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Volume II, Results

Space Station Definition and Preliminary Design, WP-01

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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 II - Results.

MARTIN MARIETTA DENVER AEROSPACE

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PRELIMINARY STUDY REPORT, VOLUME II

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1.0 INTRODUCTION

Volume II of Data Requirement (DR) Number 15 for the Space Station Definition and Preliminary Design Phase is a compilation of the study results that have been generated as part of this Phase B effort and which, for the most part, have been provided to the MSFC as documented deliverables in accordance with the Phase B DR requirements.

The basis for the studies and analyses which led to the results and conclusions documented in each of the deliverables and summarized herein was the Engineering Master Schedule (EMS) generated by the NASA and used by them as the controlling set of milestones and associated activities required to produce in a timely manner those products needed by all program participants in the establishment of an approved program baseline.

This EMS consisted of twenty themes grouped into categories covering Requirements (7), Configuration (6) and Strategies (7). Within the structure of the EMS, activities were listed for which Work Package 01 (WP01) was identified as requiring the provision of data (in a preliminary, interim or final state) as well as Conclusions and Recommendations so that the Space Station program management could make an appropriate programmatic and/or technical decision.

In support of the WP01 identified activities, the Martin Marietta Corporation Space Station Program personnel identified a number of studies and analyses that were coordinated with the MSFC program and technical personnel as being needed to provide the requisite back-up material to satisfy the EMS objectives. These studies and analyses (provided in Table 1-1) provided the data sufficient to support the conclusions and recommendations given to the MSFC in response to their EMS activity and to support the system level and conceptual design level approaches developed over the conduct of the Phase B effort and reflected in the detailed sections of this document.

The system and programmatic baseline for this document reflects those activities for which Martin Marietta was responsible in accordance with the Phase B Statement of Work as modified by decisions resulting from the Space Station Control Board as a result of RUR-1, RUR-2, IRR and SRR. It does not, however, include those program and Work Package responsibility changes that are planned for implementation as part of Phase C/D, but which have not been formally introduced as part of the Phase B scope. As a result, the Propulsion system - including our recommendation to adopt an O_2H_2 system vis-a-vis hydrazine - is included herein, whereby the Habitation Module Outfitting is not.

Additionally, the technical changes resulting from the Configuration Evaluation Task Force (CETF) activity which impact WP01 (specifically the extended resource nodes and the rearrangement of the interior of the US Laboratory and the Habitation Module by moving equipment to the nodes) are also not included. This omission is done to provide continuity and agreement between this document and the DRs which it summarizes - most of which were submitted prior to the CETF decisions and hence reflect pre-CETF baselines.

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TABLE 1-1 SE&I ACTIVITY IDENTIFICATION FOR SPACE STATON

STUDY	TITLE	TECHNICAL LEAD	EMS TRACE	DP DELIVERY
A001	TRADE PROPULSION IMPULSE VS ORBITAL ALTITUDE AND REBOOST SCENARIOS	P&VA CDT	R1.1.4	1.1A
A002	DEFINE REQUIREMENTS FOR OMV SFE	K. O'KELLY	R5.1.2	1.1B 1.2
A003	DEFINE CONTAMINANTS PRODUCED BY SS PROPELLANTS	E. FOX	C1.1.2	1.2 1.3
A007	DELETED - TRADE-OFF KEVLAR OVERWRAP FOR CONTAINMENT VS ELIMINATION OF CONTAINMENT REQUIREMENT			
A008	DEFINE SUBSYSTEM MICRO-METEOROID PROTECTION VS CONCEPTS	E. FOX	C1.1.2	1.2 1.3
A009	EVALUATE VARIOUS APPROACHES (WASTE HEAT, GAS GENERATOR, ELECTRICAL POWER) AS PROPULSIVE SYSTEM ENERGY SOURCE	E. FOX	R2.1.2	1.1A DR-02
A011	DELETED - EVALUATE IMPACT ON SS OF THE COMMUNICATION/TRACKING SYSTEM DISTANCE RQMTS			
A012	EVALUATE IMPACT ON SS OF THE GN&C SYSTEM REQUIREMENTS	D. LECK	R2.1.2	DR-02
A013	EVALUATE 3 DOF VS 2 DOF PROPULSION CONTROL REQUIREMENTS	D. LECK	C1.1.2	1.2
A014	DELETED - EVALUATE IMPACT OF ECLS DUMP RATE ON RCS DESIGN			
A015	DELETED - EVALUATE IMPACT ON ECLS NON-PROPULSIVE VENTING ON RCS DESIGN			
A019	DELETED - ESTABLISH ALLOWABLE FLUID DYNAMIC LEVELS			
A022	DETERMINE OMV PROXIMITY OPERATIONS REQUIREMENT	B. KING	R2.1.3	1.1B DR-02
A023	EVALUATE OMV RETRIEVAL BY MRMS VS DIRECT BERTHING	P&VA CDT	N/A	DR-02
A024	EVALUATE OTV SERVICING OPTIONS (SS VS FUEL FARM VS RESUPPLY IN PLACE)	P&VA CDT	N/A	1.2 DR-02
A025	DELETED - EVALUATE OTV FLIGHT RATE AS A FUNCTION OF REFUELING & SERVICING CAPABILITIES			
A026	EVALUATE SERVICE BY OMV IN-SITU AT PLATFORM VS AT SS	P&VA CDT	C4.1.1	1.3
A027	DELETED - EVALUATE IN SITU SATELLITE SERVICING VS AT SS			
A028	ESTABLISH SFE SERVICER KITS AND PROPULSION RESUPPLY FUNCTIONAL REQUIREMENTS	P&VA CDT	C4.1.1, R5.1.2	1.2
A031	EVALUATE TECHNIQUES FOR PROXIMITY OPERATIONS CONTROL - OMV GCS VS SS	B. KING	C6.1.3	1.3
A032	ESTABLISH ATTACHED PAYLOAD INTERFACE REQUIREMENTS	K. O'KELLY	R5.1.1	1.2
A033	EVALUATE FLUID SYSTEMS SERVICING FOR TETHERED VS BERTHED PAYLOADS	P&VA CDT	N/A	1.2 DR-02
A034	EVALUATE STORABLE VS GH2, GO2 PROPELLANTS SELECTION	P&VA CDT	C1.1.2	1.2 1.3
A035	EVALUATE 50 VS 1 LBS THRUST LEVELS	E. FOX	C1.1.2	1.2 1.3
A036	EVALUATE CENTRALIZED VS DISTRIBUTED PROPELLANT LOCATIONS	P&VA CDT	C1.1.2	1.2 DR-02

TABLE 1-1 SE&I ACTIVITY IDENTIFICATION FOR SPACE STATON

STUDY	TITLE	TECHNICAL LEAD	EMS TRACE	DP DELIVERY		
A037	DELETED - EVALUATE REBOOST FREQUENCY REQUIREMENTS					
A038	EVALUATE IMPACTS OF MAINTAINING 220 OR 270 N MILES AS THE OPERATING ALTITUDE	B. KING	R1.1.4	1.2	DR-02	
A039	EVALUATE VARIOUS LOCATIONS FOR STATIONING OMV/OTV ACCOMMODATIONS	P&VA CDT	C1.1.3	1.1A	1.2	1.3
A040	EVALUATE REBOOST BY OMV VS SEPARATE PROPULSION SYSTEM	P&VA CDT	R1.1.4	1.1A	1.2	DR-02
A041	EVALUATE ORBITER DOCK VS FERRY TECHNIQUES	P&VA CDT	N/A	1.1B		
A042	SYSTEM TEST APPROACH FOR P&VA	J. GRUBER	S6.1.1,S6.1.2,S6.1.3, S6.1.4,S6.1.5,S6.1.6, S6.1.7,S6.1.8,S6.1.9	1.1A	1.2	
A042	SYSTEM TEST APPROACH FOR P&VA	J. GRUBER	S6.1.1,S6.1.2,S6.1.3, S6.1.4,S6.1.5,S6.1.6, S6.1.7,S6.1.8,S6.1.9	1.1A	1.2	1.3
AM43	OVERALL WP-01 FLUID SUBSYSTEMS ASSESSMENT	E. FOX	C1.1.2,C4.1.3	1.1A	1.2	1.3
AM44	ACCOMMODATION FOR UNIQUE/MISCELLANEOUS CUSTOMER ELEMENTS	F. STEPUTIS	C4.1.3	1.3		
AM45	VEHICLE ACCOMMODATION INTEGRATION STUDY	E. LITTLER	C1.1.3	1.3		
AM46	DELETED - COMMUNICATIONS PROCESSING AND REDUNDANCY CONFIGURATION					
B001	TRADE CUSTOMER/PAYLOAD CHANGEOUT USING OMV/ORBITER VS LOGISTICS MODULE	N. OLIVA	C6.1.3	1.3		
B004	DELETED - TRADE INTERNAL VS EXTERNAL MTL WASTE DISPOSAL CONCEPTS					
B005	DELETED - ESTABLISH HAZARD CONTROL & DETECTION LEVEL REQUIREMENTS					
B007	DELETED - EVALUATE IMPACT OF HORIZONTAL VS VERTICAL INSTALLATION TECHNIQUES/REQUIREMENTS					
B008	DELETED - EVALUATE CREW ACTIVITY PLANNING DELTAS					
B009	DELETED - EVALUATE CREW RESOURCE IMPACT AS A FUNCTION OF EVA HOURS					
B013	DELETED - TRADE PAYLOAD VS CM PROVIDED DATA MANAGEMENT SYSTEM RESOURCES					
B014	DELETED - TRADE INDEPENDENT VS DEPENDENT CUSTOMER OPERATIONS AND MONITORING					
B017	SYSTEM TEST APPROACH FOR MTL	J. GRUBER	S6.1.1,S6.1.2,S6.1.3, S6.1.4,S6.1.5,S6.1.6, S6.1.7,S6.1.8,S6.1.9	1.1A		
BM15	LAB MODULE ARCHITECTURE	MTL CDT	C1.1.3	1.3		
BM16	SINGLE LAB PRACTICALITY AND ARCHITECTURE	MTL CDT	R1.1.8	1.1A	1.2	DR-02
BM17	GROWTH ARCHITECTURE/CONFIGURATION	MTL CDT	C2.1.1	1.3		
BM18	MICRO-G LEVELS, ANGULAR RATES	MTL CDT	R5.1.4	1.1A	1.2	DR-02
BM19	DELETED - LAB VOLUME					
BM20	DELETED - WINDOWS AND VIEWING REQUIREMENTS					
BM21	DELETED - PROPIETARY DATA PROTECTION REQUIREMENTS					
BM23	LAB RESUPPLY CYCLE REQUIREMENTS	N. OLIVA	S3.1.1	1.2	1.3	
BM24	DELETED - LAB GAS VENT/STORAGE/PROCESSING REQUIREMENTS					
BM25	DELETED - SCIENTIFIC AIRLOCK SIZE AND NUMBER					

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TABLE 1-1 SE&I ACTIVITY IDENTIFICATION FOR SPACE STATON

STUDY	TITLE	TECHNICAL LEAD	EMS TRACE	DP DELIVERY
BM26	LAB AUTOMATION METHODS	R. SPENCER	S2.1.1	1.1B
BM27	LAB MAINTENANCE/ORU LEVELS	N. OLIVA	S5.1.1,S5.1.4,S5.1.5	1.3
BM28	DELETED - LAB MAGNETIC FIELDS			
BM29	DELETED - LAB HUMAN PRODUCTIVITY			
BM30	DELETED - FULL-BODY SHOWER REQUIREMENT FOR CHEMICAL SPILL			
BM31	MTL PAYLOADS & EXPERIMENTS ACCOMMODATIONS ASSESSMENT	MTL CDT	C4.1.4	1.1B
BM32	DELETED - MTL SUBSYSTEM FUNCTIONAL ALLOCATIONS			
BM33	MTL CREW WORKSTATION ANALYSIS	MTL CDT	C1.1.3	1.1A DR-02
BM34	MTL FLUIDS SUBSYSTEMS ASSESSMENT	MTL CDT	C1.1.2	1.1A 1.3
BM35	DELETED - EVALUATE IMPLEMENTATION CONCEPTS/COSTS FOR MAN-TENDED MINI-LAB			
BM36	MTL CUSTOMER ACCOMMODATION REQUIREMENTS ANALYSIS	F. STEPUTIS	R5.1.1,R5.1.3	1.2
BM37	MTL IMPACTS ON NSTS PERFORMANCE	MTL CDT	R1.1.2	1.2
BM38	ALTERNATE MTL OUTFITTING ANALYSIS	MTL CDT	R1.1.5	1.2
BM39	MTL GENERIC EQUIPMENT ANALYSIS	MTL CDT	N/A	DR-02
EM64	MODULE ISOLATION REQUIREMENTS/IMPACT STUDY	N. SAENISCH	R6.1.3	1.2 DR-02
I001	INDUCED CONTAMINATION ENVIRONMENTS ANALYSIS	N. LARUE	C1.1.2	1.3
I003(A)	DELETED - PERFORM COMMONALITY ANALYSIS ACROSS ALL SSPEs TO MAXIMIZE COMMON HARDWARE, SOFTWARE INTERFACES			
I003(B)	DELETED - PERFORM COMMONALITY ANALYSIS ACROSS ALL SSPEs TO MAXIMIZE COMMON HARDWARE, SOFTWARE, INTERFACES			
I004	PERFORM AN AUTONOMY ANALYSIS TO DETERMINE PHASED ON-ORBIT AUTONOMY	B. KING		1.2 DR-02
I005	DELETED - DEVELOP A PHASED AUTOMATION PLAN FOR WP-01 ELEMENTS	R. SPENCER		
I006	ESTABLISH A MAINTENANCE CONCEPT EVALUATING GROUND VS ON-ORBIT MAINTAINABLE ACTIVITIES	N. OLIVA	S5.1.6	1.1A 1.3
I007	DELETED - ESTABLISH AND ALLOCATE RELIABILITY GOALS			
I013	DEFINE IOC TO GROWTH BLOCK CHANGE REQUIREMENTS	K. O'KELLY	C2.1.1	1.2
I015	DELETED - DEFINE RESUPPLY REQUIREMENTS DELTA FROM IOC TO GROWTH FOR SHUTTLE TENDED MODES OF RESUPPLY			
I016	DEFINE SS SENSITIVITY TO CREW SIZE CHANGES	CONFIG CDT	R3.1.3	1.1B
I018	DELETED - EVALUATE FAIL SAFE VS FAIL OPERATIONAL CONCEPTS			
I019	DELETED - DEFINE SENSITIVITY OF ECLSS TO EVA NUMBERS AND FREQUENCIES			
I021	DELETED - PROVIDE FLIGHT & GROUND OPS REQUIREMENTS			
I024	DEFINE AND EVALUATE CONCEPTS FOR RAPID SAMPLE RETURN	N. OLIVA	S3.1.4	1.3
I025	DEFINE MAINTAINABILITY CONCEPT	N. OLIVA	S5.1.1,S5.1.2,S5.1.3, S5.1.4,S5.1.5,S5.1.6	1.3

TABLE 1-1 SE&I ACTIVITY IDENTIFICATION FOR SPACE STATON

STUDY	TITLE	TECHNICAL LEAD	EMS TRACE	DP DELIVERY		
I030	EVALUATE METHODS FOR PROXIMITY OPERATIONS FEEDBACK TO CREW	B. KING	C1.1.2	1.3		
I034	DELETED - EVALUATE DISTRIBUTED VS CENTRALIZED SITE FOR CM AND OUTFITTING INTEGRATION					
I036	PRELAUNCH ASSY/INTERFACE VERIFICATION FOR WP-01 ELEMENTS	J. GRUBER	S6.1.1,S6.1. .1.8	1.1A	1.2	
I037	DELETED - DEFINE SAFETY VERIFICATION POLICY FOR WP-01 ELEMENTS					
I038	MODULE PATTERN ANALYSIS	CONFIG CDT	C3.1.1	1.1A	1.2	
IM08	PERFORM ANALYSES TO DEFINE SAFE HAVEN CONCEPTS AND DETAILED IMPLEMENTATION REQUIREMENTS	CM CDT	C3.1.1,R6.1.2	1.1A	DR-02	
IM10	DEFINE AND EVALUATE THE RADIATION PROTECTION REQUIREMENTS RELATIVE TO ONE YEAR CONTINUOUS OCCUPANCY	CONFIG CDT	C1.1.2	1.1A	1.2	1.3
IM17	DEFINE SAFE HAVEN SENSITIVITY TO DURATION CHANGES	CONFIG CDT	R6.1.6	1.1A	DR-02	
IM36	SS ARCHITECTURE DELTAS FOR ALL WP-01 ACCOMMODATIONS	CONFIG CDT		1.1B		
IM38	LOG MODULE LOCATION OPTIONS	CONFIG CDT	C3.1.1	1.1A		
IM39	ESTABLISH REFERENCE CONFIGURATION	ALL CDT'S	C1.1.2,C1.1,3	1.1A	1.2	1.3
IM40	EVALUATE EGRESS CONSTRAINTS	CONFIG CDT	R6.1.1	1.1A	1.2	DR-02
IM41	DELETED - TRADE PRESSURIZED/UNPRESSURIZED LOG MODULE					
IM42	LOG MODULE RESUPPLY ARCHITECTURE	LM CDT	S3.1.6	1.1B	1.2	1.3
IM44	ESTABLISH WP-01 FUNCTION ALLOCATIONS	K. O'KELLY	C6.1.1,C6.1.2,C6.1.3, C6.1.4	1.1A	1.3	
IM45	DELETED - WP-01 COST ALLOCATIONS					
IM46	DELETED - TETHERED CONCEPTS FOR WP-01					
IM47	DELETED - INTEGRATED LOGISTICS SIZING					
IM48	ON-ORBIT VS GROUND LOGISTICS ALLOCATIONS	N. OLIVA	S3.1.1,S3.1.3	1.2		
IM49	DELETED - END OF LIFE DISPOSAL CONCEPT					
IM50	DELETED - SCAR DEFINITION					
IM51	ANALYZE ADVANCE DEVELOPMENT FOR IOC	A. BROOK	S1.1.2	1.1B		
IM53	MERGE NASA/CONTRACTOR ADVANCE DEVELOPMENT PROGRAMS	A. BROOK	S1.1.1	1.1B		
IM54	DEFINE A&R CANDIDATES FOR IOC	R. SPENCER	S2.1.1	1.1B	1.3	
IM55	DEFINE A&R SELECTION CRITERIA	R. SPENCER	S2.1.2	1.1B	DR-02	
IM56	SELECT A&R CANDIDATES	R. SPENCER	S2.1.3	1.1B	1.2	1.3
IM57	DEFINE SCAR FOR GROWTH A&R	R. SPENCER	S2.1.4	1.1B	1.3	
IM58	DEFINE RESOURCE REQUIREMENTS FOR WP-01 ELEMENTS	K. O'KELLY	R3.1.2	1.1A		
IM59	EVALUATE IMPACT OF WP-01 ELEMENTS CONCEPT DESIGNS ON STS PERFORMANCE	L REEDER	R1.1.6	1.1A	1.2	
IM60	INITIAL INTEGRATION ASSESSMENT	R HARRIS	C1.1.3	1.1B		
IM61	IDENTIFY OPERATIONS REQUIREMENTS FOR WP-01 ELEMENTS	L. REEDER	R2.1.2	1.1B		
IM62	INTEGRATE TIME-PHASED ECLSSS, VOLUMES, & FLUIDS REQUIREMENTS FOR OP-01	K. O'KELLY	R3.1.3	1.1B		
IM63	INTEGRAL BERTHING RING VS SEPARATE DOCKING SECTION	R. HARRIS	C1.1.5,C3.1.1	1.2	DR-02	
IM65	EMERGENCY DEFINITION & CONTAINMENT STUDY	M. SAEMISCH	R6.1.4	1.2	DR-02	

TABLE 1-1 SE&I ACTIVITY IDENTIFICATION FOR SPACE STATON

STUDY	TITLE	TECHNICAL LEAD	EMS TRACE	DP DELIVERY
IM66	ON-ORBIT OUTFITTING ANALYSIS	LM CDT	R1.1.3	1.2
IM67	MAN-TENDED IMPACT ANALYSES	J. SMITH	N/A	1.2
IM68	CREW FUNCTION/TIME ALLOCATION ANALYSIS	L. REEDER	R2.1.3	1.2 DR-02
IM69	COMMON MODULE COMMONALITY DATA BASE	M BRZECZEK	S4.1.1	1.2 1.3
IM70	DELETED - WP-01 EQUIPMENT LIST DATA BASE			
IM71	SPACE STATION FUNCTION DATA BASE	M. BRZECZEK	S4.1.5	1.2 1.3
IM72	LOADS & STRUCTURAL DYNAMICS ANALYSIS	J. FROMME	N/A	DR-02
IM73	MTL OUTFITTING AUTOMATION & ROBOTICS PLAN	R. SPENCER	N/A	DR-02
IM74	IOC BASELINE AUTOMATION ANALYSIS	R. SPENCER	N/A	DR-02
IM75	RECOMMENDED SPACE STATION ASSEMBLY SEQUENCE FOR PRELIMINARY MANNED CONFIG (PMC) & MAN-TENDED ANALYSIS (MTA) ALTERNATIVES	D. BAUER	N/A	DR-02
IM76	OMV HANGAR THERMAL ANALYSIS	R. MCMORDIE	N/A	DR-02
IM77	LINE SIZE & DESIGN CONFIGURATION ANALYSIS	R. MCMORDIE	N/A	DR-02
IM78	DELETED - COMMON MODULE APPROACH & COMMONALITY JUSTIFICATION STUDY			
IM79	WP-01 SYSTEMS TEST	J. GRUBER	N/A	DR-02
IM80	EFFECTS OF SPACE SHADOWING ON TCS DESIGN	G. EMERSON	N/A	DR02-1
IM81	VIEWPORT STUDY	G. EMERSON	N/A	DR02-1
IM82	CREW WORKSTATION ANALYSIS	V. PAUL	N/A	DR02-1
L002	EVALUATE UNIVERSAL VS MISSION PECULIAR CONFIGURATION FOR LM	LM CDT	S3.1.6	1.1B 1.2 1.3
L003	DELETED - DETERMINE NUMBER OF LMs REQUIRED FOR SS PROGRAM			
L004	DETERMINE RESUPPLY FREQUENCY REQUIREMENTS (60 VS 90 VS ? DAYS)	N. OLIVA	S3.1.5	DR-02
L005	DELETED - EVALUATE END DOME VS RADIAL LOADING APPROACHES			
L006	DELETED - EVALUATE LM/ECLSS APPROACH CONSIDERING DEPENDENCY ON ORBITER VS SELF CONTAINED			
L007	EVALUATE FLUID TRANSFER METHODS - FROM TANKS VS TANK EXCHANGE	P&VA CDT	S3.1.6	1.1B 1.2 DR-02
L008	DELETED - EVALUATE VARIOUS INTERNAL CONFIGURATIONS FOR LM (SPACELAB, MODIFIED SPACELAB, OCTAGONAL, ETC.)			
L009	DEFINE WASTE MANAGEMENT RETURN REQUIREMENTS	N. OLIVA	S3.1.1	1.2 1.3
L010	DELETED - ESTABLISH & EVALUATE HEAT SINK APPROACHES FOR LM DURING ALL USAGE PHASES			
L011	DELETED - ESTABLISH & EVALUATE TECHNIQUES FOR EXTERNAL STORES THERMAL REQUIREMENTS			
L012	DETERMINE TANKAGE REQUIREMENTS CONSIDERING LOCATION, PRESSURE, SHAPE, CONFIGURATION, ETC.	LM CDT	C1.1.2,S3.1.6	1.1A 1.2
L013	DEFINE AND EVALUATE REFRIGERATOR / FREEZER CONCEPTS / REQUIREMENTS FOR LM	R. MCMORDIE	S3.1.6	1.2 1.3
L016	EVALUATE CONCEPTS FOR LOCATING MAINTENANCE WORK STATIONS	N. OLIVA	S5.1.4	1.3
L019	DELETED - EVALUATE EXISTING VS NEW GSE TO SUPPORT LM USAGE			
L020	DELETED - ESTABLISH SAFETY REQUIREMENTS FOR LM			

TABLE 1-1 SE&I ACTIVITY IDENTIFICATION FOR SPACE STATON

STUDY	TITLE	TECHNICAL LEAD	EMS TRACE	BP DELIVERY
L021	DELETED - ESTABLISH GROWTH REQUIREMENTS FOR LM			
L022	ESTABLISH MAINTAINABILITY REQUIREMENTS FOR LM	M. OLIVA	S5.1.5	1.3
L024	DELETED - EVALUATE CARGO REQUIREMENTS AS A FUNCTION OF STS VS INCREASED CARGO CAPABILITY			
L026	EVALUATE CENTRALIZED PANTRY VS DISTRIBUTED STORAGE FOR ON-ORBIT STORAGE	M. OLIVA	S3.1.1	1.2
L027	DELETED - DETERMINE AND EVALUATE RESOURCE ACQUITION TECHNIQUES FOR LM DURING USAGE PHASES			
L034	DELETED - DEFINE LM TO CREW INTERFACE REQUIREMENTS EVALUATING COMMON VS LM UNIQUE APPROACHES			
L035	DELETED - DETERMINE & EVALUATE VARIOUS STORAGE & TRANSPORT TECHNIQUES			
L036	SYSTEM TEST APPROACH FOR LM	J. GRUBER	S6.1.1,S6.1.2,S6.1.3, S6.1.4,S6.1.5,S6.1.6, S6.1.7,S6.1.8,S6.1.9	1.1A
LM37	DELETED - ECLSS RESUPPLY APPROACH			
LM38	DETERMINE MAN-TENDED LOGISTICS SUPPLY APPROACH	M OLIVA	N/A	1.2
LM39	INITIAL LOGISTICS ANALYSIS	H BAUER	S3.1.1,S3.1.2,S3.1.3	1.1B
LM40	INITIAL MAINTENANCE/MAINTAINABILITY ANALYSIS	H BAUER	S5.1.1,S5.1.2,S5.1.3, S5.1.4,S5.1.5,S5.1.6	1.1A
LM41	INITIAL LM GROWTH ANALYSIS	H BAUER	C2.1.1,C2.1.2	1.1A
LM42	LOGISTICS MODULE UNPRESSURIZED STRUCTURE - COMPOSITE VS METAL	H. BAUER	S3.1.6	1.1B
LM43	LOGISTICS MODULE UNIQUE STRUCTURE - SENSITIVITY ANALYSIS	H. BAUER	S3.1.6	1.1B
LM44	LOGISTICS MODULE OUTFITTING ANALYSIS	H. BAUER	R1.2.3	1.2 1.3
LM45	LOGISTICS MODULE ASCENT/DESCENT POWER REQUIREMENTS	C. PISTOLE	N/A	DR-02
LM46	LOGISTICS MODULE ENERGY STORAGE	C. PISTOLE	N/A	DR-02
M001	CM/ECLSS CONTAMINATION CONTROL AND MONITORING REQUIREMENTS DEFINITION	G. HOLMSTEAD	C1.1.2	1.1B 1.2 1.3
M002	CM/ECLSS FIRE SUPPRESSION AND DETECTION REQUIREMENTS DEFINITION	G. HOLMSTEAD	C1.1.2,R6.1.4	1.1B 1.2 DR-02
M004	EVALUATE CONCEPTS FOR TEMPERATURE, HUMIDITY AND VENTILATION CONTROL	G. HOLMSTEAD	C1.1.2	1.1B 1.2
M005	EVALUATE CONCEPTS FOR ARS, INCLUDING CO2 REMOVAL, CO2 REDUCTION, O2 & N2 GENERATION	G. HOLMSTEAD	C1.1.2	1.1B 1.2
M006	EVALUATE CONCEPTS FOR H2O RECOVERY AND MANAGEMENT	G. HOLMSTEAD	C1.1.2	1.1B 1.2
M007	EVALUATE CONCEPTS FOR COLLECTING AND PROCESSING FECAL WASTE AND URINE	G. HOLMSTEAD	C1.1.2	1.1B 1.2
M008	EVALUATE CONCEPTS TO SERVICE EMU/MMU	G. HOLMSTEAD	C1.1.2	1.1B 1.2 1.3
M009	EVALUATE ECLSS CONCEPTS TO SUPPORT SAFE HAVEN	G. HOLMSTEAD	R6.1.2,R6.1.3	1.1A 1.2 DR-02
M011	EVALUATE CONCEPTS FOR AIRLOCK, INCLUDING HYPERBARIC CHAMBER, VENTING & PRESSURIZING	G. HOLMSTEAD	C1.1.5,C3.1.2	1.1B 1.2 1.3
M012	EVALUATE CONTRALIZED VERSUS DISTRIBUTED ECLSS SYSTEM	G. HOLMSTEAD	R6.1.2,C1.1.2	1.1A 1.2 1.3
M013	DETERMINE DEGREE OF LOOP CLOSURE	G. HOLMSTEAD	C1.1.2	1.1A 1.2

TABLE 1-1 SE&I ACTIVITY IDENTIFICATION FOR SPACE STATON

STUDY	TITLE	TECHNICAL LEAD	EMS TRACE	DP DELIVERY		
M014	EVALUATE IMPACTS OF TOTAL PRESSURE CONSIDERING 10.2 VERSUS 14.7 PSI	G. HOLMSTEAD	C1.1.2	1.1A	1.2	
M015	DEFINE PROGRAMMING LANGUAGE REQUIREMENTS	D. LECK	C1.1.2	1.1A	1.2	1.3
M016	PERFORM DMS ELEMENTS REQUIREMENTS ANALYSIS	D. LECK	C1.1.2	1.1A	1.2	1.3
M022	DELETED - 5 POINT VS 4 POINT SPREADER BEAM					
M023	DETERMINE LEVEL OF MICRO-METEOROID PROTECTION VS WEIGHT, VOLUME, WALL THICKNESS, ETC.	CM CDT	C1.1.5	1.2	1.3	
M025	EVALUATE DEGREE OF STRUCTURES COMMONALITY VERSUS WEIGHT AND COST	CM CDT	C1.1.5,S4.1.1	1.1B	1.2	
M027	DETERMINE HATCH SIZE REQUIREMENTS CONSIDERING EQUIPMENT, COST, WEIGHT, VOLUME, ETC.	CM CDT	C1.1.2	1.1B	1.2	DR-02
M028	IDENTIFY TASKS REQUIRING ACCESS AND DEFINE WALL ACCESS REQUIREMENTS	N. OLIVA	S5.1.2	1.1B		
M029	PERFORM PARAMETRIC STUDY ON CM LENGTH	CM CBT	R1.1.1	1.1B	1.2	
M030	EVALUATE INTERNAL VS EXTERNAL AIRLOCK CONCEPTS	CM CDT	C3.1.2	1.1A	1.2	DR-02
M032	CONDUCT TRADES OF MATERIAL SELECTION VS CONSTRUCTION TECHNIQUES	CM CDT	C1.1.5	1.2	1.3	
M033	DELETED - WINDOW REQUIREMENTS FOR THE CM					
M037	STUDY IMPACT OF POWER CAPABILITY GROWTH FROM 25KW TO 75KW	J. MASSON	C1.1.2	1.2	1.3	
M038	ESTABLISH USER INTERFACE POWER TYPES REQUIREMENTS	J. MASSON	C1.1.2	1.1A	1.2	1.3
M039	DETERMINE DEGREE OF POWER SYSTEM AUTONOMY	J. MASSON	C1.1.2	1.2	1.3	
M040	EVALUATE LOAD PROTECTION VS CUSTOMER PROTECTION TECHNIQUES	J. MASSON	C1.1.2	1.3		
M041	EVALUATE EXTERNAL VS INTERNAL VS CENTRAL POWER INTERFACE ARCHITECTURE FOR INTERMODULE POWER	J. MASSON	C1.1.2	1.1B	1.2	1.3
M042	DETERMINE MODULE GROUNDING CONCEPT	J. MASSON	C1.1.2	1.3		
M044	ASSESS VARIOUS PRIMARY POWER TYPES FOR SYSTEM IMPACT	J. MASSON	C1.1.2	1.1A	1.2	1.3
M053	DELETED - PERFORM GROWTH TRADES (MODULARITY, TECHNOLOGY, AUTOMATION, ARCHITECTURAL, ETC.)					
M055	DELETED - PERFORM SAFETY TRADES (SAFE HAVEN, EMERGENCY MANAGEMENT, DUAL EGRESS, ETC.)					
M056	DELETED - PERFORM LOGISTICS TRADES (SPARES, CONSUMMABLES, ETC.)					
M057	PERFORM CM ARCHITECTURE TRADES (WINDOWS, AIRLOCKS, ATTACHMENTS, ETC.)	CM CDT	C1.1.3,C1.1.5	1.1B	1.2	1.3
M058	PERFORM NSTS INTERFACE STUDIES (CARGO BAY ACCOMMODATIONS; DOCKING UTILITIES, ETC)	CM CDT	R1.1.1	1.1B	1.2	
M060	EVALUATE CONCEPTS TO CONTROL TOTAL/PARTIAL 02 PRESSURE	G. HOLMSTEAD	C1.1.2	1.1b	1.2	
M061	COMMUNICATIONS CONFIGURATION STUDY	B. LECK	C1.1.2	1.1A	1.2	1.3
M062	CAUTION & WARNING CONCEPT DEFINITION	D. LECK	R6.1.7	1.1B	1.2	1.3
M063	SYSTEM TEST APPROACH FOR CM	J. GRUBER	S6.1.1,S6.1.2,S6.1.3, S6.1.4,S6.1.5,S6.1.6, S6.1.7,S6.1.8,S6.1.9	1.1A		
M064	WASTE HEAT ACQUISITION, TRANSPORT, & STORAGE	B. MCMORDIE	C1.1.2	1.1A	1.2	1.3
M065	WASTE HEAT REJECTION/SOLAR ENERGY COLLECTION	B. MCMORDIE	C1.1.2	1.1A	1.2	1.3
M066	MODULE STRUCTURES/ENVIRONMENT PROTECTION	B. MCMORDIE	C1.1.2	1:3		

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TABLE 1-1 SE&I ACTIVITY IDENTIFICATION FOR SPACF STATON

STUDY	TITLE	TECHNICAL LEAD	EMS TRACE	DP DELIVERY		
M067	TCS OPERATION, CONTROL, & TEST	R. MCMORDIE	C1.1.2	1.3		
MM60	MODULE VS SUBSYSTEM LEVEL NETWORK VS INTEGRATED SENSORS	CM CDT	C1.1.2	1.1B	1.3	
MM61	LOCAL VS CENTRALIZED COMMUNICATIONS CONTROL	CM CDT	C1.1.2	1.1B	1.2	1.3
MM62	MOBILE CELLULAR VOICE NETWORK VS NSTS TECHNOLOGY	CM CDT	C1.1.2	1.1B		
MM63	COMMON MODULE MAINTAINABILITY	N. OLIVA	S5.1.5	1.3		
MM64	DELETED - OUTFITTING EQUIPMENT LISTS FOR EACH MODULE CONFIGURATION					
MM65	CM INTERNAL COMMUNICATIONS - RF VS IR LINK	D. LECK	C1.1.5	1.2	1.3	
MM66	COMMUNICATIONS BANDWIDTH REQUIREMENTS	D. LECK	C1.1.5	1.2	DR-02	
MM67	DELETED - INPUTS TO REDUNDANT CONTROL STATION STUDY					
MM68	MODULE ASSEMBLY SEQUENCE	E. LITTLER	N/A	DR-02		
MM69	CENTRALIZED VS DISTRIBUTED POWER CONDITIONING	C. PISTOLE	N/A	DR-02		
MM70	LOAD CENTER OPTIMIZATION	C. PISTOLE	N/A	DR-02		
MM71	HEAT PUMP STUDY	R. MCMORDIE	N/A	DR-02		
MM72	CENTRALIZED VS DISTRIBUTED THERMAL CONTROL WITHIN MODULES	R. MCMORDIE	N/A	DR-02		
MM73	EXTERNAL PARALLEL VS INTERNAL SERIES THERMAL CONTROL DISTRIBUTION	R. MCMORDIE	N/A	DR-02		

2.0 SYSTEMS

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.

The requirements and interface development activities progressed through the following Data Requirements submittals:

DR01 - Applicability matrix for SOW C2, C3, and C4 requirements to WP-01 elements.

DR02 - Specification tree (SSP-MMC-00014, three submittals updating the tree to the work package complement. Current specification tree is shown in Figure 2.1-1.)

- Recommended changes to SOW Attachments C2, C3, C4 (SSP-MMC-00029).
- Interface Control Document (ICD) Scope Sheets (SSP-MMC-00032, submitted as preliminary ICDs for interfaces between WP-01 and other work packages. Provides basis for ICDs to be developed in Phase C.)
- Interface Requirements Documents (IRD)

The ISR submittal consisted of the following IRDs:

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

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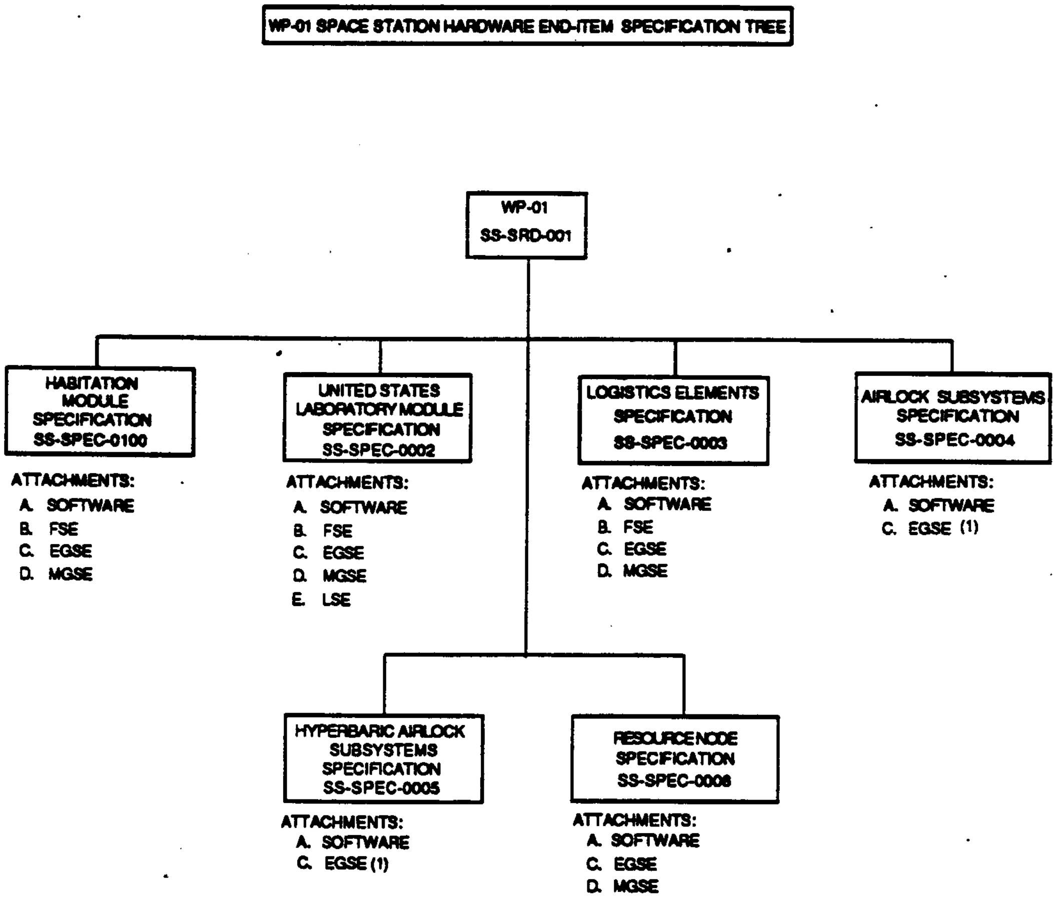

NOTE:
(1) ATTACHMENT MAY BE REQUIRED WHEN CONFIGURATION IS DEFINED.

FIGURE 2.1-1 SPECIFICATION TREE

Subsequently, SS-IRD-0902, New, Airlock to EVA was submitted as a replacement for SS-IRD-0900 when work package responsibilities were modified. Also, SS-IRD,0303, Initial, Pressurized Logistics Carrier to Space Station was prepared and submitted upon a special MSFC supplemental request.

In addition, review and comment support was provided for the preparation of the following IRDs:

SS-IRD-0200, Rev. B, Customer to U.S. Laboratory
SS-IRD-0300, Rev. B, Logistics Elements to Cargo
SS-IRD-0302, Initial, Logistics Elements to NSTS
SS-IRD-1000, Basic, Space Station Interconnect to STS Orbiter
SS-IRD-1001, Basic, Space Station Interconnect to Pressurized Attached Payloads
SS-IRD-1002, Basic, Space Station Interconnect to Japanese Experiment Module
SS-IRD-1003, Basic, Space Station Interconnect to European Space Agency Columbus System

DR03 - Contract End Item (CEI) Development Specifications.

The ISR submittal consisted of the following:

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

In addition, review and comment support was provided for the preparation of the following CEI Specifications:

SS-SPEC-0003, Outfitted Logistics Elements
SS-SPEC-0004, Airlock
SS-SPEC-0006, Module Interconnect
SS-SPEC-0007, OMV Accommodations

Subsequent modifications in the work package responsibilities resulted in updates, deletions, and combinations of the specifications in accordance with the final Specification Tree shown in Figure 2.1-1.

2.2 SYSTEM TEST AND VERIFICATION (DR-04)

A summary of the System Test and Verification Plan (STVP) which was developed during Phase B in accordance with DR-04 is provided in this section. That plan which consists of six volumes defines the Martin Marietta approach to verifying all WP-01 contract end-items. Figure 2.2-1 presents a generic flow of WP-01 elements from the development phase through IOC verification. Figure 2.2-2 presents post IOC verification in the same generic fashion. The following subsections provide more specific information and are keyed to 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 shown in Figure 2.2-3. 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.

Since Volume 1 will complement the element level plans, it establishes standard definitions, abbreviations and acronyms to be used in lower level planning documents. A verification program overview, in flow diagram format, is included. A Verification Requirements Traceability Matrix that shows where the requirements of SS-SRD-0001, Section 3, Part 4.1; Master Verification Requirements, General Verification Program Requirements have been addressed in the STVP is also included as an appendix in this volume.

An additional feature of the STVP is the initial structuring of a WP-01 Verification Analyses Plan. This initial plan which is considered an important part of the verification process is included as an appendix to Volume 1 and is further expanded in each element level volume.

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.

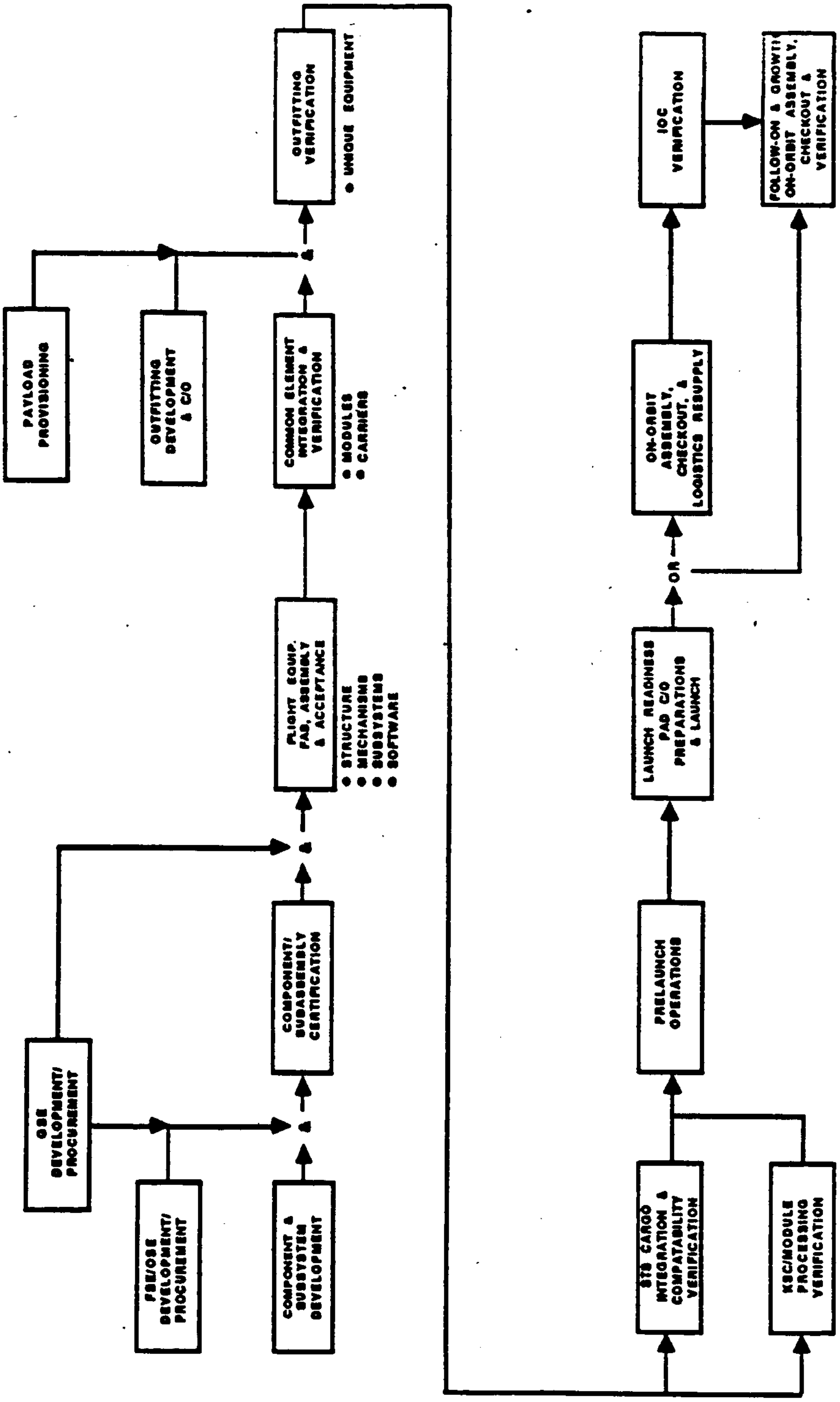

FIGURE 2.2-1 WP-01 ELEMENTS TEST & VERIFICATION FLOW

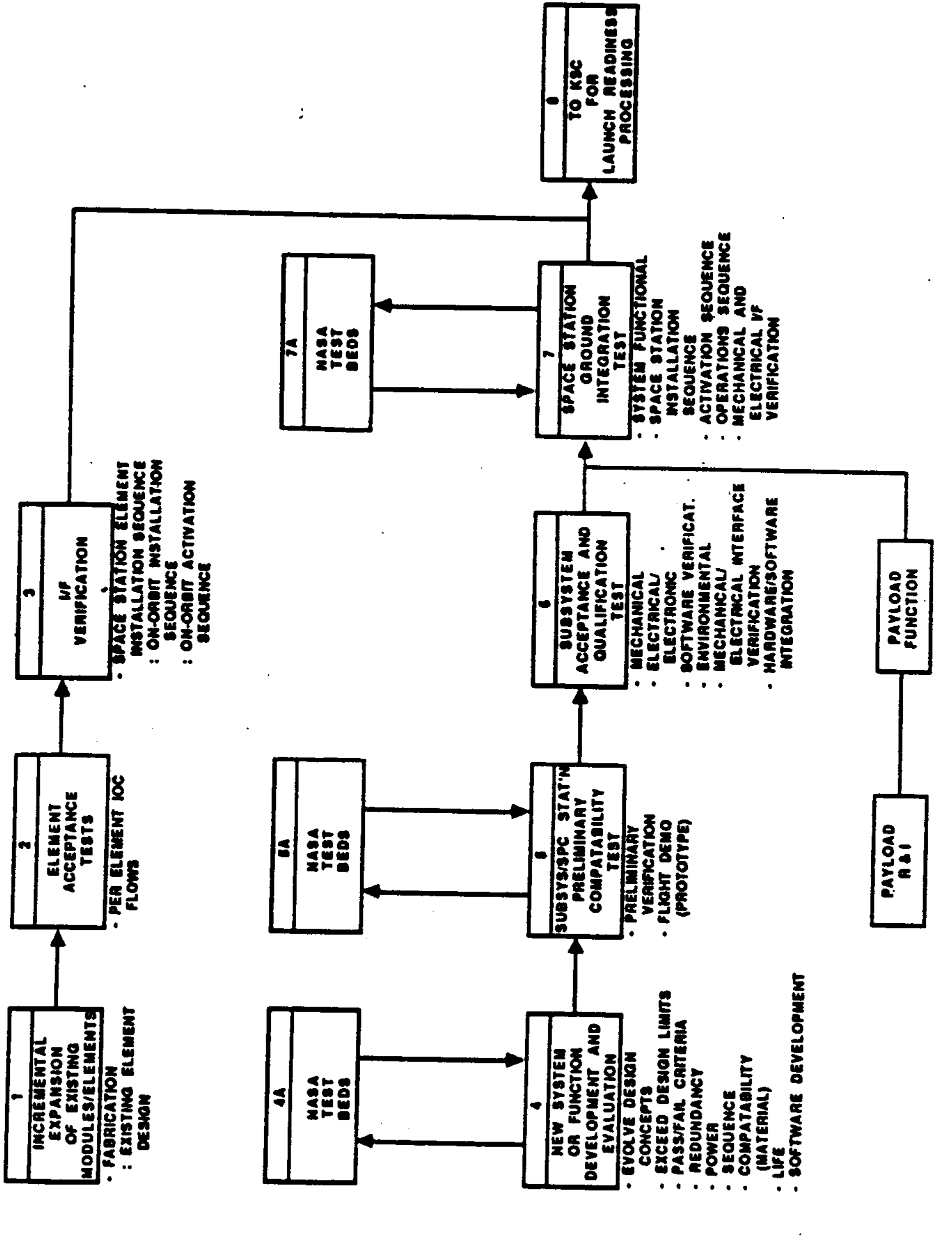

FIGURE 2.2-2 FULL OPERATIONAL CAPABILITY (GROWTH PLAN)

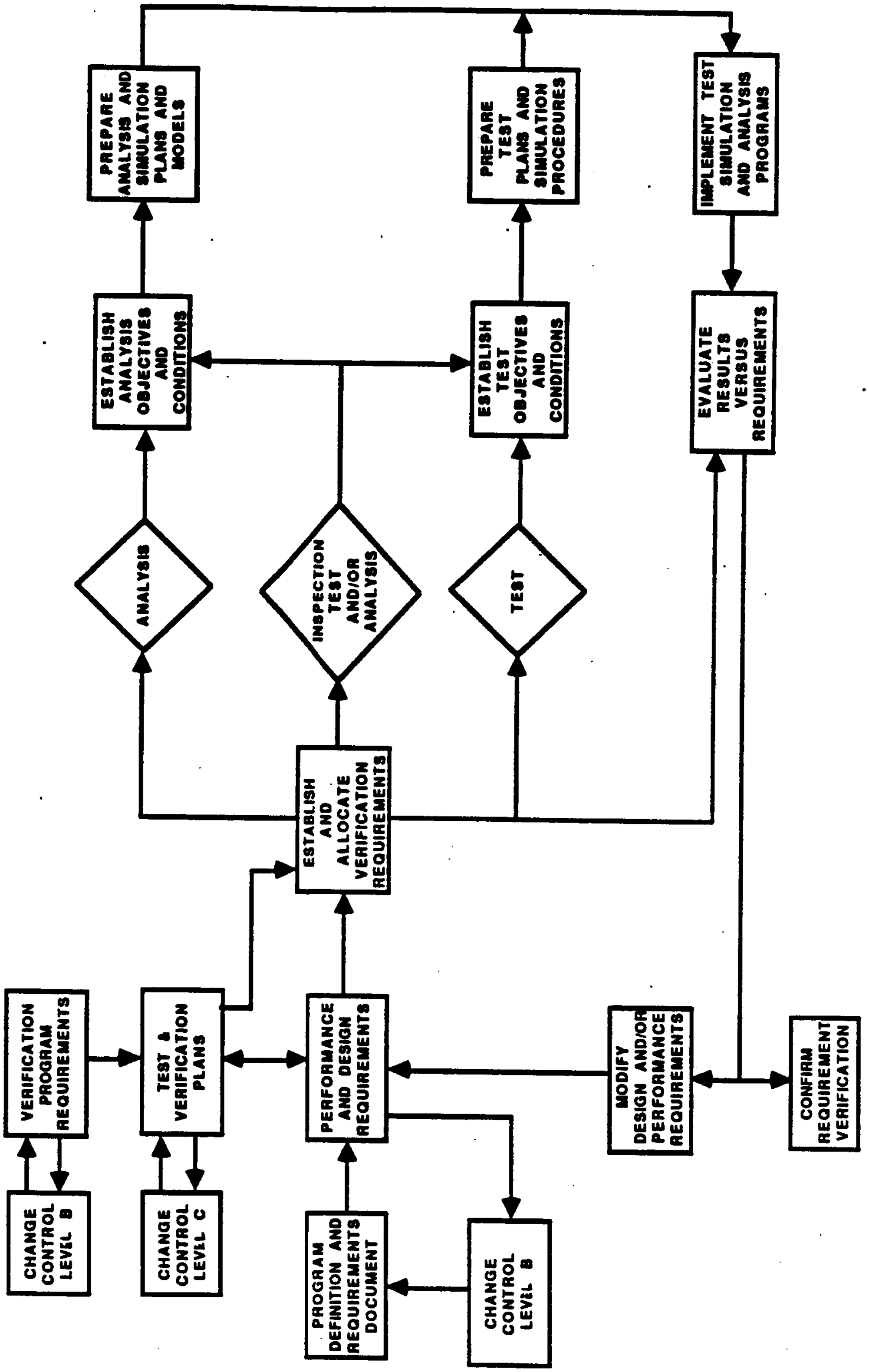

FIGURE 2.2-3 VERIFICATION PROCESS FLOW

The basic module certification program which reflects the protoflight concept is shown in Figure 2.2-4. 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. Some of these features relate to pressure shell integrity, structural loads, external interface compatibility and interface compatibility of basic module subsystems. 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 shown in Figure 2.2-5. Volume 3 defines the delta certification and final CEI acceptance testing required. 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. A generic type flow depicting WP-01 element Launch Site Activity is shown in Figure 2.2-6 and the activity required to activate the U.S. Laboratory Module is shown in Figure 2.2-7.

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. Figures 2.2-8, 2.2-9 and 2.2-10 present higher level flows for each of these logistics end-items. 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 as shown in Figure 2.2-11.

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.

