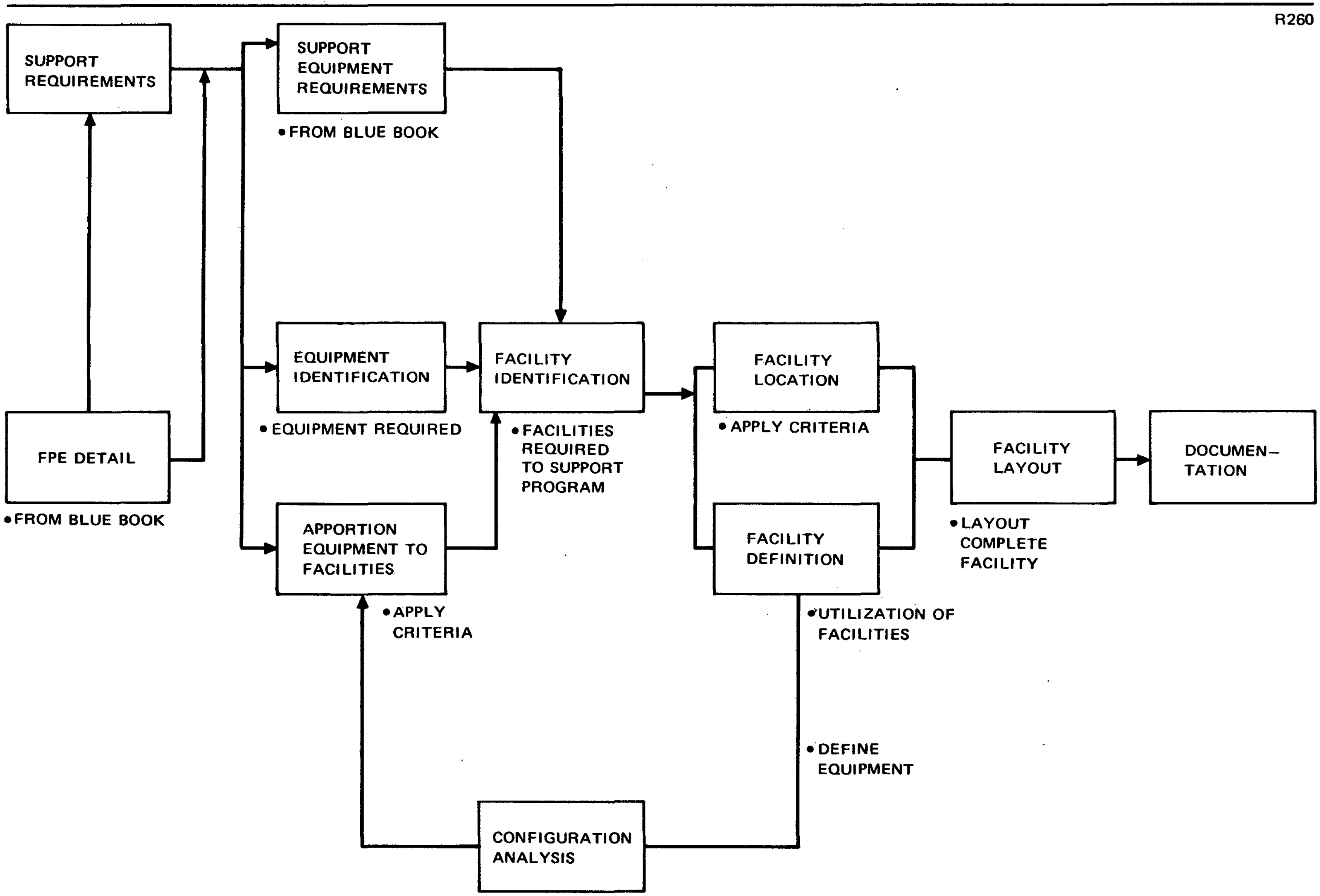


Figure 4.4-4. GPL Facility Design Flow

more stable station and put less of a burden on the stabilization system. The microfilm equipment lends itself to use by both the data evaluation area or data processing area. In this particular case, both of those facilities are adjacent to each other and the microfilmer is available to each. Other equipment allocations required the same type of choices. For example, there are support equipment requirements for a spectrometer and microdensitometer and the question arose whether the equipment should be in the Hard-Data-Processing Facility, the Data-Evaluation Facility, or the Optical Sciences Laboratory. The equipment could be placed in any one of the three facilities; in fact, in ground laboratories where film and optical equipment is utilized, this equipment is found in all three.

In this case, the spectrometer and densitometer were located to be used in conjunction with the light table in the Hard-Data-Processing Facility for film strip test and calibration. In addition, a precision microdensitometer and precision monochromator spectrometer were selected to be placed in the Optical Sciences Laboratory for FPE and experiment sensor checkout and for detail optical and film analysis. Thus, each piece of GPL equipment was allocated to a Space Station facility laboratory based on a review of maximum utilization, volume, and other resources to make the GPL and Space Station a productive, versatile facility.

4.4.2.2.2 Facility Selection Rationale

The rationale for the placement of facilities is based on evaluating related facilities for common usage, traffic flow implication, operational efficiency, safety, interface with other Space Station subsystems, and experiment performance efficiency. From this evaluation (and knowing the inherent characteristics of the individual facilities) certain conclusions were reached which allowed grouping capabilities. The basis for grouping and locating the facilities are shown in Table 4.4-4. The figure indicates some of the prime general criteria used for placement of the facilities within the GPL of the Space Station.

4.4.2.2.3 Individual Facility Accommodation Requirements

When the facilities which the GPL contained were selected, a series of accommodation data requirements for these facilities which drove the detail

Table 4.4-4

GENERAL ACCOMMODATION CRITERIA

Item	Description
1.	Equipment located on the centerline is primarily high-access equipment, i.e., film processors, data management, electronics and EC/LS. Also the processors appear to be the least flexible for shape modification to side mounting.
2.	Compartmentation of associated equipment was attempted, (i.e., data processing and evaluation equipment in one general area; electronics equipment in another; optics, mechanical, biomed, etc., each in its own area).
3.	Biomedical equipment was positioned adjacent to transverse bulkhead in radial arrangement to (1) allow easy visual access and umbilical attachment to monitor console, (2) keep this specific FPE equipment generally away from GPL-type equipment.
4.	Isolation and test facility was located at the end, away from crew module for inherent safety in distance and to provide dual function of EVA airlock activity.
5.	Remainder of the accommodation was designed to best fit the equipment within the configuration, minimizing modifications of existing equipment shapes, after all the aforementioned considerations were accounted for.
6.	The isolation factor falls out of the above, in that light control is the only specific isolation (with the exception of the isolation and test facility) uniquely provided by the configuration, i.e., curtain walls for optics equipment and data evaluation. Additional isolation is provided by safety barriers built as part of the installed equipment.

design of the GPL module were developed. Accommodations data requirements for each of the seven facilities are shown in Tables 4.4-5 through 4.4-10. In addition to the facility accommodation data requirements, the accommodation requirements were also developed from the experiment requirements for the airlock chambers within the GPL. These requirements are given in Table 4.4-11. Detail design data definition and layouts of the facilities for the associated equipment installed are covered in subsection 4.4.3.1 of this report.

Table 4.4-5

DATA EVALUATION FACILITY ACCOMMODATION DATA

Mode of accommodation recommended	Integral, utilizing modular, carry-on equipment near experiment data utilization
Special accommodation	Provide light-tight facility with illumination rheostat; 1- or 2-man utilization of facility
Contamination	Class 100,000
Location/viewing	Near data use area—no viewing requirements
GPL support	Hard-data processing
Remarks	Facility is predicated on present state-of-the-art. As technology advances, more sophisticated equipment may be available.

Table 4.4-6

ELECTRONIC/ELECTRICAL LABORATORY ACCOMMODATION DATA

Mode of accommodation recommended	GPL integral
Special accommodation	High power
Contamination	Grouped facility to meet 100,000 cleanliness level.
Location/viewing	Central location to electronics and electrical users. No viewing requirement.
GPL support	Routine electrical, electronic, mechanical assembly/disassembly tools.
Remarks	Soldering to be performed in glove-box facility.

Table 4.4-7

MECHANICAL LABORATORY ACCOMMODATION DATA

Mode of accommodation recommended	GPL integral with movable racks, benches, and equipments
Accommodation envelope	Proximity to airlocks and mechanical equipment
Special accommodation	Precision jig, tool, and bench arrangement for assembly and disassembly Provisions for mechanical or chemical decontamination. Glove boxes are provided for isolation.
Contamination	The facility should be compatible with 100,000 cleanliness level.
GPL support	Routine electromechanical maintenance and stowage.

Table 4.4-8

EXPERIMENT AND TEST ISOLATION LABORATORY ACCOMMODATION DATA

Mode of accommodation recommended	GPL integral
Accommodation evelope	Self contained
Special accommodation	Capability to take a 14.7-psi reverse pressure is required.
Contamination	Grouped facility should (1) comply with 100,000 cleanliness-level requirements (2) have provision for dumping atmosphere to vacuum.
Location/viewing	View of inside chamber from other laboratories is required (may be TV).
GPL support	Maintenance of electrical, mechanical, hydraulic, and pneumatic apparatus. Storage for airlock extension. Storage of experiments.
Remarks	External controls, monitors, and alarms are required.

Table 4.4-9

HARD DATA PROCESSING FACILITIES
ACCOMMODATION DATA

Mode of accommodation recommended	GPL integral-utilizing movable racks, consoles, and equipments; providing for carry-on update and reconfiguration.
Special accommodation	Vapor-tight capability for film-processing (may be provided within equipment) controlled light capabilities, and minimum through-traffic design for area during use
Contamination	10,000 cleanliness level (may be provided within equipment) film-processing can emit nuisance or even toxic vapors during failure. Local air circulation and scrubbing or filtering/reaction system provided under local control for air-cleaning purposes by equipment.
Location/viewing	Convenience to film users desired; no viewing requirements.
GPL support	Maintenance of electromechanical, electronic, and photo/optical systems.
Remarks	The hard data system is subject to reconfiguration and growth, and this should be considered in future plans.

Table 4.4-10

BIOMEDICAL/BIOSCIENCE ACCOMMODATION DATA

Mode of accommodation recommended	Integral
Accommodation envelope	In biomedical and bioscience area
Special accommodation	Experiments housed in special packages in racks adapted as incubators and culture chambers
Contamination	Interface with station minimized by supplying filtering from EC/LS system. Bioscience glove box required
Location/viewing	Housed in same laboratory with other biology FPE's.
GPL support	Minimum, due to bio-isolation requirements

Table 4.4-11

INTEGRAL AIRLOCK ACCOMMODATION REQUIREMENTS

FPE	Requirements
Space physics	Two scientific airlocks, one earth oriented and the other stellar oriented.
Plasma	One airlock for bow-wave (free-stream) probe and one airlock for wake probe, two scientific airlocks in same quadrant or one large airlock for simultaneous deployment of plasma jet and ion gun, an EVA airlock, a balloon deployment device.
Technology experiments	EVA airlock
Materials science and processing	An airlock device for heat rejection and for vacuum operation.
Contamination experiments	Two scientific airlocks. EVA airlock.
Exposure experiments	EVA airlock Sensor test airlock and rate stabilized platform; earth oriented; hazardous-test airlock fitted for IVA or remote operation.
Orbital EVA	EVA airlock

4.4.2.3 Space Station/RAM Support Requirements

In order to come up with a complete Space Station general purpose facility, it was necessary to analyze all the aspects of support for operational subsystems as well as for experiments. Facilities and functions are required to support the operational health of the Space Station. These facilities should be capable of assembly, disassembly, checkout, calibration as well as contingency, black-box level work. The requirement for checkout, calibration, repair of operational equipment aboard the Space Station will select the features of the subsystem design needed for redundancy, ease of maintenance, and reliability. The GPL support equipment requirements to support the operational subsystems are derived from the concept for second-level in-flight repair and maintenance; a description of these is given in the following subsections.

4.4.2.3.1 GPL Maintenance Concept

The in-flight maintenance concept governs maintainability design and equipment for safe, economical, and timely maintenance of equipment critical to crew safety and primary mission objectives considering long-life, reliability, redundancy, and desirable maintenance. The concept orients maintenance tasks and maintenance for logistics pertaining to spares, supplies, tools, test equipment, procedures, etc. GPL maintenance activities consist of:

A. Bench test and examination of deteriorated and malfunctioned experiment apparatus are performed at the discretion of the tester, to determine further action.

B. Bench fault isolation repair and checkout of experimental apparatus as necessary for reliability, economy, and conservation of logistics support, weight, and volume.

C. Repair of equipment is accomplished primarily by inflight replacement and/or minor purging rework of faulty components and parts. However, all major maintenance requiring major tools or involving casting, milling, boreing, churning, heavy pressing, etc., is to be accomplished in ground facilities. Such equipment will not be provided in the GPL of the Space Station. However, such equipment reworked, repaired, or modified, or new equipment supplied by logistics would be sent to the Space Station via logistics flights for installation in the Space Station utilizing General Purpose Laboratory facilities and equipment.

Particular types of shop tools are stowed and maintained in the individual facilities with which they are mainly associated. Specific types of tools required are noted in Subsection 4. 4. 3. 2 of this report.

The onboard checkout system in conjunction with laboratories and facilities onboard the Space Station will have the capability for fault isolation and checkout of installed assemblies onboard the Space Station. Calibration standards utilized by the onboard checkout system and maintenance test equipment shall be provided by the GPL.

Maintenance instructions and procedures will describe maintenance operation and support required for routine maintenance and for probable repairs. Procedures needed regularly will be automated in the microfilm retrieval system, which will be available onboard the Space Station. These procedures will be updated as required. Maintenance procedures not contained in the onboard storage system can be brought up for inclusion in the system on logistics flights or in the case of maintenance requirements necessary onboard between logistics flights, this information can be communicated from the ground, put on film, and put into the microfilm system.

4. 4. 2. 3. 1. 1 Environmental Effects on GPL Procedures and Utilization of Laboratory Equipment

The required environment is to be maintained for personnel working conditions, hardware decontamination, and cleanroom needs when required for component assembly, disassembly, and installing of stocks. The specific environmental characteristics of the crew work areas in the GPL and the environment within the laboratories and facilities are covered in subsequent sections of this report.

4.4.2.3.1.2 Stockroom Storage Facilities

Facilities for inflight stowage of maintenance spares and operational consumables are necessary. They will be tailored to the classes of the stocks to provide ready access and stock control within the GPL. Fast-moving items will be stowed in the GPL in appropriate storage areas in the individual laboratories. Specialized heavy or bulky items will be stored at the point of use in Space Station modules or RAMs. Slow-moving items may be stored in the Logistics Module. Facilities are also required for stowage of bulk items and consumables. These items are also stored in the appropriate laboratories or facilities with which they are associated.

4.4.2.3.1.3 Consumable Storage

Operational Consumables are required to support Space Station experiments and subsystems. These consumables include film, magnetic tape, chemicals, cryogens, fuels, oxidizers, gases (both low- and high-pressure). As noted, film requires a radiation shielding capability which is provided in the GPL by a film vault. Magnetic tape requires temperature stabilization and shielding from thermal extremes. Chemicals, cryogens, and gasses for experiments use require accommodation in the Space Station and in the GPL. These items normally will be stored in a docked Logistics Module until required for an experiment in a RAM or in the GPL. The GPL equipment will have provisions for storage of liquids and gases which are replenishable from the logistics vehicle. A method of replenishment will be to remove the used reservoir from the equipment and replace it with a new one. Detailed requirements for operation and experiment consumables are covered in subsection 4.4.2.5.

