Contract No. NAS8-36525
Data Requirement No.15

Final

Final Study Report

19 January 1987

SSP-MMC-00055
Volume I -
Executive Summary

Space Station Definition and Preliminary Design, WP-01

(NASA-CR-179023) SPACE STATION DEFINITION AND PRELIMINARY DESIGN, WP-01. VOLUME 1: EXECUTIVE SUMMARY Final Study Report (Martin Marietta Corp.) 94 p CSCL 22B

N87-17842

Unclas
G3/18 43313

Prepared for:

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Prepared By:

Martin Marietta Aerospace
Denver Aerospace
P.O. Box 179
Denver, Colorado 80201

MARTIN MARIETTA

SSP-MMC-00055
16 January 1987

Contract No. NAS8-36525
Data Requirement No. DR-15

Final
Study Report

16 January 1987

SSP-MMC-00055
Volume I, Executive Summary

Space Station
Definition and
Preliminary Design,
WP-01

Prepared by: J. A. Lenda
J. A. Lenda, Manager
Systems Analysis and Support

Approved by: Maurice A. Larue Jr.
M. A. Larue, Jr., Manager
Project Integration and
Systems Engineering

Approved by: J. W. McCown / for
J. R. Cook
Vice President
Space Station Project
Martin Marietta Denver Aerospace

Martin Marietta Aerospace
Denver Aerospace
P.O. Box 179
Denver, Colorado 80201

0103U

FOREWORD

This document is prepared for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, in response to Contract NAS8-36525 and is submitted in accordance with Data Requirement No. 15, Preliminary Study Report, Volume I - Executive Summary.

MARTIN MARIETTA DENVER AEROSPACE

DOCUMENT CHANGE LOG FOR

SSP-MMC-00015

PRELIMINARY STUDY REPORT, VOLUME I

REVISION NO.	DATE	PAGES AFFECTED	REMARKS
Basic		All	Final Phase B Submittal

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

This document provides an executive summary of our WP01 Phase B activities per the requirements of DR15. Section 2.0 summarizes our Systems activities during this effort and provides an overview of the system level engineering tasks we performed. Areas discussed include requirements, system test and verification, the advanced development plan, customer accommodations, software, growth, productivity, operations, product assurance and metrication.

Section 3 summarizes our hardware element study results. Overviews of recommended configurations are provided for the core module, the USL, the logistics elements, the propulsion subsystem, reboost, vehicle accommodations, and the smart front end.

Section 4 provides a brief overview of our costing activities.

Each of these topics is covered in greater detail in Volume II of this document.

2.0 SYSTEMS ACTIVITIES

The Systems efforts on the Phase B contract activity was initiated with a review of the Level B Engineering Master Schedule (EMS) to determine what studies and analyses needed to be conducted so that the resultant data output could permit the MSFC program and project personnel to meet their commitments established by the EMS.

For each theme activity identified in the EMS for which the MSFC was responsible for providing data to either Level B or to another Work Package Center (along with its appropriate recommendation), our systems and engineering personnel worked with the MSFC personnel to identify the data needed to provide the required output. What was identified was a listing of studies and/or analyses; what EMS activity it was related to; when it had to be completed; who was responsible for it; and what its objective was.

The results of this activity were basically recommended conceptual design approaches, new or modified requirements, and a definition of methodologies which were presented to the MSFC as part of the established DR02 and DR19 data packages in support of RUR-1, RUR-2, and other scheduled program milestones. In addition, these data were summarized and presented to the Level B Systems Integration Board (SIB) and Space Station Control Board (SSCB) as directed by the MSFC and as needed to support Change Requests (CRs) and Change Directives (CDs) of interest to the MSFC WP-01 activity.

Support to the Level B EMS activity and to the SIB/SSCB activity has continued throughout the life span of the Phase B contract effort. Initially this activity was focused on the twenty themes grouped into categories covering Requirements, Configuration and Strategies. During the IRR/SRR timeframe, the focus shifted from these themes to activities covering Data Books, the PDRD (Section 3 and other sections), Interfaces, Plans and Design Considerations, but the support activity basically remained the same; i.e., studies and analyses were conducted to support the processing of CRs and CDs through the Level C and Level B change boards.

Specifically two courses of action were taken in support of this change action. In one case the change was generated by a WP center other than WP01, and in the other case the changes was a WP01 origination. The processing and approach taken on these two was basically the same with the difference being the depth and level of detail in the study provided for those studies which were a WP01 responsibility and concern versus those CRs which were a non-impact to WP01.

In this change activity area our systems effort consisted of reviewing the CR, providing a response to the CR (including all back-up data necessary to support said position), presenting, or supporting its presentation to the WP01 Change Control Board (CCB) and, if deemed appropriate by the MSFC, presenting the technical or programmatic position to the SIB/SSCB in support of WP01.

Perhaps more importantly, this activity also consisted of taking the results of on-going studies and analyses which indicated the need for a change to existing program documentation - the PDRD or some plan or process - and after coordination with the appropriate MSFC personnel, converting this study output into a CR and assisting WP01 in processing it through their own CCB and the SIB/SSCB until it is finally approved and incorporated into the appropriate program documentation.

The final output of all of this Systems activity was the inclusion of these data from the various studies, analyses and change board support into appropriate reporting documentation such as DR02, 04, 07, etc., and its inclusion into the program controlling documentation such as PDRD, SRD, CEI specifications and the like.

Our system level engineering activities for this Phase B effort are summarized in the following paragraphs. A more detailed discussion of these topics is provided in Section 2.0, Volume II of this document.

2.1 REQUIREMENTS

The requirements development activities were comprised of two major parts; the requirements analyses and recommendations in fulfillment of SOW 3.2.2.1 and the interface analyses and definitions in compliance with SOW 3.2.2.4. These activities culminated in the preparation of preliminary Part I Contract End Item (CEI) specifications for WP-01 elements and preliminary Interface Requirements Documents (IRD) for external WP-01 interfaces, in compliance with SOW 3.3.3.

An applicability matrix for SOW Attachments C2, C3, and C4 requirements to WP-01 elements was provided in DR-01. A specification tree, recommended changes to SOW Attachments C2, C3, C4, ICD scope sheets, and nine IRDs were submitted as part of DR-02. Subsequent efforts included review and comment support for seven IRDs prepared by another contractor, and the preparation of an additional IRD.

As part of the DR-03 submittal, five contract end item (CEI) development specifications and eight attachments thereto were completed. Review and comment support was provided for four other CEIs. The IRDs and CEI specifications submitted are listed in Table 2.1-1.

2.2 SYSTEM TEST AND VERIFICATION

A System Test and Verification Plan (STVP) was developed during Phase B in accordance with DR-04. This plan consists of six volumes and defines the Martin Marietta approach to verifying all WP-01 contract and items. The following paragraphs summarize the six STVP volumes.

2.2.1 General Verification Requirements (Volume 1)

Volume 1 is the top-level STVP document and establishes a WP-01 verification program that is consistent with the NASA recognized verification process. It defines the methodology to be used across all WP-01 elements to accomplish the verification task and identifies the certification requirements that are common to all elements including support equipment and software. The document contains a flowdown of responsibilities, documentation and controls from higher level NASA requirements to the project.

TABLE 2.1-1 IRD/CEI SUBMITTALS

IRDs Submitted:

SS-IRD-0100, Rev. B, Modules to NSTS
SS-IRD-0101, Rev. A, Common Module to HSOM
(This document was subsequently deleted by MSFC)
SS-IRD-0105, Rev. B, U.S. Modules to Space Station
SS-IRD-0301, Rev. A, Logistics Elements to Space Station
SS-IRD-0401, Rev. A, OMV Accommodations to Space Station
SS-IRD-0405, Rev. A, OMV Accommodations to NSTS
SS-IRD-0501, Rev. A, OTV Accommodations to Space Station
SS-IRD-0900, Initial, Airlock to Airlock Outfitting
SS-IRD-0901, Initial, Airlock to NSTS
SS-IRD-0303, Initial, Pressurized Logistics Carrier to Space Station
SS-IRD-0902, New, Airlock to EVA

CEI Specifications Submitted:

SS-SPEC-0001, Common Module
- Attachment A, Software
- Appendix 10, Habitation Module
- Appendix 20, Materials Technology Laboratory
- Appendix 30, Logistics Module

SS-SPEC-0002, Outfitted Materials Technology Laboratory
- Attachment A, Software

SS-SPEC-0005, Hyperbaric Airlock
SS-SPEC-0008, OTV Accommodations
SS-SPEC-0009, Smart Front End
- Attachment A, Software

Attachment A, Software for SS-SPEC-0006, Space Station Interconnect
Attachment D, MGSE for all Space Station CEI Specifications

2.2.2 Basic Module (Volume 2)

Due to the fact that the specifications for the U.S. Laboratory (LAB), Habitation Module (HM) and Logistics Module (LM) contain many common features, the concept of a basic or core module for assembly and test planning purposes has been retained. Development, certification and in-process acceptance verification of a "basic module" is defined in Volume 2 of the STVP.

The basic module certification program reflects the protoflight concept. It includes sub-element development testing of selected structure and mechanisms, component/subassembly acceptance and qualification, pre-installation and post-installation testing of common subsystem equipment, and in-process acceptance/certification of those features which can best be accomplished at the Basic Module (BM) level of build. Upon completion of verification activity defined in Volume 2, the module assemblies will undergo additional outfitting, limited delta certification and final acceptance as defined in Volumes 3, 4 and 6 of the STVP.

2.2.3 U.S. Laboratory Module (Volume 3)

The assembly and test activity required to up-grade a Basic Module to a fully outfitted Laboratory Module (LAB) is identified in Volume 3 which defines the delta certification and final CEI acceptance testing. It also addresses the subject of user equipment integration and defines in general terms the verification associated with that task. Because the LAB is a deployable end-item, this volume includes verification activity required both at the launch site and on-orbit.

2.2.4 Logistic Elements (Volume 4)

The Logistic Elements (LE) consist of three separate, testable configurations: first, a pressurized carrier which is a derivative of the Basic Module; second, a propellant/fluids carrier; and thirdly, an unpressurized cargo carrier. All of the delta or initial certification and the final acceptance of these items is defined in Volume 4. Also included is the verification required at the Launch Site and for initial on-orbit activation.

2.2.5 Resource Node Structure (Volume 5)

The WP-01 effort on the Resource Node is primarily basic structure assembly and test. For the most part this activity is very similar to (although independent of) the Basic Module structural certification effort. Volume 5 defines the verification activity which is currently required prior to shipping the units to other locations for final outfitting.

2.2.6 Habitation Module (Volume 6)

The Habitation Module (HM) is also a derivative of the Basic Module for assembly and test purposes; therefore, a major portion of the basic structure and component/subassembly certification is covered by Volume 2. Delta certification of HM unique equipment and the testing associated with final outfitting and end-item acceptance is included in Volume 6. This activity includes the installation and verification of both WP-01 provided subsystem equipment and a significant amount of Government Furnished Equipment (GFE) associated with crew support and other non-WP-01 systems. The final end-item acceptance tests of the HM will include the verification of both types of equipment operating as an integrated module.

2.3 ADVANCED DEVELOPMENT PLAN

An Advanced Development Plan (ADP) was prepared and submitted in accordance with DR-05. This plan has as its objective the advancement of selected technologies to a level of maturity that will provide a sound basis to begin design/development of the Space Station. Five key technology areas were selected for advanced development: 1) Demonstration of a fluid and electrical umbilical mechanism; 2) Flight demonstration of a vaned fluid management system; 3) Subsystem fault detection, isolation, and control; 4) Materials technology for long-term space applications; and 5) Closed looop ECLSS hardware and automation.

2.3.1 Advanced Development Implementation for the Initial Space Station

Our integrated technology plan includes our IR&D projects, our WP-01 ADP for the initial elements of SSP, the NASA Advanced Development Plan and our definition-phase activities. We have identified projects in our IR&D program from which we can derive maximum concurrent benefits for SS. Our plans include the use of NASA test facilities and NSTS flights to bring the technologies we selected to the highest possible level of maturity within an affordable cost.

Martin Marietta Laboratories is integrating and organizing Corporate-wide capabilities directed toward the development of Space Station advanced technologies, with particular attention paid to the environmental control and life support subsystem (ECLSS) and its evolutionary growth requirements.

The results of our IR&D activities, advanced development tasks and outputs from the NASA studies were used in our definition trade studies. We continually monitored our integrated technology plan to ensure that we maintain the proper scope and direction of our tasks.

2.3.2 Advanced Development Recommendations and Plan for Growth SSP

During the definition phase, we prepared an advanced development plan and recommendations for the technologies required for evolutionary growth of the SSP. These recommendations considered the results of the ADP for the initial elements of the SSP and the implementation of that plan during the definition phase. We used the results of the NASA Advanced Development Program (J8400059), our Automation and Robotics Plan, the ATAC outputs as they apply to WP-01, the NASA-focused technology contracts, our IR&D program, and the other sources in formulating our recommendations. The recommendations are time-phased and based on our concept of the future capabilities of SS and the technology levels required to support those goals. Our Advanced Development Plan for Growth will stress those technologies that will allow an orderly evolution from the initial configuration to the ultimate design.

2.4 CUSTOMER ACCOMMODATIONS

The accommodations to be provided to the Users of the United States Laboratory (USL) are described in this section, which is a summary of our DR-06 submittal.

2.4.1 User Requirements

User requirements definition is based on information derived from the Mission Requirements Data Base (MRDB), from the Microgravity and Materials Processing Facility (MMPF) study, and from the Life Sciences Space Station Planning Document (Redbook).

The accommodations provided by the USL will be shared by Users from the discipline areas of Life Sciences and Materials Technology. In general, the accommodations required by the Materials Technology users are more demanding than those for the Life Sciences. This consideration, along with the long range plan to provide an additional laboratory module dedicated to life sciences, has led to a decision to use the Materials Technology requirements to design the installed resource capabilities of the USL.

The Materials Technology requirements are defined by a group of 30 User facilities in which various development and research activities can be performed. These facilities are described in Section 3.2. The resources required to support these facilities have been used to derive the design requirements for the USL.

2.4.2 Laboratory Support Equipment

User research and development activities will require a complement of Laboratory Support Equipment. This complement is identified in Section 3.2. This listing includes support equipment for both Life Sciences and Materials Technology disciplines.

2.4.3 U.S. Laboratory User Accommodations

The USL will provide the interfaces and resources necessary to support experiment/payload operation, and an environment conductive to efficient, continuous, basic and applied research activity. These accommodations are described in detail in Volume II of this document, and are listed in Table 2.4-1.

TABLE 2.4-1 USL USER ACCOMMODATIONS

- Structural/Mechanical
  - Rack Size - 1892mm x 968mm and 2032mm x 1016mm
  - Rack Secondary Structure - adapts payload/subsystem hardware to USL racks
  - Rack Mounting/Accessibility - tilt-out design with quick connect/release interfaces
  - Passageways - Center aisle 2134mm (84 in.) square
  - Rack Loading - Accommodate fully integrated double rack - 590kg (1300 lb.)
  - Workstations - Workbench and glovebox
- Electrical Power - 3kw/single rack; seven double racks with 15kw
- Communications - provided by core module
- ECLSS - Provided by core module
- Thermal Control - internal 50kw single-phase water loop; external single-phase freon loop; coldplates
- Crew systems - Standard equipment
- Vacuum - 1 x 10^{-3} torr; 1 x 10^{-8} torr with augmentation
- Process Materials Management Subsystem - stores/distributes process fluids; removes/stores/dispositions USL payload waste by-products

2.5 SOFTWARE

The Software Development Test and Verification Plan (DR16) was submitted as an initial and final copy covering the Software Development Environment requirements for Work Package 01 areas of responsibility. The Software Development Environment was renamed to be the Software Support Environment (SSE) prior to the delivery of the final version. The redefinition was more precise as to what the SSE provided to the user.

The approach taken in describing the software development tool requirements was to address the steps in the software development life cycle for both the ground and onboard environments and describe at each step the applicable tools required to perform the task. A review of commercial products was made with respect to the requirements identified for support tools and a matrix was provided identifying in many cases several commercial tools which would satisfy the requirements. The report emphasized the importance of using off the shelf products wherever possible not only to avoid development cost but also to satisfy the user that the tool has been demonstrated successfully in similar situations.

Software test was considered separate from the rest of software life cycle; however, the approach for defining and documenting test tool requirements was the same as with other steps of the cycle. In reference to the test phase the steps or tasks described were compatible with those described in DR04 Systems Test and Verification Plan.

In all cases both hardware and software tools were identified. Also all products of the software development were considered including deliverable and nondeliverable code, documentation, reports, status tracking and test results.

The initial submittal of DR16 contained the results of several trade studies which were conducted to assess some particular software development tools. The first trade concerned a recommendation for an application software language. Although Ada was recommended as the applications programming several language concerns were expressed.

An operating system trade was conducted of commercial operating systems available today. The Digital Electronics Corporation VMS and Data General's AOS/VS were the only systems which supported the Ada programming language and the majority of other criteria.

A third study was conducted concerning networking philosophy. The conclusions of the study included the following recommendations: A distributed data processing structure connected by local area networks; implementation of International Standards Organization (ISO) standard model of Open Systems Interconnection (OSI) for the exchange of information between distributed systems; recommendations for the implementation in either hardware or software of each of the seven layers; and a transaction processor used to perform common I/O for applications programs.

A study was performed on types of data base management systems (DMBS). Three different DBMS models were reviewed in reference to the requirements, the relational, heirarchical and network. The relational model was recommended.

A final study on User Interface Language was included in DR16. The study results include the definition of several categories of requirements for the user interface. Based on the diversification of users and of user requirements the study results showed that a single user interface language is unlikely to satisfy all requirements and a standard for a family of interrelated user interface languages is more likely.

2.6 AUTOMATION AND ROBOTICS

2.6.1 Summary

The Automation and Robotics Plan (DR-17) was created to meet the data requirements of contract NAS 8-36525 and represents Martin Marietta's approach to implement automation and robotics technology in Work Package 1. This brief description is a summary of its major contents.

2.6.2 Plan Elements

The plan principles and strategies scope and direct the planning, design, and implementation efforts of Space Station automation and robotics (A&R) to ensure compliance with the overall goals and the efficient use of available resources. This plan is intended to evolve throughout the Phase B program, maturing as the program itself matures, with varying stress in its four submittals.

The Phase C/D Implementation Plan is a top level description of Phase C/D segments with particular emphasis on A&R implementation. The early phases will complete the design and development activities initiated in Phase B, followed by the fabrication and integration phases. The final subsection, verification and operational phases, summarizes the final test and verification activities, plus those operational items associated with launch, placement, assembly and construction, plus final checkout and operational acceptance.

The last section, Evolutionary Growth Summary, treats, in summary form, several appendix sections dealing with growth.

2.6.2 Conclusions

a. Initial analyses results indicate no significant difference between potential applications of A&R during IOC phases (PMC and MTA) nor differences in automation levels over all phases. However, there appears to be a very significant potential for robotics at the growth phase, as compared to IOC.

b. Because of the long lead-time required to develop, test and gain a high level of confidence with robotics (that are adaptable and reprogrammable) it is assumed that there will be only limited application for robotics at IOC (both PMC and MTA).

c. Simulation studies should be carried out for the use of robots in micro-g in conjunction with micro-g experiments, so that an appropriate simulation capability can be developed to reduce the amount of hardware/software testing required.

d. Wherever possible, robots should be programmed using a teaching pendant in micro-g; since this will significantly reduce the amount of programming required in addition to requiring less time for development and testing.

e. The development and testing of robot systems should be considered a very high priority activity. Starting as soon as possible after IOC, robot teleoperated control experiments should be carried out as rigorously as any other payload experiment.

f. The time spent developing the implementation of robotics for low-g conditions will pay off with dividends in the future by vastly increasing the productivity of the human crew.

g. At IOC, automation can be applied to a wide variety of Space Station MTL tasks, especially with respect to monitor and control activities for both subsystems and payloads.

h. At IOC, robotics will have minimal application to the MTL, since the tasks to be performed are significantly complex that the use of a robot for these tasks under low gravity conditions, would be quite risky without adequate testing of the hardware/software under actual space conditions.

i. A more mature Space Station MTL would benefit from robotics significantly to increase the productivity of the humans on-board, and to reduce the hazards to which the crew are exposed.

j. Additional effort is required to determine the optimal interface between an IVA robot(s) and potential MTL payload and subsystems equipment (including characterization and support). Even though some earth-based laboratory equipment manufacturers are designing with manipulators and automation in mind, much additional effort must be placed on incorporating robot-friendly interfaces into the equipment to be used in the MTL. NASA should encourage/leverage this trend.

k. The use of robotics in the MTL may result in a laboratory with a very low level of micro-g disturbances because robots can be programmed to move in a very slow, precise manner.

l. Experiments need to be conducted with robots under low-g conditions to determine the optimum designs of arms and end effectors for various MTL tasks.

m. The state-of-the-art of machine vision needs to be improved in order to fulfill the promise of robotics on the MTL. The nature of the MTL tasks requires depth perception, peripheral vision and a greater degree of pattern recognition which allows for the interpretation of shadows; different angles of view and various levels of light.

n. Within MTL robotics would perform on a cabin wide basis, within certain specified areas of the cabin, and within enclosed zones.

o. Robotics functions within the MTL will require a Data Management System interface for command transfer from the crew, ground or payload processors and for multiple manipulator coordination.

2.7 GROWTH

2.7.1 Introduction

This section summarizes the growth plan for the WP-01 Space Station elements updated from the Permanent Manned Configuration (PMC) configuration which is the same as the IOC configuration for WP-01 elements. Note that for WP-01 elements, PMC and IOC may be used interchangeably.

2.7.2 Growth Scenarios

The unique Work Package One (WP-01) elements discussed in this plan are: The Core Module, ECLSS, USL Outfitting, and Logistics Module. The growth scenario used (Table 2.7.2-1) was based on the WP-01 Phase B Reference configuration baseline.

Beginning with the baseline configuration shown in Figure 2.7.3-1, a growth scenario was developed to meet the requirements of sections C-2 and C-4 of the RFP. The buildup is consistent with the block changes to the station defined by the WP-02 contractors. The growth scenario shown in Table 2.7.2-1 starts with two U.S. modules, one outfitted as an 8 crewmember Habitability (HAB) module and the other as a U.S. Laboratory (USL) module; plus two international modules, one the European Columbus module and the other the Japanese Experiment Module (JEM). There would be two Logistics modules on-orbit at a time, one U.S. and one Japanese, but no permanently station-based OMV. With this basing approach, the Orbiter would bring the OMV to the station, it would be operated from the Orbiter, serviced from the ground, and have only a temporary berthing station on the truss.