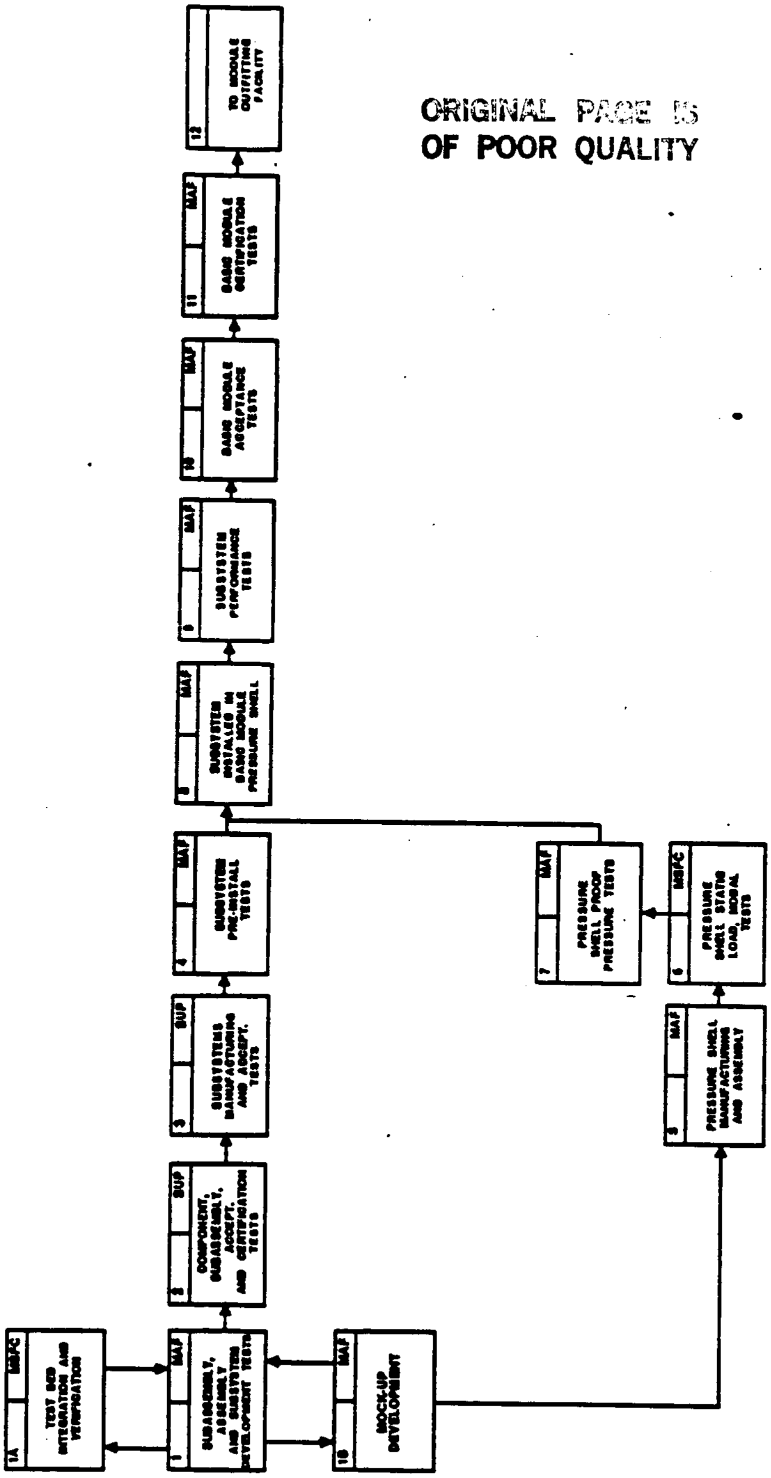

FIGURE 2.2-4 BASIC MODULE DEVELOPMENT, ACCEPTANCE AND CERTIFICATION FLOW (PROTOFLIGHT)

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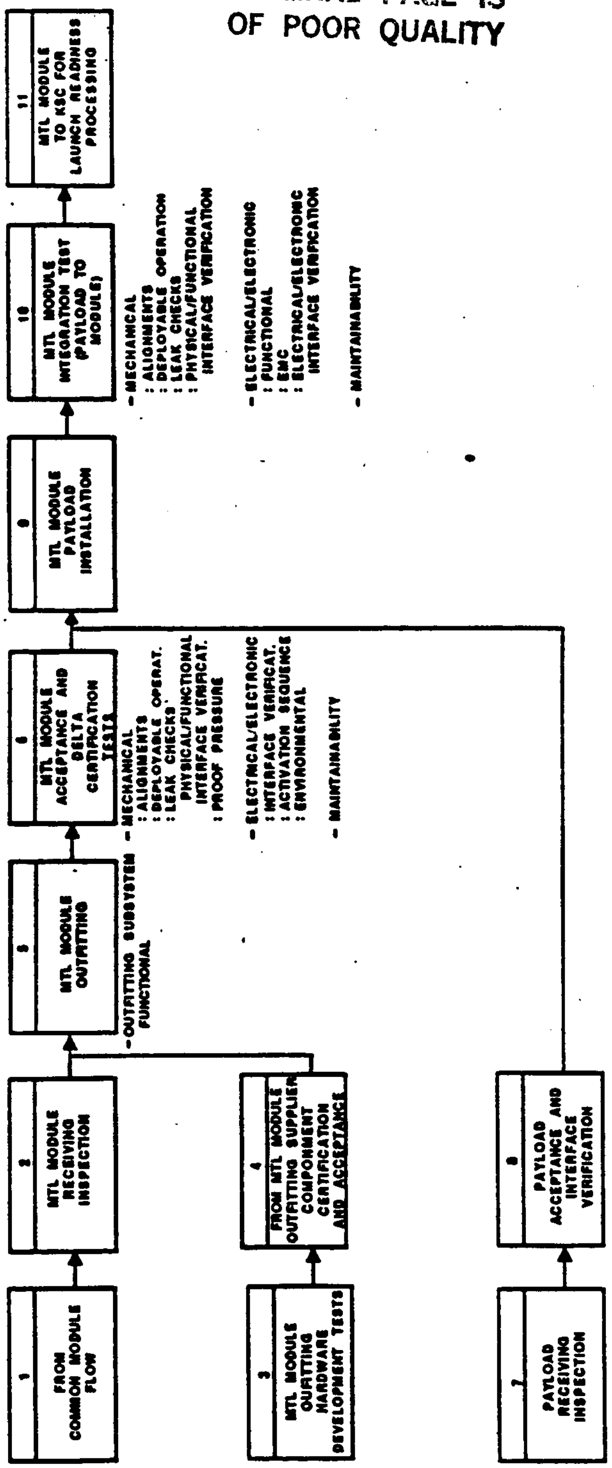

FIGURE 2.2-5 U.S. LAB DELTA CERTIFICATION FLOW (PROTOFLIGHT)

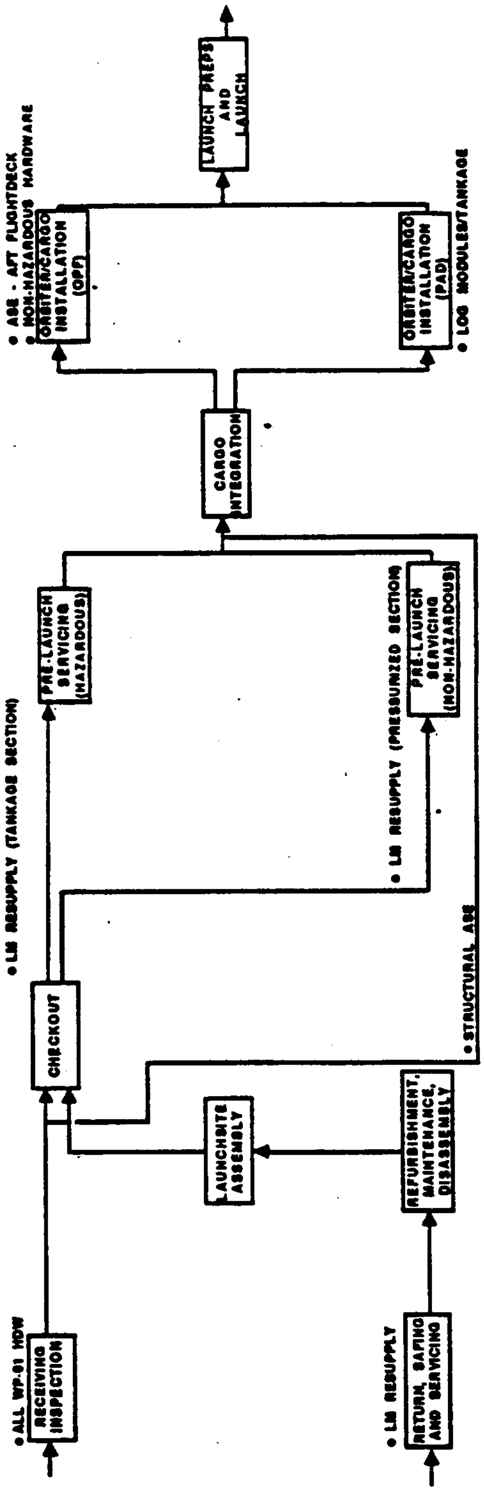

FIGURE 2.2-6 LAUNCHSITE TEST AND OPERATION FLOW

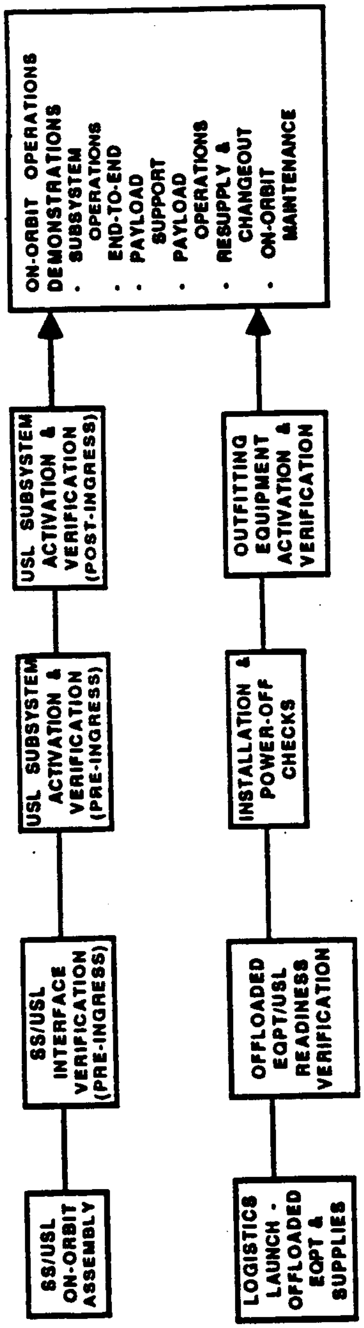

FIGURE 2.2-7 U.S. LABORATORY ACTIVATION VERIFICATION

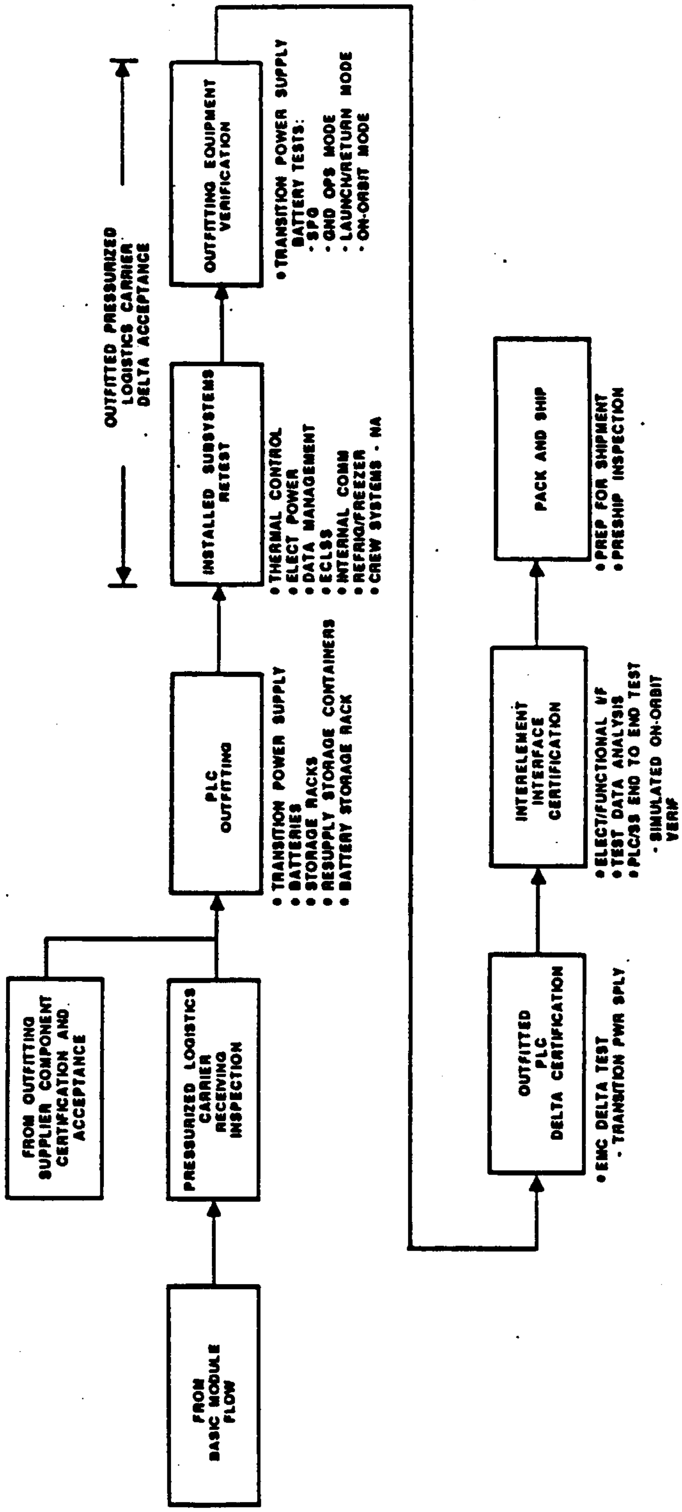

FIGURE 2.2-8 OUTFITTED PRESSURIZED LOGISTICS CARRIER CERTIFICATION FLOW

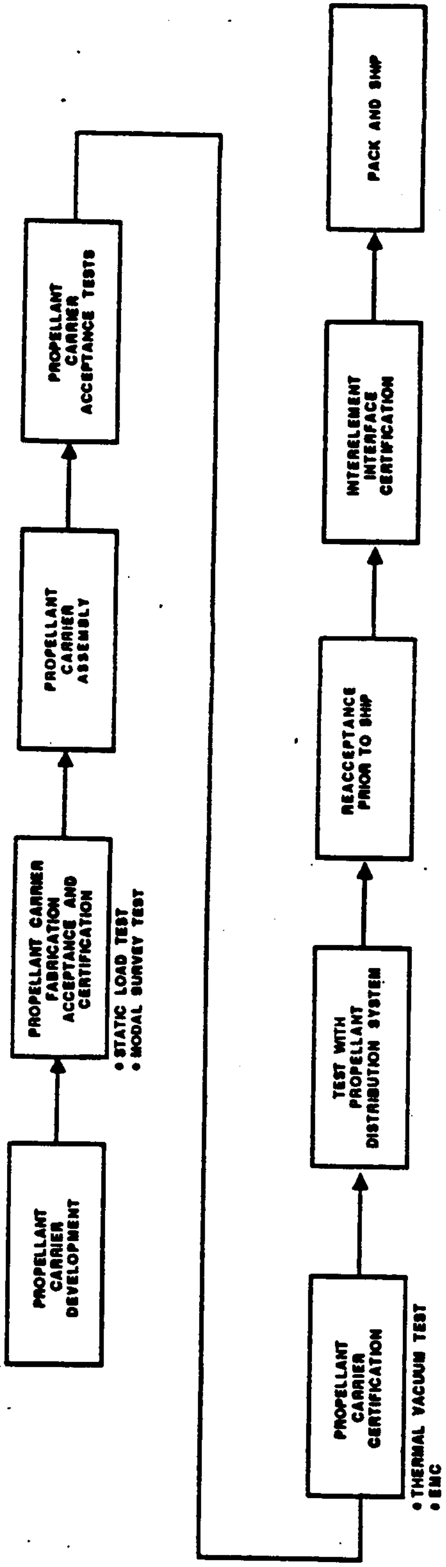

FIGURE 2.2-9 PROPELLANT/FLUIDS CARRIER CERTIFICATION

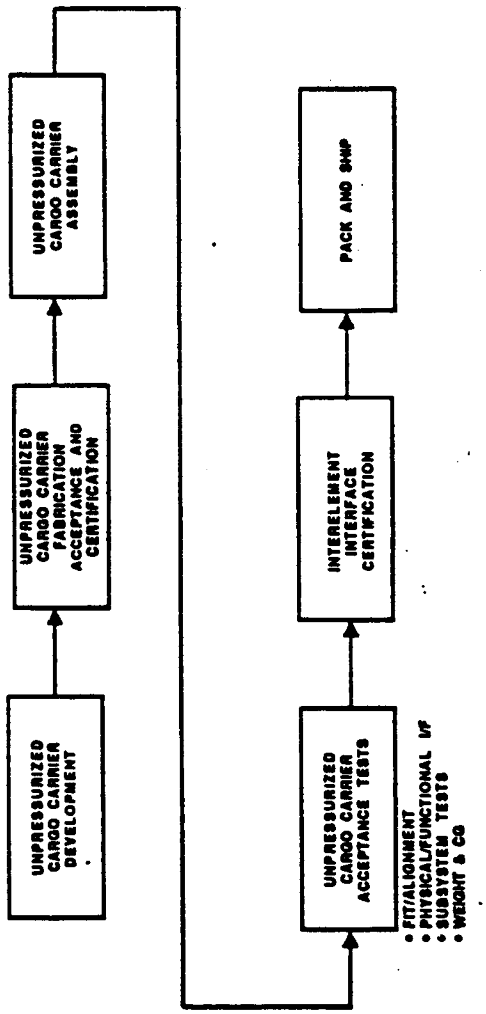

FIGURE 2.2-10 UNPRESSURIZED CARRIER CERTIFICATION FLOW

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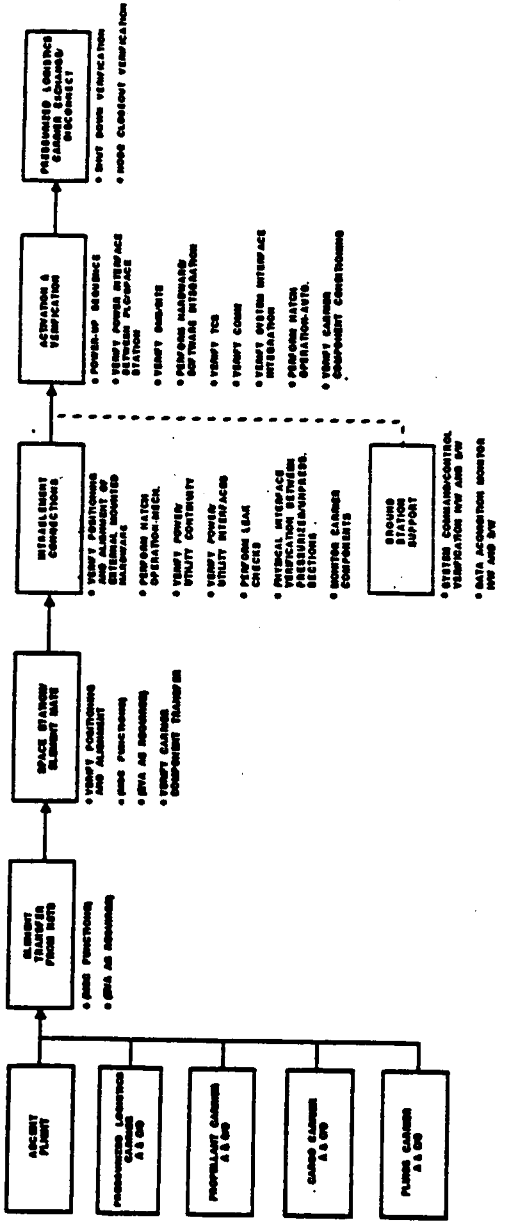

FIGURE 2.2-11 PRESSURIZED LOGISTICS CARRIER ON-ORBIT VERIFICATION FLOW

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. The ground test flow for the HM is presented in Figure 2.2-12 and the on-orbit flow in Figure 2.2-13.

2.2.7 Discontinued Test Planning

During the course of the Phase B study, Test and Verification effort was expanded on planning for Propulsion, Vehicle Accommodations, Smart Front End and Airlock elements. This activity was not fully completed when those items were removed from the WP-01 end-item list. The material that was developed was included to some extent in earlier submittals of DR-02. It is not included in DR-04.

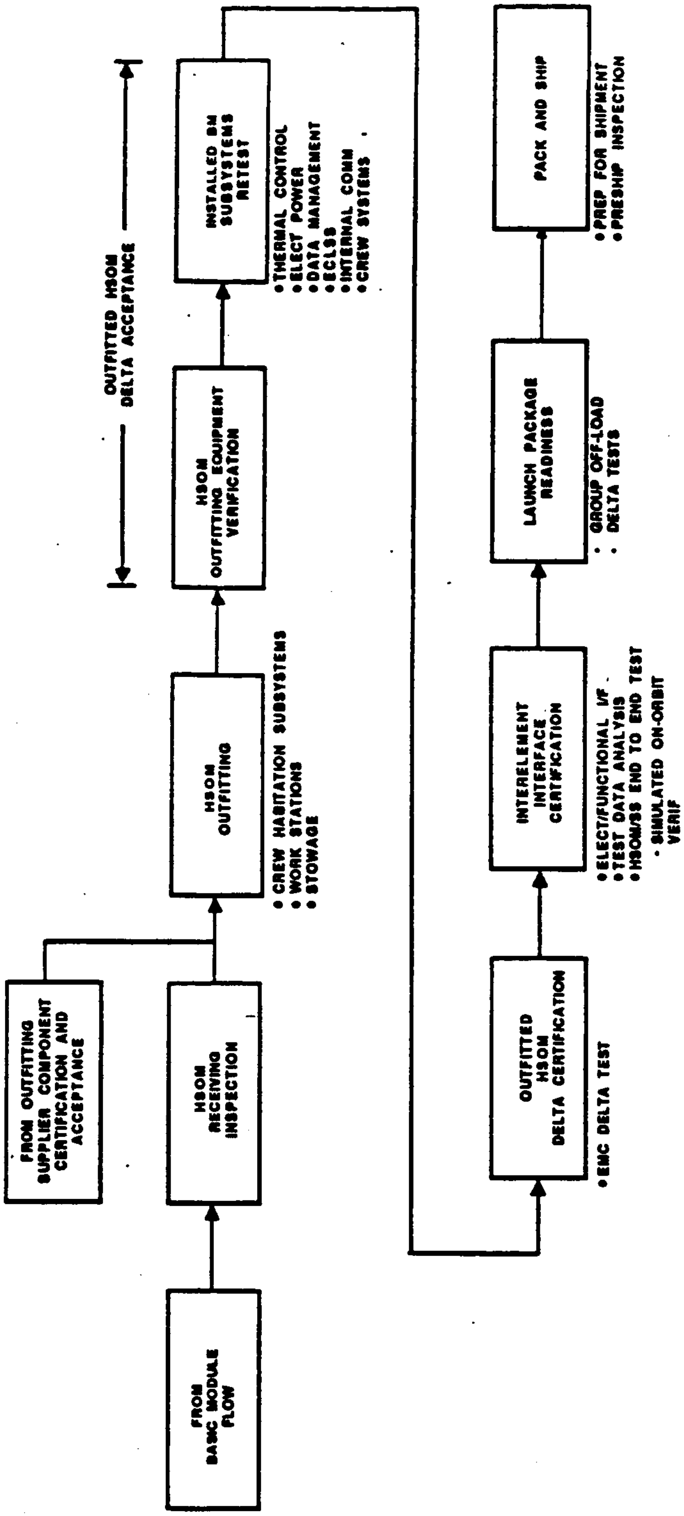

FIGURE 2.2-12 OUTFITTED HABITAT MODULE CERTIFICATION FLOW

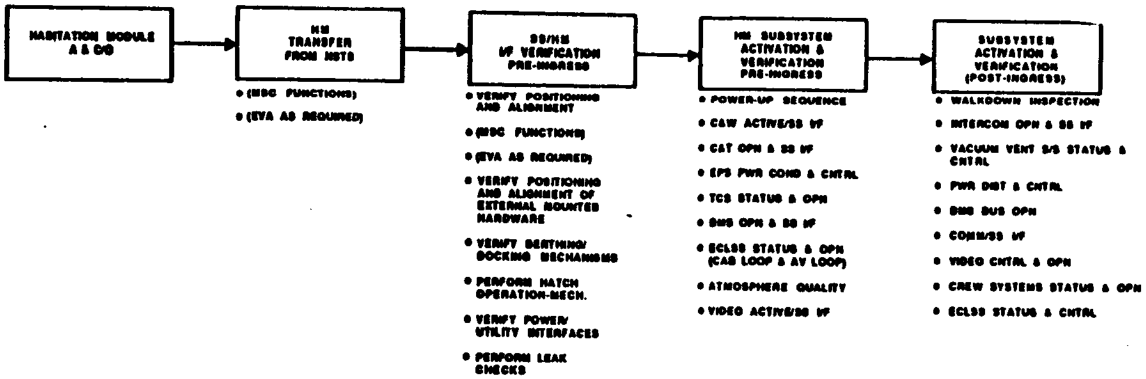

FIGURE 2.2-13 HABITATION MODULE ON-ORBIT VERIFICATION FLOW

2.3 ADVANCED DEVELOPMENT PLAN FOR THE INITIAL ELEMENTS OF THE SSP

2.3.1 Introduction

We have prepared an ADP that satisfies the requirements of DR-05 and uses our ongoing IR&D as a basis to advance key technology areas for SS applications. We are aware of the ATAC and NASA's Space Station Advanced Development Program. We will continually monitor the results and recommendations of these programs to ensure a proper focus in our advanced development activities. We are prepared to redirect our program, subject to MSFC approval, if NASA-sponsored studies or our Phase B activities identify more critical WP-01 related tasks.

2.3.1.1 Objective

The objective of Martin Marietta's ADP is to advance the selected technologies to a level of maturity during the definition phase that will provide a sound basis to begin the design/development phase of SS.

2.3.1.2 Technical Considerations

If SS construction were to proceed using only the expected technology levels of 1987, serious limitations would result in its desired operational characteristics. Our ADP pursues the development of technologies that have the dual objective of challenging the state of the art in WP-01 related generic technology areas, and enabling evolutionary growth capabilities. Our ADP will be enhanced by concurrent benefits from our IR&D work and complements NASA's Advanced Development Program in the WP-01 area. We have selected five technology areas to pursue as advanced development activities: (1) demonstration of a fluid and electrical umbilical mechanism; (2) flight demonstration of vaned fluid management system; (3) subsystem fault detection, isolation and control; (4) materials technology for long-term space applications; and (5) closed loop ECLS hardware and automation. Table 2.3.1-1 presents the technical considerations and anticipated accomplishments of our advanced development activities.

2.3.2 Advanced Development Implementation for the Initial SSP

We have developed an integrated technology plan that 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. An ADP that extends the technology levels of the IR&D tasks was prepared. 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. Our advanced development activities maintained close coordination with the NASA-focused technology studies and the results available from other NASA studies. The primary objective of our integrated technology plan is to advance the state of the art in the disciplines identified to a technology level that minimizes the cost, schedule and performance risk of the design/development phase.

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. In addition to the lab's own capabilities in electronic, mechanical, chemical and biological systems, they drew heavily on the vast scientific and engineering capabilities of the Oak Ridge National Laboratory, operated by Martin Marietta Energy Systems, Inc. for the Department of Energy (DOE).

We also maintained awareness of the total NASA program in addition to pursuing selected technology contracts to further augment the combined results of a well-integrated approach.

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.

2.3.3 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 shown in Figure 2.3.3-1 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. Particular emphasis will be given to those areas where NSTS flight opportunities can be used to validate hardware and software designs in support of advanced development.

TABLE 2.3.1-1 SUMMARY OF ADVANCED DEVELOPMENT TASKS

Technology Area	Technical Considerations	Expected Accomplishments
Robotic Umbilical Mechanism (RUM) (Electrical/Fluid)	•Required for on-board resupply of Aux Prop, OMV, OTV •Storable & Cryo Reqmnts.	• Prototype hardware • Demonstrate operation • Apply to Log Module and OMV/OTV resupply
Vaned Fluid Management Demonstration (VFMD)	• Procedures for on-orbit resupply • Demo of expulsion effic. • Fluid behavior in low - g • Acceleration effects	• Cost & operational benefits to be identified • Light weight/low-cost Manufacturing • Simplified operation
Subsystem Fault Detection, Isolation, and Control	• Expert System S/W to handle fault incl graphics interface to astronaut • Integrated sensor to support auto fault handling	• Demonstration of expert system to substitute for highly trained ground or flight crews in fault handling • Increased reliability
Materials Technology for Long-Term Space Applications - Thermal Control Coatings and Refurbishment Techniques	• Ultraviolet radiation • Atomic oxygen • Low temp radiators • Coatings refurb technique	• Devlopment of suitable performance, high integrity, resistant coatings • Refurbishment techniques for coating end-of-life
Materials Technology for Long-Term Space Applications - Module Seals Materials Evaluation	• Static and dynamic seals • Material selection criteria • Refurb techniques	• Criteria for implementtion of seal materials/designs • Preliminary test results in the combined environs
ECLS Hardware and Automation - Fecal Waste Stabilization and Processing	• Nonventing, long-term stabilization • Microbial growth control • Odor Control	• Feasibility demonstration of nonventing stabilization • Recommended bacteriostatic and odor control
ECLS Hardware and Automation - TIMES Bench Tests	• Ability to remove US Lab contaminants • Ability to handle hygiene and housekeeping effluents	• Fully characterized TIMES performance under unique SS requirements • Demonstrate contaminant removal in bench test.
ECLS Hardware and Automation - Avionics Cooling Demonstration	• Automatic control capability • No crew involvement	• Demonstrate control hardware and automation strategies in CMIS.
ECLS Hardware and Automation - 1000 psia SFSPE Upgrade	• Synergism of O2 generation in ECLS and O/H Aux Propulsion	• Upgrade SFSPE from 200 psia to 1000 psia to support use in Aux Propulsion system reducing overall cost & weight
ECLS Hardware and Automation - Two Bed Molecular Sieve	• Hydrophobic sorbent producibility, performance	• Demonstrate modified Skylab RCRS with hydrophobic carbon sorbent. • Reduced power, weight and complexity

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Assessment of technology maturity levels and WP-01 needs will define growth plan.

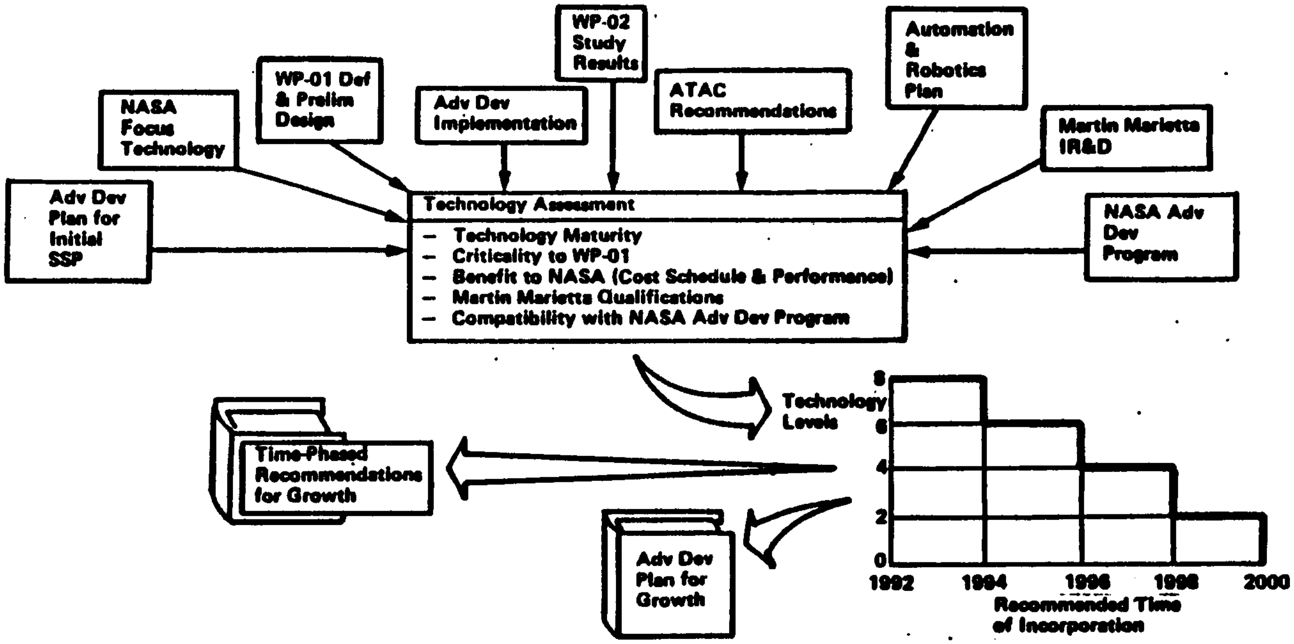


FIGURE 2.3.3-1 ASSESSMENT OF TECHNOLOGY MATURITY LEVELS AND WP-01 NEEDS WILL DEFINE GROWTH PLAN

2.4 CUSTOMER ACCOMMODATIONS

The accommodations to be provided to the Users of the United States Laboratory (USL) are described in this section, which summarizes our contract effort in this area.

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 listed in Table 2.4-1. The subgroups of these facilities that has been used for the IOC baseline are indicated by asterisks. 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 Table 2.4-2. This listing includes support equipment for both Life Sciences and Materials Technology disciplines. Performance specifications for these equipment items are defined in the Contract End Item (CEI) specification for the USL.

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. The following sections identify resource accommodations provided to the user so that scientific objectives may be achieved.

2.4.3.1 Laboratory Subsystems

TABLE 2.4-1 - MMPF STUDY USER FACILITIES

1. * Acoustic Levitator
2. * Alloy Solidification
3. Atmospheric Microphysics
4. Autoignition Furnace
5. Bioreactor/Incubator
6. Bridgman, Large
7. * Bridgman, Small
8. Bulk Crystal
9. * Continuous Flow Electrophoresis
10. Critical Point Phenomena
11. Droplet/Spray Burning
12. * Electroepitaxy
13. Electrostatic Levitator
14. EM Levitator
15. Float Zone
16. Fluid Physics
17. Free Float
18. * High Temperature Furnace
19. Isoelectric Focusing
20. Latex Reactor
21. * Membrane Production
22. Optical Fiber Pulling
23. Organic & Polymer Crystal Growth
24. Premixed Gas Combustion
25. Protein Crystal Growth
26. Rotating Shperical Convection
27. Solid Surface Burning
28. * Solution Crystal
29. * Vapor Crystal
30. Variable Flow Shell Generator

* Facilities at IOC Baseline

TABLE 2.4-2 LABORATORY SUPPORT EQUIPMENT

Recording Accelerometer Unit (3 axis)
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
Freezer
Freezer, Cryogenic (-196°C)
General Purpose Hand Tools (Including Soldering)
Glovebox
Incubator
Mass Measurement Device, Micro
Mass Measurement Device, Small
Metallographic Microscope
Microwave Steam Autoclave
Optical Microscope and Supplies
pH Meter
Refrigerator
Recorder, Multichannel (strip chart)
Sample Preparation Device, Fluid Transfer
Stereo macroscope
UV Sterilization Oven
UV/VIS/NIR Spectrometer
Work Bench
X-ray Diffraction Unit
X-ray Facility, General Purpose

2.4.3.1.1 Structural/Mechanical - The USL will provide a safe, shirt-sleeve environment for the accommodation of a payload mission complement. Provisions will be made for accommodating racks containing user payload equipment.

2.4.3.1.1.1 Rack Size - The USL is sized to accept two different size racks. For commonality with the international module, the USL will accommodate a 1892 mm x 968 mm rack. A larger rack (2032 mm x 1016 m) will also be available. A more detailed discussion of the rack configuration is given in the following paragraphs.

2.4.3.1.1.2 Rack Secondary Structure - A set of generic secondary support structure hardware will be available to adapt payload and subsystem hardware to USL racks. This will help alleviate user integration problems by providing straight forward, standard mounting options. The following parts will be included in the set.

a. A Z-bracket to bridge the gap between payload and corner post payload flange at each corner post.

b. Adapter rails which will run from front corner post to rear corner post. A pair of rails will accommodate full width payloads too deep or too heavy for a single pair of Z-brackets. All secondary structures which cross the payload volume will be supported by adapter rails.

c. Cross rails, which will support partial width equipment at varying depths.

d. Fixed shelves, which will provide support across the full width and depth of the payload volume. Partial width shelves may also be available. The USL rack shelf will provide captive floating fasteners in a square grid for equipment mounting.

e. Coldplate support structures, which will be shelves modified to accommodate coldplates and coldplate mounted equipment.

f. Pullout shelves, which will be fixed shelves mounted on drawer slides. Either a blank or a user-supplied front panel will be attached to the front of the pullout shelf for rack closeout. A locking mechanism will provide positive restraint of the drawer slides for launch and landing.

g. Drawers, in various depths.

2.4.3.1.1.3 Commonality - Because the racks must be transported to the Space Station in the Logistics Module, they must be compatible with rack mounting interfaces within the Logistics Module.

2.4.3.1.1.4 Rack Mounting/Accessibility - The USL rack will be a tilt-out design to allow fast and easy access to the payload and the interior wall of the USL. For quick installation and removal of the rack, quick connect/quick release connectors will be used. Easily removable, nonstructural side and back panels will be available for any rack requiring complete closeout for air cooling or fire suppression.

2.4.3.1.1.5 Passageways - The USL passageways will be large enough to accommodate the transfer of a double rack. The center aisle passageway measures 2134 mm (84 in.) square. The USL hatch measures 1270 mm (50 in.) square with 304 mm (12 in.) radii corners.

2.4.3.1.1.6 Interface Hardware - Resource interface connectors and mounting hardware will be standardized at each single rack location. Readily available, common hardware will be used.

2.4.3.1.1.7 Rack Configuration - The racks have optional panels to close the sides, back, top and bottom to facilitate the circulation of air flow around the rack mounted equipment for thermal control, and fire and smoke detection. Blank closeout panels will be supplied by the USL. Unique closeout panels will be supplied by the user.

2.4.3.1.1.8 Rack Loading - The load capabilities of the racks through launch and landing cycles is TBD. The USL will accommodate a fully integrated double rack weighing 590 kg (1300 lb).

2.4.3.1.1.9 Proprietary - Where required, proprietary payloads will be physically isolated by use of a proprietary curtain. Stowage containers with a securing capability will be provided for payload unique hardware of a proprietary nature.

2.4.3.1.1.10 ORU Stowage - The available stowage area to the payload user is TBD. However, current analysis indicates that adequate space will be available.

2.4.3.1.1.11 Workstations - Two workstations, a workbench and a glovebox(s) will be provided in the USL. The distinguishing feature of the USL workstations will be the presence of a specially equipped full width desk inset in the double rack. Currently, provisions for two gloveboxes, one LS, and one MPS are being studied.

The USL workbench will function as a laboratory bench, a minor payload repair facility, and a tool/supply cabinet for both MPS and LS equipment. The desk inset will provide working space for microscopy, lab work, soldering, and repair; with fire suppression and a suction vent for safety and control of fumes. A digital recording oscilloscope and a digital multimeter will be installed in the rack for electronic troubleshooting. Stowage for microscopes, tools, containers and electronic instruments will also be provided.

The USL glovebox will contain an enclosed desk insert which will utilize a liquid/gas waste handling system and an atmospheric control/revitalization system. The degree of commonality between the MPS and LS gloveboxes is being studied.

2.4.3.1.1.12 Acceleration Monitoring - Accelerometers of the required accuracy may be mounted below the USL floor. Data management provisions will be made so that payloads may receive and record necessary information. Portable accelerometers may be distributed to separate rack locations as needed.

2.4.3.1.1.13 Airlock - A scientific airlock will not be precluded from the USL conceptual design even though a payload requirement for an airlock has not been established.

2.4.3.1.1.14 Optical Window - An optical window will not be precluded from the USL conceptual design even though a payload requirement for a window has not been established.

2.4.3.1.2 Electrical Power - The USL will distribute power within the laboratory in sufficient quantities to accommodate a mission payload complement. The USL Electrical Power Distribution System (EPDS) will provide distribution and control functions for MPS payload facility, LS equipment and lab support equipment power. Each single rack will nominally be capable of distributing 3 redundant power throughout the rack via the Rack Power Control Unit (RPCU); a double rack will distribute 6 kW. Approximately seven prime double racks will provide a "high power" capability so that 15 kW of power may be distributed to these locations. The type of USL power baselined for distribution is 208V, 20 kHz, single phase AC. Standard power converters may be made available for the user to suit individual requirements. Power distribution from the RPCU to user equipment will be via user provided cable harnesses.

2.4.3.1.2.1 Circuit Protection - Facility circuit protection devices will be provided by the USL, and will be located on the USL side of the USL facility electrical interface. Users may, at their discretion, provide additional facility-internal protection devices.

2.4.3.1.2.2 Interface Connectors - Electrical interfaces will be constructed of common laboratory type hardware to the fullest extent practical in order to minimize payload refitting for the USL environment. Interfaces will be designed to minimize complexity of integration of payloads with the USL and to minimize equipment risk due to improper interfacing.

2.4.3.1.3 Data Management - The USL will provide a Data Management system to monitor and control all the subsystems of the module and perform the software control housekeeping chores for the laboratory. It will also provide monitoring, control, and data storage and transmission functions for the payload facilities.

The USL Data Management System (DMS) will be a distributed processing system which consists of a dedicated subsystem processor and peripherals which are interconnected by way of a local area network for data transfer between th different DMS elements. The payload facility to DMS interface will be accommodated by standard local controllers (LC); user-provided cable harnesses will provide the connection between the rack local controller and user equiopment. On-board data control and monitoring will be accommodated through one fixed and one portable control/display station. The fixed station will provide for the display of digital and video data through standard and high resolution display and a hardcopy printer. The portable station will provide for data display through a standard CRT readout. Data entry will be accommodated through a standard alpha/numeric keyboard, special keys, etc.

The DMS will also provide for experiment/subsystem data assimilation for up/down link communications necessary to control and monitor experiments and subsystems from the ground. Real-time subsystem and payload facility failure detection, isolation, and reconfigurations as required will be provided by the DMS to support subsystem and payload facility operations.

2.4.3.1.4 Communications System - The USL will provide a communications capability for real time transport of audio and video data and for recording, processing, and transmission at subsequent opportune times.

2.4.3.1.4.1 Video - The USL Communications and Tracking System will provide the following video capabilities:

a. Multi-channel and multi-access audio standard and high resolution color video (RS 170, 240, 330)
b. Processing, transferring, and displaying of subsystem/experiment video data within the USL, internal and external elements, and to ground stations
c. Recording and playback of video data
d. Graphics and overlay generation.
e. Scan conversion
f. Slow scan and freeze framing
g. Video compression and decompression
h. Channel selection and identification generation
i. Controls for split screening, camera operation (pan-tilt-zoon and camera selectability)

2.4.3.1.4.2 Audio

The following audio capabilities will be provided by the Communication and Tracking System:

a. Multi-channel and multi-access audio
b. Portable wireless communications units
c. Fixed speaker/microphone units in selected areas
d. Audio interfaces for orbital and ground stations
e. Caution and Warning (C&W) information to all subsystem communications equipment by general broadcast and by audio channel selection

f. Audio conferencing between orbital and ground stations
g. Recording and playback of audio signals
h. Private audio channels for crew communications between subsystem and ground stations

2.4.3.1.5 Environmental Control/Life Support Subsystem - The USL will provide a shirt-sleeve environment for the payload operation functions. This includes temperature control, humidity control, pressure level control, air quality and cleanliness control, fire detection and suppression and water recovery and management.

The major portion of the Environmental Control and Life Support Subsystem (ECLSS) will be included in the Core Module design. However, USL unique areas of the ECLSS include payload equipment air cooling duct and fan sizing, additional air contamination control and monitoring, and water services.

2.4.3.1.6 Thermal Control - The USL will provide for heat removal from the payload facilities and from the support/characterization areas.

The current deisgn concept for the USL Thermal Control System (TCS) is an internal 50 kW single-phase water loop which interfaces with external central bus heat exchangers and an external single-phase freon loop connected to MTL body mounted radiators. Waste heat acquisition from payload equipment will be by means of coldplates and heat exchangers located within the internal cooling loop. Coldplates will be provided for payload cooling. A 1.7°C (35°F) cooling loop and a 21°C (70°C) cooling loop will be available at each double rack location. Thermostatically controlled solenoid valves at each double rack location will allow cooling water to flow through the rack coldplates and heat exchangers when the equipment in the rack is activated and reaches preset temperature limits. Upon equipment deactivation the solenoid valve will close at a preset equipment temperature and prevent cooling water from flowing through a deactivated rack. Each coldplate will be capable of 1 to 1.5 kW cooling capacity.

Cooling will be consistent with 4 kW power to a single rack and 8 kW to a double rack. Cooling in high power areas will require the user to withstand the higher temperature resulting from the higher power.

2.4.3.1.7 Crew Systems - The USL will provide a safe, comfortable, convenient, environment for the on-orbit experimentation. Crew systems will provide the hardware that is required to support and accommodate the crew during USL subsystems and payload facility on-orbit operations. These items will include restraining devices, portable equipment and other crew aids.

2.4.3.1.8 Vacuum - The USL will furnish the users the capability of pump down, purge, and backfill of facility chambers. High vacuum will be provided for use in payload experiment processes. The vacuum system design will satisfy the available payload requirements for 1×10^{-3} Torr. 1×10^{-8} Torr can be achieved by augmentation from turbo molecular pumps.

2.4.3.1.9 Process Materials Management Subsystem - The Process Materials Management Subsystem (PMMS) is responsible for two major USL services. First, it provides storage and distribution of USL process fluids. Second, it provides safe handling removal, storage and disposition of USL payload waste by-products.

2.4.3.1.9.1 Types of Processed Fluids - The Processed Fluids Supply (PFS) will provide storage and distribution only for those fluids which are required in sufficient quantities by several users to justify their being provided as an USL resource. These fluids include GN_2, GO_2, He, GH_2, Ar, CO_2, H_2O, and pyrogen-free H_2O. Other fluid groups such as etchants, solvents, and fuels which are required in smaller quantities or by single users are considered to be user supplied.

2.4.3.1.9.2 Waste Handling - The Process Waste Handling (PWH) will receive gaseous, liquid and solid waste from MPS and LS equipment, lab equipment, and processes including a laminar flow workbench, fluids and particulate glovebox, emergency shower, and eyewash. The PWH shall provide the capability of phase separation of these wastes where applicable. Waste products which are compatible with the PMMS are TBD.

2.4.3.1.9.3 Pyrogen-Free Water - Potable water will be stored on orbit and be diverted to a pyrogen-free processor and/or regular distribution system as needed. Special provisions will be made to prevent the pyrogen-free water from becoming contaminated in the distribution lines between usage cycles.

2.4.3.1.9.4 Fluid Distribution - Water, nitrogen, oxygen, argon and helium are plumbed directly from storage to each double rack interface panel. Carbon dioxide and portions of argon and helium are supplied from Portable Pressure Vessels (PPV), which are plugged directly into the user equipment.

2.4.3.1.9.5 Cryogenics - The cryogenic system concept uses cryocooler units driven by pressurized working fluid delivered to the user via subfloor mounted hardlines. The subfloor hardlines carry both the compressed user interfaces with the cryogenic system at the rack interface panel and provides their own cryocooler unit at their equipment interface. Therefore, the user could customize his cryogenic application; e.g., if the user requires LN_2 he would produce LN_2 by acquiring GN_2 from the process fluid supply subsystem and producing LN_2 with their specially designed cold head.

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. The life cycle steps were discussed in detail as to the description of the task, the approach used to perform the task, subtask descriptions and the tools necessary to perform or support the task. Areas were pointed out where commonality between the ground and onboard life cycle steps allowed for common or subset implementations of tasks. In turn the same tool may be used for many different life cycle tasks and a matrix was provided to show the cross references between tasks and tools. Within the text all tools described were referenced as generic tools without mention of commercially available tools that meet the requirements. 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. Since the requirements for tools were identified according to the life cycle steps a schedule for when the tools were needed was easily specified and tagged to software life cycle milestones.

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. Several languages were considered and evaluated against a range of criteria including basic issues, software life cycle considerations, and language considerations. The Ada programming language scored the highest in the evaluation with PL/1 and C as close contenders. Although Ada was recommended as the applications programming language several 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. This trade was limited to only those systems which were available and in use currently. We anticipate that several systems will be available in the near future or that a customized system may be necessary to satisfy all the requirements.

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 models included in the study were the relational, heirarchical and network. The relational model was recommended; however, a DBMS that could interface with other DBMS of different model implementations would be the most ideal to accommodate the various data bases to be used on the project.

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.

2.6.1.1 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.

2.6.3 Plan Principles and Strategies

2.6.3.1 Principles

This section presents the top-level principles and an integrated implementation strategy which scopes and directs the planning, design, and implementation efforts to ensure compliance with overall goals and an efficient use of available resources.

Maximum technology exploitation requires the use of existing technology and the accurate prediction of future technology evolution. All IOC designs will use as much mature A&R as technology will permit, while not precluding growth. A&R must interface functionally with elements of the station in much the same manner as the crew. Increased safety, relief from drudgery, increased productivity, improved reliability, and greater autonomy are the key benefits of A&R. However, the crew must retain the capability to monitor the A&R systems performance and override them, if necessary.

The FOC station will achieve a very high level of advanced automation. To achieve this goal, the station designs will provide the hardware "scars" and software "hooks" that ensure the greatest possible flexibility in growth. The extensive A&R implementation has distinct cost benefits in increased productivity and lower cost of operations through increased autonomy. Nevertheless, A&R implementation must still recognize the "real world" design-to-cost constraints. Planning for A&R must recognize that while A&R costs are "up front", A&R benefits are distributed over the station life. Risk minimization applies in two areas; minimizing risk in station operations through the use of A&R and minimizing risk in the A&R technology development itself. Use of A&R to minimize station operating risks and to perform hazardous tasks will increase space station reliability and decrease its operating risks. Selection and implementation of appropriate levels of A&R will minimize overall system risks.

2.6.3.2 Strategies

A thorough discussion of strategies must include some statement of the resources to be employed. The approach here, as seen in Figure 2.6.3.2-1, was to use the considerable experience of the many subsystem design personnel on the program to develop the subsystem designs and for them to be guided by a dedicated team of A&R specialists, who possess considerable knowledge concerning advanced automation and robotics technologies. This technique maximizes the strengths of each select group while minimizing their individual weaknesses. Each A&R "expert" consults with their individual subsystem design counterpart for candidate identification and concept design particulars. They analyze the hardware and software requirements and apply the candidates to other subsystems as resources permit.

The first step is to develop the FOC station A&R posture then work back to the IOC configuration in manageable growth steps. Each of these steps are characterized by "scars" and "hooks" which provide the space either in hardware or software for future implementations. Additionally, the effort focuses on subsystems/elements for which the Work Package interfaces are high in control heirarchy and advanced automation studies are supported by IR&D and ADP efforts.

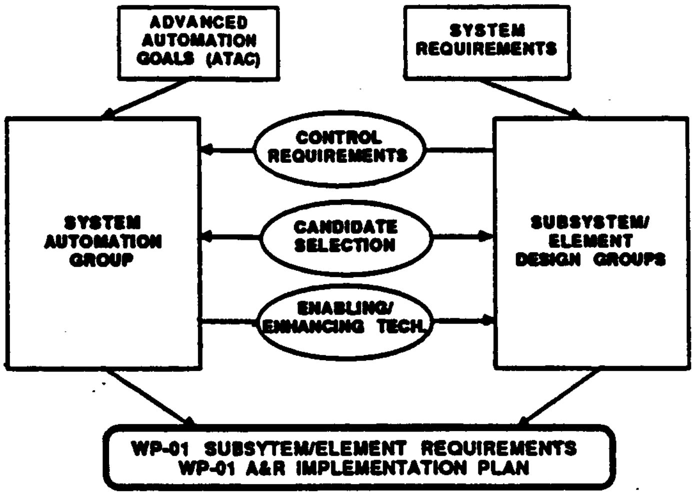


FIGURE 2.6.3.2-1 DESIGN GROUP INTERACTION

2.6.3.2.1 Target Subsystems

2.6.3.2.1.1 ECLSS

An initial effort in the area of ECLSS was to identify a station-level control interface with other Work Packages. Hamilton Standard has planned advanced automation for ECLSS at IOC and at growth stages.

2.6.3.2.1.2 CM/PMAD

The Common Module/Power Management and Distribution (CM/PMAD) subsystem is being developed around advanced automation techniques. Functional partitioning is complete, which identifies functions appropriate for advanced automation application. IR&D effort has analyzed system and subsystem level partitioning, i.e. the WP-01 and WP-04 interface. Additional IR&D effort is under way to design the appropriate subsystem components.

2.6.3.3 Approach

The study flow currently being followed is shown in Figure 2.6.3.3-1. As indicated, this flow schematic depicts the four major parts of the EMS strategy theme S2.1, Automation and Robotics, along with many of the subtasks within each part and their interrelationships.

In the initial part of this effort (A&R Candidates Development), a quick look approach was pursued in which a number of candidate A&R functions were identified using prior studies and experienced personnel. These candidate A&R functions were evaluated against various levels of selection criteria to identify performance efficiency, productivity benefits, technology readiness

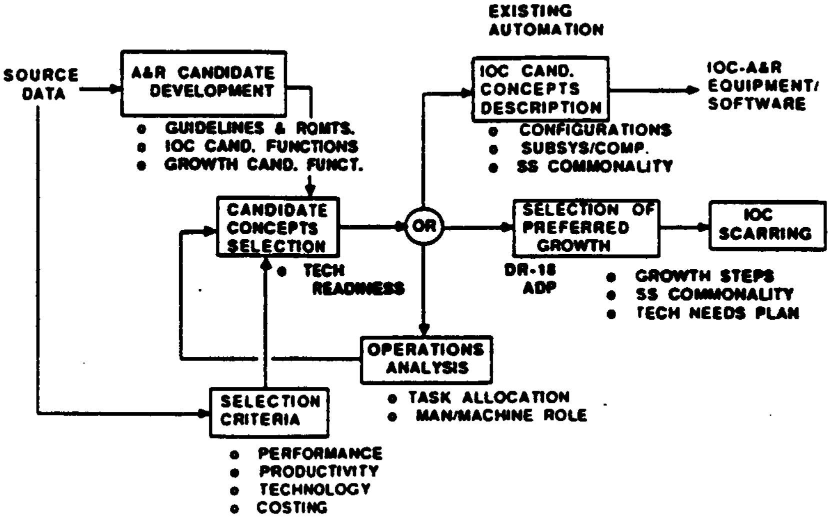


FIGURE 2.6.3.3-1 A&R PLAN APPROACH

and cost impacts. At this point, a Space Station operations analysis loop was included to verify specific Space Station operations scenarios as they apply or impact potential candidate concepts. After this step, the selected A&R concepts were separated into those recommended for IOC, for growth or for more analysis. This last part of the flow process was to define growth concepts to a level necessary to scope the type and complexity of scars and hooks that should be implemented on the IOC to accommodate future growth.

2.6.4 Implementation Plan

2.6.4.1 Introduction

The Automation and Robotics Plan embodies a time-phased, detailed functional view of the use of automation and robotics on the evolving Space Station not only to maintain an optimal partitioning of man and machine roles at each stage of evolutionary growth, but also to identify those Space Station systems that represent the best opportunities to advance automation and robotics technology both to persistently promote productivity on the Space Station as well as to enhance the national scientific and technical base in these important areas.

2.6.4.1.1 Assumptions and Guidelines - The guidelines and assumptions listed in the plan have been selected and extracted from other relevant documents. A majority of those listed were taken from the NASA Advanced Technology Advisory Committee (ATAC) report as being the more pertinent ones for automation and robotics.

2.6.4.2 Candidate Selection Evaluation and Technology Assessment

2.6.4.2.1 IOC Candidate Selection Criteria Development - ATAC indicated that the criteria for Space Station use of projected new technologies should focus on measurable issues such as productivity and annual operating costs, and on potential benefits such as the merits of transferring space A&R technology back to terrestrial applications. To do this requires logical approaches to developing task problem definitions, preparing functional flows, and allocating functions to humans and automation.

The following is a list of considerations for developing selection criteria.

- o Man/Machine role
- o Automation and Robotics role
- o Specific role of AI and Expert Systems
- o Alternate concepts evaluation criteria

2.6.4.2.1.1 Criteria Development - Function allocation strategies, to be effective, must include not only the capabilities and limitations of humans and machines, but also the adaptability, reliability, and cost effectivity with both automation and human components.

2.6.4.2.1.2 Criteria Implementation Process - An eight-step process is shown in Figure 2.6.4.2.1.2-1 and used to define the problem, establish and weight the selection criteria, perform a comparison analysis, identify and evaluate alternative solutions, assess risk, and select preferred candidates. The emphasis on this effort is to focus on the problem set and identify, classify, define, and prioritize those selection criteria across the various roles.

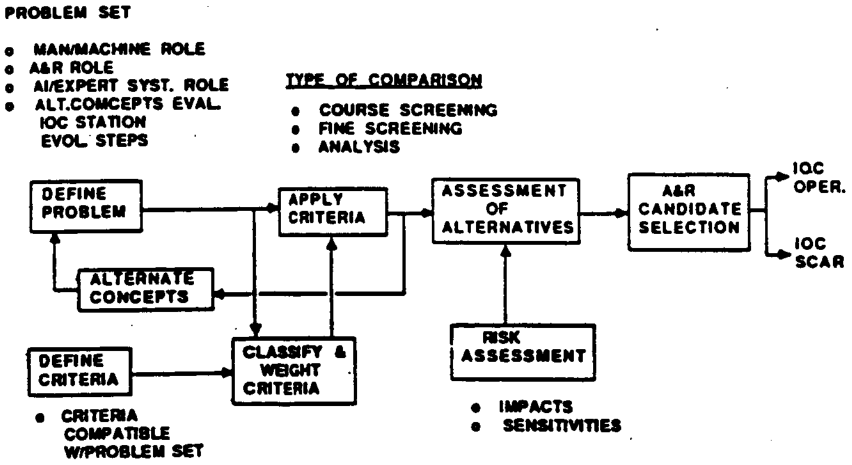


FIGURE 2.6.4.2.1.1-1 CRITERIA IMPLEMENTATION PROCESS

2.6.4.2.1.3 Man/Machine Roles - Consider task functions for automation that display the following characteristics:

- High perceptual saturation
- Time, consuming, boring, or unmotivating tasks
- Tasks with concurrent event activities
- Tasks with compressed timelines
- Large memorization requirements
- Laborious activities
- Many time critical sequences
- Tasks having time-to-complete constraints
- Emergancy-Prevention functions (Fail-Safe Fail-Operational)*
- Complex mathematical or logical analysis required
- High potential for dangerous elements
- Intensive data handling rates

Ref: Van Cott and Kinkade, 1972

2.6.4.2.1.4 Automation/Robotics Role - Factors to be considered during the automation vs. robotic determination are summarized below:

- Task concentrated or distributed

- Task functions embedded in existing system/subsystem

- Mobility required

- Manipulation required

- What type of sensors required

- What human interactions are eliminated

- Task physical or "mental"

2.6.4.2.1.5 Criteria for Applying Artificial Intelligence/Expert Systems - One of the more visible and successful technologies to emerge within AI is Expert Systems (ES). Expert Systems show promise of providing a new dimension: the power to solve problems, in well focused areas, that normally only an expert with on-the-job experience can resolve. However, expert systems are expensive and require time to develop. In addition, no established methods are available for verification and validation. Figure 2.6.4.2.1.5-1 represents a first cut at developing criteria for the application of AI/ES.

2.6.4.2.1.6 Concepts Evaluation Criteria - The criteria selected to identify the preferred A&R concepts includes a top level set of five major comparison parameters, ie, performance, productivity, risk, cost, and programmatics. An expansion of this criteria to identify the next level of discriminators has indicated 18 such items that have roles in defining an optimum system.

AUTOMATION

←→

CONVENTIONAL (HARD)	ADVANCED (INTELLIGENT)
QUANTITATIVE-STATIC, INFLEXIBLE FIXED FUNCTIONS STRUCTURED ENVIRONMENT SEQUENTIAL/REPETITIVE CALCULATIONS	QUALITATIVE-DYNAMIC, FLEXIBLE AND MAY LEARN FROM EXPERIENCE UNSTRUCTURED ENVIRONMENT CREATIVE REPRESENTATION OF DATA STRUCTURE
LOW LEVEL CONTROL (SENSORS/ACTUATORS) PRE-DEFINED/MODELED DETERMINISTIC, GOAL ORIENTED	HIGH LEVEL CONTROL (SUPERVISORY) HEURISTIC/HIGH ORDER PRINCIPLES OPPORTUNISTIC GOALS (NOT KNOWN A-PRIORI)
VARIABLES WITH CONCISE RANGES SMALL FACTUAL DATA BASE	DYNAMIC/ACTIVE VARIABLES LARGE DYNAMIC DATA BASE
COMPLETE/CONCISE DATA AVAILABLE	DATA IS VAGUE, AMBIGUOUS OR INCOMPLETE
HANDLING OF SINGLE FAULTS REQUIRES COMPLETE/FACTUAL RESULTS	HANDLING OF MULTIPLE/CAUSAL FAULTS REQUIRES EXPLANATION & POSSIBILISTIC RESULTS

FIGURE 2.6.4.2.1.5-1 CRITERIA FOR APPLYING AI/EXPERT SYSTEMS

Alternate Concepts Evaluation Criteria

Performance	o Weight/Volume o Accuracy o Flexibility o Contamination	Derived from various levels of program requirements (facility), also, services required for user accommodations.
Productivity	o Human Timelines o Automation Mode o Commonality	Driven by human requirements on time and the split of time between onboard or on ground
Risk	o Technology Read. o Critical Failures o Schedule Risk o Cost Sensitivities	Driven by system configuration, maturity,complexity, and amount of preflight testing
Costs	o DDT&E o Life Cycle Cost	Largest cost driver in front end includes qualification
Programmatics	o Safety o Program Policy o Customer Rqmts Reliability/Maintainability	Driven by prior space programs and mission objectives

2.6.4.2.2 Technology Assessment Summary - During the past two decades aerospace was considered to be the leading edge for technology in areas such as miniaturization, materials science, information handling, component and system reliability enhancement, high performance to weight ratio equipment design, and so forth. However, over the past few years there has been a world-wide renaissance in the area of information handling and associated peripheral technologies. Major examples include: microprocessors, CAD/CAM/CIM/CAE, microelectronics, robotics, artificial intelligence, and biotechnology. These rapid advancements in technology require the aerospace community to prepare to jump to the new, more efficient technologies or find themselves with antiquated methods and capabilities and with fewer qualified hardware/software suppliers. The plan includes an extensive assessment of A&R technology.

2.6.4.2.3 A&R Selection Trade Results - In order to assess candidate A&R concepts major A&R issues were identified, normalization of comparison data was discussed, and the various key trade studies were identified. The candidate functions derived have been compared to the selection criteria developed. The results of this synthesis are the automation and robotics concepts shown in the plan.

Before detailed concepts can be formulated involving new automation and robotic approaches, the issues appearing below must be considered.

a. Level of A&R applied at IOC
b. Feasibility of evolutionary growth stages
c. Hard (traditional) vs flexible (intelligent) automation
d. Productivity and safety
e. Ground vs on-orbit hardware and software location
f. User accommodations applicability
g. Reliability and maintainability
h. Technology readiness and projected development needs
i. Costs

2.6.4.2.3.1 A&R Commonality Summary and Task Characterization - Once initial candidate functions were identified by subsystem and element, they were organized. Once this was accomplished, these lists were combined and their characteristics were defined and shown in Figure 4.2.3.1-1 which categorizes each function by physical and "mental" attributes. Additionally, each characteristic was factored as to playing a primary or secondary role in each functions accomplishments. Further, these data were screened for common characteristics in order to define "hard" and advanced automation and robotics tasks. The results are reflected in Figure 2.6.4.2.3.1-1 which shows both types of automation candidates plus the robotics candidates.

2.6.4.3 Evolutionary Growth Summary

2.6.4.3.1 Growth Philosophy - The ultimate goal of station evolutionary growth is to create smooth transitions for each growth step as capabilities and productivities expand. Current projections forecast increased amounts of payload and experimental activities in the years following IOC. The automation approach to expansion and growth is to apply increasing amounts of A&R to operational activities thereby increasing each crewmembers productive span control. The result of this approach is to increase station productivity while minimizing or possibly eliminating a need for crew size growth. In this approach major physical growth is achieved through addition of laboratory modules or co-orbiting platforms.

COGNITIVE TASKS	PHYSICAL PLUS COGNITIVE COMBINED	PHYSICAL TASKS
"Advanced Automation"	**Robotics**	**"Hard Automation" (Conventional)**
1.Intelligent Monitor and Recorder		1.Monitor and Inspection
2. Built-In Tester		2.Module/ORU Changeout
3.Intelligent Computer Aided Instruction (ICAI)		3.Refuel, Umbilical Connect/Disconnect
4.Fault Prediction/FD/FI Controller →	FD/FI	← 4.Fault Diagnosis (Trans)
5.State Estimator (Housekeeping/Statusing)		5.Status Assessment
6.Event Previewer	Robot Servicer	← 6.Gofer Robot, Free Flying/Mobile (EVA/IVA)
7.Software Application Generator	Robot Servicer	← 7.Pressure Leak Detect and Repair
8.System Reconfiguration Manager		8.Structural Member Repair
9.Atmosphere Manager →	Atmos. Mgmt.	← 9.Contamination Detect, Isolation, Warn & Remove
10.Inventory Management →	Inventory Mgmt.	← 10.Inventory Management Robot
11.Audio Distribution Scheduler		11.Fluid Spill/Leak Handling/Cleanup
12.Thermal Load Management		12.Equip Exchange (Raditators, Solr Panels)
13.Waste Material Sizing →	Waste Mgmt	← 13.Waste Collection/Processing
14.Maintenance Scheduler →	Maintenance	← 14.Maintain/Repair Common Equipment (Mobile)
15.MTL Experiment Scheduler		15.Hazardous/Toxic Material Handling
16.Resource Management	Robot Servicer	← 16.Instrument Calibration
17.Intelligent C/O &Diagnosis Unit		17.Isolation Area Caretaker
18.Trend Analysis →	Trend Analysis	← 18.Trend Analysis
19.Station Safety Advisor →	Safety Monitor	← 19.Safety Monitor/Crew Alert
20.Data Base Manager		20.Arm/Disarm Explosive Devices
21.Spacecraft Refueling System →	Fuel Servicing	← 21.Mobile Services Supply (Elec,Gas,Fuel)
	Maintenance	← 22.Contamination Cleanup (Vents/Surfaces)
	Exper. Aide	← 23.Experimenter Aide
	Robot Oper.	← 24.Intelligent Robotic Operator/Maintainer
	Lab Tech.	← 25.Specimen (Animal) Handling/Removal
		26.Material Handling/Transfer (Parts, Trash)

FIGURE 2.6.4.2.3.1-1 A&R TASK COMPARISON

2.6.4.3.2 Growth Steps Definition - The objective of the A&R program relative to WP-01 is to exploit the potential of artificial intelligence and robots to decrease the cost of ground control, acquisition and number of growth elements, and increase the productivity and safety of space operations. The program has two major thrusts, system automation and robotics. Each has a logical sequence of integrated evolutionary capabilities from 1994 to 2005.

2.6.4.3.2.1 Subsystem Automation - The evolution of automation technology will enhance the capabilities of onboard subsystems to manage themselves thus lowering the level of support required from both crew and ground personnel. The station must accommodate both new computer hardware and software in order to capitalize on the support capabilities of advanced automation. As a result of the relative ease with which new technology can be exploited in ground-based development systems, the precise configuration of the initial stage of Space Station control implementation will depend on the assumed progress of automation technology up to PMC. The onboard portion will, of course, be constrained to technologies proven several years in advance of PMC (Phase C). The advanced automation technologies incorporating expert systems in planning and advisory roles would be under development on the ground on machines optimal for such development efforts.

Ground personnel will have primary responsibility for monitoring station systems and for all planning and scheduling except on the next shift activity timescale. Crew personnel will perform monitoring and control, maintenance and servicing and payload operations. Until automation applications are sufficiently mature that their presence on orbit enhances station productivity, they should remain on the ground. The rate at which applications can be developed to the point of onboard test may be significantly increased through use of high quality ground simulation facilities.

The next logical step will be to host the various advanced automation applications on their target architectures. The expertise gathered from station operations during the initial development phase will be incorporated into these systems.

Onboard or ground implementation of high level control and planning can be expected to dramatically shift the Station Specialist time allocation toward payload activities and to shift ground personnel toward supervisory monitoring and extreme contingency operations.

2.6.4.3.2.2 Automation of Robots - In the PMC, the automation of robotics will be limited to low level manipulator control. The initial PMC configuration of the Smart Front End will use a teleoperation control mode. Ground control of the telerobot will relieve the station crew of the requirement for teleoperation during external repair and inspection missions. As technological advances in vision processing and planning occur, robots directed by the Space Station control system will enhance crew productivity by performing routine internal maintenance tasks such as filter changeout and materials transport. The capability for routine and non-routine repair will also decrease the time crew members must devote to maintenance and servicing.

The Smart Front End (SFE) being developed for robotic use is a flexible, dexterous manipulator system which will be designed to function as a human analog, capable of performing many tasks. The SFE is also an example of a robotic system which will continuously evolve in ability and artificial intelligence. The intelligence evolution of the SFE is shown in Figure 2.6.4.3.2.2-1.

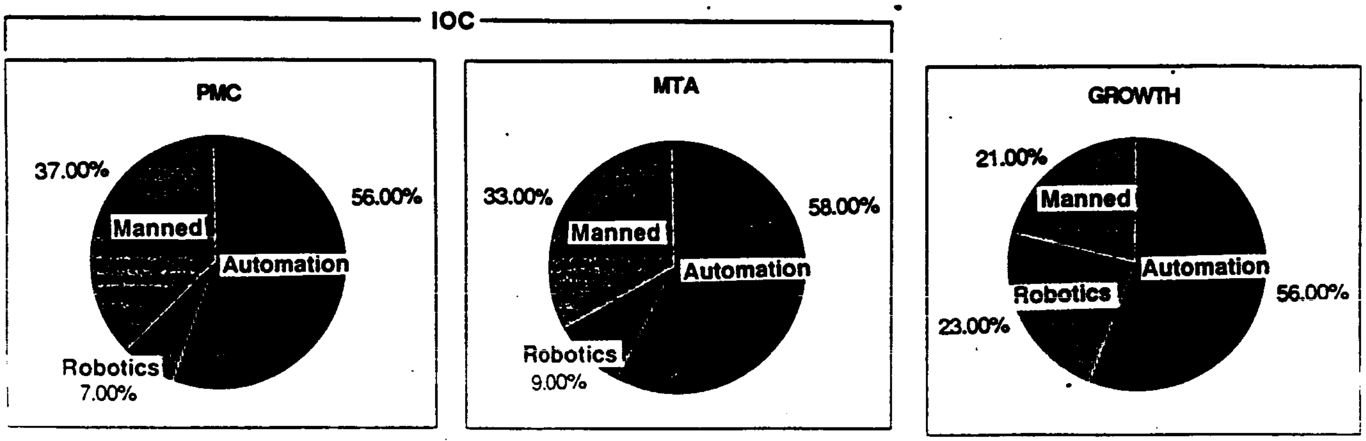


FIGURE 2.6.4.3.2.2-1 POTENTIAL FOR A & R AND MAN IN THE PERFORMANCE OF MTL TASKS DURING PMC AND GROWTH

Figure 2.6.4.3.2.2-2 shows the growth of robotics by reflecting increases in Telerobotic Systems (TS), Fluid Resupply System (FRS) and control evolution. Each additional robotic device increases station capabilities, while each evolutionary step in control technology will enable the TS to perform more autonomously further increasing station productivity by relieving crew members of robotic control tasks.