4.4.2.4 General Purpose Laboratory Support of Subsystems

Space Station subsystems have the requirement for on-orbit maintenance, part replacement, and contingency repair. To accomplish these on-orbit tasks, certain equipment and facilities are required; these facilities and equipment are supplied by the GPL. Table 4.4.12 is a listing of each selected Space Station subsystem and the support required from the GPL. Small tools and instruments are stored where they are most likely to be utilized in the GPL. For example, small mechanical tools are located in

Table 4.4-12

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS

Subsystem	Operations	Facility	Equipment	Tools
Data management	Cable/plug repair	Storage in test facility		Wire strippers Flat-cable strippers Wire printer Diagonals Longnose pliers Portable volt-ohmmeters Solder gun Connector/pin tools Terminal crimper Screw drivers Allen wrenches
	Equipment analysis & repair	Test facility	Power supplies Oscilloscope Digital multimeter Digital counter Function generator Vacuum/nitrogen source Fluke/null meter Ultrasonic cleaner Micro search terminal Signal sources	
Onboard checkout	Component removal & replacement	Storage		Circuit card puller Screw driver Standard removal tools (depends on package concepts)
	Cable/plug repair	Storage	Volt-ohmmeter	Wire strippers Flat cable strippers Wire printer Wire cutters Needle-nose pliers Connector/pin tools Crimping tools Screwdriver Allen wrenches
	In-place equipment analysis and fault isolation	Electrical/electronics lab	Same as below	Circuit card extender/puller Test leads Breakout box
	Bench level equipment analysis	(Multi-instrument test bench	Multichannel oscilloscope Volt-ohmmeter Multifunction signal generator Power supplies	Circuit tap plug Screwdriver Test leads Alligator clips Pliers

Table 4.4-12 (Continued)

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS (Continued)

Subsystem	Operations	Facility	Equipment	Tools
Onboard checkout (Continued)			Electronic counter Oscilloscope camera	Holding device Mallet Magnifier
S/AC	Sensor replacement[1]	Deploy/retract pressurizable compartment	Volt-ohmmeter Oscilloscopes Power supplies	Standard
S/AC	Electronics module replacement[2]	Electronics test lab	Oscilloscope, signal generator, etc.	Standard
S/AC	CMG replacement	NA	Mechanics tools	Standard
S/AC	CMG repair	NA	Mechanics tools, bearing puller	Standard
G/N	Sensor replacement[3]	Deploy/retract pressurizable compartment	Volt-ohmmeter Oscilloscopes Power supplies	Standard
G/N	Electronics module replacement[4]	Electronics test lab	Oscilloscope, signal generator, etc.	Standard

[1]Includes the following sensors: horizon sensor, gyros

[2]Includes the following electronic assemblies: sensor interface electronics, CMG electronics, control electronics and jet drivers, power conditioners

[3]Includes the following sensors: star trackers, star sensors, rendezvous radars

[4]Includes the following electronic assemblies: sensor interface electronics

Table 4.4-12 (Continued)

GPL SUPPORT REQUIREMENTS

ELECTRICAL POWER SUBSYSTEM

Assemblies	Operations	Facility	Equipment	Tools
Solar array & orientation	Replacement of solar panels (feasibility TBD— requires EVA)	Storage	Special handling tools to transport panels	Wrenches Torque wrench
	Replacement of motors, bearings & dynamic seals, pumps	Storage	Special puller for exposing bearings & seals	Wrenches Torque wrench
Energy storage	Replacement of battery modules	Storage		
T/C/D & control	Connect/ disconnect electrical umbilicals	None		Special electrical disconnect tool
	Replacement of black boxes, inverters, battery chargers, battery load regulators, & shunt regulators	Storage		Screw drivers Torque wrench Electrical disconnect tool Plug pin tools
Subassemblies-components	Switches Circuit breakers Limiters Relays Motors Instruments Sensors Lights Circuit cards Brushes Cable Battery modules	Magnifier Circuit card vise Clean box Storage Test facility	Oscilloscope VTVM Load box Tachometer meters Circuit card tester	Allen wrenches Screw drivers Inspect mirror Nylon gloves Torque wrench Side cutters Solder gun Continuity test light Circuit card puller Plug pin tools

Table 4.4-12 (Continued)

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS

EQUIPMENT AND FACILITIES FOR SUBSYSTEM MAINTENANCE

Subsystem	Operations	Facility	Equipment	Tools
Communications	Normal maintenance and replacement			Connector pliers Mounting rack tool Other small hand tools*
	Replacement of coaxial cables, connectors	Communications equipment test facility	Signal generators Oscilloscope Spectrum analyzer Multimeter Power meter	

*Tools chosen for data management may also be used for emergency repairs at lower levels.

Table 4.4-12 (Continued)

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS

PROPULSION SUBSYSTEM

Functions or Operations	Operational Monitors & Controls	Facilities	Equipment	Tools
Checkout Leak check Valves/bellows Connections		Gas supply	Gas bottle Hand valves Pressure gauges Bubble soap solution	Miscellaneous hand tools
Subsystem	Visual display (P;T)			
Functional Valve control Sequence checks	Propellant control panel Visual display (P_1 events)			
Instrumentation calibration		Instrument calibration & functional check	Gas supply Pressure gage Temperature sensors Voltammeter/current tester Ohmmeter	Miscellaneous electrical and mechanical hand tools
Electrical Continuity Function Resistance check		Component test areas	Gas supply Pressure gages Hand valves Voltammeter/current traces Ohmmeter	Miscellaneous electrical and mechanical hand tools
Regulator	Strip charts (P)			
Response Thrustor Valves	Strip charts (volts) Strip chart (events)	Contingent test area	Gas supply Pressure gages Hand valves Voltammeter/current traces Event recorder	Miscellaneous electrical & mechanical hand tools
Heaters Resistance Functions	Strip chart (temperature)	Component test area	Temperature control box Temperature sensors Ohmmeter Voltammeter/current traces	Miscellaneous electrical hand tools
Replacement		Spare storage		Miscellaneous hand tools
Components/Inst		Cleaning (liquid)		EVA tethers
Tankage (load or unload)		Hazard storage	Handling dolly/fixture	Hand tools
Thrustor modules		Cleaning (liquid)	Handling fixture	Hand tools
Umbilicals		Cleaning (liquid)		PLSS
Instrumentation		As noted above		PSA

Table 4.4-12 (Continued)

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS

PROPULSION SUBSYSTEM (Continued)

Functions or Operations	Operational Monitors & Controls	Facilities	Equipment	Tools
Checkout (Continued)				
Cleaning/ decontamination		Purge gas	Built in capability	Hand tools
Line repair		Argon purge gas	Brazing equipment	Braze heads
		Cooling water	Tube benders	Tube cutters/deburrers
		Cleaning (liquid)		
Propellant check		Propellant lab	Propellant sampler (bottle and valves)	Hand tools
NO, FE, H_2O particle content			Filters	
			Lab equipment	

Table 4.4-12 (Continued)

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS EQUIPMENT AND FACILITIES FOR EC/LS MAINTENANCE

Subsystem	Operations	Facility	Equipment	Tools
	Component	Storage bin	Conventional portable checkout equipment, such as	Conventional hand tools modified for zero-gravity use, such as
	Replacement of			
	Valves		Volt-ohmmeter	Tubing wrenches
	Fans		Oscilloscope	Screw drivers
	Pumps		Electronic counter	Pliers
	Compressor		Special portable plug-in equipment, such as	Allen wrenches
	Connectors			
	Sensors		Flow meter	
	Heaters		Temperature meter	
	Filters		Pressure sensor	
	Canister		Portable leak detector	
	Electronic control		Plumbing repair equipment	
	Separator		(Contingency tube cutters, tube flare, etc.)	
	Motor		(Same as propulsion)	
	Hoses			
	Module replacement of			
	Heat exchanger subassembly			
	Tank subassembly			
	Membrane module			
	Radiator repair		Brazing (contingency)	Wrenches

Table 4.4-12 (Continued)

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS

Functions or Operations	Operational Monitors & Controls	Facilities	Equipment	Tools
Housekeeping equipment	Replace Repair Adjust	GPL	Pneumatic system leak detector	Continuity test light Phillips screwdrivers (3- and 6-in.)
Recreation equipment	Repair Adjust	GPL	None	Allen wrench, size (TBD)
Radiation and meteoroid detection equipment	Repair Adjust	None	Calibration instrument	Circuit card tester Circuit card puller Continuity test light
Maintenance equipment	None	None	None	None
Food & food management equipment	Repair Replace Adjust Sensor, electrical unit	None		Repair kit contents
Religious worship provisions	Repair	None	None	
Emergency equipment	None	None	None	Special emergency equipment repair kit
EVA support equipment		None	None	Special EVA repair kit
Pressure suit assembly support equipment	PSA monitor panel	None	None	Special PSA repair kit
Damage control and safety	None	None	None	Hole plug kit
Medical equipment	None	None	None	Special medical equipment repair kit
Mechanical	Maintenance of mechanical system; i.e., gimbal rollers, hydraulic systems, elevators, and cargo-handling devices	Tool-storage areas, mechanical assembly/disassembly areas	Holding fixtures	Wrenches
	Docking shock struts; door mech., door seals, window seals			Torque wrenches Allen wrenches Glove box
Personal equipment	Repair	GPL	None	Circuit card tester Soldering gun Soldering needle Continuity test light

Table 4.4-12 (Continued)

GPL SUPPORT REQUIRED BY SPACE STATION SUBSYSTEMS

Functions or Operations	Operational Monitors & Controls	Facilities	Equipment	Tools
Restraint equipment	Replace/repair restraint locking clamping device and fabrics	GPL	None	Allen wrench (size TBD) Fabric mending kit (contents TBD)
Exercise equipment	Repair of mechanical linkage-cables, electrical alternator load control	None	Volt-ohmmeter	Socket set with 3/8 drive, and 3/8, 7/16, 1/2, 9/16 sockets Same as personal equipment
Hygiene equipment	Adjust Repair	GPL		Same as personal equipment Allen wrench, 5/32 Phillips screwdrivers, (3- and 6-in.) B-nut wrench, (TBD)

the mechanical sciences laboratory. Large support units become an integral part of the GPL. (For example, the brazing facility utilized in the mechanical sciences laboratory glove box.) Test equipment and checkout equipment becomes part of the GPL permanent facilities. (for example, oscilloscopes, voltmeters, multimeters, visual counters and function generators.)

Experiments will need the same type of support as subsystems for on-orbit maintenance, part replacement, and contingency repair. Because the specific experiment equipment has not been designed in detail, it is assumed that the same types of tools and equipment used in support of subsystems will also support the experiments.

4.4.2.5 Spares and Consumable Support Requirements

Table 4.4-13 presents the spares and consumables requirements for the Space Station FPE's. The three categories (operational, spares and maintenance) represent a natural breakout for the different types of items used to support the experiments.

The operational consumable weights and volumes (film, gases, etc.) are obtained from the experiment definitions which describe the consumables necessary to complete the experiments. Film weights and volumes were derived using the criteria set forth in the McDonnell Douglas publication entitled "Task C - Orbital Astronomy Support Facility Concepts" Volume IV, Book 2 of 3. Other operational consumable weights and volumes were based on experience and information of similar items.

Maintenance consumables are items that are not peculiar to a given experiment but must be available on the Space Station for use by all experiments. The weights and volumes assigned are based on the type of equipment, and its complexity, size, and maintenance functions. These consumables (cleaning supplies, solder, lubricants, etc.) support the experiment equipment and represent each experiment's share of the total weight and volume of all maintenance consumables onboard.

The spares shown are peculiar to the experiment in most cases, although some commonality is expected and is highly desirable. The weights and volumes are assigned to each experiment or FPE, based on the equipment's type, complexity, size, failure rates, and criticality category. These data are according to past experience on similar systems and equipment used on launch vehicles, and weights and volumes assigned. The return weights and volumes will include those repairable items returned for ground third-level maintenance, failure analysis, repair, or disposition. Scrap or waste materials are not included in this category.

4.4.2.6 Mode of Accommodation

The primary determining factors of FPE accommodations were attitude and stability capability, g-level contamination, and size. As can be seen from Table 4.4-14, the primary factors in accommodation-determination were size and contamination. The instruments that were accommodated as free-flyers due to attitude and stability problems were those that would be susceptible to manned disturbances in the Space Station. It also turns out that the FPE's that are most susceptible to contamination are also those that are susceptible to attitude and stability disturbances. With the present Space Station baseline, it is anticipated that the major contamination factor will be from the shuttle docking and the resultant contamination in the vicinity of the Space Station. Other than this, it would appear from the baseline that the contamination resulting from the free-flying modules would be very nearly the same as that resulting from the Space Station.

As shown in the size factor, many FPE's are shown as free-flyers or attached modules because of the specific design postulated for the particular FPE. In many cases, a design modification of the FPE will allow it to be flown as integral with the Space Station. Another factor in the size function driving experiments to attached modules is that large experiments utilize large volumes of the Space Station and would preclude doing simultaneous experiments through an airlock or with EVA involved at the same time. In addition, experiments that involve large antennas and large amounts of equipment aboard the Space Station would preclude conduct of other experiments. Experiments that fall in these categories are the small astronomy

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 4.4-13

LOGISTIC SUPPORT REQUIREMENTS

FOLDOUT FRAME 3

Requirements / FPE	Type	Operational Consumables Initial Weight X_g (lb)	Operational Consumables Initial Volume M^3 (Ft^3)	Operational Consumables Resupply (30 Days) Weight X_g (lb)	Operational Consumables Resupply (30 Days) Volume M^3 (Ft^3)	Operational Consumables Return (30 Days) Weight X_g (lb)	Operational Consumables Return (30 Days) Volume M^3 (Ft^3)	Spares and Maintenance Consumables Initial Weight g_g (lb)	Spares and Maintenance Consumables Initial Volume M^3 (Ft^3)	Spares and Maintenance Consumables Resupply (30 Days) Weight X_g (lb)	Spares and Maintenance Consumables Resupply (30 Days) Volume M^3 (Ft^3)	Spares and Maintenance Consumables Return (10 Days) Weight K_g (lb)	Spares and Maintenance Consumables Return (10 Days) Volume M^3 Ft^3)	Remarks
A1 X-Ray Astronomy														
- HI Res Telescope	None	0	0	0	0	0	0	25.2 (56)	0.06 (2)	12.6 (28)	0.03 (1)	12.6 (28)	0.03 (1)	
- Large Area Telescope	Cryogenics	20 (44)	0.03 (1)	3.3 (7.3)	0.005 (0.14)	0	0	22.2 (48.8)	0.06 (2)	11.1 (24.4)	0.03 (1)	11.1 (24.4)	0.03 (1)	
- Supplementary Experiments	None	0	0	0	0	0	0	0	0	0	0			
A2 Advanced Stellar Astronomy	Film	37	0.06	37	0.06	37	0.06	2.3	0.01	2.3	0.01	2.3	0.01	Update of Exp. will require about 306 KC. (6750); 1.3M3 (26.3 ft.3) per year
- 3-Meter Telescope		(81)	(2)	(81)	(2)	(81)	(2)	(5)	(0.3)	(5)	(0.3)	(5)	(0.3)	
A3 Advanced Solar Astronomy														
- 1.5 M Photo-heliograph		76 (167)	0.12 (4.1)	76 (167)	0.12 (4.1)	76 (167)	0.12 (4.1)	12.5 (27.5)	0.02 (0.67)	12.5 (27.5)	0.02 (0.67)	12.5 (27.5	0.02 (0.67)	Note: Operational consumables listed are to support a film system, if used.
- XUV Spectro-heliograph		15.3 (34)	0.03 (1)	15.3 (34)	0.03 (1)	15.3 (34)	0.03 (1)	6.7 (14.7)	0.01 (0.33)	6.7 (14.7)	0.01 (0.33)	6.7 (14.7)	0.01 (0.33)	
- X-Ray Grazing Incidence		2.5 (6.6)	0.006 (0.02)	2.5 (6.6)	0.006 (0.02)	2.5 (6.6)	0.006 (0.02)	7.5 (16.5)	0.01 (0.35)	7.5 (16.5)	0.01 (0.35)	7.5 (16.5)	0.01 (0.35)	
- Solar Coronagraph		10.7 (23.3)	0.02 (0.5)	10.7 (23.3)	0.02 (0.5)	10.7 (23.3)	0.02 (0.5)	3.3 (8.2)	0.005 (0.17)	3.3 (8.2)	0.005 (0.17)	3.3 (8.2)	0.005 (0.17)	
A4 Intermediate Size UV Telescopes														
- 0.94M Narrow Field	35MM Film	33.6 (74)	0.057 (2.0) (600 ft Reel)	5.7 (12.3)	0.017 (0.6) (600 ft Reel)	5.7 (12.3)	0.017 (0.6) (600 ft Reel)	-	-	-	-	-	-	
- 0.3M Wide Field	150MM Film	33.6 (74)	0.057 (2.0)	9.1 (20)	0.017 (0.6)	9.1 (20)	0.017 (0.6)	-	-	-	-	-	-	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

PRECEDING PAGE BLANK NOT FILMED

Table 4.4-13

LOGISTIC SUPPORT REQUIREMENTS (Continued)

FPE \ Requirements	Type	Operational Consumables						Spares and Maintenance Consumables						Remarks
		Initial		Resupply (30 Days)		Return (30 Days		Initial		Resupply (30 Days)		Return (10 Days)		
		Weight X_g (lb)	Volume M^3 (Ft^3)	Weight X_g (lb)	Volume M^3 (Ft^3)	Weight X_g (lb)	Volume M^3 (Ft^3)	Weight g_g (lb)	Volume M^3 (Ft^3)	Weight X_g (lb)	Volume M^3 (Ft^3)	Weight K_g (lb)	Volume M^3 (Ft^3)	
A6 Infrared Astronomy MSS	Cryogenics L Ne	273 (600)	0.23 (8)	45.5 (100)	0.04 1.4	- -	- -	0 0	0 0	0 0	0 0	0 0	0 0	
	L Ne	227 (500)	1.53 54	38 (83.4)	0.25 8.8	- -	- -	0 0	0 0	0 0	0 0	0 0	0 0	
P1 Space Physics Research Laboratory		13.5 (29.8)	0.13 (4.6)	8.03 (17.9)	0.07 (2.6)	8.03 (17.9)	0.07 (2.6)	19.53 (44.6)	0.18 (6.32)	9.82 (23.3)	0.09 (3.16)	8.8 (19.3)	0.06 (2.16)	
P2 Plasma Physics and Environmental Perturbation Laboratory	Polaroid Film Balloons Batteries Subsat Fuel	881 (1937)	0.64 (22.5)	516 (1135)	0.53 (18.9)	207 (455)	0.53 (18.5)	37 (81)	0.05 (2.0)	19 (41)	0.02 (1.0)	19 (41)	0.02 (1.0)	Polaroid Film weighs 17 lb. Magnetic tape for data recording determined separately as part of data management study.
P3 Cosmic Ray Physics Laboratory	Argon/Methane for Spark Chambers.	66 (146)	1 (35.2)	186 (410)	1.2 (40.5)	151 (333)	1.2 (40.5)	273 (600)	0.57 (20)	60 (150)	0.14 (5)	68 (150)	0.14 (5)	
Station and Shuttle/FF	Nuclear Emulsions and Magnet/Dewar	Emulsions and Magnet/Dewar Included in Exp Launch Weight		Magnet/Dewar, Once Per Year 1360 (3000)	5.6 (197)	680 (1500)	5.6 (97)							
P4 Physics and Chemistry Laboratory	Film, Magnetic Tape, etc., Gas, Fuels, Oxidant	225 (500)	0.364 (13.0)	112 (250)	0.364 (13.0)	45 (100)	0.028 (1)	37.6 (83.0)	0.227 (8.1)	18.8 (41.5)	0.114 (4.1)	18.8 (41.5)	0.114 (4.1)	
ES1 Earth Observation Facility	Magnetic Tape, Film	197 (437)	0.31 (10.1)	197 (437)	0.31 (10.1)	197 (437)	0.31 (10.1)	368 (820)	0.57 (20.5)	368 (820)	0.57 (20.5)	368 (820)	0.57 (20.5)	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FOLDOUT FRAME 3