TABLE 2.7.2-1 GROWTH SCENARIO - ON-ORBIT CONFIGURATION

	YEAR									
	92	93	94	95	96	97	98	99	00	01
HAB	1	1	2	2	2	2	2	2	2	2
USL	1	1	2	2	2	3	3	3	3	3
AIRLOCKS	2	2	2	2	3	3	3	3	3	3
FOREIGN	2	2	2	2	2	2	2	2	2	2
US LM	1	1	1	1	1	2	2	2	2	2
JEM LM	1	1	1	1	1	1	1	1	1	1
NODE	4	4	8	8	8	10	10	10	10	10
CREW	8	8	8	10	12	14	16	16	16	16
OMV	0	0	1	1	1	2	2	2	2	2
OTV	0	0	0	0	0	0	0	1	1	1
ATTACHED P/L	4	4	6	6	6	9	9	9	9	9

The station would operate for 2 to 3 years with a crew of 8 before additional modules were added. This scenario proposes to add modules incrementally until a total of 5 U.S. modules are attached. These modules include an SLM, another USL, HAB and OMV plus an additional Logistics module to support the increased needs of the required crew buildup. There will actually be a double set of logistics modules needed - one set on-orbit and the other on ground being reloaded. The OTV would be expected in 1999. This eventual growth version would meet all the defined requirements of the RFP and would have the capability within the Habs to support additional international modules' crewmembers if more international modules are added.

2.7.3 Configuration and Module Pattern

Growth was assumed to begin from the baseline Permanently Manned Configuration (PMC) as shown in Figure 2.7.3-1. This configuration was baselined by NASA's Level B based on the SE&I Office drawing AAA029A1 dated 27 March 1986. It uses the 5 meter truss, twin keel vertical orientation with two U.S. modules and two international modules mounted in a "raft" pattern above a trailing horizontal truss platform off the solar power cross truss. The solar power truss supports a pair of photovoltaic solar arrays on each side of the station centerline along the y-axis, plus a solar dynamic generator located immediately outboard of each paired solar array. The U.S. modules are interconnected by nodes at each end and tunnels to the adjoining module. Two international modules, a European Columbus and a Japanese Experiment Module (JEM), are mounted aft of the U.S. Modules and supported by a "back porch" truss (Figure 2.7.3-2). The U.S. laboratory module, and the Columbus, immediately aft of it, are mounted on the station centerline to be within the lowest microgravity envelope. An OMV is Orbiter based and only used at the station when the Orbiter is present during PMC, but is station based at IOC. By optimum spacing and location of the truss mounted experiments, the center of mass of the station could be made nearly coincident with the laboratory modules' center of mass along the x-axis. The growth version of the IOC configuration features the addition of two more solar dynamic receptors, making a "clover leaf" configuration, at each end of the solar power horizontal truss. This provides the increased power needed to support three additional modules, two labs and an additional Hab. The crew size increases to 16 to handle the increased workload. To maintain the minimal debris/micrometeoroid hazard the modules grow in a horizontal raft pattern, which also keeps them in the minimal microgravity envelope (Figure 2.7.3-3). This results in a total of 5 U.S. modules plus the Logistics module and two International modules.

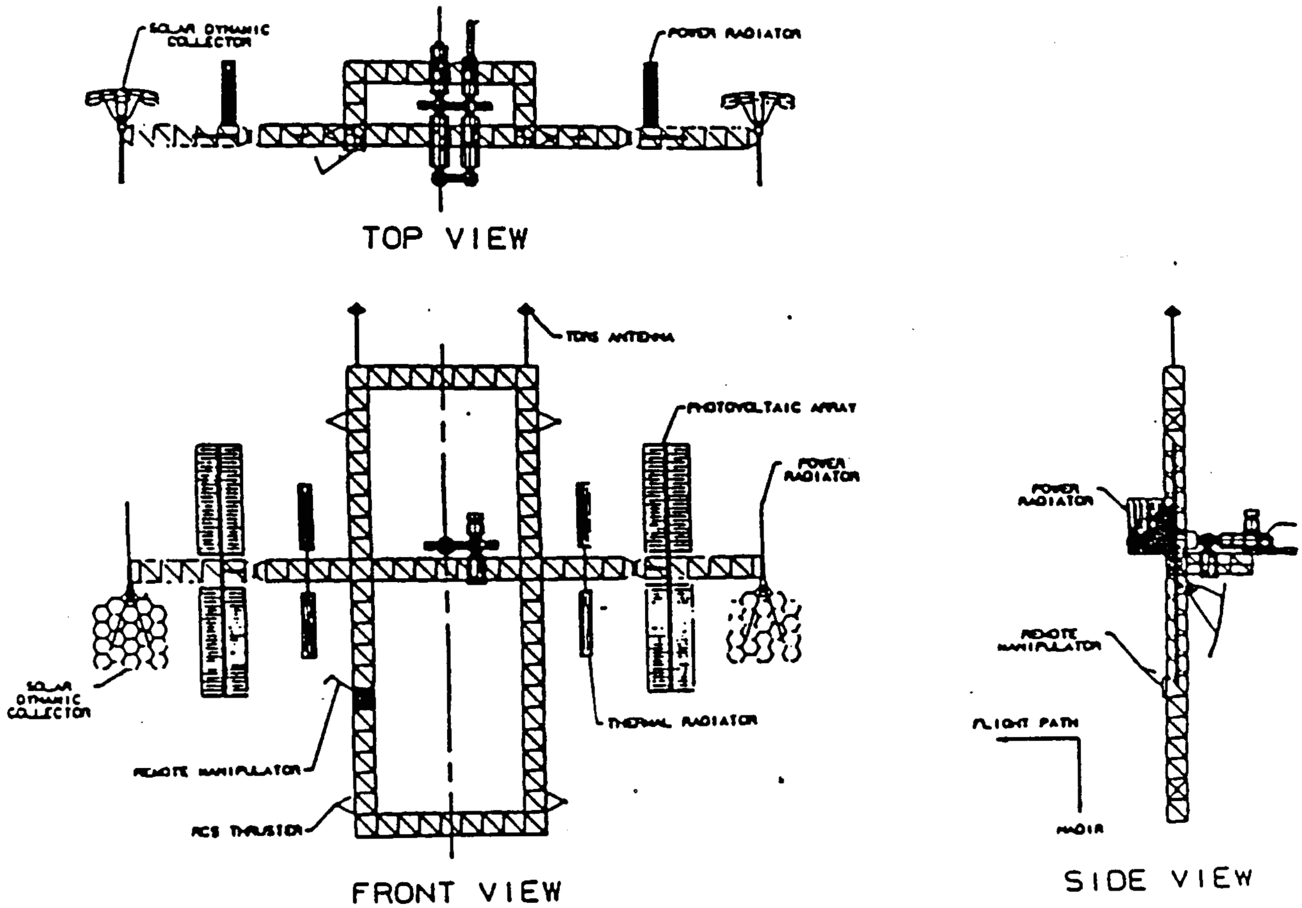

FIGURE 2.7.3-1

SPACE STATION BASELINE PERMANENT MANNED CONFIGURATION (PMC)

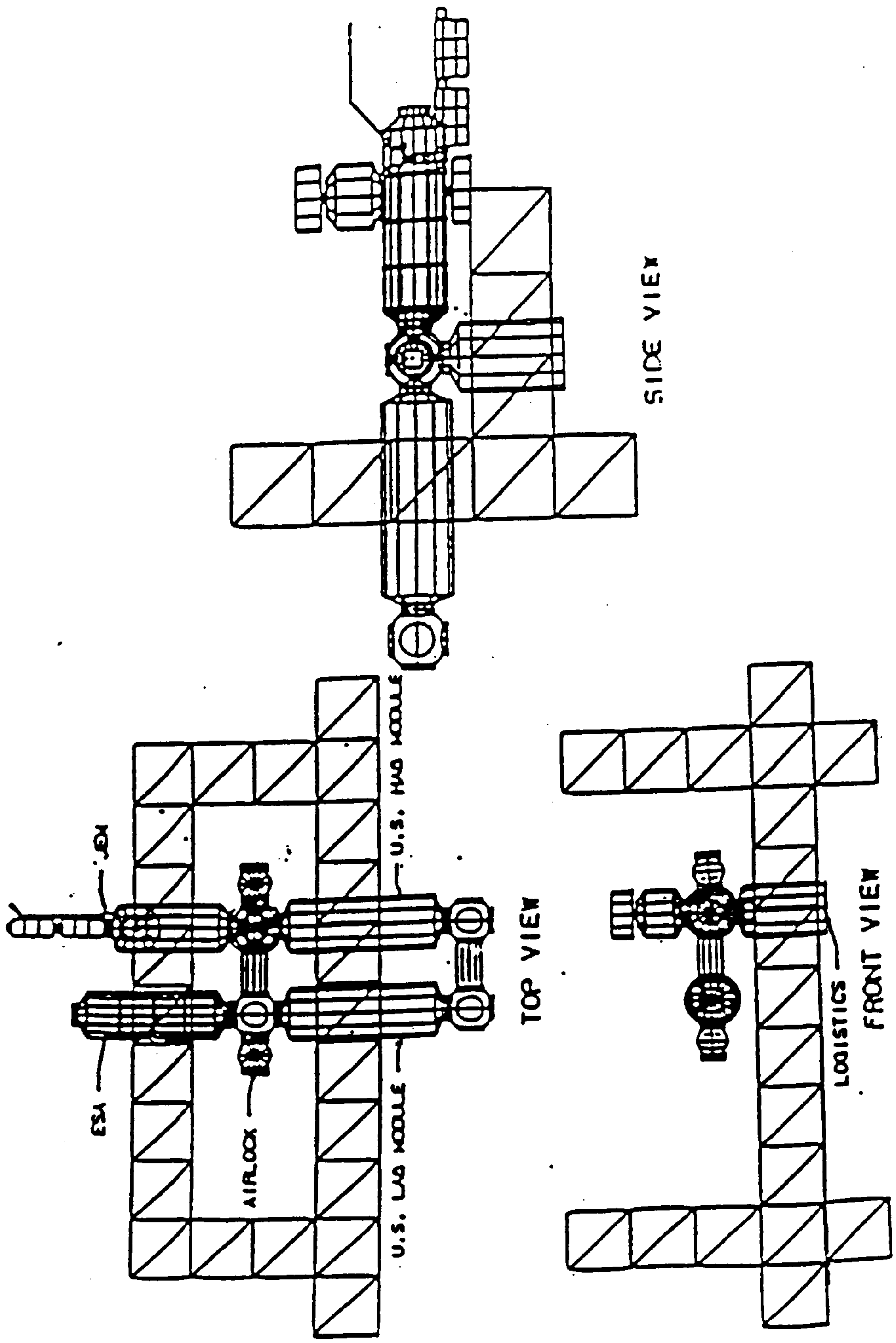

FIGURE 2.7.3-2

SPACE STATION MODULE PATTERN - BASELINE PERMANENTLY MANNED CONFIGURATION

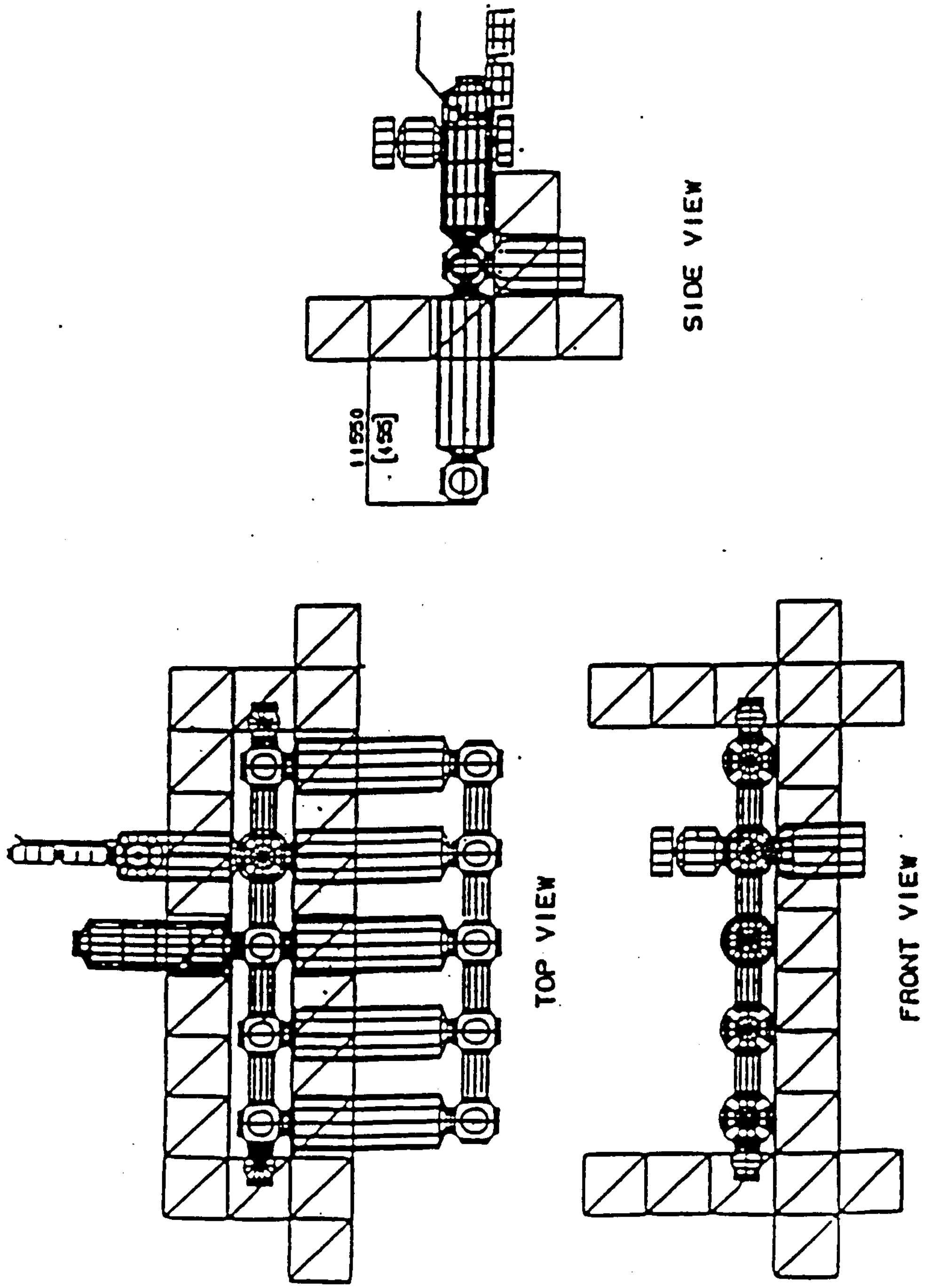

FIGURE 2.7.3-3

SPACE STATION MODULE PATTERN - BASELINE GROWTH CONFIGURATION

2.7.4 WP-01 Element Growth Concepts and SCAR

2.7.4.1 Core Module

The growth concept for the Core Module is essentially to add modules to the existing Space Station module cluster. The design of the Core Module, and the utilities interfaces provided at the ports, will accommodate added modules without scar penalties in the PMC design. Subsystems included in the Core Module PMC configurations are duplicated from module-to-module and provide all services required of those subsystems in the respective modules, as well as providing the required services to interface ports. An exception is the ECLS subsystem that has both distributed and centralized features. All modules contain certain common ECLSS functions; other functions are distributed to optimize space, cost and subsystem efficiency. The growth concept of adding modules effectively allows growth using common hardware and obviates the need for scars in the PMC design.

Core Module subsystems do include design flexibility and margin features that could benefit growth concepts. At this time, there are no scars in the Core Module PMC design concept required to support the growth scenario.

2.7.4.1.1 ECLSS - The ECLSS is configured for PMC to provide all required functions for two modules in those two modules. ECLSS growth requires increased capacity in the ARS and the water processing capability.

ARS capacity growth reflects module growth, because two ARSs are installed in each of the two PMC modules, and two ARSs are assumed to be added with each new habitability module but not laboratory modules. In addition, other than the PMC configuration, all growth versions meet the desired requirement of fail safe in safe haven. The growth in crew and water processing capacity is based on the same assumptions as the AR subsystem.

2.7.4.2 USL Provisions

This section addresses provisions for growth within the United States Laboratory (USL). USL growth will be accommodated through PMC design margins and growth scars.

2.7.4.2.1 Design Margin - Design margins within the USL will consist of additional resource capabilities which will be provided at PMC to accommodate Growth requirements. The design margin at PMC is driven by the design of the Space Station common module which will preclude the need for the on-orbit installation of additional cable runs and plumbing within the module.

2.7.4.3 Logistics Elements

2.7.4.3.1 Design Concept for Growth - Logistics Element growth accommodations provides the capability to accept increased crew/station/user resupply requirements. Several methods are being applied to accommodate the growth effectively including modular additions (e.g., refrigerator/freezer volume, LN_2 tanks), increased storage capability, inclusion of rapid sample return and trash disposal techniques.

2.8 PRODUCTIVITY

This section summarizes our efforts in Phase B to define a productivity program for implementation in Phase C/D.

2.8.1 Approach

At the outset of Phase C/D, an Operations Directive (OD) will be issued by the Vice President Project Manager, Space Station, to all functional organization elements and groups implementing the productivity program.

To assure that the productivity program meets its objectives, a steering committee will be formed composed of senior members from each functional organization. The committee will serve as the "performing function" by which each productivity improvement initiative will be screened and evaluated to determine its technical and economic advantages.

A productivity director will be assigned to direct and manage the productivity efforts and will be the productivity steering committee chairman. He will be the focal point for all submitted improvement initiatives. The productivity director will report directly to the Vice President Project Manager, Space Station. This direct attention and commitment of top management is crucial to the achievement of the productivity objectives.

2.8.2 Methodology

All submitted productivity initiatives will be categorized according to type and whether they involve either design changes, process changes, material changes, production techniques or management system changes. The initiatives will receive a qualitative benefit screening and be ranked according to potential benefits.

Those improvement initiatives with the highest ranking will be given an in-depth, quantitative analysis to determine technical acceptability, producibility, and schedule feasibility. The remaining initiatives, according to their category, rank and priority will also be screened to establish investment required, potential cost benefits and schedule for implementation.

2.8.3 Implementation - Functional Assignments

Critical to the success of the productivity program will be the interactions and interrelationship among the functional departments and how they each relate to the Space Station Project organization. Specific responsibilities and authority with respect to execution of the productivity improvement effort will be assigned to appropriate functional elements.

2.9 OPERATIONS

The Space Station Definition and Preliminary Design, WP-01, Operations Planning (DR-07) document provides the Operations Planning for Space Station support. The document presents the major features in five areas of operations, which are addressed in detail in five appendices:

Appendix A	Prelaunch Operations Plan
Appendix B	Orbital Operations Plan
Appendix C	On-Orbit Maintenance
Appendix D	Logistics, Resupply and Resupply Plan
Appendix E	Integrated Logistics Support Plan (Deleted)

The primary document provides an introduction to operations planning and general supporting data for the above appendices. The following sections summarize the basic document and the five appendices (A through E).

This document was submitted in original form on 18 December 1985 and was consistent with the SS configuration requirements baselined at that time. Changes to the configuration and requirements were documented and submitted to MSFC in June 1986. This summary does not attempt to revise passages which are dependent on the station configuration.

2.9.1 PRIMARY DOCUMENT

2.9.1.1 Introductory Material

The first section of the document (DR-07) contain the basic introductory material for all appendices. The items discussed are:

- o Ground Rules and Assumptions
- o Inter/Intra-WP Operations
- o Operations Issues
- o Space Station Operations
- o KSC Operations
- o International Elements
- o Hazardous Materials Processing

The data consists of system level definitions, descriptions, and preliminary operational issues and concerns based on the WP assignments of responsibility at the time of issuance. The intent of this document was to serve as a vehicle for presenting operations concepts which would, as the Space Station design and configuration matured, evolve into a true operations plan for accomplishing the Space Station mission.

The scope of the five appendices are to address the specific operational support required for those WP-01 responsibilities assigned to MSFC in the RFP/SOW. Those assignments are summarized in Table 2.9-1, and include hardware/software elements and subsystems, as well as system level responsibilities.

TABLE 2.9-1 WORK PACKAGE ONE, SUMMARY DEFINITION

- o WP-01-MSFC
  - o SE&I Support
    - ECLSS Analysis
    - Logistics Analysis
    - OMV/OTV Interface Analysis*
    - Common Module Commonality Analysis
    - Propulsion Analysis*
    - Reboost Analysis*
    - Laboratory Analysis
    - Common Workstation
- o Hardware/Software
  - o Common Module
  - o Structure
  - o Distribution for:
    - DMS*
    - Power*
    - ECLSS
    - Thermal
    - Communications
  - o ECLS System
  - o Propulsion System*
  - o Laboratory Module Outfitting (1)
  - o Logistics Module Outfitting (2 or 3)
  - o OMV/OTV Accommodations
  - o Applications Software*

* WP-01 responsibility reduced or deleted by subsequent NASA direction.

2.9.2 APPENDIX A, PRELAUNCH OPERATIONS PLAN

This appendix defines the operations planning concepts for the prelaunch phase and recovery/turnaround of Space Station WP-01 element processing. Processing includes the receiving, test and checkout, integration, and launch of the initial and follow on Space Station WP-01 elements as well as the return, refurbishment, maintenance, reconfiguration, and relaunch of the cyclical elements. In addition, the general Space Station ground operations philosophy is defined in this appendix. Key ground rules and assumptions are also identified. Documentation necessary for requirements identification and implementation is provided, with particular emphasis on WP-01 elements. Standardized launch site operations are discussed along with preliminary flows and schedules for initial, cyclical, and follow on Space Station elements. This appendix also describes the facility and equipment requirements and implementation approaches, addresses customer interfaces and safety and security aspects, and provides planning for some Space Station contingencies.

2.9.3 APPENDIX B, ORBITAL OPERATIONS PLAN

The Orbital Operations Plan, Appendix B, presents the on-orbit operations concept/plan for the preliminary Space Station design. It describes the plan for operating the on-orbit Space Station systems and the ground support systems relative to Work Package 01 (WP-01) elements. The plan describes the preliminary concept for managing, planning, monitoring, control, maintenance, and training. It covers the following orbital operational phases:

a. Space Station Assembly
b. Initial Operational Capability (IOC)
c. Growth Operations
d. Man-Tended Option Operations

Emphases are placed on operational functions, interfaces, roles, responsibilities, scenarios, and support systems. Related issues and concerns are discussed as appropriate to the Phase B contract effort. The plan also defines the related ground operations, functions, interfaces, roles, responsibilities, scenarios, along with required support systems for the Space Station assembly operations and IOC operations. The preliminary on-orbit operations concept of WP-01 man-tended option concept is described as well as the on-orbit operations plan for the preliminary growth version of the Space Station. Candidates for automation and autonomy applications to Space Station operations are also discussed. Figure 2.9-1 illustrates the Space Station operations support system architecture presented in this appendix/operations plan.