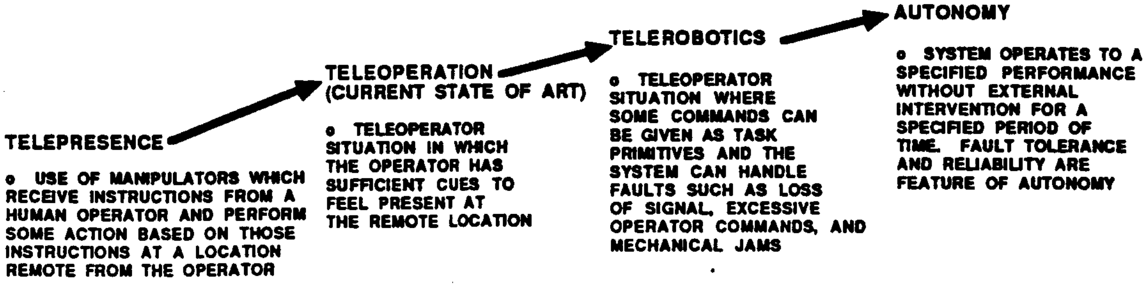


FIGURE 2.6.4.3.2.2-2 SMART FRONT END INTELLIGENCE EVOLUTION

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. Section 2.7.2 summarizes the Space Station growth requirements for which WP-01 is responsible. The scenario used was presented to the Systems Integration Board on 14 January 1986, and revised by Level B in February 1986.

In Section 2.7.3, the SS Initial Orbital Configuration (IOC) as currently approved by Level B is described. With this configuration as a starting point, the growth configuration was conceptualized utilizing applicable Level B decisions as to pattern, vehicle accommodations and servicing reserved volumes.

Section 2.7.4 discusses the growth concept by element and the scar required (if applicable) for each element as the station grows to its desired growth capability. The operational growth limits permitted by a three orbiter and a four orbiter fleet are analyzed in Section 2.7.5, as are the practical cost limits.

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 scenarios used (Tables 2.7.2-1 and 2.7.2-2) were 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.

Table 2.7.2-2 illustrates the additional systems needed to support the OMV and OTV throughout the station's growth. Although Table 2.7.2-1 carried growth only to year 2001, it is anticipated that by 2008 another OTV could be supported.

TABLE 2.7.2-2 VEHICLE ACCOMMODATIONS GROWTH SCENARIO

PMC	1 OMV (Shuttle Based) OMV Battery Charger	
PMC Growth	1 OMV (Space Based) - 2 OMVs After 3 Years 1 Smart Front End - 1 Telerobotic System - 1 ORU Carrier - 1 Fluid Resupply System	OMV Tools & Handling Equipment
Growth (1 OTV)	2 OMVs 1 OTV 1 Smart Front End - 1 Telerobotic System - 1 ORU Carrier - 1 Fluid Resupply System	OTV ORU Storage OMV/OTV Tools & Handling Eqpt 1 OTV Propellant Farm
Growth (2 OTVs)	2 OMVs 2 OTVs 1 Smart Front End - 1 Telerobotic System - 1 ORU Carrier - 1 Fluid Resupply System	OTV ORU Storage OMV/OTV Tools & Handling Eqpt 2 OTV Propellant Farms

2.7.3 Configuration and Module Pattern

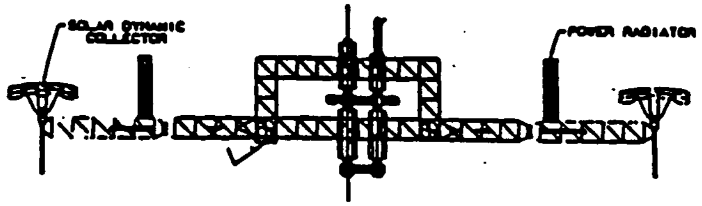
Growth was assumed to begin from the baseline Permanently Manned Configuration (PMC) as shown in Figure 2.7.3-1. This configuration was baselined by NASA's Level B based on the SE&I Office drawing AAA029A1 dated 27 March 1986. It uses the 5 meter truss, twin keel vertical orientation with two U.S. modules 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. This resulted in a C.G. 5.816 meters (19.08 ft) above the power cross truss centerline, while the modules' C.G. was 5.94 meters (19.5 ft) measured from the same reference. Maximum operational C.G. excursion of the station at PMC would be +1.54 meters (down) and -2.136 meters (up).

Basic characteristics of this configuration are:

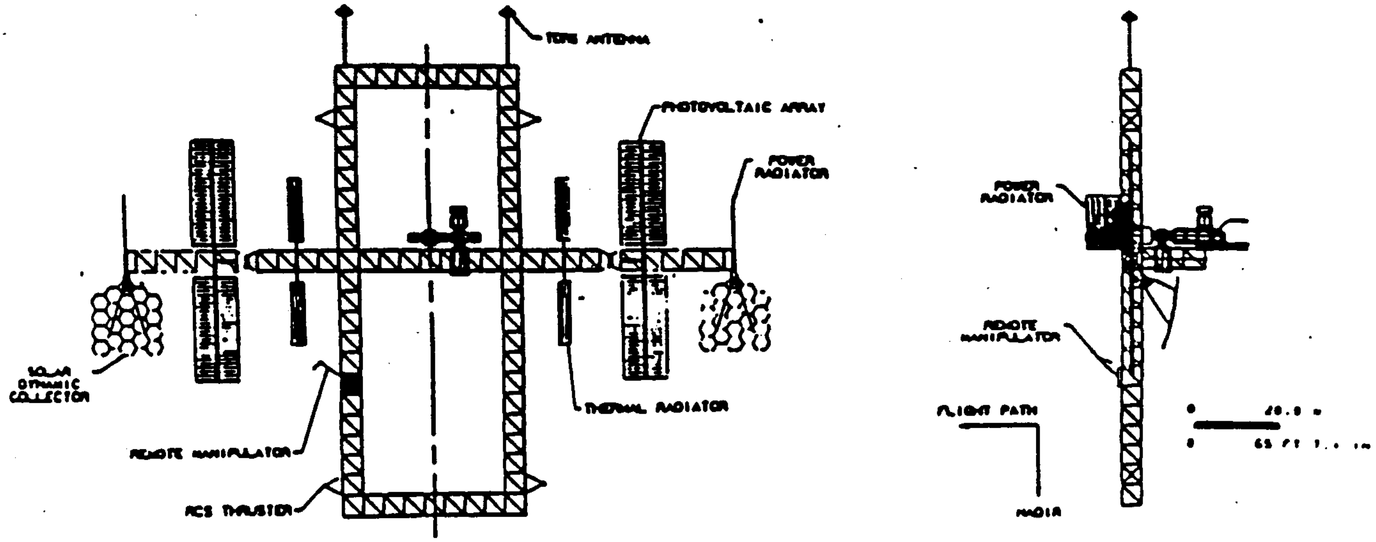
Height	110 Meters	(361 ft.)
Width	170 meters	(558 ft.)
Weight	187,066 kilograms	(412,481 lbs.)
Center of Mass:	X = -2.995 meters	(- 9.83 ft.)
	Y = -3.208 meters	(-10.52 ft.)
	Z = -5.816 meters	(-19.08 ft.)
Inertia Moments	Ixx = 148,398,233 $KG\text{-}M^{-2}$	
	Iyy = 87,172,864 $KG\text{-}M^{-2}$	
	Izz = 79,253,551 $KG\text{-}M^{-2}$	

X, Y, and Z distances measured from the centerline of the tower for the X and Y axes and from the centerline of the solar array cross-truss for the Z 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.



TOP VIEW



FRONT VIEW

SIDE VIEW

FIGURE 2.7.3-1

SPACE STATION BASELINE PERMANENT MANNED CONFIGURATION (PMC)

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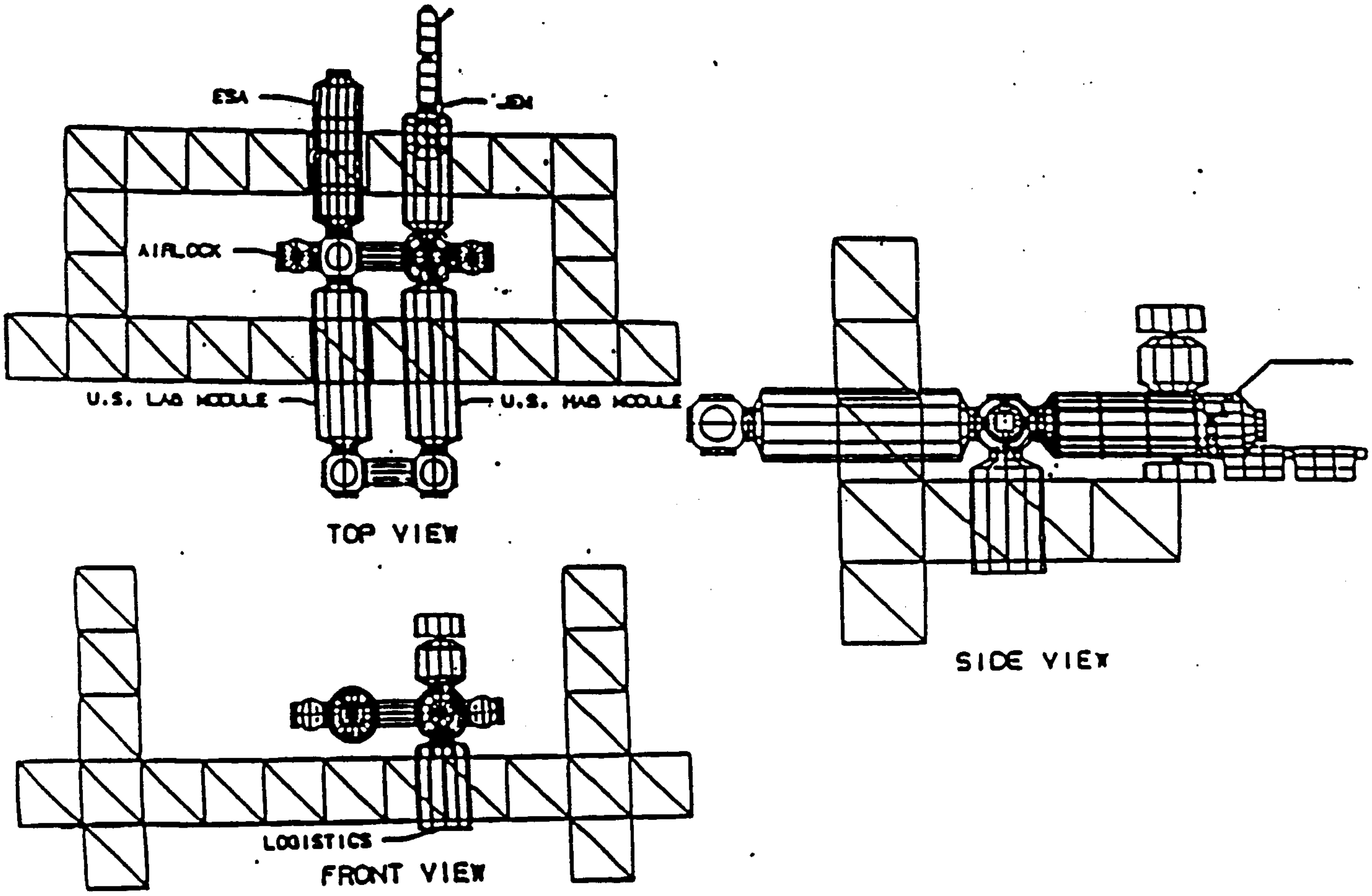

FIGURE 2.7.3-2

SPACE STATION MODULE PATTERN - BASELINE PERMANENTLY MANNED CONFIGURATION

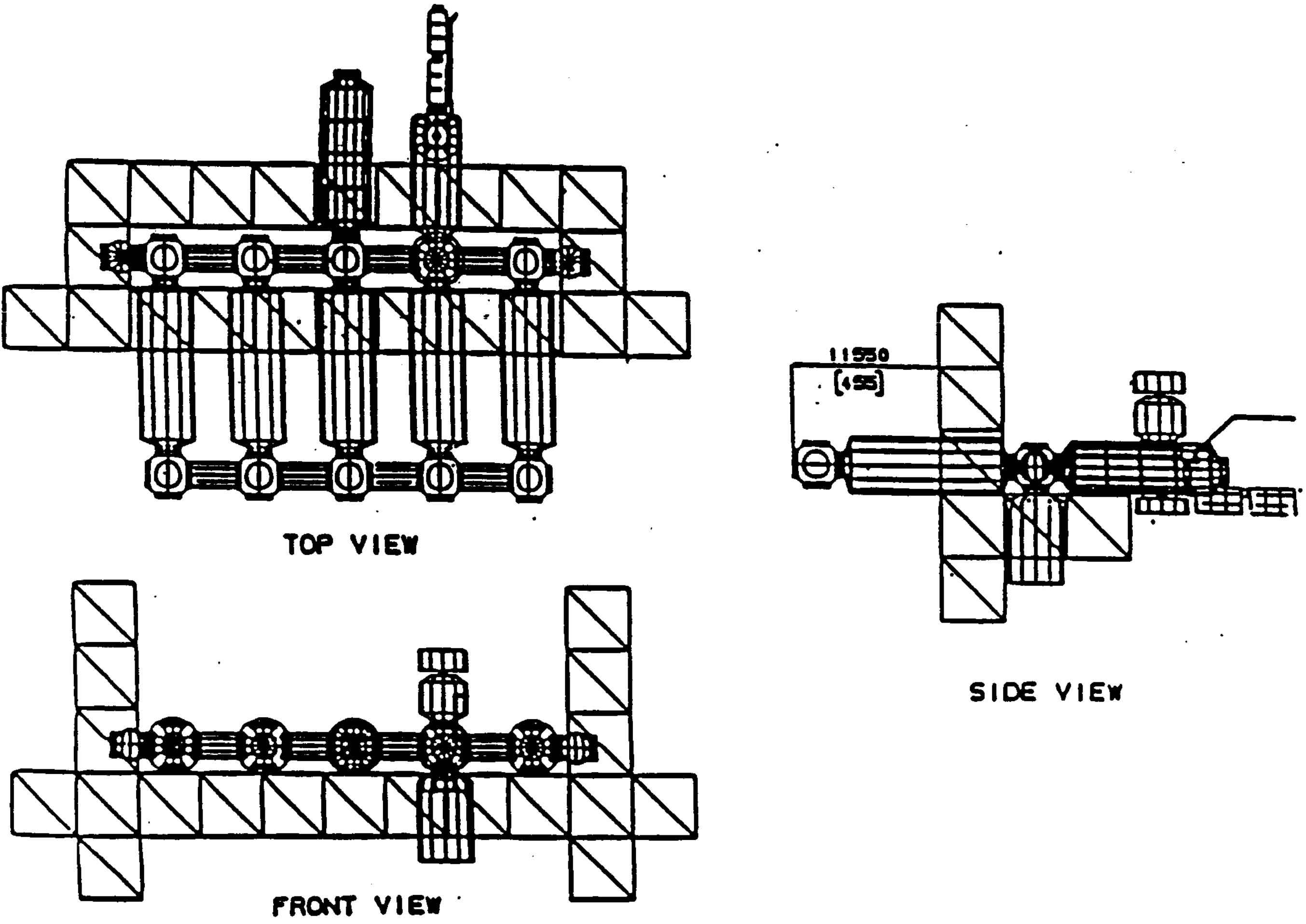

FIGURE 2.7.3-3

SPACE STATION MODULE PATTERN - BASELINE GROWTH CONFIGURATION

The vehicle accommodations grow from a minimal OMV berthing connection on the truss at PMC to a facility capable of accommodating two OMVs and two OTVs plus associated fuels and maintenance tools. This accommodation will be located in the reserved area proposed in Figure 2.7.3-4, however, we recommend that this facility be moved up as close to the modules as practical. This is desirable for the following reasons. If located in the proposed area, under operational conditions, the C.G. travel from maximum up to maximum down could be 7.13 meters (23.4 ft.), and under nominal conditions the C.G. will be 2.13 meters (7.0 ft.) below the centerline of the modules, which impacts the desired microgravity levels. Also, time to access the facility from the modules would be reduced if it were nearer.

Basic characteristics of the growth configuration both with and without an OTV, are:

With OTV -		
Height	110 Meters	(361 ft.)
Width	200 meters	(656 ft.)
Weight	418,468 kilograms	(922,721 lbs.)
Center of Mass:	X = - .633 meters	(- 2.08 ft.)
	Y = -5.353 meters	(-17.56 ft.)
	Z = -2.589 meters	(- 8.49 ft.)
Inertia Moments	Ixx = 411,449,843 KG-M^{-2}	
	Iyy = 192,864,591 KG-M^{-2}	
	Izz = 250,502,067 KG-M^{-2}	
Without OTV -		
Height	110 Meters	(361 ft.)
Width	200 meters	(656 ft.)
Weight	354,646 kilograms	(781,994 lbs.)
Center of Mass:	X = - .688 meters	(- 2.26 ft.)
	Y = -1.893 meters	(- 6.216ft.)
	Z = -7.612 meters	(-24.97 ft.)
Inertia Moments	Ixx = 325,694,549 KG-M^{-2}	
	Iyy = 133,993,739 KG-M^{-2}	
	Izz = 223,410,363 KG-M^{-2}	

(X, Y, and Z distances are measured from the same zero axes as the PMC configuration.).

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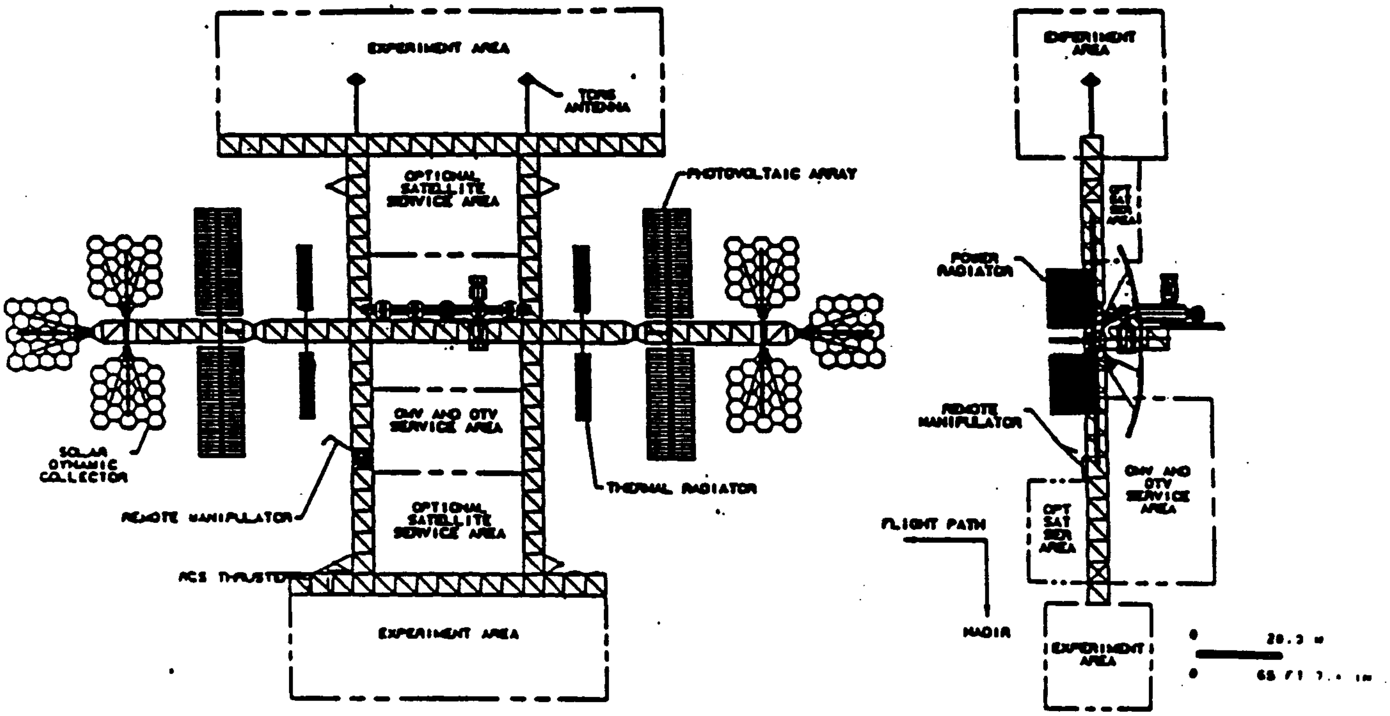

FRONT VIEW

SIDE VIEW

FIGURE 2.7.3-4

SPACE STATION BASELINE SERVICES AREA & EXPERIMENT LOCATIONS - GROWTH

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. Although these features are not construed as growth scars, they are identified in the following sections. 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 Structure - The Core Module PMC primary structural design inherently supports growth by the addition of modules, as required. Identical subsystem interface mounting provisions are located at each of the two hatch areas of the module. Interface attachments are identical for interconnecting PMC module cluster elements, to support attached payloads, and to support additional (growth) modules.

EVA mobility aids are provided externally on each module for S/S PMC assembly and maintenance operations; these same aids serve, as well, for growth assembly of additional cluster elements.

Internal equipment containers, e.g., racks and pallets, and their mounting provisions are common within each module and from module-to-module. Although these features are primarily to support the economies of commonality and reconfiguration flexibility requirements, they also facilitate any on-orbit reconfiguration required for our growth concept.

2.7.4.1.2 Thermal Control System - The module TCS is sized for 25 kW heat rejection capability which will accommodate PMC requirements as well as growth for individual modules. The growth pattern for the Core Module TCS will be the addition of modules completely outfitted with Thermal Control. Each additional module will also have a 25 kW heat acquisition capability when it is added to the Space Station. In general, the TCS within each module will not change with the growth of the Space Station and therefore, there will be no growth scars.

2.7.4.1.3 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. Hygiene processing is not recommended for location in every module, just the habitability modules. This should be acceptable if crew and habitability modules are added at the same time. Each unit is sized for half the crew since a failure of either unit allows total production rate to be halved according to the 90-day degraded requirements of the RFP. In the event of hygiene processing failure, the urine processing treats sufficient water to satisfy O_2 generation by electrolysis needs. If the PMC habitability module is lost, safe haven in the MTL requires a water storage penalty to satisfy emergency O_2 generation needs.

Potable water processing capacity grows with the addition of each module since two 8-man processing units with storage tanks are part of each Common Module. However, growth in potable water capacity requires careful analysis due to the requirement to process water on one day and hold that water for 2 days to verify sterility prior to crew consumption. As such, three full size (8-man) processing units are used on a rotational basis to make up one potable water processing system with a fourth unit needed as backup. For potable processing though, the addition of two common modules with two (2) processing units each are needed to make up an 8-man increment of increased capacity. The simple addition of one processing unit does not increase capacity, because it only provides water to the crew on 2 days out of every 6.

The sizing of any ECLSS subsystem should account for the growth scenario for the station and not just PMC. To avoid unnecessary overcapacity as the station grows, it is more feasible to install ARS processing equipment in only the habitability modules. These findings are summarized in Table 2.7.4-1.

There is no significant impact anticipated for advancements in ECLSS technology. The recommended PMC ECLSS incorporates loop closure for both atmosphere revitalization and water recovery and management. Therefore, advances in these ECLSS technologies are not expected to result in enhanced performance or need for replacement.

However, development effort continues on supercritical wet oxidization for waste management. This development may impact waste treatment technology, but no impact is anticipated for 10-15 years.

TABLE 2.7.4-1 GROWTH ARRANGEMENT - MAJOR FINDINGS

- GROWTH OF CREW AND MODULES IS RELATED
- GROWTH ECLSS CAPACITY TO SUPPORT GROWTH IN CREW IS AUTOMATICALLY ACCOUNTED FOR IN THE ADDITION OF COMMON MODULES
- ARG, POTABLE WATER PROCESSING, AND URINE PROCESSING ARE ONLY REQUIRED IN EACH NEW HABITAT MODULE TO AVOID EXCESS CAPACITY
- PMC IS FAIL OP/FAIL SAFE BUT NOT FAIL SAFE IN SAFE HAVEN IN ALL SCENARIOS
- GROWTH CONFIGURATIONS ARE FAIL SAFE IN SAFE HAVEN
- THE PMC ECLSS IS BASELINING ADVANCED REGENERATIVE TECHNOLOGIES. NO GROWTH OR EVOLUTION OF TECHNOLOGY IS PROJECTED AT THIS TIME

Other areas of "new technology" include enhanced computer capability, as manifested by artificial intelligence, and robotics. Advances in these technologies are expected to reduce the monitoring and routine maintenance requirements of the crew. These advances have a slight impact on the design or performance of the ECLSS as allowances must be made for instrumentation for automatic monitoring and maintenance.

2.7.4.1.4 Application Software - The WP-01 Application Software growth concept includes software books to accommodate the growth and evolution of hardware and software systems that are expected beyond the PMC. A software design that includes a distribution of functions and modularized software elements will support the addition or change of software functions without requiring redesign. The software will also be table driven wherever possible to allow modification/addition/deletion of table elements so as to allow the relatively simple incorporation of new requirements. The software design will also influence the memory size and processing capacity of the DMS processors. Our requirements include wide margins for growth in terms of unused memory size and processing capacity.

The anticipated evolution of the software to accommodate not only new and changing requirements but also the transition to more automated techniques and possibly to expert systems requires the software design to be very flexible. The software design will also be augmented as the SSP evolves from ground control to on-board control. The software size is expected to grow with the addition of new functions and at the same time decrease in size as the code becomes more efficient.

Each subsystem will have its growth requirements identified in the respective software requirements documents. The actual implementation scheme will be included in the specification documents when the software design has been baselined. We believe the modular design that is being recommended is the most efficient means of satisfying both modification and maintenance requirements.

Figure 2.7.4-1 is a preliminary assessment of anticipated application software changes for each subsystem. These software changes result from changes to any of five drivers; subsystem hardware, programming techniques, subsystem operating requirements, increased automation and the inclusion of expert systems.

CHANGES DUE TO:	ECLSS	POWER	STRUCT /MECH	DMS	THERM	INT COMM	USL	LOG	PROP	OMV OTV SFE
SUBSYSTEM HARDWARE	X	X		X			X		X	X
IMPROVED SOFTWARE TECHNIQUES	X	X		X	X	X	X			X
SUBSYSTEM OPERATING REQUIREMENTS	X	X	X	X	X		X	X	X	X
AUTOMATION		X		X	X			X	X	X
EXPERT SYSTEM	X		X	X	X			X		X

FIGURE 2.7.4-1 ANTICIPATED APPLICATION SOFTWARE CHANGES

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 as shown in Table 2.7.4-2. 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.

TABLE 2.7.4-2 USL DESIGN MARGINS

	Design Martin		
Subsystem	Growth	PMC	Growth
Power Distribution	50 kW		Additional payload and subsystem power requirements (A&R,Autonomy)
Data Management			Additional payload and subsystem data requirements.
Data Rate	100 MBPS	90 MBPS	
Data Storage	4.46 BYTES	100%	
Communications			
Audio Dist.	20 Channels	12 Channels	Increased audio requirements.
Video Dist.	23 Channels	9 Channels	Increased video requirements.
Process Materials Mgmt.	100%	100%	Increased (concurrent processing rates).
Water Pump Cap.	TBD		basis.
Line Capacity	TBD		
Recovery	TBD		
Pyrogen	TBD		
Waste Vent Line	TBD		
Waste Vent Contam.	TBD		
Control Capacity	TBD	100%	
Thermal Control	50 kW	25kW	Additional payload and subsystem power

Growth Scars

Growth scars consist of hardware modifications to PMC USL for the express purpose of accommodating support, characterization or experiment hardware which will be delivered after PMC. USL growth scars are summarized in Table 2.7.4-3, and include accommodations for new technologies and new or increased interface or functional requirements.

TABLE 2.7.4-3 USL GROWTH SCARS

Subsystem	Growth Scar	Growth
Structural	Space and interface provisions for robotics within module	Addition or enhancement of robotics capabilities.
Power	Output ports to accommodate additional user power interfaces.	Addition of new modules at rack level.
Data Management	Space at SUB-ORU level to accommodate additional modules and input/output ports.	Additional/new modules (PC boards) and interfaces
Caution & Warning	Interfaces at rack level to accommodate user interface requirements.	Reconfiguration/addition of payloads within USL.

2.7.4.3 Logistics Elements

2.7.4.3.1 PMC Major Element Description - This section describes the elements which make up the logistics system as follows:

a. Logistics Module consists of a pressurized section and an unpressurized structure as described below:

- Pressurized Module - An LM configured Core Module (CM) consisting of a pressure shell provisioned with common internal structure and subsystem equipment.
- Unpressurized structure - Consists of a cylindrical structure containing LN_2 tanks, tank supports, an umbilical system and minimal EPS and DMS subsystem equipment.

b. Fluids Pallets - Consists of tankage, structure and minimal EPS and DMS subsystem equipment for the resupply of either propellants or laboratory fluids.

c. Unpressurized Cargo Carrier - A structure that can accommodate up to three containers approximately the size of a double stowage rack and is used to transport/store dry supplies that are used exterior to the pressurized volumes.

2.7.4.3.2 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:

a. Scarring - No Logistics Elements require scarring for growth. Any modifications required for growth will be accomplished on the ground between missions.

b. Modular Additions - The addition of refrigerator/freezer volume in the pressurized module to accommodate increases in crew size and the addition of LN_2 tanks for ECLSS to the unpressurized structure are growth examples of the module elements.

c. Increased Storage Capability - The utilization of dense packing concepts and the incorporation of an on-orbit "warehouse" storage concept are examples of increased storage capability. Using a warehouse concept assumes that there will be additional STS flights available to stockpile resupply goods.

d. Increased Number of Elements - As block changes occur, elements can be added as required to accommodate various resupply requirements. In conjunction with these additions, new technology can be utilized in the design of the various elements, i.e., composites, etc. to provide lighter elements thus increasing payload capability. More STS flights would be required to support this concept.

e. Rapid Sample Return (RSR) - Rapid Sample Return (RSR) can be used to offload return payload requirements on the Logistics elements and thus provide increased return weight capability.

f. Trash Disposal - As growth occurs, trash disposal becomes an increased concern since the STS is restricted in return payload capability, and some method of on-orbit trash disposal will have to be employed. Return to Earth via alternate methods, or de-orbit burnup, are possible growth alternatives.

g. Tether Applications - Various tether applications can be employed to accomplish both RSR and trash disposal. Using tethers can significantly reduce launch costs along with providing a cost effective means of accomplishing both material return and increased payload capability.

2.7.5 Growth Limits and Cost

2.7.5.1 Operational Limits

Within the WP-01 context, there are three key issues affecting the operational growth of the Space Station: (1) Crew utilization, (2) NSTS fleet support, and (3) Space Station facilities and support capabilities. The analyses performed to date were based on the four module Baseline SS configuration. The various Space Station growth factors that impact element growth are depicted in Figure 2.7.5-1.

2.7.5.1.1 Crew Utilization - As the Space Station grows in size and capability, increased demand will be placed on the utilization of crewtime. Analyses show that from about 15 to 20 percent of the total crew time will be available for user payload and experiment operations onboard the station.

Increases in crew productivity and hence station productivity will require a phased evolutionary application of onboard automated and robotic systems. Consideration of ground resources is inherent to the crew utilization/Space Station productivity formula. These ground resources must be phased down as the station grows.

On-orbit systems, such as the Smart Front End (SFE) robot on the Mobile Remote Manipulator System (MRMS), can significantly reduce crew involvement in external maintenance operations. Use of a MRMS/SFE provides a 40% increase in crew time availability.

Current estimates of external maintenance man hours required for the PMC station range from 500 to 2000 per year and will increase as facilities are added to the station. If external maintenance is a crew responsibility with little or no robotic support, then crew availability for payload operations is severely restricted. EVA is extremely costly, requiring 24 man hours for each EVA at an overhead rate of 100%. As the crew size increases, additional station facilities will be added requiring increased operations and maintenance until confidence is gained in these facilities and appropriate automation techniques are incorporated and verified. These analyses for the growth of the station indicate that the crew resource must be carefully considered as part of the overall Space Station growth equation.

2.7.5.1.2 NSTS Fleet Support - Space Station growth operational limitations associated with NSTS support include total number of flights allocated to SS, capability of each (volume, mass, etc.,) and cost. Currently, only 9 of the 24 flts/yr maximum may accommodate SS operations (payload and logistics transportation), based on a 4 orbiter fleet. This corresponds to one orbiter dedicated to SS support. However, a three orbiter fleet would reduce the growth rate by at least 25%. Also, processing time required to accomplish orbiter payload manifesting launch delivery significantly influences growth and customer return rate, but does not restrict growth capability.

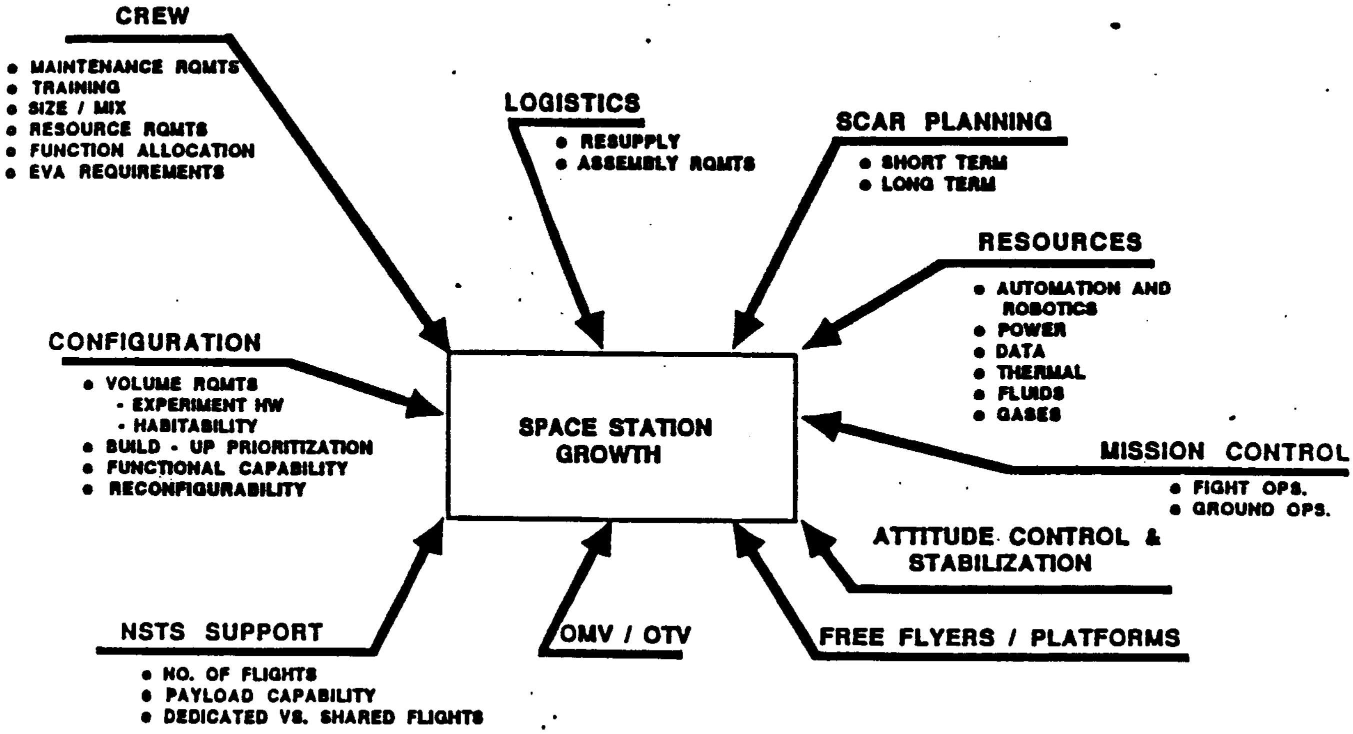

FIGURE 2.7.5-1 OPERATIONAL FACTORS AFFECTING GROWTH

C-2

2.7.5.1.4 Automation and Robotics - The objective of the A&R program relative to WP-01 is to exploit the potential of artificial intelligence and robots to decrease the cost of ground control, acquisition and number of growth elements, and increase the productivity and safety of space operations. The basic trend will be to apply artificial intelligence to reduce the size of the ground control contingent, and robots to enable a progressive capability to assume more of the crew activity in the area of space operations, servicing, assembly and repair.

The program has two major thrusts, system automation and robotics. Each has a logical sequence of integrated evolutionary capabilities from 1994 to 2005. Underlying the capability to identify growth steps and probable milestones are the evolving technology areas: Sensing and perception, control, task planning, reasoning and learning, man-machine interface, application software development, and advanced processing architecture. To meet this plan requires the leveraging of relevant technology being developed under other government agencies along with industry and universities.

A more detailed description of potential growth steps as a function of both productivity requirements and technology advancements is presented in the following paragraphs.

2.7.5.1.4.1 Subsystem Automation - The evolution of automation technology will enhance the capabilities of onboard subsystems to manage themselves thus lowering the level of support required from both crew and ground personnel. It is plausible to consider a staged approach to providing the ultimate configuration of Space Station control systems.

As a result of the relative ease with which new technology can be exploited in ground-based development systems, the precise configuration of the initial stage of Space Station control implementation will depend on the assumed progress of automation technology up to PMC. The onboard portion will be constrained to technologies proven several years in advance of PMC. A conservative view of the initial stage would see only conventional automation technologies (SOA 1986) onboard in the 1994 PMC timeframe. The advanced automation technologies incorporating expert systems in planning and advisory roles would be under development on the ground on machines optimal for such development efforts.

Initially, crew and ground personnel will play roles similar to those played in STS. Ground personnel will have primary responsibility for monitoring station systems and for all planning and scheduling except on the next shift activity timescale. Crew personnel will perform monitoring and control, maintenance and servicing and payload operations. This is the man-machine mix on which current PMC operational planning is based.

The primary difference between PMC Space Station and STS is that the hardware and software technologies will be 15 years newer and capable of supporting subsequent stages of automation technology growth.

Until automation applications are sufficiently mature that their presence on orbit enhances station productivity, they should remain on the ground. The rate at which applications can be developed to the point of onboard test may be significantly increased through use of high quality ground simulation facilities.

Onboard or ground implementation of high level control and planning can be expected to dramatically shift the Station Specialist time allocation toward payload activities and to shift ground personnel toward supervisory monitoring and extreme contingency operations. Provided the Space Station Information System is designed to incorporate expansion of all its physical resources, the development and implementation of advanced automation should require only incremental additions of hardware and software to steadily improve the support capabilities of Space Station control systems.

Additional PMC station scars which are needed to accommodate system automation growth were derived for submittal in the Martin Marietta, Preliminary Automation and Robotics plan for MSFC, December 18, 1985, and a current revision is presented in Table 4.1.4.1-1.

An analysis of the potential of A&R and crewmembers in the performance of USL related tasks, during PMC and Growth phases, indicate no significant difference between the PMC and Growth phases of Space Station in relation to automation tasks. However, as evident from data, robotic applications will be applied in an evolutionary manner, thus requiring scarring of the station and early robotic systems at PMC to accommodate future robotic development.

Table 2.7.5-1 Automation Growth Scars

- Intelligent system access to sensors, actuators and controllers
- Flexible Space Station Information System (SSIS) data model
- Message priorities for distributed real-time controllers
- Addition of processors with parallel/advanced architecture
- Synchronization mechanism for cooperating intelligent systems
- Resource/redundancy management for symbolic and parallel processors
- Data logging/telemetry for intelligent automation development/enhancement.

Table 2.7.5-2 Robotic Growth Scars

- Provide a rail system for module transfer in the CM that is compatible with robots
- Accommodate berthing/docking ports at multiple locations
- Design system to have "hard" points at worksites and at structure nodes
- Label, mark, or code all modules, assemblies and components within viewing access
- Provide modularity in all designs to accommodate servicing, growth, and updating
- Standardize attachments, fasteners and connectors that are compatible with IVA/EVA and manipulators
- Accommodate autonomous checkout and trouble shooting capability with multiple/accessible test ports in the DMS

2.7.5.2 Growth Costs

2.7.5.2.1 Growth Scenario - The PMC configuration, as pertains to WP-01 elements, will consist of two Core Modules, each outfitted with its required subsystems - with one configured as a Habitation/Systems Operation (HSO) module and the other as a United States laboratory (USL) module; two Logistics element sets (one on orbit and one on the ground); four nodes; two tunnels; two airlocks; and vehicle accommodations consisting of supporting structure, a telerobotic system, and an OMV battery recharging system. This configuration is as represented by the year 1992 column of Tables 2.7.5-3.

The growth scenario, in its final form, includes the addition of three more Core modules, two as USL modules and one as a HSO module. It includes two additional logistics element sets and expanded vehicle accommodations as represented by the year 2001 column of Table 2.7.5-3. Also included are six additional nodes, six additional tunnels and one additional airlock.

2.7.5.2.2 Ground Rules and Assumptions - The ground rules and assumptions used in the determination of the acquisition costs for the WP-01 growth elements are as follows:

- Costs are fixed year $1987.
- Costs are total prime contractor costs excluding fee.
- Acquisition costs include D&D and production hardware.
- Common module, node, tunnel, airlock, and Logistic element set average unit costs are based on the DR-09 (POP 86-2) submittal and include learning curve adjustments.
- Each Logistic element set includes a pressurized section, a propellant carrier, a special fluids carrier and an unpressurized carrier.
- Core modules include all required subsystems (ECLSS, DMS, Thermal, Communications & Tracking, Power, Software).

TABLE 2.7.5-3 GROWTH SCENARIO FOR WP-01 GROWTH ELEMENTS AND BLOCK CHANGES

GROWTH SCENARIO(1)	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
CORE MODULES	2	2	4	4	4	5	5	5	5	5
LOGISTIC ELEMENT SETS	2	2	2	2	2	4	4	4	4	4
NODES	4	4	8	8	8	10	10	10	10	10
TUNNELS	2	2	6	6	6	8	8	8	8	8
AIRLOCKS	2	2	2	2	3	3	3	3	3	3
USL OUTFITTING	1	1	2	2	2	3	3	3	3	3
VEHICLE ACCOMMODATIONS(2)	MIN.	MIN.	STG1	STG1	STG1	STG2	STG2	STG3	STG3	STG3
BLOCK CHANGES(3)										
INCREMENTAL D&D COSTS ($M)										
-HARDWARE	REF		48			11		102		
INCREMENTAL PROD COSTS ($M)										
-HARDWARE	REF		347		8	358		100		
TOTAL D&D AND PROD COSTS ($M)			395		8	369		202		

NOTES:

(1) THE IOC PROPULSION SYSTEM WILL NOT REQUIRE GROWTH UNTIL SOMETIME AFTER THE TEN YEAR GROWTH SCENARIO (SEE SECTION 3.6.3).

(2) VEHICLE ACCOMMODATIONS:

STAGE 1
- Misc. Structure
- 2 OMV Propellant Modules
- OMV ORU Storage
- Tools and Handling Equipment
- Fluid Resupply System
- ORU Carrier

STAGE 2
- Additional Misc. Structure
- Additional OMV ORU Storage

STAGE 3
- Additional Misc. Structure
- 1 OTV Propellant Module
- OTV ORU Storage
- OTV Tools and Handling Equipment

(3) The costs shown for each year represent the total cost of the Block Change corresponding to that year, but do not represent the actual year in which the costs will occur because the expenditure of funds must precede the delivery of the new hardware by some time frame.

2.7.6 Summary

The recommended design configurations for the WP-01 elements have sufficient inherent design margins to allow evolution to the growth Space Station with minimal scarring. The PMC configuration and the recommended growth configuration possess certain features, described previously, which enhance Space Station capabilities.

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. He will serve as the monitoring "agent" to assure the proper flow of productivity improvement candidates for evaluation and implementation on a planned scheduled basis. In addition, the productivity director will function as the project's "integrator" to assure that the effort is coordinated throughout the Space Station Project organization and that the functional groups implement their assigned tasks. The productivity director will also be responsible for initiation of follow-up audits to verify or confirm cost benefits of implemented 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.

Specific productivity goals will be assigned to each functional group as a percentage of the total productivity improvement plan. Each functional group's performance will be measured and regularly reported to management via the Space Station Project reviews on all productivity initiatives.

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. An existing procedure will be used to quantitatively assess and reflect each initiative according to category, such as design, process, procedure, the return on investment, disposition, and action to be taken. This analysis will also resolve specification interpretation issues thereby avoiding surprises and allowing cost trade-off for the alternate methods. It will identify risks associated with high technology, state-of-the-art manufacturing methods, processes and materials.

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.

3.0 DESIGN

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.

A design goal of the CM is to exhibit combined qualitative and quantitative maintainability characteristics of hardware and software design, installation and support which enable the accomplishment of operational objectives with a minimized expenditure of maintenance resources (manpower, personnel skills, tools/test equipment, technical data, facilities, cost) under stated operational conditions.

3.1.1 Subsystems

3.1.1.1 Structures/Mechanisms

General Description

The external configuration of the CM HSO and USL configurations is a cylinder 4445 mm (175.0 in.) in diameter and 12.8m (42.09 ft) in length. This total length and diameter are the maximums that can be accommodated in the available Orbiter payload envelope defined by the Level B SSCB and still maintain a space allocation for the berthing assemblies. The CM LM configuration is 6.9m (22.75 ft) in length, utilizing two barrel sections of the CM HSO/USL configuration.

The external surface consists of on-orbit removable space debris/micrometeoroid bumper panels that form part of the module integrated wall concept. The bumper panels cover the entire surface area of the module with the exception of the hatch openings, viewport locations and STS attachments. The principle of the integrated wall design is to have an external bumper that reduces the impacting particle energy by either fragmentation or vaporization. A standoff distance between the bumper and the pressure wall enables the fragments of the particle to be dissipated over a larger area upon impact thus minimizing damage to the pressure wall.

There are five STS attach fittings that protrude through the bumper panels at three locations; two primary longeron fittings, two stabilizing fittings, and one keel fitting.

Two RMS grapple fittings are also located outside the OSL of the module at +/- 45° from the +Z axis.

In the aft section of the module are three viewports located to meet the outfitters minimum viewing requirements.

Each end of the module has a 1270 mm (50.0 in) x 1270mm (50.0 in) access hatch opening to accommodate equipment and crew transfer on-orbit.

Figure 3.1.1-1 illustrates the external configurations of the CM.

3.1.1.1.1 Pressure Shell Configuration - The CM pressure shell is a VPPA (variable polarity plasma arc) welded structure of 2219 aluminum alloy. VPPA and 2219 were chosen over other welding techniques and aluminums because of their low cost and high weld quality thus minimizing NDE.

The pressure shell is a cylinder 11.79m (38.7 ft) long and 4216 mm (166.0 in.) internal diameter closed at each end by a 30° truncated cone. The conical end cone closure was selected for the best volume to weight efficiency ratio over other profiles. The overall 13m (42.6 ft) length of the pressure shell, exclusive of the berthing interfaces, when installed, is the maximum module cylinder length along with two 30° end cones that can be accommodated in the available Orbiter payload envelope as defined by the Level B SSCB.

The cylindrical part of the pressure shell consists of four barrel sections and five external ring frames. Each barrel section consists of four welded 90° panels with the exception of the aft barrel section which utilizes (2) 90° panels,(2) 72° panels and (2) 18° longeron panels. Each of the five ring frames stabilize the pressure shell during launch. The external ring frames provide a smooth inside skin line and fit within the bumper standoff area. This four barrel, five frame configuration maximizes Common Module length and provides an optimum length Logistics Module derivative from common elements.

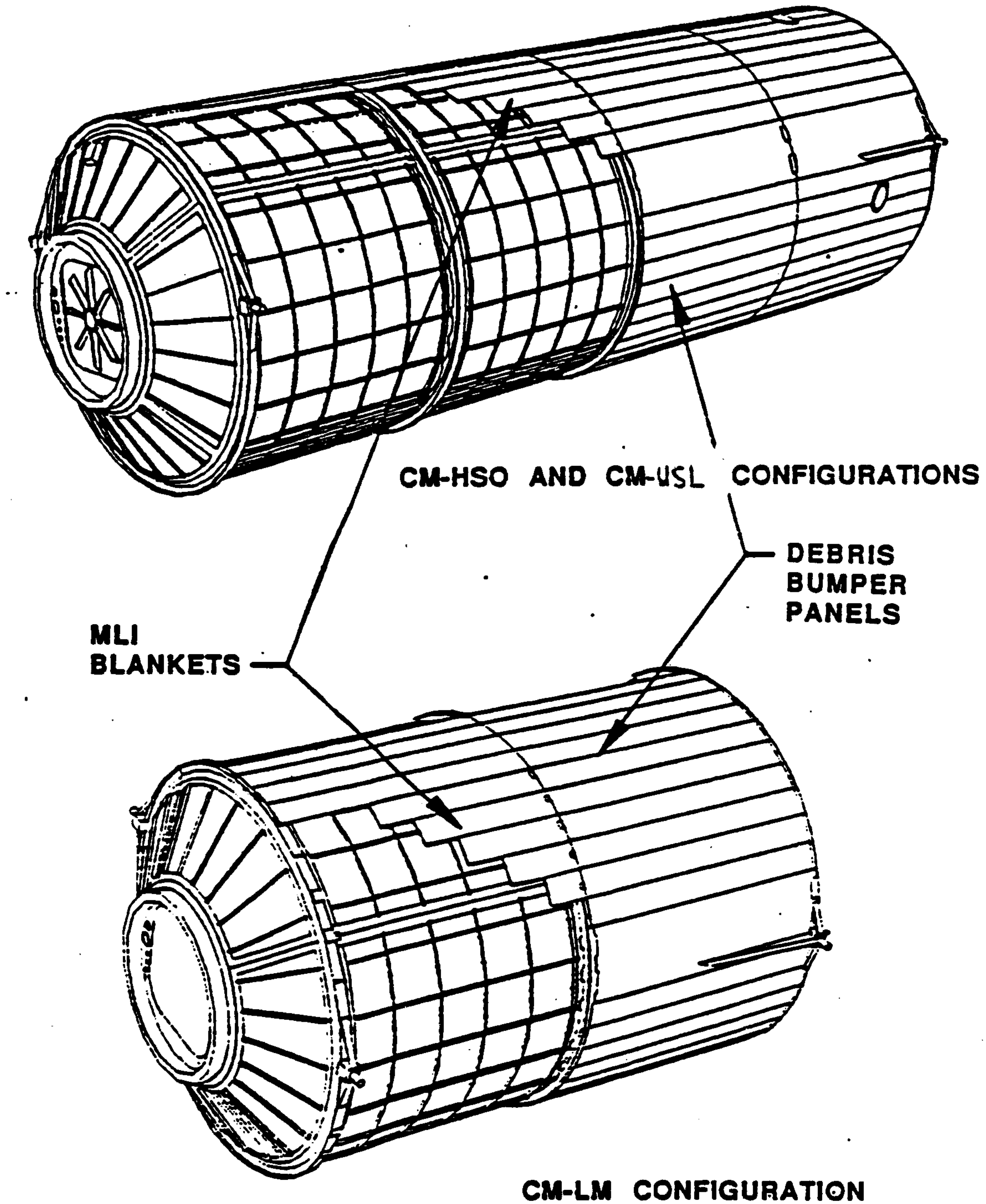

FIGURE 3.1.1-1 CORE MODULE EXTERNAL CONFIGURATIONS

Each conical end cone closure consists of 4 gore panels and an end frame which contains the CM hatch and berthing mechanism interface.

Pressure shell membrane thickness is 3.2 mm (.126 in) throughout the cylindrical and conical areas, and is derived from space debris/micrometeoroid protection requirements.

3.1.1.1.2 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 3.1.1-2, 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 3.1.1-3 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 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.

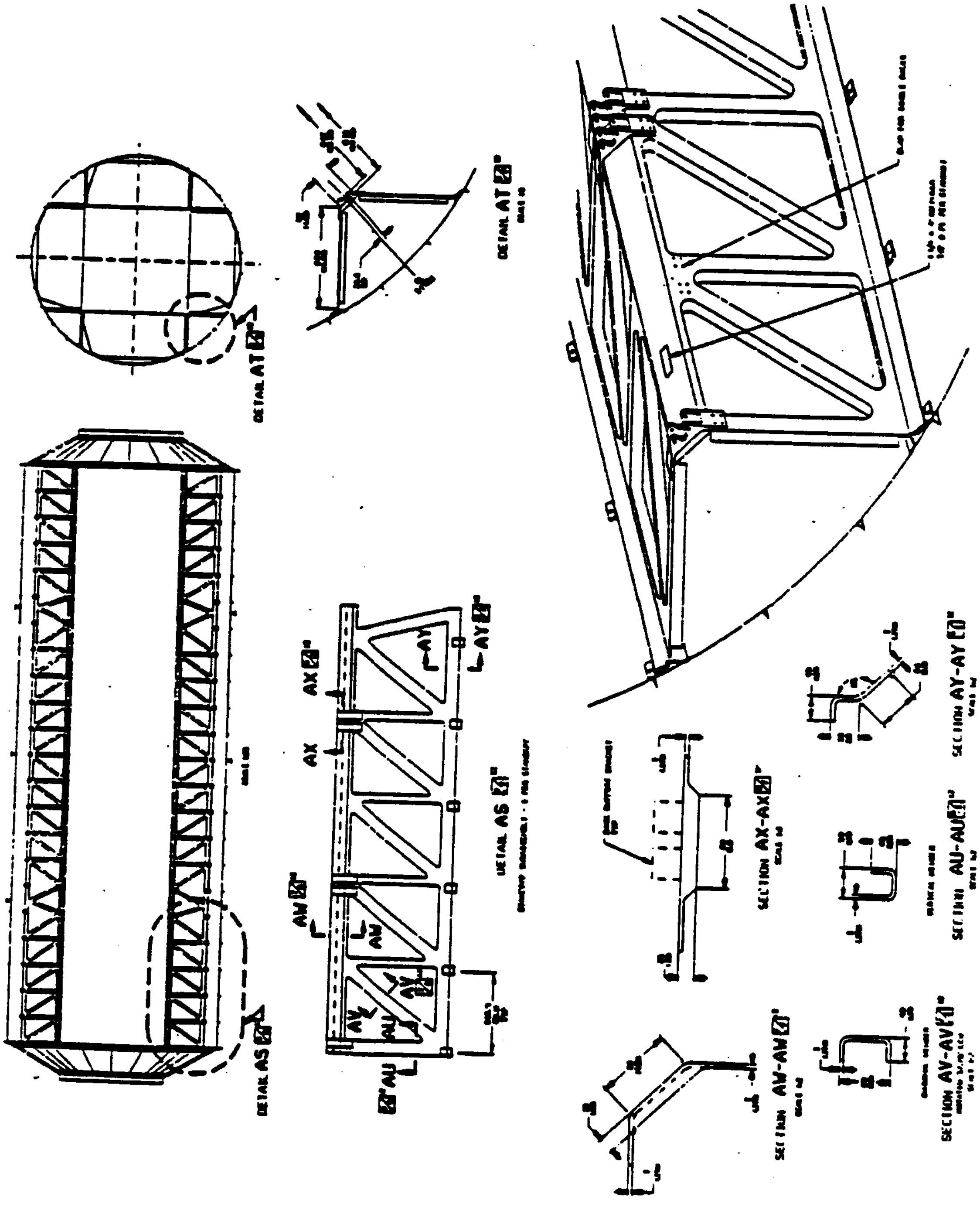

FIGURE 3.1.1-2 INTERNAL CONFIGURATION-STANDOFFS

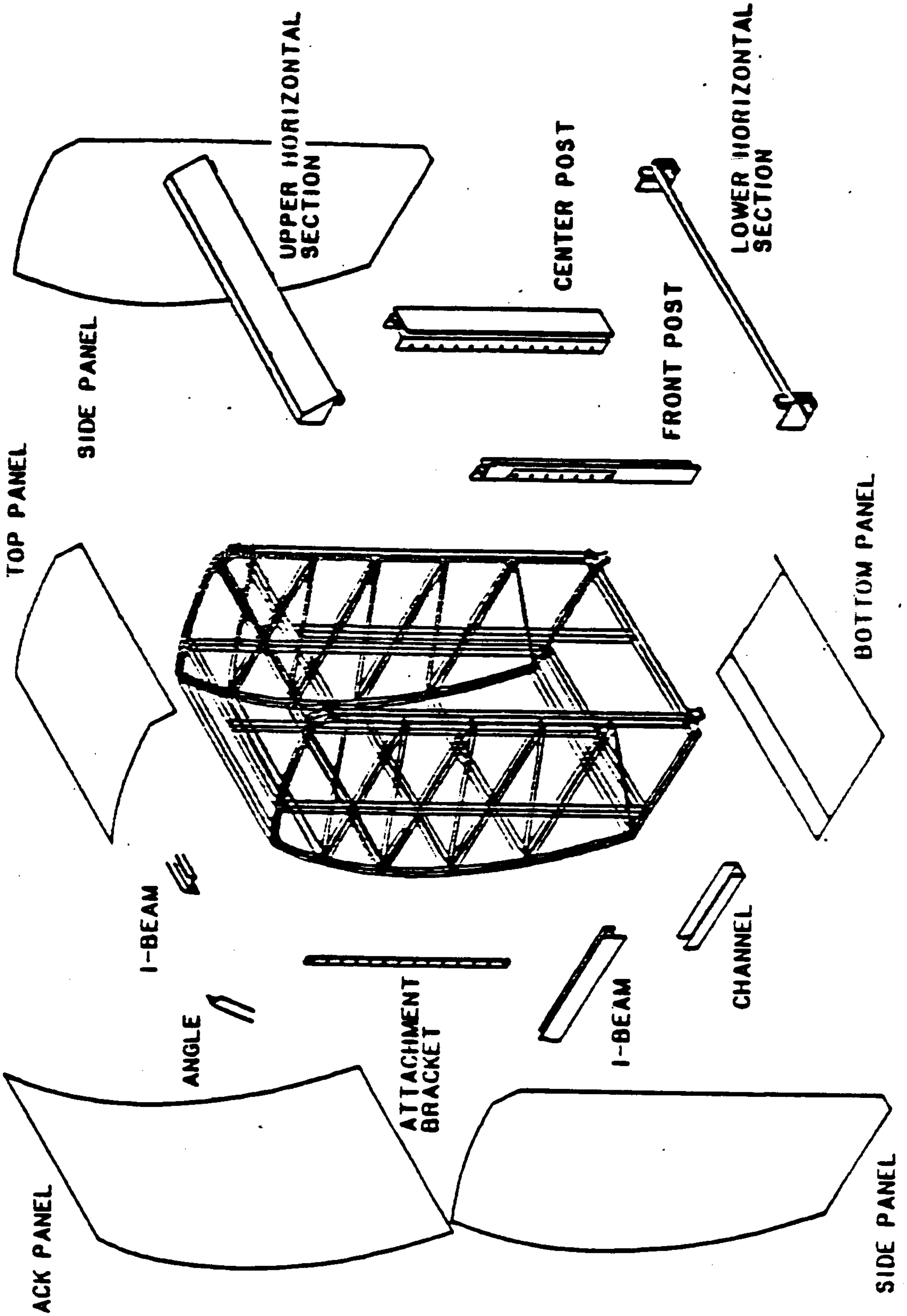

FIGURE 3.1.1-3 EQUIPMENT RACK

The structural attachments are adaptable to accept either avionics or experiment standard drawers per EIA Standard RS-310-C or larger nonstandard experiments or subsystem components or habitable functional unit such as a shower or crew compartment.

3.1.1.1.3 Configuration Differences - The CM provides the outfitter with all subsystems and utility hardware and software required to create a habitable volume and fulfill the requirements of the Space Station program.

Additional subsystem and utility hardware and software shall be provisioned into the CM to provide a foundation to support each outfitter's unique requirement.

Each of the provisioned CM end items provides the maximum structural subsystem and utilities foundation to the outfitters that is deemed to be cost effective across the SSP. This is a design and development goal that shall be achieved by defining a database of component, subassemblies, systems and subsystems that are truly common across all CM end items.

The provisioned CM is based upon a CM system and subsystem hardware and software database that supports the creation of the CM-USL, CM-HSO and CM-LM end item modules. Whereas the CM has been defined as a database only and not an end item, the provisioned CM consists of all subsystem elements that create a pressurized, habitable and operational Space Station volume.

3.1.1.2 Electrical Power

The CM power distribution subsystem shown in Figure 3.1.1-4 is sized to provide the capability of 50 kW to module subsystems and outfitted equipment. In addition, 25 kW of power is routed to the module ports. The input utility power is 440V, 20 KHz, 1 phase and is stepped down by a 50 kW transformer to 208V, 20 KHz, 1 phase and is distributed to 44 outfitting bays within the CM and to subsystem equipment located in the end cones.

The CM power subsystem consists of primary, secondary power, and module interconnect power distributions. Primary power distribution (PPD) is defined as the power provided to the external module interconnect and to the secondary distribution assembly. The primary power distribution assembly (PPDA) provides the capability to select one of two input busses, provide monitoring and circuit protection, and distribution of power to the module interconnect and secondary power distribution assembly.

The secondary power distribution consists of the secondary distribution assembly and associated cabling. The secondary power distribution provides monitoring and control, and circuit protection to the system.

Power control is provided by a power control unit (PCU) and microprocessors embedded in the various assemblies. Capability is provided to implement power distribution, load health and status management, and fault isolation.

Electrical power subsystem equipment location is described in Figure 3.1.1-5.