PRECEDING PAGE BLANK NOT FILMED

Table 4.4-13

LOGISTIC SUPPORT REQUIREMENTS (Continued)

FPE \ Requirements	Type	Operational Consumables: Initial Weight X_g (lb)	Initial Volume M^3 (Ft^3)	Resupply (30 Days) Weight X_g (lb)	Resupply (30 Days) Volume M^3 (Ft^3)	Return (30 Days) Weight X_g (lb)	Return (30 Days) Volume M^3 (Ft^3)	Spares and Maintenance Consumables: Initial Weight g_g (lb)	Initial Volume M^3 (Ft^3)	Resupply (30 Days) Weight X_g (lb)	Resupply (30 Days) Volume M^3 (Ft^3)	Return (10 Days) Weight K_g (lb)	Return (10 Days) Volume M^3 (Ft^3)	
ES1 5 Day Shuttle		Not a Payload for a 5-Day Shuttle (See Subgroup Requirements)												
C/N1 COM/NAV	Film Magnetic Tape *Reentry Vehicles	28.6 (63)	0.03 (1.0)	28.6 (63)	0.03 (1.0)	28.6 (63)	0.03 (1.0)	30 (66)	0.21 (7.3)	15 (33)	0.11 (3.7)	15 (33)	0.11 (3.7)	*Host Vehicle supplied
MS1 Materials Science and Manufacturing in Space	Experiment Materials	650 (1432.2)	0.16 (19.95)	650 (1432.2)	0.16 (19.45)	412 (906.4)	0.22 (7.72)	393 (865)	2.41 (86.3)	314 (692)	1.94 (69.2)	157 (346)	0.97 (34.6)	
T1 Contamination Measurements Station	Film	1.8 (4)	0.011 (0.4)	0.9 (2)	0.006 (0.2)	0.9 (2)	0.006 (0.2)	7.7 (17)	0.044 (1.6)	3.8 (8.5)	0.022 (0.8)	3.8 (8.5)	0.022 (0.8)	
	N_2	4.5 (10)	0.018 (0.64)	2.27 (5)	0.009 (0.32)	0	0							
	Samples	0	0	1.8 (4)	0.02 (0.8)	1.8 (4)	0.02 (0.8)							
T2 Fluid Management Station	Liquid Hydrogen	0	0	450 (985)	11 (391)	0	0	54.7 (132.5)	0.046 (1.55)	10.2 (27)	0.007 (0.25)	54.7 (132.5)	0.046 (1.55)	Spares are electronic and mechanical parts
T3 EVA Logistics Spares		493 (1084)	0.44 (15.8)	462 (1015)	0.44 (15.1)	23.2 (51)	0.006 (0.2)	97 (213.6)	0.62 (22.3)	31.5 (69.3)	0.12 (4.4)	31.5 (69.3)	0.12 (4.4)	
T4 Advanced Spacecraft Systems Tests	ACS Fuel	0	0	75 (165)	0.08 (3)	0	0	30 (65)	0.045 (1.6)	15 (32.5)	0.022 (0.8)	15 (32.5)	0.022 (0.8)	Spares are electronic and mechanical parts
T5 Teleoperation		137 (307)	4.14 (148)	30 (67)	0.45 (16)	0	0	52 (116)	0.33 (11.9)	13.6 (30)	0.09 (3.1)	39.1 (H6)	0.25 (8.8)	
LIFE Sciences Stations	Gas, Food, Charts, Containers, Samples	30 (64)	0.1 (3.5)	30.0 (3.0)	0.1 (3.0)	1.0 (22.0)	0.06 (2.2)	100 (220)	0.3 (12.0)	25 (55)	0.05 (2.5)	3 (150)	0.02 (0.75)	

PRECEDING PAGE BLANK NOT FILMED

Table 4. 4-14

MODE OF ACCOMMODATION

FPE or Subgroup	Name of FPE Subgroups	Allowable MOA	Primary Determining Factors				
			Attitude Stability	G-Level	Contamination	Size	Remarks
A-1	X-Ray Stellar Astronomy (FF)	FF	X		X	X	
A-2	Advanced Stellar Astronomy (FF)	FF	X	X	X		
A-2A	Intermediate Stellar Telescope (FF)	FF	X		X	X	FF—Free Flyer
A-3AA	Advanced Solar Astronomy (FF)	FF	X		X	X	
A-3CC	ATM Follow-On (FF)	FF	X		X	X	DM—Attached Module Dedicated to one Experiment Group
A-4A	C-9M Narrow Field UV Telescope (ATT)	AM			Clean	X	
A-4B	C-3M Wide Field UV Telescope (ATT)	AM			Clean	X	AM—Attached Module with Approximately 1/2 Volume as Airlock Accommodates More Than One Experiment Group
A-4C	Small UV Survey Telescope (ATT)	AM			Clean	X	
A-5A	X-Ray Telescope (FF)	FF			X	X	
A-5B	Gamma Ray Telescope (ATT)	AM				X	
A-6	IR Telescope (ATT)	AM			Clean	X	
P-1A	Atmospheric and Magneto Science						I—Integral to Station or Pressured Section of AM
P-1B	Cometary Physics	I			Clean		
P-1C	Meteoroid Science	AM				X	
P-1D	Thick Material Meteoroid Penetration						
P-1E	Small Astronomy Telescopes						
P-2A	Wake Measurements From Station and Booms	I					
P-3	Cosmic Ray Physics Lab (ATT)	DM				X	
P-3C	Plastic/Nuclear Emulsions	I					
P-4A	Airlock and Boom Experiments	I					
P-4B	Flame Chemistry and Laser Experiments						
P-4C	Test Chamber Experiments						
ES-1	Earth Observation Facility (ATT)	DM			Clean	X	
ES1A	Earth Observation Sequential (ATT)				Clean	X	

Table 4.4-14

MODE OF ACCOMMODATION (Continued)

FPE or Subgroup	Name of FPE Subgroups	Allowable MOA	Primary Determining Factors				Remarks
			Attitude Stability	G-Level	Contamination	Size	
ES-1G	Minimum Payload (CORE)	AM			Clean	X	
CN-1	Communications/Navigations Facility (ATT)						
CN-1A	COM/NAV Subgroup A (ATT)	AM				X	
CN-1B	COM/NAV Subgroup B (ATT)						
MS-3A	Crystal Growth, Biological and Physical Processes	I				X	
MS-3B	Crystal Growth From Vapor						
MS-3C	Controlled Density Materials						
MS-3D	Liquid and Glass Processing						
MS-3E	Supercooling and Homogeneous Nucleation						
T-1A	Contamination Experimental Package	I					
T-1B	Contamination Monitor Pkg.						
T-2A	Long-Term Cryo Storage (FF)	FF		X			
T-2BB	Short Term Cryos (FF)						
T-3A	Astronaut Maneuver Unit	I				X	
T-3B	Manned Work Platform (ATT)	AM				X	
T-4A	Long Duration System Tests	I					
T-4B	Medium Duration Tests						
T-4C	Short Duration Tests	I/FF	(Partial)				
T-5A	Initial Flight, Teleoperator	I					
LS-1A	Minimal Medical Research Facility	I					
LS-1B	Minimal Life Science Research Facility						
LS-1C	Intermediate Life Science Research Facility						
LS-1D	Dedicated Life Science Research Facility	DM				X	

telescopes, some physics payloads, small Earth Surveys sensor complement experiments, some of the technology experiments, and the more-complex life science payload. As a result of this analysis, all of the experiments marked "I" are accommodated or performed in or from the GPL of the modular Space Station. All other experiments, whether free-flying or attached modules, are supported in one way or another in the GPL. Detailed discussion and examples of the performance and acommodation of experiments in the GPL and module support performed by the GPL are covered in detail in subsequent sections of this report.

4.4.3 General Purpose Laboratory Selected Design

This section covers the detailed requirements, definition, and configuration of the GPL, and the individual facilities comprising it. The operation of the GPL is described as is the operation of each individual facility. Equipment in each facility is specified and defined, physical data of each facility is given, a detailed equipment layout is shown, and description of the utilization of the equipment in each facility is provided. As described earlier, the GPL is subdivided into laboratories and facilities which are related. Primary performance characteristics in some of the basic equipment will be utilized throughout the total life of the Space Station. Other equipments will be changed as the mission and experiment requirements change. However, all equipment is built in a modular manner so that it can be removed from the GPL and other equipment installed in its place.

Clear access, 5-ft in dia, is provided along the whole length of the GPL. A rail serving as a track for a small trolley to move and restrain large items being moved from one area to another – is provided along the top of the 5-ft dia access to provide controlled movement in the aisle.

Each piece of equipment will have foot restraints and pelvic restraints where appropriate to allow hands-free operation of the equipment. In addition, the equipments will have hand rails to allow mobility within the GPL. All work stations will have restraining or holding devices to keep experiment items and equipment and tools in place.

Attachments for emergency suit preparation, breathing, and communications facilities are located strategically within the GPL as is an emergency aid station. Also, the GPL contains emergency provisions in case other modules of the Space Station become inhabitable. All work areas have appropriate fire fighting and other emergency equipment.

Storage will be provided for bench-type equipment and hand tools in the labor- laboratory or facility with which the equipment and tools are associated.

Figure 4.4-5 is an inboa rd profile of the General Purpose Laboratory show ing facilities and their locations. Figure 4.4-6 is a cut-away view of the GPL showing the facilities that support the Space Station experiments, RAMs, and subsystems. As shown, the GPL is configured to support an initial experiment program with further equipment being brought up at a later date. The laboratories and facilities in the General Purpose Laboratory include:

A. A Mechanical Sciences Laboratory for materials science analysis, assembly and disassembly of equipments, and any other functions normally requiring mechanical-type tests or assembly and dis- assembly equipments.

B. An Optical Sciences Laboratory for checkout, calibration, and analy- sis of optical experiments or operational equipment.

C. An Electronic/Electrical Laboratory for all functions associated with checkout, tests, stimuli generation, and contingency repair of electronic/electrical equipment.

D. An Experiment and Test-Isolation Laboratory which allows experi- ments and operations to be isolated from the environment of a Space Station for safety purposes or when it is required that the function be performed in an isolated area.

E. Hard-Data Processing Facility mainly for the processing, develop- ment, and quick-look of any film-related operations.

F. A Data-Evaluation Facility which functions to evaluate and process any data required by Space Station experiments or operational systems.

Page intentionally left blank

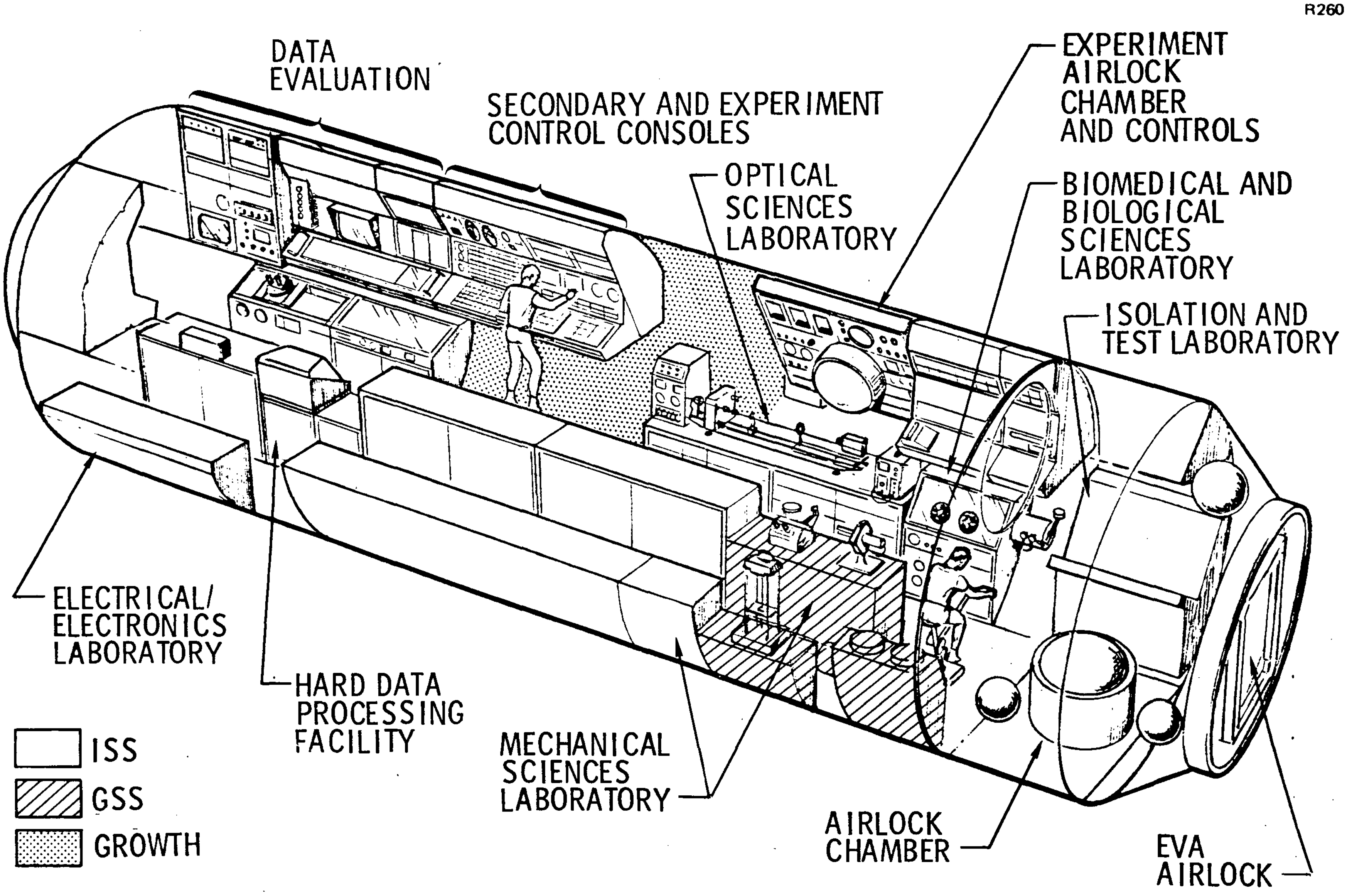


Figure 4.4-6. General Purpose Laboratory – Cut Away View

G. A Biomedical/Bioscience Laboratory for redimentary biomedical and bioscience experiments as well as for monitoring astronaut well-being. Table 4.4-15 presents an assembly data sheet summarizing the major characteristics of the GPL and facilities, showing requirements of each of the laboratories and facilities which have been designed into the GPL, the major subsystem interface associated with each laboratory, and any special characteristics that may influence design of other portions of the Space Station. Table 4.4-16 is a listing of all major equipment in the GPL with the weight and volumes of each piece of equipment given.

4.4.3.1.1 Data Evaluation Facility

Table 4.4-17 is a list of equipment in the GPL Data-Evaluation Facility. The Data-Evaluation Facility includes both functions or capabilities that are logically related to or associated with the availability of film, video, analog, and digital data and the handling, processing, and evaluation of such data.

This facility is both an experiment and operations support facility and, as such, provides services to all experiments and subsystems. The Data-Evaluation Facility is an integral part of the Information Management system as seen on the assembly data sheet, Table 4.4-18. Many pieces of equipment that are located in the Data Evaluation Facility are part of the Data Management subsystem and will be described in the Data Management section of this report. Figure 4.4-7 is a perspective view of the Data-Evaluation Facility showing equipments as placed in the GPL and with the multi-format viewer/editor in use. The equipment in the Data Evaluation Facility, as shown on the assembly data sheet of Table 4.4-18 is based on state-of-the-art ground equipment and the sizes as shown are based on rectangular configurations or swept volume of equivalent ground equipment. As can be seen from the perspective view, the equipment shown is modified to accept the form factor of the Space Station and, as such, the equipment does not lend itself to specification of length, width and height. However, the volumes allowed in the Space Station are equivalent to those of volumes show shown on the assembly data sheet. In addition, it has been determined for

Table 4.4-15

GENERAL PURPOSE LABORATORY

Facility	Requirements	Major Interfaces	Remarks
Hard-Data Process	Fluid-Tight Equip Filter System; Light Tight Closure	Water System, ECLS, Power	
Electronics/ Electrical Lab	Power to Electronic Equip, High Voltage & Power Safety	Power	
Mechanical Sciences Lab	X-Ray Safety, Cleaning & Purging, Glove Box Mechanical Assembly/ Disassembly, Metals Testing, Storage Space for FPE Equip	Power, ECLS, Waste Management	Experiment & Test Isolation Facility in Mech Lab.
Experiment & Test Isolation Lab	Isolation for Pressurized Gases, Fluids, & Cryogenics. Airlock with Heat Exch, Hydraulic/ Pneumatic Test Bench, must take reverse press.	ECLS, Power	Remote Detection for Environment Required.
Optical Sciences Lab	Light Closure, Storage Space for FPE Equip, Heat Exchanger for High-Energy Light Sources, Rigid Optical Flat & Optical Bench	Power Filter	Airlock & Viewport in Facility

Table 4.4-15

GENERAL PURPOSE LABORATORY (Cont.)