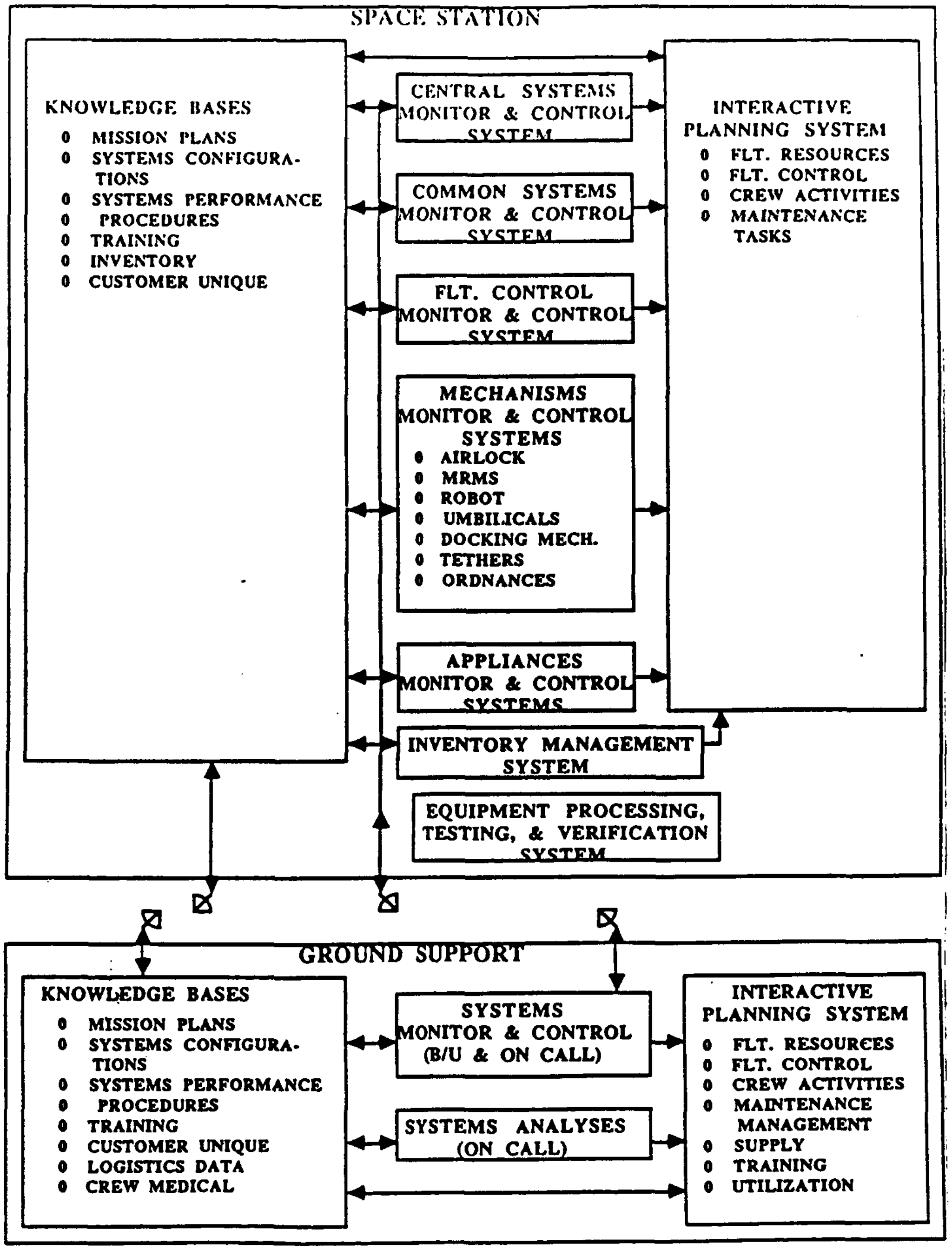

FIGURE 2.9-1 SPACE STATION OPERATIONS SUPPORT SYSTEMS CONCEPT

2.9.4 APPENDIX C, ON-ORBIT MAINTENANCE PLAN

The On-Orbit Maintenance Plan for WP-01 is a Level C program planning document. It establishes guidelines for on-orbit maintenance of WP-01 preliminary design hardware. The plan also establishes the on-orbit maintenance parameters and requirements necessary to assure effective planning and implementation, in order to meet or exceed the required maintenance goals of the Space Station.

This plan addresses both scheduled and unscheduled maintenance and provides a description of the recommended maintenance management data system. It also provides general groundrules, assumptions and criteria applicable to accomplishing on-orbit maintenance. Table 2.9-2 provides an overview of the approach Martin Marietta has taken in the Operations Plan (DR-07).

TABLE 2.9-2 SPACE STATION MAINTENANCE CONCEPT

MAINTENANCE LEVELS	LOCATION WHERE MAINTENANCE IS PERFORMED		WHO DOES IT	TYPE OF MAINTENANCE FUNCTIONS PERFORMED	
ORGANIZATIONAL	ON-ORBIT	ON-LINE	FLIGHT CREW (OR FLY-IN MAINT. CREW GROWTH/ CONTINGENCY OPTION)	-INSPECT -LUBRICATE -CALIBRATE -TIME CHANGE ITEM -HOUSEKEEPING	PREVENTIVE
				-FAULT ISOLATE (BACKUP) -REMOVE/REPLACE ORU -VERIFY AND RESET -CALIBRATE	CORRECTIVE
	GROUND	ON-LINE	MAINT. CREW	-INSPECT -LUBRICATE -CALIBRATE -TIME CHANGE ITEM -CLEAN	PREVENTIVE
				-FAULT DETECT -FAULT ISOLATE -REMOVE/REPLACE ORU/LRU -FUNCTIONAL REVERIFY AND RECALIBRATE	CORRECTIVE
INTERMEDIATE	ON-ORBIT (GROWTH OPTION)	OFF-LINE	FLIGHT CREW OR FLY-IN MAINT. CREW	-FAULT DIAGNOSE -REPAIR CRITICAL ORU -VERIFY -CALIBRATE	LIMITED CORRECTIVE
	GROUND	OFF-LINE	MAINT. CREW	-SUBASSEMBLY: +FAULT DETECT +FAULT ISOLATE -HW/SW MOD. INSTALLATION -ORU/LRU REPAIR -CALIBRATE -FUNCTIONAL VERIFICATION -ASSETS DISPOSITION -FAILURE ANALYSIS SUPPORT	CORRECTIVE
DEPOT	GROUND	OFF-LINE (GOV/ CONTRACTOR/ VENDOR)	REPAIR PERSONNEL	-COMPONENT LEVEL: +FAULT DETECT +FAULT ISOLATE -HW/SW MOD. INSTALLATION -ORU/LRU REPAIR -CALIBRATE -FUNCTIONAL VERIFICATION -ASSETS DISPOSITION -MANUFACTURE -OVERHAUL/REBUILD -FAILURE ANALYSIS SUPPORT	CORRECTIVE

2.9.5 APPENDIX D, SPACE STATION LOGISTICS, RESUPPLY AND RECYCLE PLAN

This plan is the Space Station Work Package 1 (WP-01) Logistics, Resupply and Recycle Plan now referred to as the WP-01 Logistics Support Plan in accordance with the agreement with Mr. J. Lusk, MSFC Logistics Project Officer. The preliminary issue of this document is based on the current guidelines being considered by the Space Station Integrated Logistics Support Working Group. Subsequent issues will be prepared to specific contract and applicable document requirements and will detail the Martin Marietta procedures and specific methods for the logistics support of WP-01 requirements.

The primary objectives of this appendix are to provide the approach to satisfy the logistics requirements of the program, to establish an orderly development and integration of the required contractor logistics elements, to assure comprehensive communication and coordination among participating organizations. These objectives are met through the discussions of the following:

a. Organizational Relationships and Responsibilities
b. Logistics Engineering Analysis
c. Logistics Elements

The plan relates logistics activities directly to the contractor's preliminary design and to the performance of that design in meeting the Space Station's operational and mission requirements and include the following:

a. Description of logistics support analysis tasks, methodologies, and outputs.

b. Methodology for spares provisioning, replenishment and material management.

c. Recommended on-orbit/ground spares warehousing philosophy including overall facility requirements.

d. Technical documentation requirements and on-orbit utilization concepts.

2.10 PRODUCT ASSURANCE

2.10.1 Product Assurance Requirements (DR10)

Product Assurance Programmatic Requirements are documented in JSC 30000 Section 9 titled "Product Assurance Requirements for the Space Station Program". DR10 requested that individual Safety Reliability and Quality Assurance plans be prepared and submitted under separate covers from the Project Implementation Plan.

The Safety Reliability Quality Assurance and Software Product Assurance plans (documents SSP-MMC-00037, SSP-MMC-00038, SSP-MMC-00039 and SSP-MMC-00040) were prepared in accordance with JSC 30000 Section 9 and were submitted on 1 June 1986 per the DR10 schedule. These plans describe the organization, task and activities and program relationship to be utilized by Martin Marietta to assure program product assurance goals and objectives for achieving safe reliable quality elements of the Space Station are achieved.

The Safety, Reliability, Quality Assurance and Software Product Assurance plans provide the baseline programs for these disciplines and will be updated and submitted as a part of the Phase C/D proposal.

2.10.2 Safety Analysis (DR11)

The Preliminary Safety Analysis (PSA) was initiated and completed in response to Contract NAS8-36525, in accordance with Data Requirement No. 11, Preliminary Safety Analysis. The PSA was conducted by safety organizations at Martin Marietta Denver Aerospace, Martin Marietta Michoud Aerospace, McDonnell Douglas-Huntsville, Hamilton Standard and USBI-BPC-Huntsville. The Martin Marietta Denver Safety Organization integrated the analysis inputs and performed the analysis of WP-01 areas not directly in the scope of the other aforementioned team members.

The Phase B PSA effort applies to all Work Package 01 elements. The PSA addresses all WP-01 element concepts, GSE, GFP, related software, and conceptual ground and flight operations including integration, ascent and descent, assembly, checkout, operations and maintenance. The scope of the PSA was directly related to the corresponding stage of WP-01 preliminary design development at that time. The then current configuration was analyzed in a top-down manner. Energy sources, hazardous functions and operations were systematically analyzed to derive a list of inherent hazards. Hazard causes were identified based on known subsystem designs and operating scenarios, lessons learned from previous programs, and related analyses (e.g., FMEA). Each identified hazard and cause(s) were reviewed against existing Space Station requirements for applicability. If there were no applicable existing requirements or an existing requirement did not appear to be adequate to control the hazard derived requirements were generated. The derived requirements were based as firmly as possible on existing Space Station requirements, they were intentionally worded to support direct implementation into the appropriate CEI specification. If appropriate requirements could not be identified or derived, or if impacts appeared prohibitive, the need for additional study was noted. The hazard reporting format was developed specifically for the Preliminary Safety Analysis effort, it was derived based on the applicable features of other hazard reporting formats and DR-11 guidelines.

The Preliminary Safety Analysis effort was continued throughout Phase B and will support the phase C/D safety analysis activity by establishing a baseline of hazards that will be tracked, controlled and verified. Safety evaluation of impacts incurred by recent change activity is ongoing, additional hazards and applicable controls will continue to be identified and assessed as the program progresses on through phase C/D.

2.10.3 Failure Modes and Effects Analysis (FMEA) (DR12)

Two submissions of DR-12 preliminary FMEA have been made as required. The first submission was on 11 December 1985 and included analyses of the Propulsion Subsystem, Thermal Control Subsystem, and the Power Distribution Subsystem. Each FMEA consists of: subsystem functional description, assumptions and groundrules, subsystem block diagram, the FMEA worksheets and a summary.

The second submission of DR-12 was on 30 June 1986 and included analyses of the Common Module structure performed by Martin Marietta Michoud Aerospace, the MTL Outfitting performed by McDonnell Douglas-Huntsville, and the ECLSS performed by Hamilton Standard.

The preliminary FMEA's have identified a number of critical items. Solutions are available for those items where the design has been finalized. For those items in areas where the design is still fluid, the critical items will be tracked and controlled.

2.11 Metrication

In accordance with the requirements of paragraph 3.8.6 of the Statement of Work, we have studied the impact of utilizing the International System (SI) of units in the design, development, manufacture, test and operations of the Space Station program elements for which the MSFC will be responsible.

The key question in the conduct of the study was what level of metrication is really implied when applying SI units to the Space Station program. Does this application infer complete or hard metrication across the entire program? Does it infer soft metrication only? Or does it infer partial metrication, wherein documentation uses the International System of units and only hardware elements that are the results of new designs are metric, but use of commercial and/or off-the-shelf hardware taken "as is" are generally recognized as non-metric?

Our analysis considered the overall range of options implied above from no-to-soft-to-hard metrication and an impact assessment was developed for each.

Our analysis has indicated that to use only English units for the U.S. Space Station elements use would have the least impact on us in terms of cost and schedule since it would afford us the opportunity to operate and perform in a status quo situation. But this option would have a detrimental impact on the interface area due to the planned, active participation of our international partners and the metric hardware provided by them.

The adoption of a full, or hard metric program, would have the most impact in terms of both cost and schedule. This would be felt most strongly in the areas of the non-availability of metric parts or the O&M problems associated with having a hybrid system - the natural result of neither being able to afford the cost nor the schedule delay associated with providing an all metric part availability.

Use, of, and adoption of, a soft metric program - wherein documentation is all in SI as well as English, but no attempt is made to convert the hardware to metric - appears to be an approach that will overcome the interface problems with our SI international partners and do so without incurring the significant cost and schedule penalties associated with the hard metric approach.

While there would be a small cost associated with the adoption of a soft metric program - i.e., in the conversion of existing documentation and in the training of our personnel to understand, to use, to think and to be comfortable in metric - we feel that if NASA made the decision to adopt a soft metric approach as a requirement for Phase C/D, then we, as contractors, would start our documentation transition and our training immediately, thus minimizing any cost impact resulting from this decision. With a deferred decision - i.e., until the Phase C/D RFP - a more significant cost would probably result.

As a result, we recommend that a soft metric program - i.e., the use of dual dimensioning in SI and English units - be adopted and imposed on Space Station. Further, we recommend this requirement be imposed on all program participants as soon as possible to permit accomplishment of the dual dimensioning activities with minimal cost.

3.0 HARDWARE ELEMENT STUDY RESULTS

The following sections summarize our recommended WP-01 hardware/software configurations established as a result of our Phase B contract efforts. See Volume II of this document for additional concept details, rationale and hardware descriptions.

3.1 CORE MODULE

The Core Module (CM) is a habitable volume equipped to supply a life sustaining environment and utility services needed by all SS pressurized module elements. In order to cost effectively optimize commonality across all three SS module elements (HSO, USL, LM) and minimize manufacturing type operations required of outfitters, and satisfy outfitting requirements, three tailored CM configurations have been defined. These three configurations, when properly outfitted, will serve as a Habitat/Station Operation Module (HSOM), a United States Laboratory (USL), or a Logistics Module (LM). Each has unique features, which are derived from standard design options selected by the outfitters, to meet the requirements of the respective end uses. In addition, the LM is uniquely configured for its role as a resupply container.

A high degree of commonality has been employed among the three configurations, both in structural components and in the subsystem installations. The external envelopes of the HSO and USL modules are identical. The tailored CM configuration for LM outfitting consists of common portions of structure used to form a shorter, pressurized, habitable section of the LM. Some primary and secondary structure and portions of the subsystem installations are uniquely configured or derived from common parts to suit the different size and use of the LM. The CM configurations as defined herein are subsequently outfitted with additional unique equipment, including the installations of CM subsystems ship-loose items. It is a goal of the CM build phase that no major rework such as drilling, welding, or structure subsystem modification, will be required by the outfitter in the outfitting phase of module production.

3.1.1 Subsystems

The CM is comprised of the following subsystems: Structures/Mechanisms, Electrical Power, Data Management, Communications, Environmental Control and Life Support, Thermal Control, Crew Systems, and Software. These subsystems are distributed throughout the Space Station as shown in Figure 3.1.1-1.

3.1.1.1 Structures/Mechanisms

The Structures/Mechanisms subsystem provides the structure of the core modules, nodes and tunnels which, in turn, provide a volume for habitation. This volume gives protection from the environments of the Space Station launch, build and operational phases. The volume will be pressurized and will provide structural interfaces for outfitting equipment. Berthing mechanisms will allow the pressurized elements to be connected in a reconfigurable pattern. Hatch mechanisms will provide entry, exit and isolation of the pressurized elements.

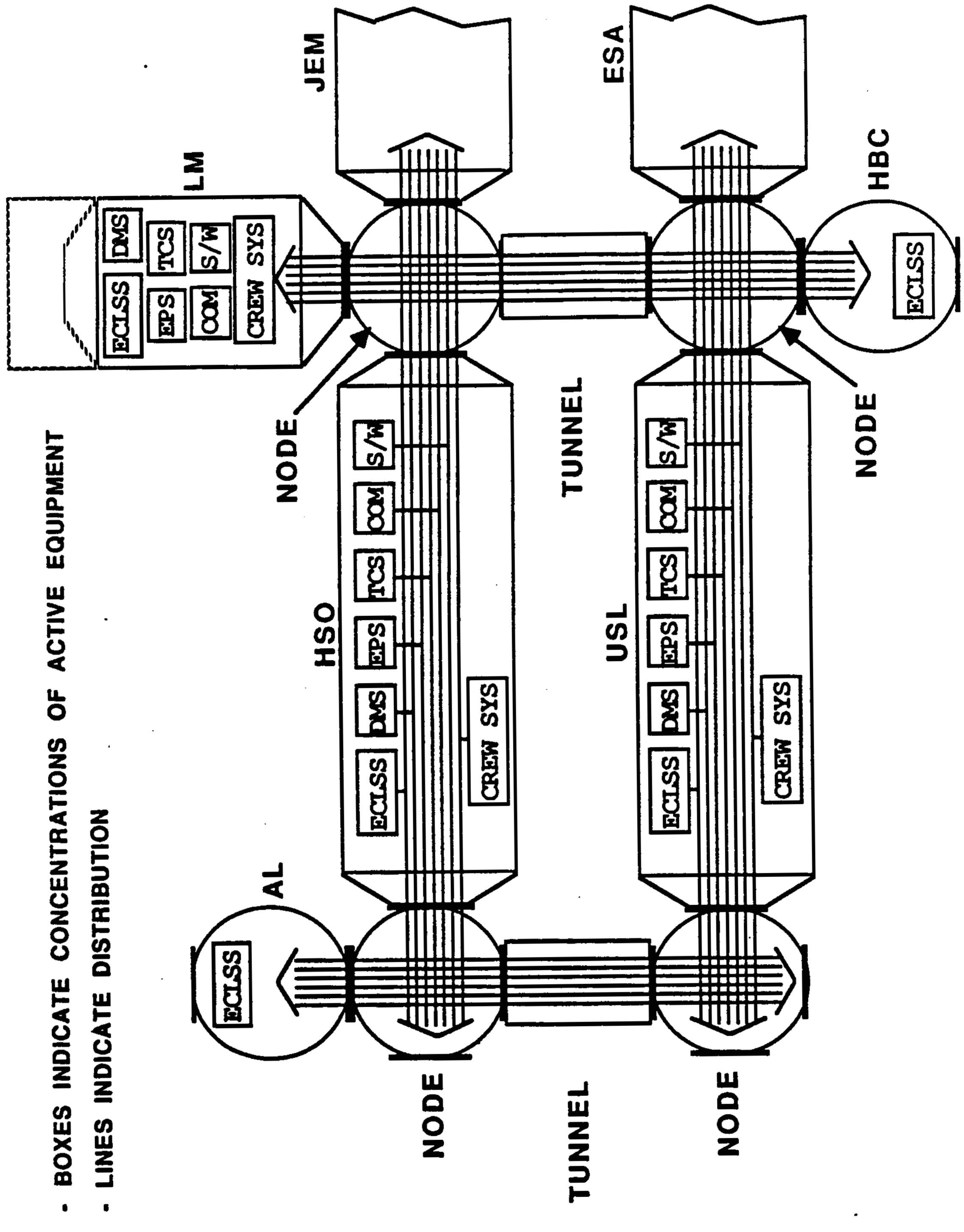

FIGURE 3.1.1-1 WP-01 SYSTEM SCHEMATIC - SUBSYSTEM DISTRIBUTION

3.1.1.2 Electrical Power

The Electrical Power subsystem accepts input utility power from the Space Station solar arrays and feeds into a transformer to step the input voltage down to a distribution voltage. The subsystem provides distribution of electrical power within the core elements. Distribution of electrical power is also provided for the nodes and tunnels. Electrical power is available at all of the berthing mechanisms of the nodes for use by attached payloads.

3.1.1.3 Data Management

The Data Management subsystem (DMS) includes cabling, electronic hardware and software used to distribute data within the pressurized elements. Signal processing, multiplexing, data processing, and caution and warning functions are accomplished by the DMS. The man-machine interface of the DMS is the multi-purpose application consoles (MPACs) which are located in the HSO and USL module elements. The DMS will interface with the Space Station global DMS in order to communicate within the elements and with external systems.

3.1.1.4 Communications

The Communications subsystem allows establishing and maintaining audio and video contact within the pressurized elements. Private and secure, as well as conference communication will be possible. Interfaces will be provided for communications with external systems. Voice recognition and synthesis will be provided. Recording and playback capabilities will be provided for both audio and video signals.

3.1.1.5 ECLSS

The Environmental Control and Life Support subsystem (ECLSS) provides the habitable volume of the Space Station with an environment capable of supporting and maintaining human life. ECLSS is comprised of the following functional subsystems: 1) Temperature and Humidity Control; 2) Atmosphere Control and Supply; 3) Atmosphere Revitalization; 4) Fire Detection and Suppresion; 5) Water Recovery and Management; 6) Waste Management; and 7) EVA Support. The Space Station crew will be provided all aspects of a safe and supportive atmosphere and environment by the ECLSS.

3.1.1.6 Thermal Control

The Thermal Control subsystem (TCS) will provide for the transfer and rejection of thermal loads from the pressurized elements of the Space Station. Payloads attached to the nodes will be thermally supported by TCS. The refrigerator/freezer function of Space Station will be supported by TCS. Both active and passive means of thermal control are used by TCS.