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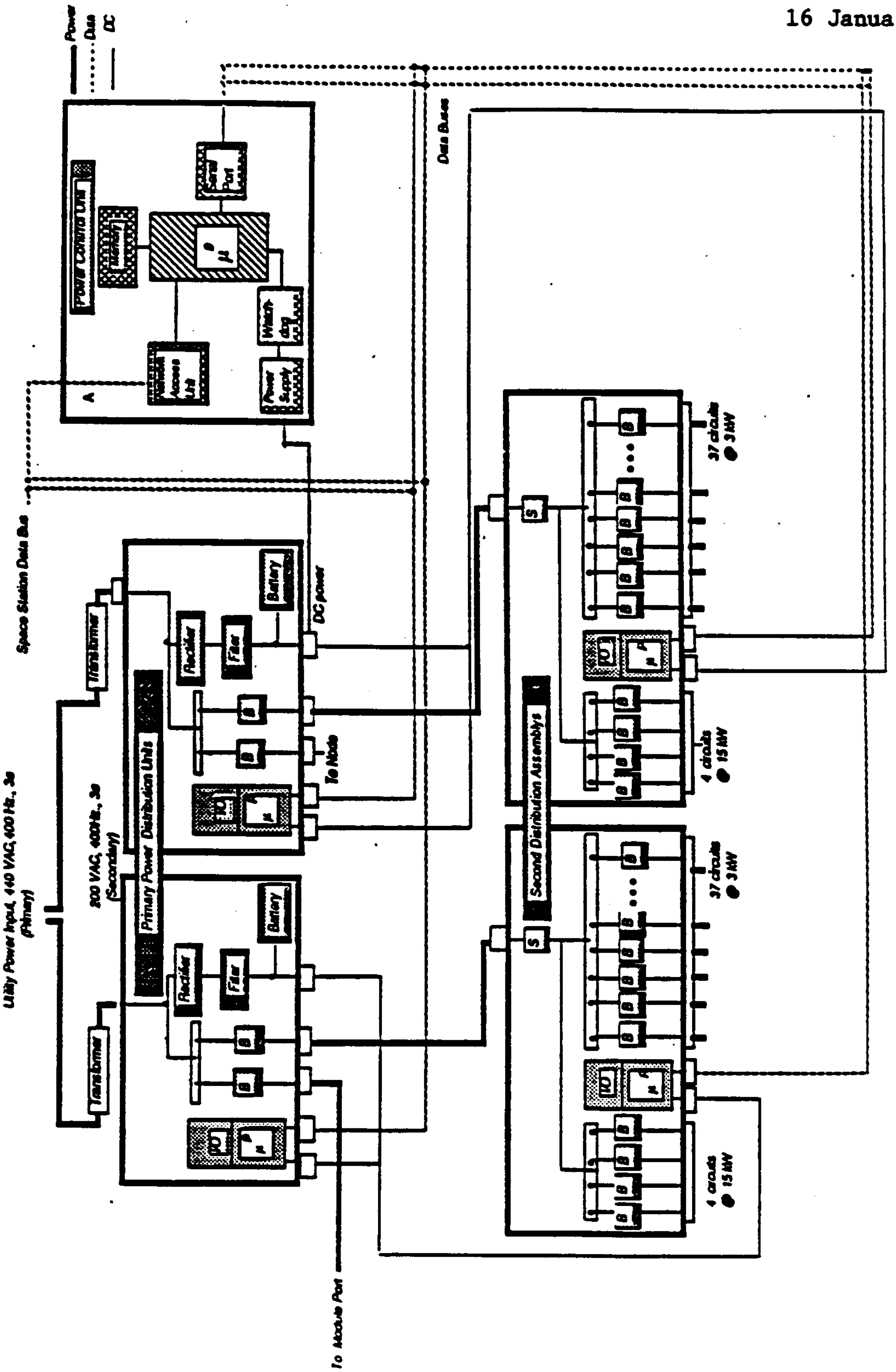

FIGURE 3.1.1-4 CM POWER DISTRIBUTION SUBSYSTEM

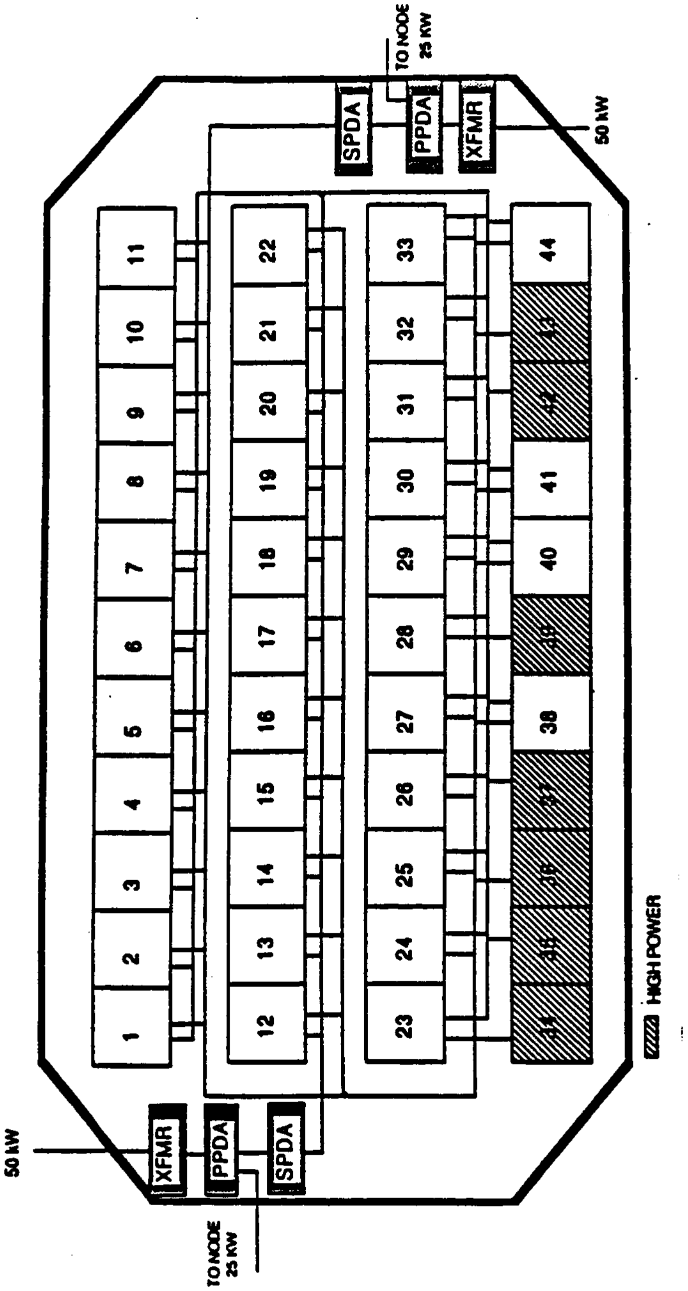

FIGURE 3.1.1-5 CM POWER DISTRIBUTION

3.1.1.3 Data Management Subsystem (DMS)

The CM DMS equipment distributes data within the CM. The data distribution equipment is comprised of cabling, electronic hardware, and software. The equipment is configured to provide data distribution networks rather than point-to-point wiring for every function.

Instrumentation equipment includes signal conditioning, multiplexing and data processing hardware and software. This equipment is used for control and monitoring of subsystem processes.

Caution and warning equipment distributes information to the on-board crew concerning safety hazards. Hardware and software for accomplishing this is associated with the DMS. Caution and warning equipment includes processors to perform the logic functions and annunciation devices to make the crew aware of potentially hazardous events.

Standardized Multi-purpose Application Consoles (MPACs) located in the HSO and USL modules house the data distribution and management equipment and provide redundant "workstation" man-machine interfaces. Control, monitor and utility functions can be accomplished at any of the workstation locations.

The CM DMS equipment will interface with the global DMS in order to communicate with other modules and external systems. Figure 3.1.1-6 illustrates the approach to DMS distribution.

3.1.1.4 Communications

The CM communications subsystem as described in previous paragraphs is designed to provide the greatest possible flexibility for establishing and maintaining voice/or video contact either private, secure, or clear, among all crewmen as well as with ground elements. The topology for accomplishing this is depicted in figure 3.1.1-7.

The baseline audio and video systems process and distribute various sources of crew voice and other signals through the Space Station. Wireless infrared (IR) intercom and paging channels are provided, along with full duplex voice channels to the ground and to EVA/MMUs, and shuttle orbiter(s). Voice recognition and synthesis are provided, along with the capability of high and standard resolution CCTV, audio and video playback and record, artificial capabilities intelligence information interfaces, and caution and warning interfaces. Conferencing capabilities of both inter- and intra-module communications are also provided.

Within Each Module:

- Core DMS Network for Inter- and Extra- Module Data Distribution
- Module Local Area Network for Subsystem-to-Subsystem Data Distribution
- Subsystem Busses for Subsystem Status and Control

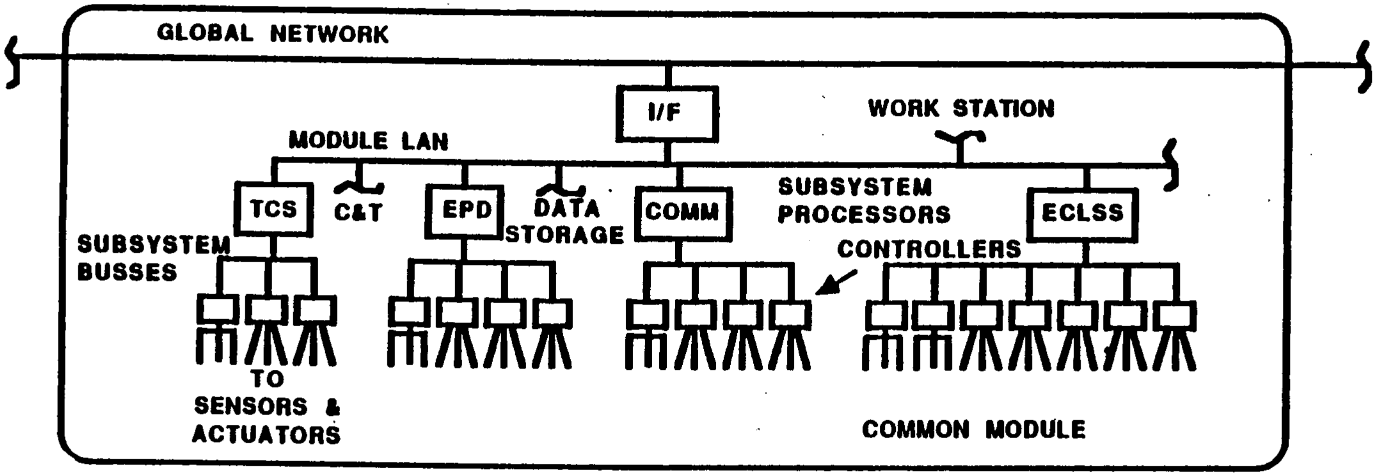

FIGURE 3.1.1-6 DATA DISTRIBUTION TECHNIQUE APPROACH

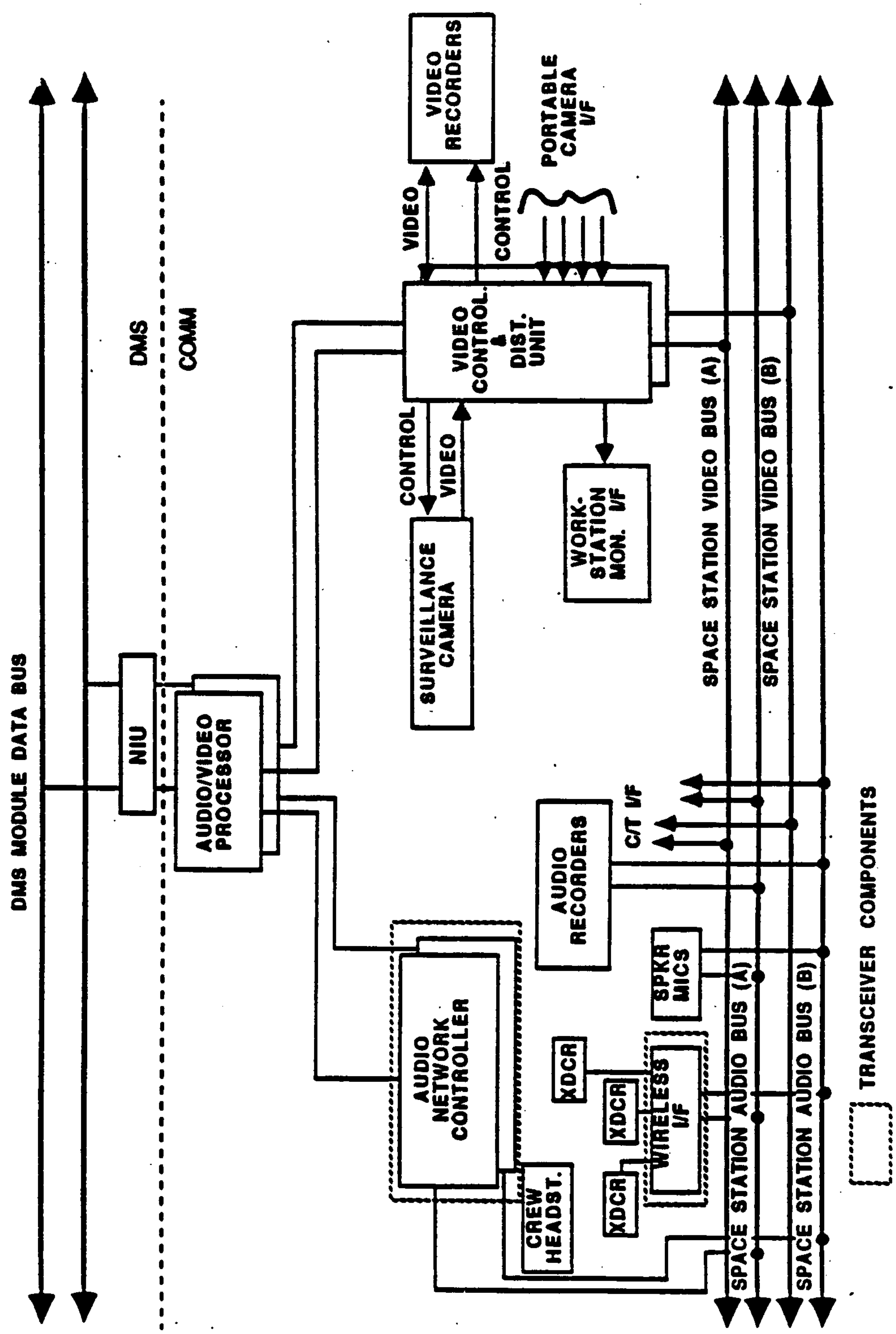

FIGURE 3.1.1-7 INTERNAL COMMUNICATIONS, COMMON MODULE

3.1.1.5 ECLSS

The Environmental Control and Life Support (ECLSS) subsystem provides the following basic functions to the Space Station Program: 1) Temperature and Humidity Control, 2) Atmosphere Control and Supply, 3) Atmosphere Revitalization, 4) Fire Dectection and Suppression, 5) Water Recovery and Management, 6) Waste Management and EVA Support. The major functions within each of these functional areas are shown in Figure 3.1.1-8.

a. Temperature and Humidity Control - The temperature and humidity of the atmosphere and other equipment are controlled within the pressurized module. These control systems also provide ventilation throughout all areas of the pressurized module. Specialized equipment (refrigerators/freezers) are also provided with heat rejection interfaces to the Thermal Control subsystem (See Figure 3.1.1-9).

b. Atmosphere Control and Supply - Atmospheric pressure and composition control functions provide for monitoring and regulating the partial and total pressure of oxygen and nitrogen in the module atmosphere. Vent and relief pressure functions are also provided along with the distribution and storage of O_2 and N_2 for the module (See Figures 3.1.1-10 and 3.1.1-11).

c. Atmosphere Revitalization - Atmospheric revitalization systems regenerate the module atmosphere, as necessary, to provide a safe and habitable environment for the crew. Monitoring and control of atmospheric contaminants including microbial assessments are provided (See Figure 3.1.1-12).

d. Fire Detection and Suppression - Fire detection and suppression equipment is provided for the entire pressurized volume with both fixed and portable extinguishers and emergency portable breathing equipment as required (See Figure 3.1.1-13).

e. Water Recovery and Management - The collection, processing and dispensing of water to meet crew and experimental needs is accommodated. Pretreatment of waste water to prevent chemical breakdown and microbial growth prior to processing is provided (See Figure 3.1.1-14).

f. Waste Management - A means is provided for collecting fecal matter from crewmembers and disposing or processing fecal matter and urine. Trash collection and processing of both biologically active and inactive trash, is also provided. Specialized general housekeeping items are included as required (See Figure 3.1.1-15).

g. EVA Support - The ECLSS provides the capability to service and checkout the shuttle-derived Extravehicular Mobility Unit (EMU) and service the Manned Maneuvering Unit (MMU). These services are provided within the airlocks. Support is also provided for the airlock and for the airlock/hyperbaric chamber as required (See Figure 3.1.1-16).

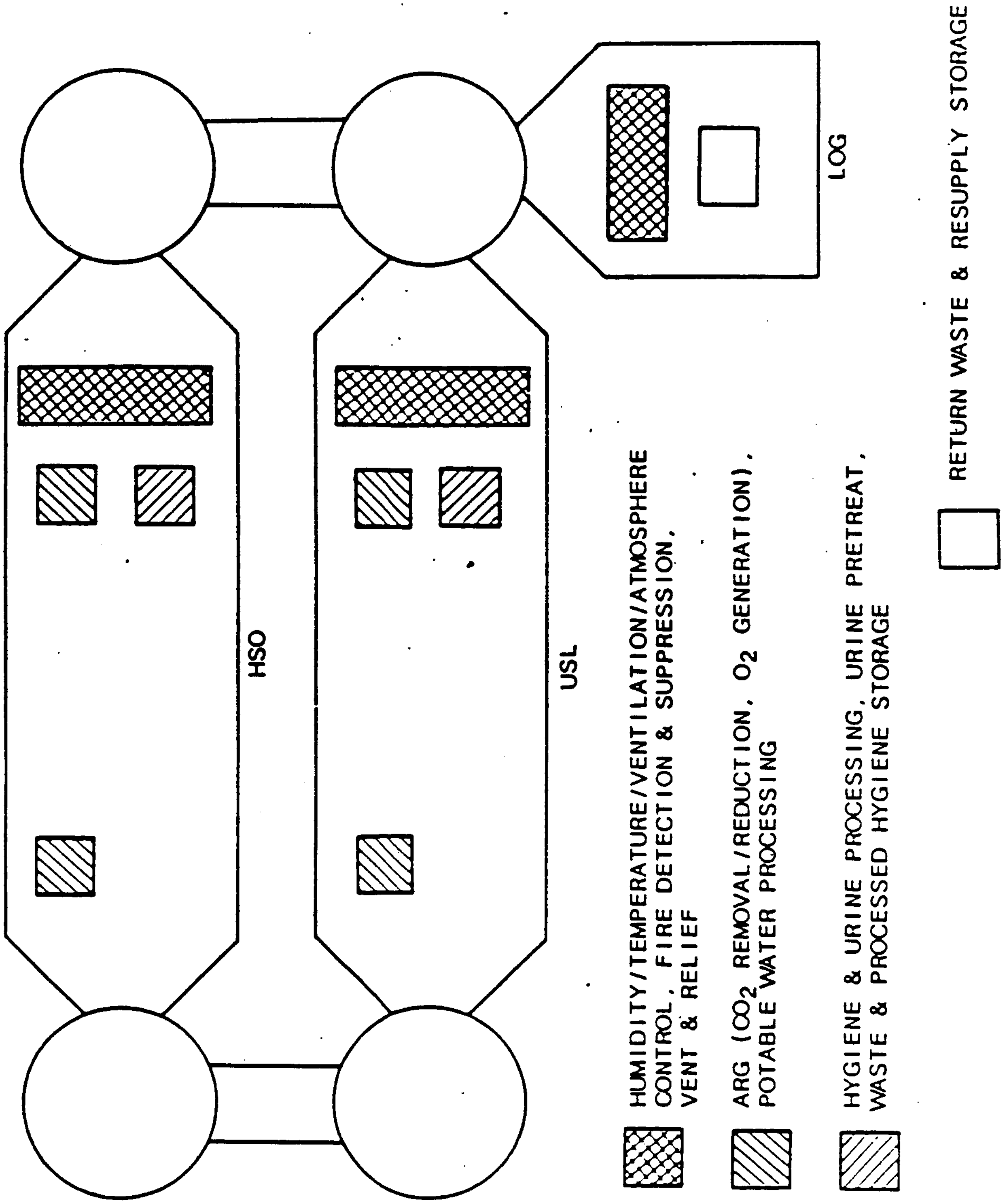

FIGURE 3.1.1-8 IOC ECLSS DISTRIBUTION

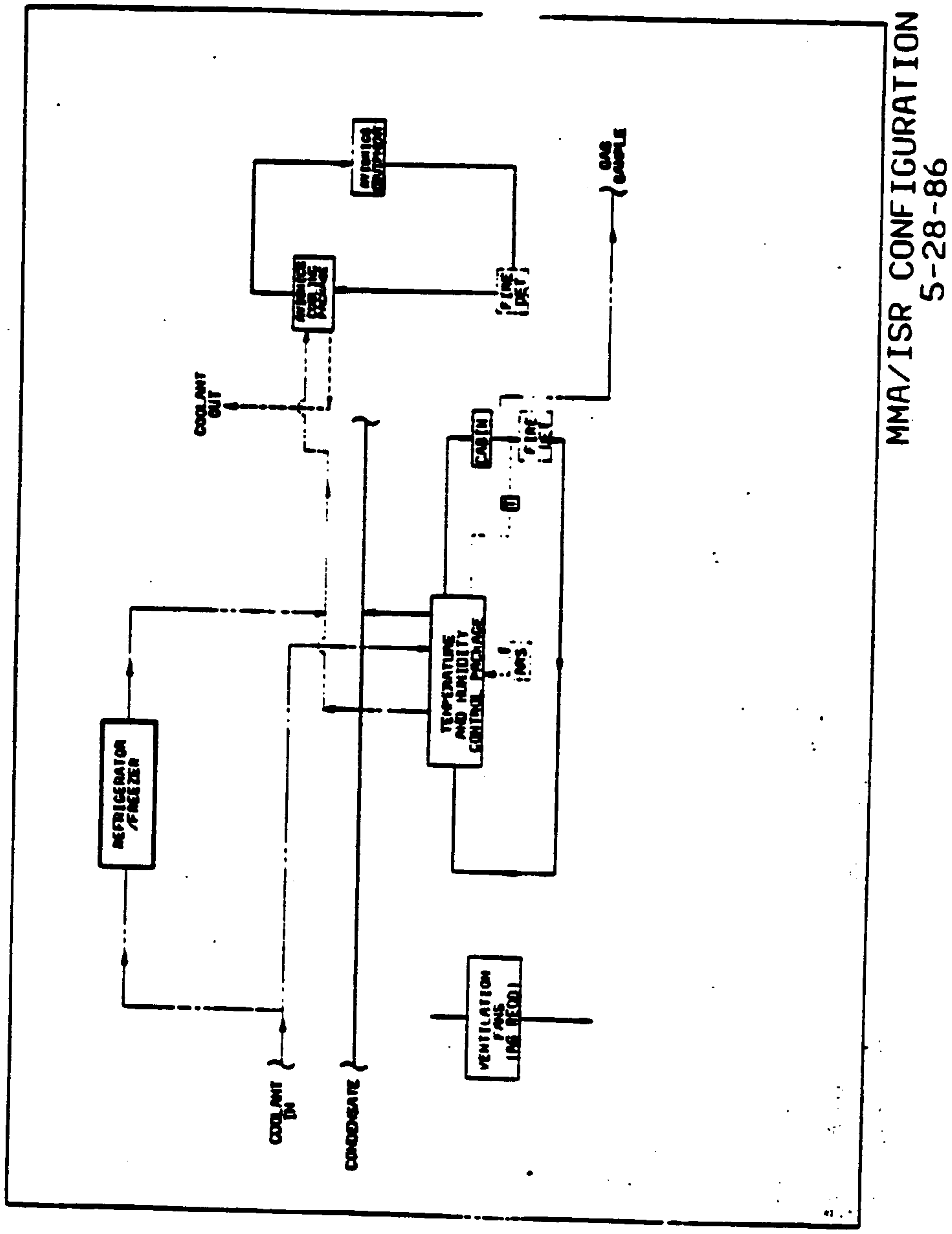

FIGURE 3.1.1-9

FUNCTIONAL SCHEMATIC CABIN AIR TEMPERATURE AND HUMIDITY CONTROL (THC)

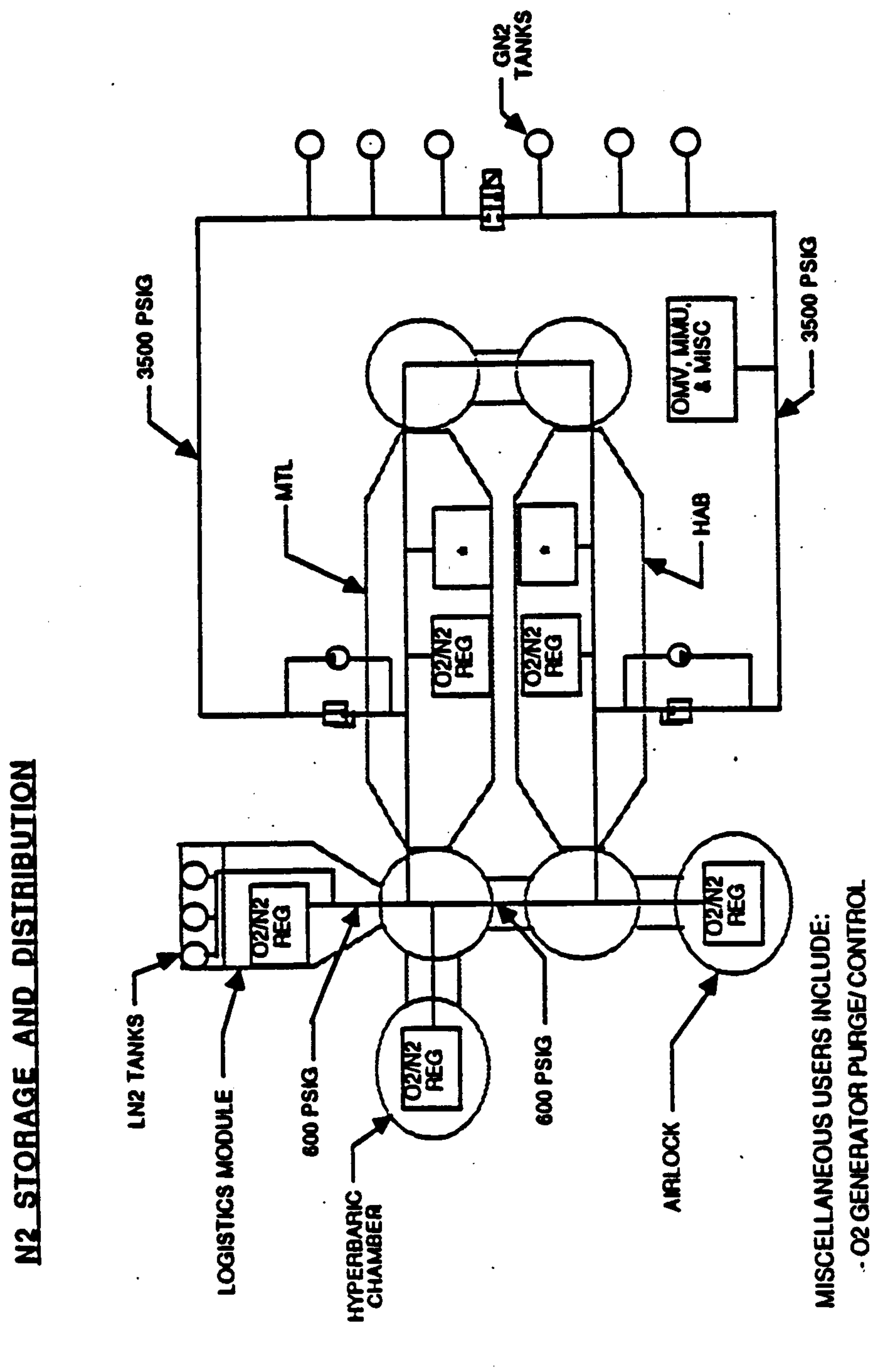

FIGURE 3.1.1-10 ATMOSPHERE CONTROL AND SUPPLY - N_2

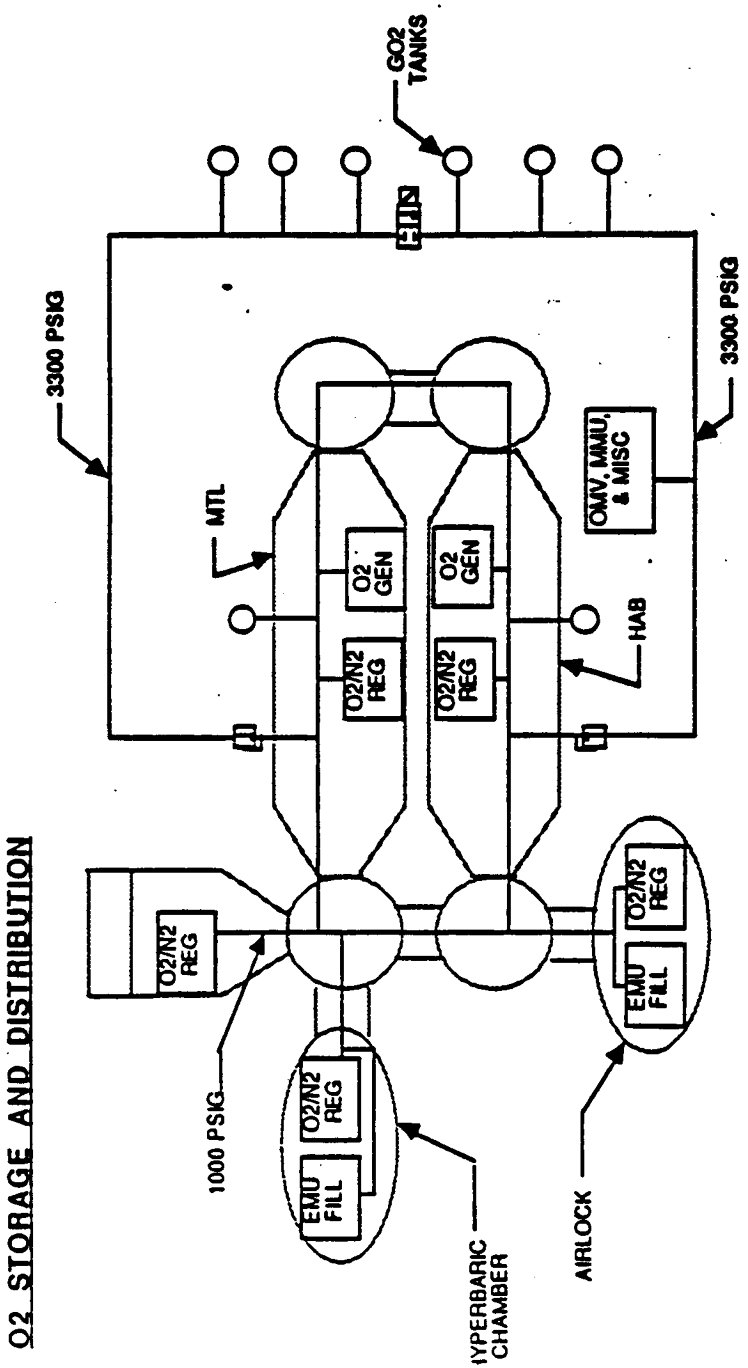

FIGURE 3.1.1-11 ATMOSPHERE CONTROL AND SUPPLY - O_2

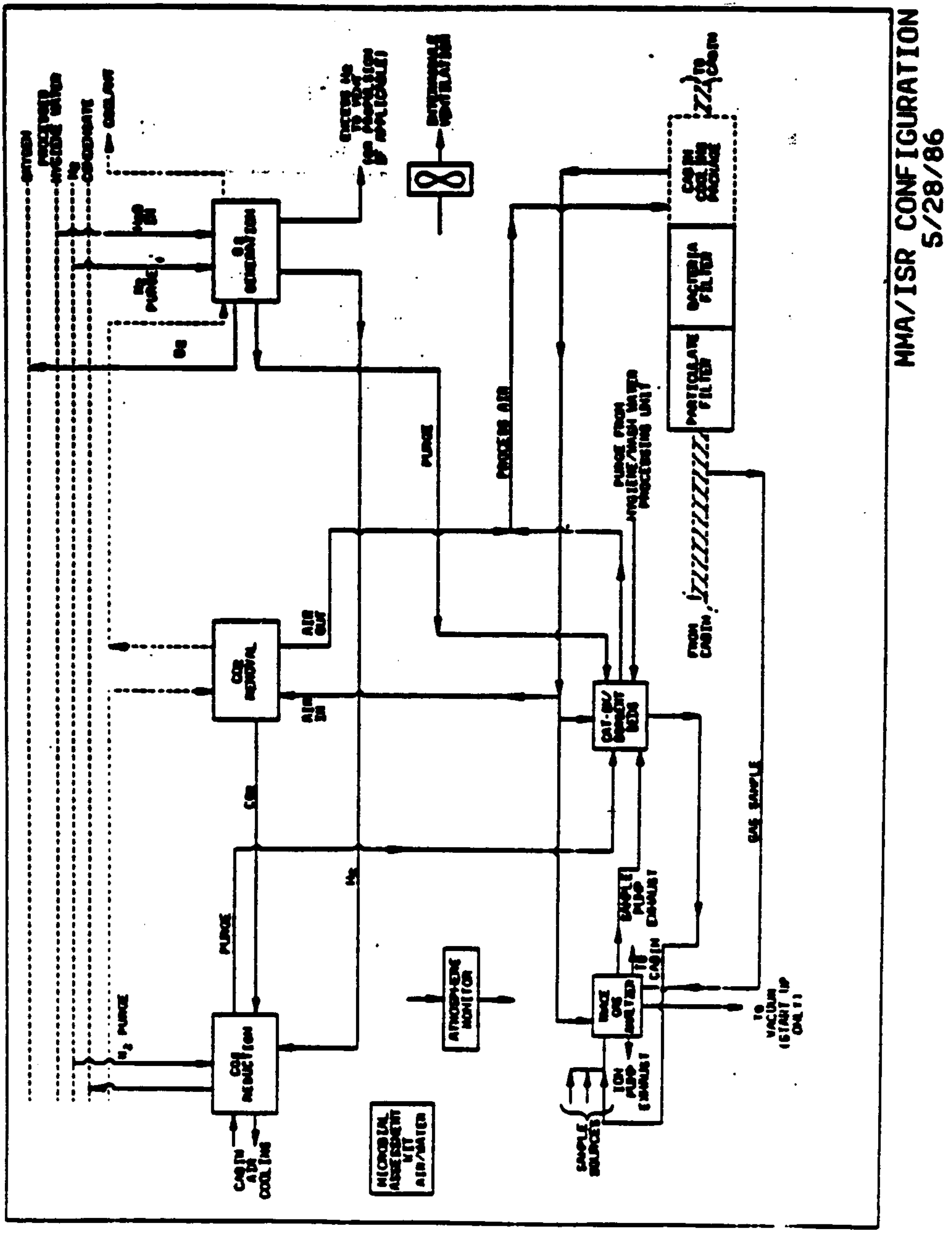

FIGURE 3.1.1-12

FUNCTIONAL SCHEMATIC ATMOSPHERE REVITALIZATION (AR)

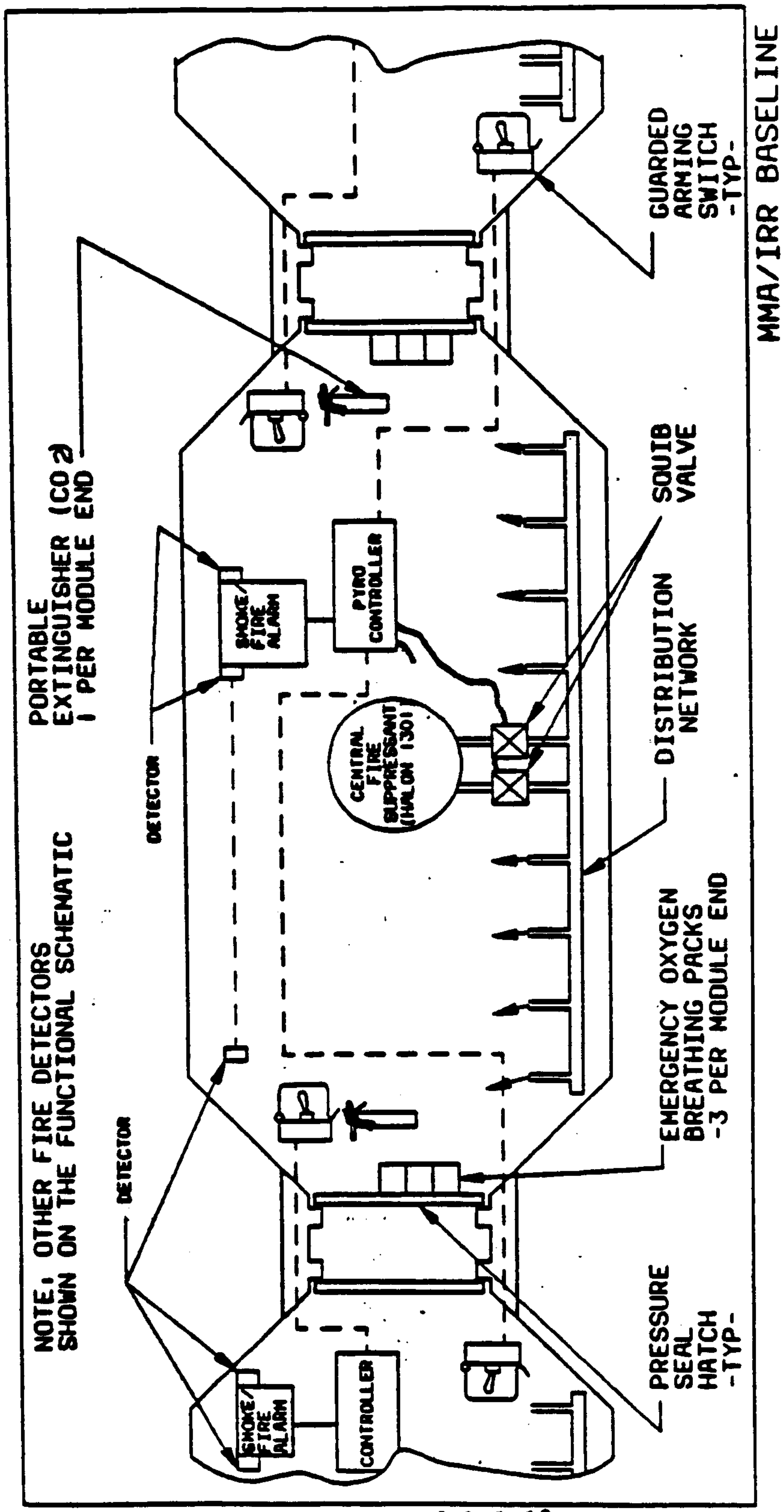

FIGURE 3.1.1-13

FUNCTIONAL SCHEMATIC FIRE DETECTION AND SUPPRESSION (FDS)

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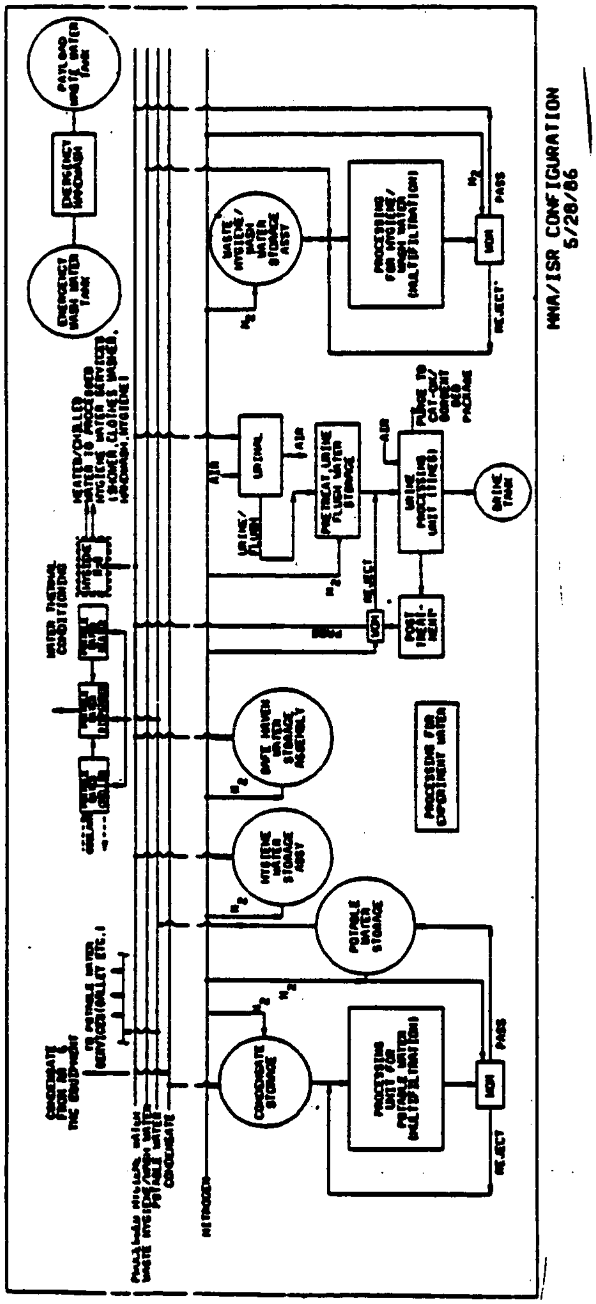


FIGURE 3.1.1-14

FUNCTIONAL SCHEMATIC WATER RECOVERY AND MANAGEMENT (WRM)

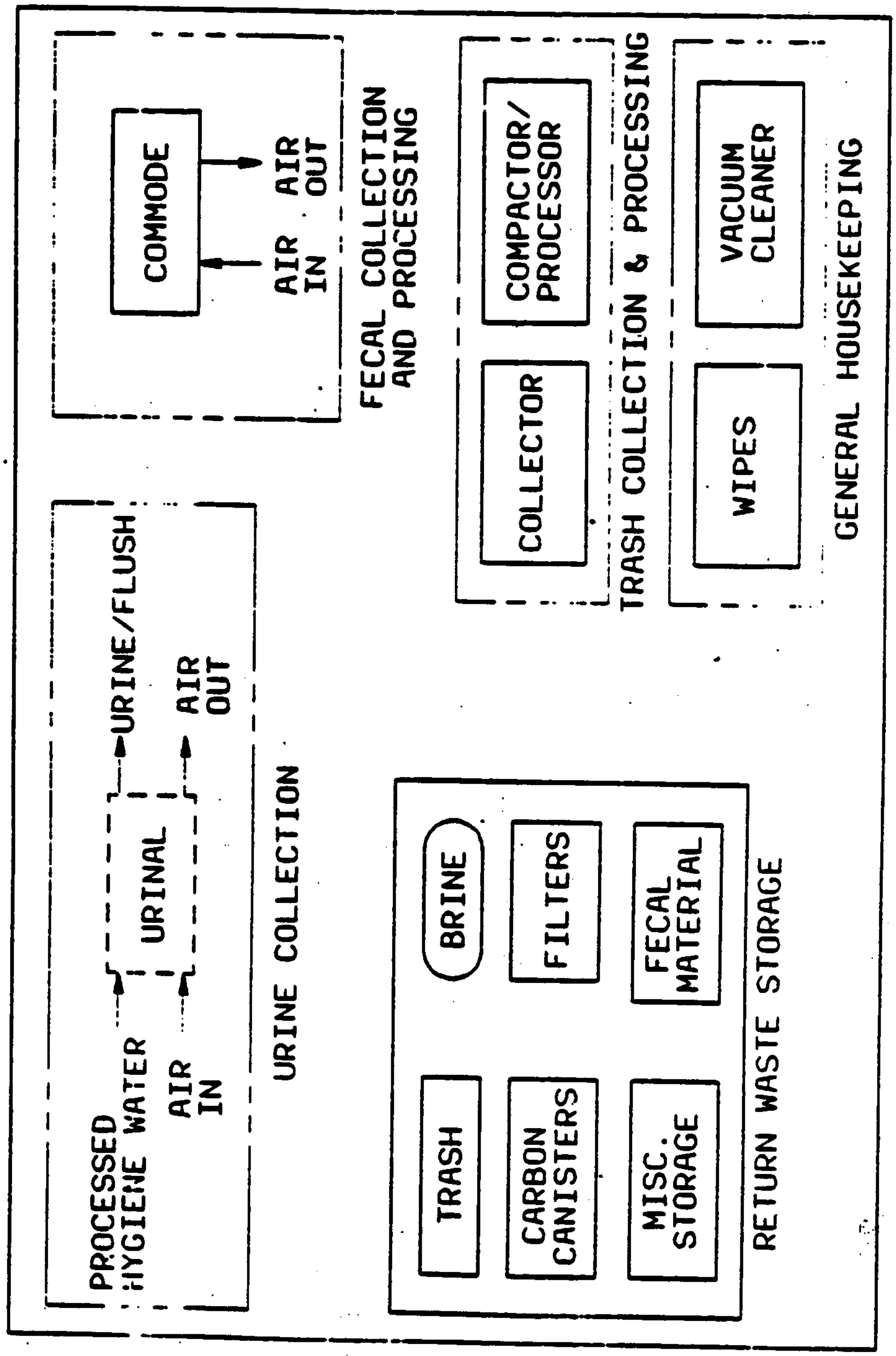
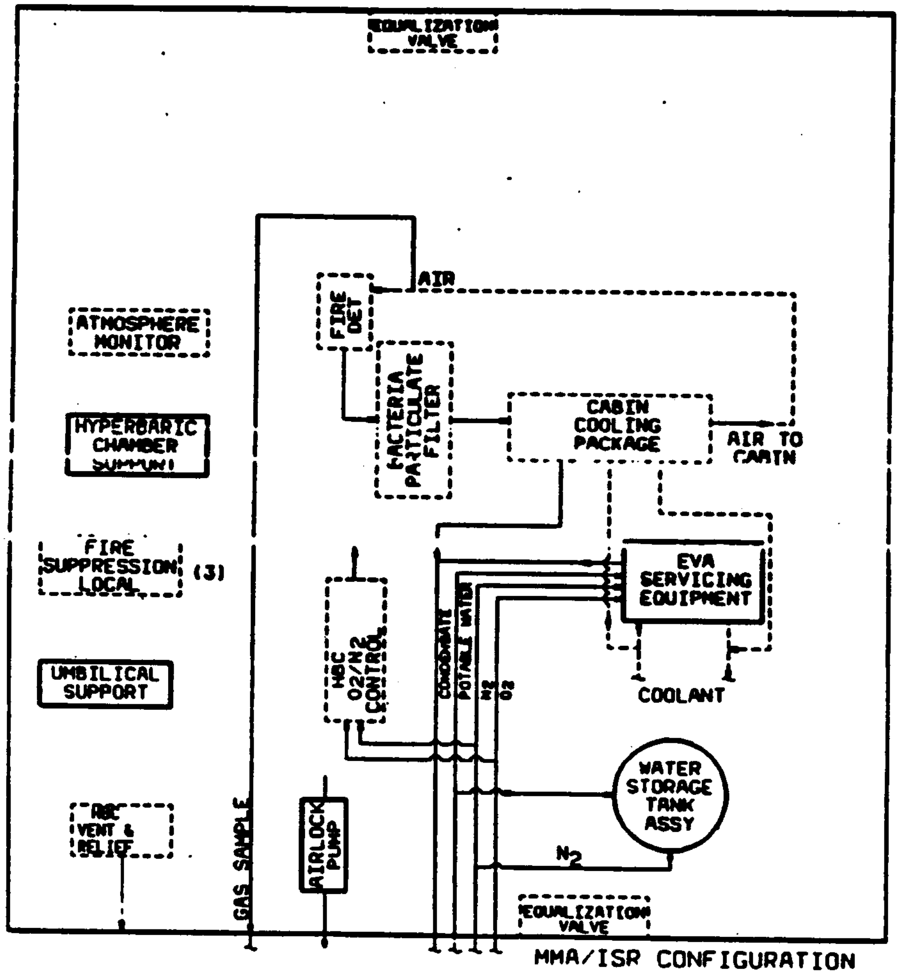


FIGURE 3.1.1-15

FUNCTIONAL SCHEMATIC WASTE MANAGEMENT (WM)



MMA/ISR CONFIGURATION
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FIGURE 3.1.1-16

FUNCTIONAL SCHEMATIC EVA SUPPORT (ES)

3.1.1.5.1 Study Efforts - The Phase B efforts focused strongly on determining the optimum overall architecture for the station to meet program objectives as well as design requirements. Efforts in ECLSS included fitting the ECLSS architecture to the overall station configuration, and evaluating specific technologies which impact the architecture of the ECLSS functional groups. ECLSS trade studies were re-evaluated as the overall station configuration evolved. Although the studies were sensitive to the configuration changes, the major findings were unchanged as a result of configuration changes.

A major trade study involving most ECLSS functions considered a centralized versus distributed architecture for location of the hardware and utility lines throughout the modules. A distinction was made between functional distribution (distribution of the function via ductwork and piping) and physical distribution (location of actual hardware). The trade included such considerations as duct size requirements for functional distribution, safe haven scenarios, and commonality as well as weight, power and volume. Results for atmosphere control and temperature and humidity control favored a distributed architecture. Air revitalization and water recovery functions were best suited to a distributed hardware concept to maximize commonality and safe haven capabilities, but included the ability to operate in a centralized manner.

The degree of ECLSS loop closure, or recycling of air and water within the station, was another major trade impacting the overall station architecture. This trade required, in addition, an evaluate of ECLS regenerable technologies. Logistics resupply requirements, and to a lesser degree the requirement for a 28 day safe haven, pointed out the importance of completely closing both the air and water loops. Evaluation of technologies currently under development support the technological capability of achieving a closed loop for ECLSS for IOC, although the present design allows partially-closed loops for the man-tended configuration.

Integration at the subsystem level was an important consideration in the overall station architecture. Martin Marietta developed an integration scheme to provide synergism between the ECLSS and propulsion systems on the station, with an equally important interface with the Orbiter. The scheme involves the use of recovered water in upsized ECLSS electrolysis units to produce oxygen and hydrogen fuel for station reboost and attitude control. Excess water from the Orbiter fuel cells is transferred to the station during docking periods to augment the potable water supply and offset the use of water for propulsion. This concept provides many advantages such as minimized logistics resupply requirements, increased commonality, and the potential for improved safety through shared redundancy and the use of a valuable Orbiter resource.

Another major architectural trade involved the cabin total pressure control. Since this parameter had major impacts on considerations such as EVA prebreathe requirements, the focus of the trade was to evaluate the impact of various pressures on the ECLSS designs, such that the ECLSS impacts could be considered in a higher level evaluation by NASA Level B. Although the impacts was not major, a single pressure control points of 14.7 was recommended.

A more complete listing of the ECLSS trade studies performed in Phase B is presented in Table 3.1.1.-1. The study options and recommendations of each trade study are included.

TABLE 3.1.1-1 ECLSS TRADE STUDIES AND ANALYSES - SUMMARY

SUBSYSTEM	TRADE STUDY	OPTIONS	RECOMMENDATION
THC	THC Concept	- Centralized - Distributed	Distributed - Minimum Weight, Volume
	Cabin Total Pressure	- Single Pressure Between 10.2 Psia and 14.7 Psia - Dual Pressure 10.2 Psia and 14.7 Psia - On-Orbit Selectable between 10.2 Psia and 14.7 Psia	Single Pressure 14.7 Psia
	Temperature/Humidity/ Vent Control	- Combined Sensible and Latent Heat Exchangers - Separate Sensible and Latent Heat Exchangers - Thermoelectric Regenerative Condenser and Sensible Heat Exchanger	Combined Latent/Sensible Heat Exchanger for Cabin Temperature and Humidity Control - Minimum Power, Weight, Volume
	Module Air Flow Approach	- Combined vs. Separate Cabin/Avionics	Separate Cabin/Avionics
	Refrigerator/Freezer	- Vapor Cycle - Thermoelectric - Direct Cooling - Air Cycle	Direct Cooling
	Heat Load Definition	----	Established maximum, nominal and minimum heat loads for cabin air, avionics air and TCS fluid loops for each module
	Fan/Heat Exchanger/Ducts Sizing	----	Preliminary Sizing Completed
	Intermodule Ventilation	- Seven Concepts Studied	Simple Fan/Duct Concept Selected

TABLE 3.1.1-1 ECLSS TRADE STUDIES AND ANALYSES - SUMMARY (Continued)

SUBSYSTEM	TRADE STUDY	OPTIONS	RECOMMENDATION
ACS	Central vs. Distributed	- All Central - Uniform Distribution - Combination	For ACS: O_2/N_2 Control Distributed Central O_2 & N_2 Storage
	Total Pressure (10.2 Psia vs. 14.7 Psia)	- One Pressure Between 10.2 and 14.7 Psia - Dual Pressure of 10.2 and 14.7 - Selectable Pressure Between 10.2 and 14.7	Select Single Pressure at 14.7
	ECLSS Concepts for Safe Haven	- Redundant ECLSS Systems for Safe Haven - Alternate Technology/Consumables for Safe Haven - Combination of Above	Installed Redundancy of Primary Technology Critical Systems to be Fail Safe in Safe Haven
	Supercritical/Subcritical N_2 Resupply	- Subcritical LN_2 Resupply - Supercritical LN_2 Resupply - PRSA - Supercritical LN_2 Resupply - New Tank	Use PRSA Technology Tanks
ARS	Centrally Distributed	- Centralized - Distributed - Combination	Combination - Distributed, Atmosphere Monitoring O_2 Generation, CO_2 Removal and Reduction, Contaminant Control are Distributed but Operate in Centralized Manner.
	Degree of Loop Closure	- Seven Options From All Expendables to Complete Loop Closure	Complete Closure of Air and Water Loops - Minimum Installed and Resupply Weight.
	Safe Haven Support	- Redundant ECLSS - Alternate Technologies - Combination	Redundant ECLSS - Minimizes Weight and Cost

TABLE 3.1.1-1 ECLSS TRADE STUDIES AND ANALYSES - SUMMARY (Continued)

SUBSYSTEM	TRADE STUDY	OPTIONS	RECOMMENDATION
	ARG Concept	- CO Removal - EDC - SAWD - LiOH - 4-Bed Mole Sieve - Hydrophobic Mole Sieve - Mole Sieve Vent-to-Vacuum - CO_2 Reduction - Sabatier - Bosch - CRS - O_2 Generation - Static Feed - Liquid Feed SPE - Kon Water Electrolysis - Water Vapor Electrolysis	CO_2 Removal - SAWD CO_2 Reduction - Bosch O_2 Generation - Static Feed SPE
	ARG Control	- CO_2 Accumulator - H_2 Accumulator - N_2 Accumulator	CO_2 Accumulator
	Contamination Control	- Expendable or Regenerable Charcoal - High Temperature, Low Temperature or Combined Catalytic Oxidizer	Expendable Charcoal with Combined HTCO, ATCO.
FDS	Fire Detection & Suppression Study	- Detector/Suppression/Cleanup Approaches for Both Localized and Major Fires	- Ionization Detectors - Localized Fires CO_2 Suppression/Cleanup by ARS - Major Fires, Halon 1301/Cleanup By Cabin Dump
WRM	Technology Selection	- Processing Technology for - Potable Water - Hygiene Water - Urine	- Multifiltration for Potable - Times for Combined Processing of Washwater and Urine

TABLE 3.1.1-1 ECLSS TRADE STUDIES AND ANALYSES - SUMMARY (Continued)

SUBSYSTEM	TRADE STUDY	OPTIONS	RECOMMENDATION
	Microbial Analysis	- Impact of Heat Disinfection - Impact of 24 and 48 Hour Hold for Monitoring	~

	Water Synergism	- Requirements for
		  - Potable
		  - Hygiene
		  - EVA
		  - Orbiter
		  - Life Sciences Experiments
		  - MTL Experiments
		  - Propulsion
		  - Regenerative Fuel Cell
			Several Distinct Loops with Common Hardware

	MTL Wastewater	- Impact of Processing Anticipated Experiment Wastewater	- Recommended Tailoring for Processing Candidates
WM	Feces	- II Concepts Evaluated	Biodegradation (ADP Testing)
	Wet Trash	- II Concepts Evaluated	Store in Freezer
	Dry Trash	- Compaction w/o Processing - Combine with Wet Trash	Combine with Wet - Difficult to Segregate
	Volume Reduction	- Compaction - Shredding	Compaction
	Waste Storage	- Storage - Jettison	Storage

TABLE I ECLSS TRADE STUDIES AND ANALYSES - SUMMARY (Continued)

SUBSYSTEM	TRADE STUDY	OPTIONS	RECOMMENDATION
EVA Support	AL/HBC Depress/Repress	Depress/Repress - To Vacuum/Consumables - To Accum/From Accum - To SS Volume/From SS Volume - Investigate Umbilical for EVA - Investigate "Other" ECLSS for AL/HBC	One Airlock One AL/HBC One Compressor Per AL HBC Vented Overboard ECLSS in AL Not Needed ECLSS in HBC Needed ECLSS Functions for EMU Servicing
	Evaluate EMU/MMU Servicing Concepts	- O_2 From Dedicated Supply - O_2 From Water Electrolysis - CO_2 to LiOH in EMU - CO_2 to ECLSS for Processing - Water From ECLSS Recovery - Water From Dedicated Supply - GN_2 From Station Supply	MMU GN_2 From External Compressor Servicing Both MMU and OMV. Station Supply O_2 From ECLSS Water Electrolysis CO_2 to LiOH (STS EMU)

3.1.1.6 Thermal Control

The CM Thermal Control Subsystem (TCS) schematic is shown in Figure 3.1.1-17. This basic 25 kW CM system consists of a single phase interior water loop for module waste heat acquisition and transport. The interior loop is coupled to the central bus via heat exchangers in all modules. The bus/module interface for the CM consists of two heat exchangers, one operating at 35°F and the other at 70°F. A redundant internal water loop will maintain critical components in the event of a failure of the primary loop.

In addition to the basic 25 kW loop shown in Figure 3.1.1-17, there will be an additional 25 kW cooling loop in the HSOM and USL modules. This system will thermally support payloads attached to the nodes. The heat rejection from this loop will be to additional central bus heat exchangers, one at 35°F and one at 70°F. The USL module will also have a special 25 kW loop which will be similar to the basic 25 kW CM loop except it will not be coupled to the ECLSS components. The special USL loop will also be coupled to the 70°F central bus. The HSOM and USL modules will each have an additional loop for refrigerator/freezers. The radiator on the HSOM will be sized to handle the LM refrigerator/freezer load as well. The refrigerator/freezer loop will be thermally coupled to body mounted low temperature radiator panels. Contact heat exchangers provide the interface between the loops and the panels.

The current TCS capability for all modules at IOC is 125 kW, which is 50 kW in excess of the 75 kW electrical power generation capability of the IOC design. The current design provides excess capability in all modules except the USL.

In general, growth of the TCS will be the addition to the Space Station of fully equipped modules. The only assembly requirements would be to couple the module TCS to the central TCS. Additional modules would necessitate the expansion of the central TCS radiators to handle the increased waste heat load.

The man-tended option should not impact the TCS. The fully automatic TCS is suitable for tended or man-tended operation. The body mounted radiators could handle the entire waste heat rejection load for the man-tended option and eliminate the need for connection to the central radiators.

3.1.1.7 CREW SYSTEMS

The man system hardware is representative of that required; final CM architecture and layout will be used to determine the customized designs for crew and equipment restraints.

Crew restraints will be provided to assist the crewmen in performing both intra-vehicular (IV) and extra-vehicular (EV) tasks, within WP-01 responsibilities. These restraints will include handholds, handrails, adjustable foot and body restraints - both fixed and portable, as required. These restraint hardware items will be provided in all Core Modules (HSO, USL, and LM) to support crew operations related to CM subsystems operations and maintenance, translation through hatches and to support OMV/OTV accommodations. Restraints for outfitted workstations, for the conduct of experiments in the USL will be provided by the module outfitter. A crew restraint concept is illustrated in Figure 3.1.1-18.