Facility	Requirements	Major Interfaces	Remarks
Airlock Facilities	Airlocks with Deployment Mech. Viewing Ports into Airlock, for Airlock to look outside Station. Heat Exchanger on Airlock in Experiment & Test Isolation Facility. Remote monitoring and Control of Airlock in Experiment & Test Isolation Facility.	Power, ECLS	Airlock in Experiment & Test Isolation Facility. Airlock in Optics Facility.
Data-Evaluation Facility	Fluid Tight Equipment, Filter System, Light Closure	Data Management, ECLS, Power	
Biomedical/ Bioscience Lab	Fluid-tight equip; Filtered atmos in equip	Water, ECLS Power, Data Management	Operational for astronaut well-being and experimental

Table 4.4-16

GENERAL PURPOSE LABORATORY MAJOR EQUIPMENT

Item	Weight (Kg)	Volume ($M^3 \times 10^{-2}$)
1. Hard-Data Processing Facility	22.6	45.0
Film Processor - Rapid	22.6	45.0
Film and Plate Processor - Color	44.0	168.0
Film Processor - Black and White	33.0	75.0
Film Storage	775.0	210.0
*Video Data Display and Control Console	22.6	45.0
Micro Filmer	22.6	45.0
Light Table	22.6	75.0
**Spectro Photometer	4.54	5.6
Densitometer	9.00	5.6
*Operations Console	22.6	45.0
*Experiment Display and Control Unit	22.6	75.0
2. Electronic/Electrical Laboratory		
Electronic Work Station	45.0	90.0
Multi-instrument Test Bench	90.0	90.0
Battery Charger	22.6	45.0
High-Voltage Source	45.0	45.0
High-Energy Counter Calibration Equipment	22.6	45.0
Miniature Glove Box	9.0	33.0
3. Experiment and Test Isolation Laboratory		
Hazard Detection System	13.5	33.0
Electrical and Vacuum Power Center	45.0	75.0
Hydraulic/Pneumatic Work Station	45.0	75.0
Cryogenic and Fluid Storage	22.6	45.0
High-Pressure Gas Storage	22.6	45.0
Airlock/Environmental Chamber	180.0	100.0
Chemistry and Physics Glove Box	34.0	67.0
Chemistry and Physics Analysis and Storage Unit	45.0	75.0
4. Optical Sciences Laboratory		
Optical Work Station	45.0	168.0
Optical Bench	90.0	90.0
**Precision Work Fixtures	22.6	5.0
**Microdensitometer	9.0	5.0
**Monochromator Spectrometer	9.0	5.0
**Modulation Transfer Function Measurement System	9.0	10.0
**Optical Spectrum Analyzer	9.0	5.6
Scientific Airlock Chamber	90.0	33.5
Precision Optical Window	9.0	.2
5. Mechanical Laboratory		
Mechanical Workbench	45.0	90.0
Experiment and Isolation Test Laboratory Monitor Panel	22.6	67.0
Laminar Flow Vacuum Glove Box	90.0	67.0
Specimen Structural Tester	45.0	45.0
Metallographic Tester and Microscope	45.0	75.0
Thermo-Structural Test Equipment	45.0	45.0
X-ray Generator	67.0	45.0
**Precision Work Fixture	9.0	2.8
6. Biomedical/Bioscience Laboratory		
Biochemical and Biophysical Analysis Unit	45.0	67.0
Bioscience Glove Box	67.0	67.0
Bicycle Ergometer	9.0	33.5
Lower Body Negative Pressure Device	18.0	33.5
Body Mass Measuring Device	18.0	45.0
Biomedical Display and Control Unit	45.0	67.0

*Combined into an Experiment/Secondary Control Console.
**This equipment normally stored.

Table 4.4-16 (Continued)

Item	Weight (Kg)	Volume ($M^3 \times 10^2$)
7. Data Evaluation Facility		
Multi-format Viewer Editor	67.0	75.0
Microfilm Retrieval System	180.0	75.0
Automatic Film Reader	90.0	67.0
Copy Machine	45.0	45.0
Stereo Viewer	45.0	75.0
*Image Processing and Data Management Control Station	45.0	75.0
Working Image Storage	5.0	5.6
Permanent Video Storage	45.0	5.6
Permanent Digital Storage	18.0	5.6
Time Reference Unit	4.5	5.6
Printer	22.6	45.0
*T.V. Camera Control Unit	9.0	12.0
Video Tape Unit	22.6	45.0
Scientific Computer	90.0	75.0
Analog Recorders	90.0	45.0
Digital Storage	67.0	45.0
*Experiment Control Console	454.0	75.0

*Combined into an Experiment/Secondary Control Console

Table 4.4-17

DATA EVALUATION FACILITY

Multi-Format Viewer Editor	Permanent Video Storage
Microfilm Retrieval System	Permanent Digital Storage
Automatic Film Reader	Time Reference Unit
Copy Machine	Printer
Stereo Viewer	Video Tape Unit
Image Processing and Data Management Control System	Scientific Computer
Working Image Storage	Adjustable Multi-Channel Filter

each piece of equipment (by the nature of the specific hardware) that the equipments can easily be modified to the Space Station form factor without changing any basic hardware concept of existing state-of-the-art equipment. An example of this approach is shown when Figure 4.4-7 is compared with Figure 4.4-8. Figure 4.4-8 represents a multi-format viewer/editor which is currently being produced for institutional and military applications by a prominent U.S. manufacturer. This multi-format viewer-editor can accept film widths from 35 mm up to 9 inches and can accept film plate. It projects images and film frames up to 30 times magnification, has the capability of producing hard copy of select frames, has a film-speed control which allows searching for a specific frame, and has the capability of projecting the image that the Earth receives through a TV system to any TV monitor linked to the Space Station data bus. This piece of equipment was used as a model for the multi-format viewing editor selected for the Space Station Data Evaluation Facility. It is versatile, has a built-in modular format, is easily serviceable, is reliable, and has proven itself in usage.

The micro-film retrieval system is capable of storing 30 million frames of data with a maximum search time of 20 seconds. The micro-film retrieval system can be updated using the micro-filmer and the hard-data processing

Table 4.4-18

DATA EVALUATION FACILITY ASSEMBLY DATA SHEET

Unit Name	Size (ft)	Access Location	Interface	Remarks
Multiformat Viewer Editor	3 x 2 x 4	Front and Back	Electrical	Low light level
*Microfilm Retrieval System	6 x 2 x 4	Front	Electrical	
Image Processing Control	3 x 2 x 4 H	Front, some maintenance from back	Electrical Data channels OCS	Playback unit, need for verifying recording capability, particularly two or more FPE's at the same time.
*Video Tape Unit	3 x 2 x 3 H	Front, some maintenance from back	Electrical Data channels	Video Data
*Automatic Film Reader	4 x 2 x 5 H	Front and rear	Electrical Data channels	
Copy Machine	2 x 1 x 3 H	Front and top	Electrical OCS	
Printer	2 x 2-1/2 x 3 H	Front	Electrical	
Stereo Viewer with Film Transport, and crosshead feed; fitted for viewing	4 x 2 x 3 H	Front and top	Electrical OCS	Mounted on bench
*Adjustable Multichannel Filter		Over editor and from back	Data channels	
*Time Reference Unit	1 x 1 x 2	Two sides	Electrical Data channels	
*Permanent Digital Storage	3 x 2 x 2 H	Front, some maintenance from back	Electrical Data channels OCS	Playback unit, need for verifying recording capability, particularly two or more FPE's at the same time.
*Permanent Video Storage	3 x 2 x 3 H	Front, some maintenance from back. Provide over-head racks	Electrical Data channels OCS	Video data evaluation
*Working Image Storage	3 x 2 x 1 H	Front		Possibly tape stowage

*Equipment part of Data Management Subsystem, located in and utilized as part of the data evaluation facility.

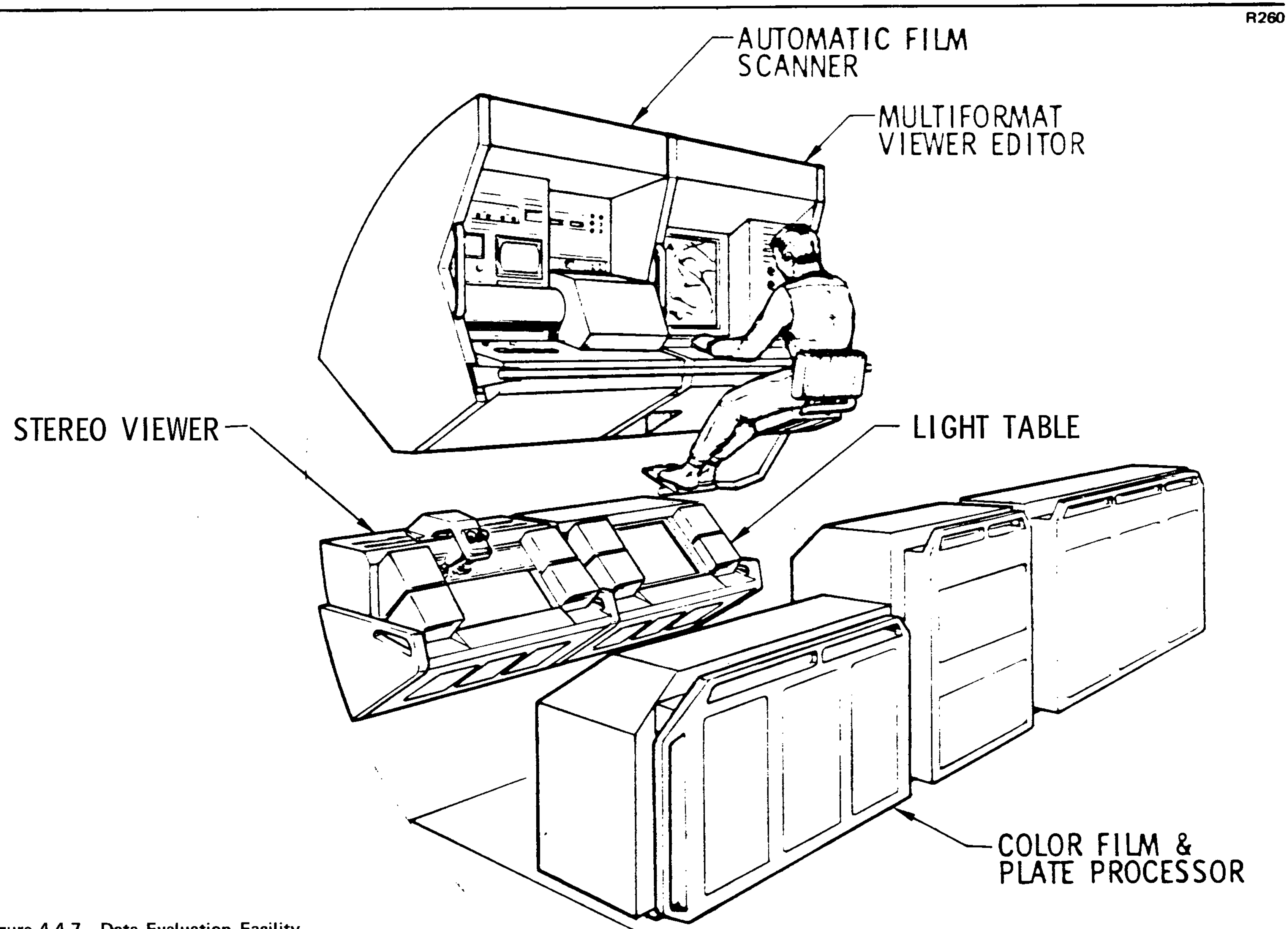


Figure 4.4-7. Data Evaluation Facility

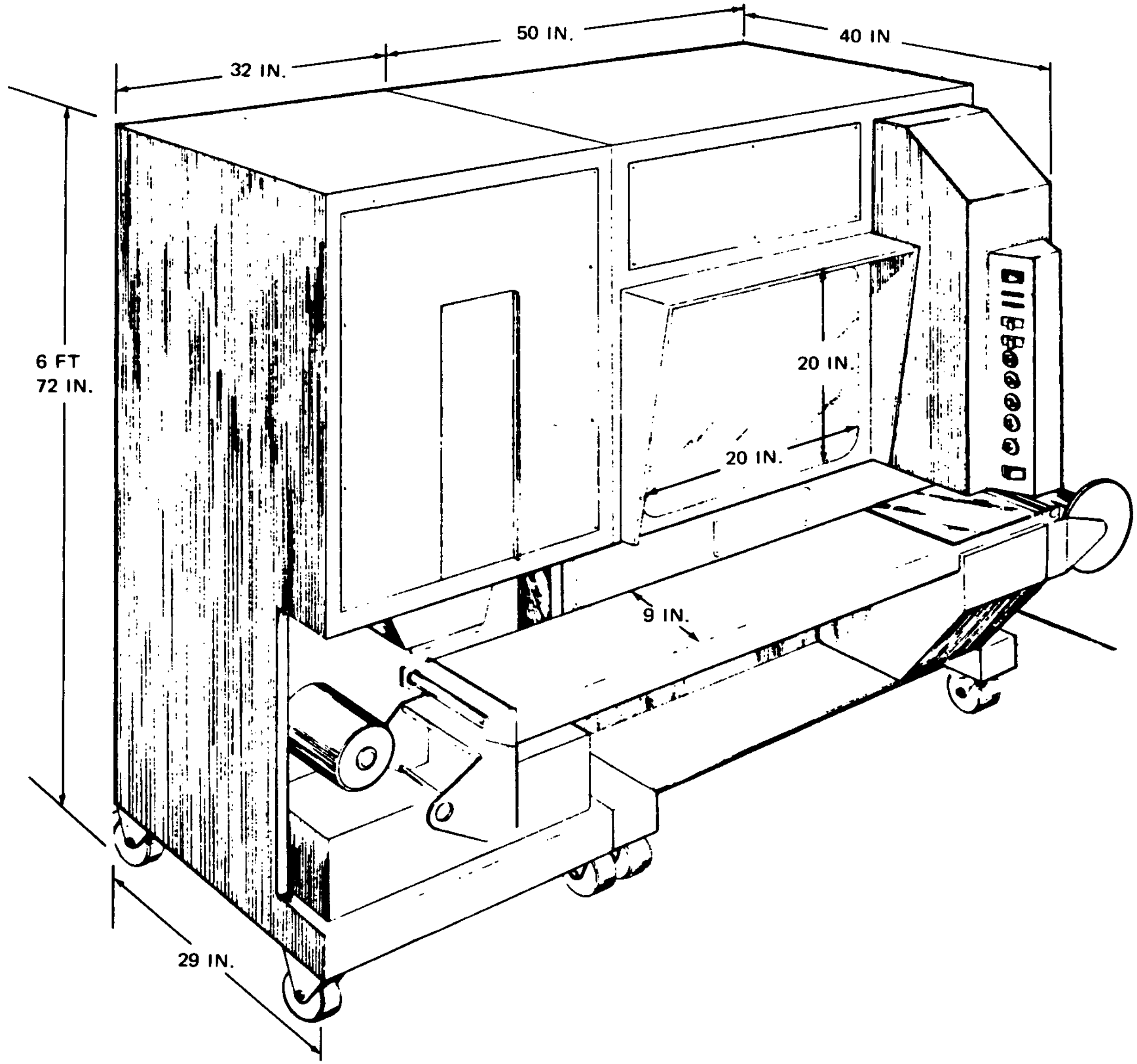


Figure 4.4-8. Multi–Format Viewer Editor

facility; when the system is loaded to lower than the 30-million frame capacity, it has a proportionally shorter search time. 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. This piece of equipment also has been modelled after an existing piece of equipment now in the field and being used by government agencies for reliable rapid microfilm searches and storage.

The copy machine in the Data-Evaluation Facility is a Xerox-Type copier which can produce high-contrast copies of black and white documents on a multiple or single basis. These types of equipments have been in use for many years and are highly reliable and versatile.

The stereo viewer is a standard piece of equipment utilized for stereo film evaluation and analysis. The stereo viewer shown in the Data-Evaluation Facility is modelled after equipment currently in wide-spread use by the military.

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 take 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. Other equipments in the Data-Evaluation Facility are described in data-management section of this document.

4.4.3.1.2 Mechanical Sciences Laboratory

The Mechanical Sciences Laboratory supports the widest range of experiments and operational functions of any GPL facility. Many types of mechanical, electromechanical, and chemical functions can be accommodated by the equipment in this Laboratory. These equipments, while supporting specific FPE's, have a potential use for operational capability and other uses that

9⊕

makes them valuable in a GPL. Table 4.4-19 lists the equipment in the Mechanical Sciences Laboratory and Table 4.4-20 is the assembly data sheet listing the installation requirements and interfaces of the equipment.