3.1.1.7 Crew Systems

Aids will be provided by Crew Systems for crew mobility and restraint. There will be crew mobility aids and crew restraints for use in both intra-vehicular and extra-vehicular tasks. Devices to contain, restrain or move Space Station hardware or resupply items will be provided by Crew Systems. Trash collection equipment, stowage provisions, in-flight maintenance, tools and equipment for both IVA and EVA, and portable fire extinguishers are also provided by crew systems.

3.1.1.8 Software

WP-01 software architecture requirements involve a distributed software system which allows a module or subsystem to operate autonomously for most operations. The distributed Space Station onboard software functions are partitioned to three operation levels within the Space Station. The Network Software and Subsystem/User Man/Machine Interface is common software at each of the three levels. The operating systems data base management systems may also be common. The common software is the same set of code operating in several processors. The Man/Machine Interface via the work station is available at each level. Access to each level is through the Multi-Purpose Access Console (MPAC) which is available in each module as a fixed or portable station.

3.1.2 Internal Configuration - Four symmetrically spaced graphite/epoxy composite standoff assemblies provide substructure mounting for equipment racks and for supporting the internally mounted cable trays and utility ducts. Symmetrical spacing for the standoffs was selected to accommodate the maximum number of standard racks. Each standoff accommodates the currently defined subsystem utility requirements while providing good access to the pressure wall and the utilities themselves.

The geometry of the standoff structure, Figure 3.1.2-1, provides excellent flexibility for all outfitting requirements and is removable in sections. The aisle widths of 2134 mm (84.0 in) facilitate traffic flow while still maintaining efficient usage of the remainder of the CM volume for equipment and utilities.

All equipment, subsystem provisioning or outfitting, is mounted to standard attach fittings located along the standoff structure. Installed equipment may be hinged at the attach fittings to allow easy access to the pressure wall, standoff and utilities for maintenance and repair. Utility interface plates are located at 1067 mm (42 in.) centers along each standoff.

The CM equipment racks, shown in Figure 3.1.2-2 are designed to accommodate all subsystem provisioning and user outfitting application. The racks are configured as either single or double width structures. The CM will be provisioned to accommodate single or double racks at standard mechanical

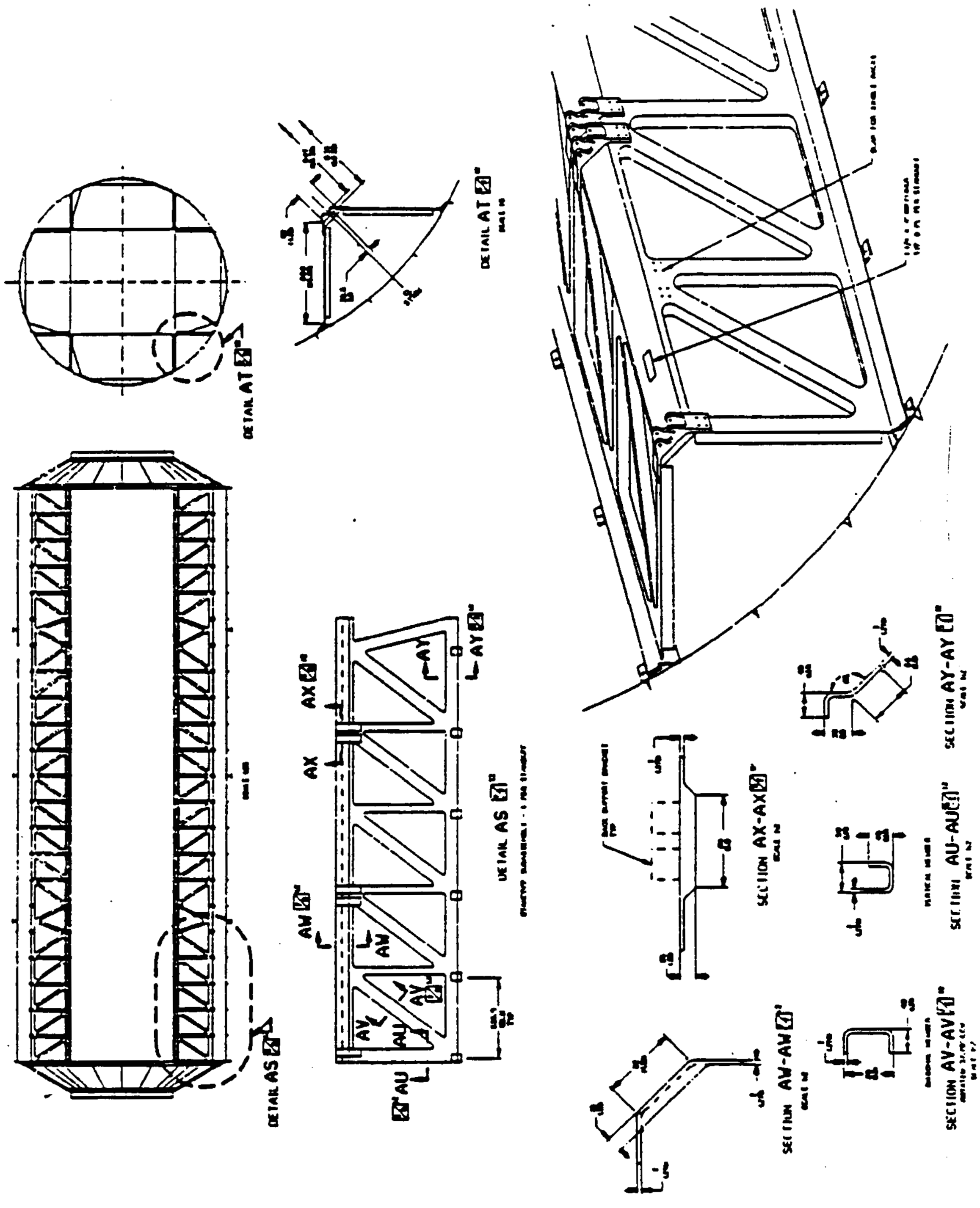

FIGURE 3.1.2-1 INTERNAL CONFIGURATION-STANDOFFS

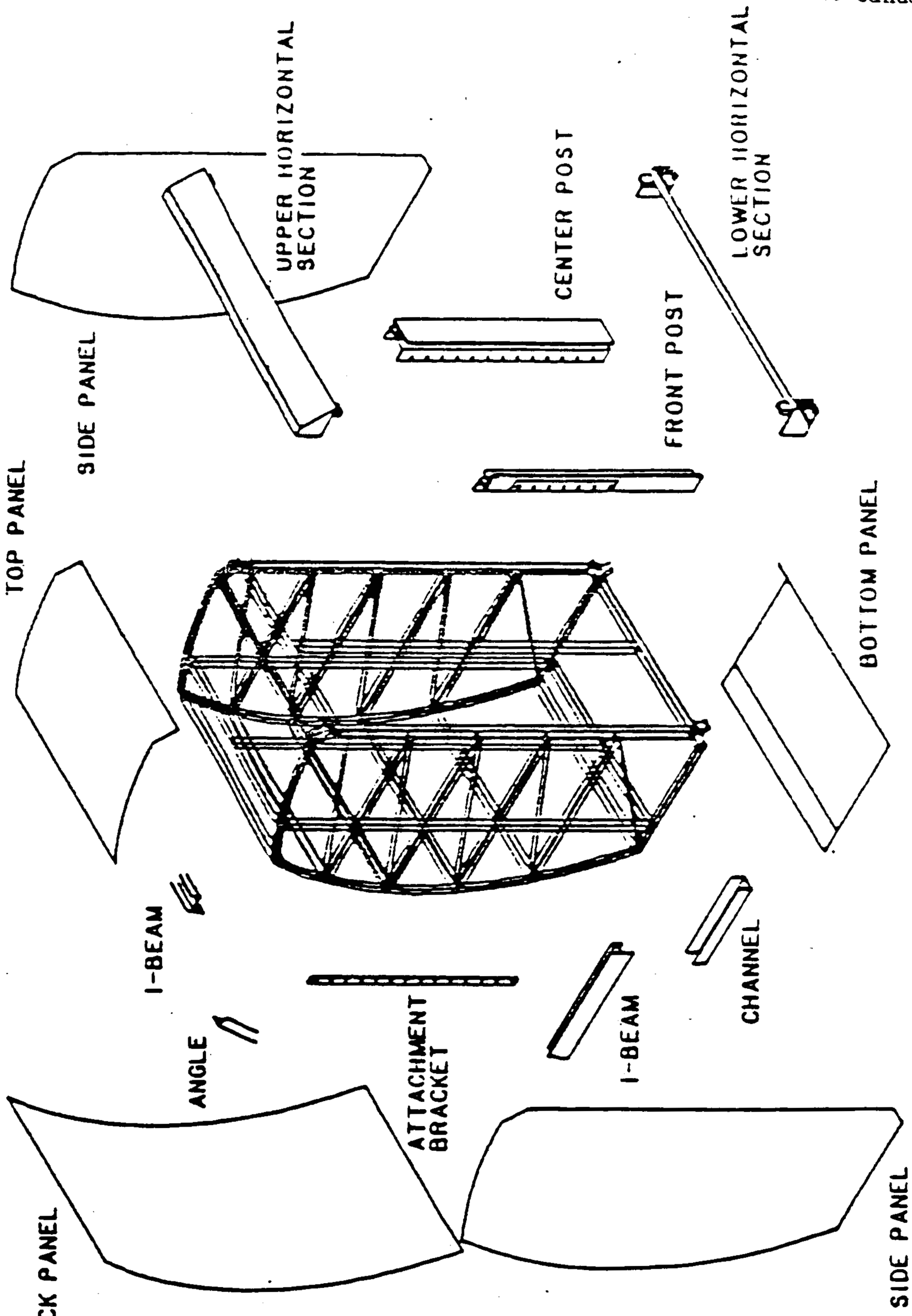

FIGURE 3.1.2-2 EQUIPMENT RACK

interfaces, spaced at 1066.8 mm (42 inch) pitch along the length of the module. The CM can accommodate 22 single or 11 double racks in each of four bay rows (left and right walls, floor and ceiling).

The racks are mounted to the module structures with a statically indeterminate-four-point kinematic attachment to prevent module structural and thermal distortions being induced into the rack structures. The rack or pallet is removed from the module by first releasing the latches on the rack and allowing the rack to rotate 75° into the aisle of the module. The electrical, fiber optics, fluids and/or vacuum are then manually disconnected. The rack is lifted from the two hinges at the bottom allowing it to be removed.

The rack structures consists of a basic structural framework enhanced by removable top, bottom, side and rear panels. The panels are nonstructural and provide subsystem containment, environment protection, and fire suppression delta pressure. The panels, along with the outfitter supplied front panel, constitute the rack envelope.

3.2 U.S. LABORATORY

3.2.1 Mission Description

The U. S. Laboratory (USL) is a multidiscipline facility for payload accommodation within a pressurized habitable volume. Principal disciplines to be accommodated include, but are not limited to, the following:

a. Materials research and development most sensitive to acceleration.

b. Research in basic science requiring long duration of extremely low acceleration levels.

c. Life Sciences research relating to benefits of and adaptation to long duration exposure to extremely low acceleration levels.

d. Control and monitoring of user-attached pressurized modules (payloads) and selected external attached payloads.

The micro-gravity requirement of 10^{-5}g for payload operations will enhance materials processes and allow for the advancement of knowledge and the development of process controls. The USL will also accommodate the scale-up to pilot plant operations and the operation of pre-production and commercial facilities in space.

The USL will have a high degree of commonality and interaction with the other Space Station elements. Unique USL outfitting will allow for provisions to mount workstations and equipment using rack and non-rack installations. It will be outfitted and checked out on-ground to the maximum extent practical with the possibility of rack outfitting and payload configuration taking place on-orbit because of launch weight limitations.

Assuming a manned Space Station, on-orbit USL operations will be performed by assigned USL crewmembers with periodic augmentation from other Space Station personnel. Resupply of USL equipment and supplies will be accomplished by periodic Logistics Module changeout.

3.2.2 USL Configuration Overview

The USL will be a Space Station module dedicated to operation as a laboratory. In addition to the standard subsystem racks (such as ECLSS and the MPAC) the IOC USL combined lab configuration will include a number of Space Station support racks, such as attached payload control and communication and tracking. A total of 29 double rack spaces (out of 44) will be available for laboratory service subsystems, laboratory support equipment, and user facilities.

The USL structures/mechanisms subsystem will include the pressure shell, hatches, standoff structures, racks, rack integration hardware, workstation desk inserts (including the glovebox) and unique support structures for USL equipment which will not fit in a standard rack.

3.2.2.1 USL Structures and Mechanisms

The baselined Core Module design is defined in Section 3.1 of this document. Rack structures (single and/or double) can be integrated into the module floor, ceiling, or sides. The USL will be outfitted such that payload facilities, support, and characterization equipment will be mounted along the sides of the module. These side-wall racks are referred to as prime racks. The floor racks will primarily house subsystem equipment while ceiling racks will be used to stow equipment such as loose tools, spares, microscopes, etc. in containers. Limited power and cooling will be available for ceiling rack equipment. Refer to MMC DR-02 Core Module Data Book for specific information on the Core Module USL configuration. Figure 3.2-1 is a representation of an outfitted USL.

Four functions have been identified for the USL racks: exchangeable payload carriers, modular, easily accessible subsystem packages, stowage facilities, and workstations. To fulfill all of these roles effectively, the USL racks must:

a. Provide equipment with structural support during launch and landing as well as restraint and confinement on-orbit.

b. Allow access to rack-mounted equipment without removal of rack structure or disconnection of utilities.

c. Provide a dedicated payload volume, clear of primary structure, with standardized, dedicated mounting interfaces. The front panel mounting interface should conform to EIA Standard RS-310-C.

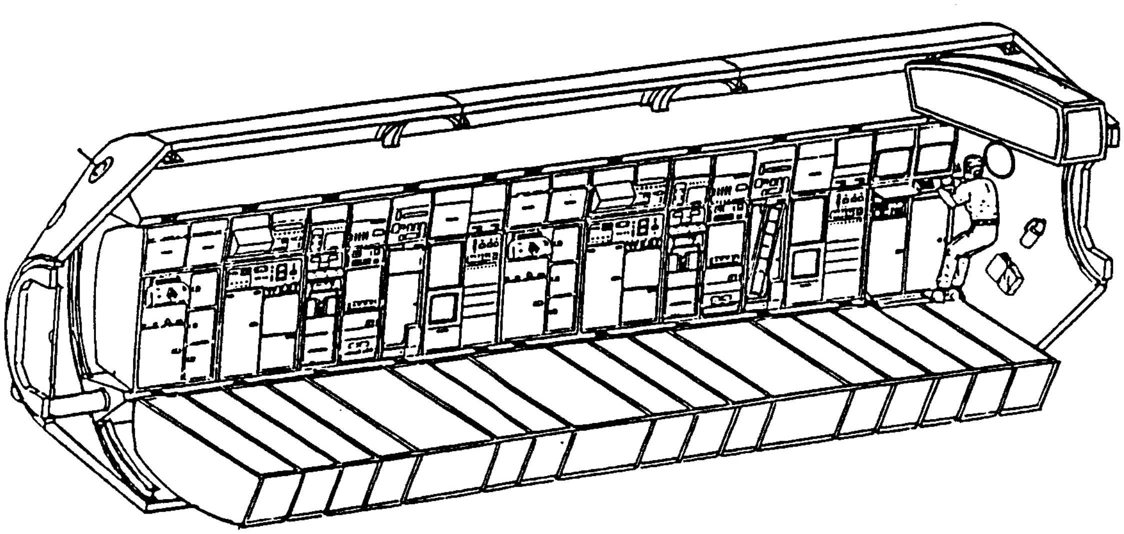

FIGURE 3.2-1 OUTFITTED USL

d. Provide a dedicated volume for subsystem equipment and utility distribution, with dedicated mounting interfaces, to simplify rack integration and reconfiguration.

e. Be completely interchangeable and reconfigurable; any rack should fit in any location within the USL and support any of the functions listed above. Also, some racks must be interchangeable with international module racks.

3.2.2.2 Electrical Power Subsystem

The USL electrical power is supplied by the core module subsystem and is tailored within the USL. Unique USL EPDS outfitting accommodations include rack level power distribution, protection, monitoring and control functions through a Rack Power Control Unit (RPCU). This device is designed to be integrated into a standard location in the rack lower utility volume and provide the necessary branching, switching and circuit protection for subsystem and user equipment. This device may be configured for standard rack power (three 1 kW outputs or one 3 kW output from either bus A or B) or may be configured for high power applications (two 6 kW outputs or two 15 kW outputs from either bus A or B). By locating this branching function within the rack, the rack power interface complexity to the standoff interface plate is greatly reduced.

3.2.2.3 Data Management

The USL Data Management Subsystem (DMS) is provided principally by the common core and is characterized by a distributed architecture which interfaces with the subsystems and users through a Local Area Network (LAN). Unique USL DMS provisions include a Customer Facility Support Processor (CFSP) which interfaces with the basic LAN and acts as a payload operations executive by providing payload scheduling and resource conflict resolution functions. A laboratory support processor provides general computational services such as data reduction and data base management functions to the users. Within the USL subsystem and user racks a Local Controller (LC) performs data multiplexing functions which combine multiple user data streams into a single serial data stream to simplify the interface with the module LAN. The Local Controller provides standard RS 232, IEEE 488, A/D, D/A, and discrete input and output for user and subsystem data support.

The unique USL subsystems (PMMS and Vacuum vent) include subsystem processors which are common to similar processors located in other Space Station subsystems. These processors host the activation, deactivation, control, and failure detection software required to operate the system in the DMS distributed processing environment.

3.2.2.4 Communications

The USL Communications and Tracking (C&T) system is provided by core module subsystems.

3.2.2.5 ECLSS

The ECLSS provides mainly an indirect support function to laboratory operations through the control of the working environment for the crew. Three functions, however, constitute a direct functional interface to Laboratory operations. These are:

a. Avionics air cooling of rack mounted subsystems and user equipment
b. Laboratory water makeup from the potable water system
c. Nitrogen and oxygen supply for user process support

Items b. and c. are discussed in the Process Materials Management Subsystem overview of Section 3.2.2.10.

3.2.2.6 Thermal Control

The USL Thermal Control System (TCS) provides waste heat acquisition from subsystem and experiment equipment through cold plates and heat exchangers; waste heat rejection through central space station radiators and low temperature body mounted radiators; and passive thermal control of the USL module by multilayer insulation (MLI) and thermal coatings.

3.2.2.7 Crew Systems

Crew equipment uniquely provided for the USL includes an emergency shower and handwash capability. The emergency shower and handwash are identical to the standard units located in the Habitation Module with special provisions to segregate potentially contaminated waste water from the ECLSS potable and hygiene water systems.

3.2.2.8 Software

The USL applications software will operate in the USL DMS hardware described in Section 3.2.2.3 of this document. The USL unique software will interface with the Core Module software described in Section 3.1 to access common software functions provided by the Core Module software.

The USL unique software applications reside in the customer facility support processor, laboratory support processor, local controllers, and USL unique subsystem controllers. These applications will be designed in accordance with the hardware architecture of these common controllers and will interface with the standard operating system and Space Station Operations Management System (OMS). Development of the USL unique applications will follow the guidelines for design, code, validation, configuration control and language standards defined in the software development test and verification plan.

3.2.2.9 Vacuum Vent

The function of the USL experiment Vacuum Vent System is to maintain a high quality vacuum resource for the USL user community. A low rate/high vacuum approach has been taken which provides a $1x10^{-3}$ Torr vacuum to USL users at a pumping rate of 0.03 scc/sec per rack bank. The vacuum resource is provided by 6-inch lines which service each prime rack bank. The user interface is through 2-inch lines which are available on 42-inch centers. The low pumping rate of this system results in a minimal impact on the external contamination environment and allows a totally passive design. Experiment chamber purge and waste dump functions are the responsibility of the USL Process Material Management System and are described in Section 3.2.2.10.

3.2.2.10 Process Material Management Subsystem

The Process Material Management Subsystem (PMMS) was formed by combining the former process fluid subsystem with the process waste management subsystem. The PMMS is, therefore, responsible for two major USL services. First, it provides storage and distribution of USL process fluids. Second, it must provide safe handling. removal, storage, and disposition of USL payload waste by-products. Figure 3.2-2 gives an overview of the subsystem functions.

3.2.2.10.1 Process Fluids Supply - The PMMS is responsible for the storage and distribution of specific consumable gases and liquids used by USL facilities and laboratory support equipment. The liquid phase process fluids are handled in a closed loop linked to the waste handling system for appropriate processing and possible dispensation to the station integrated Fluid Management System (FMS). The gas phase process fluids are part of an open loop which interfaces with both the USL waste handling system and station FMS. In either case, most waste gases are stored for 15 days then vented overboard during station non-operational periods. These waste handling functions will be discussed in Section 3.2.2.10.2

To be considered as a process fluids supply candidate, each fluid must meet the following criteria:

a. The fluid must be an essential ingredient which is used in an experiment process.
b. The fluid must be used by more than one piece of equipment in sufficient quantities to justify providing a supply for general use.

The MSFC MMPF database was examined for possible process fluid candidates from the Materials Processing Science equipment and the AMES database was used for Life Sciences. This database contained 50 USL facilities and laboratory support equipment which require fluid inputs. The required consumables for each piece of equipment were assessed for possible process fluid candidacy.