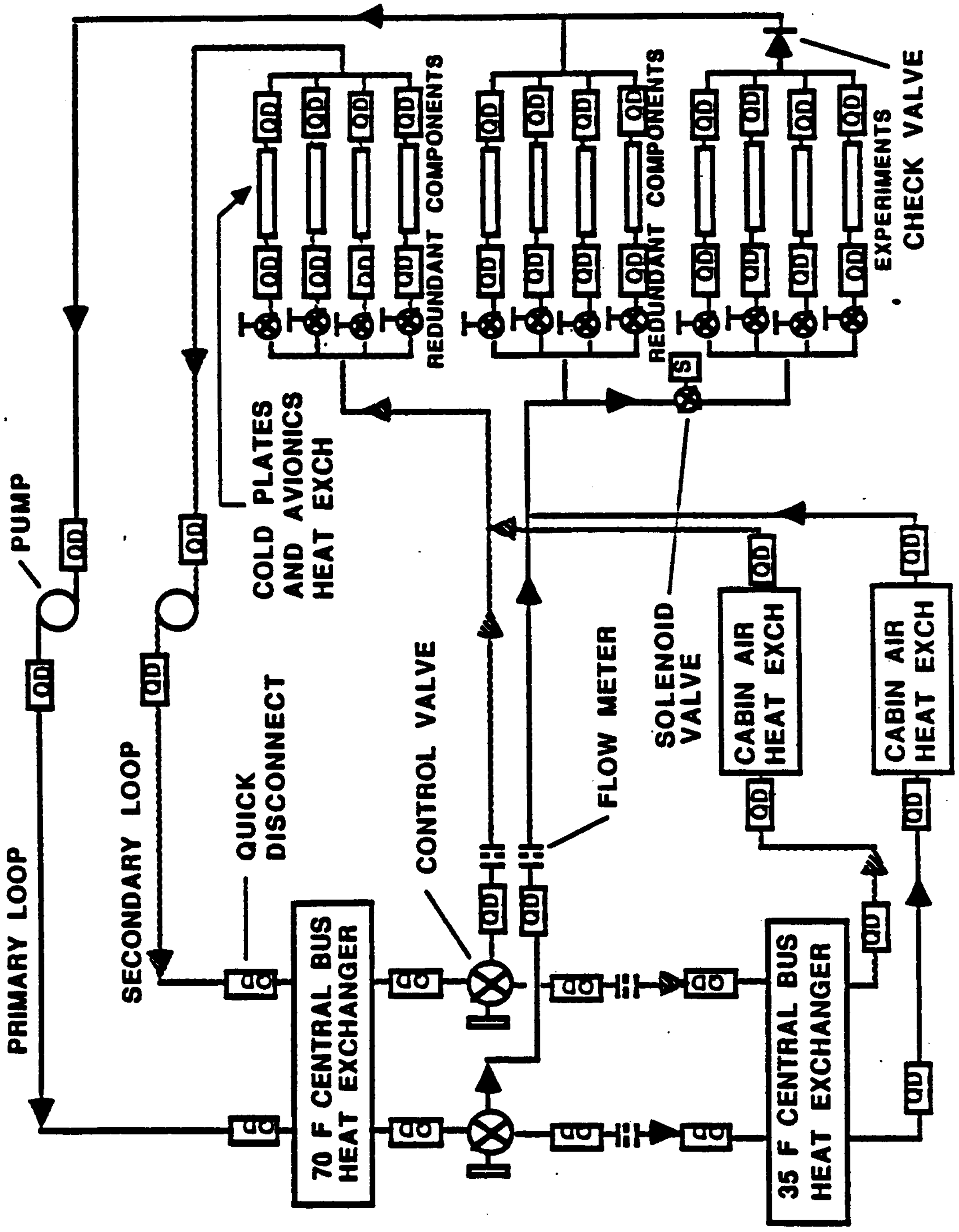

FIGURE 3.1.1-17 COMMON MODULE THERMAL CONTROL LOOP

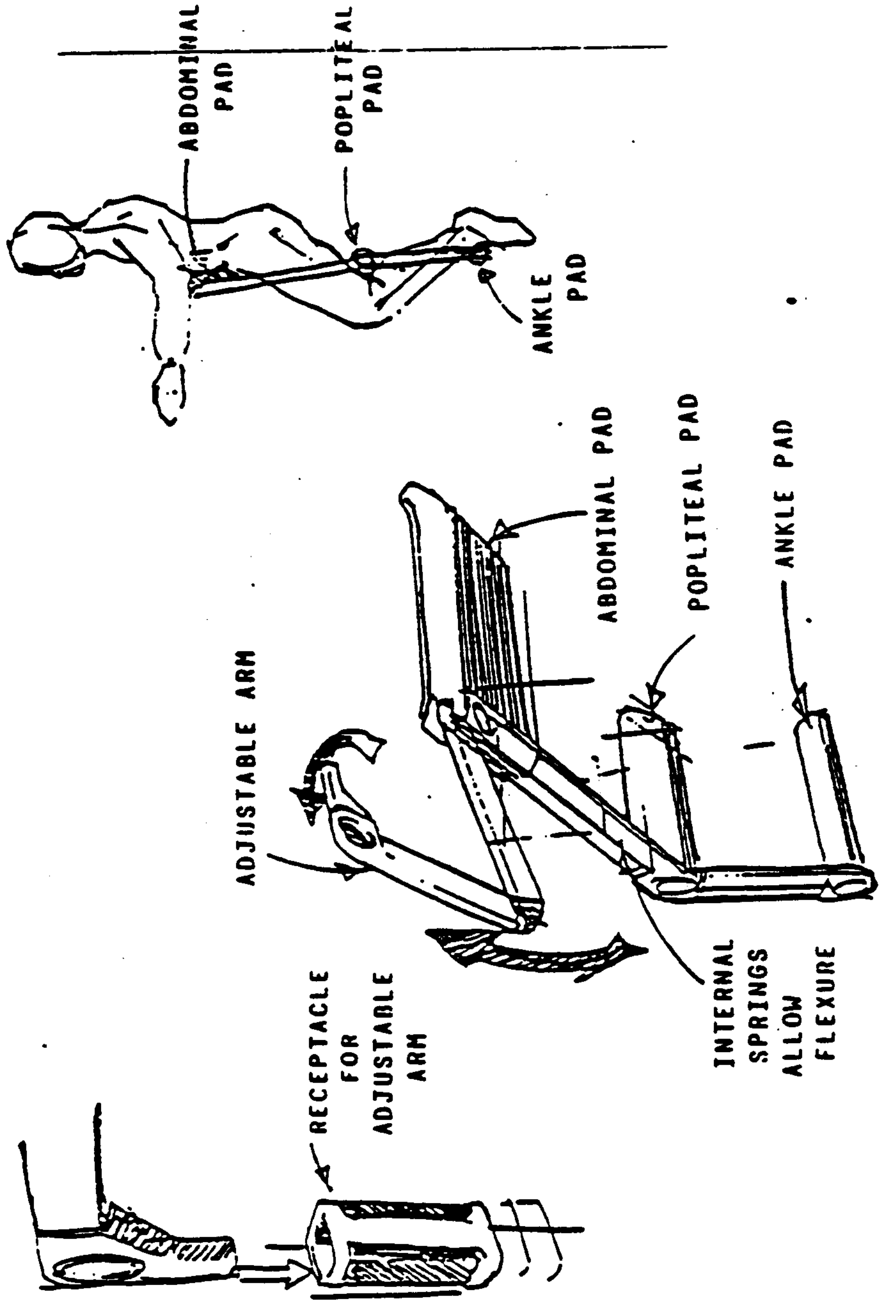

FIGURE 3.1.1-18 BODY WEDGE RESTRAINT SYSTEM

Devices used for the purpose of containing and/or restraining various types of hardware at use locations have historically been bungees and velcro. Similar devices will be utilized within the CM because of their flexibility, simplicity and adaptability for use at almost any location. Areas compatible with pre-installed hardware restraint devices will be determined via task analyses and mockup utilization as experiments, housekeeping, overhead and other crew functions are further refined. New restraint devices are being investigated to augment existing devices.

Other items of crew hardware to be provided as part of the CM include:

a. Trash Collection (trash compactor compatible)

b. Stowage Provisions

c. In-Flight Maintenance Tools and Equipment (IVA/EVA)

d. Portable Fire Extinguishers

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.

The highest level of software within the architecture is identified as Space Station Global software which includes Space Station Operating System software, Network Operating software, Space Station Data Management software and a common element; Subsystem/User Man/Machine Interface software. The Space Station Global software includes services and interfaces for subsystems and users external to the module. The operating system, data base and data base management software are unique to this level; however, it is possible that the operating system and DMS software will contain common software modules that are also used at other levels. (Reference Figure 3.1.1-19, Onboard Space Station Distributed Software Architecture.)

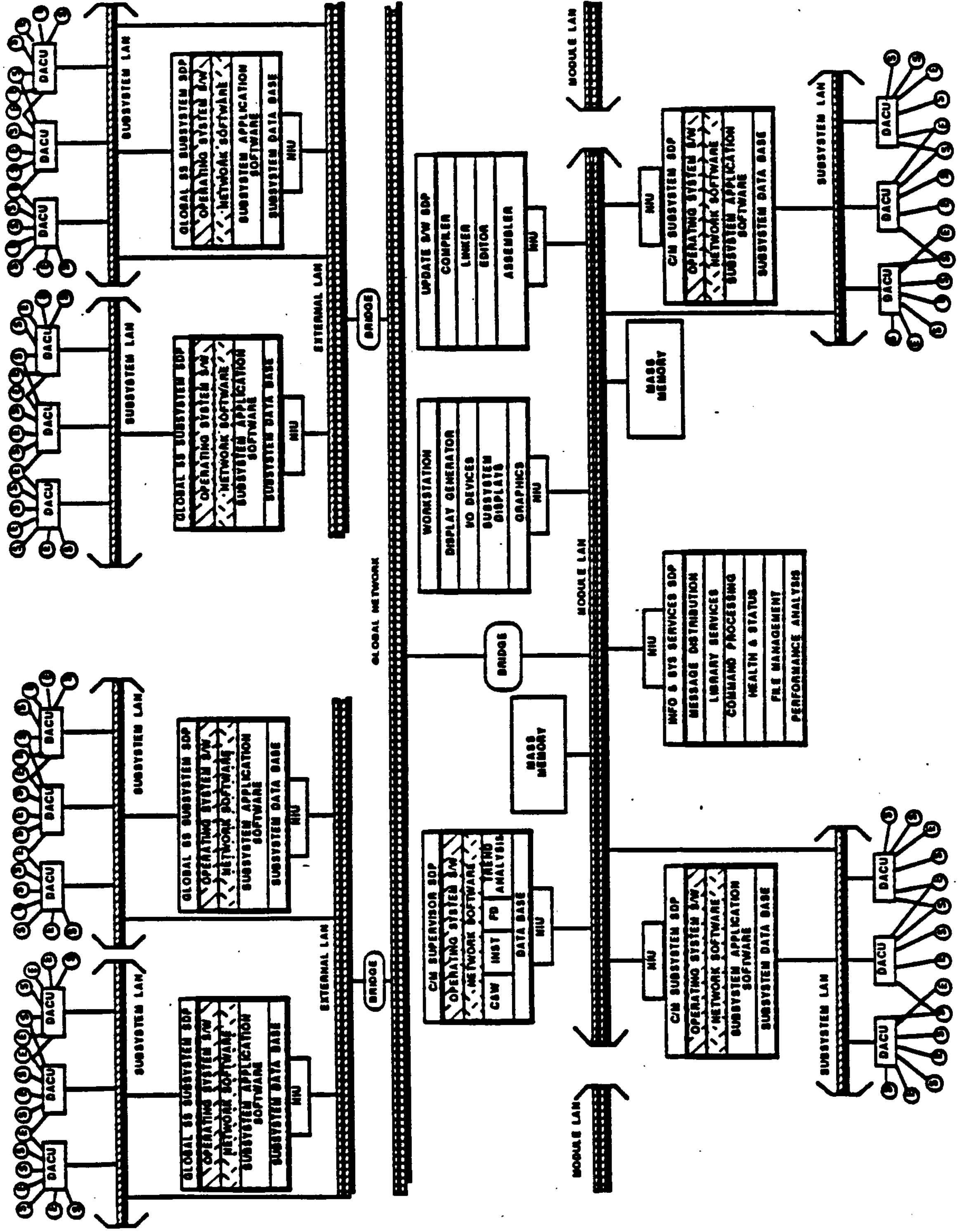

FIGURE 3.1.1-19 ON-BOARD SPACE STATION DISTRIBUTED SOFTWARE ARCHITECTURE

The second level, Core Module Data System software includes Module Operating System software, Network software, Module Support software, Module Data Base software and Subsystem/User Man/Machine Interface software. The Core Module Data System Operating System software is available for interfaces between subsystems, system health and status, software update services and support software required at the module level. The CM software allows the module to operate autonomously, if necessary, because the software provides all the interfaces and support required within the module. Interfaces between the Global software and the Core Module Data System software should be minimized.

The third level includes Subsystem/User software for both the module and the global subsystems. Both software sets perform similar functions and often have common components; however, in the first case, the software supports subsystems internal to the module and, in the second case, the support is for subsystems/users external to the CM. The software sets include common Subsystem/User Operating System software, Network software, unique Subsystem/User Data Base software and Subsystem/User Man/Machine Interface software.

The Subsystem/User Operating System software is a common set of software that is available in each subsystem/user standard data processor. It is not necessary to tailor this software for each subsystem/user. This software allows the subsystem/user software to act autonomously without interface to the higher levels.

The subsystem/user application software is specifically tailored to the needs for command control, monitor, maintenance and fault processing of the subsystem/user requirements. This software design allows the subsystem to be developed, tested, and to be operated autonomously as long as there is no requirement for subsystem external data. The Module Subsystem/Users software interfaces with the Core Module Space Station software. The Global Subsystem/Users software interfaces with the Space Station Global software.

3.2 U.S. LABORATORY

An Executive Summary of the U. S. Laboratory (USL) operations and subsystem configurations are provided in Volume II of this DR. This Volume will provide a more in depth review of the USL subsystem configuration, performance projections and a review of major trade studies and analyses which contributed to the concept selection. The information contained herein represents a summary of the data provided in the USL End-Item Data Book submitted in accordance with the requirements of DR-02. The reader is referred to this DR for additional information.

The USL hardware which support the payload are grouped into eleven subsystems which consist of:

a. Structures and Mechanisms
b. Electrical Power Subsystem (EPS)
c. Data Management Subsystem (DMS)
d. Communication
e. Environmental Control and Life Support (ECLSS)
f. Thermal Control Subsystem (TCS)
g. Manned Systems
h. Software
i. Vacuum Vent
j. Process Materials Management
k. Laboratory Support Equipment

The following sections provide descriptions of the USL subsystems and includes both Core Module and USL outfitting hardware. Emphasis has been placed on the subsystems unique to the USL and the unique aspects of the Core Module systems. Detailed descriptions of the Core Module subsystems are provided in Section 3.1.

3.2.1 Structures/Mechanisms

3.2.1.1 Assembly Configurations

The fully integrated IOC USL combined lab weight of 30858 kg exceeds the maximum USL launch weight of 16116 kg, therefore, USL outfitting will be completed on-orbit. The launch configuration, shown in Figure 3.2-1, provides basic science capability on-orbit while remaining within post 51-L Orbiter weight and C.G. limitations. Sufficient services and experiments are present on the USL launch configuration to allow operation in a man-tended mode (Figure 3.2-2). With the addition of more experiments, lab support racks, PMMS racks, and the remaining ECLS racks, the USL will support minimum permanently manned operations (Figure 3.2-3). Figure 3.2-4 shows the IOC USL combined lab configuration which has a full complement of 44 double racks. Finally, with the completion of the international Space Station, the USL will be configured as a materials processing laboratory (Figure 3.2-5).

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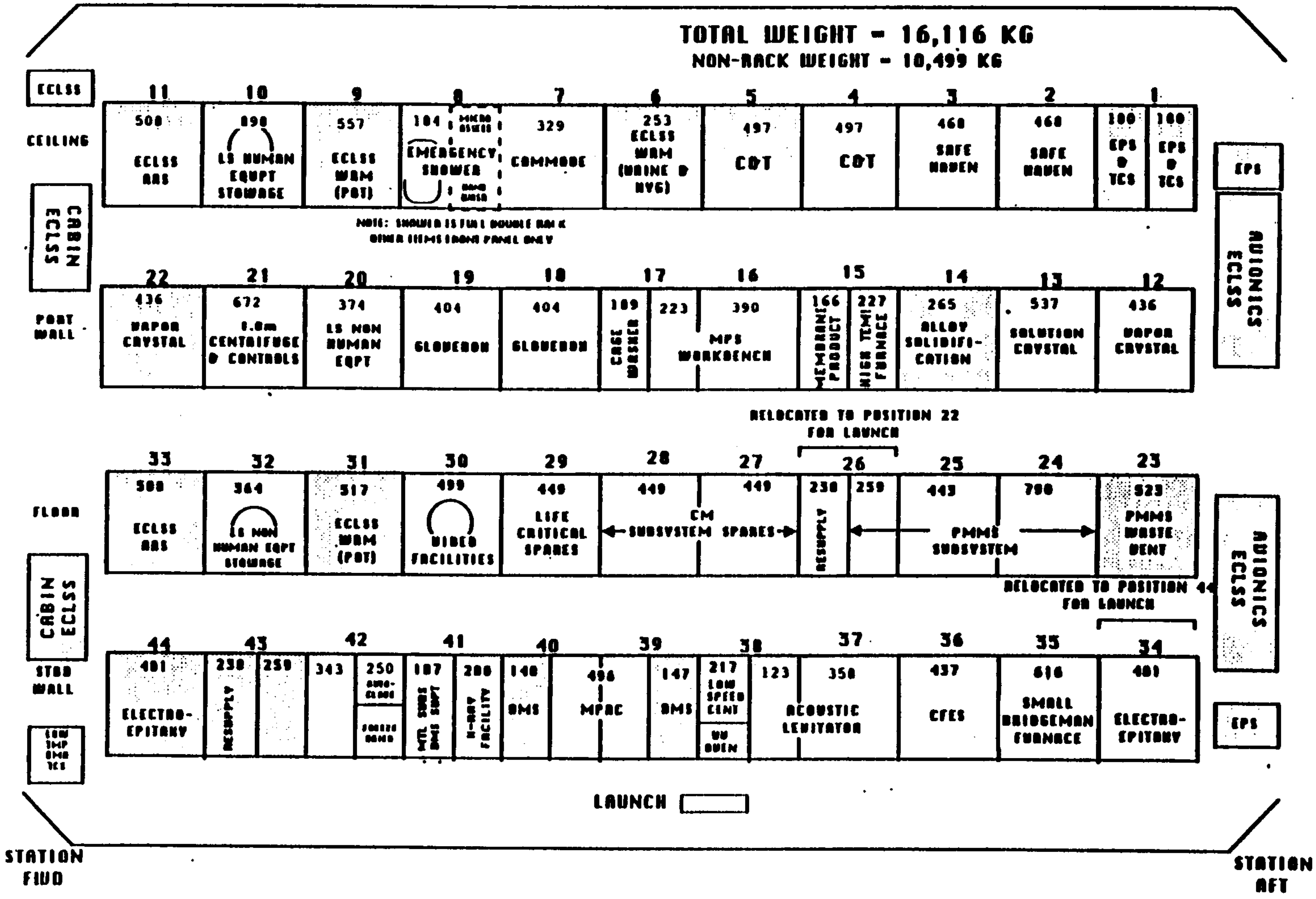

FIGURE 3.2-1 U.S. LABORATORY LAUNCH CONFIGURATION

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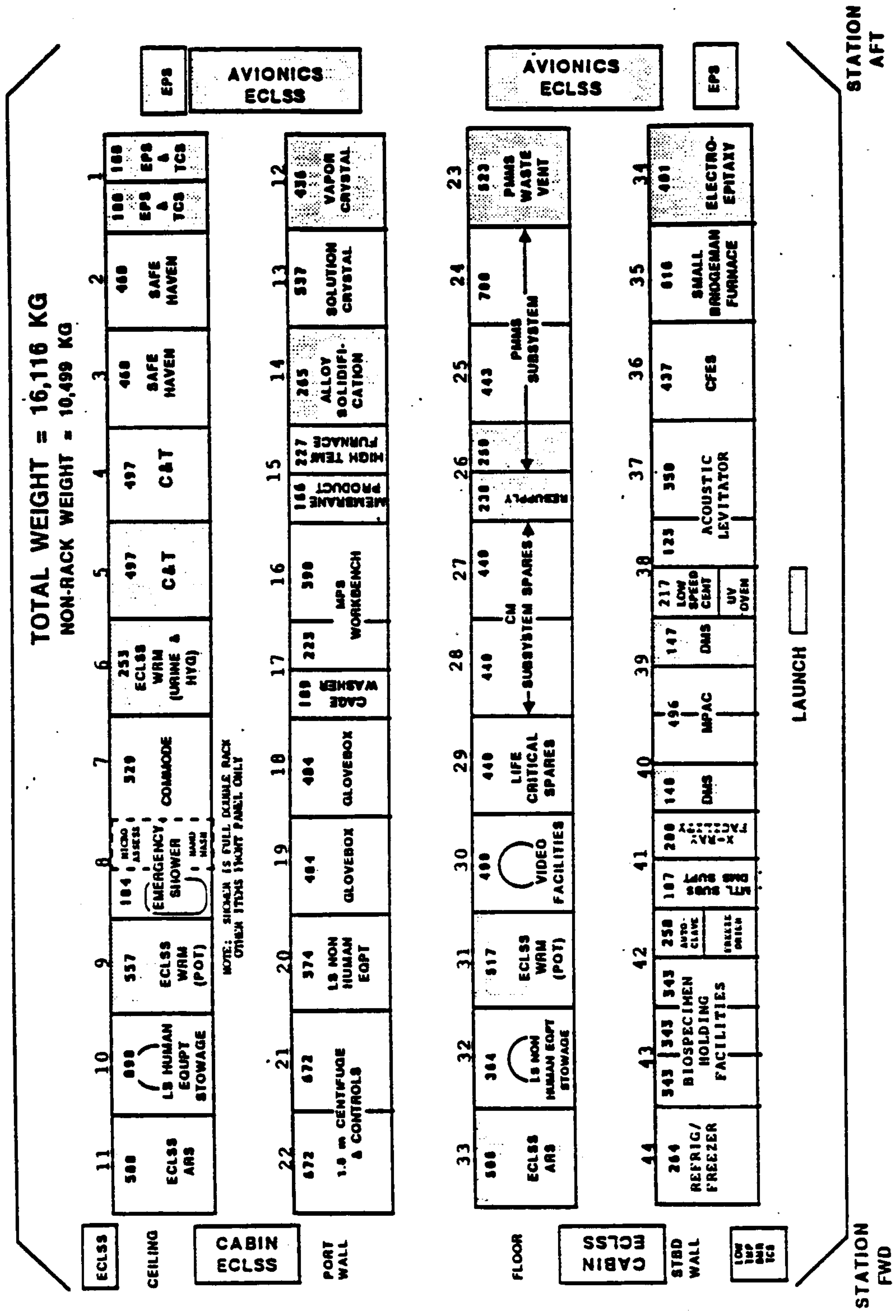

FIGURE 3.2-2 U.S. LABORATORY MAN TENDED CONFIGURATION

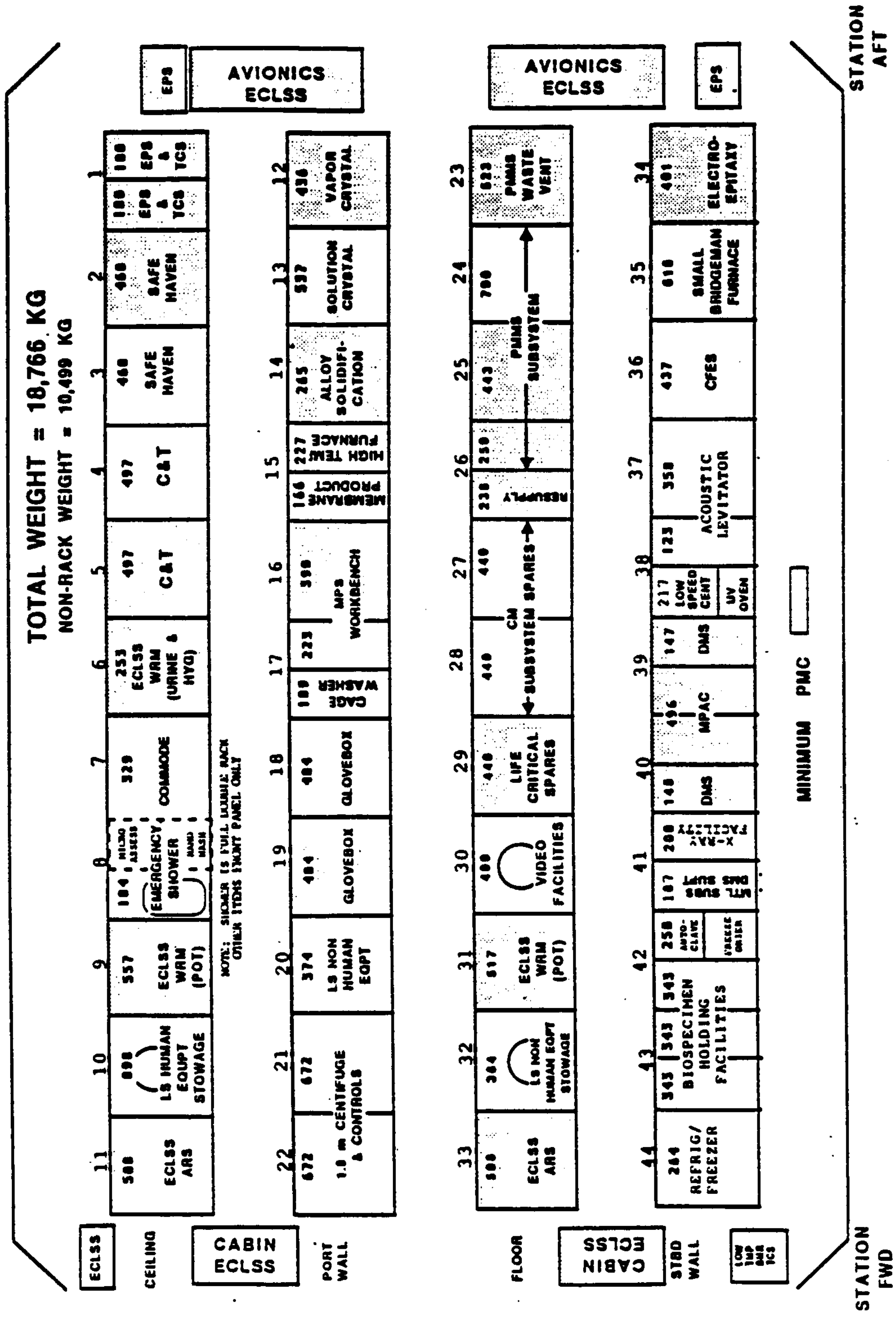

FIGURE 3.2-3 U.S. LABORATORY PERMANENTLY MANNED CONFIGURATION

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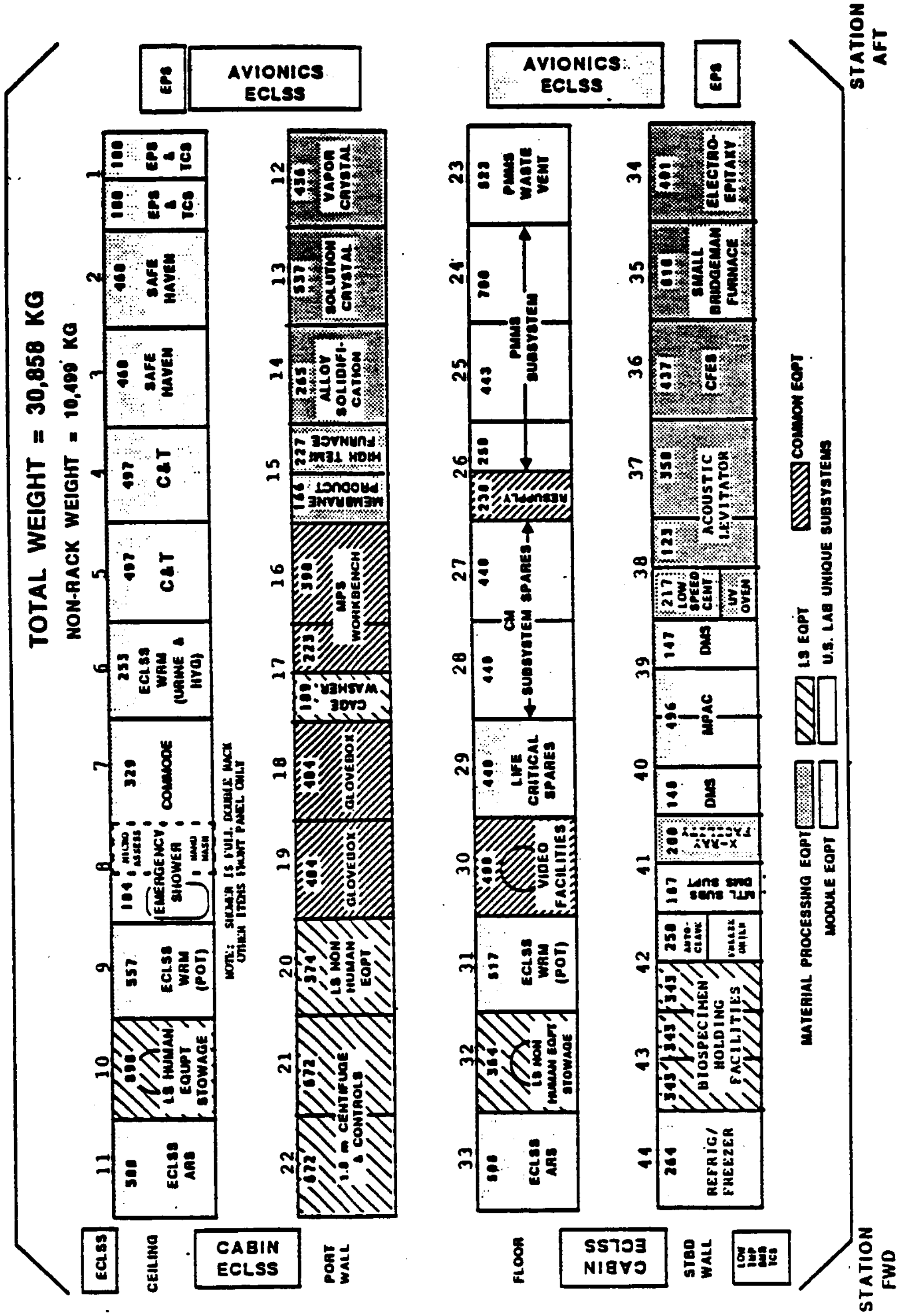


FIGURE 3.2-4 U.S. LABORATORY COMPLETED COMBINED LABORATORY

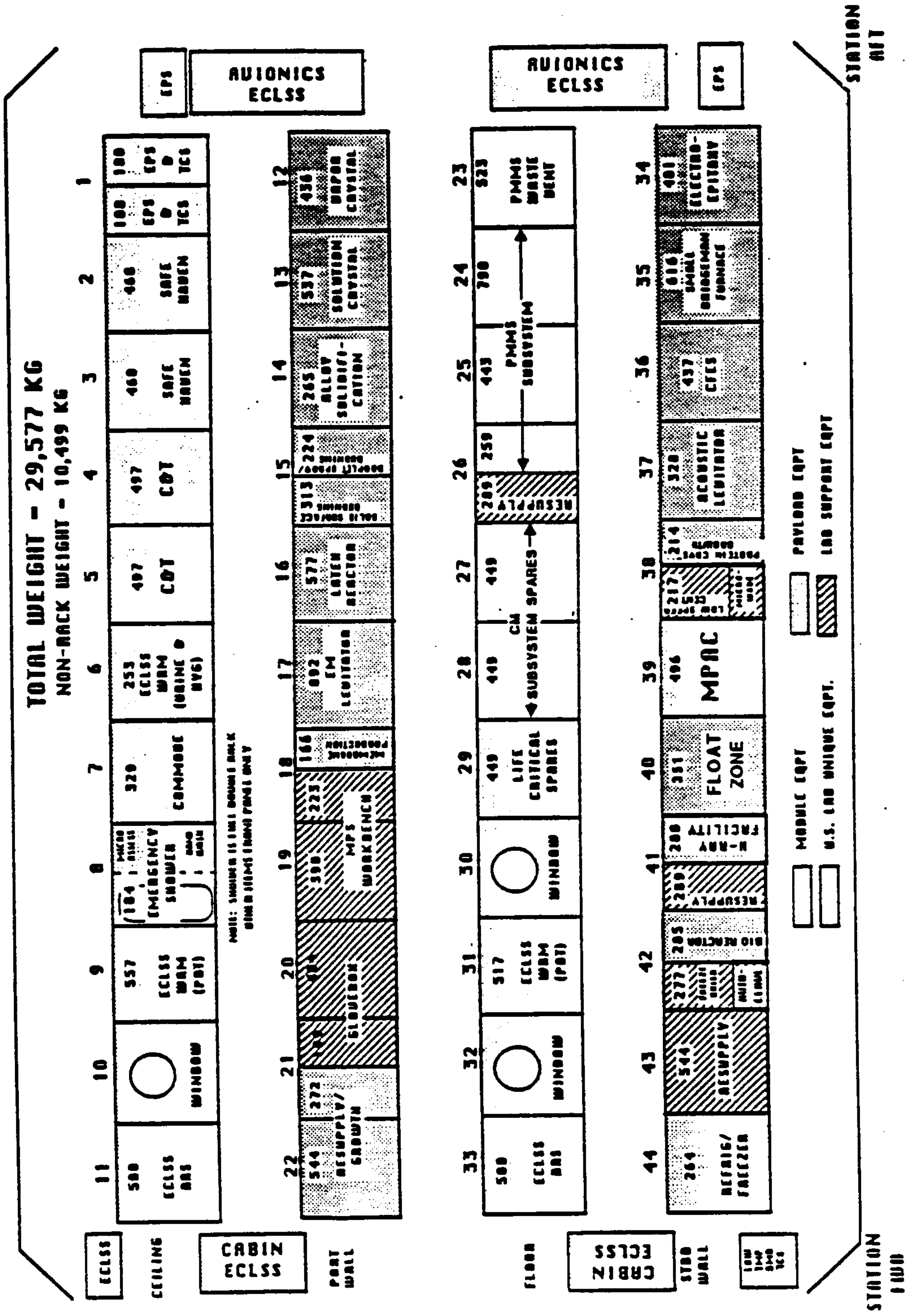


FIGURE 3.2-5 U.S. LABORATORY MATERIALS PROCESSING CONFIGURATION

3.2.1.3 USL Rack Accommodations

The USL rack will be a tilt-out design developed from the four standoff U. S. module configuration. Currently, the U. S. modules are sized to accept a 2032 mm x 1016 mm rack (to accommodate HAB module functional units); however, the USL rack size is currently 1892 mm x 965 mm, for commonality with international modules. Overall size and payload available volume for single and double racks of both heights appears in Figures 3.2-6 and 3.2-7. The rack will be an open, rigid frame with dedicated payload mounting flanges on the corner posts. Dedicated mounting flanges will also be provided along the rear of the utility routing bay. The front corner posts (and the removable center post of the double rack) will accommodate EIA-RS-310-C equipment (on both sides, for the double rack) and will provide floating, captive fasteners behind the front panel mounting flanges. Optional partial-height center posts will be available for accommodation of mixed-width payloads in double racks.

3.2.2 Electrical Power

The design of the Electrical Power Distribution Subsystem (EPDS) will provide the capability to receive, condition, monitor, protect, control and distribute redundant 50 kW of power via redundant distribution networks. Figure 3.2-8 shows the USL power distribution functional block diagram.

Primary power from Space Station will interface with the USL via redundant penetrations each capable of providing 50 kW. Transformer Assemblies (TA) located at each penetration will convert Space Station primary power (440 VAC, 20 kHz, single phase) to internal distribution power (208 VAC, 20 kHz, single phase). Power outputs from the TA will be routed to the Primary Power Distribution Assemblies (PPDA) via 50 kW power lines. The PPDA will accept power from the TA, and control, protect and distribute power to the Secondary Power Distribution Assembly (SPDA) and the module -ports. The SPDA will control and distribute power to the USL rack interface. The SPDA will provide protection for input and output power ports.

Power control and distribution within the racks will be provided by the Rack Power Control Unit (RPCU) which will be located in the base of those racks requiring power. Figure 3.2-8 shows the RPCU Functional Diagram. The RPCU will accept dual inputs and provide protection for input and output power ports. The function of the RPCU will be to distribute and control power within a rack. Each RPCU will nominally be capable of distributing 4 kW redundant power. The RPCU will receive and distribute power from the SPDA and will be the principle source of overload protection within the payload racks. The RPCU will provide power to all rack users including payloads, subsystems, support equipment, Local Controller (LC), Portable Multi-Purpose Applications Console (PMPAC), and various sensors and effectors.

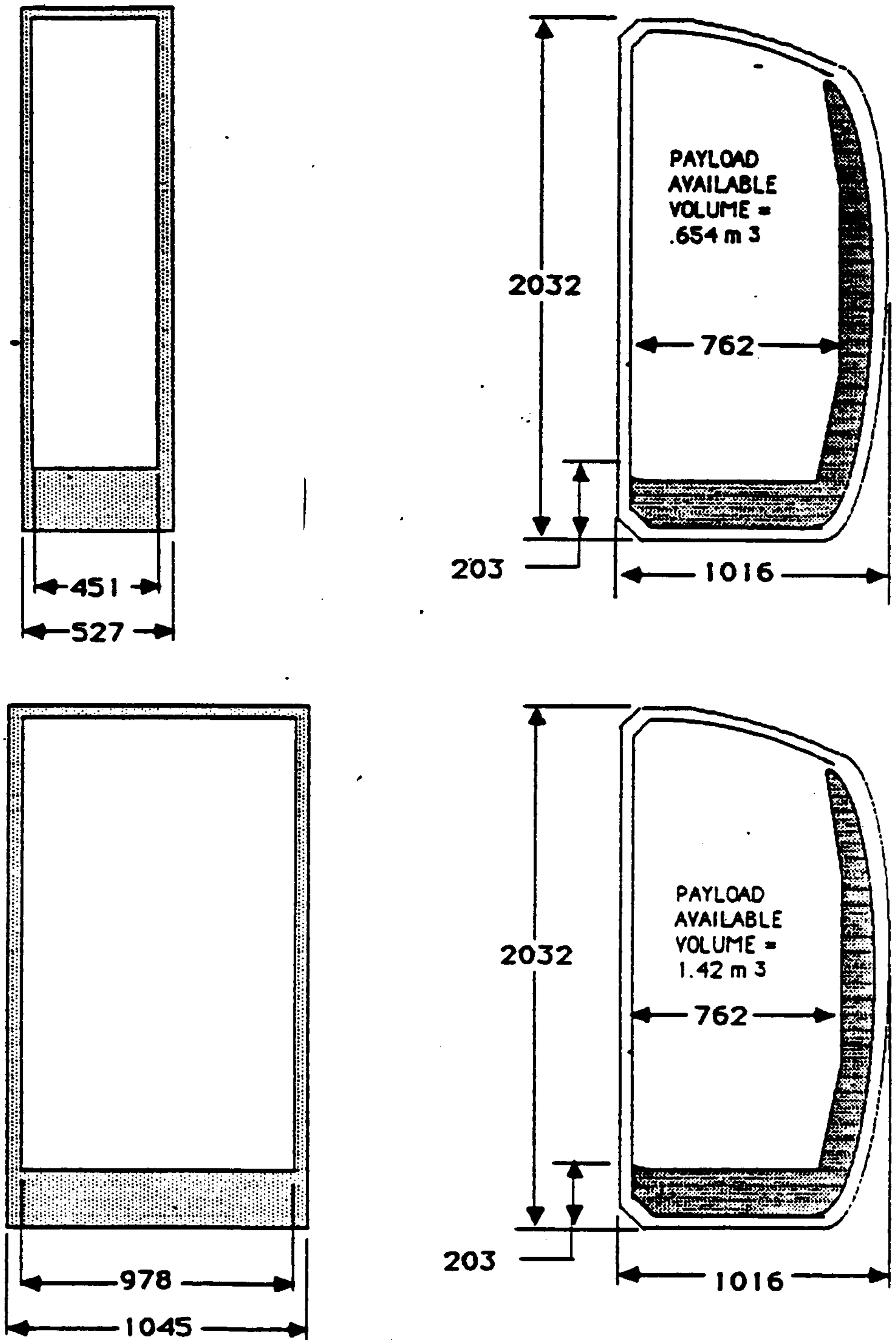


FIGURE 3.2-6 PAYLOAD ACCOMMODATIONS 80-INCH RACK

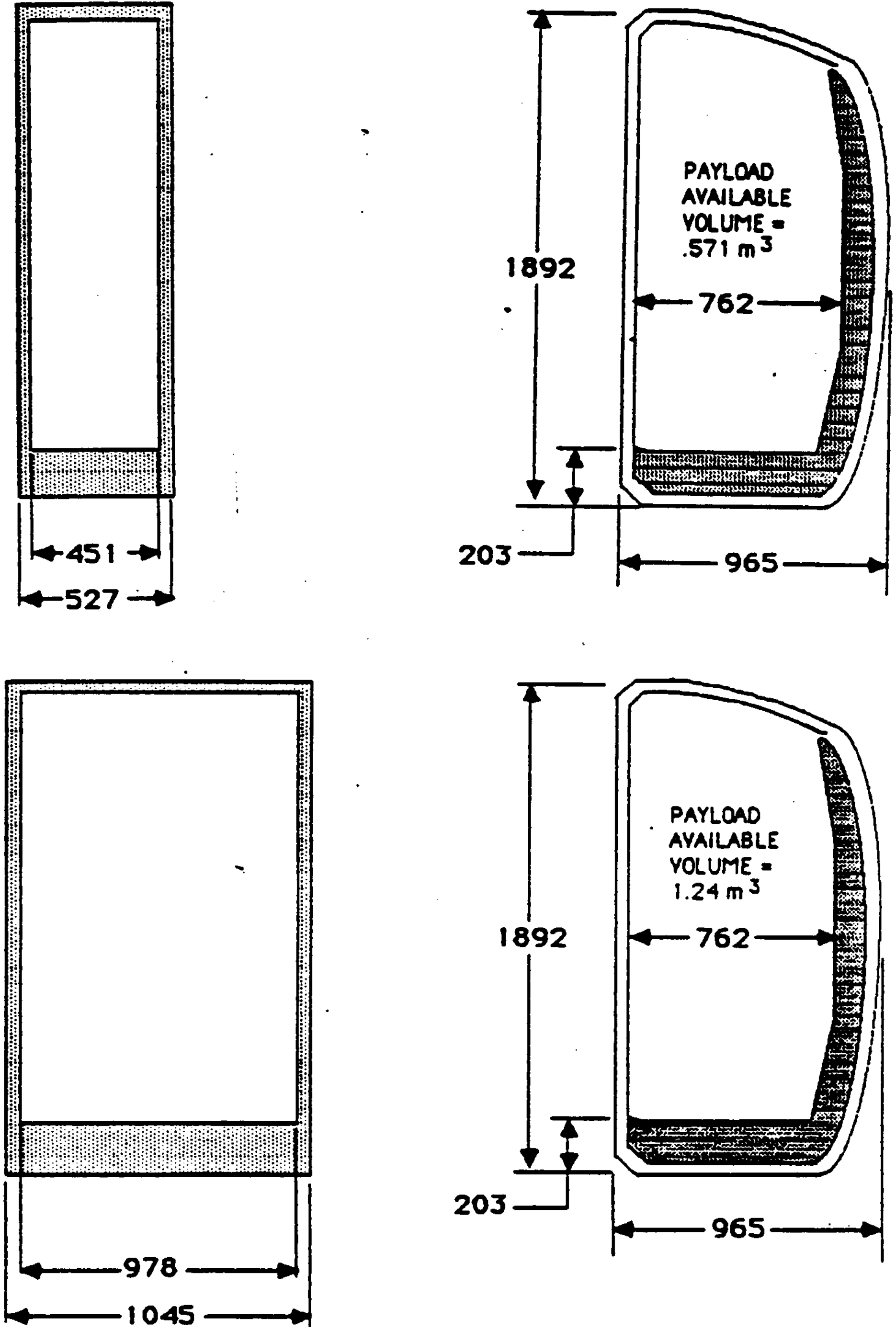
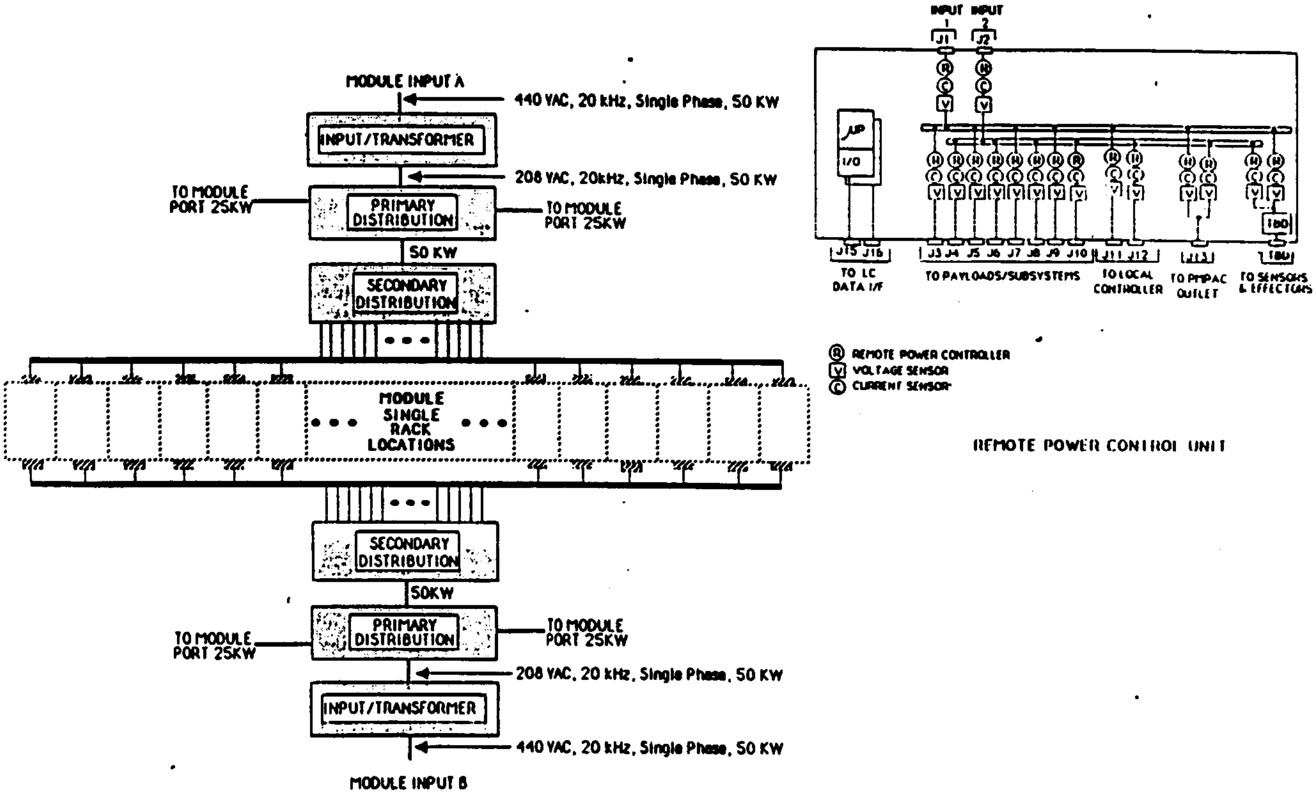


FIGURE 3.2-7 PAYLOAD ACCOMMODATIONS 74.5-INCH RACK



REMOTE POWER CONTROL UNIT

FIGURE 3.2-8 U.S. LABORATORY ELECTRICAL POWER

Payload Rack Power Control will be accomplished by switching devices within the RPCU under the direct control of the RPCU microprocessor. Switching commands will be relayed to the RPCU microprocessor via the payload rack local controller which will have hardwired interfaces to payload processors within the rack and bus (fiber-optic or coax) interfaces with payload support, characterization and subsystem controllers. This system will allow automated switching of equipment upon command of payload or subsystem controllers and for the coordination of such switching with the EPDS processor for purposes of statusing and forecasting.

Power requirements for payload facilities and payload support equipment range from 10 W to 15 kW. The output power sizing was established by analyzing the MMPF and USL data bases which show that approximately 85% of the user requirements are met with 1 kW outputs and over 90% of the user requirements are met with a combination of 1 kW and 3 kW outputs. The remaining user requirements can be met with enhanced power combinations of 6 kW and 15 kW.

The following assumptions were made for determining the RPCU output requirements:

a. A typical rack configuration may include as many as four payloads.
b. Payloads will require single phase power.
c. Total payload power per low power rack will be 3 kW maximum.
d. Total payload power per high power rack will be 15 kW maximum.

Total payload outputs were therefore established at eight 208 VAC, 20 kHz, single phase, power outputs. The following is a breakdown of these.

a. Low power rack

  1. Three 1 kW outputs via bus A
  2. Three 1 kW outputs via bus B
  3. One 3 kW output via bus A
  4. One 3 kW output via bus B

b. High power rack

  1. Two 6 kW outputs via bus A
  2. Two 6 kW outputs via bus B
  3. Two 15 kW outputs via bus A
  4. Two 15 kW outputs via bus B

The outputs derived from the two busses A and B are provided to meet the user redundancy requirements. These busses cannot be combined but must either be used for redundancy with the payload supplying adequate switching to the redundant bus or may be used by a payload not requiring redundancy provided the busses are supplying separate isolated loads.

3.2.3 Data Management

The USL Data Management System (DMS) as shown in Figure 3.2-9 will be a distributed processing system which consists of dedicated subsystem processors and peripherals which are interconnected by way of a Local Area Network (LAN) for data transfer between the different DMS elements.

The DMS interfaces with the Space Station basic LAN through a data bridge for the transfer of data and commands between the USL and other Space Station program elements and the ground.

The subsystem data bus provides for the transfer of command and control, random access data, deterministic data and time and frequency.

The payload LAN provides for the transfer of payload commands and data between the USL payloads, and internal data entry/display devices and the ground.

DMS peripherals will consist of a Fixed and Portable Multi-Purpose Applications Console (FMPAC and PMPACS)) which will provide for data entry and display (including hardcopy) and a mass memory, which will provide storage for data and programs.

The USL DMS will consist of the following principal elements:

a. Workstations
b. Mass Memory
c. Caution and Warning
f. Instrumentation
g. Customer Facility Support Processor
h. Laboratory Support Processor
i. Local controllers
j. Subsystem Processors

Two types of workstations, a Fixed Multi-Purpose Applications Console (FMPAC) and a Portable Multi-Purpose Application Console (PMPAC), will support laboratory operations including subsystem command and control and payload activation, monitoring and control. These workstations can also provide command and control functions for non-laboratory station functions for contingency situations or for crew convenience.

The mass memory will interface with the USL LAN through an NIU and provide for the storage of payload and subsystem programs and data. The current baseline provides nine G bytes of mass storage to support laboratory operations.

The Caution and Warning DMS functions will interface with selected subsystem and payload sensors to provide for the display of subsystem and payload off-nominal status and general emergencies including contamination release and fire.

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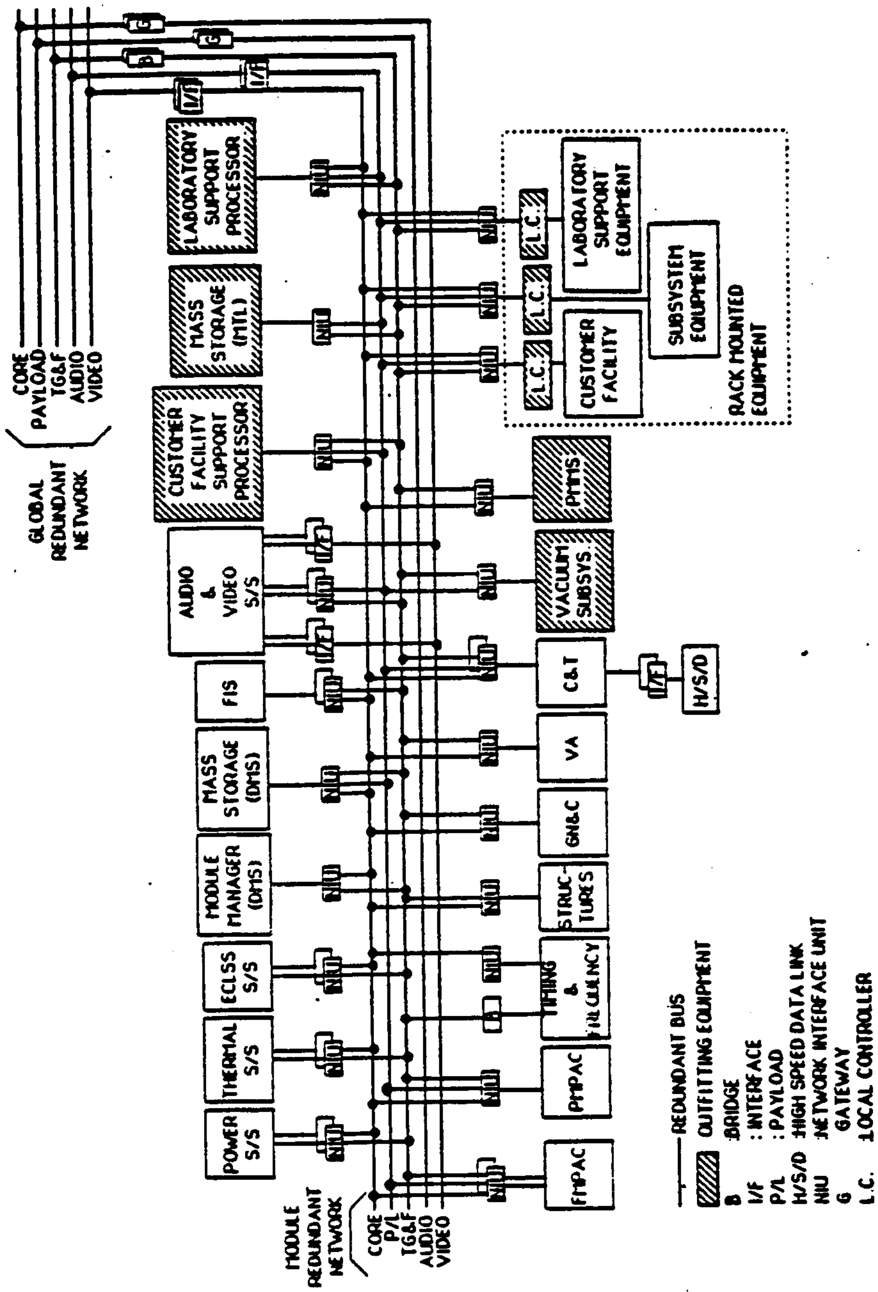

FIGURE 3.2-9 U.S. LABORATORY DATA MANAGEMENT

The instrumentation consists of sensors, transducers, valve and mechanism position and interlock status, and multiplexers which will be used for the collection of subsystem and payload data. The collected data will be transferred to the Data Management System (DMS) through instrumentation interfaces to the USL LAN for the purpose of on-board or ground analysis and verification of payload and subsystem health.

The Customer Facility Support Processor (CFSP) will provide processing functions for the support of payload operations within the USL under software control as described in Section 3.2.8 of this Volume. The processor hardware is common to the other space station module executive processors which are elements of the station distributed DMS architecture. The functions under the control of the CFSP include payload scheduling and resource conflict resolution.

The Laboratory Support Processor (LSP) will provide standard interfaces including RS 170 (video) RS 232, IEEE 488 (digital) and computational processing functions including data analysis, data base storage and retrieval and equipment monitor and control for the USL or user provided characterization, process support and automation equipment identified in Section 3.2.13 of this Volume.

Payloads, lab support equipment, and rack mounted subsystem equipment will interface with the LC which will provide data multiplexing and standard interfaces including RS 232, RS 422, IEEE 488, discrete input/output (DI/DO) and analog input/output (AI/AO) for the transfer of commands and data between the payloads and rack mounted equipment to other DMS equipment, and the ground via the USL module LAN.

3.2.4 Communications and Tracking

The USL Communications and Tracking System supports laboratory operations primarily through communications functions. These functions consist of the video and audio equipment configured as shown in Figure 3.2-10. These functions in conjunction with the DMS are considered key to the efficient and effective utilization of the USL by the user community.

The USL audio functions are provided by a multi-channel multi-access wireless (infrared) communications subsystem which is provided by the core module (see Section 3.1 for additional hardware information). Through this system the USL crew may be in continuous contact with fellow crewmembers within the lab, within other modules, with crew performing EVA operations, and with ground personnel including USL or station systems support personnel and the experiment/facility principal investigators.

The video communications elements provided by the Core Module include surveillance cameras both within and external to the USL, camera interfaces at

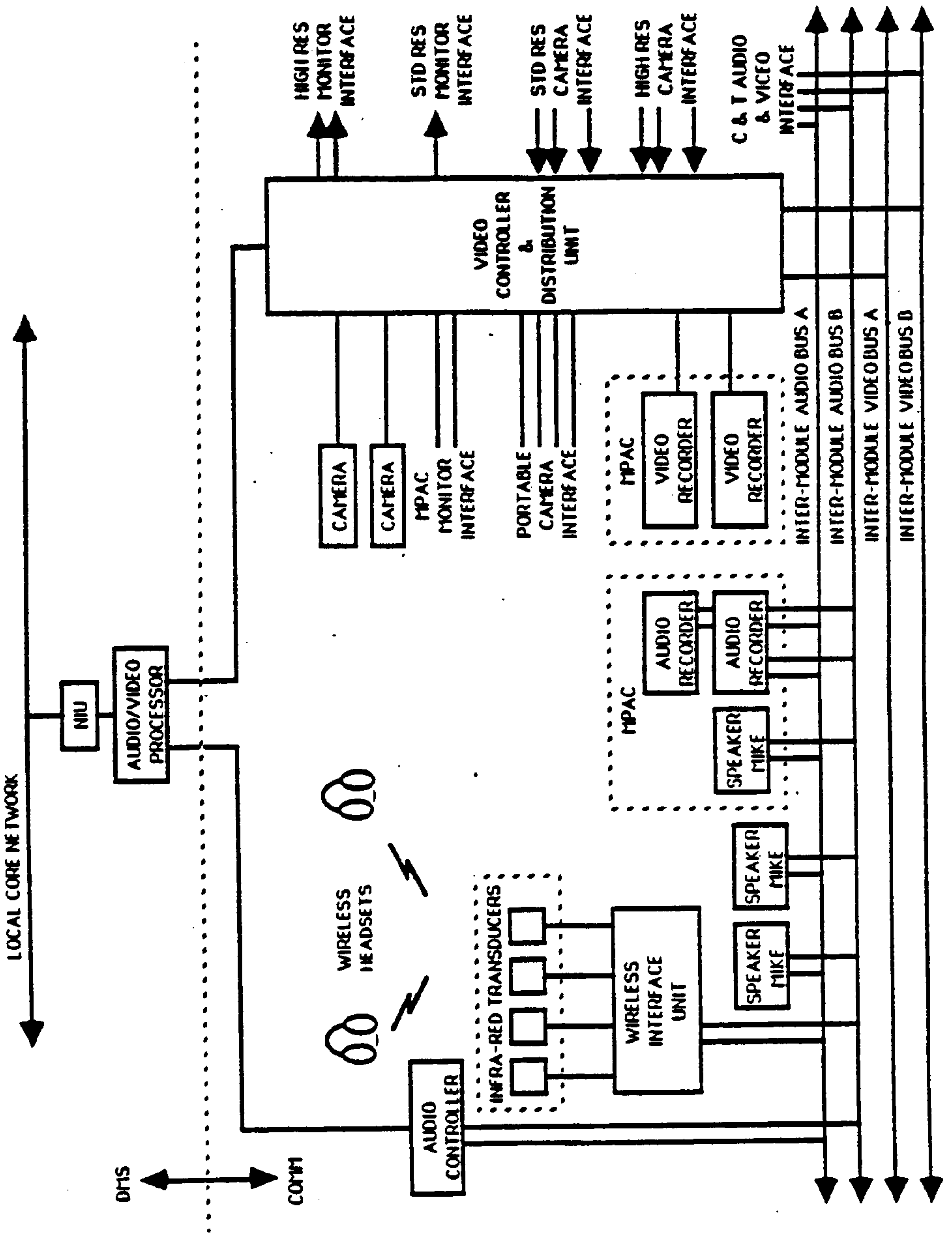

FIGURE 3.2-10 U.S. LABORATORY COMMUNICATIONS AND TRACKING

strategic locations within the module and monitors located in the MPAC. Video interfaces are provided at each USL rack location to support user provided video equipment (facility imbedded) or for the use of generic portable video devices provided as USL support equipment. The USL video subsystem supports NTSC standard video in accordance with RS 170, 240 and 330 which allows standard resolution (525 lines x 380 horizontal) at 30 frames/sec. User video requirements not accommodated by this standard, such as high resolution (1280 lines by 1024 lines, are assumed user provided and may utilize the USL DMS accommodations in accordance with user guidelines and constraints for digital transfer and processing or may utilize user provided recording and playback to match high rate video (more than 30 frames/sec) to the 30 frame/sec standard.

High resolution monitors and video recording provisions are provided in a dedicated USL video facility to support payload operations. Multi-channel two-way video communication with the ground is provided to support information exchange with subsystem support personnel and principal investigators and to provide image data for ground analysis of experiment results. Uplink and downlink video conforms to the video standards noted in the previous paragraph. Because the USL video data is only one component of the overall station uplink/downlink data stream it is subject to the data rate limitations of the TDRS system (300 MBS). The number of simultaneous channels is therefore subject to management as an overall station resource. Techniques to maximize the scope and utility of the video communication resource are under study including:

a. Very low sample rate (less than 1 frame/sec) "snap-shot" video for slow response requirements (crystal growth, plant growth, etc.)
b. low sample rate 10 frame/sec video for video conference interactions between ground and USL

The Audio and video communications baselined for the USL in conjunction with the DMS accommodations provide a practical implementation of a telescience operations philosophy which maximizes the involvement of ground personnel in the execution, analysis, and refinement of the USL research and development activities.

3.2.5 ECLSS

The USL ECLSS will be provided as part of the Core Module. The USL Environmental Control and Life Support System primary function is to maintain a habitable environment in which the crew members can perform laboratory experiments.

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 3.2.10.

The avionics air cooling of rack mounted subsystems is provided through a centralized ducted air distribution system which collects heat from the individual rack units through surface cooling or suction cooling mechanisms. The rack air cooling resource conforms to the ARINC 404A standard with a total of 1 kW of thermal load accommodated in a double rack. The energy collected from the rack air flow is dissipated to the central water cooling loop through an air/liquid heat exchanger.

3.2.6 Thermal Control

A schematic of the USL Thermal Control System (TCS) is shown in Figure 3.2-11 and consists of three basic loops:

a. Primary experiment loop
b. Attached payload loop
c. Refrigerator/Freezer loop

The primary experiment loop is a pumped single-phase water coolant loop which services all four rack banks and is capable of rejecting 50 kW of waste heat. The 70°F loop collects waste heat from the avionics heat exchanger as well as from subsystem and experiment cold plates and/or heat exchangers mounted in the racks. The 35°F loop collects waste heat from the cabin condensing heat exchanger as well as from subsystem/experiment cold plates and/or heat exchangers. The 35°F coolant interface will only be provided on one side of the module because of limited demand, primarily from the biological experiments. USL waste heat from this primary experiment loop is transferred to the Space Station Heat Rejection and Transport System (HR&T) via 70°F and 35°F central bus heat exchangers mounted on the exterior of the USL endcone structure. Redundant pump packages will be provided for safety.

An attached payload loop, sized for 25 kW, will be provided to cool equipment in USL adjacent nodes and/or interconnects. This loop will also be pumped single-phase water.

Refrigerator/freezer services are required in the USL. Low temperature body mounted radiators will be provided to reject the heat necessary to meet the -30°C freezer requirement.

The TCS interfaces with the users are through cold plates and/or heat exchangers for waste heat acquisition from experiment equipment mounted in the USL or adjacent nodes. The TCS interfaces with the Core Module include ECLSS atmospheric revitalization components, avionics heat exchanger and cabin heat exchanger.