As seen in Figure 4.4-9, the Mechanical Sciences Laboratory features a laminar-flow glove box for heavy duty and light-duty repair, replacement, purging, cleaning of experiment 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 washings or treating and must be isolated from the Space Station environment and flight crew. The glove box also provides the capability to work on materials, such as cutting, chipping, sawing, turning, and any other similar-type operations. The Mechanical 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 a type of general-purpose equipment found in a metallurgical mechanical research laboratory and is necessary for performance and analysis of material sciences experiments, as well as operational support of subsystems. Other equipments utilized for mechanical sciences experiments that might be provided at a later data for detail and complex scientific analysis of materials are x-ray diffraction units and a scanning electron microscope. These items have not been provided aboard the GPL because of the detailed scientific knowledge necessary to operate these equipments and the high power required.

To illustrate the technique used for selection of equipment in the mechanical sciences laboratory, the Blue Book called for onboard data analysis of material sciences experiments. The research metallograph is a multipurpose piece of equipment which includes magnification capabilities for specimens up to 2000 times and contains a hardness tester, a notch tester and the capability of accepting micro-photographic equipment and cini-microphotographic equipment. The metallograph, in conjunction with sample preparation equipment utilizing the vacuum laminate flow glove box and photographic processing equipment, in the hard data processing facility, will be used to conduct analysis and investigations on welding, plating, bonding, corrosion,

Table 4.4-19

MECHANICAL SCIENCES LABORATORY

Mechanical Workbench
Experiment and Isolation Test Laboratory Monitor Panel
Laminar Flow Go Laminar Flow Glove Box
Specimen Structural Tested
Metallographic Tester and Microscope
Thermo-Structural Test Equipment
X-Ray Generator

Table 4.4-20

MECHANICAL SCIENCES LABORATORY
ASSEMBLY DATA SHEET

Name	Physical Description (lb)	Installation	Interfaces	Remarks
Chemical and Mechanical Vacuum Glove Box	100 dry	Access to front	Electrical Plumbing Vacuum Pumpdown	Contamination Test Equipment
Metallographic Tester and Microscope	55	Access top and front		
Electro/ Mechanical Heavy Duty Workbench	175	Access front and top	Electrical	
Thermo-structural Test Equipment	45	Access top and front	Radiator	
Specimen Structural Tester	50	Access top and sides	Electrical	
X-Ray Generator	75	Access front	Electrical	X-Ray Shielding built into equipment
Experiment and Isolation Test Laboratory Monitor Panel			Data Bus	TV and View-port into Isolation and Test Laboratory

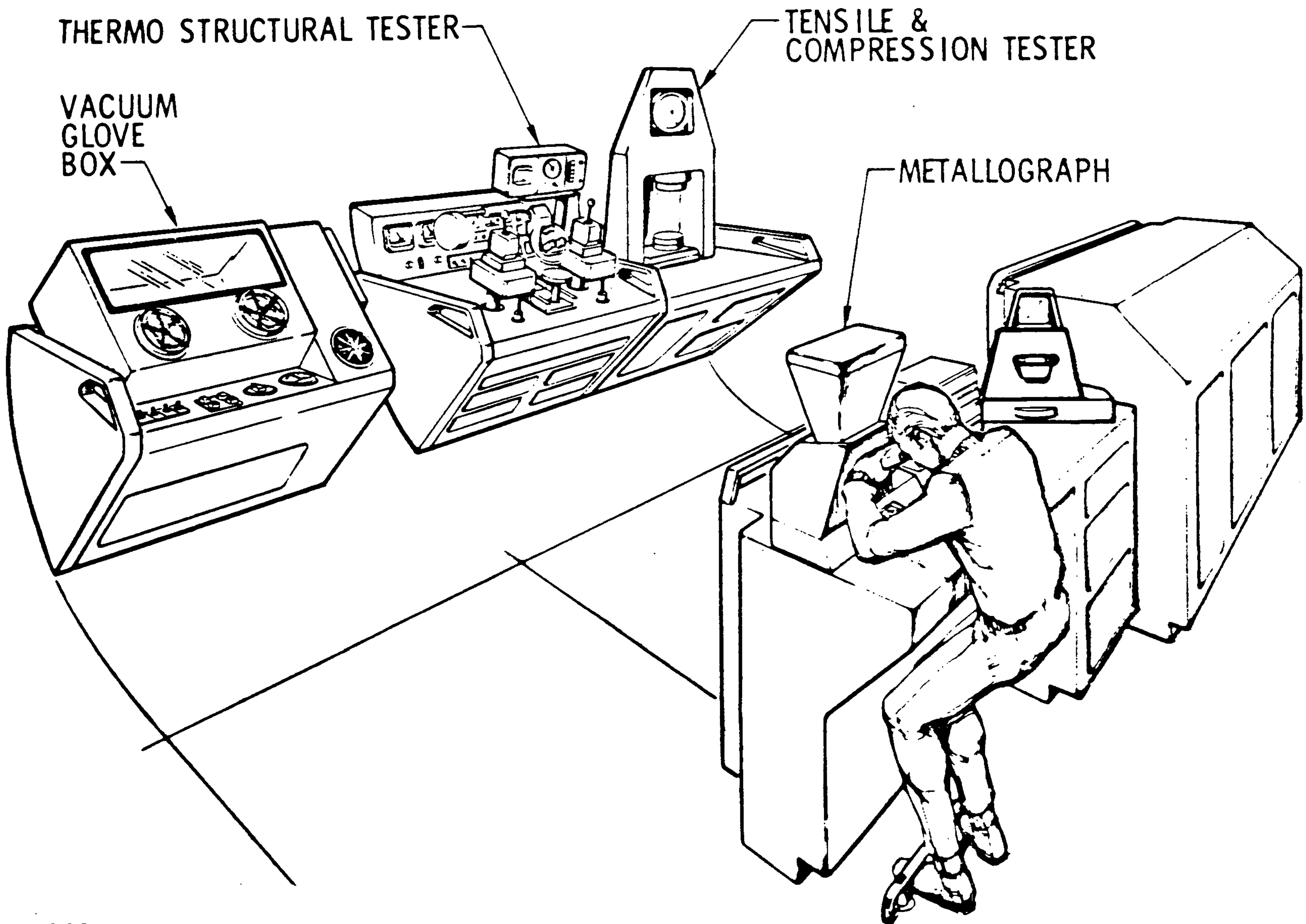


Figure 4.4-9. Mechanical Sciences Laboratory

grain structure, etc. The equipment shown is modeled after an existing piece of equipment now in use in metallurgical research laboratories.

4.4.3.1.3 Optical Sciences Laboratory

The Optical Sciences Laboratory is capable of setting up and performing FPE's, maintenance, and operations requiring optical support. The Laboratory includes equipments and facilities to provide a capability for a wide range of optical calibrations, maintenance, measurements, and tests. Table 4.4-21 shows a list of the equipments in the Optical Sciences facility and Table 4.4-22 is an assembly data sheet showing the physical characteristics and interfaces of the equipments. Figure 4.4-10 shows the Optical Sciences Laboratory as installed in the GPL in use performing analysis of an experiment specimen.

The Optical Sciences Laboratory is utilized for optical test calibration and alignment of equipment of FPE's. This equipment supports a wide range of experiments and experiment of operational equipment such as cameras navigation equipment, electronic imagers, tracking equipment, contamination sensors, and any other equipment that requires spectral or light-related or optical-related calibration setup, normalization, or diagnosis.

The Optical Sciences Laboratory contains a scientific airlock chamber for per-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 ultra-violet rays for astronaut safety. The scientific airlock chamber is 0.61 m in dia. However, space in the GPL is available if further definition of the experiment packages require a larger scientific airlock chamber associated with the Optical Sciences Laboratory.

An experiment and airlock display and control unit is mounted adjacent to the airlock for control and operation of the experiments associated with the

Table 4.4-21

OPTICAL SCIENCES LABORATORY

Optical Workbench, Zero-g
Bench, Optical, with Ancillary Apparatus and OCS
Precision Work Fixture
Modulation Transfer Function Measurement System
Microdensitometer
Optical Spectrum Analyzer
Monochromator Spectrometer

Table 4.4-22

OPTICAL SCIENCES LABORATORY ASSEMBLY DATA SHEET

Name	Physical Description (in.)	Installation	Interfaces	Remarks
Bench, Zero-G, Light Duty	60 x 30 x 76 H Wt = 120 lb		Electrical	
Bench, Optical Ancillary Apparatus including MTF Analyzer. Has OCS/OCS Ancillary Interface Unit	150 x 24 x 36 H Wt = 500 lb	Install with long focal length path to precision table in electro-mechanical shop.	Electrical OCS	Scientific apparatus. Handle lens systems for alignment and calibration
Precision work fixture	50 x 24 x 24 H	Stowed when not in use	Mechanical Lab	Use for Opto-mechanical Calibration
Modulation transfer function measurement system	24 x 24 x 36 H Wt = 50 lb	Use with optical bench	Electrical	Lens and sensor testing calibration, etc.
Micro-densitometer	24 x 24 x 36 Wt = 75 lb	Use on bench top	Electrical	Requires low management level
Optical Spectrum Analyzer	12 x 12 x 24 H Wt = 25 lb	Use on bench top	Electrical	
Monochromator Spectrometer	12 x 12 x 24 Wt = 25 lb	Use on bench top	Electrical	

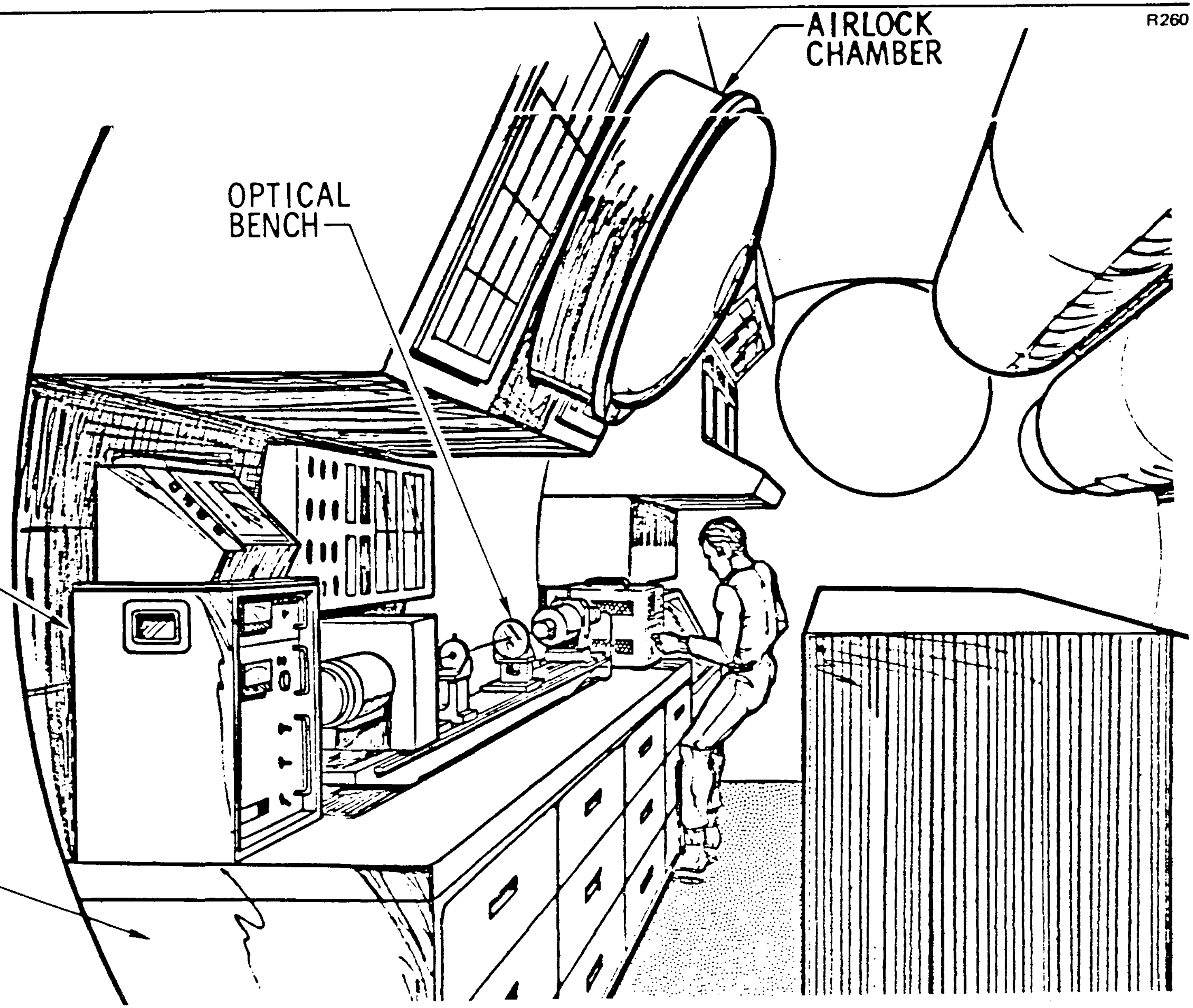


Figure 4.4-10. Optical Sciences Laboratory

Optical Sciences Laboratory on the experiment airlock chamber. An airlock chamber extension is provided which allows the chamber to accommodate experiment packages up to 7 feet in length. Included in the Optical Sciences Laboratory is a heat dissipation unit which will work in conjunction with a high-intensity light source when used on the optical bench.

Figure 4.4-10, in addition to showing the equipments in the Optical Sciences Laboratory, is an example of performance of an experiment in the laboratory; the figure shows a specimen in the process of being evaluated. The specimen is a coated lens which has been exposed to the environment outside the Space Station. The crewmen is shown checking and recording the spectral transmission characteristics of the lens that has been exposed. A calibrated, white-light source with appropriate filters is utilized as a light-transmission vehicle. The spectral record is compared with the record made before the lens is exposed to determine the extent of the spectral changes.

Also shown on the optical bench is a modulation transfer function measurement unit. After the spectral degradation of the lens has been measured, the lens will be tested for resolution (modulation transfer function) degradation by transmitting a collimated light source (laser) through gratings and slits to the lens and recording the ability of the lens to pass frequencies generated by the grating and slit. The resulting recording is then compared with the modulation transfer function that was recorded before exposure to determine the extent of resolution degradation.

When working with these types of equipments, a swing-aside light suppressing panel will be drawn around the optics bench to cut off extraneous light from the equipment and to close off the Optical Sciences Laboratory from outside interference.

4.4.3.1.4 Hard-Data Processing Facility.

The Hard-Data Processing Facility provides all the equipment that is utilized for film, film handling, processing, film spectral and density calibration, and quick-look film strip evaluation. The hard-data process facility services all experiments and operations that utilize film and, as such, is used widely for many FPE's and operations. Table 4.4-23 shows a list of the equipment in the hard-data processing facility; Table 4.4-24 is an assembly data sheet listing the characteristics of this equipment. Figure 4.4-11 is a perspective of the proposed hard data processing facility, showing the equipment as it is installed in the GPL.

Film and plate storage is carried out 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 temperatures can be used to lengthen film shelf life. Most film will be stored in the film vault for use; however, it is not necessary for slow-speed films to be stored in the film vault as long as they are kept away from extensive and excessive heat.

The film and plate processors will be based on current technology for spray-type processors with double barriers and seals added to equipment for safety against potential emission of toxic fluids or gases.

The rapid film processor can use a dry or semi-dry process as has been used previously on spacecraft such as the Lunar Orbiter. This type of film processor has proven itself,is 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 on the Logistics Module flight, kept on board the Space Station for further evaluation, microfilmed, analyzed in the data evaluation facility, or copied on the contact printer or the photo copier. It is not anticipated that any difficulty would occur in producing film processors for use in the Space Station as spray processors have been used for many years, as long as there is spray under pressure, they can be used in zero-g. In addition, processors aboard military aircraft have been used for many years and have proven highly successful.