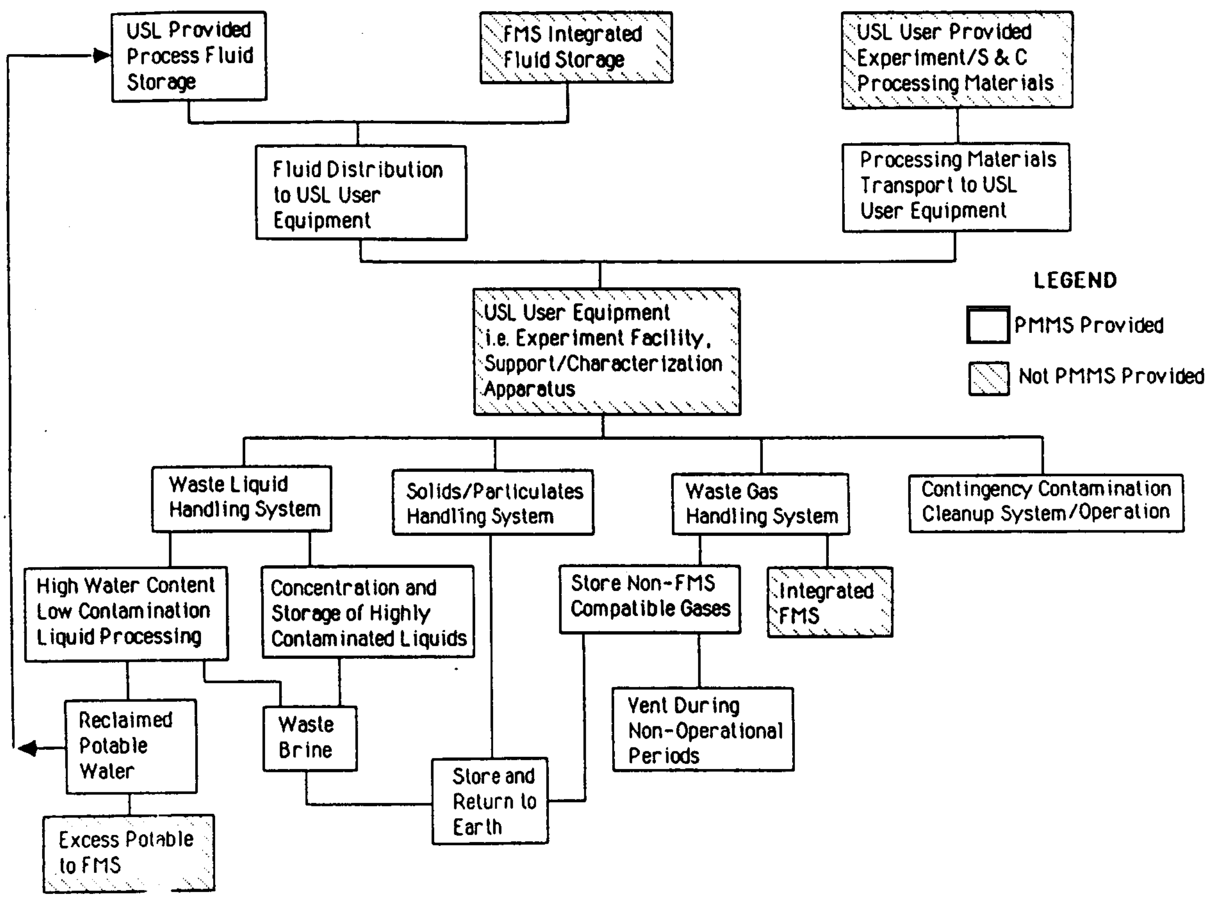

FIGURE 3.2-2 PMMS SUBSYSTEM OVERVIEW

The following fluids met the criteria mentioned above. This list corresponds to the fluids specified in the USL CEI.

a. Water
b. Helium gas
c. Nitrogen gas
d. Argon gas
e. Oxygen gas
f. Carbon dioxide gas
g. Hydrogen gas

Fluid groups such as etchants, solvents, buffers, cleaning fluids, and fuels were identified in the database, but are required in small quantities or by single users and are considered user supplied. Only one of the 50 pieces of equipment required xenon or acetylene gas. As a result these materials are considered user provided.

According to the MMPF database, several users require cryogenics such as liquid nitrogen and liquid helium. These fluids are required for their thermal properties and not necessarily for the fluids themselves. The Critical Point Facility is the only exception and utilizes LN_2 and LHe as part of the experiment other than for cooling. Long term storage of these fluids presents several technical challenges with expensive and complex design solutions. In addition, intra-module cryogenics transport introduces several safety issues. A closed-loop helium based cryogenic refrigeration system has been selected to satisfy the USL cryogenic requirements. This concept provides LN_2 temperature levels at the point of use, and in the process eliminates cryogenic fluid storage and transportation design complexities.

Liquid helium is only required by the Critical Point Facility. Because of this, and the large amount of power required for liquid helium production, it is felt that LHe should be user provided. The closed-loop cryogenic refrigeration system has the capability of providing the first stage of helium liquifacation. This will reduce the equipment burden on the LHe user.

3.2.2.10.2 Process Waste Handling - The Process Waste Handling System (PWHS) is responsible for the safe removal, storage, and disposal of USL payload waste by-products. The source of waste is from payload, characterization/support equipment, and support processes including a work bench, glovebox, emergency shower, and handwash. The PWHS provides the capability of phase separation of these wastes where required. The system provides accommodations for collection and storage of hazardous and non-hazardous solid waste, recoverable and non-recoverable water, non-recoverable fluid waste segregation and storage, and gaseous waste disposition.

The system is designed to be capable of long-life operation in a corrosive environment in addition to the safe storage, transportation, and containment of toxic waste. The PWHS provides a transport function which has the capability of interfacing with all payload experiments and characterization/ support equipment where the experiment process requires transport of hazardous materials from one rack location to another. In addition, the PWHS is designed to comply with all internal and external contamination requirements in its disposition of USL wastes.

3.2.2.11 Laboratory Support Subsystem

Laboratory Support Subsystem equipment includes the two categories previously referred to as Support Equipment and Characterization Equipment. This hardware includes common items required to support materials processing and life sciences research in space. The laboratory support equipment functions include pre- and post processing of materials samples, storage and handling, and product analysis and characterization. The list of items provided in Table. 3.2-1 represents the laboratory support hardware which has been designated as candidates to be supplied as generic equipment to support the USL payload operations.

Two principal workstations, each consisting of an adjacent double rack and single rack, will be provided in the USL. The two workstations currently planned for the USL are the workbench and the glovebox.

TABLE 3.2-1 LABORATORY SUPPORT EQUIPMENT

Accelerometer unit, 3-axis recording
Automated cutting/polishing unit
Battery charger
Cameras and camera locker
Centrifuge, standard laboratory
Centrifuge, refrigerated
Chemical supply storage facility
Cleaning equipment
Digital multimeter
Digital pressure transducer
Digital recording oscilloscope
Digital thermometers
Dosimeter, passive
Dynamic environmental measuring system
Electrical conductivity probe
EM-shielded storage locker
Etching equipment
Film locker
Fluid handling tools
Freezers, cryogenic (-196°C)
General purpose hand tools (including soldering)
Glovebox Incubator
Mass measuring device, micro)
Mass measuring device, small)
Metallographic microscope
Microwave steam autoclave
Optical microscope and supplies
pH Meter Refrigerator
Recorder, multi-channel (strip chart)
Sample preparation device, fluid transfer
Stereo macroscope
UV/VIS/NIR spectrometer
UV sterilization oven
UV/VIS/NIR spectrometer
Work bench
X-ray diffraction unit
X-ray facility, general purpose

3.3 LOGISTICS ELEMENTS

Logistics elements have been defined that will be used to transport the needed equipment, fluids, and raw materials to support Space Station crew and user operations. Four types of elements are required: a Pressurized Logistics Carrier (PLC) and Unpressurized Logistics Carriers (ULC) which consist of dry goods pallets, fluids pallets, and propellant pallets. Each of these elements has been defined to transport specific categories of logistics resupply items for crew/station support and user requirements.

The PLC element will transport items used in the SS pressurized volume for station/crew/user resupply. The PLC will be launched in the Shuttle payload bay and be docked to one of the interconnecting nodes on the Space Station. After assuring proper operation of the carrier, the opened hatch will provide shirt sleeve access to the carrier from the other Space Station modules.

ULC's are required to resupply a variety of consumables to the Space Station. These requirements include propellants (monopropellant and bi-propellant), fluids (ECLSS and Laboratory), and dry goods (ORU's and spares). It is anticipated that a common carrier structure, which provides manifest flexibility, can be outfitted to satisfy the varied resupply requirements.

The ULC's will be launched in the shuttle payload bay and be removed and docked to a convenient SS location to provide equipment/fluid transfer as required to Space Station experiments/subsystems located outside of the pressurized modules. The MSCS will be used to transfer dry goods and umbilicals will be connected to provide the fluid transfer path as required.

3.3.1 Pressurized Logistics Carrier - (PLC)

The PLC consists of Core Module (CM) hardware consisting of a pressure shell provisioned with common internal structure and subsystem equipment. The design of the PLC was predicted on use of the CM, which incorporates a high degree of commonality in the structural components, CM subsystmes, and CM standard options. Commonality will be extended to include ducting, cabling and fluid lines when practical depending on the weight impacts. The PLC provides approximately 1025 cu ft of stowage volume for logistics resupply. This volume can be enhanced by using the aft end cone and by dense packing within the center aisle. Figure 3.3.1-1 depicts the current PLC configuration.

3.3.2 Unpressurized Logistics Carrier - (ULC)

The proposed ULC concept is an open sided, ring frame and truss beam structure consisting of attach points for dry goods, fluids, and propellant pallets as shown in Figure 3.3.2-1. Access to the payload volume is via any of four circumferential locations. Various payloads and sizes can be accommodated by this baseline configuration. The ULC's will be transported in to the STS orbiter and after orbiter docking, they will be removed by the MSCS from the payload bay to a SS docking fixture.

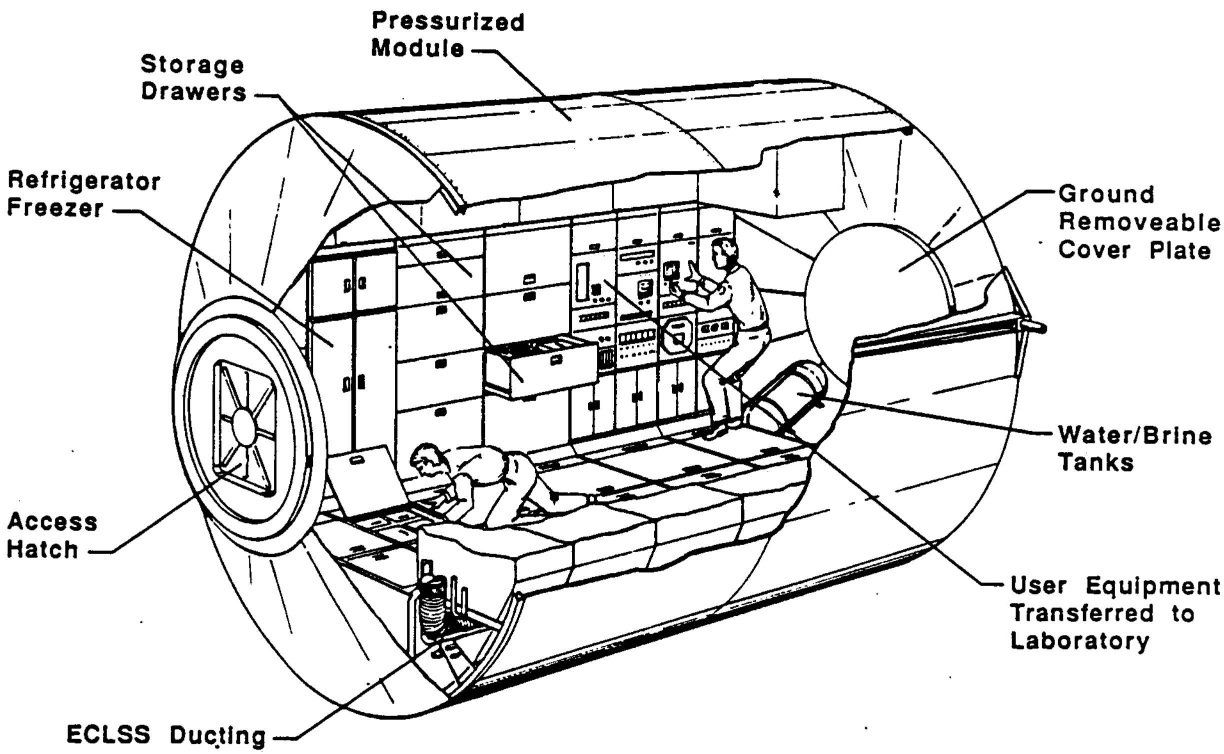

FIGURE 3.3.1-1 PLC CONFIGURATION

ORIGINAL PAGE IS
OF POOR QUALITY

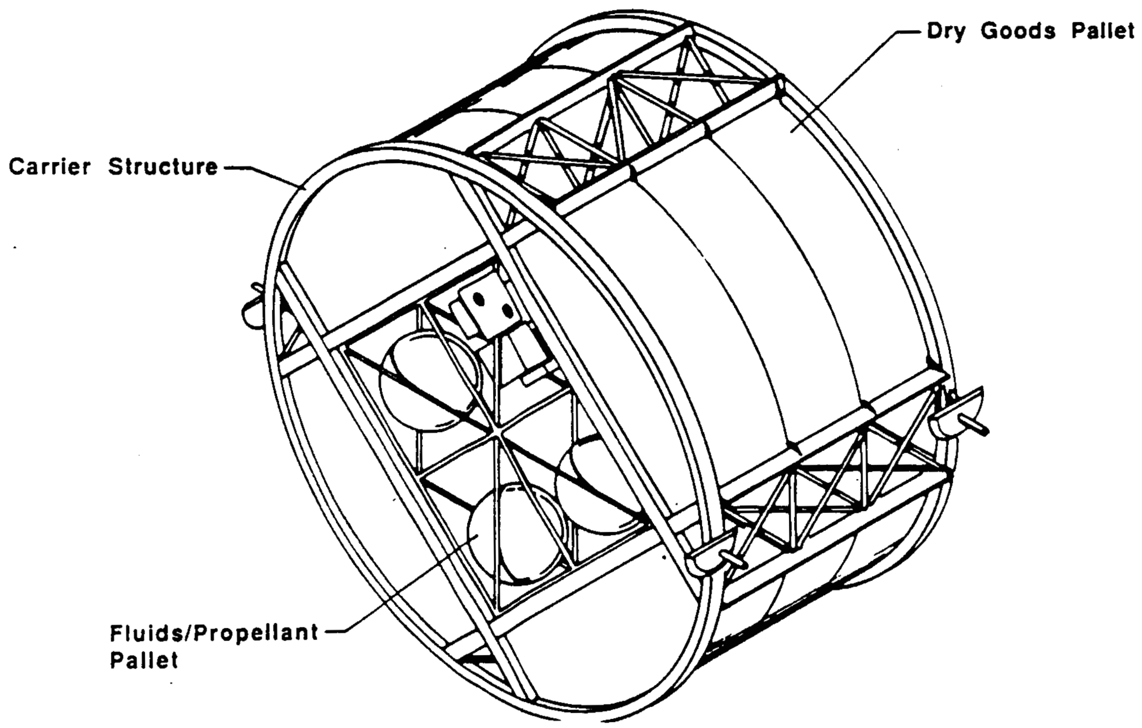

FIGURE 3.3.2-1 PROPOSED ULC CONCEPT

3.3.3 Subsystems

The PLC is comprised of the following subsystems: structures/mechanisms, electrical power, data management, communications, environmental and life support, thermal control, crew systems, and software. The ULC's are comprised of the following subsystems: structures/mechanisms, electrical power, data management, thermal control, and fluids. Only Logistics Elements unique subsystem features will be discussed.

3.3.3.1 Structures/Mechanisms

The Structures/Mechanisms subsystem provides the structure of the PLC, which in turn, provides a volume for storage of resupply items. This volume gives protection from the environments of the Space Station launch, build and operational phases. The volume will be pressurized and will provide structural interfaces for outfitting equipment. Berthing mechanisms will allow the PLC to be docked to a SS node. A Hatch mechanism located in one end cone of the PLC will provide entry, exit and isolation of the carrier. The other end cone opening, which is used for ground processing, contains a large diameter access hole with a simplified closeout plate.

This subsystem also provides the structure of the ULC's which consist of ring frames, truss beams, and structure for dry goods, fluids, and propellant pallets. These structures will withstand all unpressurized environments of space along with the environments induced by launch/landing and operational phases.

3.3.3.2 Electrical Power

The PLC power subsystem, while based on the core module design, is modified to fit the role of the PLC. The power subsystem must provide power to the installed subsystem equipment as well as Logistics Payloads during three modes of operations: ground operations, ascent, descent, and on-orbit operation. During ground operations, power is provided from ground support equipment. During ascent and descent, power is provided by the STS power system. On-orbit operations power is provided to the PLC from the adjacent node through the berthing ring.

Power distribution is provided for the ULC's to support requirements for heaters and data acquisition equipment. Any required power conditioning equipment will be keel mounted to minimize pallet weight.

3.3.3.3 Data Management

The PLC DMS will provide data acquisition and control for the ECLSS, Power, and Thermal subsystems. The DMS design will be autonomous to reduce the requirements for GSE and to minimize PLC impact on station operations. DMS and payload data networks will be provided. Interfaces to the global core will link the carrier to the core module data system which will provide mass data storage and inventory management. The PLC will be launched and returned in the shuttle many times and will require monitoring via shuttle data systems during transport.

The ULC DMS will provide a common controller for all subsystem monitoring, and carrier supervision. A special interface card in the controller will enable communication on the Shuttle data bus for status during transport.

3.3.3.4 Communications

The PLC communications system is a reduced version of the core module configuration. Video and audio buses are in place just as in the core module. Audio/video control and processing will be accomplished by processors in either the habitat or U.S. Laboratory modules. The video camera and speaker/Mic will be removed from the PLC during carrier changeout and reinstalled in the replacement carrier.

3.3.3.5 ECLSS

The Environmental Control and Life Support subsystem (ECLSS) provides the PLC with an environment capble of supporting and maintaining human life. ECLSS is comprised of the following functional subsystems: 1) Temperature and Humidity Control; 2) Atmosphere Control and Supply; 3) Atmosphere Revitalization; 4) Fire Detection and Suppression; 5) Waste Management; and 6) EVA Support. The Space Station crew will be provided all aspects of a safe and supportive atmosphere and environment by the ECLSS. Refrigerators and freezers are provided for resupply/return of perishable commodities.

3.3.3.6 Thermal Control

The Thermal Control System for the PLC is similar to that of the Core Module except the PLC has no body mounted radiators and no external fluid loop. The system for the PLC includes a pumped single phase water loop inside the carrier for acquisition and transport of internal heat loads. The passive thermal control for the PLC consists of multilayer insulation (MLI) and silverized teflon. Refrigerator/freezer heat loads are rejected via the HSOM body mounted radiators.

The Thermal Control System for the ULC's consists of MLI, silverized teflon and fluids heaters as required.

3.3.3.7 Crew Systems

Aids will be provided by Crew Systems for crew mobility and restraint. Devices to contain, restrain or move Space Station hardware or resupply items will be provided by Crew Systems. Trash collection equipment, stowage provisions, in-flight maintenance, tools and equipment for both IVA and EVA, and portable fire extinguishers are also provided by crew systems.

3.3.3.8 Software

All aspects of the Core Module Data System software are available within the PLC via the Space Station network. Unique items include tailored Logistic displays and menus and inventory management control. The Logistic Element (LE) interfaces with a set of software to handle all phases inventory management control.

3.3.3.9 Fluids

The fluid resupply system consists of ULC's which provides for the transport, storage and transfer of all fluid consumables requiring resupply. The ULC configuration transports fluids on separate pallet structures to supply N_2, propellants and user fluids.

3.4 PROPULSION SUBSYSTEM

The propulsion system is an oxygen/hydrogen propellant system as shown in Figure 3.4-1, that receives high pressure gases from the ECLSS electrolysis units. The gases are supplied by a propellant resupply port in the ECLSS that is dedicated to refilling O_2 and H_2 accumulators. Water for the electrolysis process is supplied to the ECLSS system from the NSTS orbiter. The water is a by-product of NSTS power generation fuel cells.

Oxygen/hydrogen propulsion using orbiter fuel cell water was selected over a state-of-the-art hydrazine system because it's development costs are comparable to hydrazine, however, the propellant logistic costs are reduced by 400 million dollars considering scavenged water from the orbiter fuel cells.

Oxygen/hydrogen propellants have a safety advantage compared to hydrazine since they are stored as either water or high pressure gases. Leakage which is considered a difficult problem to solve using hydrazine is a much lower concern with oxygen and hydrogen gases.

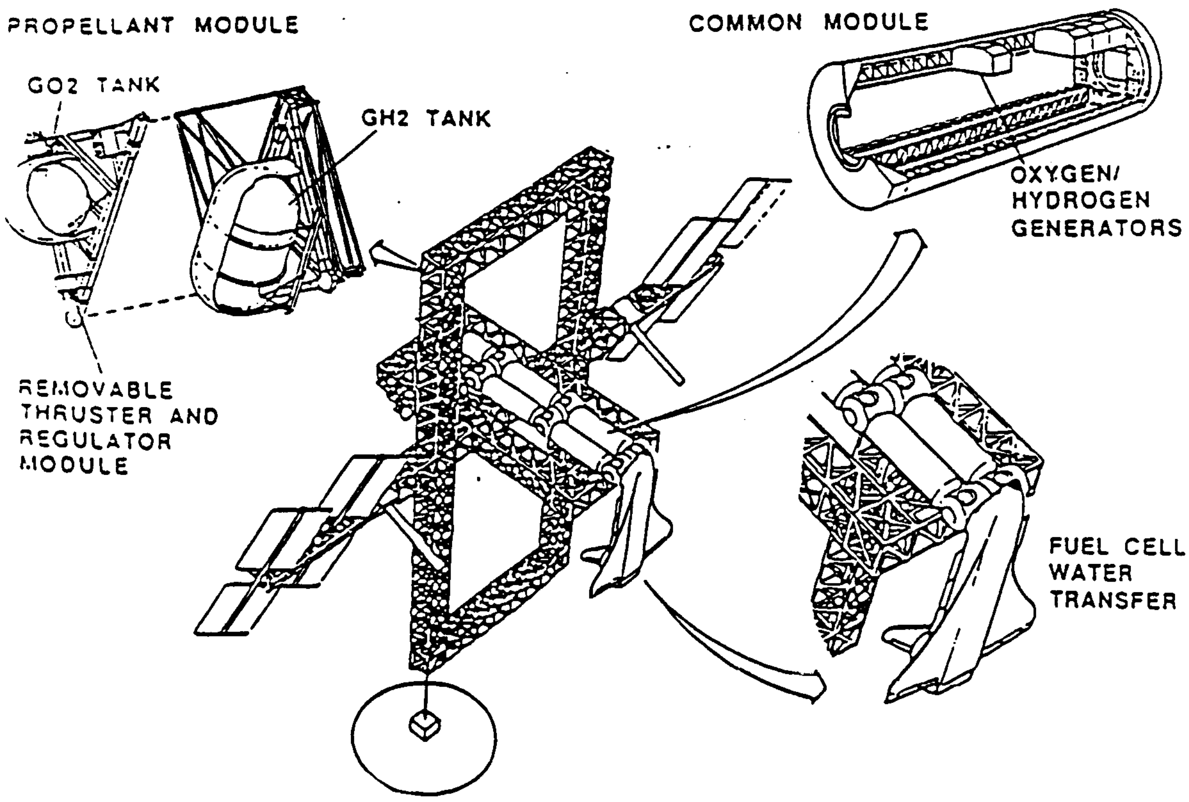

FIGURE 3.4-1 PROPULSION SYSTEM - WATER ELECTROLYSIS

3.4.1 Propulsion Module Configuration

The propulsion module, shown in Figure 3.4.1-1, and in schematic in Figure 3.4.1-2. The modules are made up of two sub-modules, one which contains the hydrogen tank and one which contains the oxygen tank thrusters and the majority of the remaining propulsion hardware. The modules are resupplied with gaseous oxygen and hydrogen at the propellant refueling station. In addition to the propulsion and structures hardware the propulsion modules include a thermal control, power distribution controller and DMS to interface with the Space Station. The following paragraphs provide additional design detail for the propulsion module.