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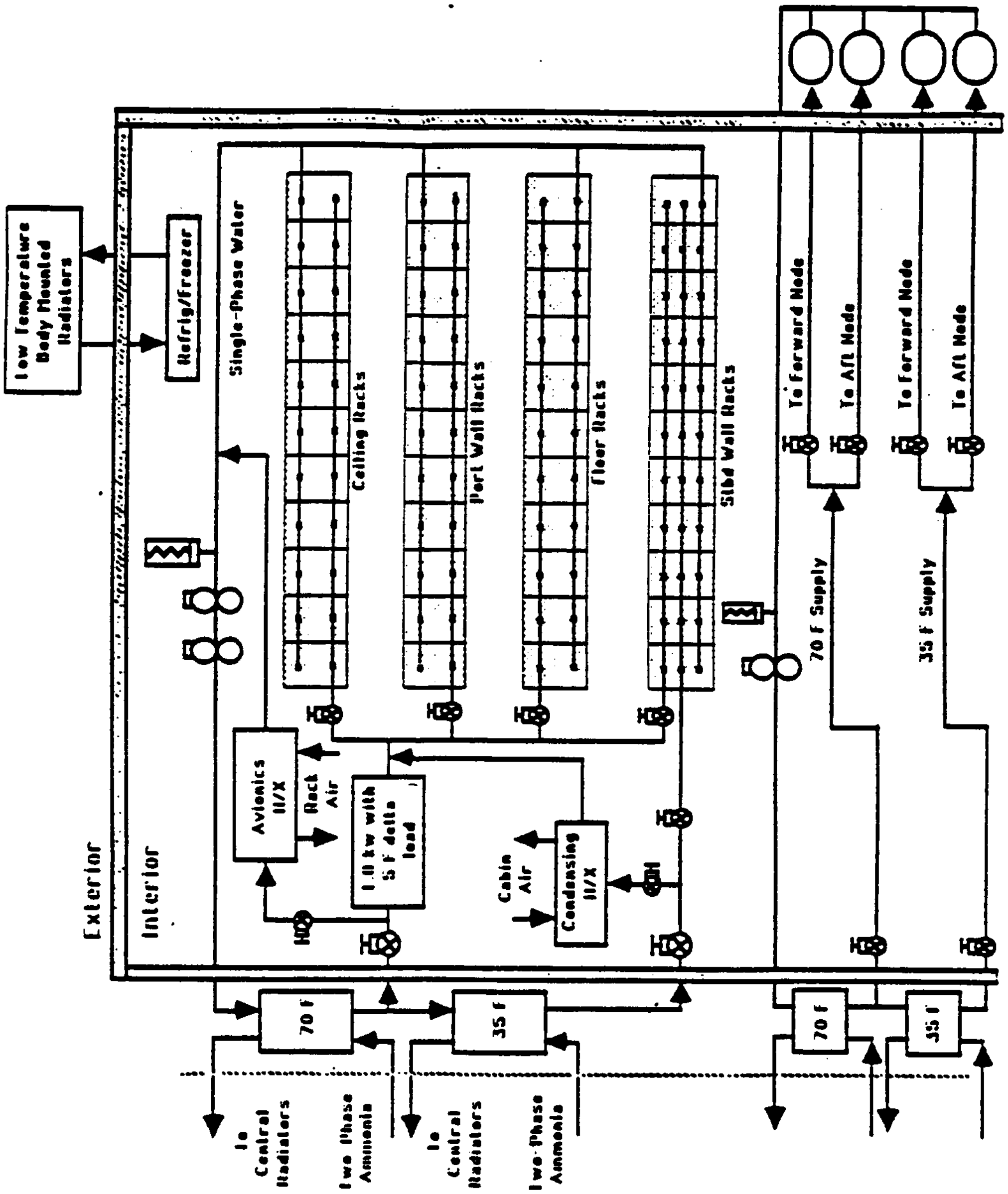

FIGURE 3.2-11 U.S. LABORATORY THERMAL CONTROL

The TCS interfaces with the Space Station HR&T system via central bus heat exchangers.

3.2.7 Crew Systems

This section addresses the hardware required to support and accommodate the crew during USL subsystem and payload on-orbit operations.

Restraints will be required which provide stability and control for equipment and cables. A universal equipment restraint is illustrated in Figure 3.2-12.

To aid in the control and elimination of dry and moist trash, portable collection and removal devices will be required, as is depicted in Figure 3.2-13. The trash container will have a removable, moisture proof liner bag, which can be compacted. The vacuum cleaner should also be able to pick up fluids.

Figure 3.2-14 shows a typical desk/platform as a work surface for a potential maintenance task. This device will provide a portable surface for writing or holding tools, tool caddies, etc. and an interface for mating Velcro, bungees, etc.

Proprietary protection can be provided by a simple visual curtain which will permit passage of air and sound but will block vision. It will interface with any double or single rack. Privacy of conversations will be protected by a sound absorbing mouthpiece containing a microphone. This audio signal can be encrypted and transmitted to the Communications Subsystem.

The emergency shower and handwash are provided in the laboratory to decontaminate a crew member who has been exposed to toxic or reactive materials. The design of these emergency provisions maximizes commonality with similar hardware located in the Habitation Module for general hygiene use. Unique plumbing interfaces are added to the shower and handwash design to re-direct potentially toxic waste water into holding tanks for disposal as opposed to the standard ECLSS hygiene water processing system. This feature is provided in addition to the standard fluid interface and is the default configuration upon activation by the crew. Use of the emergency shower and handwash for casual hygiene functions will be permitted but will require actuation of a diverter valve to allow processing of the waste water by the ECLSS hygiene water system.

3.2.8 Software

The laboratory unique DMS accommodations include the following processors which have been described in Section 3.2.3.

a. Customer facility support processor
b. Laboratory support processor

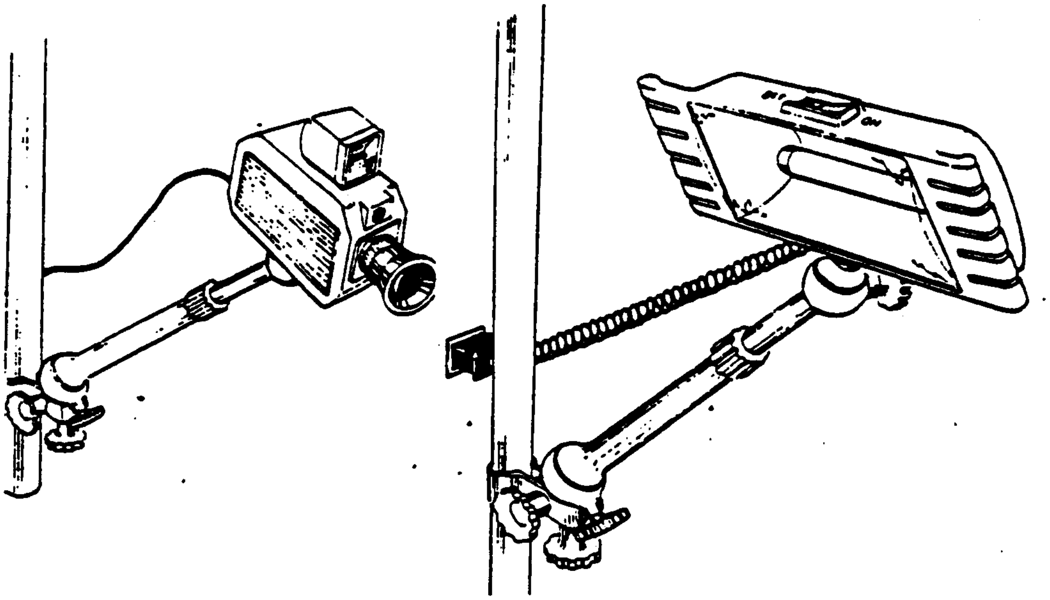

FIGURE 3.2-12 UNIVERSAL EQUIPMENT RESTRAINT

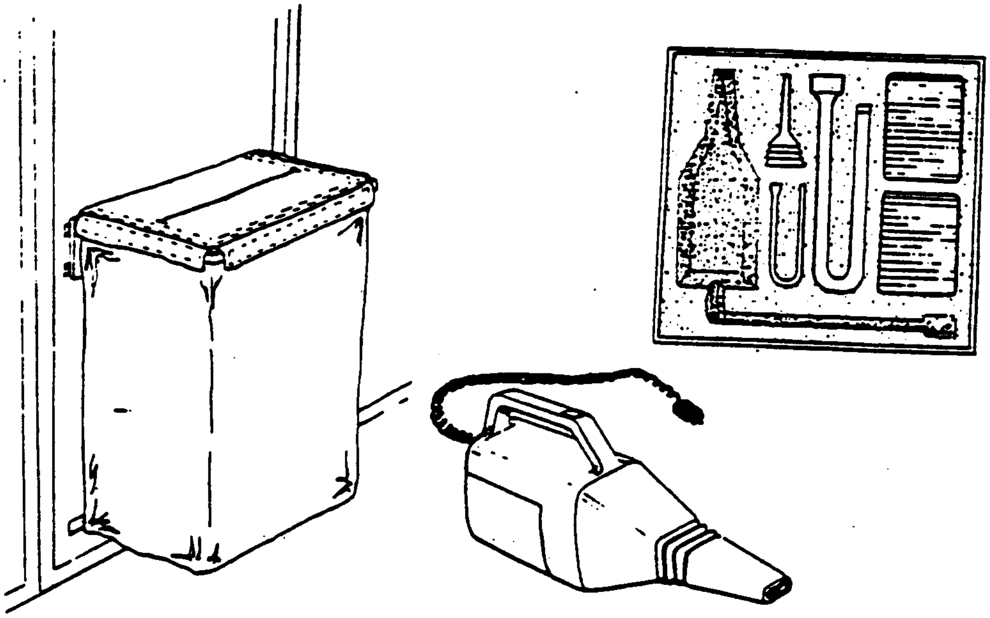

FIGURE 3.2-13 TRASH/DEBRIS COLLECTION EQUIPMENT

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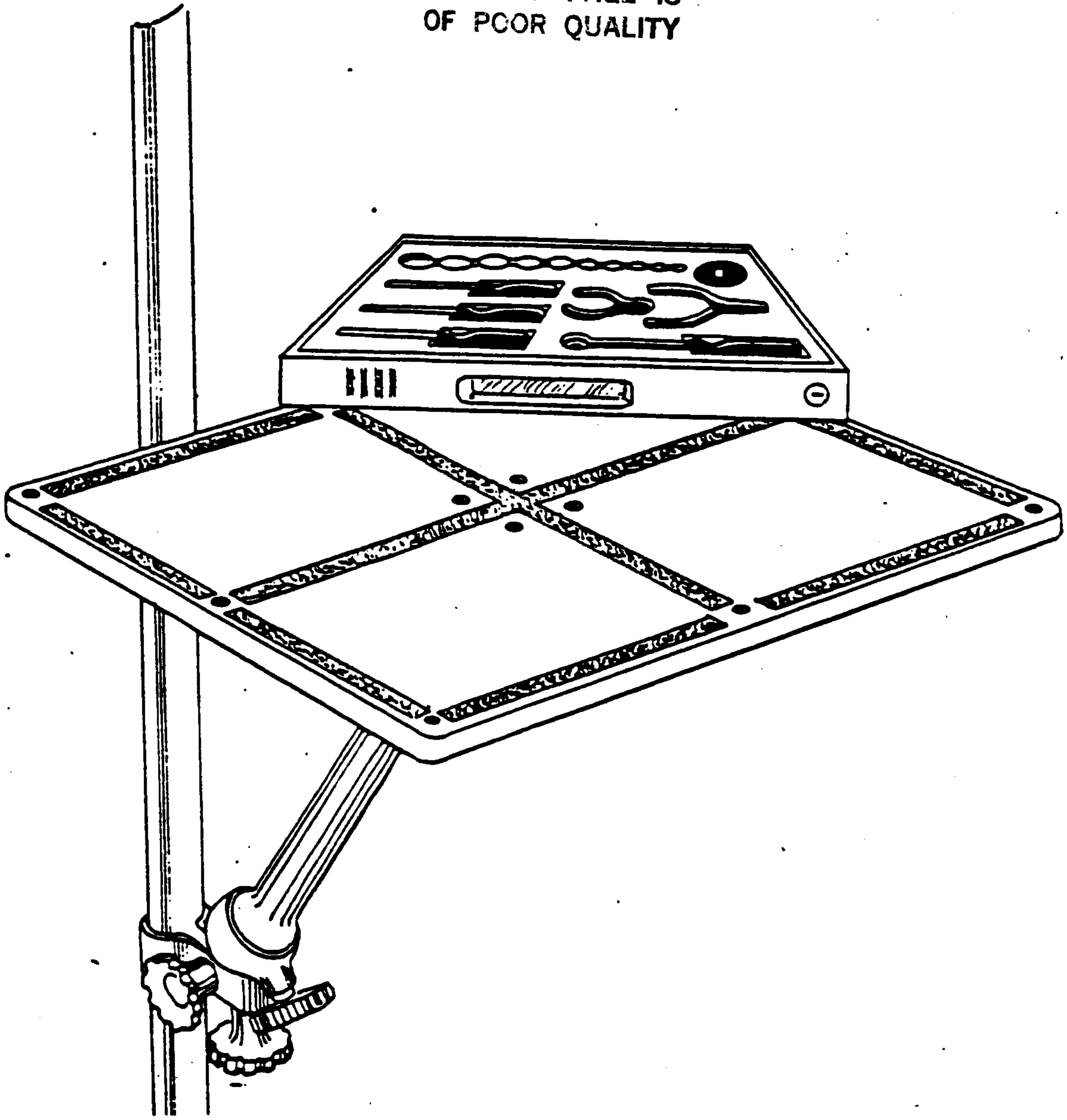

FIGURE 3.2-14 PORTABLE DESK, MAINTENANCE PLATFORM

c. Local controllers
d. Subsystem processors (unique systems)

The principal software functions residing in each of these unique processors is described in the paragraphs which follow.

a. Customer Facility Support Processor (CFSP)

1. Provide data base management functions for payload operational characteristics. The capability to update operating characteristics (power, run time, etc.) based on as-run conditions will be provided to the extent permitted by system instrumentation. The data base will be managed both on-ground and on-orbit.

2. Manage USL central resources such as recorders, mass memory, printers and other peripherals to avoid usage conflicts. Exception notification will be provided to on-board and/or ground personnel and, where possible, the conflict window will be defined for use in schedule adjustment.

3. Manage USL distributed resources such as power, thermal and fluids for mission cumulative and transient utilization. Based on operational characteristics and timelines keyed to cycle activation, resource conflicts will be estimated and margin violations reported.

4. Provide command and control processing for user facilities and support equipment.

b. Laboratory Support Processor (LSP)

1. Provide an operating multi-tasking environment for user defined and generic computational services. Scheduling of the LSP will be performed by the CFSP. Security provisions will prevent memory and mass storage partition violations.

2. Provide an environment for real time modification to on-board user algorithms and data bases by on-orbit or ground input.

c. Local Controller (LC)

1. Provide cold start and soft reset functions for data multiplexing and data formatting functions.

2. Provide an interface for programmable unit functions resident in non-volatile memory.

3. Provide command processing, data multiplexing and data interface configuration and conversion.

d. Subsystem processors

1. Provide fault detection, annunciation and redundancy management for subsystem hardware.

2. Provide health status monitoring and respond to status query from higher level processors.

3. Perform trend analysis on hardware subject to transient or life limited performance characteristics and project end-of-life to support maintenance planning.

4. Coordinate subsystem operations with subordinate or supporting systems through inter-system advisories.

5. Provide primary control of subsystem processes through access and interpretation of subsystem instrumentation resulting in control action to primary control points, such as electro-mechanical values and relays.

6. Provide controlled activation and deactivation sequencing.

3.2.9 Vacuum Vent

The USL Vacuum Vent system design is driven by user requirements and consists of a totally passive design. The Microgravity and Materials Processing Facility (MMPF) data base currently has identified vacuum requirements for 26 experiments. Currently there is no requirement for Life Science payload vacuum service. Between 71% and 90% of the MPS experiments require 10^{-3} Torr or greater pressure. Therefore, vacuum vent design efforts were directed at providing a 10^{-3} Torr passive system.

An initial analysis was performed to determine the capabilities of a passive vacuum system. This worst case analysis assumed the total system throughput originates in the rack farthest from the pipe exit. Parameters in the analysis included primary vacuum line size and pumping rate. A 6-inch vacuum line with a pumping rate of 0.03 sec/sec at 10^{-3} Torr vacuum was selected as the configuration. Any vacuum pumping rate higher than this would be unrealistic with a passive system in the USL because of pipe volume restrictions in the standoffs.

With the main vacuum line sized to 6-inch diameter, a second analysis was performed to determine performance characteristics of the entire rack bank. Eleven double racks were modeled and three different scenarios were analyzed. In all cases the pressure was measured at the worst case rack 11 interface panel location. The first scenario assumed that the entire system throughput originated in rack 1 or the rack closest to the pipe exit. The second scenario assumed that the entire system throughput originated in rack 11 or the rack farthest from the pipe exit. In the third scenario, the total system throughput was divided equally among the 11 racks. The performance curves for all three scenarios are shown in Figure 3.2-15. The 10^{-3} Torr design pumping rates for the three scenarios were 0.24, 0.027, and 0.068 SCCS, respectively.

Experimenters have indicated two general uses for high vacuum:

a. Thermal vacuum jacketing for furnaces.
b. Crystal growth chamber evacuation to prevent oxidation of outer crystal layer.

Figure 3.2-15 shows the experiment vacuum vent system design concept in a cut-away view of the USL module. The system consists of the following:

a. Two 6-inch diameter primary vacuum lines, one under each rack bank.
b. 2-inch stub-ups to rack interface resource panels at every double rack location.
c. Four electric and two manual main vacuum shut-off valves.
d. One electric rack vacuum shut-off valve at each wall double rack.
e. Pipe support hardware.

For users requesting vacuum levels better than 10^{-3} Torr, a rack mounted turbomolecular pump would be required. Because only a few experiments need this resource, it is felt that the pump should be user supplied equipment. Many off-the-shelf turbomolecular pumps are available that occupy minimal rack space.

External contamination requirements/constraints for the Space Station do exist but because the high quality vacuum vent system operates at such a low pumping rate, the contribution to external contamination will be very low and may be neglected.

In order to maintain the 10^{-3} Torr quality, purging and backfilling of experiment chambers will be performed using the PMMS waste vent system. Both the PMMS and the high quality resources will be available at each user rack.

3.2.10 Process Material Management Subsystem

3.2.10.1 Process Fluids Supply

Process fluids can be separated into three separate storage categories:

a. USL dedicated PMMS storage
b. Space Station integrated FMS fluids storage
c. User unique fluids storage

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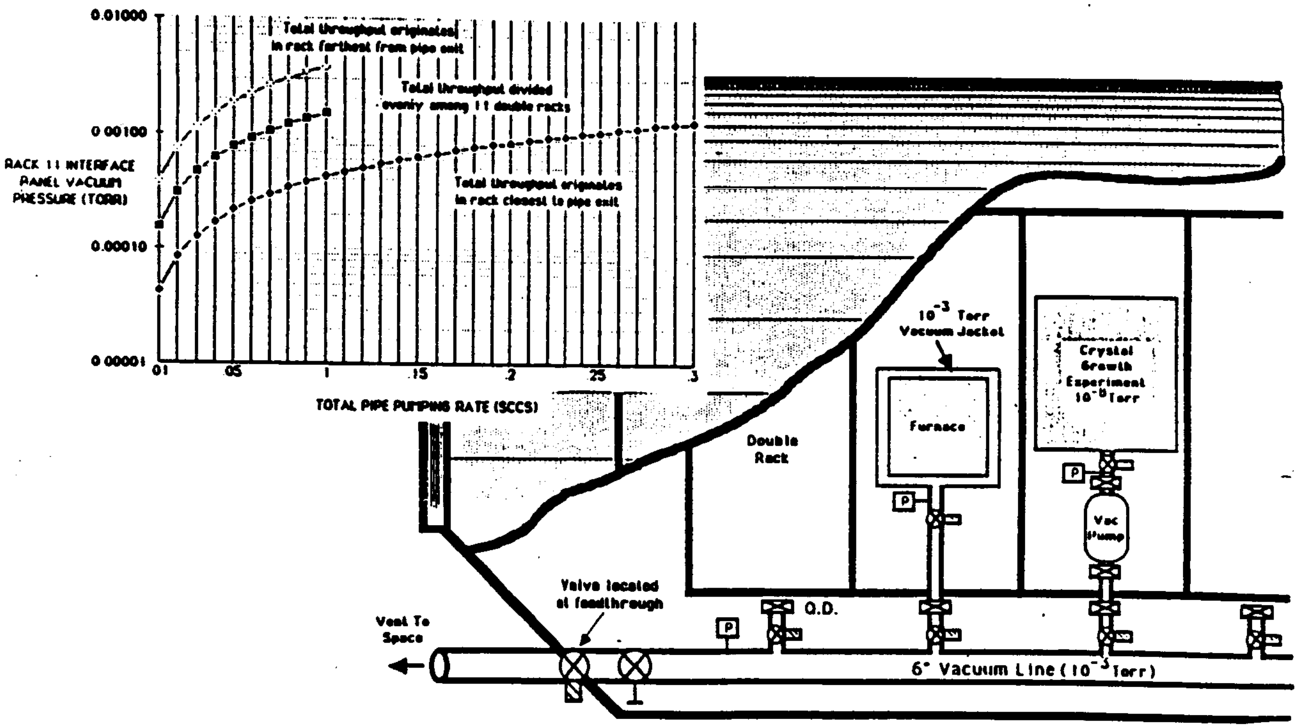

FIGURE 3.2-15 U.S. LABORATORY VACUUM MAINTENANCE

The fluids which require USL dedicated storage include helium, argon, carbon dioxide, and water. Integrated fluid candidates include nitrogen and water (through ECLSS and/or Orbiter excess). Excess oxygen and possibly hydrogen generated by the ECLSS may be utilized for payload use. The PMMS is also responsible for providing cryogenic (LN_2 level) temperatures for the user. User unique fluids refer to the remainder of the fluids required by USL payload equipment.

The PMMS must be designed to provide a 90-day supply of these fluids. Because the USL process fluid users will constantly change over the life of station, the following assumptions were made to aid in subsystem design.

a. MMPF and AMES data was used to generate fluid mass requirements (on a per cycle basis) for each of the experiments (including support and characterization).

b. Using the 28 facilities identified in the MMPF data base, 1,000 payload complements were generated and analyzed for their fluid requirements.

c. The number of experiment cycles to be performed per 90 days was calculated using the following assumptions:

1. Crew time available for USL experimentation ranged from 12, 20, 30, 40 hours/day.
2. Eighty days per 90-day period were available for microgravity use.
3. Up to three copies of each facility can be placed in a payload complement.
4. Number of double racks available for payload use ranged from 12 to 21.

The individual fluid requirements for each of the 28 USL facilities is shown on a per cycle basis in Table 3.2-1. The fluid masses given in this table represent the requirements for the experiment facility and the associated support and characterization equipment. Also shown is the total fluid mass/cycle for each facility. This data was used by the Resource Allocation Program (RAP) to perform payload complement resupply requirement calculations. The detailed fluid requirements data generated by RAP for various USL operating conditions was performed in a separate trade study. This trade contains detailed parametrics on the effects of crew time, number of payload racks, and number of identical experiment in a complement on PMMS fluid requirements. The results of these trades are shown in Table 3.2-2. Here, the minimum and maximum quantities of 14 fluids are shown on a per cycle and 90 day basis. The current IOC payload complement fluid requirement are also given for reference.

The fluids provided as a generic USL resource will be stored in a combination of racks located in the floor. Figure 3.2-16 shows the general design concept for storage and distribution of these fluids. The three gases will be stored

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TABLE 3.2-1 PAYLOAD FLUID REQUIREMENTS

EXPERIMENT NAME	FLUID MASS REQUIRED ON A PER CYCLE BASIS																EXPERIMENT TOTAL (kg.)
	PROCESS FLUID SUPPLY CANDIDATES																
	WATER	NITROGEN	OXYGEN	HELIUM	HYDROGEN	ARGON	CO2	LN2	LHe	FREON	XENON	AIR	CLEANING FLUIDS	ACETYLENE	BUFFER SOL.	
ACOUSTIC LEVITATOR	2.50	0.377	0.001	0.018	0.000	0.258	0.000	1.26	0.00	0.000	0.605	0.164	2.000	0.000	0.000	7.19
ALLOY SOLIDIFICATION	2.50	0.373	0.000	0.000	0.000	0.342	0.000	1.01	0.00	0.000	0.000	0.210	0.100	0.000	0.000	4.54
ATMOSPHERIC MICROPHYSICS	1.00	0.484	0.009	0.009	0.000	0.100	0.004	0.51	0.00	0.000	0.000	0.042	0.600	0.001	0.000	2.75
AUTO-IGNITION FURNACE	1.00	3.440	0.853	0.014	0.000	0.391	0.000	0.51	0.00	0.014	0.000	0.038	0.500	0.001	0.000	6.76
BIOREACTOR/INCUBATOR	0.75	0.373	0.302	0.000	0.000	0.000	0.921	0.25	0.00	0.000	0.000	0.518	0.500	0.000	0.000	3.62
SMALL BRIDGEMAN FACILITY	2.50	0.435	0.000	0.000	0.000	0.342	0.000	0.15	0.00	0.000	0.000	0.270	0.100	0.000	0.000	3.80
CONT. FLOW ELECTROPHORESIS	17.75	0.373	0.219	0.000	0.000	0.000	0.667	0.25	0.00	0.000	0.000	0.377	0.500	0.000	0.000	20.14
CRITICAL POINT PHENOMENA	0.00	0.249	0.000	0.036	0.000	0.000	0.000	15.17	1.00	0.000	0.000	0.240	0.000	0.000	0.000	16.69
DROPLET SPRAY BURNING	0.52	0.532	0.090	0.020	0.000	0.221	0.000	0.51	0.00	0.000	0.000	0.303	0.500	0.001	0.000	2.69
ELECTROEPITAXIAL CRY. GRO.	0.50	1.057	0.000	0.000	0.045	0.000	0.000	0.15	0.00	0.000	0.000	0.661	0.000	0.000	0.000	2.41
ELECTROSTATIC LEVITATOR	0.60	0.373	0.000	0.002	0.000	0.023	0.000	0.00	0.00	0.000	0.000	0.000	0.010	0.000	0.000	1.01
EM LEVITATOR	0.80	0.373	0.000	0.002	0.000	0.023	0.000	1.01	0.00	0.000	0.000	0.014	0.100	0.000	0.000	2.32
FLOAT ZONE	1.50	0.373	0.000	0.000	0.000	0.083	0.000	1.01	0.00	0.000	0.000	0.051	0.100	0.000	0.000	3.12
FLUID PHYSICS	23.50	0.883	0.000	0.000	0.000	0.000	0.000	0.15	0.00	0.000	0.000	0.492	0.100	0.000	0.000	25.13
FREE FLOAT	0.60	0.373	0.000	0.000	0.000	0.000	0.000	1.01	0.00	0.000	0.000	0.108	0.010	0.000	0.000	2.10
HIGH TEMPERATURE FURNACE	1.50	0.995	0.000	0.000	0.000	0.055	0.000	1.01	0.00	0.000	0.000	0.634	0.100	0.000	0.000	4.30
ISOELECTRIC FOCUSING	21.25	0.373	0.000	0.000	0.000	0.000	0.000	0.25	0.00	0.000	0.000	0.031	1.000	0.000	0.000	22.91
LATEX REACTOR	0.00	0.373	0.000	0.000	0.000	0.000	0.000	1.01	0.00	0.000	0.000	0.000	0.000	0.000	0.000	1.38
MEMBRANE PRODUCTION	0.50	0.784	0.000	0.000	0.000	0.055	0.000	1.16	0.00	0.000	0.000	0.430	0.250	0.000	0.000	3.18
OPTICAL FIBER PULLING	1.50	0.401	0.000	0.000	0.000	0.043	0.000	0.00	0.00	0.000	0.000	0.053	0.100	0.000	0.000	2.10
ORGANIC & POLYMER CRY. GRO	4.00	0.560	0.398	0.000	0.000	0.055	0.650	1.01	0.00	0.000	0.000	0.370	0.010	0.000	0.000	7.05
PREMIXED GAS COMBUSTION	0.10	0.159	0.009	0.020	0.000	0.220	0.000	0.51	0.00	0.014	0.000	0.303	0.000	0.001	0.000	1.41
PROTEIN CRYSTAL GROWTH	0.70	0.821	0.051	0.000	0.000	0.070	0.000	0.00	0.00	0.000	0.000	0.043	0.000	0.000	0.000	1.69
ROTATING SPHERICAL CONVECT	0.50	0.376	0.000	0.000	0.000	0.000	0.000	1.01	0.00	0.000	0.000	0.000	0.010	0.000	0.000	1.90
SOLID SURFACE BURNING	0.50	0.159	0.090	0.020	0.000	0.221	0.000	0.51	0.00	0.014	0.000	0.303	0.000	0.001	0.000	1.81
SOLUTION CRYSTAL GROWTH	18.40	0.885	0.000	0.000	0.000	0.000	0.000	0.15	0.00	0.000	0.000	0.492	0.000	0.000	0.000	19.93
VAPOR PHASE CRYSTAL GROWTH	0.50	0.316	0.000	0.009	0.000	0.411	0.000	0.66	0.00	0.000	0.000	0.600	4.000	0.001	0.000	6.49
VARIABLE FLOW SHELL GENERA	0.50	0.373	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.000	0.000	0.360	0.000	0.000	0.000	1.23
TOTALS	105.97	16.845	2.102	0.151	0.045	2.914	2.242	30.23	1.00	0.041	0.605	7.110	10.590	0.007	0.000	130.27

TABLE 3.2-2 INTEGRATED USL FLUID REQUIREMENTS

Fluid Quantities in Kg

FLUID TYPE	MAN-TENDED	PERMANENTLY MANNED			IOC			GROWTH		
		MIN	MEAN	MAX	MIN	MEAN	MAX	MIN	MEAN	MAX
H_2O	288	1688	2208	2633	1172	1760	2109	41.6	817	3279
- RECYCLING	60	490	584	663	409	516	582	36.6	292	867
- VAPOR	2.8→9.8	17→57	22→75	26→89	12→40	18→60	21→72	0.5→1.4	8→28	33→111
N_2	3.0	33.3	37.3	41.3	68.7	73.0	77.2	43.3	107	243
O_2	0.1	6.50	8.12	10.09	8.00	10.37	12.87	0	9.90	40.9
He	0.02	0.15	0.23	0.32	0.72	0.85	0.98	0	0.94	2.94
H_2	0.1	0.09	0.27	0.36	0.14	0.30	0.36	0	0.05	0.36
Ar	1.76	5.38	7.02	8.62	13.00	14.81	16.78	0.52	16.28	42.0
CO_2	0	1.95	4.64	7.80	6.28	11.84	16.46	0	5.50	25.8
FREON	0	173.5	173.5	173.5	0.31	0.36	0.43	0	0.32	1.58
AIR	2.98	12.20	15.19	18.21	36.66	40.48	44.29	2.63	32.2	79.7
XENON	0	1.81	4.36	7.26	2.42	4.94	8.47	0	2.40	20.6
CLEANING SOL.	9.0	25.3	43.4	64.5	32.5	53.1	75.1	1.28	51.7	176
- VAPOR	0.1→0.3	0.3→0.9	0.5→1.5	0.6→2.2	0.3→1.1	0.5→1.8	0.8→2.6	.01→.04	0.5→1.8	1.8→6.0
COOLING (LN_2)	267	135.5	144.2	153.7	137.5	146.0	157.7	147.5	251.5	429.1
COOLING (LHe)	0	0	0	0	0	0	0	0	1.02	11.95
Urine	0	77	77	77	0	0	0	0	0	0

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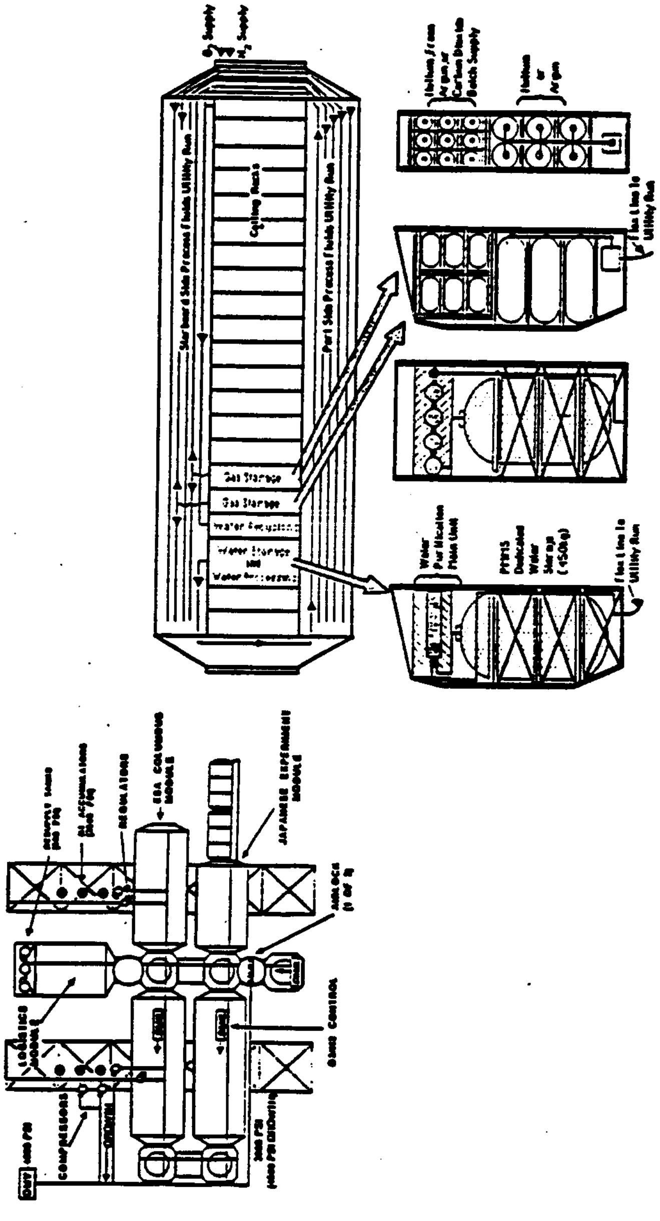

FIGURE 3.2-16 PMMS FLUIDS AND GAS SUPPLY

under pressure in two types of vessels. Carbon dioxide and small quantities of helium and argon will be stored in small portable pressure vessels (PPV). These vessels support a batch mode of fluid distribution. These vessels are approximately 14" x 6" cylinders designed to fit in both the fluid storage rack and the fluid user rack. The other gas storage vessel is a high operating pressure vessel which feeds helium and argon into the general hardline distribution system. These vessels are approximately 30" x 9" cylinders which operate up to 2,000 psi. All pressure vessels will be designed to meet leak before burst criteria and will not contain sufficient gas to cause module overpressure or asphixiation hazards if a leak were to go undetected.

Nitrogen will be supplied by the Integrated Gas Distribution System located on the station truss structure (Figure 3.2-16). The maximum 90 day supply requirements of 243 kg N_2 was used in sizing the integrated system .

Providing hydrogen presents several safety related design concerns. Because of the explosive potential, large quantities should be avoided. Hydrogen also has a propensity for leakage through fittings. Ninety day hydrogen storage is therefore not considered desirable. Hydrogen can be provided on an "on-demand" basis by integrating with the ECLSS electrolysis unit which produces excess hydrogen when providing oxygen for cabin air revitalization. Depending on the hydrogen purity requirements, a "dryer" may be installed to dehumidify the electrolysis output before USL use. Excess ECLSS H_2 amounts to 0.21 kg/day based on an 8-man crew. USL resource analysis shows the maximum H_2 demand is 0.4 kg/90 days. The ECLSS therefore, can supply eighteen times the maximum anticipated demand.

Oxygen, like hydrogen, is produced on-orbit by ECLSS electrolysis equipment. If this equipment is sized accordingly, it can produce excess O_2 for payload use. The possibility of providing 12 kg/90 days at IOC and up to 41 kg/90 days during growth from the ECLSS is considered within reasonable hardware limits.

PMMS water can be supplied from several potential sources. The PMMS will furnish a dedicated water storage tank as shown in Figure 3.2-16. The tank storage capacity requirement is based on three contributing factors.

a Design case water requirement
b. Excess ECLSS water availability
c. Excess Orbiter fuel cell water availability

The growth design case for USL payload water requirements is 867 kg/90 days with water recycling or 3279 kg/90 days without recycling. Both cases are based on 40 crew hours per day for USL use and full on-orbit experiment support and characterization.

Excess ECLSS water is expected to be available because of the crew metabolic mass balance. Based on an eight person crew, the ECLSS will provide 2.28 kg/day of excess potable water. This assumes the food has a water content of 1.1 lbm/man/day. This water is a result of excess potable water produced by the ECLSS condensate recovery system. The effective ECLSS contribution to the PMMS is then 205 kg/90 days.

The amount of excess Orbiter fuel cell water which will be made available to the USL is dependent upon the extent of Orbiter modifications (power cord or tank off-loading) made. The currently baselined Orbiter fuel cells produce 600 kg/visit of excess potable water based on a minimum Orbiter power level of 10.4 kW and a 5.6 day docking period. If this water were made available to the PMMS it would greatly reduce the weight and cost of USL logistics resupply. Any excess potable water not required by the USL can be used by other elements or the O_2H_2 propulsion system.

The PMMS dedicated water tank shown in Figure 3.2-16 is sized to hold 450 kg of potable water. Used in conjunction with excess ECLSS water it will provide enough water to support all IOC type payload complements (415 kg/90 days) in addition to several growth payload complements. Without supplemental water from the Orbiter, a single tank PMMS water supply will not be sufficient in supporting all of the growth payload complements anticipated unless water recycling is included. Several of the 450 kg tanks can be brought up to furnish all anticipated USL water requirements but at the expense of the logistics module carrying capacity. These tanks can be brought up, however, on flights which are not at capacity and stored on the station for later use. The output of the water purification unit must be certified as meeting the applicable water quality specification. The following basic parameters must be monitored.

a. Resistivity
b. pH
c. Total Organic Carbon (TOC)
d. Endotoxin Count
e. Microbial Count

Current technology allows "in-line" monitoring of resistivity and pH which can be done easily and inexpensively.

The current endotoxin and microbial tests operate on a grab sample basis. There are three types of endotoxin tests available. Chromatic LAL, LAL, and Gel LAL. Of these, the Chromatic LAL appears the most attractive for PMMS application. It requires no support equipment, has the shortest test time (30 minutes), and requires the least amount of water (1.5 ml/test).

Neither of the two known microbial detection tests seem acceptable for PMMS use. The D.B Microbial Test requires 10 hours incubation time and a 5-minute test while the Membrane Filter Test requires 48 hours (1st check) and 168 hours (2nd check) with a 5-minute test. These long incubation times would require holding tanks for water waiting for certification. During these long holding times, pyrogens would have an opportunity to reestablish themselves.

The measurement of Total Organic Carbon (TOC) also offers design challenges. Five different "state-of-the-art" technologies are currently being studied of which only three have continuous monitoring capabilities; however, all require large amounts of power (≈ 500 watts) and are relatively large units.

Water quality monitoring is considered a major advanced technology area which must be addressed to ensure the USL users receive water which will meet specifications. Currently considerable R&D effort been directed to this area as a result of ECLSS requirements for similar water monitoring capabilities.

The MMPF data base has identified station USL user requirements for cryogenic fluids. In particular, liquid nitrogen and liquid helium are identified as the cryogenic fluids required for USL payload applications. The design of a USL cryogenic resource requires detailed knowledge of the user requirements driving the selection of the specified cryogens. For example, does the cryogenic fluid user require a saturated LN_2 bath for maintaining very accurate temperature gradient control at cryogenic temperatures, or does the user require only moderate gradient control or temperature stability such as a cold trap? The latter application can be supplied relatively simply in a space vehicle. However, the use of cryogenics such as an LN_2 bath surrounding a high temperature core will generate substantial LN_2 boiloff which is beyond the capability of the PMMS waste gas vacuum system. Another major design hurdle in a spacecraft cryogenic fluid supply system is the cryogenic fluid pumping system and the associated problems of cold-line insulation for the prevention of condensation. The best solution to avoid pumping the cryogenic fluid throughout the module is to pump only the thermodynamic working fluid to the locations where cryogenic fluids are required. Therefore, the requirement is best met with a closed-loop cryogenic refrigeration system with a helium thermodynamic working fluid.

The following hardware comprise a closed-loop, helium-working fluid, cryogenic refrigeration system that would be appropriate for USL applications:

a. Compressor Package - water cooled reciprocating or turbo compressor, heat exchanger, and the associated electrical controls.

b. Cold Head - one or two stage Stirling Cycle expansion device for LN_2 generation.

c. Distribution Line - supply and return lines for the helium-working fluid.

The current cryogenic system concept routes the helium thermodynamic working fluid to the user via subfloor mounted hardlines. The subfloor hardlines consist of both the compressed helium supply line and the decompressed helium return line. The user interfaces with the cryogenic system at the rack interface panel and provides equipment interface. The user may therefore customize the cryogenic application; e.g., if the user requires LN_2 he would produce LN_2 by acquiring GN_2 from the process fluid supply subsystem and producing LN_2 with their specially designed cold head. This distributed cryogenic system provides the best growth capabilities for the USL. In addition, the PMMS provides a cold head at the compressor unit rack to provide LN_2 in batch mode including a LN_2 Dewar for USL intra-module transport.

3.2.10.2 Process Waste Handling System

The wide variety of chemical substances identified by users as potential waste and the mixed phase waste discharge impose several design requirements on the PWHS. These design requirements include:

a. Crew safety
b. The capability of long-life reliable operation in a corrosive environment
c. Waste effluent phase separation
d. Safe storage and containment of toxic waste
e. Treatment of waste
f. Ease of equipment maintainability and ORU capability with minimal crew interaction
g. Separation of incompatible waste components
h. Leak detection and isolation
i. Utilization of common hardware and existing technology to minimize subsystem cost
j. Compliance with the limitations entailed by logistics resupply
k. Assurance of the USL 10^{-5} microgravity requirement
l. Interface with the station FMS

The design concept is based on several assumptions summarized as:

a. A three phase waste effluent from some of the waste producing experiments, facilities, or characterization/support equipment.

b. Rack volume will be available in the racks that require waste management capabilities to accommodate the associated hardware.

c. Crew time availability will allow PWHS equipment maintenance and storage container changeout.

d. Overboard venting of gases is not feasible; as a result, the PWHS is responsible for safe storage of non-FMS compatible waste gases. In addition, the PWHS will provide the FMS with the appropriate water.

e. Some common flight hardware can be modified to provide long-life reliable operation for a corrosive application.

The single most important design consideration for the PWHS is crew safety. Therefore, from both a crew safety and hardware complexity standpoint, the optimal PWHS design would be one in which the waste is contained at or as close to the waste producing equipment as possible. Transport and common stowage of toxic waste and corrosive chemicals presents the unnecessary risk of system leaks and mixing of incompatible materials. The system consists of a waste containment chamber located in the experiment/facility or support equipment rack. The waste containment chamber is employed only in those racks where the waste effluent consists of mixed liquids and gases. Racks containing equipment that produce only solid and gaseous waste will be provided exclusively with the waste vacuum capability, e.g., a low quality vacuum (250 microns) for waste gas removal or experiment purge operations. A high quality vacuum system is addressed in Section 3.2.9.

The waste containment chamber provides gas/liquid separation and temporary waste liquid storage. Also, the waste containment chamber will be pressure regulated to provide low level vacuum containment of the toxic waste handling hardware. The PMMS waste gas vacuum lines are routed through the utilities supply volume to all racks requiring this capability. The waste gas is routed to the waste gas handling system for disposition and interfaces with the station FMS.

Water is a resource which is used by 27 of the 50 different pieces of USL fluid using equipment reported in the MMPF data base. It is required in various quantities ranging from 0.02 to 140 liters/cycle. Based on studies addressing 1000 possible USL payload complements, total water throughout requirements range from 41 to 3279 kg per 90 days. Using a cost of $6600/kilogram for logistics launch cost makes on-orbit water recovery an attractive solution. Effective water recycling measures can bring USL growth water requirements down to 867 kg/90 days.

Because of the purity specifications of the water users and the degree of water contamination produced by certain users, it is impractical to assume all waste water can be recycled. There are several possible candidates for water recovery, including Continuous Flow Electrophoresis, Protein Crystal Growth, Solution Crystal Growth, Organic and Polymer Crystal Growth, and Isoelectric Focusing. Four of the five experiments listed above are biological processing apparatus. The CFES experiment waste product constituents (not quantities) is assumed to be typical of the biological experiments. At the other end of the waste liquid spectrum is the waste water resulting from glovebox operations which is highly contaminated. The waste from this type of equipment will be maintained as close to the production source as possible and disposed of by Logistics Module stowage and return.

User equipment which meets recoverable water standards will be connected to the system through a 3/8" waste line. The user/system interface occurs at the users apparatus via self sealing quick disconnect. A waste stream pretreatment unit may be required to make the user waste water comply with the recovery system standards. Pretreatment may take the form of pH balancing, biocide injection, particulate filtration or a combination of each, depending upon the characteristics of each individual waste stream. The waste water then leaves the payload rack through flex line which connects to the subrack Q.D. panel. The waste is then pumped into a common return line in the utility run which delivers all recoverable waste to a temporary holding tank. This tank acts as a buffer for the water recovery unit which has throughput limitations.

The Thermoelectric Integration Membrane Evaporation Subsystem (TIMES) has been chosen as the main water recovery unit. This is a phase change technology based system which is currently baselined by the ECLSS for performing potable water recovery tasks. It uses hollow fiber membranes and tangential flow with a evaporation level WP to separate water from contaminants. It is a continuous circulating system which builds up a waste brine in the service loop which goes to a removable storage tank. Once the brine reaches about 40% solids by weight, the tank must be changed out with spares kept onboard. This type of unit is excellent at targeting dissolved solids such as salts for removal. However, anything that has a boiling point lower than water, such as alcohols or dissolved gases, will pass through with only partial removal.

Upon leaving the TIMES, the water is close to potable in purity; it is then passed through a multifiltration system. This unit contains a pretreatment cartridge for removing colloids, bacteria, organics, and chloride which may have entered the system. Next, the water passes through mixed-bed deionization cartridges for improving resistivity characteristics by reducing inorganic and TOC levels. At this point, the water is mixed with the main supply water for processing and delivery back to the users.

An overview of the waste liquid accommodations and the water recycling systems concepts are presented in Figure 3.2-17.

A major function of the PMMS Process Waste Handling System (PWHS) is the disposition of USL waste gases. The requirement for large quantities of process gases indicates there is a requirement for the removal of these gases from the USL payloads. A summary of key design drivers for the Waste Gas Handling System (WGHS) follows:

a. The WGHS will provide a minimum of 0.25 torr vacuum pressure for waste gas removal from all USL payloads which require this resource.
b. The WGHS will provide a minimum pumping rate of TBD SCCM for waste gas removal.
c. The WGHS will not prohibit microgravity research in the USL.
d. The WGHS will comply with Space Station external contamination constraints.
e. If vented, the WGHS vent will be non-propulsive.
f. The WGHS will interface with the Space Station integrated Fluid Management System (FMS).
g. The WGHS will be capable of storing all non-FMS compatible gases for a minimum of 15 days.
h. The WGHS will operate in a safe manner.

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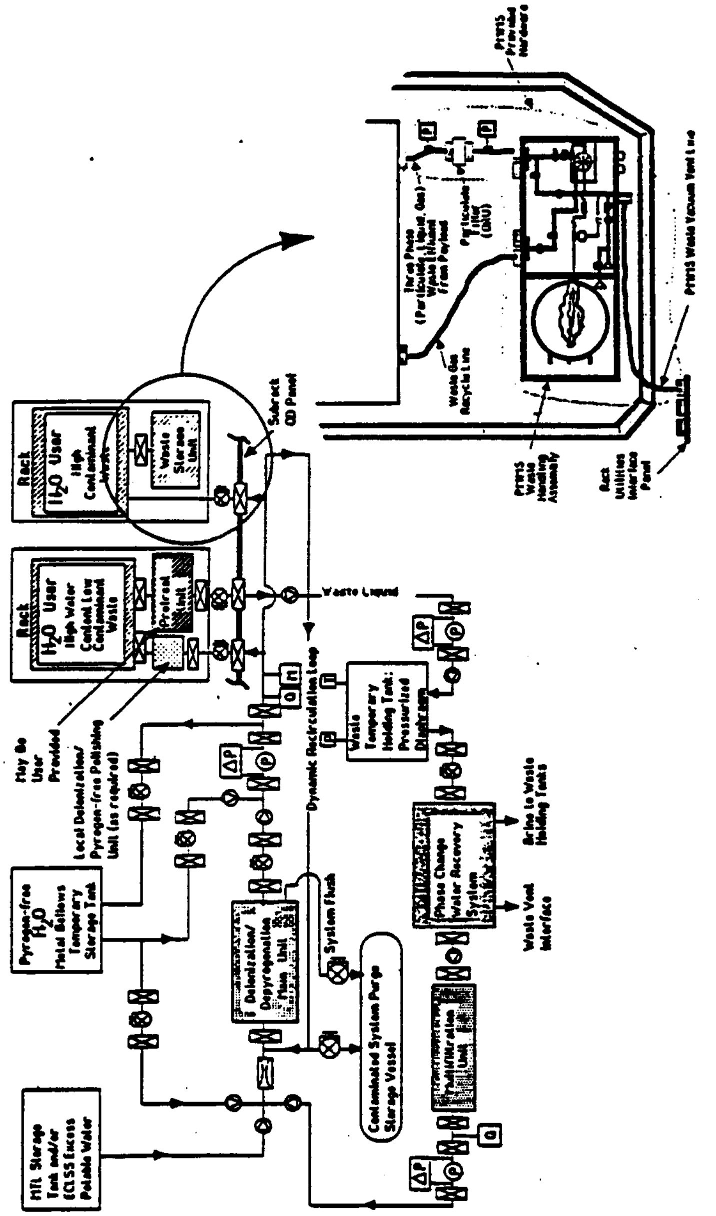

FIGURE 3.2-17 PMMS FLUIDS WASTE AND WATER RECYCLING

The continuous vent-to-space system, previously baselined for the USL, was a low operating pressure system (0.04 torr to 10 torr). These low operating pressures were below the lower limits established for combustion reactions which is 10 torr. Because of recent tightening of external contamination allowables several WGHS design changes were required. The WGHS must now be designed to store all waste gases generated by USL payloads for a 15 day period. This requirement was devised to accommodate the external attached payload viewing environment.

The responsibilities of the integrated FMS have been recently expanded to include SSPE waste handling. The current FMS will provide common storage for fluids which are compatible with the materials of the design. Currently a list of fluids which are compatible with the FMS does not exist.

Because of the 15 day storage requirement and the amount of waste gas produced by the USL during this period, a high pressure storage system is required. Such a system can create hazardous conditions because of the nature of the potential chemical reactions and the increased probability of reaction with increased pressure. To minimize the possibility of a combustion reaction taking place in the WGHS vent lines and storage tanks, oxidizers and fuels will be segregated at their source.

There are several impacts associated with such a segregated system. It requires segregated lines to handle oxidizers and fuels. This increases the user interface complexity, and utility run congestion. If the FMS does indeed take hardware responsibility for storing FMS compatible waste gases, there will be as many as four waste gas vent lines in each utility run, and up to four waste gas interfaces at each user double rack.

A vacuum pump must be installed in each waste gas line to provide both the 0.25 torr vacuum resource and TBD pumping rate to the users. Both of these functions were previously handled by the passive vent to space concept. The power requirement per vacuum pump which operates from 0.25 torr inlet to 760 torr outlet is approximately 5.5 kW to achieve a 1.5 l/min flow rate. With the fully segregated system four such vacuum pumps would be required.

Compressors are required to take the waste gas storage from 14.7 psi (760 torr) to approximately 500 psi for more efficient storage. Compressors operating in this range require 0.028 kW to handle the same 1.5/1 min throughput as the pumps. The resulting 34 to 1 compression ratio will probably require staged compressors increasing the maintenance and complexity associated with the waste gas handling system.

An overview of the waste gas accommodations including storage and safing options are illustrated in Figure 3.2-18.

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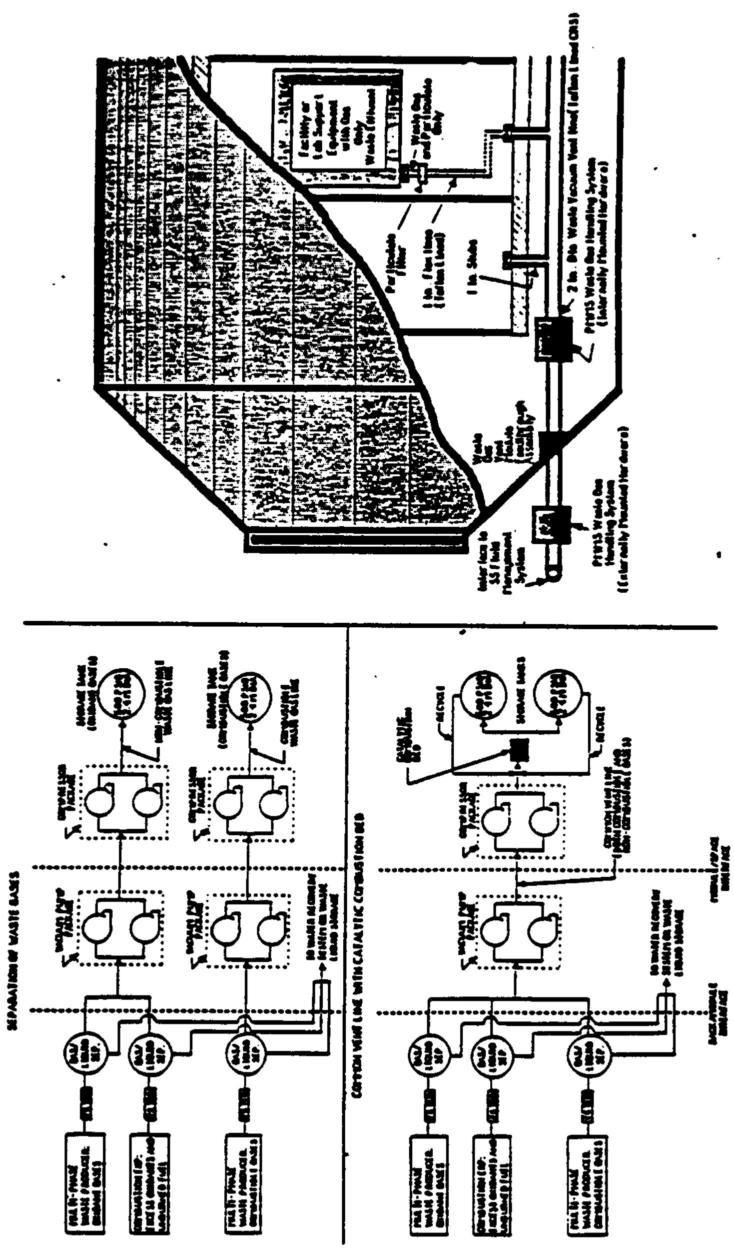

FIGURE 3.2-18 PMMS WASTE GAS ACCOMMODATIONS

Disposable trash will be handled manually by the crew. The crew will make a judgement, based on the physical size, quantity, or previous use of the disposable trash, whether or not the trash is compatible with other solid waste. If the trash is primarily paper or fabric with no other extraneous chemicals adhering to the surface, then, based on the physical mass and dimensions of that particular trash, the decision will be made to compact the trash as is or to store the benign trash in a storage container.

Some of the disposable trash generated in materials processing operations may be contaminated with cleaning fluids, solvents, corrosives, or other reactive or toxic fluids thereby requiring special operations. Contaminated refuse will be handled by placing the contaminated item in a sealable storage bag constructed of a fluoropolymer (polytetrafluoroethylene. The results of the materials compatibility study indicate the use of a Fluorinated Hydrocarbon polymer such as Teflon possesses the best chemical resistance properties for USL application. The use of vacuum sealing procedures in conjunction with the PMMS waste vent will allow the expulsion of volatile matter and maximum volume reduction without compaction. By storing contaminated trash in individual storage bags, the potential for exothermic or toxic gas producing chemical reactions is essentially eliminated. These individual storage bags can be collected in a large storage bag for eventual transfer to the logistics module and subsequent return to earth for final disposal.

3.2.11 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 the Volume II Executive Summary 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 primary workstations, each consisting of an adjacent double rack and single rack, will be provided in the USL. The distinguishing feature of the USL workstations will be the presence of a specially equipped full width desk inset in the double rack. The two workstations currently planned for the USL are the workbench and the glovebox. The following paragraphs describe the workstations.

3.2.11.1 Workbench

The USL workbench will function as a laboratory bench, a repair facility, and a tool/supply cabinet. The desk inset will provide working space for microscopy, lab work, soldering, and repair; with fire suppression and a suction vent for safety and control of fumes. A digital recording oscilloscope and a digital multimeter will be installed in the rack for electronic troubleshooting. Stowage for microscopes, tools, containers and electronic instruments will also be provided. In order to support the functions of the USL workbench, the desk inset will have the following features:

a. Clamps and/or other fastening provisions for microscopes and other equipment.
b. Power outlets, DMS access, and lighting.
c. Mounting and connection provisions for a portable MPAC.
d. Clips, velcro, cages, and brackets to retain, bottles, etc., along both sides.
e. Crew restraints.
f. A pullout desk top.

3.2.11.2 Glovebox

The USL glovebox will be a double/single rack pair with an enclosed desk insert and liquid/gas waste handling systems. The USL glovebox will provide:

a. An isolation cell for handling hazardous and toxic materials.
b. Containment and control of spills and fumes generated by operations such as etching.
c. Processing and disposal of liquid/gas waste and toxic by-products.

To accomplish these ends, the USL glovebox will contain a waste processing and containment facility which will be plumbed into a specially equipped desk insert. This liquid-and-gas-tight desk insert will be closed out in the front by a panel with a full-width, low glare window and a pair of glove inserts. An airlock will also be provided for inserting and removing samples from the glovebox. Inside the glovebox, a control panel within reach of a gloved hand will allow operation of lights, purging and the airlock. Bottle racks and tool bins will also be installed in the glovebox within glove reach. Fire suppression and process gases will be provided to the glovebox. The glovebox rack will be equipped with leak detection and will provide leak warnings to the DMS and to the glovebox control panel.

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 categories are as follows:

P - Used in Pressurized Volume
U - Used Outside Pressurized Volume
F - Fluids (ECLSS Gases and User Fluids)
L - Propellants (Mono and Biprop)

The PLC element will transport Category P items 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.

ULCs 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 ULCs will include dry goods pallets to transport Category U equipment to the station and be docked to a convenient position to provide access for transfer as required to Space Station experiments/subsystems located outside of the pressurized modules. The fluids and propellant pallets have been defined as structures designed to support tanks which will transport propellants (Category L) and other types of fluids (Category F) to the Space Station. Umbilicals will be connected to provide the fluid transfer paths.

The maintainability goal of the Logistics Elements is to minimize maintenance resources (manpower, personnel skills, tools/test equipment, technical data, facilities, cost, etc) under standard operational conditions. One design goal for the Logistics Elements is to minimize or eliminate scheduled on-orbit maintenance and to minimize unscheduled on-orbit maintenance. Failed internally mounted ORUs will be replaced by spares transported in the PLC and stored in the SS. For externally mounted ORUs, spares will be transported and stored in an ULC which is attached to the Space Station structure. A second design goal will be to eliminate the need for manual tests and calibration actions when conducting replacement of ORUs or consumable resupply items.

Table 3.3-1 shows the Logistic Element weights including contingencies. It includes the PLC and the ULCs, consisting of propellant and fluids pallets and dry cargo pallets.

TABLE 3.3-1 LOGISTICS ELEMENTS WEIGHTS

ITEM	WEIGHT-kgs (lbs)	
PRESSURIZED LOGISTICS CARRIER (PLC)	6716	(14806)
Structure	4420	(9744)
ECLSS	1413	(3144)
TCS	343	(756)
EPS	353	(778)
COMM	25	(54)
DMS	163	(360)
UNPRESSURIZED LOGISTICS CARRIER (ULC)		
Propellant Pallet	1739	(3832)
Structure	1261	(2780)
EPS	41	(90)
DMS	30	(66)
Fluid System	406	(891)
TCS	3	(5)
Dry Goods Pallet	1305	(2877)
Structure	1261	(2780)
TCS	N/A	(N/A)
EPS	41	(90)
DMS	3	(7)
Fluids Pallet	1699	(3743)
Structure	1261	(2780)
EPS	41	(90)
DMS	30	(66)
Fluids Management	364	(802)
TCS	3	(5)

NOTE: Weights shown for the Unpressurized Logistics Carrier are being re-evaluated for the proposed design concept shown in Figure 3.3.2-1.

Figure 3.3-1 identifies the interfaces for the Logistics Elements. These interfaces are separated into two categories: Pressurized Logistics Carriers and Unpressurized Logistics Carriers. Both categories have interfaces with cargo, orbiter, and the Space Station. The Pressurized Logistics Carrier also interfaces with the Space Station Interconnects.

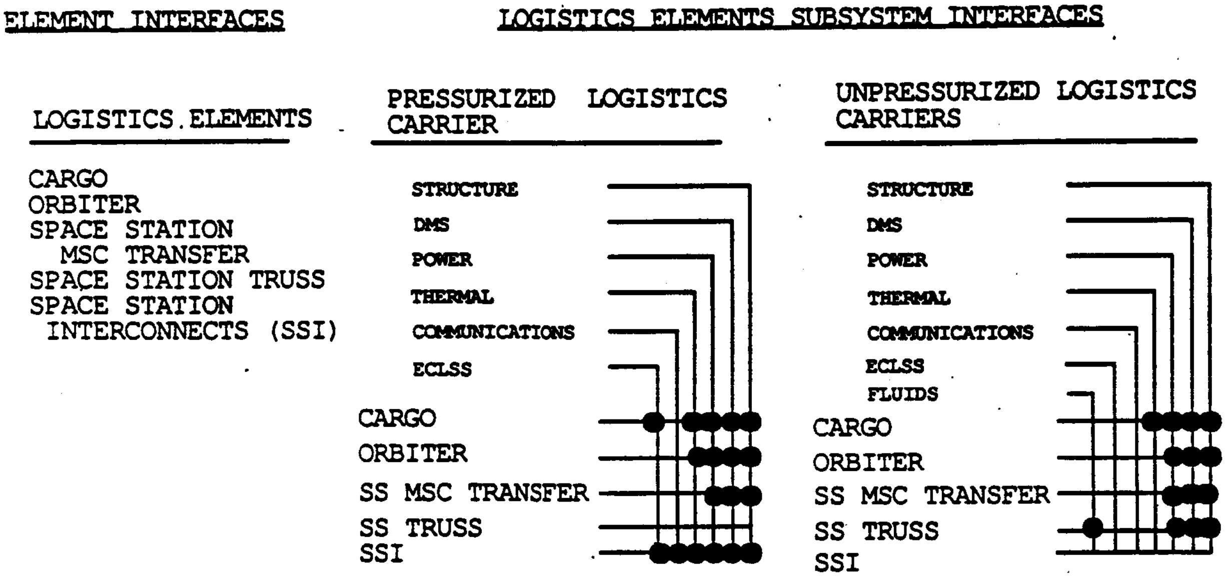

FIGURE 3.3-1 LOGISTICS ELEMENTS INTERFACES

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. Only PLC unique subsystem features will be described in this document. Subsystem packaging within the carrier is achieved by utilizing both provisioning bay (barrel) volumes and end cone volumes. The present subsystem design indicates that the entire forward end cone and 2 single racks will be needed for subsystem equipment installation. The net result is a PLC which provides approximately 1025 cu ft for logistics resupply. This volume can be enhanced by using the aft end cone and by dense packing within the center aisle (water and brine tanks would be an example of end cone stowage utilization).