Table 4.4-23

HARD DATA PROCESSING FACILITY

Film and Plate Processors Film Storage Video Data Display and Control Console* Micro Filmer Light Table Spectrophotometer Densitometer Operations Console* Display and Control Unit**
*Included in Experiment/Secondary Control Console **Included as part of each item of equipment

Table 4.4-24

HARD DATA PROCESSING FACILITY ASSEMBLY DATA SHEET

Name	Size (ft)	Access Location	Interfaces	Remarks
Film & Plate Processor, Color	4 x 1.5 x 3	Access front & top	Electrical	High resolution
Film Processor, B&W		Access front	Electrical	High resolution
Film Processor, B&W, Rapid	1 x 2 x 2	Access two sides	Electrical	Non-critical B&S
Film Storage	3 x 1 x 6	Access front	Electrical	Daily usage. Radiation shielding
Video Data-Display Console	2 x 3 x 5	Access front & rear	Electrical (OCS)	
Microfilmer	2 x 2 x 5	Access front & top	Electrical	
Light Table	1.5 x 4 x 3	Access top & front	Electrical	
Spectrometer	1 x 1 x 1.5	Access top	Electrical	
Densitometer	1 x 2 x 2	Access top & front	Electrical	
Operations Console	3 x 2 x 5	Access front & rear	Electrical	

R260

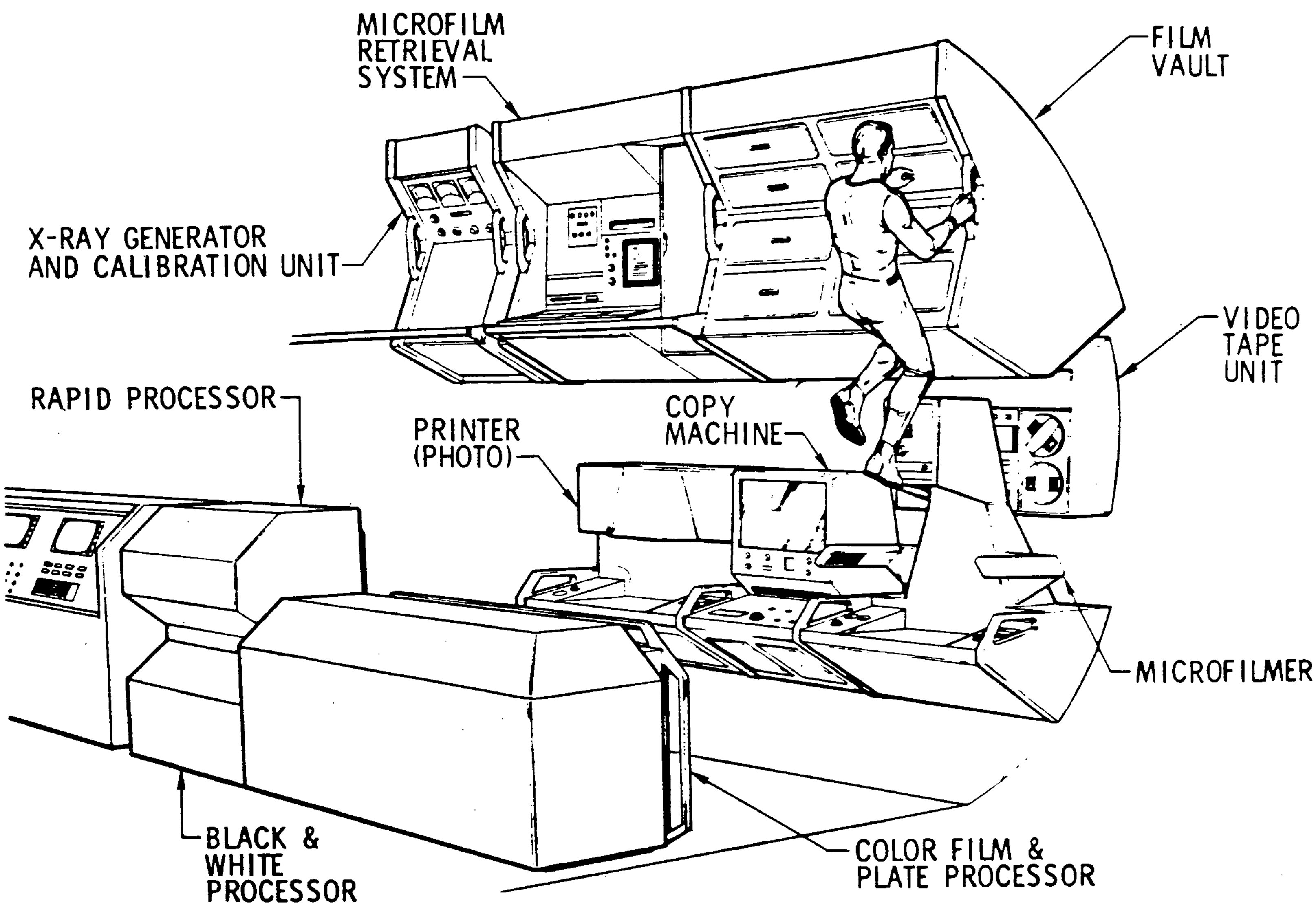


Figure 4.4-11. Hard Data Processing Facility

4.4.3.1.5 Experiment and Test Isolation Laboratory

The Experiment and Test Isolation Laboratory is a separate compartment within the GPL with the ability to 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 requires 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 that are potentially hazardous, such as welding, cryogenics, high-pressure gases and fluids, and experiments that have extremely high temperatures associated with them. Table 4.4-25 lists the equipment in the Experiment Test Isolation Laboratory and Table 4.4-26 is an assembly data sheet showing the characteristics of the equipment in the facility. Figure 4.4-12 is a perspective of the facility and shows the space relationship of the installed equipment and how the equipment would be utilized. 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 and a TV is used to monitor and observe experiments and activity within the laboratory. Set up of hazardous experiments to be conducted in the Isolation facility will be conducted with the astronaut in the facility and the facility pressurized but sealed off from the remainder of the Space Station. Activities of the astronaut in the Isolation Laboratory will be observed outside the facility by another member of the crew. In the event of emergency, the facility can be purged to vacuum, can remain sealed off or can be opened to allow the astronaut to escape, and then sealed off again and purged to vacuum. A blow-out panel is provided both in the external portion (space side) of the airlock chamber in the facility and the facility itself to relieve extremely high pressures. Cryogenic storage as well as toxic fluids and the high pressure gases will be stored in the Isolation facility and used in the isolation facility.

Figure 4.4-12 shows an experiment being set up in the Experiment and Test Isolation Laboratory. This particular experiment is a material science

Table 4.4-25

EXPERIMENT AND TEST ISOLATION LABORATORY

Hazard Detection System
Electrical and Vacuum Power Center
Isolation and Test Workbench
Cryogenic and Fluid Storage
High-Pressure Gas Storage
Airlock/Environmental Chamber
Chemistry and Physics Glove Box
Chemistry and Physics Analysis and Storage Unit

Table 4.4-26

EXPERIMENT AND TEST ISOLATION LABORATORY
ASSEMBLY DATA SHEET

Name	Installation	Interfaces	Remarks
Pneumatic/hydraulic workbench with Display Unit	Access front	Electrical OCS	
Electrical & Vacuum Power Center	Access two sides	Electrical Vacuum	Circuit breakers, switches, lights, etc. associated with airlock chamber
Chemistry & Physics Glove Box	Access front	Electrical Data Management System	Laminar flow & vacuum capability
Chemistry & Physics Analysis & Storage Unit	Access front	Electrical Data Management System	Liquid purge
Storage, Cryogenic, & High-Pressure Gas	Near airlock chamber		Stored in safety spheres
Airlock Chamber	1.25 m dia	Gases, fluids, leak detection, hazard detection	Interlocks required
Hazard Detection System	Sensors in facility	Critical function warning system	

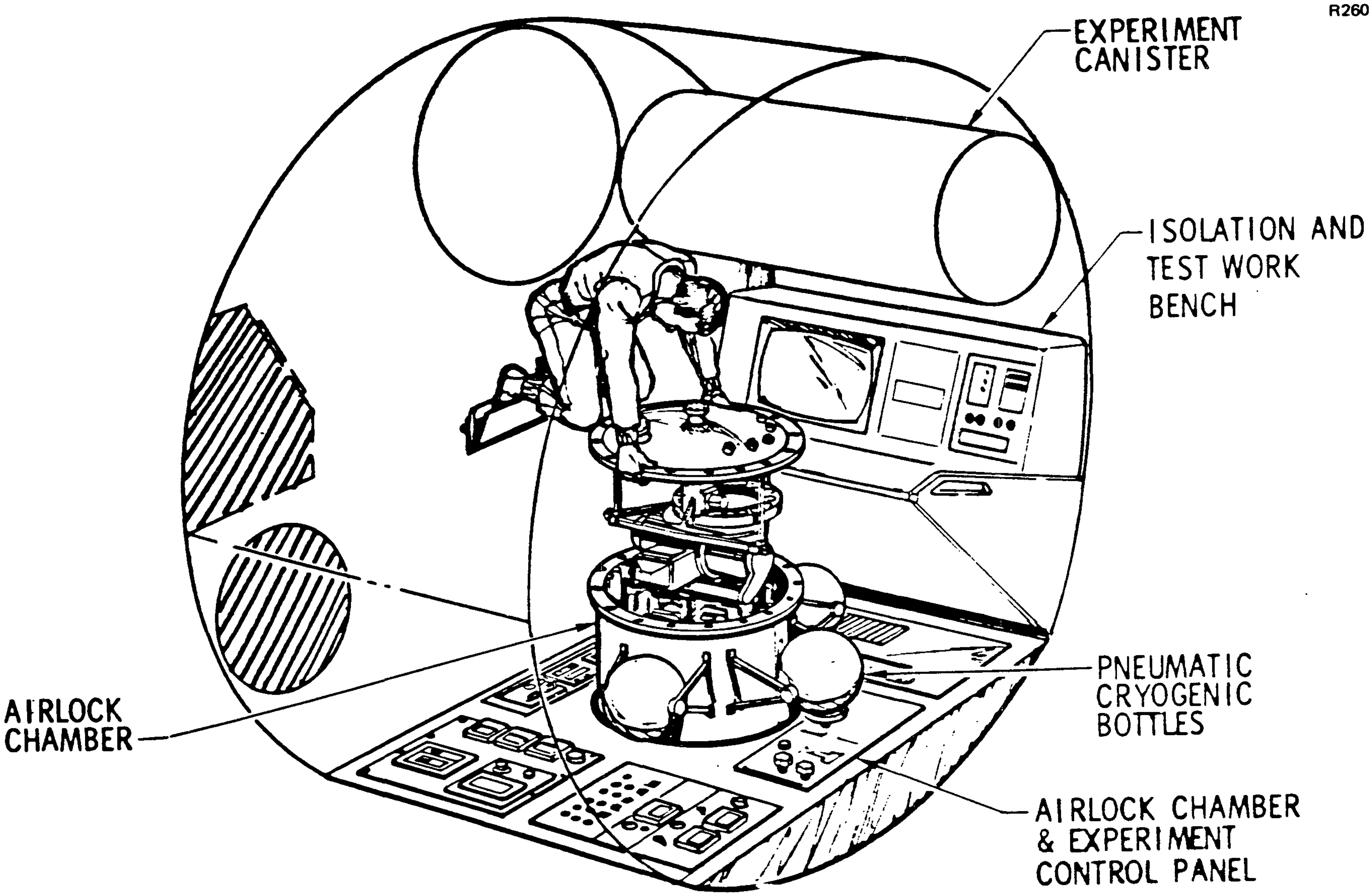


Figure 4.4-12. Experiment and Test Isolation Laboratory

levitation-casting experiment being positioned in the airlock chamber. The crewman is taking the experiment out of its canister, making a final visual check of the integrity of the experiment, and inserting it into the chamber. All necessary plumbing and electrical connections will be hooked up when the experiment is in the chamber and the chamber door will be bolted, secured, and checked for leaks. Then the crewmen will perform a preliminary check of the integrity of the experiment, leave the Isolation and Test Laboratory, and proceed to the Isolation Laboratory monitor console where all subsequent operations of this experiment will be controlled. After testing the airlock chamber seals for integrity, the airlock chamber will be purged to vacuum to get a clean environment in the chamber and then resealed for conduct of the experiment. The crewmen then provides the resources, such as gases, liquids, molten materials, etc., to the experiment from the remote console and continues to monitor and control the experiment. Experiments of long duration can be monitored and controlled from the experiment secondary control console with the critical functions on the critical warning function network which would alert a crew member to any potentially hazardous conditions. In summary, the Experiment and Test Isolation Laboratory provides the General Purpose Laboratory with an isolatable area in which to perform experiments and functions which, in case of failure, could present a hazard, nuisance, or discomfort to the crew and the mission.

The Experiment Test Isolation Laboratory also contains an isolation test work bench which provides the capability for bench calibration repair of hydraulic, pneumatic, and other type 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 in lines and equipments being tested.

4.4.3.1.6 The Electronics/Electrical Laboratory

The Electronics/Electrical Laboratory provides all the instrumentation, test, gear stimuli, controls, and displays necessary for testing and electronic calibration and maintenance of experiments and Space Station subsystems.

The work station includes all types of fixtures, hold-downs, and tools for working on electronic equipment. As in all other GPL laboratories and facilities, the equipment will be built modular so that carry-on equipment can be utilized and the laboratory can be reconfigured. Table 4.4-27 is a list of the equipment in the Electronics/Electrical Laboratory; Table 4.4-28 is an assembly data sheet showing the characteristics of each of the pieces of equipments and the installation requirements.

The list of equipment at this time can only be indicated on a relatively gross basis. The specific test equipment for experiments has not yet been selected; however, the test equipment and checkout equipment required for support of operational subsystems, as indicated in Section 4.4.2.3 of this report, is provided in the Electrical/Electronic test and checkout center. In addition, the common FPE equipments as developed in the commonality assessment are also included in the Electronic/Electrical Laboratory. As a minimum, the 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, these equipments will be augmented by modular plug-in test equipment for support of experiments when unique equipment is required to supply stimuli for checkout and test of experiments or to calibrate experiments. Figure 4.4-13 shows a view of the Electronical/Electrical Laboratory with a crewman at one of the pieces of the equipment in the laboratory calibrating a piece of equipment and adjusting the high-voltage supply to the required level.

As shown in the figure, the main service facility is a multi-instrument test bench console which provides the capabilities for bench checkout, calibration, and contingency repair of electronic/electrical equipment. The instruments in the multi-instrument test bench and the electronic/electrical test and checkout center can be unplugged and utilized in a remote location as portable test equipment. The equipment can also be used in place with signals sent to the appropriate areas through cabling provided in the Space Station. Built into the electrical/electronic test and checkout work bench is a miniature

Table 4.4-27

ELECTRONIC/ELECTRICAL LABORATORY

- Electronic Work Station
- Multi Instrument Test Bench
- Battery Charger
- High Voltage Source
- High-Energy Counter Calibration Equipment
- Miniature Glove Box

Table 4.4-28

ELECTRONIC/ELECTRICAL LABORATORY
ASSEMBLY DATA SHEET

Name	Installation	Interfaces	Remarks
High voltage source	Access bottom & front	Electrical	
Battery changer	Access top side	Electrical	
Multi-instrument test bench	Access front & bottom	Electrical OCS	OCS interface
High energy counter calibration equipment	Access front	Electrical	
Electronic work station and Glove Box	Access front & top	Electrical Vacuum liquid	

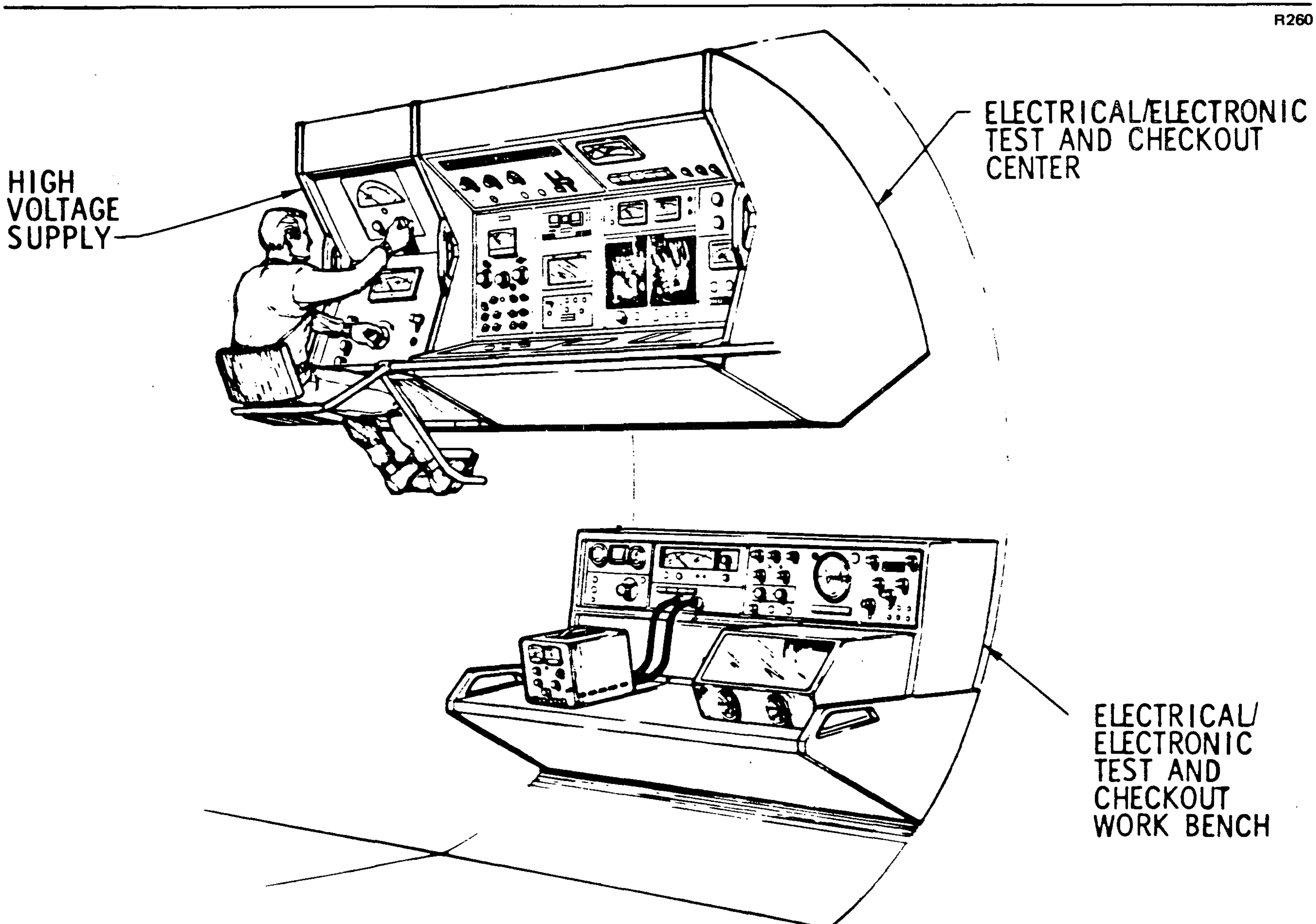


Figure 4.4-13. Electronic/Electrical Laboratory

laminar/flow glove box for cleaning, assembling, disassembling, soldering, and spot welding. The multi-instrument test bench also contains storage for hand tools required for contingency bench-level work on electronic equipment.