3.4.1.1 Propulsion Sub-Module Structure

Hydrogen Sub-Module

The 4.84 m^3 gaseous hyrogen accumulator tank is mounted to single Standard Attach Mechanism (SAM) with a tubular truss arrangement. The truss is attached to an H beam substructure that runs parallel to the hypotenuse of the triangular SAM. The substructure is attached to the SAM with tapped aluminum spacer plates that are filament wound onto the graphite composite box section. The plates provide mounting pads for bolting the substructure to the SAM. A micrometeoroid shield protects the tank with a 10 cm stand-off distance and is bolted to the top flange of the H beam substructure. The shield is removable to allow for tank assembly and maintenance. The propellant transfer lines, electrical lines and line heaters are run through the enclosed substructure for micrometeoroid protection.

Oxygen Sub-Module

The 2.1 m^3 Gaseous Oxygen (GO_2) accumulator tank is mounted to a single SAM using a square H beam that spans across the SAM for added support and rigidity. The substructure is attached to the SAM through aluminum mounting pads which are filament wound onto the graphite composite box beam. The H beam is then bolted to the aluminum pad with four bolts at each corner. The tank is supported by a tubular truss arrangement where one end is supported by two diagonal members and the opposite end by a tripod truss. This configuration allows for thermal expansion and contraction of the tank. The micrometeoroid shield with a 10 cm stand-off distance is mounted to the top flange of the H beam and is removable for ease of installation and maintenance. The substructure is also used as protection for the tubing and the electrical wires that connect to the remote umbilical connector. The RCS thrusters are mounted in an enclosed box made of 0.05 cm thick aluminum. The triangular shaped box is bolted to the top flange of the substructure and can be replaced as a unit or the back cover can be removed for installation and maintenance of the thrusters and double valves. A remote umbilical refueling mechanism connects the GO_2 module to the Gaseous Hydrogen (GH_2) module and both of these to the Space Station propellant and thruster control distribution lines.

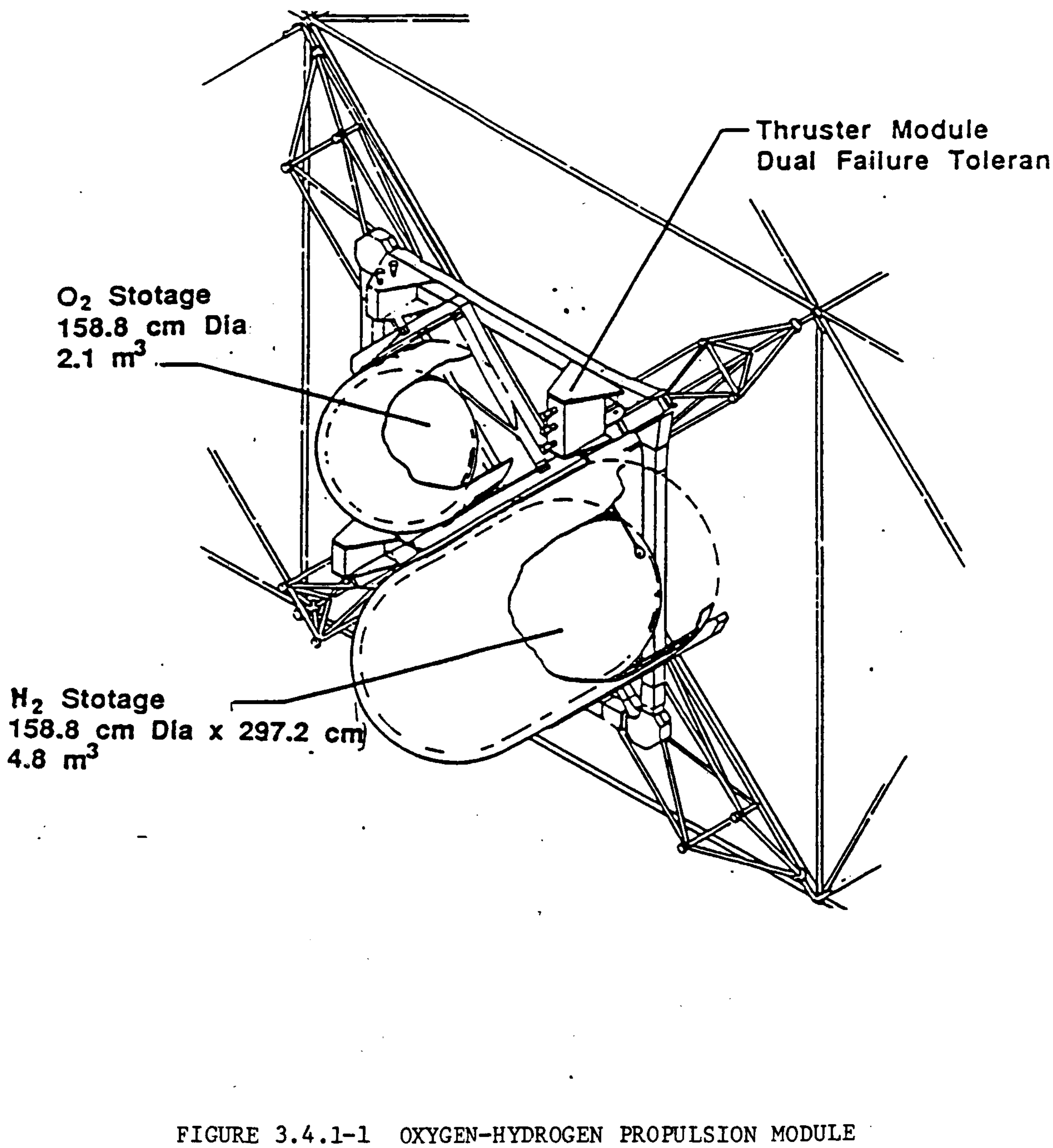

FIGURE 3.4.1-1 OXYGEN-HYDROGEN PROPULSION MODULE

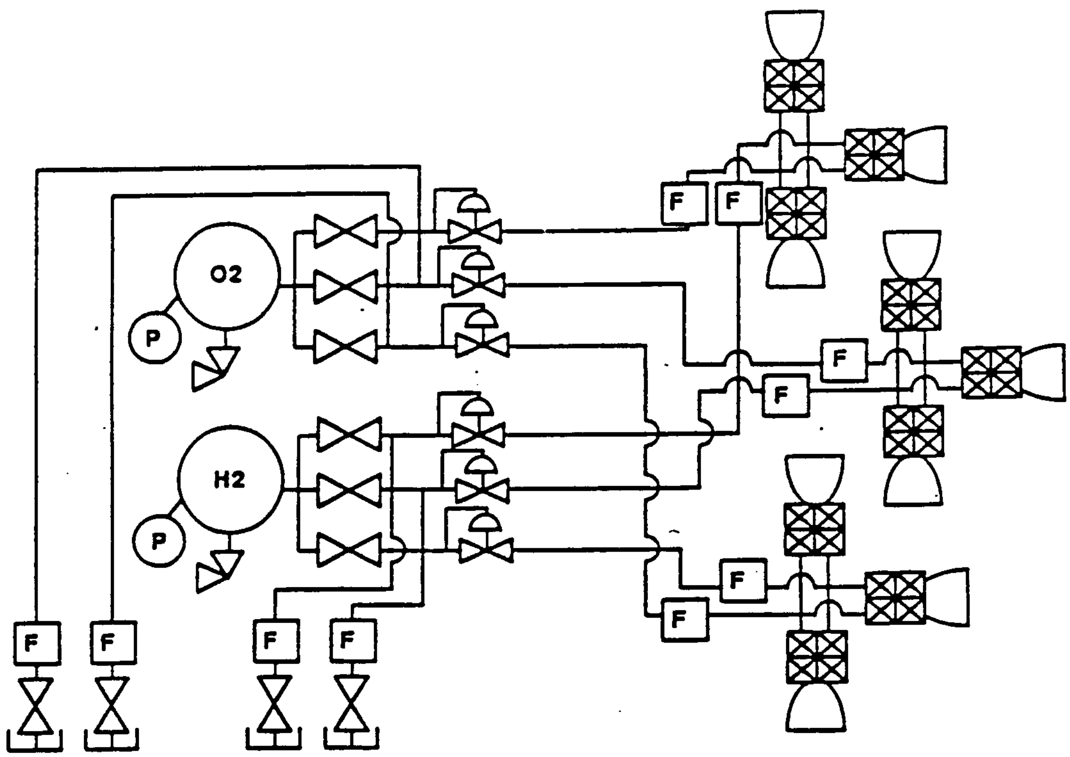

FIGURE 3.4.1-2 OXYGEN/HYDROGEN PROPULSION MODULE SCHEMATIC

3.4.1.2 Thrusters

Thruster programs at LeRC and MSFC are designed to support the Space Station. These thrusters were designed for the 4.5:1 MR but the mixture ratio has been extended to 8:1 MR to accommodate the Space Station O_2/H_2 propulsion requirements mixture ratio. Performance at 8:1 MR is off significantly from the peak at approximately 3:1 MR. However, operation of the system at less than 8:1 MR implies the production of excess oxygen that must be disposed of. For each gram of oxygen "thrown away", 567 grams of water is needed, which more than offsets any reduction in propellant needed due to the GO2/GH2 thruster performance at 111 N can be considered as a function of improved performance. If the excess oxygen can be utilized elsewhere on the station, then the system can be operated economically at less than 8:1 MR. This is one of two "fringe benefits" derived from integration, the ECLSS with propulsion takes the form of excess hydrogen from the ECLSS to the propulsion system since the ECLSS does not utilize all the hydrogen generated in the production of cabin oxygen.

3.4.1.3 Propellant Refueling Station

The propulsion/ECLSS interface consists of GO_2 and GH_2 quick disconnects to which the propulsion system distribution line connect. Resupply propellant gases cross the interface from ECLSS to propulsion by means of these disconnects. The ECLSS controller will need to accommodate the variation in propellant requirements as a result of atmospheric conditions anticipated for the next 90 day cycle so that sufficient propellant reserves are maintained. The actual transfer will take place at the propulsion refueling station, located on the Space Station Truss Structure away from the pressurized modules.

3.4.1.4 Electrical Power Distribution Subsystem

Figure 3.4.1-4 shows the electrical power distribution subsystem which includes power conditioning, load center cabling, and valve drive amplifiers. The power will be controlled by the propulsion controller. 28 VDC power will be distributed to each of the four RCS module locations. Power conditioning equipment is located at the valve drive amplifiers to minimize low voltage power distribution and thus minimize line losses. A double redundant configuration was selected, consistent with anticipated prime power bus configuration. Each of the power conditioning assemblies contains redundant power conditioning modules.

3.4.1.5 Data Management

The data system contains data storage and retrieval services, and other commonly required data processing services for the propulsion system. The health monitoring instrumentation includes pressure transducers and temperature sensors. Pressure transducers are included between each of the fluid "hard points". These will aid in the determination of leaks. Temperature sensors will be placed about the systems to monitor the thermal control system performance and, in some cases, the performance of components like the thrusters. Other special sensors will also be needed. These will include leak detectors and thrust level measurement devices.

3.4.1.6 Propulsion Controller

The GN&C System is responsible for all the guidance and navigation functions related to the use of the Reaction Control System. This also includes the phase plane computations and propulsion module jet selection. The functional interface between GN&C and the propulsion

3.4.1.7 Application Software

Space Station software requirements for propulsion are focused in three functional elements: propellant, thruster, and reboost management. However, in order to properly coordinate the activities of the propulsion elements there will be scheduling and configuration management software. The man and machine interface will be through the workstation which is available in each module. The propulsion application software components augment the data system software.

3.5 REBOOST

Our Phase B activities related to Space Station reboost strategies and recommended implementation approach are summarized in this section. See Volume II of this document for a detailed discussion of the Reboost effort.

Pre-ISR Reboost Strategy was to utilize a 250nm minimum altitude scheme. This is shown in Figure 3.5-1. Associated with this is the impulse requiremennts for 10 yrs (Figure 3.5-2). Post ISR studies showed that lowering the operating altitude and allowing the altitude to vary could significantly increase the net payload delivery to SS (50,000 - 114,000 lbs of payload over a 10 year cycle). Figures 3.5-3 and 3.5-4 show the altitude trace and impulse requirements for the variable altitude strategy for 2 values of Space Station ballistic coefficient. Table 3.5-1 shows the comparison of the two strategies. Currently, a variable altitude strategy is baselined by NASA; Martin Marietta's recommended implementation procedures for the variable altitude strategy is shown on Figure 3.5-5.

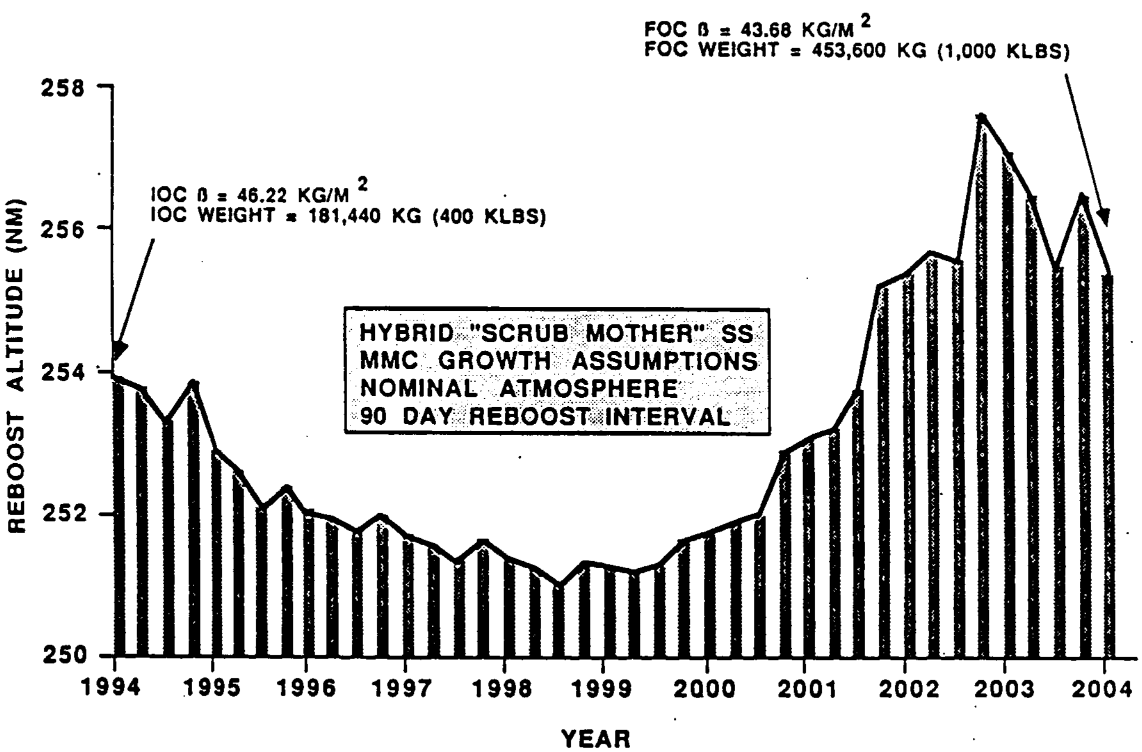

FIGURE 3.5-1 SPACE STATION ALTITUDE TRACE FOR 250 NM MINIMUM ALTITUDE REBOOST STRATEGY

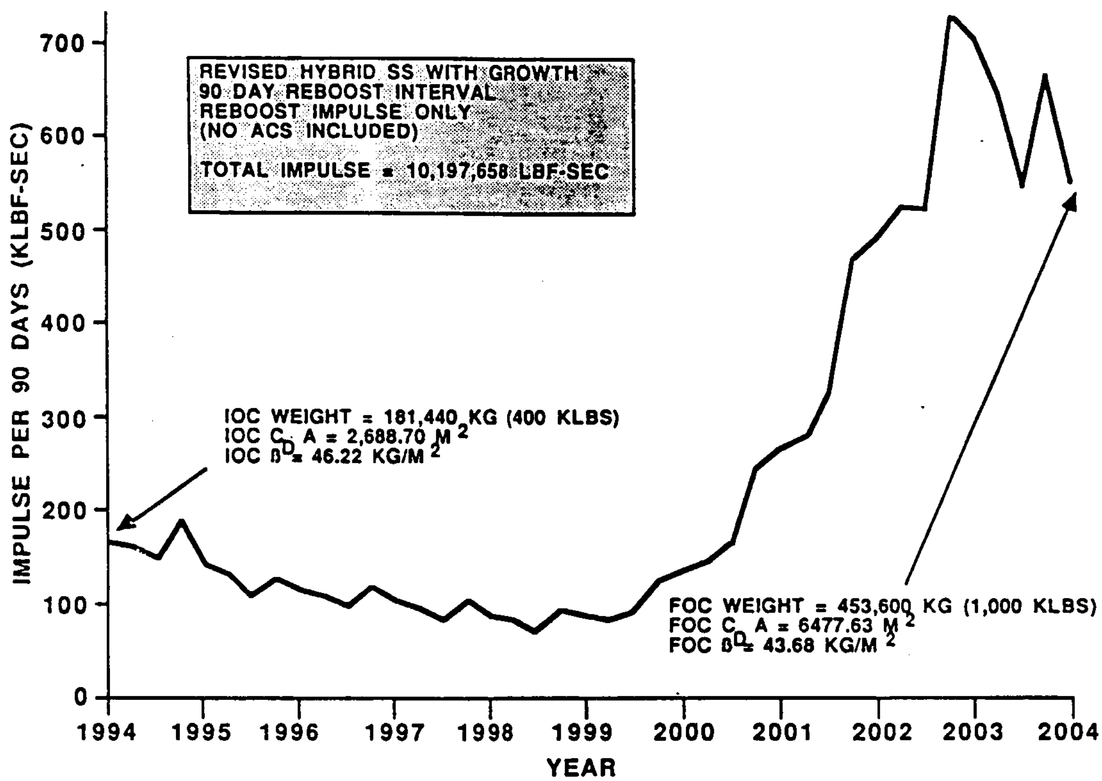

FIGURE 3.5-2 10 YEAR TOTAL IMPULSE RQMT FOR REBOOST - 250 MINIMUM ALTITUDE STRATEGY (REVISED 4/5/86)

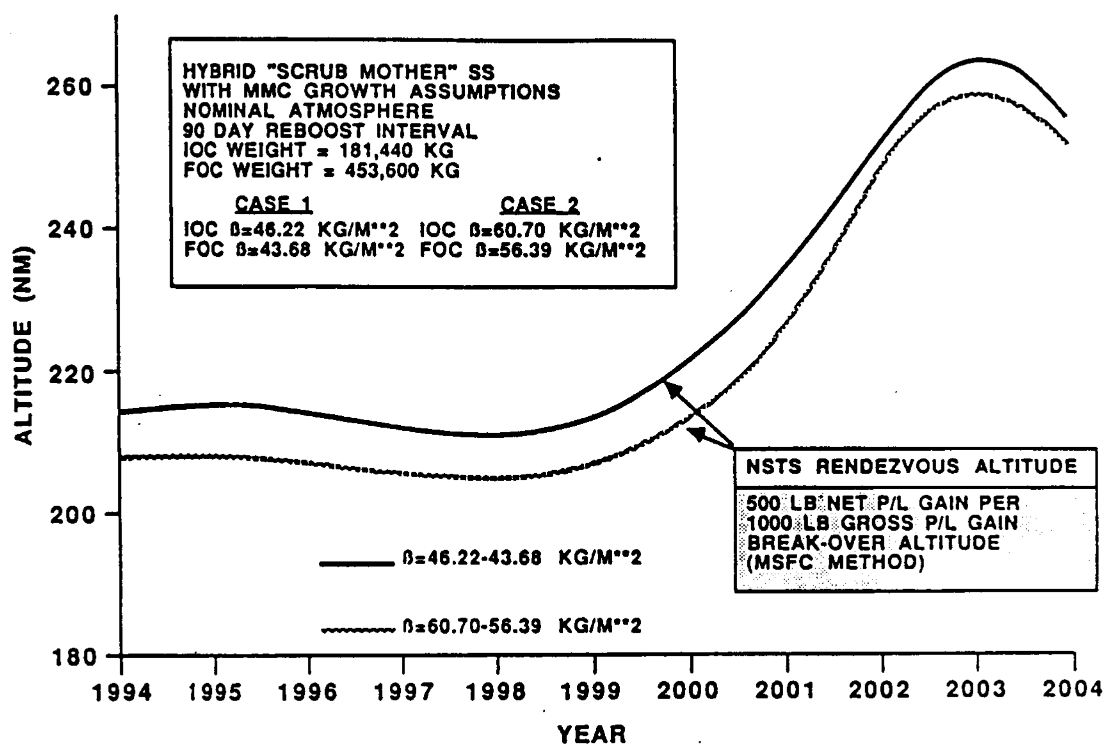

FIGURE 3.5-3 SPACE STATION ALTITUDE EXCURSIONS FOR VARIABLE ALTITUDE SCHEME (B=46.22 & 60.70 KG/M**2)