3.3.1.1 External Configuration - PLC

The PLC configured core module consists of a pressurized, habitable structure derived from CM elements. This section will contain resupply station support goods, spares and experiments. The basic envelope of the PLC is a 6.98m (22.9 ft) long cylinder 4450mm (175.2 in) in diameter (see Figure 3.3.1.1-1). The envelope is exceeded only by launch support STS interface hardware, on-orbit grapple interface hardware and a berthing adaptor located at the forward end of the carrier. The carrier size is the optimum determined for studies based on logistics and user resupply requirements. The external surface consists of removeable space debris/micrometeoroid bumper panels that form part of the module integrated wall concept. The bumper panels cover the entire surface area of the pressurized section. A 5 point STS attachment that consists of two primary longeron trunnions, two stabilizing trunnions and one keel fitting is used for interfacing with the Orbiter cargo bay. The Oribter interface locations are at X_o 1175.2 for the primary (aft) fittings, X_o 1061.2 for the keel fitting and X_o 943.13 for the stabilizing (forward) fittings.

Two RMS grapple fittings are located outside the OSL at ± 45° from the +Z axis and longitudinally at station X_o 1080.3. These fittings will be used on-orbit to remove and relocate the PLC within the Orbiter cargo bay.

One end of the PLC has a 1270mm (50 in) x 1270mm (50 in) access hatch, interfacing with a SS node, to accommodate equipment and crew transfer on-orbit. The other end cone opening, which is used for ground processing, contains a large diameter access hole with a simplified closeout plate.

3.3.1.2 Internal Configuration - PLC

Four symmetrically spaced standoff assemblies provide equipment rack mounting and utilities support (cable trays, pipework, ducts, etc.). Symmetrical standoffs were selected over asymmetrical ones because they accommodate more standard double racks.

Four structural standoffs, located at the ±45° locations, provide support for all major internal subsystems and equipment outfitting. Each standoff consists of one 2024 aluminum section. The standoff members are pitched at a double rack width of 1066.8mm (42 in) and are fastened to the pressure wall at similar intervals. Attachment to the pressure wall is achieved utilizing thread inserts in the barrel panel. Attached to the standoff are hinge fittings. Each fitting supports the adjacent sides of two racks. The hinge concept is utilized for ease of managing racks on-orbit. Each standoff also contains provisions for the rack latch pin. The rack attach fitting and latch pin together provide the load path from the rack into the standoff.

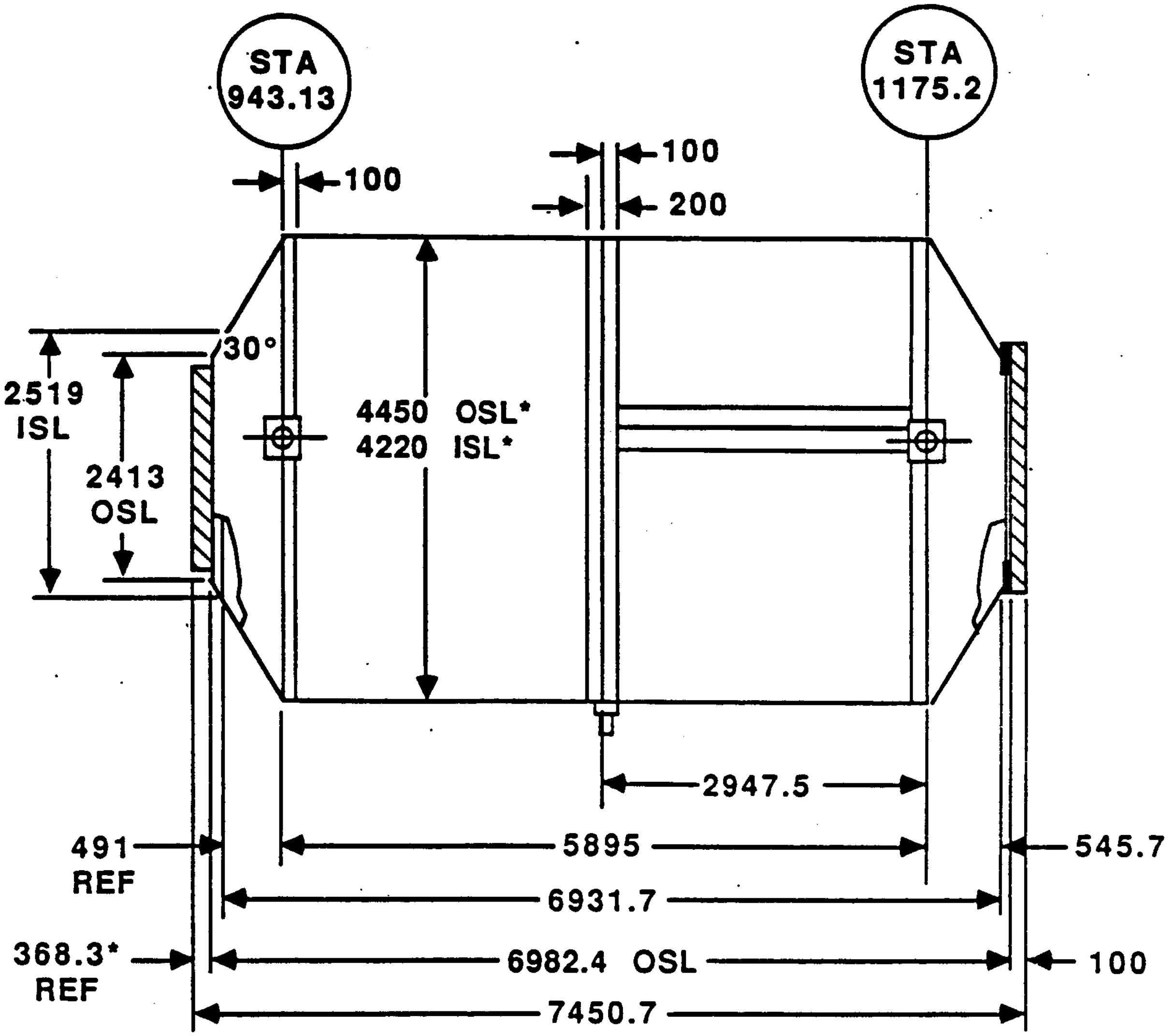

FIGURE 3.3.1.1-1 PRESSURIZED LOGISTICS CARRIER ENVELOPE GEOMETRY

The geometry of the standoff structure provides excellent flexibility for PLC outfitting requirements. The aisle width of 2134 mm (84.0 in) allows easy passage within the carrier and easy manipulation of racks/containers.

Supplies, spares, equipment and subsystems are mounted in standard racks or support pallets that are hinged at the standoff locations as shown in Figure 3.3.1.2-1. This allows easy access to the pressure wall, standoff and utilities for maintenance and repair. A utility interface plate and flexible lines are located at the base of the refrigerator/freezer racks to facilitate this concept.

The PLC equipment racks, are designed to accommodate all subsystem provisioning and user outfitting applications. The racks are configured as either single or double width structures and are adaptable to accept avionics, experiment standard drawers, larger nonstandard experiments, subsystem components or multiple sizes of stowage drawer/containers. The PLC can accommodate 11 single or 5 double racks and 1 single rack in each of four bay rows (left and right walls, floor and ceiling).

3.3.1.3 Electrical Power System - (PLC)

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 MSCS prior to berthing and from the adjacent node through the berthing ring subsequent to berthing.

The PLC power distribution system provides single phase, 208 volts, 20 kHz power to subsystem equipment and logistics payload equipment. While in the STS payload bay, 28 Vdc power is received via an umbilical to redundant interface conversion assemblies (ICA). The ICA converts 28 Vdc power to 20 kHz power which is provided to secondary power distribution assemblies (SPDA). During orbital operations, 20 kHz power is provided through the carrier's berthing ring to redundant secondary power distribution assemblies. These SPDA circuits are sized for 3 kW and provide redundant power to 22 single rack equivalents and the aft end cone. Subsystem equipment racks in the PLC will contain load centers that provide power to subsystem equipment within the PLC. Subsystems in need of rack distribution and protection will be provided with load centers.

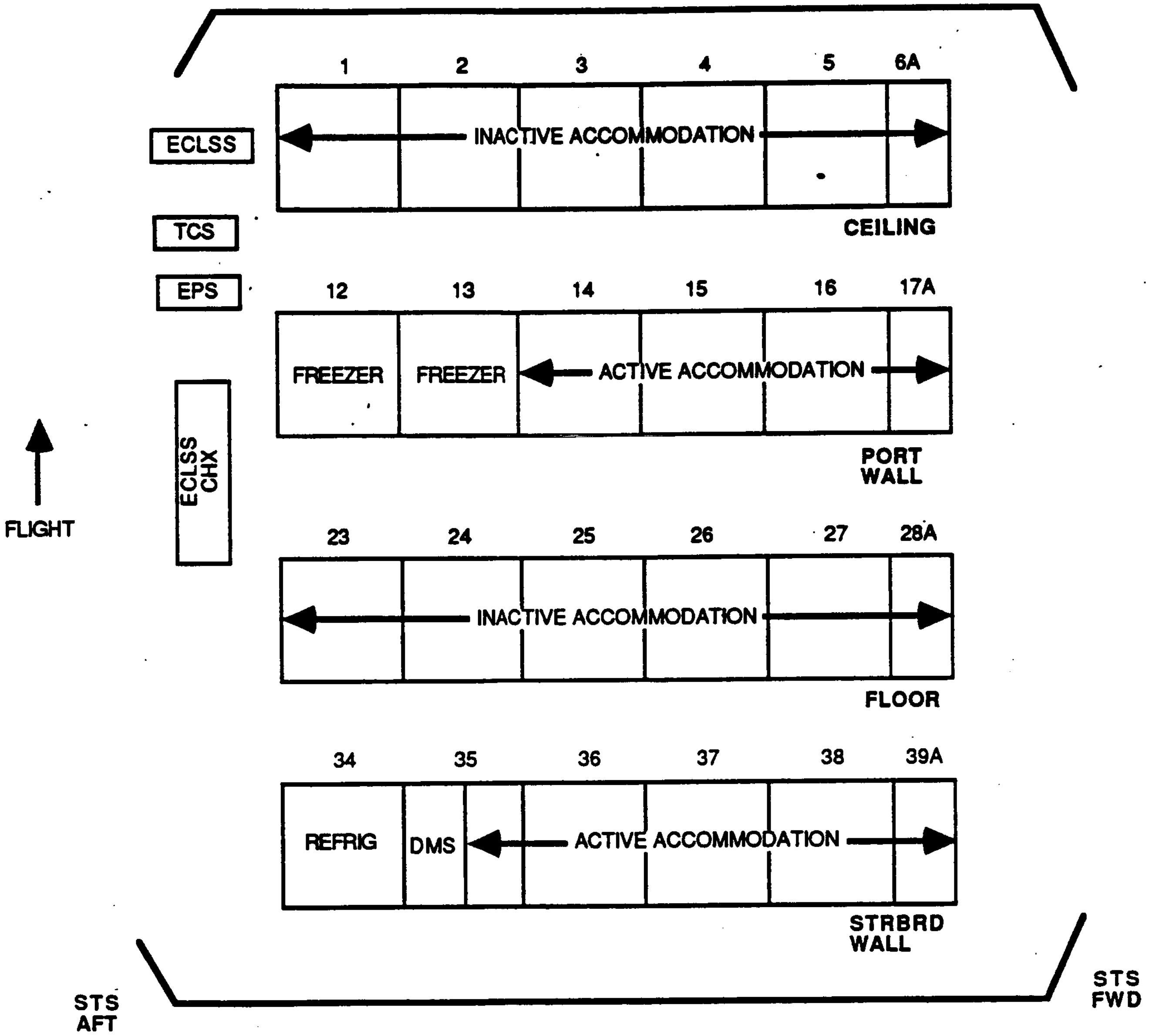

FIGURE 3.3.1.2-1 PLC INTERNAL LAYOUT

3.3.1.4 Data Management System - (PLC)

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.

Interfaces to the global core DMS and payload data networks will be provided. These interfaces link the carrier to the core module data system which will provide mass data storage, the inventory management system, and more extensive man-machine interfaces.

The PLC will be launched and returned in the shuttle many times and will require monitoring via shuttle data systems during transport. A standard shuttle interface will be utilized, necessitating a unique interface to the carrier data system. As a shuttle payload, the PLC will be designed to be two fault tolerant against catastrophic hazards.

A distributed processing system will minimize cabling weight and complexity. Space Station common controllers will control and monitor the core module type subsystems. Receptacles will be provided to allow portable workstation (PMPAC) use within the carrier for real-time control and monitoring of specific subsystems. The portable workstation will include an inventory management input device such as a bar-code scanner to be used in the PLC during inventory movements. DMS equipment is co-located with the ECLSS, Thermal, and Power equipment wherever local control is required.

The DMS will also provide Caution and Warning annunciators within the carrier, both visual and audible. Data on the type of failure and recommended actions will be provided through the PMPAC, if available, and the core module workstations.

3.3.1.5 Communications - (PLC)

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 except that the length requirements of each bus are less due to the shorter module. The wireless I/F which is part of the transceiver system is located in the ceiling. Audio control and processing will be accomplished by the audio processor in either the habitat or U.S. Laboratory modules. The PLC will have two wireless IR detectors, one at each end of the carrier and a speaker-microphone located in the center of the carrier.

Video processors which provide control for the PLC camera are located in either the habitat or U.S. Laboratory modules. A portable video camera at the aft end of the PLC provides area surveillance.

The camera and speaker/Mic will be removed from the PLC during carrier changeout and reinstalled in the replacement carrier.

3.3.1.6 ECLSS - (PLC)

The Environmental Control and Life Support Sytem (ECLSS) for the PLC provides the following basic functions:

a. Temperature and Humidity Control (THC) - The temperature and humidity of the atmosphere and other equipment are controlled within the PLC. These control functions also provide ventilation throughout all areas of the PLC. The heat collected is transferred to the Thermal Control Subsystem for dissipation. Specialized ECLSS equipment (refrigerators/ freezers) also dissipate their waste heat to the Thermal Control Subsystem.

b. Atmosphere Control and Supply (ACS) - Atmospheric pressure and composition control functions provide for monitoring and regulating the partial and total pressure of oxygen and nitrogen in the PLC atmosphere. Vent and relief pressure functions are also provided along with the distribution of 02 and N2 for the PLC.

c. Atmosphere Revitalization (AR) - Monitoring of atmospheric constituents and control of particulates/bacteria is provided.

d. Fire Detection and Suppression (FDS) - Fire detection and suppression equipment is provided for the pressurized volume with both fixed and portable extinguishers and emergency portable breathing equipment as required.

e. Waste Management (WM) - Return waste storage for trash, carbon canisters, filters, brine, and fecal material is provided as required.

f. EVA Support - Provide makeup/return tanks for extra H2O.

g. Resupply/Return -- Resupply consumables and emergency provisions for the entire ECLSS in the SSP are provided. Tankage for N2 is located on the fluids pallet. Tankage for H_2O is located in the PLC. Replacement kits/ORU's for all ECLSS functions are also included such as filters, wipes, water treatment resupply, etc. Waste return is also provided for waste water (brine), fecal material, trash, carbon filters, etc.

3.3.1.7 Thermal Control System - (PLC)

The Thermal Control System (TCS) for the PLC is similar to that of the Core Module (CM). The PLC has no body mounted radiators and no external fluid loop which reduces PLC weight. The TCS for the PLC includes a pumped single phase water loop inside the carrier for acquisition and transport of internal heat loads. This loop rejects up to 10 kW of module waste heat via direct connection to the CM attached payloads loop. The passive thermal control for the PLC consists of 20 layers of multilayer insulation (MLI) and silverized teflon as an optical coating on the exposed surfaces.

A low temperature body mounted radiator system is being proposed over a mechanical refrigeration system. Through the body mounted radiators, this system utilizes space as a heat sink for the refrigerator/freezers in the pressurized logistics carrier. To save PLC weight, the plumbing for the PLC refrigerator/freezer is routed to the HSOM. The HSOM radiators are sized to reject both the PLC and the HSOM loads.

The Orbiter will provide the necessary heat rejection capability to the PLC during the ground and ascent mission phases. A significant time lag may occur between the disconnection of the PLC from the Orbiter active thermal control system and the connection of the PLC to the Space Station central thermal control system. Body mounted radiators, a flash evaporator system, a sublimator system, or a liquid/solid phase change device are viable options for rejection of the PLC waste heat load during this phase.

3.3.1.8 Crew Systems - (PLC)

Crew restraints will be provided to assist the crewmen in performing both intra-vehicular (IV) and extra-vehicular (EV) tasks, within WP-01 responsibilities. These restraints will include handholds and handrails necessary for translation through hatches and also the necessary foot and body restraints to support crew operations related to CM provided subsystems operations and maintenance and to assist the crew in the removal/replacement of a standard rack to its use module location.

3.3.1.9 Logistics Elements Software - (PLC)

All aspects of the Core Module Data System software are available within the PLC via the Space Station network. The network will provide the transfer of fault data from the subsystems and elements throughout the station. Transmission of data to and from the ground will be via the space/ground network. Manual interface will be available by two means. The first is via the portable work station. Unique items within the portable work station would include tailored Logistic displays and menus. The basic interface is common. The second interface will be through a reader for inventory control. In this area, unique software will be required to accept optically scanned data.

The Logistic Element (LE) interfaces with a set of software to handle inventory management control. This software will be part of the Data Management Software and will be accessible from any module including the PLC. The software includes inventory management, spares and consumable status and ground interface for reorder/statistical analysis. The Logistic Elements interfaces with a data base to support inventory control.

The PLC Power and DMS software will have an interface to the orbiter for the transport to and from orbit of hazardous materials and life science deliverables.

The Logistic Elements will contain interfaces to subsystem software for the following subsystems; ECLSS, Internal Communication, Power, Fluids Resupply, Structures and Mechanisms and Thermal. Unique subsystem application software requirements exist in the ECLSS, Power, Fluids Resupply, and Thermal Subsystems. All unique subsystem functions will interface with the DMS.

3.3.2 Unpressurized Logistics Carrier - (ULC)

The proposed ULC concept is an open sided, ring frame and truss beam structure 3.5m (11.5 ft) long by 4.42M (14.5 ft) diameter consisting of attach points for dry goods pallets, fluids pallets, and propellant pallets as shown in Figures 3.3.2-1, and 3.3.2-2. Access to the payload volume is via any of four circumferential locations. However, core volume through access is only accomplished at two of the four circumferential locations. Various payloads and sizes can be accommodated by this baseline configuration. The ULC will be mated to the STS orbiter via a 5 point attachment system having 2 primary trunnions, 2 stabilizing trunnions, and 1 keel fitting. Two grapple fittings are located on the +Z axis within the truss beam. Figure 3.3.2-2 shows the ULC structure and trunnion/keel locations. Docking to the Space Station will also use the attach trunnions mated to a docking fixture located in the station truss stowage area. After orbiter docking, the ULC will be removed from the payload bay to the docking fixture using the MSCS interfaced with Flight Release Grapple Fixtures (FRGF). Not depicted on the figure but included in subsystem definition is the additional subsystem equipment necessary to make the carrier functional, such as multi-layer insulation, electrical power distribution and DMS sensors and wiring.

3.3.2.1 Dry Goods Pallet

The dry goods pallets will be inserted into the ULC and will have the capability to carry and store cargo that is to be utilized in an unpressurized environment. The container structure is derived from CM rack components and can accommodate standard rack drawers. Figure 3.3.2-1 depicts the relative location of the dry goods container in the ULC structure. Not depicted is the additional subsystem equipment required to make the container functional such as electrical power distribution and DMS sensors and cabling.

3.3.2.2 Fluids/Propellant Pallets

The fluids necessary to support the Space Station will be transported in pallets mounted to the ULC structure as shown in Figure 3.3.2-1. The envelope of the pallets is a standard envelope able to be accommodated in the central core of the container. Tanks containing N2, laboratory fluids, and propellants will be mounted to the pallet structure along with quick disconnect umbilicals to provide the fluid transfer path to storage locations on the Space Station. These umbilicals will be connected/disconnected using the MSCS or other remote means. Not depicted on the figure, but included in subsystem definition is the additional subsystem equipment necessary to make the subpallet functional. Multi-layer insulation and heaters will be necessary to prevent fluid freezing. Sensors will be supplied to gather pressure, temperature and fluid level data for transmission to the Space Station DMS. Electrical power will be provided for the thermal control heaters, DMS sensors, and fluid valve actuation.

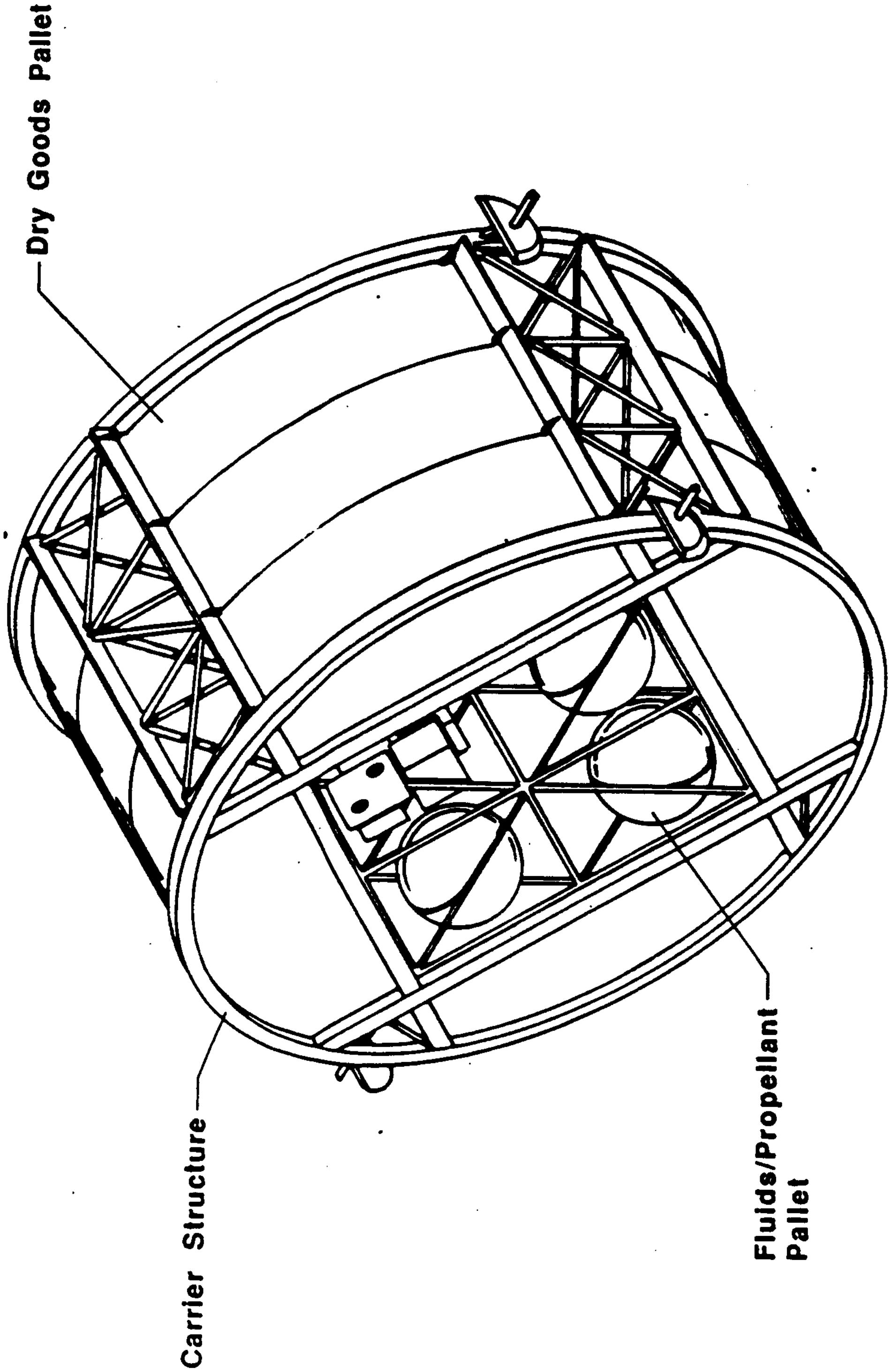

FIGURE 3.3.2-1 PROPOSED UNPRESSURIZED LOGISTICS CARRIER CONCEPT

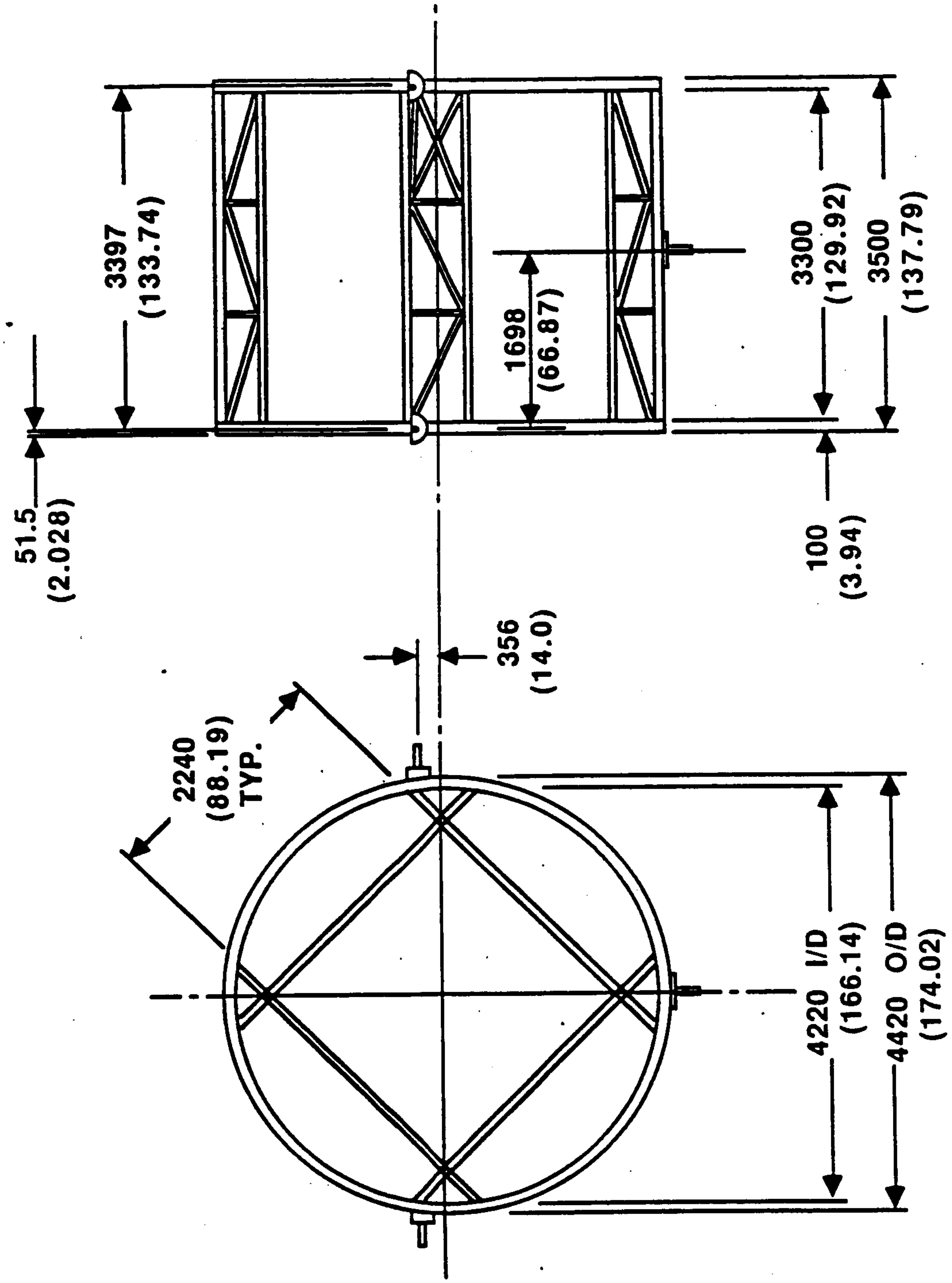

FIGURE 3.3.2-2 ULC GEOMETRY

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 its 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.

The driving requirements for the Propulsion System are summarized in Table 3.4-1.

TABLE 3.4-1 DRIVING REQUIREMENTS FOR THE PROPULSION SYSTEM

	Driving Requirement	Requirement Source/Explanation
1.	Provide orbital velocity increments to compensate for atmospheric drag forces, perform orbit adjustments, and execute collision avoidance maneuvers for man-tended and manned Space Station configurations.	C-4, 2.2.8 Provide capability to maintain Space Station in orbit.
2.	Provide 3 axis control thrust for altitude control during reboost, as back up in the event of failures in momentum exchange devices, and to stabilize disturbances resulting from docking, berthing and MRMS movements which exceed the capability of the momentum exchange devices.	C-4, 2.2.8 Provide capability for 3 axis reaction control for reboost and as a back up to the momentum exchange system.
3.	Provide fuel storage and transfer capability, and maintain an adequate reserve margin for a missed 90-day resupply period.	C-4, 2.2.8 Enables station to reboost and maintain orbit in the event of a missed resupply.

TABLE 3.4-1 DRIVING REQUIREMENTS FOR THE PROPULSION SYSTEM (CONT)

Driving Requirement	Requirement Source/Explanation
4. Provide two fault tolerant redundancy for the thruster, propellant lines and valves.	C-4, 2.1.10.1 Provides a high level of redundancy for a critical subsystem, enabling orbit maintenance in the event of a failure.

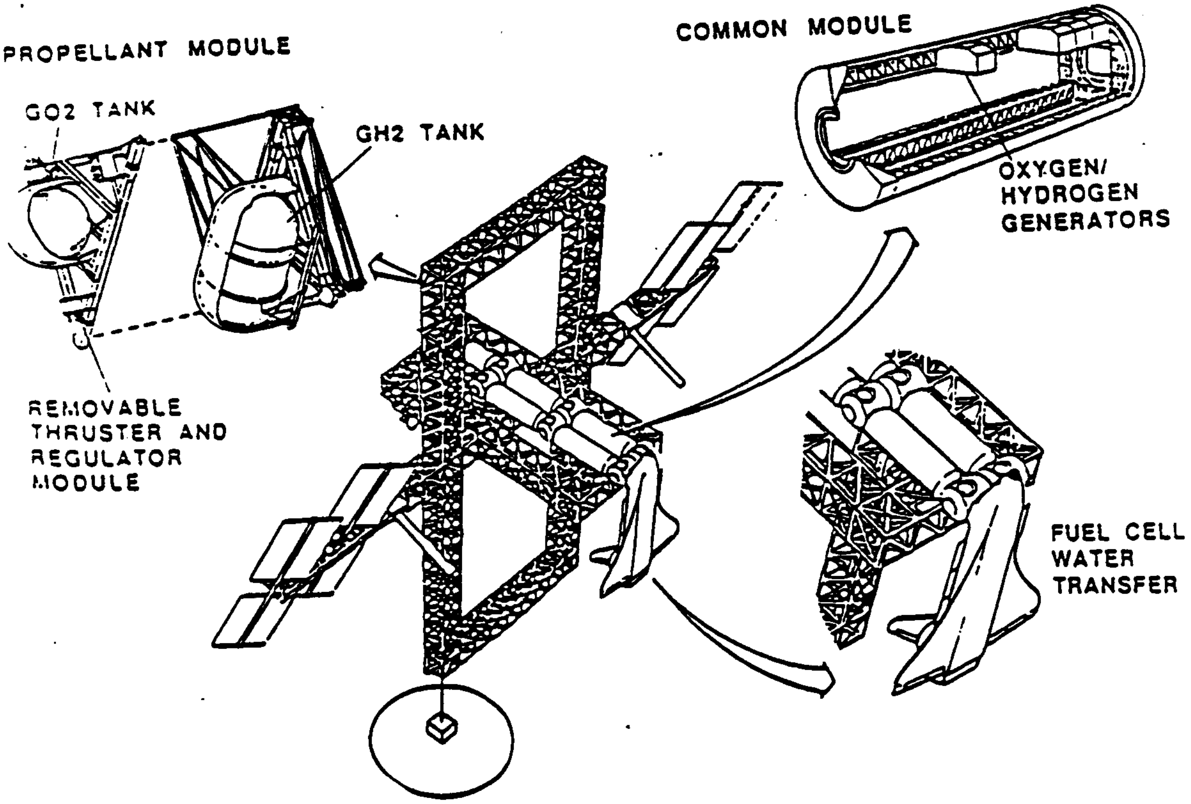

FIGURE 3.4-1 PROPULSION SYSTEM - WATER ELECTROLYSIS

3.4.1 Propulsion Module Configuration

The propulsion module is shown in Figure 3.4.1-2, 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.

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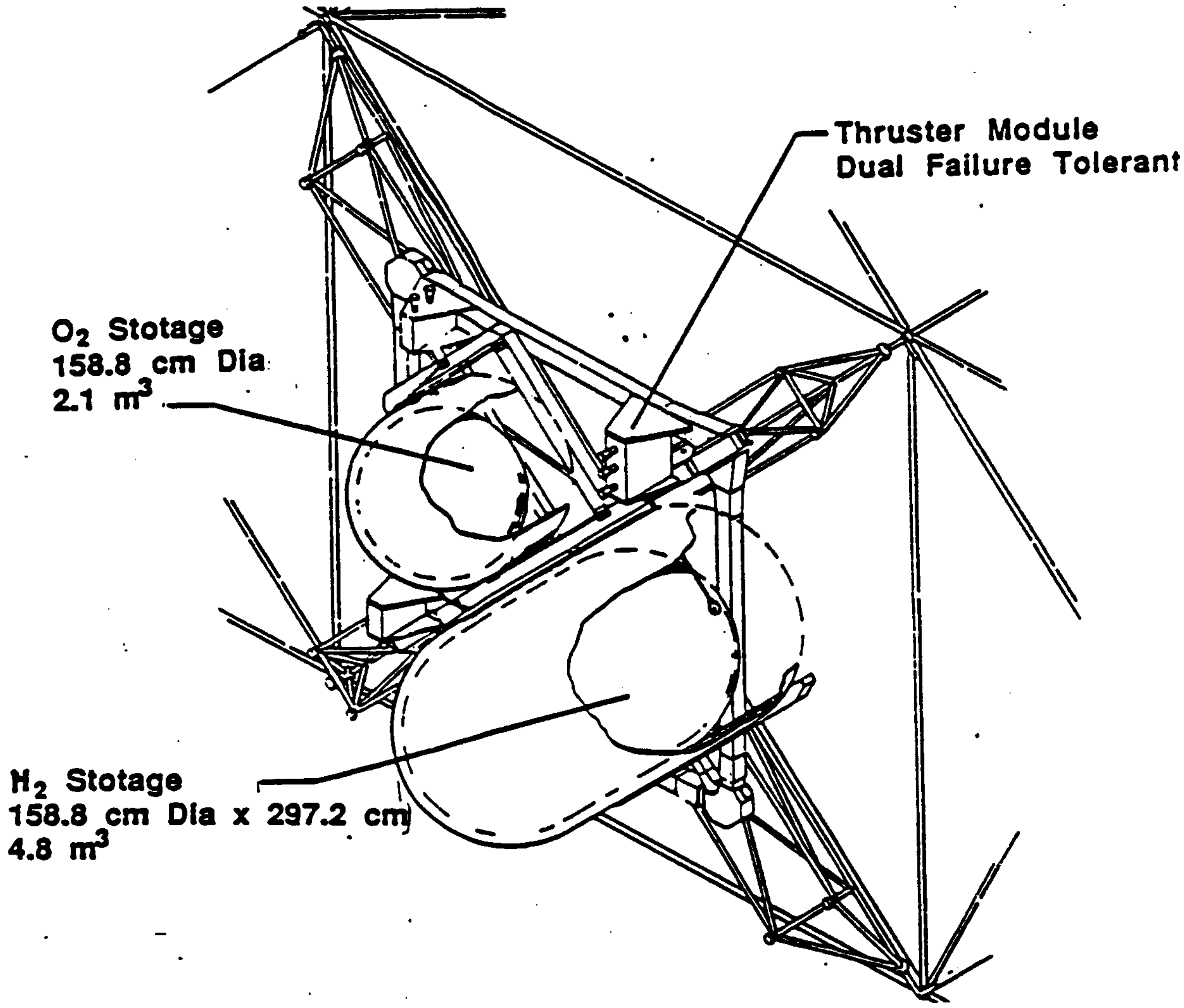


FIGURE 3.4.1-1 OXYGEN-HYDROGEN PROPULSION MODULE

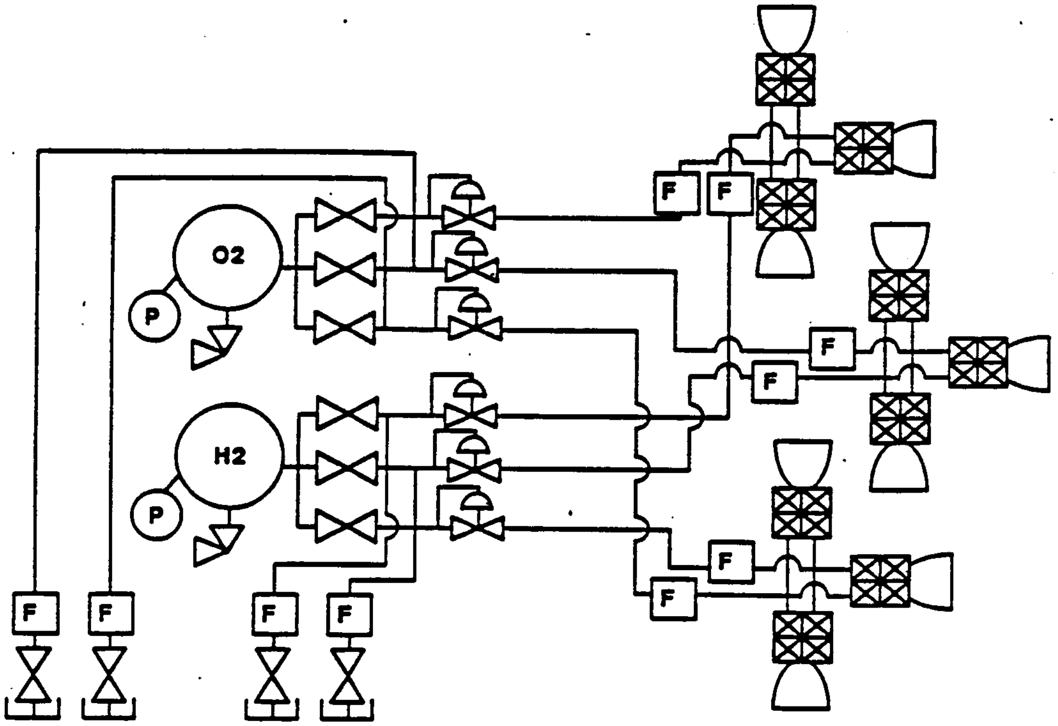


FIGURE 3.4.1-2 OXYGEN/HYDROGEN PROPULSION MODULE SCHEMATIC

3.4.1.2 Accumulator Tanks

Four sets of accumulators are used, one set at each of the four thruster locations. At an 8:1 mixture ratio, the hydrogen volume is twice that of the oxygen, for a given temperature and pressure. Composite tanks are baselined. Composite tanks are attractive because they offer a 1984 kg/module weight savings over comparable metallic tanks at the same factor of safety of 2:1. A thermal analysis characterized the accumulator performance over the mission duty cycle. This entailed both an environmental and fluid simulation during typical propulsion maneuvers. The accumulators are currently sized assuming isothermal blowdown. The relatively short burn time and large size of the accumulators should result in isothermal accumulator blowdown, which will be verified during development testing. The accumulators are sized to provide 3.6 MNs of total impulse while operating between 7 MPa and .7 MPa. The accumulator propellant mass will be determined from a Pressure, Volume, Temperature (PVT) relationship based on the individual propellants.

3.4.1.3 Thrusters

The 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. The thrusters will be modularized in sets of three provide for +X and -X and +Y or -Y thrust. The module will be designed to be removed and replaced robotically in space.

3.4.1.4 Valves and Regulator Modules

Several sizes and types of valves will be needed, predominantly latch valves, compatible with the fluids consistent with their use. The main use of solenoid type valves is the thruster valves. Hand valves are indicated on the tanks for ground loading. Test ports used for ground testing prior to launch would be needed. For on-orbit testing, pressure transducers and other means of sensing will be used. Pressure regulators are used downstream from the accumulators to maintain constant thruster inlet conditions. Since there is not much line volume between these regulators and the thrusters, these will need to account for this. At this point, variable set point regulators are not anticipated. The regulators will delivery .38 ± .03 MPa to the thrusters while operating over an inlet range of 5.9 to .7 MPa.

3.4.1.5 Interface Quick Disconnects

Conventional high pressure gas disconnects are used to resupply hydrogen and oxygen and to connect the hydrogen tankage to the remainder of the system.

3.4.1.6 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.

3.4.2 Other Interfaces

The interfaces for the Propulsion system include the following Space Station Subsystems.

3.4.2.1 Electrical Power Distribution Subsystem

Figure 3.4.2.1-1 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.

3.4.2.2 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.

3.4.2.3 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 module, is therefore limited to the GN&C commanding the jets on and off. The propulsion controller receives these commands and activates the valve drive amplifiers directly, inhibiting the command only if it is deemed necessary for Space Station safety. To avoid commanding a jet which is inhibited, the GN&C will make the jet selection consistent with a jet availability table which is generated by the propulsion controller.

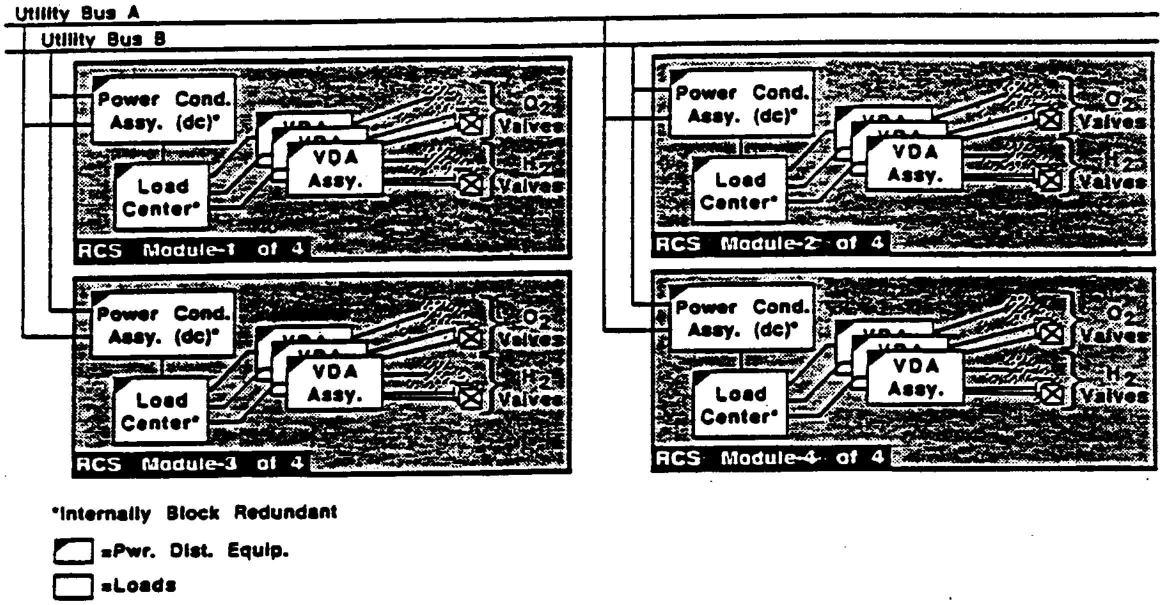


FIGURE 3.4.2.1-1 PROPULSION SYSTEM POWER DISTRIBUTION

3.4.2.3 Thermal

The thermal requirements of the water electrolysis propulsion system are as follows: (The -101°C temperature coincides with the critical point temperature for oxygen.)

	deg C
Vapor Lines	-101 to 38
Accumulators	-101 to 38
Thrusters	-101 to 38
Electronics	-2 to 83

The components of the thermal control subsystem for the GO_2 and GH_2 propulsion system consist of multilayer insulation, thermal control coatings, electric heaters, temperature sensors, and controls. The vapor lines, accumulators, and thrusters will require only a thermal control coating such as white paint. The multilayer insulation will be aluminized mylar separated with dacron net and covered with silverized teflon. The teflon provides mechanical protection as well as protection from atomic oxygen for the mylar/dacron insulation and the kapton heaters. Both the silverized teflon and white paints degrade with time from exposure to UV radiation and atomic oxygen, therefore studies are underway in order to determine if these materials are suitable for Space Station application. The kapton heaters are covered with insulation for protection from atomic oxygen.

The structural attachment points for the propulsion lines present a special thermal control challenge. The design of these thermal and structural elements must accommodate line thermal expansion, limit line vibration, and limit the heat leak at the attachment point. The thermal and structural design of the attachments will be performed in the preliminary design phase of the Phase C/D contract.

3.4.2.5 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

The following section provides a definition and description of the Martin Marietta Reboost Strategy and Operating Altitude. Subsection 3.5.1 describes the requirements and operating strategy. This segment includes both Pre ISR and Post ISR strategies (minimum altitude and variable altitude strategies). Subsection 3.5.2 describes how the reboost function is implemented.

3.5.1 Requirements

The system requirements for reboost are functional and operational. Hardware or implementation requirements are found in the Propulsion End Item Data Book. The system requirements for Propulsion may be found in SS-SRD-700, Space Station Propulsion System Requirements Document. Interface requirements are found in the following:

a. SS-IRD-700, Propulsion System to Space Station

b. SS-IRD-701, Propulsion System to Space Station Platforms

c. SS-IRD-702, Propulsion System to Orbiter

Top-level reboost system requirements are summarized in section 1.1

The IOC space station** will weigh 181,440 kg (400,000 lbs) and its ballistic coefficient* will be approximately 46.22 kg/m^2 (9.47 lbs/ft^2). Section 3.5.1.2 contains discussion of the FOC Space Station (with Solar Dynamic Collectors) and a full complement of payloads, weighing approximately 453,600 kg (1,000,000 lbs).

** ISR Configuration
* Ballistic Coefficient = Weight/(Drag Coefficient x Reference Area)

3.5.1.1 Systems Requirements

The Top-level reboost system requirements are:

a. Provide reboost for maintenance of Space Station at or above the minimum operational altitude of 463.25 km (250 nm), for up to 37.06 (20 nm) orbit adjustment, and for collision avoidance. (Reference: SSCB-BB000046 specifies 463.25 km (250 nm) as minimum operational altitude.)

b. The steady-state gravity level shall be less than 10^{-5}g.

c. There shall be no reboost while the NSTS orbiter is attached to the Space Station. The orbiter may be attached for 14 days per quarter. (Reference: NASA/MSFC direction.)

3.5.1.2 Impulse Requirements

Impulse requirements vary as a function of solar activity and Space Station maturity (growth). Propellant quantities are determined by considering the effects of drag makeup, attitude control, missed resupply, and two sigma solar activity contingencies.

Table 3.5.1-1 shows the NASA value recommended at RUR-1 for worst case design. We feel that this is a reasonable, though conservative, value. Impulse requirements and sample propellant budgets are shown in this section.

TABLE 3.5.1-1 IOC SPACE STATION 90 DAY REBOOST REQUIREMENT*
(NASA RECOMMENDATION AT RUR-1)

Ground Rules

- +2 sigma solar activity at the peak value during the 11 year solar cycle
- Initial altitude 500.31 (270 nm)
- Design for orbital decay of 90 days before reboost back to 500 km (270 nm)
- Case 1:IOC Maximum Weight, BC = 45.08 Kg/m^2 (9.23 lb/ft^2) Weight = 451,712 lbs (204,893 Kg)
- Case 2:IOC Minimum Weight, BC = 36.62 Kg/m^2 (7.50 lb/ft^2) Weight = 274,082 lbs (124,321 Kg)

	CASE 1*	CASE 2*
Total Impulse in N-sec (lbs-sec)	4,488,032	3,407,168
• Reboost for 90 Days Orbital Decay	3,798,592	2,926,784
• Collision Avoidance	311,360	186,816
• 10% Reserve (Finite burn, Guidance & Control losses)	378,080	293,568
Total Impulse in N-sec (lbs-sec) for 10 year mission (4 collision avoidance maneuvers assumed)	64,113,472 (14,414,000)	49,154,848 (11,051,000)

This represents results at RUR-1, section 3.5.1.2.3 shows impulse requirements for the synthesized IOC Space Station (weight = 181,440 kg (400,000 lbs)).

3.5.1.2.1 Operating Altitude - The nominal operating altitude addressed in the Space Station RFP was 500.31 km (270 nm) with a range of 463.25 - 555.90 km (250-300 nm). The current baseline of 463.25 km (250 nm) is represented in this section, however current studies of a variable operating altitude scenario indicate that it can result in a significant cost savings or an increase in the amount of payload that can be delivered to Space Station. The current range of altitudes for this scenario is 352.07 - 444.72 km (190 - 240 nm). Analysis of a variable altitude strategy is continuing at this time. (Note, the altitude for Space station assembly should be lower than the nominal operating altitude of 463 km (250 nm) in order to increase NSTS payload capability; 407.7 km (220 nm) is the baselined assembly altitude at this time). The current NASA baseline is a variable operating altitude. The MMC variable altitude strategy is discussed in Section 3.5.1.4.

3.5.1.2.2 Candidate Reboost Strategies - Table 3.5.1-2 shows the candidate reboost strategies considered for Space Station and Figure 3.5.1-1 shows an example of the 463km minimum/90 day reboost stragety.

TABLE 3.5.1-2 CANDIDATE REBOOST STRATEGIES

Option	Features
Continuous Reboost	Narrow altitude variation, very low acceleration levels. Lifetime of thrusters and contamination are issues.
500.31 km (270 nm) Maximum/ 90 Day Reboost	Reboost to 500.31 km (270 nm) after each resupply cycle. Near repeating orbit, average altitudes = 491.05 km (265 nm), acceleration = 6.7 x 10-4 g's
463.25 km (250 nm) Minimum/ 90 Day Reboost	Reboost only high enough to decay to 463.25 km (250 nm) in 90 days for predicted solar activity, average altitude 472.52 km (255 nm). Minimum altitude (+2 sigma quarter) = 444.72 km (240 nm), resupply at 444.72 - 463.25 km (240-250 nm).
463.25 - 555.90 km (250-300 nm) Altitude/Variable Reboost	Utilize the full range of altitude. Reboost only every 180-300 days except in +2 sigma quarter, variable resupply at 463.25 - 537.37 km (250-290 nm). Long, infrequent reboost burn.
10 Day Reboost with CMG Desaturation	Energy advantage of desaturating CMG with the reboost burn. Small reboost burn each 10 days. Accel. = 6.7 x 10-4 g's. Some impact on customers.
407.66 km (220 nm) Minimum	Drag makeup high, +2 sigma solar activity causes 40.77 km (22 nm) decay in 30 days—feasible only with continuous or frequent reboost.
Variable with Space Station Maturity and Solar Activity	Establish IOC and pre-IOC operating altitudes. Increase operating altitude in OPS time frame and bias altitude for high solar activity.

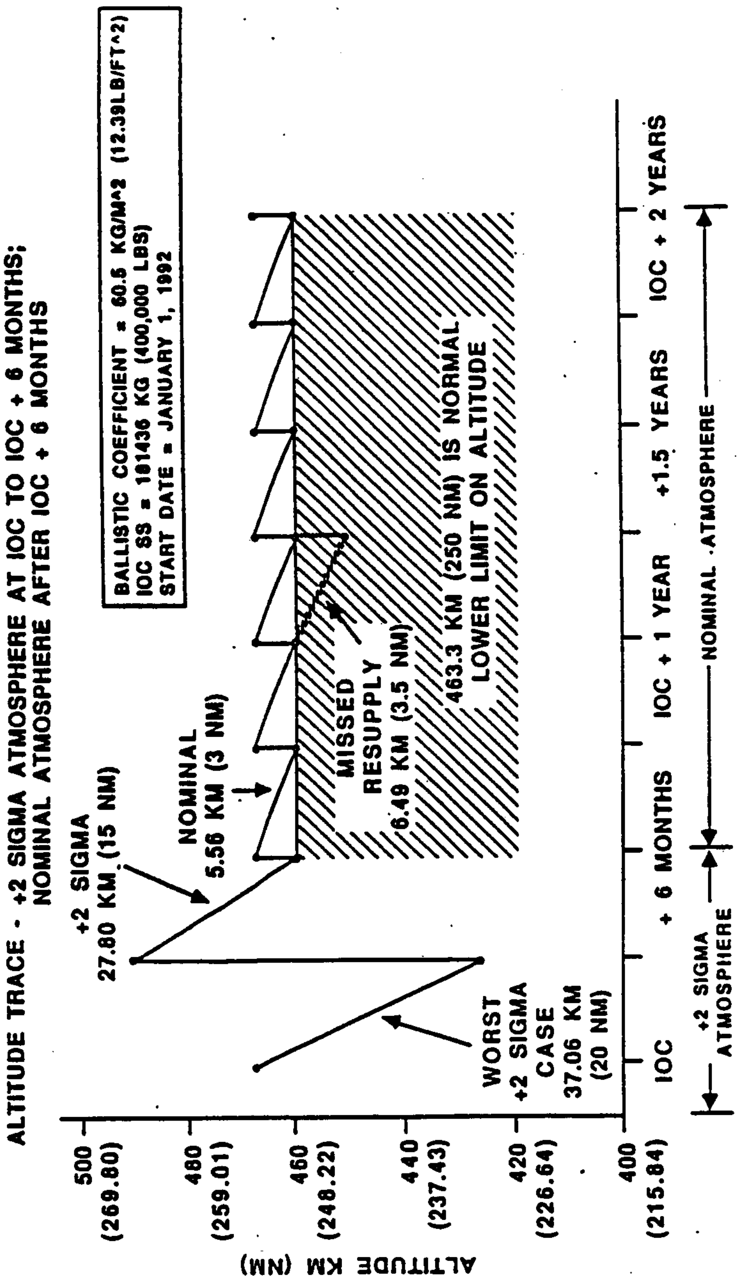


FIGURE 3.5.1-1 REBOOST - MINIMUM ALTITUDE SCENARIO (IOC - 250 NM)

3.5.1.2.3 ISR Updated 90 Day Impulse Requirements - The contributing factors to the total 90 day impulse requirement for the Space Station are listed in Figure 3.5.1-2. Figure 3.5.1-3 depicts a worst case impulse requirement for the NASA Phase B ATP configuration. This total 90 day impulse requirement includes a +2 sigma contingency, an altitude adjust capability and a missed resupply contingency. It is felt that this contingency stacking is unnecessary since it is assumed that multiple contingencies will not occur simultaneously. Thus, it is suggested that the altitude adjust and missed resupply requirements be eliminated as part of the Space Station resupply tank considerations. Figure 3.5.1-4 shows how the impulse requirements for the missed resupply contingency can be accommodated for by using the same propellant stored for the +2 sigma contingency impulse requirement for the MMC/MSFC/BAC synthesized configuration of 12/1/85. The recommended impulse requirements for the MMC/MSFC/BAC synthesized configuration and the MMC revision (3/86) are shown in Figure 3.5.1-5. The top portions of the "barrels" represent the impulse requirements for each 90 day period, while the shaded portions represent the contingency impulse requirements which may be stored onboard the Space Station. These budgets represent deviations from the Space Station RFP in the following respects:

a. The "missed resupply" contingency developed in preliminary requirements is ignored because the "+2 sigma contingency impulse" may be used for the missed resupply case (thus, the same propellants may be reserved for high solar activity and missed resupply, assuming that both contingencies do not occur simultaneously).

b. The requirement for altitude adjustment of the Space Station for contingencies has been eliminated, consistent with the MSFC position established at RUR-1. This is based on the same argument, that the requirement for Space Station altitude adjustment, high solar activity and missed resupply are unlikely during the same solar activity period. We also expect that the altitude adjustment would likely be upward; thus accomplishing part of the reboost requirement for the next 90 day period.

The recommended total impulse requirements for the MMC/MSFC/BAC synthesized configuration and the MMC revision (3/86) are 5,048,035 N-Sec (1,139,900 lbf-sec) and 4,016,099 N-Sec (902,900 lbf-sec) respectively (see Figure 3.5.1-5).

CATEGORY	PRIMARY REASON
NOMINAL REBOOST	PROVIDE 90 DAYS ALTITUDE
+2 SIGMA CONTINGENCY	PREPARE FOR HIGH SOLAR ACTIVITY
ACS FOR REBOOST	EXTRA ACS REQ'D FOR REBOOST BURN
ACS FOR NORMAL OPERATIONS	NORMAL ACS TO BACK UP CMG'S
BACKUP ACS	EXTRA ACS FOR EXTRA 90 DAYS
RESERVE	PERFORMANCE & LINE UNCERTAINTIES
COLLISION AVOIDANCE	AVOID SPACE DEBRIS
ALTITUDE ADJUST	MOVE SS TO OTHER ALTITUDE OR CLOSER TO ANOTHER ELEMENT
MISSED RESUPPLY	STORE PROPELLANT IN CASE THE NSTS IS DELAYED FOR A FULL RESUPPLY CYCLE (N2H4 OR MONO PROPS ONLY)

FIGURE 3.5.1-2 SOURCES OF REBOOST IMPULSE REQUIREMENTS

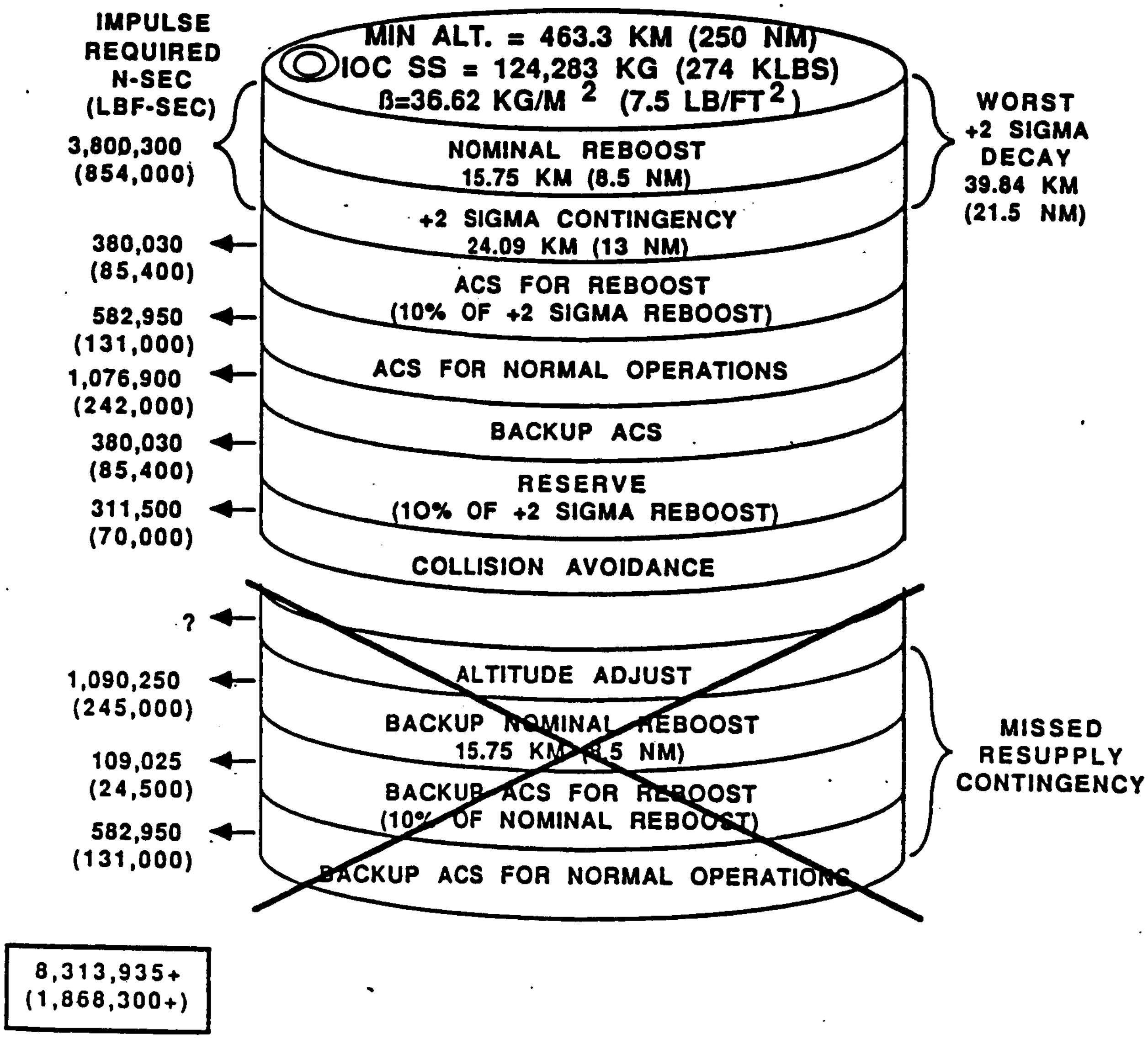


FIGURE 3.5.1-3 SPACE STATION TOTAL IMPULSE REQUIREMENTS - NASA AT PHASE B ATP

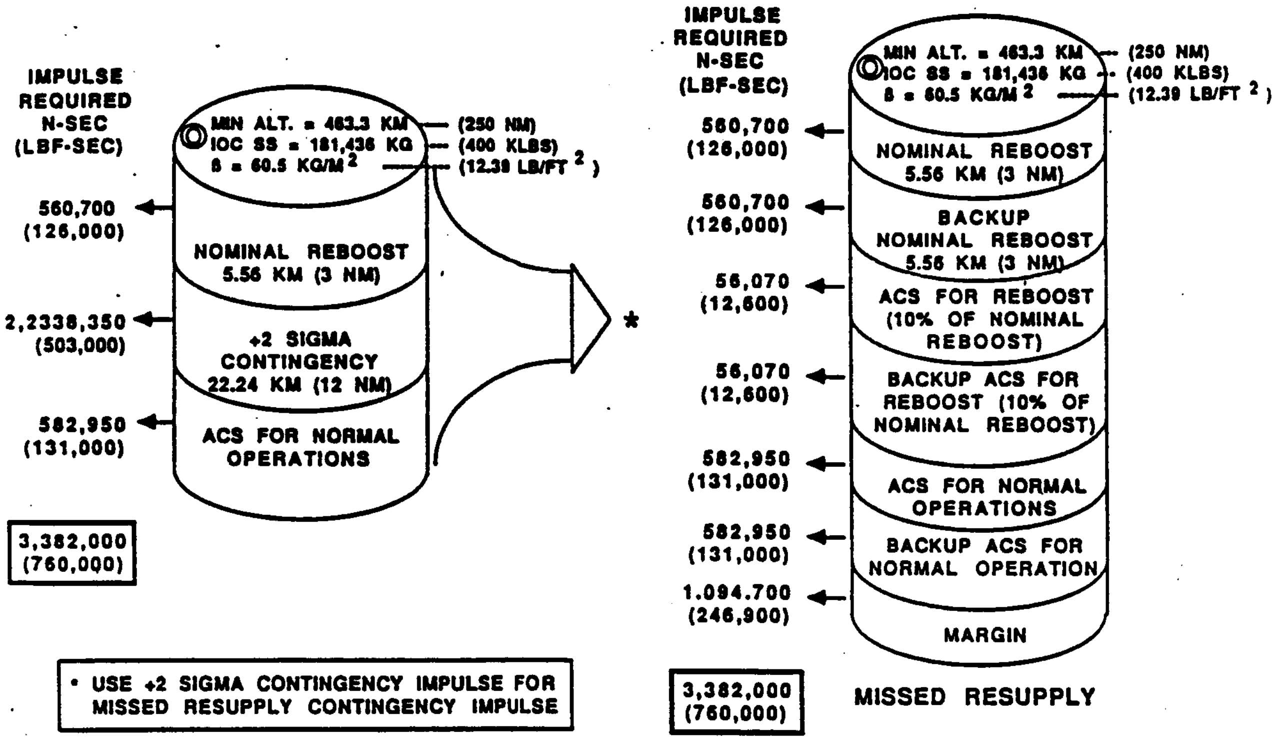


FIGURE 3.5.1-4 SS TOTAL IMPULSE REQUIREMENTS FOR MISSED RESUPPLY -
MMC/MSFC/BAC SYNTHESIZED (12/1/85)

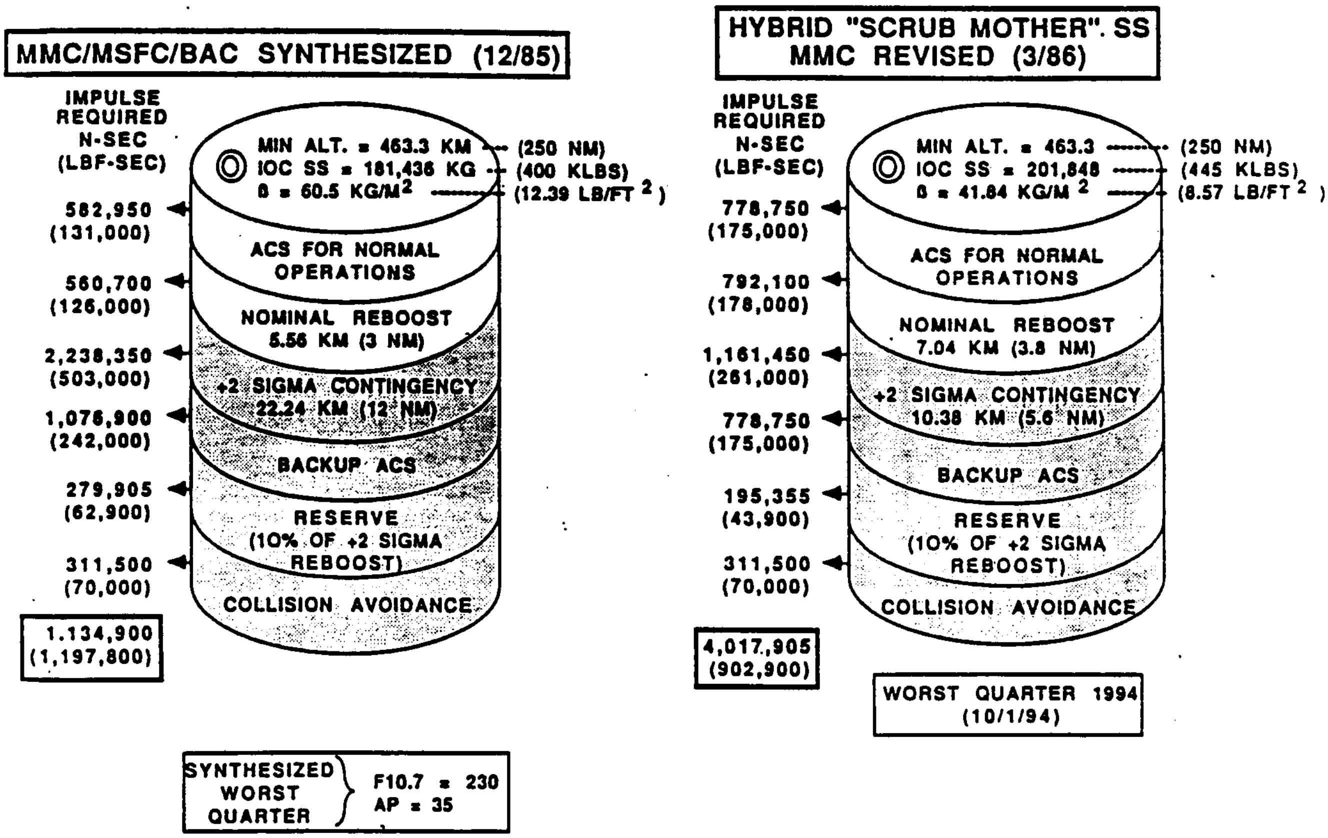


FIGURE 3.5.1-5 REVISED SPACE STATION 90 DAY TOTAL IMPULSE REQUIREMENTS

3.5.1.2.4 ISR Updated 10 Year Total Impulse Requirements - The total impulse requirement for the 10 years from IOC to FOC is 45,359,183 N-Sec (10,197,658 lbf-sec) assuming the station grows from 181,440 kg (400,000 lbs) to 453,600 kg (1,000,000 lbs) and that IOC occurs on 1/1/94 (see Figure 3.5.1-6). The altitude profile for the 10 years from IOC to FOC is shown in Figure 3.5.1-7. From the curve it can be seen that there is an annual peak in reboost altitude during the October quarter. The peak altitude for the entire 10 year cycle of 477.15 km (257.5 nm) occurs during late 2002 and early 2003, which corresponds to the peak of the solar activity cycle during the 10 years analyzed.