Because of the many possible types of electronic/electrical test and checkout equipment possible aboard the Space Station, the facility will be built with a modular capability so that equipments can be brought up, plugged in, and utilized in the GPL without major rewiring or reconfiguration. It is also anticipated that the Electronic/Electrical Laboratory will be a major checkout and work station in the GPL.

4.4.3.1.7 Biomedical/Bioscience Laboratory

The research objectives of a small bioscience program and rudimentary 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 consists of support equipment for microbiology, plant physiology, and invertebrae research. Table 4.4-29 is a listing of the major categories of equipment in the Biomedical/Bioscience Laboratory; Table 4.4-30 is a further breakdown of equipment necessary to support the rudimentary bioscience program as structured. As shown on Table 4.4-30, many of the equipments are already onboard the Space Station in other facilities and are not required to be provided in the Biomedical/Bioscience Laboratory. The equipment for bioscience experiments consists of plant, invertebrae 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.

Table 4.4-31 is a list of the rudimentary astronaut well-being experiments included in the facilities of the Biomedical/Bioscience Laboratory;

Table 4.4-29

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

Table 4.4-30

BIOSCIENCE SUPPORT EQUIPMENT

Plant Physiology	Microbiology	Invertebrates
Video*	X	X
Monitor Console*	X	X
Film Storage*	X	X
Film Processor*	X	X
Analog Storage*	X	X
Cryogenic Storage*	X	X
Onboard Data Evaluation		
Experiment Storage	X	X
Dissection Facility	X	X
Specimen Preparation	X	X
Biological Fluid Handling	X	X
Specimen Storage	X	X
Specimen Centrifuge	X	X
Microscope	X	X
Photo-Micrography*	X	X
Separate ECLS Filter	X	X
Freezer	X	X
Refrigerator	X	X
Trace Contamination Monitor*	X	X
Work Bench*	X	X
Experiment Racks	X	X
Isotope Trace Equipment	X	X
Specimen Mass Measurement	X	X
Special Illumination*	X	X
	Isolation	X
	Glove Box	X
	Sterilization	
		Gas Analysis
	Chemical Handling	X

*Provided by other GPL facilities.

Table 4.4-31

BIOMEDICAL EXPERIMENTS

Lower-Body Negative Pressure Device
Vector Cardiogram
Biochemistry of Body Fluids
Specimen Mass Measurement
Body Mass Measurement
Blood Volume and Red Blood Cell
Special Hematological Effects
Immunity - In Vitro
Exercise Conditioning

Table 4.4-32 is a list of the equipments associated with those experiments installed in the Space Station GPL. The biomedical equipment will be capable of measuring heart functions with an electrocardiogram and a vector-cardiogram, 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 of the equipment shared with the bioscience laboratory and 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 biological 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. Figure 4.4-14 shows the Biomedical/Bioscience Laboratory being used by two astronauts. One astronaut is using the Bioscience Glove Box for preparing a specimen; the other astronaut is using the Bicycle Ergometer for exercise conditioning with automated monitoring. While he is exercising, his heart rate and heart function are being recorded.

Table 4.4-32

BIOMEDICAL EQUIPMENT

Data Management Console L.S. Experiment Support Console Biomedical Measurement Console Lower Body Negative Pressure Device
Vector Cardiogram, Consoles from LS-1-2.1
Automated Urinalysis Automated Blood Analysis M/Body - Mass Measurement Device
Specimen Mass Measurement Device
Body Mass Measurement Device
No Flight Hardware
No Flight Hardware
No Flight Hardware
Bicycle Ergometer, Vector Cardiogram

4.3.1.8 Experiments/Secondary Control Center

The Experiments/Secondary Control Center is an integral part of the GPL; it is used for monitoring, some control of experiments and operational functions in the GPL, and as the backup to the primary control center of the Space Station. It has the capability to call up any data that is on the data bus or has been programmed into the computer memory. It also can control equipments and the data Evaluation Laboratory and has the capability of doing equipment diagnostic checks when they have been hard wired or programmed to the experiment control center. Figure 4.4-15 is a perspective of the Experiments/Secondary Control Center in operation. A detailed description of the Experiments/Secondary Control Center is in Section 4.10 of this document.

R260

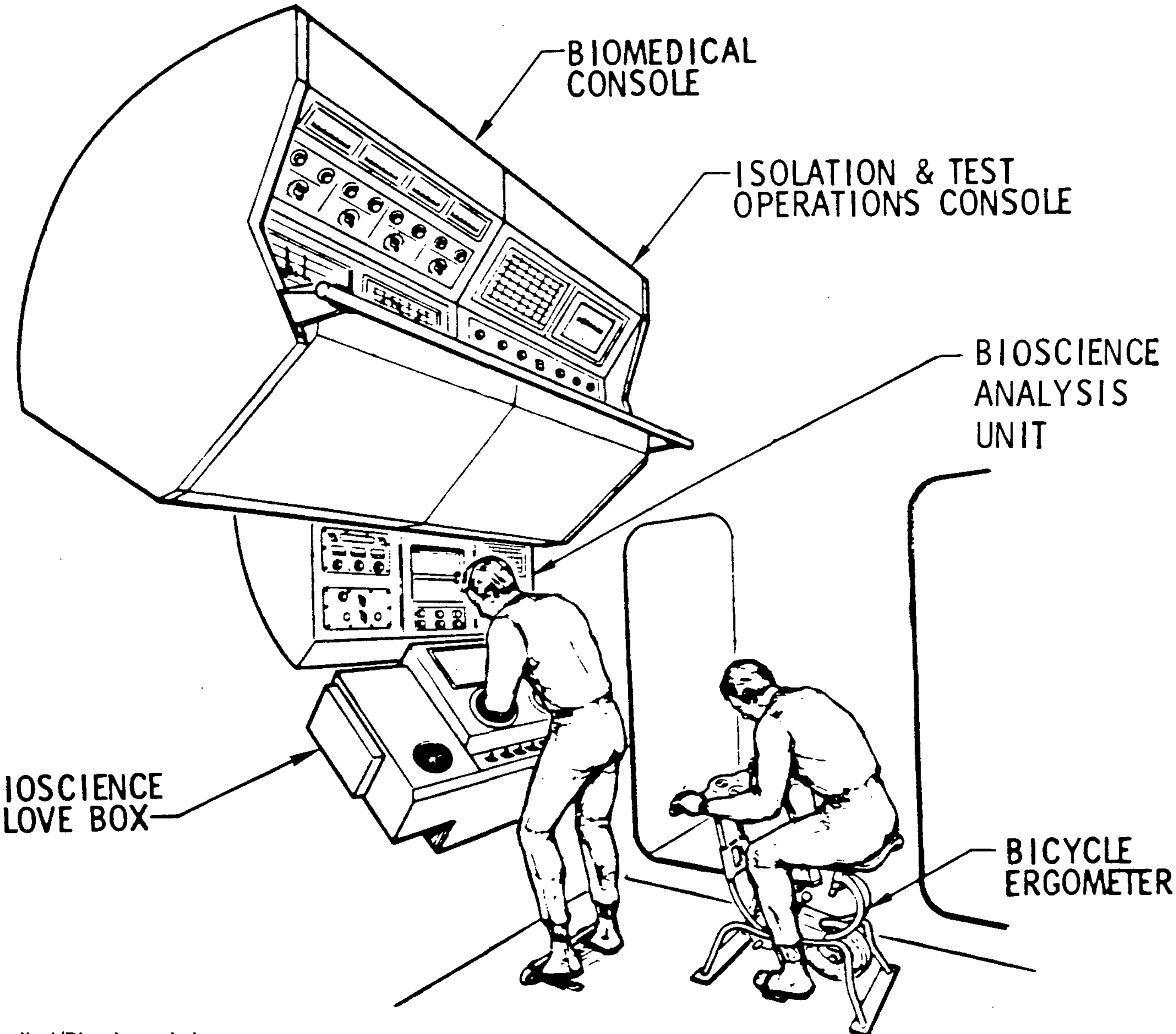


Figure 4.4-14. Biomedical/Bioscience Laboratory

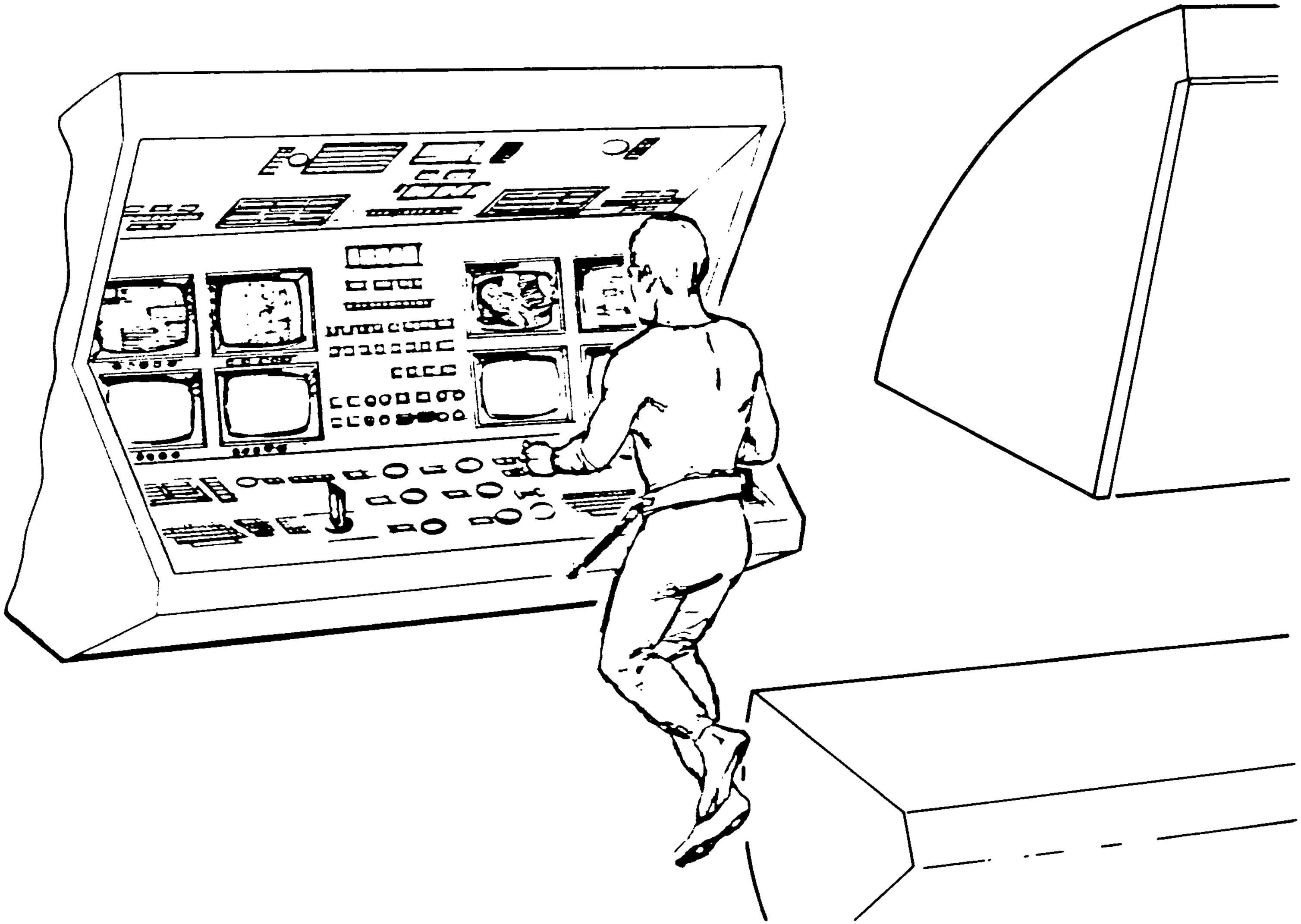


Figure 4.4-15. Experiment/Secondary Control Center

4.4.3.2 Interfaces

This subsection of the report covers two interface areas; the first deals with experiment interfaces with the GPL and the second section denotes each subsystem and the portions of the Experiment Support Subsystem and the experiment functions supported by the Space Station subsystems.

4.4.3.2.1 Experiment Support Subsystem Interface

Table 4.4-33 is a table showing the FPE's and the specific facility, function, and capability required by the FPE which is supplied by the GPL.

4.4.3.2.2 GPL Interfaces with Subsystems

Table 4.4-34 lists each of the Space Station subsystems and each subsystem's interface with the GPL. Some of the interfaces are in general terms and are only described to the level of specific experiment support from the subsystems, as known at this time. Parametric interfaces between experiment support and the Space Station subsystems are covered in the document entitled "Experiment Requirements Summary of Modular Space Station and Space Shuttle Orbital Application Requirements," two volumes, dated April 28, 1971, submitted to NASA as technical information during the Modular Space Station study contract

4.4.3.4 Growth Space Station Consideration

The basic design of the GPL has been established so that each laboratory has broad capability to support a wide range of experiments. Each item of equipment in the facility has been designed so that each console, work station, glove box, etc., can be disconnected and removed from the GPL, loaded onto a Logistics Module for return to the earth, and a new, updated or different set of equipment can be installed in its place. Figure 4.4-16 is a diagram showing how the initial Space Station configuration grows from the initial Space Station to the Growth Space Station. The growth requirements on the GPL to support the experiments as defined in the Blue Book are minimal. However, in a long-lifetime Space Station, it is anticipated that many improvements, as yet undefined, would be desirable or required. Therefore, the laboratories as shown are all the laboratories required to conduct the full experiment program known at this time.

Table 4.4-33

EXPERIMENT/GENERAL PURPOSE LABORATORY INTERFACE

FPE	Item	Remarks
A1	X-Ray Calibration Source Checkout Facility — Combine with Secondary Control Console Console — Combine with Secondary Control Console Optics Lab - Portable Equipment (Stored)	
A2-A2A	Film Fault - Combine all Vaults Film Processor - B&W, Color (2) Optics Lab C/O Facility — Combine with Secondary Control Console Ops Console — Combine with Secondary Control Console	
A3A-A3B	Film Vault - Combine all Vaults Film Processor Optics Lab C/O Facility — Combine with Secondary Control Console Ops Console — Combine with Secondary Control Console	
A4A-A4B	Film Vault - Combine all Vaults Film Processor - Rapid (1) Computer - Part of Data Mgmt Facility Optics Lab Calibration and C/O - Combine with Secondary Control Console Control and Display Console - In Module	
A5A	Gas Supply - Stored in Bottles in Cargo Module and in Experiment & Test Isolation Facility	
A5B	Gas Supply — Stored in Bottles in Cargo Module & in Experiment & Test Isolation Facility Cryogenics — Stored in Bottles in Cargo Module & in Experiment & Test Isolation Facility	
A6	Liquid Neon — Stored in Bottles in Cargo Module & in Experiment & Test Isolation Facility Liquid Helium — Stored in Bottles in Cargo Module & in Experiment & Test Isolation Facility	
P-1	Airlock - 3 in. dia Airlock Booms - Stored in Canister & Mounted in Airlock Pointing - Stored in Canister & Mounted in Airlock EVA - Utilizes Large Airlock/Docking Port or Logistics Module Airlock Subsatellite - Launch from Station or RAM Computer - In Data Mgmt Area Storage - Experiment Storage Workbench - (1) in Mech Lab, (1) in Isolation & Test Lab Film Vault - Combine all Vaults Film Processing Control, Display - (1) Console near Airlock, (1) Monitor Console in Secondary Control Console NH_3 Canisters - Store in Experiment & Test Isolation Lab when scheduled ICN Canisters - Store in Experiment & Test Isolation Lab when scheduled	

Table 4.4-33

EXPERIMENT/GENERAL PURPOSE LABORATORY INTERFACE (Continued)

FPE	Item		Remarks
P-2	Airlock - Use Optical Sciences Laboratory Airlock Platforms - Canister Storage - Installed in Airlock Laminar Flow Workbench (Glove Box) Volt/OAM/Amp Meter - In Multi-Instrument Test Bench Spot Welder - In Mechanical Lab - Done in Glove Box Control & Display - (1) Console near Airlock Oscilloscope - (2) Multi-Instrument Test Bench Subsatellite Subsatellite Comm. and Track Equipment - Utilize RAM Comm. & Track Equipment Battery Charger Oscilloscope Camera - Store TV System - In Secondary Control Console - Also at each C&D Experiment Console		
P-3	All in Attached Module except Photomultiplier Tube Calibration - Store in Optics Lab		
P4-A, B, C	All in GPL		
	Extendable Boom	Support Equipment	1 Shared by 3 Experiments
	Spectrophotometer		In Optics Lab
	Electronic Field Meter		Electronics Lab
	Data Displays		1 Shared by 3 Experiments - Console
	Oscilloscope		Electronics Lab
	Voltmeter Ammeters, etc.		Electronics Lab
	Frequency Meter		Electronics Lab
	Displacement and Vel Sensors		Total for 3 Experiments - On Platform
	Acceleration Sensors		Total for 3 Experiments - On Platform
	Special Purpose Power Supplies		Shared by 2 Experiments - In Console
	Polarimeter		On Platform
	Gas Supplies	Initial Consumables	
	Film Magnetic Tape, etc.		
	Test Surfaces		
	Canisters		Contain Test Fluids and Gases
ES-1G	Core	In Module	
	Metric Camera		
	Multispectral Camera		
	Multispectral Spectrometer		
	Passive M/N Scanner		
	Multispectral Radiometer		
	Radar Imager		
	Support - ES-1 through F		
	Control & Display - In Secondary Control Console Observation Telescope - In Module TV Computer - In Data Management Electronic Data Analysis - In Data Mgmt Photo Path Analysis - In Data Evaluation Maintenance & Repair - Work Station in Mech Lab		