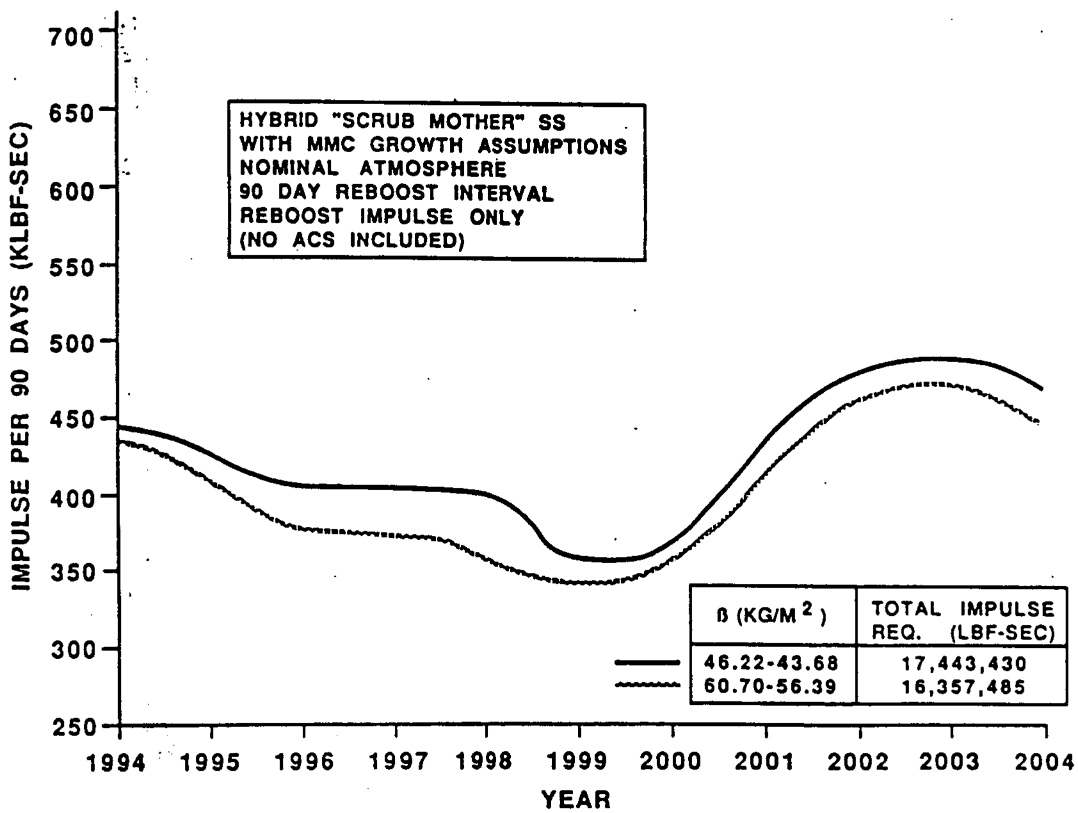

FIGURE 3.5-4 SPACE STATION TOTAL IMPULSE REQUIREMENTS
FOR B VARIATIONS

TABLE 3.5-1 VARIABLE ALTITUDE STUDY - SUMMARY

SPACE STATION ALTITUDE/ REBOOST PHILOSOPHY	BETA(ß) IOC/FOC (KG/M**2)	RENDZ. ALTITUDE RANGE (NM)	TOTAL IMPULSE (LBF-SEC)	NET PAYLOAD GAIN (LBS)
MMDA HYBRID/SCRUB IOC' (FLIGHT 13) - BOOST UP FROM 250 NM - UPDATED 4/7/86	46.22/ 43.68	250	10,197,658	0
MMDA CASE (ß = 46 KG/M**2) DISCRETE OPTIMUM ALTITUDE	46.22/ 43.68	209/ 264	17,443,430	63,626
MSFC DELTA CASE (ß = 60 KG/M**2) DISCRETE OPTIMUM ALTITUDE	60.7/ 56.4	207/ 257	16,357,485	78,455
MMDA O2/H2 CASE (ß = 46 KG/M**2) DISCRETE OPTIMUM ALTITUDE	46.22/ 43.68	194/ 242	29,743,369	113,893

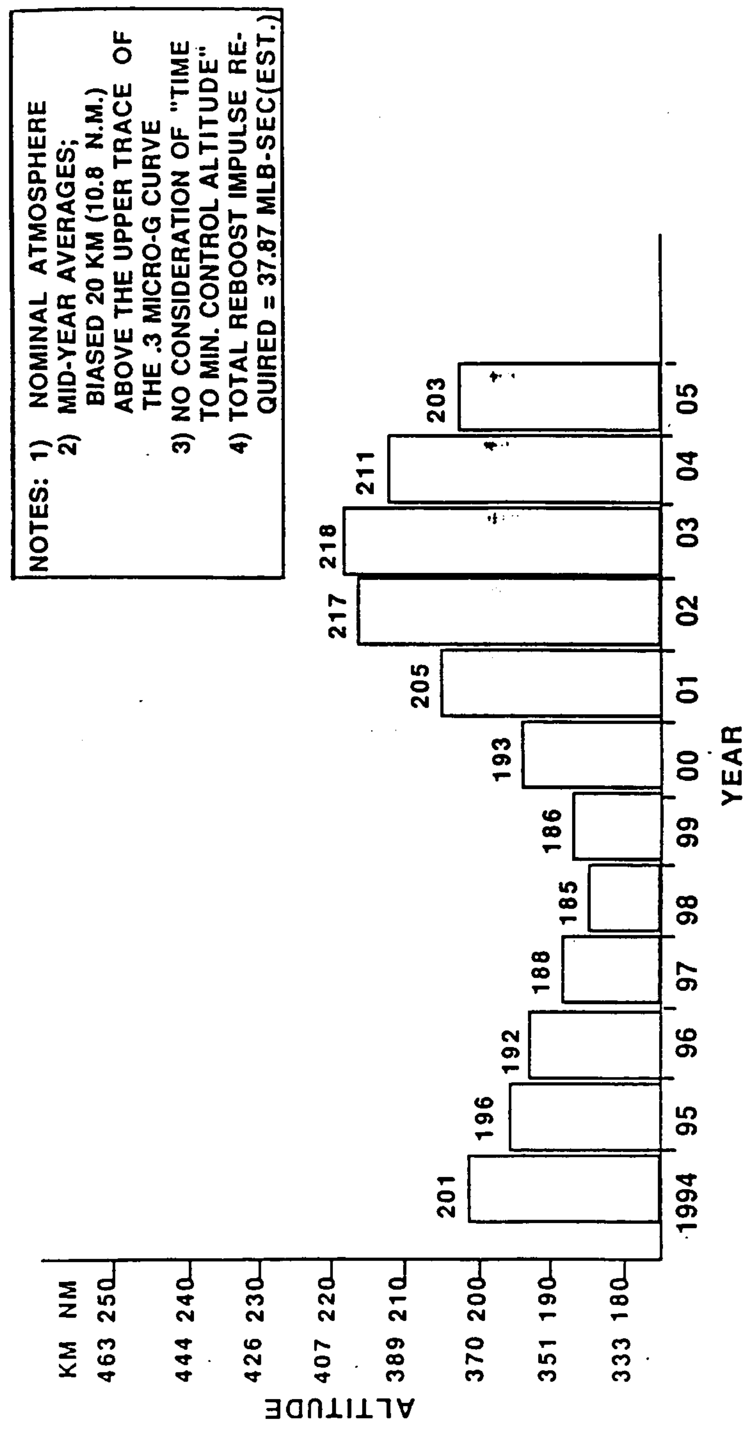

FIGURE 3.5-5 MMC BASELINE VARIABLE ALTITUDE FOR SPACE STATION

3.6 VEHICLE ACCOMMODATIONS

This section will outline the recommended Vehicle Accommodations configuration based upon the results of several design analyses and tradae studies performed during the conceptual design phase of the Space Station project. These trades and analyses were driven by key top-level requirements identified for accommodating space based vehicles. The requirements include providing thermal conditioning, meteroid, debris, and contamination protection, electrical power, data management access, video communications, software, control and displays for proximity operations, capture, transport and berthing, and storage.

A summary of the design analyses and trade study results and conclusions can be found in Section 3.6.2.

3.6.1 Recommended Vehicle Accommodations Configuration

3.6.1.1 IOC Configuration

The recommended IOC configuration is shown in Figure 3.6.1-1, as derived from the trades and analyses results. It consists of two major design components - the vehicle Berthing Structure and the electronics module.

The Berthing Structure is comprised of graphite epoxy truss members and standard end fittings for commonality with the existing Langley truss concept. The latches utilized for vehicle berthing are GSFC latches currently being developed for shuttle missions. Also included as part of the Berthing Structure is the remote umbilical mechanism which provides data management access, power, and a communications link to the berthed vehicle. The umbilical also has a fluid resupply scar for growth resupply operations.

The electronics module is designed to house the local area electronics and provide meteroid and electromagnetic interference protection, along with thermal environment conditioning. To maintain commonality with existing space qualified equipment, the Multi-Mission Spacecraft's (MMS) Electronics Housing Module was identified to be best suited to protect the electronic equipment associated with the Vehicle Accommodations. The module will contain the electrical load center which distributes power to the separate accommodations elements; the power conditioning unit which converts the space base main power supply to 28 Vdc, compatible with the vehicle; the exterior light controller which monitors and controls the lighting within the accommodations area; the DMS network interface unit which converts data signals from metal cabling to optical fibers; and the service area controller which is the local area microcomputer that controls the accommodations operations such as latch actuation, umbilical operations, etc.

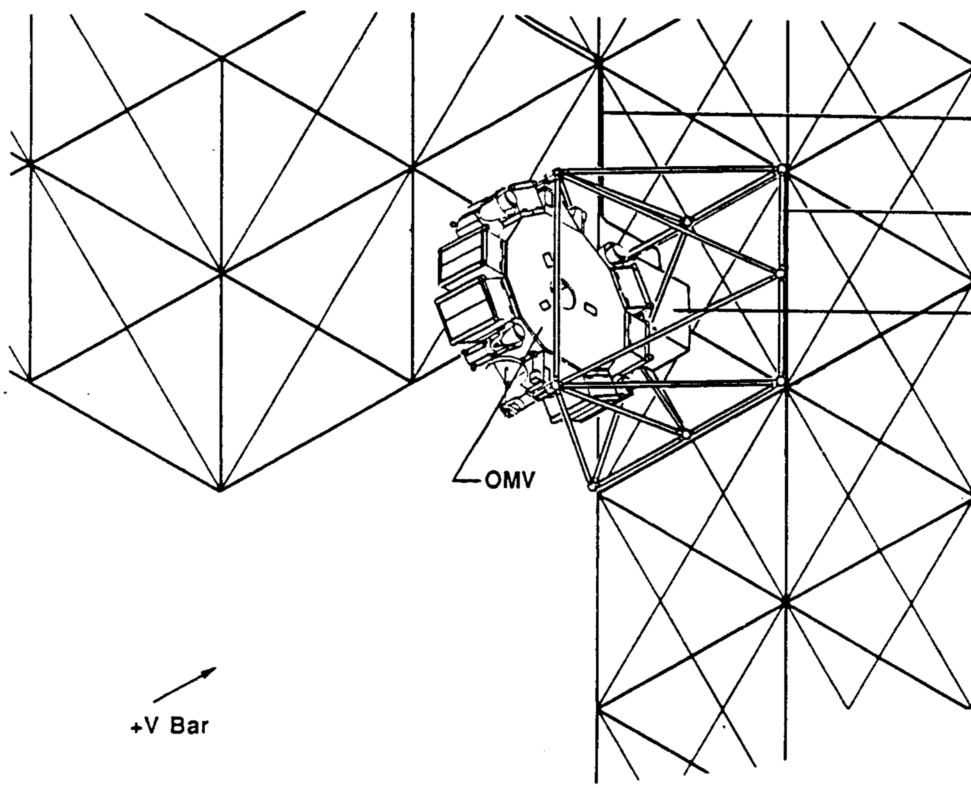

FIGURE 3.6.1-1 IOC - OMV ACCOMMODATIONS

3.6.1.2 Growth Configuration

For the growth configuration, pictured in Figure 3.6.1-2, a satellite servicing bay is added (WP-03) to allow for payload servicing and environmental protection. To accommodate integration of payloads with the OTV/OMV, a truss boom is extended in the -V bar direction, with a Spacecraft Positioning Unit (SPU) used to secure the entire stack until launch. The truss book is also used to extend the MRMS reach envelope for greater retrieval capability.

3.6.2 Trades and Analyses Summary

Study efforts for vehicle accommodation were focused in two main areas; (1) determining an optimal location and configuration of the berthing truss and associated support subsystems, and (2) assessing the vehicle proximity operations control requirements, including retrieval, berthing, and storage. All requirements, both imposed and derived were included in the studies that produced the recommended configuration shown in Figure 3.6.1-1.

A summary of the major trade studies and design analyses performed, which shows the description, objectives, and results of each study can be found in DR-15, Volume II, Table 3.6.2-1. Details of the individual trades and analyses can be found in the "Conceptual Design Analyses & Trade Studies" DR-02 submittal (SSP-MMC-00056), dated 31 October 1986.

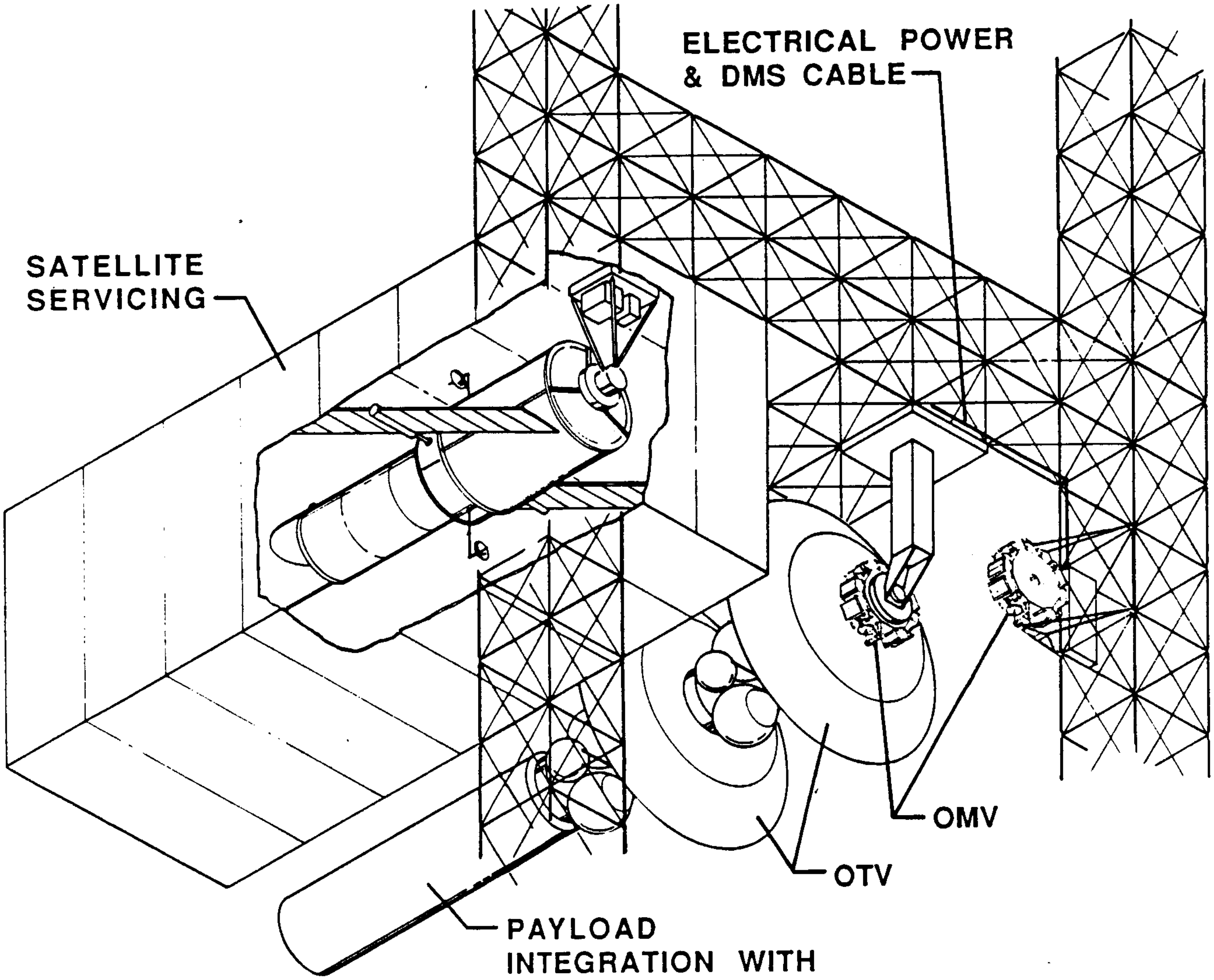

FIGURE 3.6.1-2 VEHICLE ACCOMMODATIONS - GROWTH

3.7 SMART FRONT`END

The Smart Front End (SFE) will be an evolutionary remotely-controlled servicing system with the SFE elements also providing test bed functions for technology evolution.

At SS IOC, the SFE will consist of the Telerobotic System (TS). The Mobile Servicing Center (MSC), will provide primary mobility for the TS, and will also provide communication and power. The system will perform satellite and payload servicing, Station assembly, and other ORU replacement and EVA assistance tasks.

The growth SFE will add the ORU Carrier and Fluid Resupply System (FRS). The OMV will transport the SFE in-situ servicing of satellites, and will also provide basic communications and power. The FRS may perform fluid resupply at SS.

SFE configurations require greater power and communications resources than provided by the OMV, thus requiring supplemental kits. Future missions will also require kits for particular missions.

The following paragraphs provide top level descriptions of the major elements of the SFE. More detailed descriptions of the SFE elements and subsystems are presented in Volume II.

3.7.1 Telerobotic System

The TS is a remotely-controlled, teleoperated robotic system. The TS baseline configuration is shown in Figure 3.7.1-1. It consists of two 7-degree-of-freedom (DOF) manipulators and one 7-DOF stabilizer arm. The vision system contains stereo video cameras and dual lights on a pan/tilt assembly. The IOC TS will be remotely controlled by an operated at the SS. In-situ operations at growth will be controlled from the ground.

The OMV-compatible TS (growth) mounts the arms and a single stabilizer arm on the perimeter of a T-shaped section, attached to a centrally-mounted docking mechanism. Figure 3.7.1-2 shows the concept for the OMV-transported TS.

The baseline end effector accepts EVA standard tools and is shown in Figure 3.7.1-3.

The growth OMV-SFE combination will dock with repairable satellites via an RMS grapple fixture, EVA handrails, or similar structures.

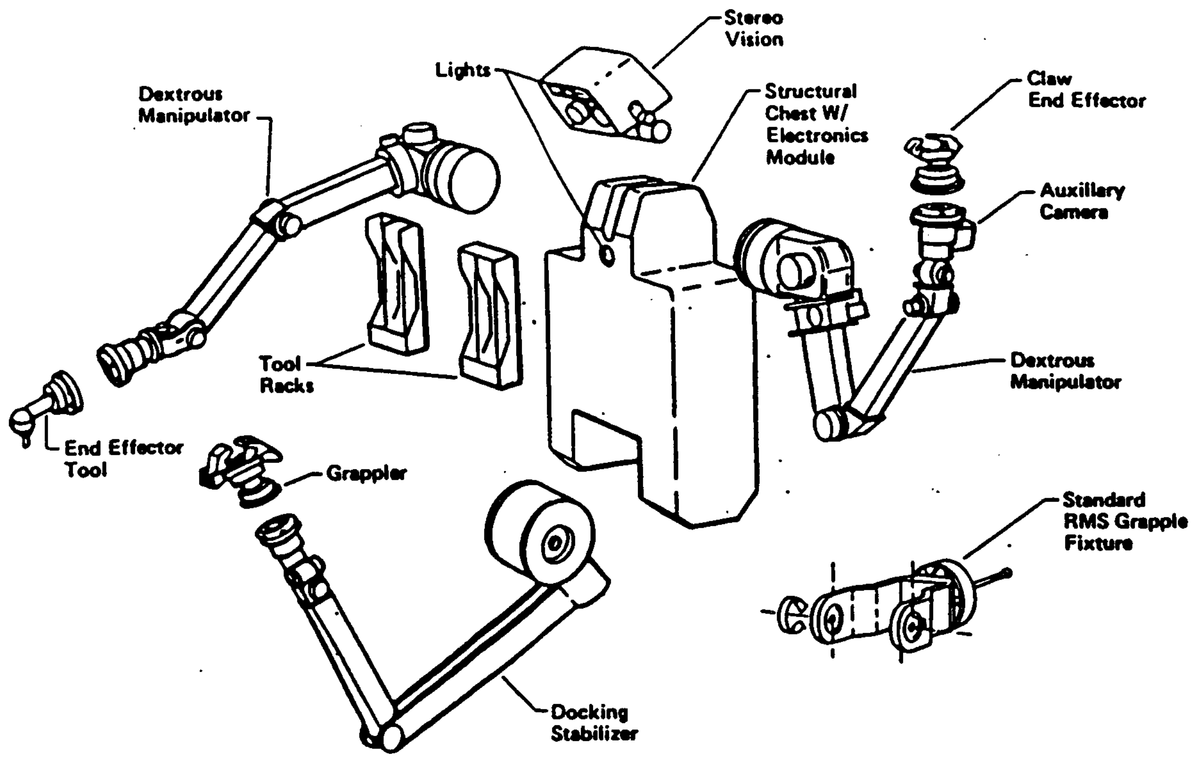

FIGURE 3.7.1-1 TS COMPONENTS

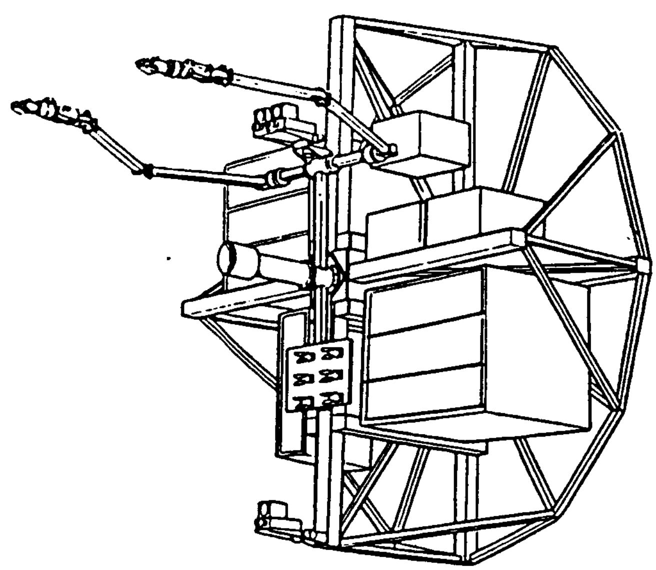

FIGURE 3.7.1-2 IN-SITU SERVICING TS CONFIGURATION

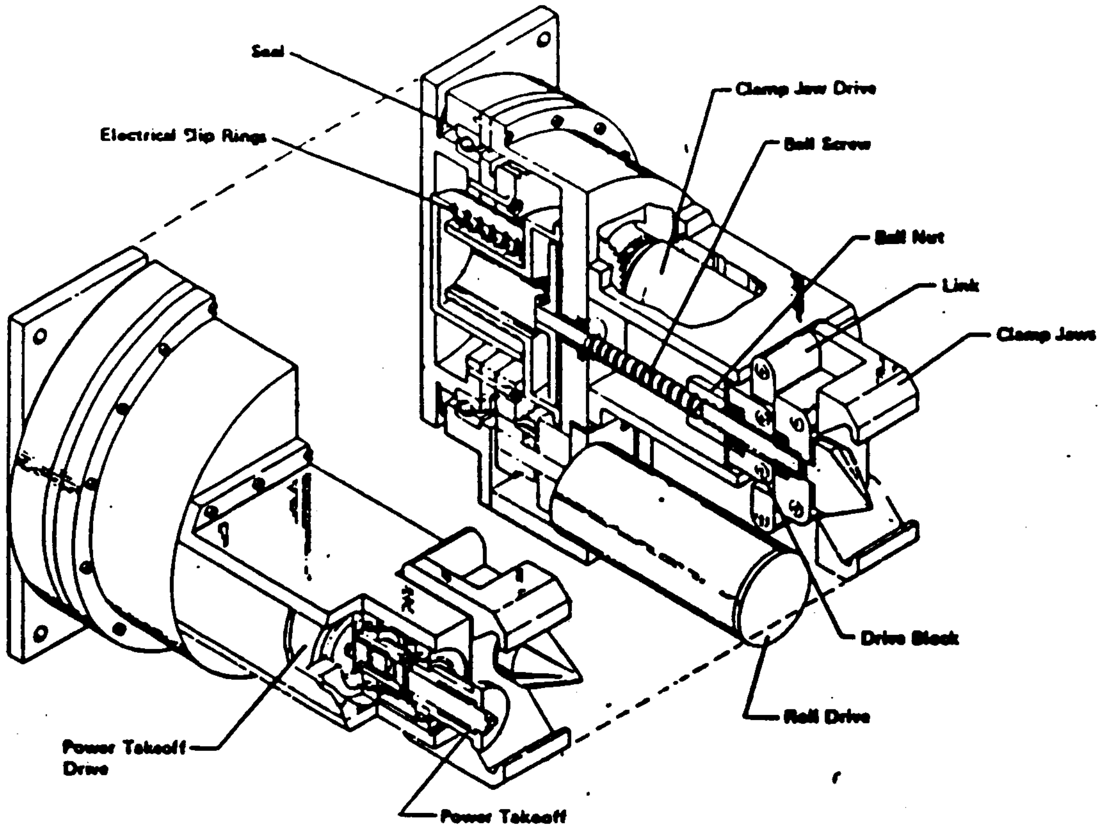

FIGURE 3.7.1-3 END EFFECTOR WITH A POWER TAKE-OFF

3.7.2 ORU Carrier

The ORU Carrier provides space for URUs and SFE kits during OMV/SFE in-situ satellite/platform servicing. The ORUs may vary in size and shape from a few inches on a side to telephone booth size.