Table 4.4-33

EXPERIMENT/GENERAL PURPOSE LABORATORY INTERFACE (Continued)

FPE	Item	Remarks
C/N-1	Electronics/Electrical Lab	
MS-1	Experiment Airlock Chamber	
	S.01 Process Control Computer	In Console
	S.02 Heat Rejection System	Part of Airlock Installation
	S.03 Cleanup and Refurbishment Equip	Stored in Work Station
	S.03 Materials Analysis Equip	Stored in Work Station
	S.04 Materials Analysis Equip	Stored in Work Station
	S.05 Photo Processing Lab	Hard Data Processing
	S.06 Open Materials and Fluids Storage	Stored
	S.07 Controlled Atmos Fluids Storage	Stored
T-1A	Airlock - Use Common 1.25 Meter Booms - Use Common Boom Gimbal - Use Common Gimbal Computer - In Data Mgmt Storage - For Experiment Storage Workbench - Use Common Mechanical Lab Facility Film Vault - Use Common Film Vault Deposition Analyses - Optics Lab + (1) 3 x 6 x 42 ft Console Contamination Analysis - Optics Lab and Mechanical Sciences Lab Gas Storage - In Isolation Facility EVA Airlock - Common Airlock	
T-2	TV Monitor C&D — Console (Combined with Experiment/Secondary Control Console	
T-2A, B	Airlock - In RAM Battery Charger Camera - Common Film Storage - Common Film Processor Propellant Storage - In RAM or Cargo Module	
T-4A, 4B-4C	CEVA Airlock - Common Airlock Glove Box-Airlock - Airlock with Manipulation Devices Deployment Boom - Common Boom	
T-5	Airlock - In RAM Console (Task Board) - FPE Equipment (Special Purpose)	
LS-1A	Minimum (Medical)	
	Visual Records - Microscopy Voice Recorder Data Management Console Power Distribution Unit Biochemical/Biophysical Analysis Unit Micromass Measurement Device — See Section 4.4.3.1.7	

Table 4.4-33

EXPERIMENT/GENERAL PURPOSE LABORATORY INTERFACE (Continued)

FPE	Item		Remarks
LS-1A (Cont)	Macromass Measurement Device		
	Storage		
	Biomedical Measurement Unit	See Section 4.4.3.1.7	
	Specimen Mass Measurement Device		
	Body Mass Measurement Device		

Table 4.4-34

INTERFACES SUBSYSTEMS/EXPERIMENT SUPPORT

GUIDANCE/NAVIGATION/CONTROL

Attitude Control/Precision Reference/CMG and GPL or Research and Applications Module System to provide off-set angles, gimbal drive motor commands, & flex gimbal torquer commands (up to 17K bits/sec from ISS and up to 58K bits/sec to ISS) vis Data Bus.

Command initiation of experiment pointing
Update inertial attitude reference
Terminate experiment pointing

Free-Flying Module Interface via communication/data management

Initialize Free-Flying Module Inertial Attitude Reference System

Command Inertial Attitude and star tracker off set angle for reference acquisition (viewing)

Interface with primary & secondary command-control-display centers

Delivery of attitude control/reference information (for experiment scheduling, subsystem status, maintenance monitoring)

Interface from control centers or experiments to attitude control activiation (orientation changes)

Interface between TBS docking ports on Power/Subsystems Module & Crew/Operations Module with free-flying modules (GSS phase)

DATA MANAGEMENT SYSTEM

Interface GPL to attached Research and Applications Systems to command/monitoring experiments/subsystems (duplex link @ 500 MHz) (via Crew/Operations Module and Power/Subsystems Module)

Interface GPL to Crew/Operations Module via Data Bus to transfer GPL subsystem data

Interface GPL to Crew/Operations Module via Data Bus to transfer experiment data and Free-Flying Module commands.

Interface from Power/Subsystems Module and Crew/Operations Module to GPL (control console) for back up subsystem monitoring.

Table 4.4-34

INTERFACES SUBSYSTEMS/EXPERIMENT SUPPORT
(Continued)

DATA MANAGEMENT SYSTEM (Continued)

Interface from GPL - Portable Display and Control Units - to Crew/Operations Module control console via Data Bus to monitor Research and Applications Module System

Interface from Power/Subsystems Module and Crew/Operations Module to GPL control center for backup subsystem control/ monitoring

OCS

Interface from each Research and Applications Module System (attached) to GPL and Crew/Operations Module via hardwire to provide local caution/warning data to both primary and secondary control centers (data bus)

Interface from each attached Research and Applications Module System to GPL control center for checkout and fault isolation via the Data Bus.

Interface from Power Subsystems Module, Crew/Operations Module, and GPL with prelaunch GSE via Data Bus from ground-support operations.

Interface from Crew/Operations Module/GPL via RF interfaces between ground and ISS to transmit any or all checkout data to the ground.

Interface from GPL to all attached Research and Applications Module Systems for checkout and fault isolation, via the Data Bus

COMMUNICATIONS

Interface from GPL to Free-Flying Module for command/control (data rate 10K bps) rf

Interface from Crew/Operations Module intercom to and from GPL and Research and Applications Systems

Interface from Research and Applications Systems to GPL for experiment data via data bus

Interface from GPL (experiment data control) to Crew/Operations Module then via Ku-band high-gain antenna to ground via DRSS (experiment data)

Table 4.4-34

INTERFACES SUBSYSTEMS/EXPERIMENT SUPPORT
(Continued)

COMMUNICATIONS (Continued)

Interface from GPL (experiment data control) to Power/Subsystems Module for VHF to ground via either DRSS or MSFN (including Research and Applications Systems)

Interface from GPL (experiment data control) to Power/Subsystems Module for S-band link to MSFN (includes Research and Applications System)

PROPULSION (Hi Thrust)

Interface from Power/Subsystems Module to free-flyer Research and Applications Module System to transfer N_2H_4.

Interface from Power/Subsystems Module to free-flyer Research and Applications Module System to transfer high-pressure N_2.

ENVIRONMENTAL CONTROL/LIFE SUPPORT

Interface from GPL (CO_2 removal) to Power/Subsystems Module - CO_2 storage tank.

Interface from Power/Subsystems Module to GPL - solar collector thermal loop to CO_2 removal equipment.

Interface between (Power/Subsystems Module) O_2/N_2 gas storage (repressurization supply) and GPL.

Interface between Power/Subsystems Module and GPL/Research and Applications Module airlocks for pumpdown and repressuring. (2 in. line repressuring and 3 in. line pumpdown.)

Interface from GPL to Crew/Operations Module - condensate return line.

Interface from Crew/Operations Module to GPL - potable H_2O.

Interface from Logistics Module to GPL/Research and Applications Module System (via Crew/Operations Module) - water supply to experiments (closed water-loop operation for experiment)

Interface from GPL/Research and Applications Module System to Logistics Module - return waste water from experiment.

Interface from Power/Subsystems Module to GPL for thermal power rejection load sharing (radiator)

Table 4.4-34

INTERFACES SUBSYSTEMS/EXPERIMENT SUPPORT
(Continued)

ATTACHED RESEARCH AND APPLICATIONS MODULE SYSTEM

Interface from Research and Applications Module System to Power/Subsystems Module via Data Bus to guidance and navigation computer, to provide error signals, gimbal angles, and experiment platform rates (at rates up to 58K bits/second)

Interface from Research and Applications Module System to GPL Experiment Control Center to obtain station orientation change or hold

Interface from Research and Applications Module System to GPL Control Center for:

Experiment Data Acquisition at 10 MBPS	Display and Control
Computation	Timing
Storage	Checkout and Test
Distribution	

Interface between Research and Applications Module System and Power/Subsystems Module/Crew Operations Module/GPL for pumpdown and repressurization (3 in. pumpdown line, 2 in. repressurization line)

Interface between Research and Applications System and Power/ Subsystems Module/Crew Operations Module/GPL for atmospheric supply and return (8 in. ducts).

Interface from Research and Applications System to GPL and Crew/Operations Module Control Center for intercommunication (via Data Bus) (3 voice channels plus closed circuit TV).

Interface from Research and Applications System to GPL and orbiter for critical subsystem/equipment monitoring, during launch and buildup.

Interface from Research and Applications System to GPL via Data Bus for subsystem monitoring, fault isolation, trend analysis, and OCS.

Interface from Research and Applications System to GPL Control Center for verification of experiment commands.

Table 4.4-34

INTERFACES SUBSYSTEMS/EXPERIMENT SUPPORT
(Continued)

ATTACHED RESEARCH AND APPLICATIONS MODULE SYSTEM (Continued)

Interface from Research and Applications Module System to GPL/Crew/Operations Module via hardwire to provide local caution and warning data to the primary and secondary control centers.

Interface from Research and Applications Module System to Crew/Operations Module/Power/Subsystems Module/GPL for electrical power supply. (4 circuits at 115 ± 3 vdc, 2.4 kwe AVG; 3.6 kew 1 hr. avg; 2 circuits at 115/200 vac, 400 Hz, 0.5 kwe avg, 0.75 kew 1 hr. avg, and 2.8 kwe 5 min peak for Research and Applications Module System and Ground Propulsion Laboratory). 4.8 kwe total to Research and Applications Module System and GPL experiments.

FREE-FLYING RESEARCH AND APPLICATIONS MODULE SYSTEM

All interfaces listed for attached Research and Applications Module System plus the following interfaces.

Interface from Free-Flying Module to GSS via communications - DMS/GPL to

- Initialize free-flying module intertial attitude reference prior to undocking
- Command intertial attitude and Star Tracker offset angles for reference acquisition
- Initiate experiment pointing
- Update inertial

ELECTRICAL POWER

Interface between Power/Subsystems Module and Crew/Operations Module, GPL, Logistics Module, and Research and Applications Module System to provide DC electrical power experiment equipments. (4 checkouts at 115 vdc).

Interface from Power Subsystems Module to Crew Operations Module/GPL to connect battery energy storage units.

Interface from Power Subsystems Module to GPL/Crew Operations Module to provide ac power (2 checkouts at 115/200 vac, 400 Hz; 1 phase 60 Hz)

Interface from Power Subsystems Module battery chargers to Crew Operations Module/GPL battery sets

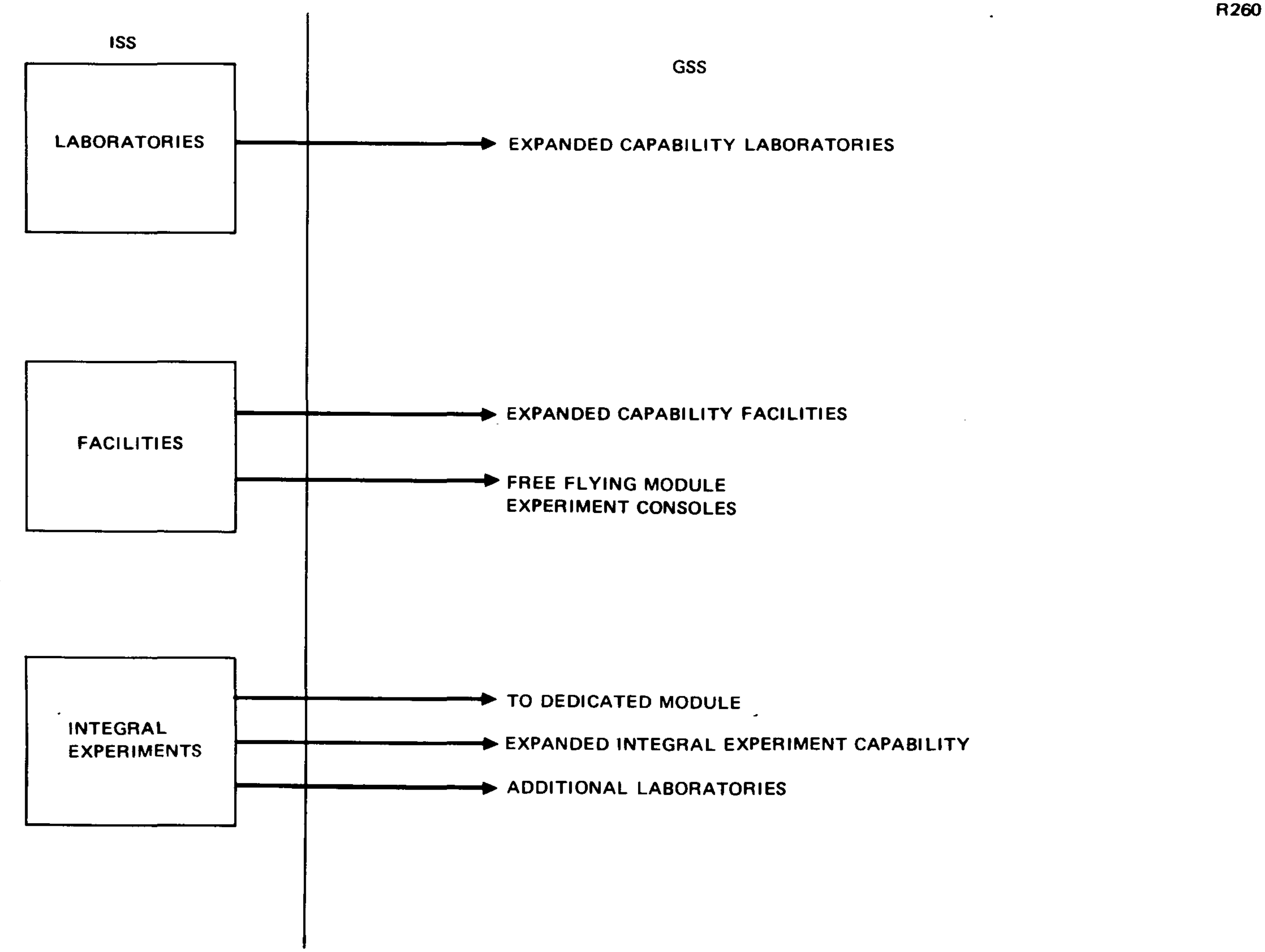


Figure 4.4-16. GPL Growth Evolution

In the case of the Biomedical/Bioscience Laboratory, in the Growth Space Station time period, it may be desirable to remove these functions from the GPL and perform all biomedical and bioscience functions in a dedicated RAM. Facilities provided within each laboratory can be expanded, updated, or changed as required.

There is growth space allocated in the GPL and these facilities can be expanded to accommodate more sophisticated, different, or more complex experiments. An example of this growth is in the Mechanical Sciences Laboratory material science experiments where an x-ray diffraction unit and a scanning electron microscope would be required for advance material analysis.

In the control and operation of experiments in free-flying modules, space has been allocated in the GPL for consoles for controlling free-flying RAM's, and for controlling experiments in the free-flying RAM's. Sufficient space has been allocated so that the number of free-flying RAM's are only limited by the resources of the Space Station and the number of docking ports available.

In the case of the integral experiments, larger more sophisticated experiments than are done integrally in the initial Space Station would be done in dedicated RAM's during GSS. In addition, expanding the GPL facility capability as indicated for Mechanical Science Laboratory will allow the GPL to support more sophisticated and more complex integral experiments. Should the need for additional laboratories be required, the growth space allotted in the GPL will accommodate these laboratories that can be packaged into consoles of the size installed typically in the GPL. Table 4.4-35 is a summary of the GPL Purpose Laboratory facilities, the initial capability supplied by the GPL to support performance of experiments, and any additional capability that may be required for the Growth Space Station support of a larger, and possibly more complex experiment program.

4.4.4 Design Analyses and Trade Studies

Various design analyses and trade studies have been done in the experiment support area; one is the Space Station orientation trade study with respect to

Table 4.4-35

IMPLEMENTATION OF GPL GROWTH REQUIREMENTS

Laboratory or Facility	Initial GPL Capability	Additional Capability Required for GSS
Electronic/Electrical	Experiment support, maintenance and conduct	None
Experiment and Test Isolation	Experiment support and maintenance	
Mechanical Sciences	Conduct and support experiments; perform maintenance on Space Station and experiments	Advance materials science, test and analysis lab, (add x-ray diffraction unit & scanning electronic micro-scope)
Optical Sciences	Optical experiment & calibration facility; optical & spectrum analysis facility	None
Data Evaluation	Detail evaluation	None
Hard-Data Processing	High resolution film and plate processing color processing	None
Bi-medical/Bioscience Bioscience	Astronaut well being, plant physiology, micro-biology, and inventrate research (1) EVA (2) Scientific	None

orientation of the Space Station for experiments. This trade study will be covered in the appropriate section of this document (SE-04). Another trade study accomplished was the Guidance Navigation and Control Evaluation for Experiments. This trade study will also be covered in the appropriate section of SE-04, as will studies done on experiment controls and displays and the depressurizable, pressurizable, compartment pumpdown trades. All of these subsystems have been analyzed with respect to their effects on experiments and the requirements resulting from the trades have been incorporated into design of the GPL.

Orbit selection and mission trade studies, as affected by the Blue Book experiments, are documented in MP-01 (Mission Analysis) delivered as part of the Modular Space Station study.

Two analyses—which add additional depth to the experiment definition—were completed during the study. These are 1) a complete support-equipment list for all experiments and FPE's in the Blue Book, and 2) a contamination analysis which examines FPE's and experiments for optical contamination requirements. The length of these data precluded incorporation into this report.