The ORU Carrier structure has the same diameter as the OMV, and will interface with the OMV payload latches and the SFE structure. It will accommodate payload-unique ORU latch kits. Two or more ORU carriers may be stacked together to provide capacity for very large ORU's. Figure 3.7.2-1 shows an ORu Carrier.

3.7.3 Fluid Resupply System

The FRS is an OMV-sized module utilizing common structure with the fluid resupply pallets of the LM. The FRS contains six 114.3 cm (45") diameter spherical tanks developed for the Olympus satellite which are currently in production and are Shuttle qualified.

Two OMV pressurization spheres provide pressurant supply for the FRS tanks and for resupply. The pressurant spheres could contain nitrogen or helium or one of each.

The FRS configuration is shown in Figure 3.7.3-1. The arrangement is similar to the OMV tank farm with the tanks plumbed in series to allow more flexible propellant transfer operations. The FRS will be as autonomous as possible during the fluid resupply processes, but will always allow operator override of procedures or control of an entire process. The FRS can hold up to 17,600 kg (8000 lbm) of storable propellants.

**ORIGINAL PAGE IS
OF POOR QUALITY**

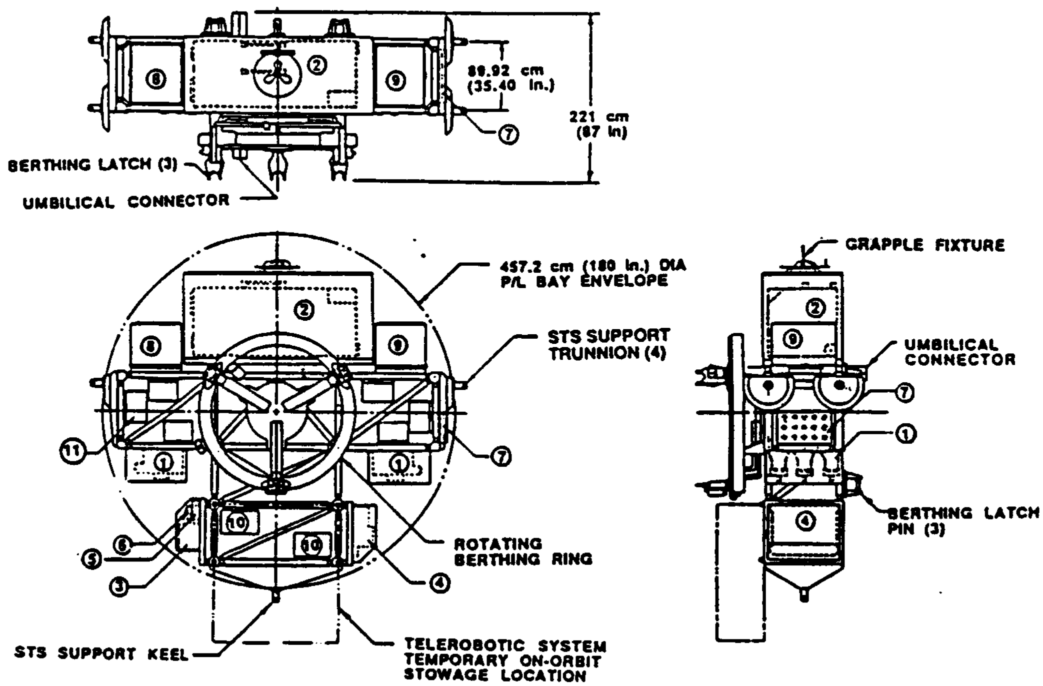

FIGURE 3.7.2-1 ORU CARRIER

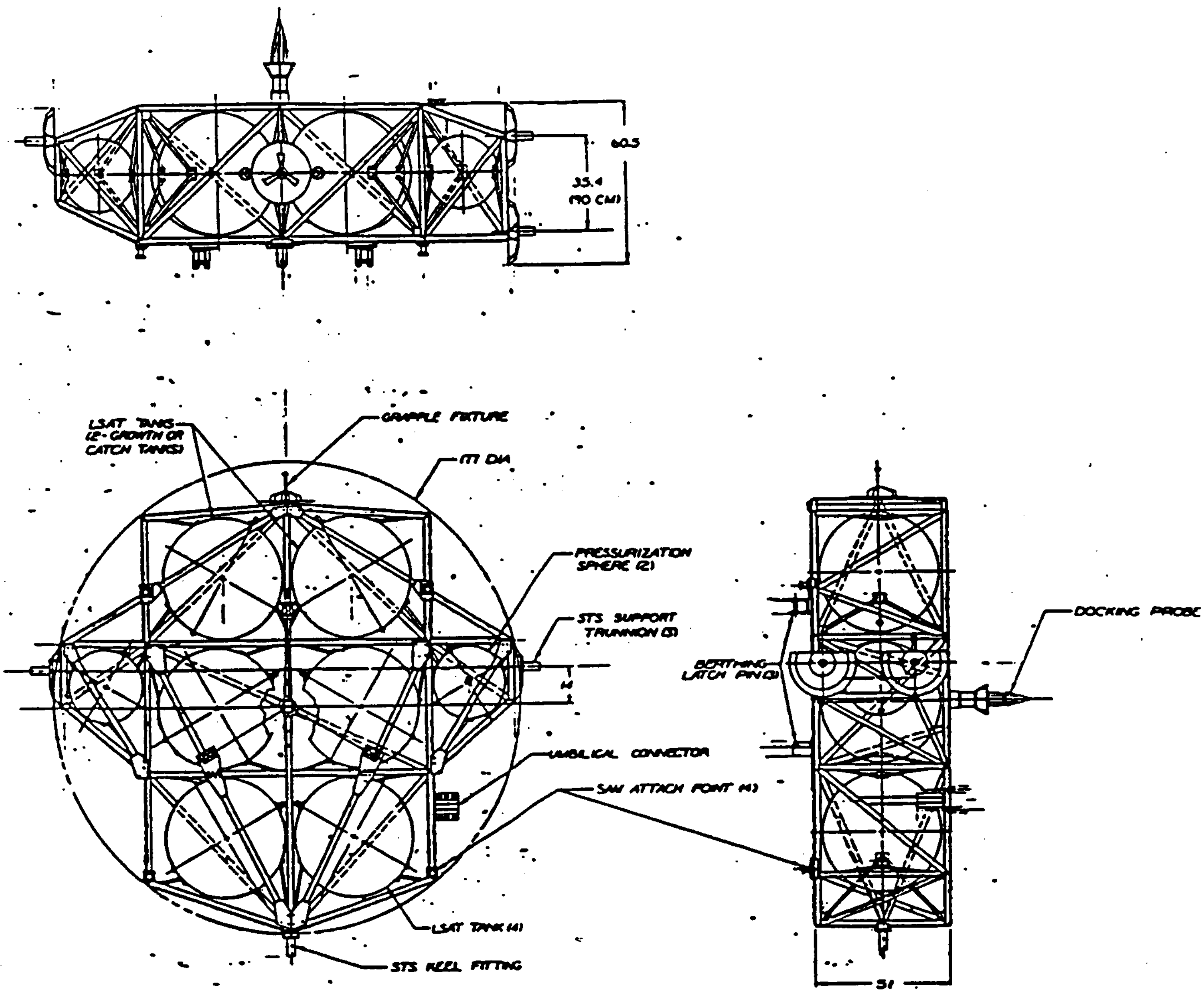

FIGURE 3.7.3-1 FRS CONFIGURATION

The FRS will be expected to operate normally with automatic umbilicals which will connect upon hard docking. The necessary verification sequences will then be performed, followed by the fluid transfer steps and disconnect sequences.

Alternatively, the FRS may be operated with the TS, entailing use of the manipulator arms to position a flexible FRS umbilical to connect with the satellite or platform. Verification, fluid transfer, and disconnect steps would be similar to those performed by the automatic umbilical.

The TS and FRS could also be used independently to perform ORU exchange and fluid servicing on the same vehicle, being conducted in series to avoid contamination or safety concerns.

3.7.4 SFE Mission Kits

The SFE mission (or function) kits enable it to perform functions beyond those for which the basic SFE elements are capable, or provide support beyond the capabilities of the SFE mobilility system. These modular kits will permit an efficient basic design and yet provide for growth in the functions that can be accomplished.

Several mission kits may be needed for the SFE to perform all the IOC servicing missions as well as the potential future missions. The functional kits for IOC are:

- Docking/Berthing Kit will provide non-standard docking or berthing interfaces between the SFE and the payload, satellite, or platform.

- Electrical Power Kit will provide additional power if the capability of the host mobility system is insufficient for a particular mission. Because of limited volume internal to the TS, the battery kit will be externally located.

- Communications/DMS Kit will provide data transfer and communications capabilities beyond those normally available through the OMV.

3.7.5 SFE Control Station

SFE development will evolve in close step with that of its control station. Numerous configuration constraints define the requirements for the integrated SFE control and display station. A functional analysis identified top level constraints by considering all SFE subsystems and a minimum set of transporter vehicle subsystems. The primary emphasis was on visual displays and manipulator control elements. The findings are summarized in Table 3.7.5-1.

SUMMARY OF C&D STATION ELEMENTS

TABLE 3.7.5-1
OVERVIEW OF MAN-IN-THE-LOOP IMPACTS ON CONTROL STATION CONFIGURATION

OPERATIONAL DRIVERS	SELECTED BASELINE	CONSOLE CONFIGURATION CONSTRAINTS
Viewing Worksite:	Indirect:	
- Depth Perception	Stereo & Monoscopic (Stereo type still open)	Fresnel Stereo requires fixed LOS from operator to monitor
Manipulator Control: - Two Arms	Two 6-DOF position controllers	Limits operating envelope at console, keeps operator's hands committed
Camera Assy Control:	Pan/Tilt joy stick auto follow or voice	Keep job stick close to 6-DOF Controller
Operator Console:		Requires dual C&D functions (displays, Data Call-up, Emergency Controls)
- Numbers	One primary and one support (minimum)	
- Size	Accommodate 5th percentile female through 95th percentile male	Console/operator interface adjustment (seat, reach, etc)
- Comfort	Seated through standing	Seat back, seat belts, arm rest, foot restraints, hand holds, etc.
Other Features:		
- Data Display	Continuous and stored (Graphics)	Locations and computer size
- Keyboard	Operations support tool	Requires hand/eye coordination (Keyboard Located on side of Operator Console)
- Automated	Automated Ops. Segments (Limited Supervisory)	Additional Software

4.0 COSTING ACTIVITIES

4.1 SUMMARY OF METHODOLOGIES

Throughout Phase B, we have treated cost as a key trade study discriminator. Cost estimates were developed for each alternative using the tools described in the Cost Estimating Approach (Figure 4.1-1). Credible and verifiable estimates were insured by blending parametrics, analogies and engineering estimates. Each cost estimate considered design, development, production, operations and support costs to properly balance LCC for affordability. As shown in the Trade Study Approach (Figure 4.1-2) our cost analyses also highlighted tall poles, quantified risk and examined the cost sensitivity to key cost drivers.

4.2 DESCRIPTION OF COST OPTIMIZATION TECHNIQUES

Our DTC program provided the forum for organized cost optimization during Phase B. DTC was practiced program wide including participation by our subcontractors: Hamilton Standard and McDonnell Douglas. To guide the implementation of DTC on the Space Station Program, we developed a tailored DTC/Productivity management plan. The plan was disseminated to the project in November of 1985. DTC trades were identified by challenging requirements, design approaches, and management methods, and by examining the producibility, maintainability, reliability and the level of commonality of proposed designs.

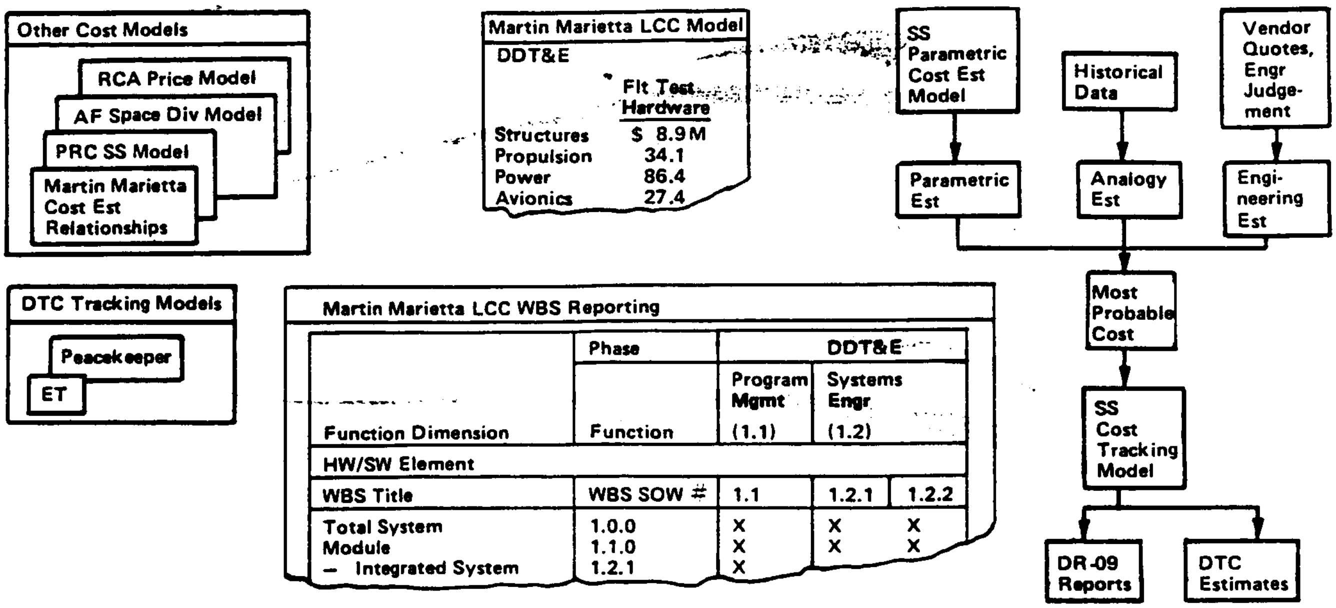

FIGURE 4.1-1 COST ESTIMATING APPROACH

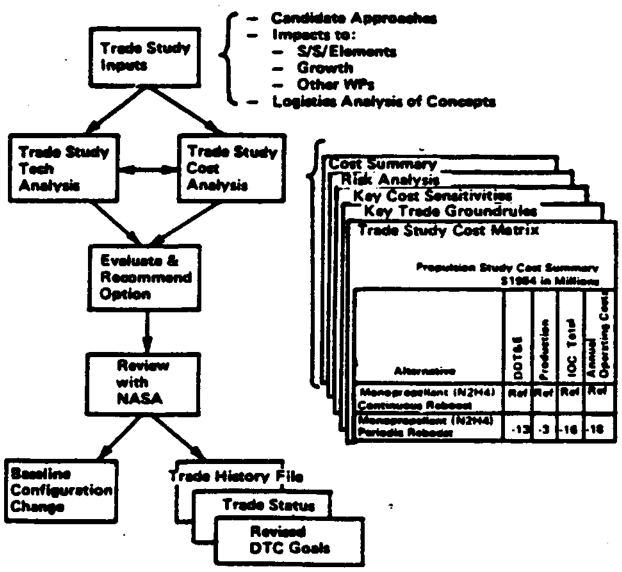

FIGURE 4.1-2 TRADE STUDY APPROACH

5.0 PHASE C/D PROGRAMMATIC ACTIVITIES

Our planning activities for the design, development and operations phase (C/D) of Work Package 01 for the Space Station project are provided in DR-10, Project Implementation Plan (SSP-MMC-00036) dated 1 June 1986. That document addresses each of the WP-01 project elements described in the Work Breakdown Structure (WBS) (DR08), and describes the approach to accomplish the task associated with each element, to integrate the resources generated under DR-09, and provides schedules for accomplishing each element. The plans provided with that document describe the program management approach and controls we will use for product assurance, configuration management, performance measurement, SE&I, design and development, manufacturing, and productivity. The following paragraphs briefly summarize the major sections of DR-10. Volume 2 of this document provides an expanded summary of DR-10.

5.1 PROGRAM MANAGEMENT REQUIREMENTS

The responsibility for the management of the Martin Marietta WP-01 Phase C/D Space Station activities will be assigned to our Michoud Aerospace Division. Our management approach is based upon the Policy, Procedure, and Practice (P^3) media and operating plans currently in place at Michoud and successfully managing the External Tank program. These media and plans will be revised to reflect the innovative cost and productivity improvements made available through automated, paperless systems. This section of DR-10 describes the management systems required to manage and control the design, development, and operations phases of the program. Detailed descriptions are provided for our program planning, element/systems schedules and networks, our utilization of government-furnished equipment and our make-or-buy assumptions. Our project risk assessment plan is also described and includes technical and schedule risk assessment and cost risks. This section also describes our management systems including performance measurement, financial management, technical and information system management, procurement planning, configuration and data management, engineering and manufacturing systems, product assurance and our documentation tree. Finally, our facilities requirements and capabilities are described.

5.2 SYSTEMS ENGINEERING AND INTEGRATION

This section describes the Systems Engineering and Integration (SE&I) organization and methodology planned for the Design, Development and Operations phase of the Space Station project. The functions to be accomplished, responsibility for those functions, and the methodology and scheduling of those functions are described herein. Functional and organizational interfaces are also defined. Both horizontal activities, those which cut across hardware/software elements, and vertical activities, those which are performed for each element, are described.

The Systems Engineering disciplines will together ensure that requirements, design integration, operations and logistics, support and test planning activities are accomplished horizontally, and will work in concert with the hardware element teams to achieve proper vertical integration. Systems Requirements will identify, maintain and ensure traceability of all performance requirements. Systems Design will support system configuration development and integration. Systems Analysis will conduct trade studies required to support design development. The Operations and Logistics disciplines will support the definition of and training for orbital operations and pre-launch operations including checkout and integration of flight hardware, ASE and GSE and will perform logistics and maintenance engineering analyses for the WP-01 elements. Systems Support will conduct design to cost/life cycle cost, reliability, mass properties and contamination analyses for the Phase C/D effort. Engineering change control will ensure proper coordination and review of design changes throughout the design/development effort. Systems Test will provide test plans, procedure reviews, test support and test data reviews as part of the verification process. Systems Engineering will also support the monitoring and review of subcontractor effort by assuring that end item requirements are satisfied by subcontractor products.

5.3 DESIGN AND DEVELOPMENT PLAN

The design and development plans for the hardware elements of WP-01 are described in this section of DR-10. For each hardware element a summary of requirements is provided, the specific element hardware and software are described, and a design and development plan is provided which includes design engineering, integration, trades and analyses required, tests and verification requirements, and technology development status.

5.4 MANUFACTURING

Our manufacturing plan has as its objective to produce the various end items of Work Package 01 in order to have an operational Space Station in the early 1990's, and within the budget limitations as established by the Congress. The keys to achieving these primary objectives involve a goal-oriented development program that will require the introduction of innovative concepts in the area of Manufacturing Systems, coordinated engineering/manufacturing design, and the development of a manufacturing and tooling approach to produce the Space Station elements with the highest quality at the lowest possible cost.

The Production Operation shall be managed to insure that the most cost-effective method shall be incorporated and that the introduction of innovative operations and systems shall be performed in a timely manner to reduce program cost and increase productivity. Manufacturing Planning which has been emphasized in the Phase B Preliminary Design shall continue throughout Phase C/D, to assure Producible Designs, to maintain a flexible manufacturing approach adaptable to growth changes, and to assure lowest possible production cost.

This section of DR-10 describes our project plan and schedules and follow-on production, manufacturing requirements including the manufacturing master schedule, manufacturing technology, tooling and test. In addition, facilities, long lead items and producibility are discussed. A detailed manufacturing plan is provided for each hardware element.

5.5 PRODUCT ASSURANCE

Details of the Martin Marietta safety, reliability, quality assurance and software product assurance implementation plans are provided in SSP-MMC-00037, SSP-MMC-00038, SSP-MMC-00039, and SSP-MMC-00044, respectively.

5.6 PRODUCTIVITY

The Productivity Management Plan for WP-01 is provided in SSP-MMC-00040.