The impulse required per 90 days (i.e. per reboost) versus time is shown in Figure 3.5.1-8. The impulse requirements over the 10 years range from 314,091 N-sec 170,614 lbf-sec) to 3,286,262 N-sec (738,818 lbf-sec). The peak in impulse required corresponds to the peak in the delta altitude required for reboost (i.e. late 2002 and early 2003). The total impulse required over the 10 year cycle is 45,359,183 N-sec (10,197,658 lbf-sec).

TEN YEAR TOTAL IMPULSE:

IOC SS WEIGHT = 181,440 KG (400,000 LBS)

IOC ß = 46.22 KG/M^2 (9.47 LB/FT^2)

FOC (IOC + 10 YEARS) SS WEIGHT = 453,600 KG (1,000,000 LBS)

FOC (IOC + 10 YEARS) ß = 43.68 KG/M^2 (8.95 LB/FT^2)

10 YEAR SOLAR CYCLE CONSIDERED

START DATE = 1/1/94
STOP DATE = 1/1/04

10 YEAR TOTAL IMPULSE = 45,359,183 N-SEC (10,197,658 LBF-SEC)

FIGURE 3.5.1-6 SPACE STATION 10 YEAR TOTAL IMPULSE REQUIREMENTS ASSUMPTIONS AND RESULTS (REVISED 3/86)

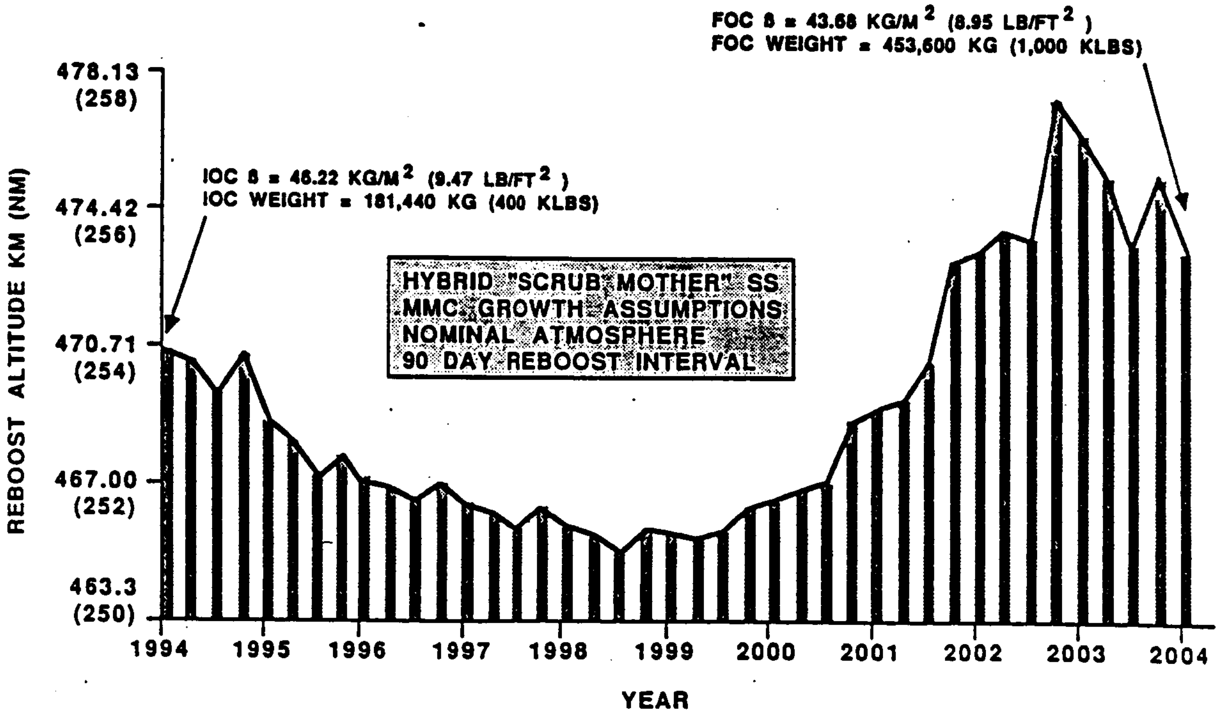


FIGURE 3.5.1-7 SPACE STATION ALTITUDE TRACE FOR 463.3 KM (250 NM) MINIMUM ALTITUDE REBOOST STRATEGY

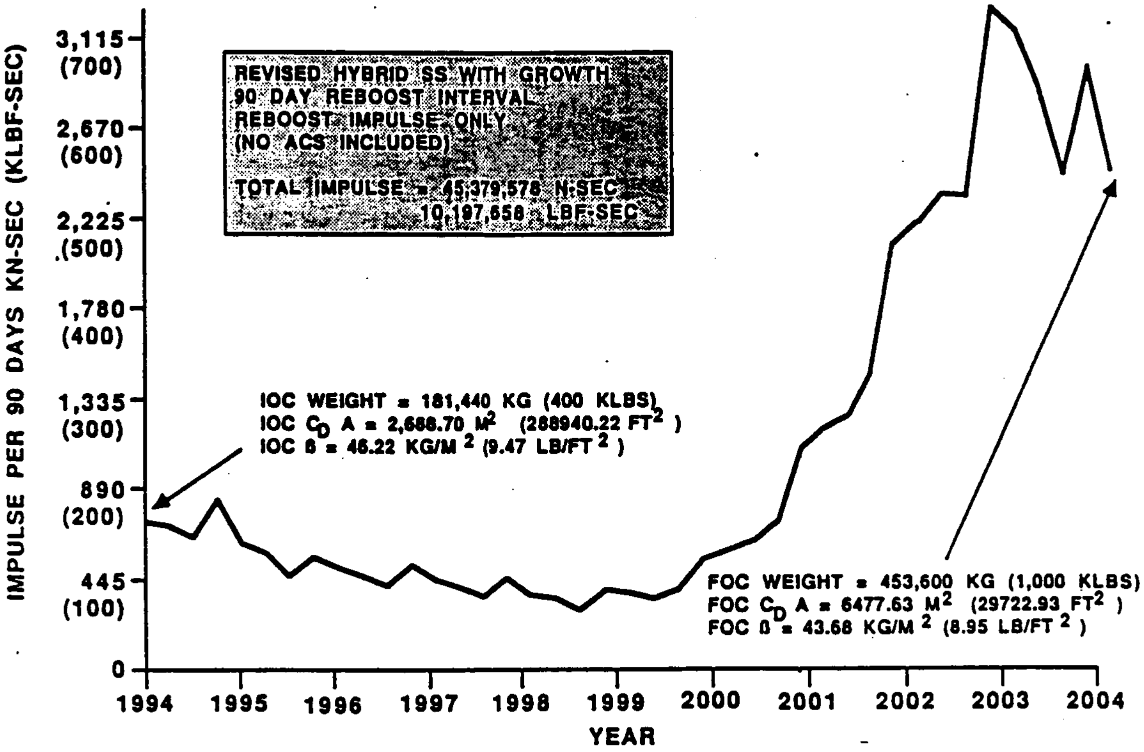


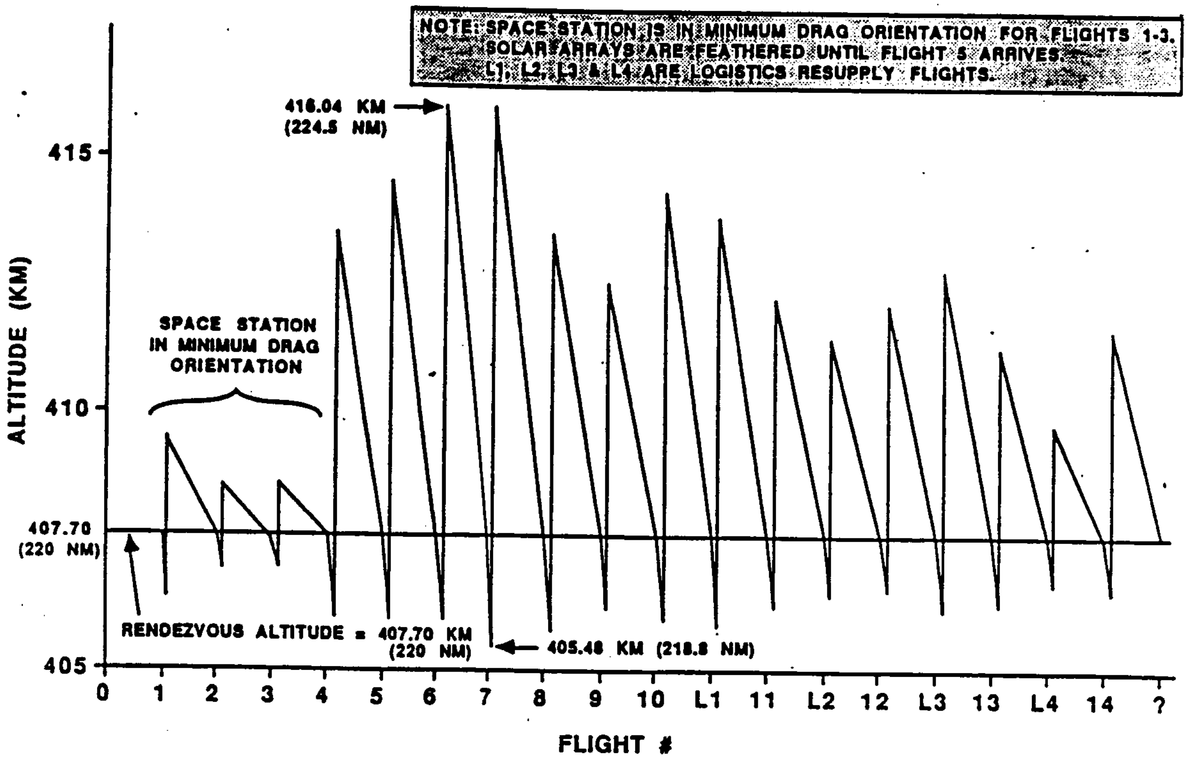
FIGURE 3.5.1-8 10 YEAR TOTAL IMPULSE RQMT FOR REBOOST 463.3 KM (250 NM) MINIMUM ALTITUDE STRATEGY (REVISED 4/5/86)

3.5.1.2.5 Impulse and Altitude Requirements for Space Station Buildup - Space Station assembly is currently scheduled to begin 1/1/93 with assembly flights occuring every 45 days for flights 1-10. Following flight 10, NSTS visits will still occur every 45 days, however, every other flight will be a Logistics resupply flight, not an assembly flight (These flights are noted by L1, L2, L3 etc. on the following figures). The current assembly sequence requires 14 assembly flights to achieve IOC. Figure 3.5.1-9 shows the altitude profile predicted for the assembly time frame. As can be seen, the NSTS will rendezvous with the space station at 407.66 km (220 nm) and will remain attached for approximately 5 days, during which time the space station will continue to decay in altitude. Following NSTS departure the space station will reboost to an altitude such that in 40 days (45 days minus 5 day NSTS stay time) it will have decayed to 407.66 km (220 nm) to rendezvous with the next NSTS flight. It should be noted that the space station was assumed to be in a minimum drag orientation for flights 1-3 and that the solar arrays are feathered until flight 5 arrives. Figure 3.5.1-10 is a tabular listing of space station weight, SS/STS final altitude, reboost altitude, and reboost impulse required for each 45 day cycle and the total reboost impulse required for assembly. Trade study IM75 has details of the elements manifested on each flight.

3.5.1.2.6 Reboost Implications of Platforms - Free-flying and co-orbiting satellites near Space Station's altitude present a unique problem: if the platforms do not reboost strategically, their orbits will become non-coplanar with Space Station's orbit and become difficult to reach with all but the NSTS Orbiter. This arises from differential orbit plan precession at different altitudes. Altitude differences between Space Station and Platforms arise due to different orbital decay rates (different ballistic coefficients). This problem can be minimized by starting the platform below or above the Space Station's altitude such that the platform's time averaged altitude is the same as Space Station's. This minimizes accumulated plane differences. This will also minimize propellant used on the platforms for reboost and formation flying by minimizing plane corrections, which at their altitude is a major propellant consumption issue.

Table 3.5.1-3 lists the issues we considered in the formation flying analyses. Figure 3.5.1-11 shows operating altitudes for both Space Station and Free Flying platforms, and parametrics completed. Space Station will nominally be at 463.25 km (250 nm) within a current range of 463.25 - 555.90 km (250-300 nm). Free Flying platforms will typically be within a range of 463.25 - 1000.62 km (250-540 nm) altitude. These platforms will be a minimum of 185.30 km (100 nm) downrange of Space Station to keep them out of Space Station Control Zones #1, #2, #3, and #4.

Figure 3.5.1-12 describes some typical free-flying platforms that might exist during Space Station era as described in the Space Station configuration document. This figure also lists their nominal operating altitudes.



NOTE: SPACE STATION IS IN MINIMUM DRAG ORIENTATION FOR FLIGHTS 1-3. SOLAR ARRAYS ARE FEATHERED UNTIL FLIGHT 5 ARRIVES. L1, L2, L3 & L4 ARE LOGISTICS RESUPPLY FLIGHTS.

FIGURE 3.5.1-9 ALTITUDE PROFILE FOR ASSEMBLY SEQUENCE 5/86)

FLIGHT #	WEIGHT		SS/STS FINAL ALT.		REBOOST ALT.		REBOOST IMPULSE	
	[KG]	(LBS)	[KM]	(NM)	[KG]	(NM)	[N-SEC]	(LBF-SEC)
1	15,350	(33,840)	406.44	(219.34)	409.61	(221.00)	26,661	(5,994)
2	30,222	(66,627)	406.96	(219.62)	408.68	(220.55)	29,415	(6,613)
3	43,933	(96,854)	407.01	(219.65)	408.68	(220.55)	41,380	(9,303)
4	57,912	(127,673)	406.08	(219.15)	413.59	(223.20)	245,236	(55,134)
5	76,964	(169,673)	406.01	(219.11)	414.61	(223.75)	373,321	(83,930)
6	91,021	(200,664)	405.99	(219.10)	416.00	(224.50)	513,691	(115,488)
7	108,209	(238,556)	405.47	(218.82)	416.00	(224.50)	642,371	(144,418)
8	121,088	(266,949)	405.79	(218.99)	413.59	(223.20)	533,022	(119,834)
9	136,216	(300,300)	406.25	(219.24)	412.66	(222.70)	492,874	(110,808)
10	150,907	(332,687)	406.01	(219.11)	414.42	(223.65)	716,235	(161,024)
L1	150,907	(332,687)	405.83	(219.01)	413.87	(223.35)	684,761	(153,948)
11	166,607	(367,299)	406.23	(219.23)	412.29	(222.50)	569,771	(128,096)
L2	166,607	(367,299)	406.49	(219.37)	411.55	(222.10)	475,740	(106,956)
12	185,179	(408,244)	406.65	(219.42)	412.20	(222.45)	586,811	(131,927)
L3	185,179	(408,244)	406.18	(219.20)	412.85	(222.80)	697,126	(156,728)
13	199,480	(439,770)	406.33	(219.28)	411.37	(222.00)	567,547	(127,596)
L4	199,480	(439,770)	406.71	(219.49)	409.88	(221.70)	461,173	(103,681)
14	214,913	(473,794)	406.60	(219.43)	411.74*	(222.20)	622,649	(139,984)
						TOTAL IMPULSE =	1,861,462	(8,279,744)

NOTE: THE NSTS RENDEZVOUS ALTITUDE FOR ALL FLIGHTS IS 407.66 KM (220 NM)

* THIS ASSUMES THE NEXT NSTS RENDEZVOUS ALTITUDE IS 407.66 KM (220 NM); IF 463.25 KM (250 NM) IS THE RENDEZVOUS ALTITUDE, THE REBOOST ALTITUDE IS 464.73 KM (250.8 NM) & THE IMPULSE REQUIRED IS 6,982,497 N-SEC (1,569,806 LBF-SEC).

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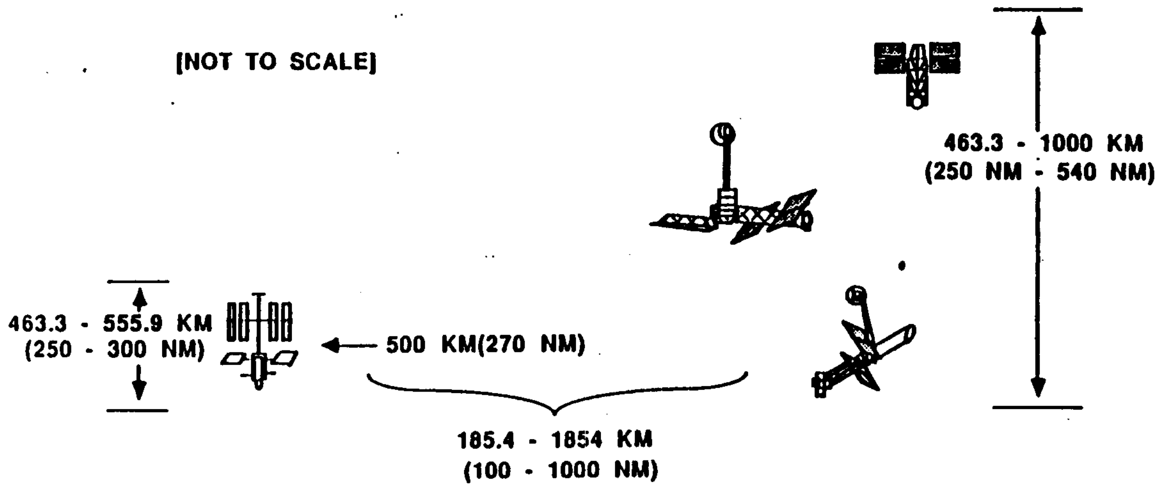
FIGURE 3.5.1-10 IMPULSE RQMTS FOR ASSEMBLY SEQUENCE (5/86)

TABLE 3.5.1-3 FORMATION FLYING ISSUES

- CHANGES IN ORBIT ALTITUDE
- NODAL DRIFT
- RELATIVE POSITION
  - CONTROL ZONES
  - LINE OF SIGHT
- SERVICING OPPORTUNITIES
- PLATFORM REBOOSTS TO "KEEP UP"
  - HOW OFTEN
  - IMPULSE REQUIREMENTS FOR PLATFORMS
  - BIAS ORBITS FOR NODAL DRIFT
- SPACE STATION MANEUVERS AFFECTING FORMATION FLYING



PARAMETRICS COMPLETED:

SS AT 463.3 KM (270 NM)

PLATFORM AT
1000 KM (540 NM)
555.9 KM (300 NM)
444.7 KM (240 NM)

ß = 20 KG/M^2 (4.193 LB/FT^2)
= 40 KG/M^2 (8.190 LB/FT^2)
= 60 KG/M^2 (12.29 LB/FT^2)
= 80 KG/M^2 (16.39 LB/FT^2)
=100KG/M^2 (20.48 LB/FT^2)

CONCERNS:
NODAL DRIFT
COMMON PROPULSION
SERVICING
REBOOST STRATEGY

FIGURE 3.5.1-11 FORMATION FLYING WITH SPACE STATION

VEHICLE	SS OPERATIONAL ERA	ALTITUDE KM (NM)	ESTIMATED* BALLISTIC COEFFICIENT KG/M^2 (LB/FT^2)
SPACE INFRARED TELESCOPE FACILITY (SIRTF)	IOC	700.5 - 1853 (378-540)	8.45 (41.26)
STARLAB	IOC	500 (270)	29.30 (6.00)
PINHOLE/OCCULTATION FACILITY (P/0F)	IOC	500 (270)	41.01 (8.40)
ADVANCED SOLAR OBSERVATORY (ASO)	GROWTH	500 (270)	41.01 (8.40)
HIGH THROUGHPUT EXPERIMENT (HTP)	GROWTH	500 (270)	46.48 (9.52)

*SS's BALLISTIC COEFFICIENT IS 36.62 KG/M^2 (7.50 LB/FT^2) AT IOC AND 80.00 KG/M ^2 (16.39 LB/FT^2) AT FOC

FIGURE 3.5.1.12 CO-ORBITING PLATFORMS/FREE-FLYERS (LOW INCLINATION)

As shown, fuel consumption is fairly low for nominal atmospheric conditions, but increases for +2 sigma solar activity conditions. This increase is mostly to adjust orbital plane, and arises because average delta altitude becomes greater during +2 sigma conditions, which translates into a significantly greater plane change angle after 90 days.

To minimize the effects of platform to Space Station orbital drift and the corresponding effects on OMV or platform propellant usage, a scheme can be derived so that orbital mechanics can be used to subtract the orbital precession effects from the formation flying problem. Such a scheme is shown in Figure 3.5.1-13. So, for known platforms and predicted solar activity, plane change maneuvers will be minimized. The following conclusions have been drawn from these studies:

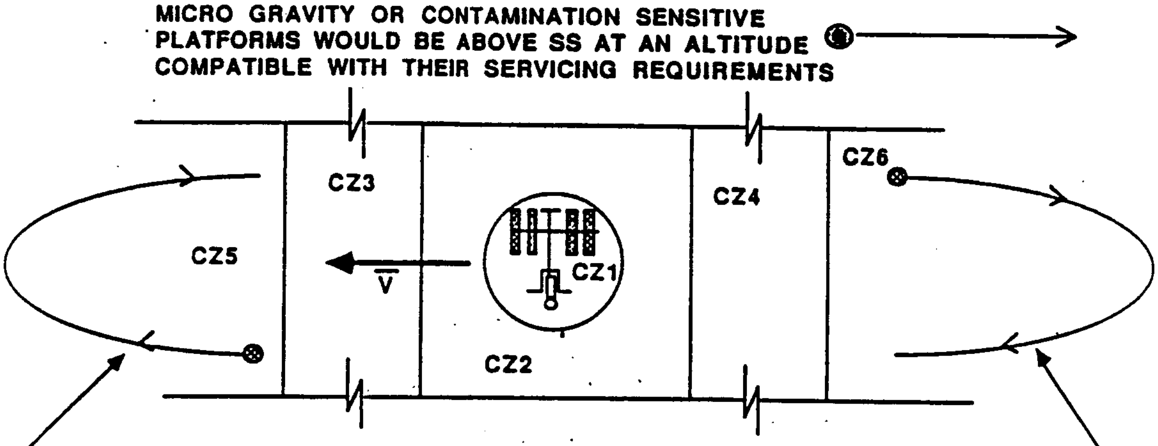
- Formation flying does not require a constant altitude Space Station reboost strategy; the platforms need a predictable (predicted) average Space Station altitude.

- Continuous reboost may be desirable for platforms which are not contamination sensitive; this would make formation flying less complex.

- Periodic reboost is desirable for platforms which are contamination sensitive.
  - Low frequency and thrust for those sensitive to g-level
  - Develop scheme to keep the same "average" altitude as Space Station
  - Solar activity will affect reboost schedule significantly due to drift variations (orders of magnitude)

- Higher altitudes may be desirable for co-orbiting platforms due to a decrease in differential drag effects (such as orbital drift) which can complicate formation flying significantly.

- The "synthesized" platforms (Figure 3.5.1-14) have been used for analyses prior to IRR decisions. These are representative for early Space Station platforms (circa 1995).



MICRO GRAVITY OR CONTAMINATION SENSITIVE PLATFORMS WOULD BE ABOVE SS AT AN ALTITUDE COMPATIBLE WITH THEIR SERVICING REQUIREMENTS

PLATFORMS WITH HIGHER BETA THAN SS WOULD BE STARTED LOWER THAN SS

IF +2 SIGMA SOLAR ACTIVITY IS PREDICTED IT WOULD ALSO BE STARTED SLIGHTLY OUT OF PLANE

PLATFORMS WITH LOWER BETA THAN SS WOULD BE STARTED HIGHER THAN SS

IF +2 SIGMA SOLAR ACTIVITY IS PREDICTED IT WOULD ALSO BE STARTED SLIGHTLY OUT OF PLANE

NOTE: DRAWING NOT TO SCALE & MOTION INDICATED IS RELATIVE TO SS IN A SS CENTERED RELATIVE COORDINATE FRAME

FIGURE 3.5.1-13 FORMATION FLYING STRATEGY

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	POLAR	CO-ORBITING	SYNTHESIZED POLAR/ CO-ORBITING
MASSES -DRY(NO P/L) W/PROPULSION	6976-8933 KG (15347-19652 #) - GE 5000-6845 KG (11000-15059 #) - RCA	8681-10326 KG (19100-22717 #) - GE 4827 KG (10619 #) --RCA	POP: 8578 KG (18871 #) COP: 8410 KG (18502 #)
-P/L'S W/O CARRIERS	4000-5000 KG -GE&RCA (8800-11000 #)	6000-10000 KG (13200-22000 #) - GE 9000-10000 KG (19800-22000 #)	POP: 1673 KG (3681 #) COP: 4181 KG (9198 #)
-P/L CARRIERS	1545-2155 KG - GE&RCA (3399-4741 #)	1880 KG (4136 #)	1880 KG (4136 #)
ALTITUDES -OPERATIONAL	DEPLOY AT 220KM—GE (119NM) 400-900 KM (216-486NM)	DEPLOY AT SS 500 - 1000 KM (270-540 NM)	POP:705 KM (380 NM) COP: AT SS
-STS REND. OR SERVICING	220KM (119NM) W/CONT -GE 350KM (189NM) - RCA	AT SS AT SS	POP:220 KM (119 NM) COP:AT SS
TOTAL MASS ON ORBIT			POP:15000 KG (33000 #) COP:15000 KG (33000 #)
BALLISTIC COEFFICIENT	30-50 KG/M^2 (6.14-10.24 LB/FT^2)	30-50 KG/M^2 (6.14-10.24 LB/FT^2)	POP:62 KG/M^2 (12.7 LB/FT^2) COP:62 KG/M^2 (12.7 LB/FT^2)
ONBOARD TOTAL PROPELLANT	2425 KG (5335 #) @ 705 KM (380NM) (Isp=305 SEC) +250KG (550 #) ACS	360 KG/YR (Isp=305 SEC)	POP:2675 KG (30 MO) (5885 #) COP:360 KG (12 MO) (792 #)
POWER AVAIL.FOR PROPULSION	5 KW DURING BURN 0.5KW CONT.	5 KW DURING BURN 0.5KW CONT.	5 KW DURING BURN 0.5KW CONT.
NSTS LIFT CAPABILITY			9135 KG (20100 #) TO 705 KM (380NM) 13463 KG (29660 #) TO 500 KM (270NM)

FIGURE 3.5.1.14 SYNTHESIZED SS PLATFORMS

3.5.1.3 Thrust Level Requirements

This section discusses the derived requirement of thrust level for the reboost system. Higher thrust levels are desirable from the hardware and mission analysis standpoint; lower thrust levels are desirable if the Space Station is to minimize the effects of reboost on the Low g experiments and structure of the Space Station. Table 3.5.1-4 describes ground rules used for the thrust level evaluation. Table 3.5.1-5 summarizes results of Space Station thrust level analyses which led to the recommendations summarized in Table 3.5.1-6. For an IOC Space Station with Hydrazine thrusters (Isp = 230 sec), a total thrust level of 44.48 N (10 lbs) is recommended. The Space Station total thrust level for the FOC Space Station should be at least 88.96 N (20 lbs). The primary driver for these recommendations is the operations time required for very low thrust levels (more than two crew shifts). For the electrolysis system, Isp approximately 385 sec, these recommended values must be approximately doubled; e.g. 88.96 and 177.92 N (20 and 40 lbs) for IOC and FOC configurations respectively. Further data on thrust levels is included in the Propulsion book of DR-02.

TABLE 3.5.1-4 GROUND RULES - SPACE STATION THRUST LEVEL STUDY

- Reboost from 444.72 km (240 nm) to 500.31 km (270 nm) (worst case)
- IOC Space Station weight = 122,926 kg (271,000 lbs)
- Thrust vector parallel to velocity vector (inertial angle of attack [ALPHA] = 0°)
- Hydrazine* Reboost engine ISP = 230 sec.
- Constant thrust assumed during thrust period - coast periods simulated
- Reboost trajectories simulated with POST trajectory simulation program
- Altitude dependent nominal atmosphere assumed during entire transfer operation

* This study was done with Hydrazine engines assumed. Some differences would exist if electrolysis or another propellant is used, primarily due to burn time variations (Table 1.3-3 contains increased thrust level requirements for higher Isp systems).

TABLE 3.5.1-5 SUMMARY OF RESULTS - SPACE STATION THRUST LEVEL

- All reboost burn thrust values above 4.54 kg (10 lbs) have minimal velocity losses during transfers (approximately 0.06 m/s (0.2 fps))
- Single burn orbit transfers are practical and are the most efficient for low thrust levels.
- Two burn transfers more efficient for thrust levels above 68.04 kg (150 lbs)
- Space Station may remain in a gravity gradient attitude during thrust periods
- Studies are developing theoretical levels of thrust/acceleration values vs burn times, coast times and boost orbit attitude changes

TABLE 3.5.1-6 RECOMMENDED THRUST LEVELS

Assumes 1 crew shift burn time for nominal reboost
(approximately 2 crew shifts for +2 sigma reboost)

	Space Station Configuration			
	Man Tended	IOC	IOC/P/L's	FOC
Minimum Weight	51,710KG (114,0001bs)	122,926KG (271,0001bs)	203,666KG (449,0001bs)	475,826KG 1,049,0001bs)
Recommended Total Thrust Level (Isp = 230 sec)	22.24 N 5 lbs)	44.48 N (10 lbs)	66.72 N (15 lbs)	88.96 N (20 lbs)
*Thrust Level (Isp = 385 sec)	44.48 N (10 lbs)	88.96 N (20 lbs)	133.44 N 30 lbs)	177.92 N (40 lbs)

* The increased burn time for a high Isp system such as electrolysis implies nearly doubling burn time, thus recommended thrust levels are doubled. This apparent increase in the "total thrust level required" because of our desire to keep the reboost burn within two crew shifts does not imply that the electrolysis propulsion system will have significant disadvantages because of the increased burn time. Operations analysis will be needed to evaluate the effects of longer burn times on experiment time and crew time. For instance, it is likely that many experiments will be able to tolerate the low thrust levels that will be experienced during the reboost burn and that crew time may be used for other purposes during the burn. since only minor crew involvement is expected due to automation and expert systems which will likely be in place.

3.5.1.4 Variable Altitude Reboost Strategy

3.5.1.4.1 Introduction

The following section outlines the MMC recommended variable altitude strategy. Using the previous 250nm minimum altitude strategy as a reference and the NSTS payload capability, the optimum altitude was determined. The optimum is defined as where a payload gain of 1000 lbs would require only 500 lbs ± 10 lbs of additional propellant also referred to as a 2:1 payback. (2 lbs of payload for each pound of propellant required.)

3.5.1.4.2 Altitude Profiles

The altitude range for the discrete optimum altitude scenario for case 1 is from 211 to 264 NM, where as the altitude range for the maximum payload gain altitude for this case is from 189 to 241 NM. Figure 3.5.1-15 shows the rendezvous altitude traces for these two scenarios. The solid curves represent only January quarter data points for each year, where as the dashed curves are for one data point for each quarter of the year 1994. The dashed curves again show a peak during the October quarter corresponding to the annual peak in solar activity. The altitude range (i.e. reboost altitude to rendezvous altitude) that the space station will be operating in over the 10 year period for this case is shown in Figure 3.5.1-16.

The discrete optimum altitude trace for case 2 is shown in Figure 3.5.1-17 along with the altitude trace for case 2 for comparison. As can be seen, the higher the ballistic coefficient the lower the optimum altitude for rendezvous, which results in a higher net payload capability increase.

Figure 3.5.1-18 shows the results of a missed resupply on the altitude of the space station for case 1. As can be seen, the altitude never falls below 205 NM, which is well above the 160 or 180 NM recommended absolute minimum altitude.

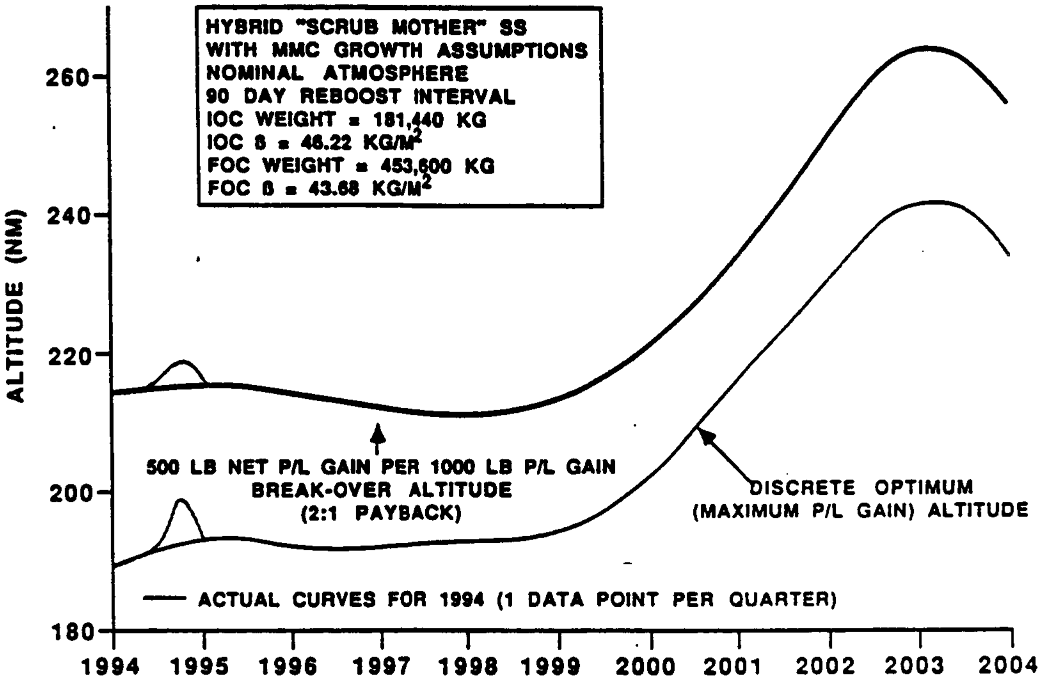


FIGURE 3.5.1-15 SPACE STATION VARIABLE ALTITUDE TRACES -
(DISCRETE OPTIMUM & BIASED)

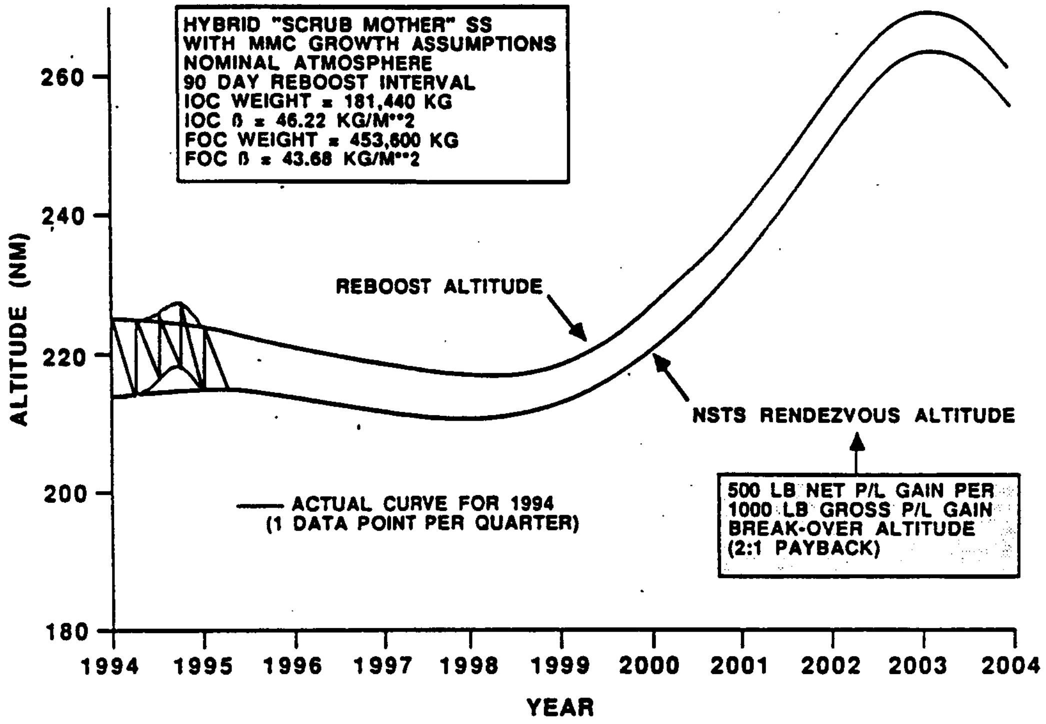


FIGURE 3.5.1-16 SPACE STATION VARIABLE ALTITUDE TRACE

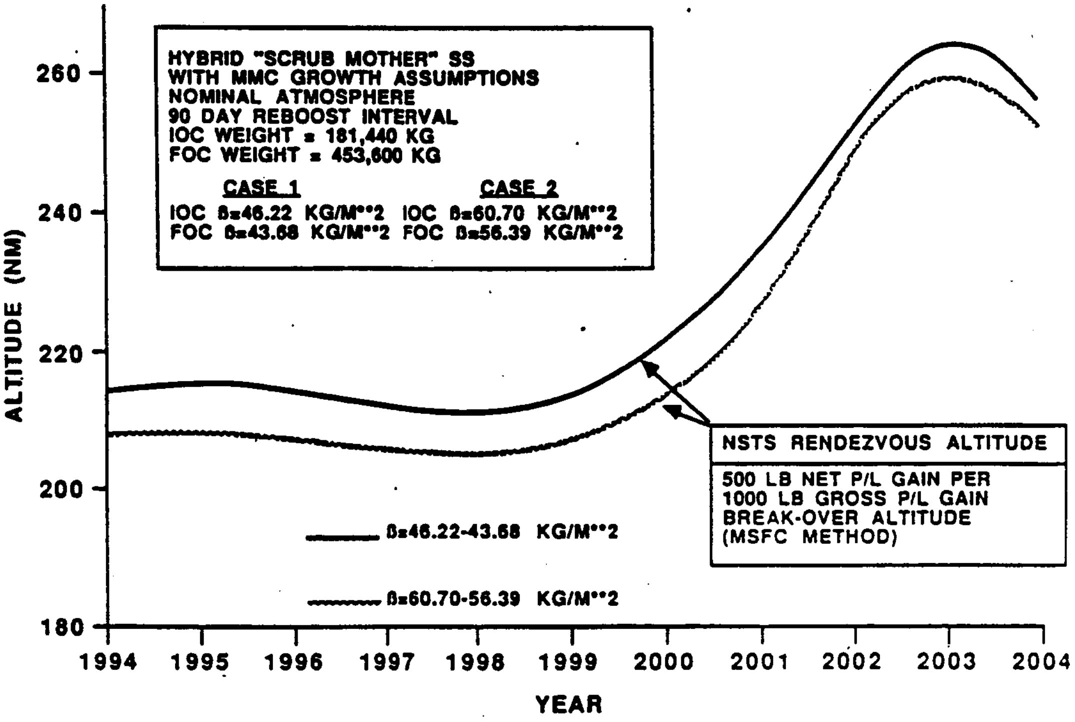


FIGURE 3.5.1-17 SPACE STATION ALTITUDE EXCURSIONS FOR VARIABLE ALTITUDE SCHEME (B=46.22 & 60.70 KG/M**2)

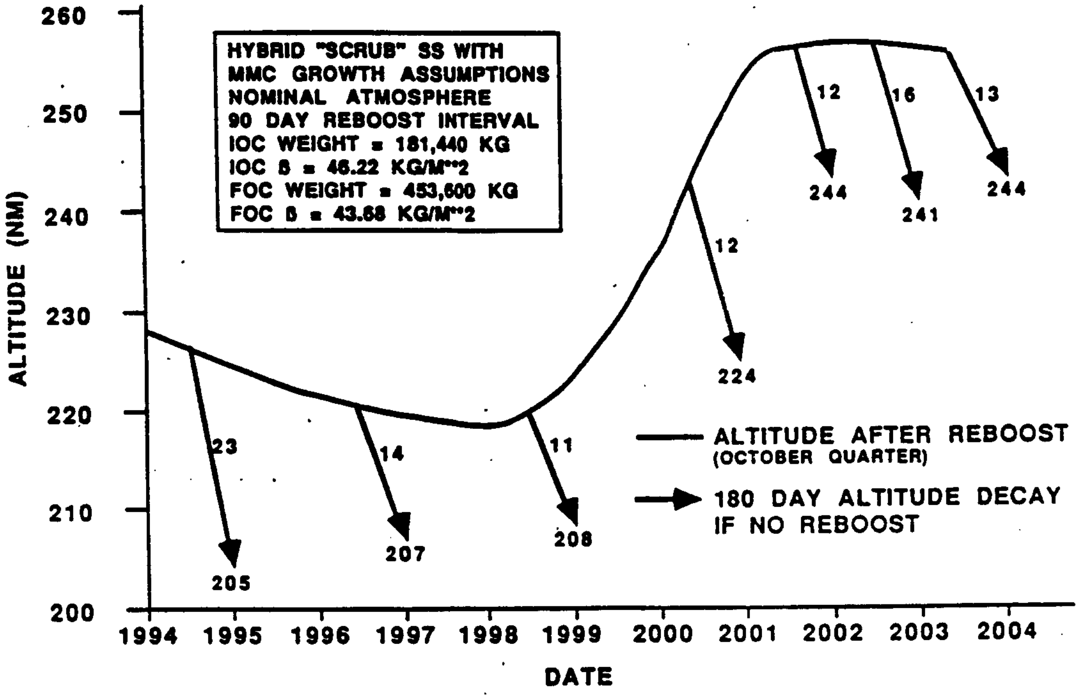


FIGURE 3.5.1-18 SPACE STATION ALTITUDE AFTER 180 DAYS

3.5.1.4.3 10 Year Total Impulses Requirements - The 10 year total impulse requirement for case 1 is estimated to be 17,443,430 LBF-SEC and for case 2 it is estimated to be 16,357,485. Figure 3.5.1-19 shows the impulse required per quarter versus time for both cases. Although these numbers for the 10 year total impulse are considerably larger than that for the 250 NM minimum altitude reboost strategy (10,197,658 LBF-SEC), the increase in net payload capability, approximately 63,626 LBS for case 1 and approximately 78,455 for case 2, should more than compensate for this:

3.5.1.4.4 02/H2 Propellant Option - Another option considered in this study was the use of 02/H2 instead of Hydrazine as the propellant for the space station. The system was assumed to have an Isp of 385 SEC, and only the $B = 46.22\ KG/M^2$ case was analyzed. The minimum (rendezvous) altitude range for this case (case 3) was from 194 to 242 NM and the reboost altitude range was from 206 to251 NM, see Figure 3.5.1-20. Again, the only data points looked at were for the January quarter of each year. The total net payload gain (gross payload gain minus reboost propellant) for this case was 113,893 LBS, which is approximatley 50,000 LBS greater than for the same case using Hydrazine as the propellant. Figure 3.5.1-21 shows net payload gain per year versus time. As can be seen, most of the payload gain occurs during the years 1994-1999. This is due to the lower altitudes achievable during these years, which increases the gross payload capability gained; and to the lower space station weight during these years, which keeps the reboost propellant smaller. The 10 year total impulse for this case is approximately 30,613,000 LBF-SEC, which is considerably higher than the Hydrazine impulse requirement of approximatley 17,443,430 LBF-SEC. The increase is due to the increased impulse required to counteract the drag at the lower optimum altitudes achieved with the 02/H2 propellant. Figure 3.5.1-22 shows the impulse required per year for reboost vs. time for this case.

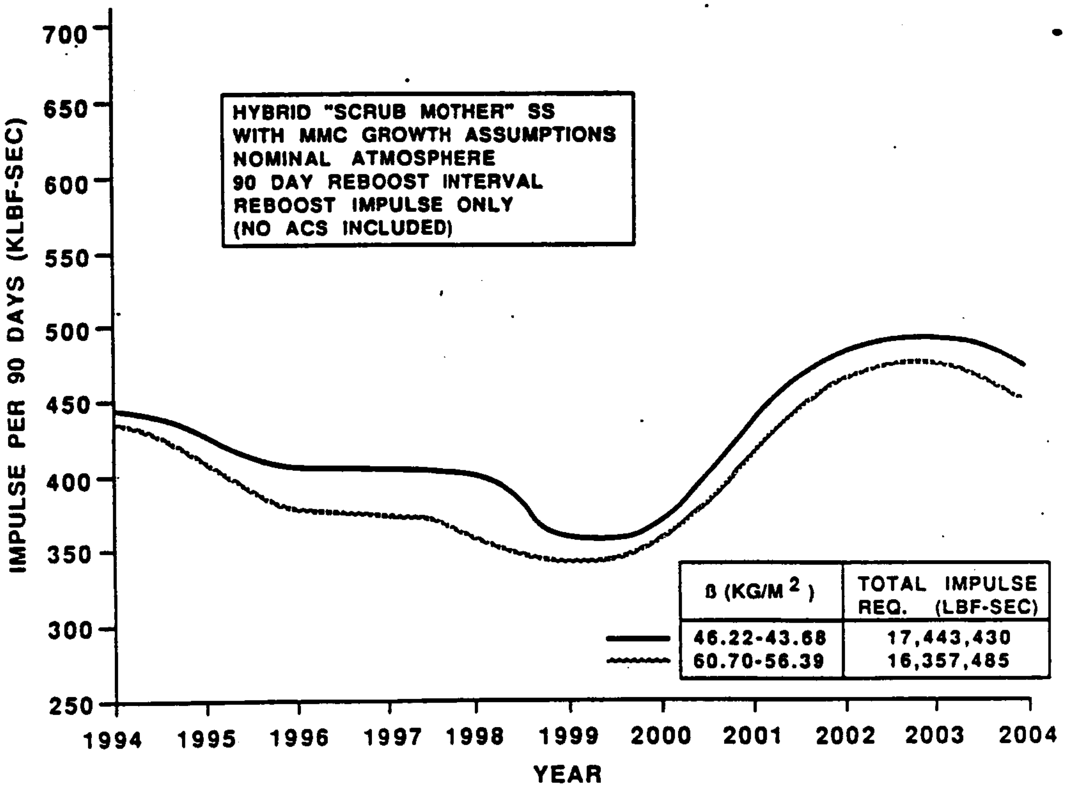


FIGURE 3.5.1-19 SPACE STATION TOTAL IMPULSE REQUIREMENTS FOR B VARIATIONS

NOTE: BETA = β = 46.22 - 43.68 KG/M ^{2} (IOC-FOC)
S.S.WEIGHT = 400,000 LBS -1,000,000 LBS (IOC-FOC)
TOTAL IMPULSE REQUIREMENT =30,613,000 LBF-SEC(+7,000,000 LBF-SEC)
TOTAL P/L GAINED (AFTER DRAG MAKE-UP) = 113,893 LBS IN 10 YEARS
(+ 50,000 LBS OVER HYDRAZINE)

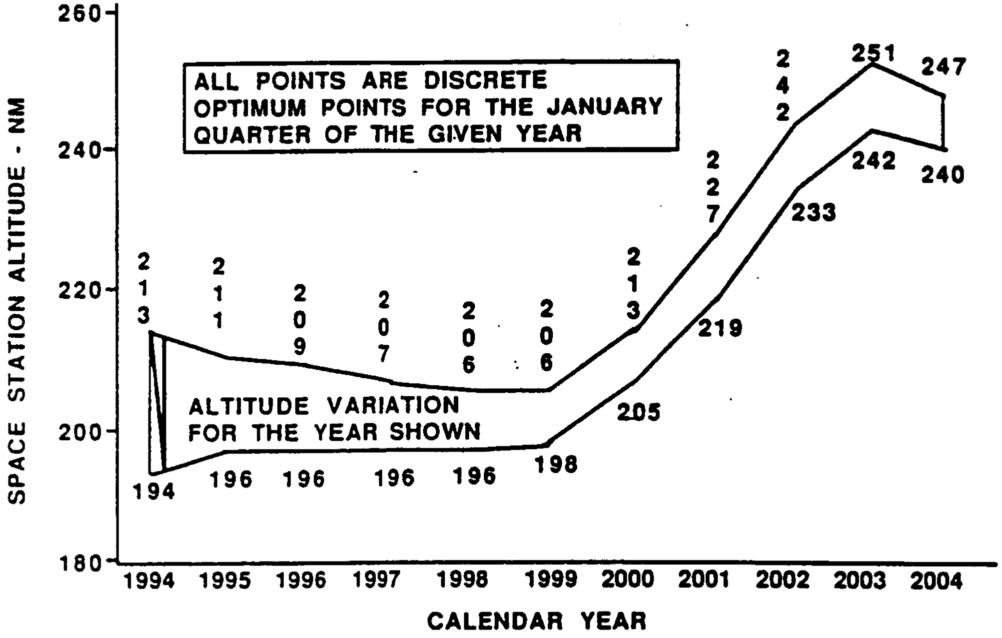
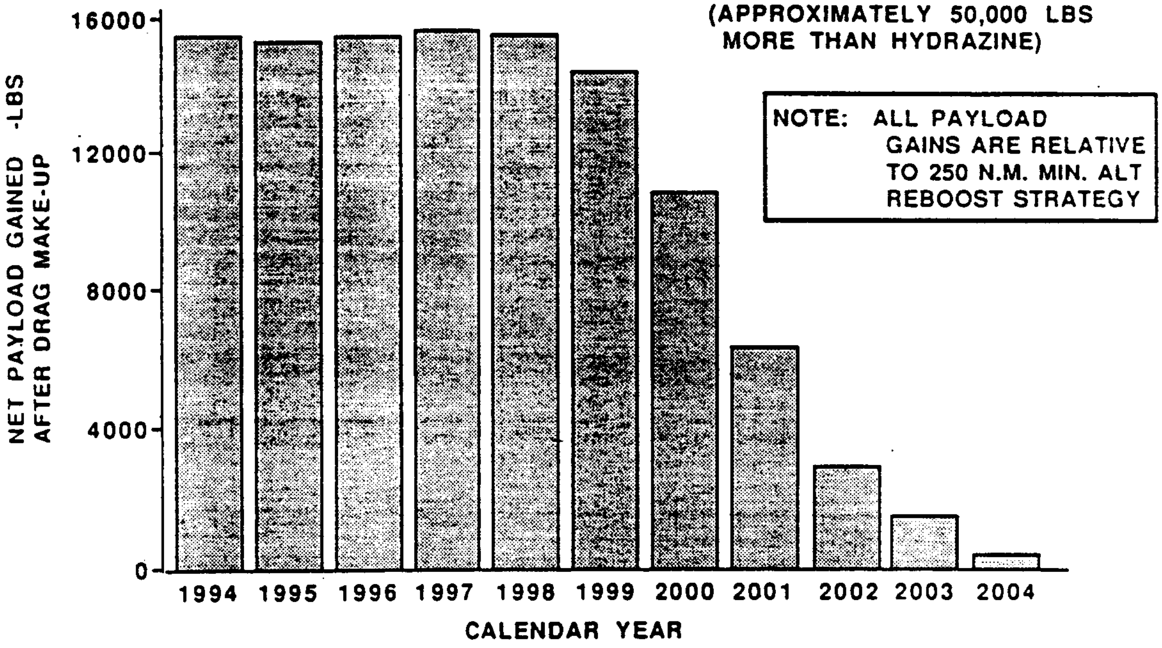


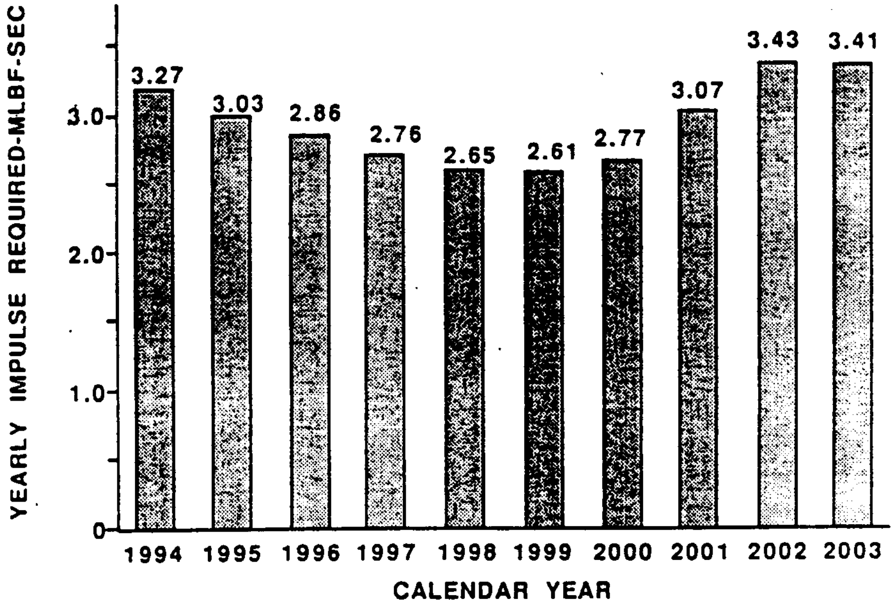
FIGURE 3.5.1-20 VAS - ALTITUDE TRACES FOR DISCRETE OPTIMUM ALTITUDE STRATEGY - O2/H2 PROPRELLANT

NOTE: BETA = ß = 46.22-43.68 KG/M ^{2} (IOC'-FOC)
S.S.WEIGHT = 400,000 LBS-1,000,000 LBS (IOC'-FOC)
TOTAL IMPULSE REQUIREMENT = 30,613,000 LBF-SEC(+7,000,000 LBF-SEC ACS)
TOTAL P/L GAINED (AFTER DRAG MAKE-UP) = 113,893 LBS IN 10 YEARS
(APPROXIMATELY 50,000 LBS MORE THAN HYDRAZINE)



NOTE: ALL PAYLOAD GAINS ARE RELATIVE TO 250 N.M. MIN. ALT REBOOST STRATEGY

FIGURE 3.5.1-21 VAS - PAYLOAD GAINED FOR DISCRETE OPTIMUM ALTITUDE STRATEGY - 02/H2 PROPELLANT



NOTE: BETA = ß = 46.22 - 43.68 KG/M ^{2} (IOC'-FOC)
S.S.WEIGHT = 400,000 LBS -1,000,000 LBS (IOC'-FOC)
TOTAL IMPULSE REQUIREMENT = 30,613,000 LBF-SEC(+ 7,000,000 FOR ACS)
TOTAL P/L GAINED (AFTER DRAG MAKE-UP) = 113,893 LBS IN 10 YEARS

FIGURE 3.5.1-22 VAS - IMPULSE REQUIREMENTS FOR DISCRETE OPTIMUM ALTITUDE STRATEGY - O2/H2 PROPELLANT

3.5.2 Reboost Implementation

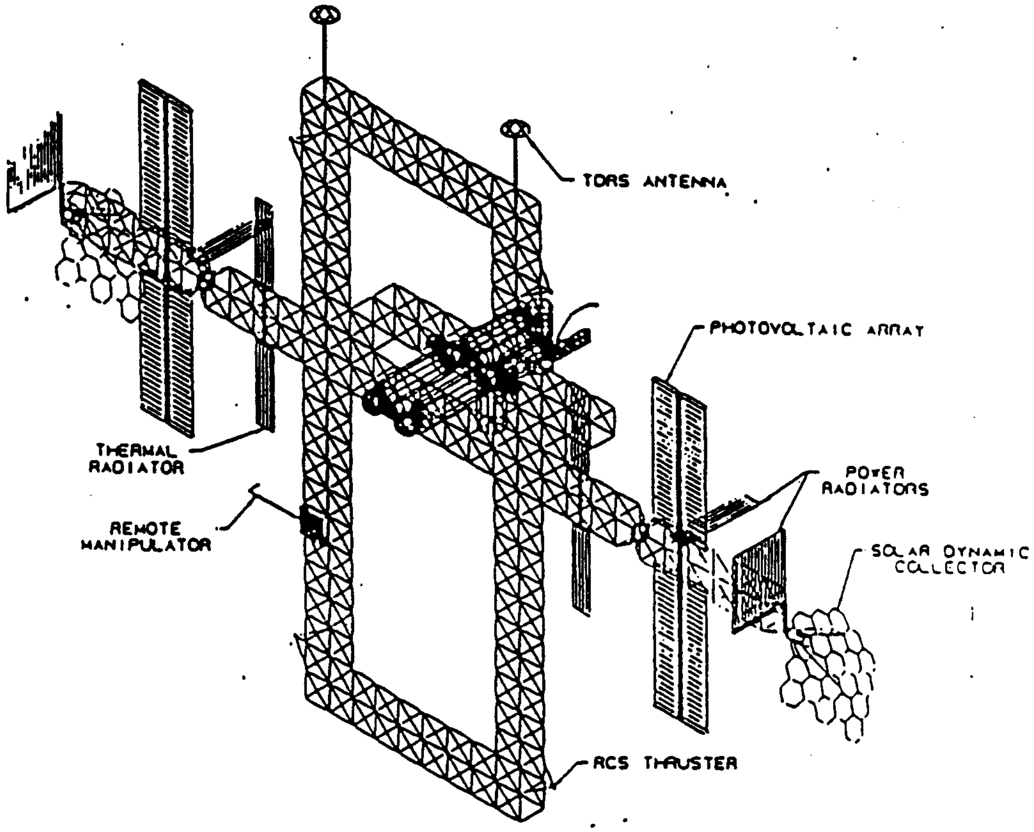
The Space Station configuration considered in this document is the IOC Dual Keel configuration (see Figure 3.5.2-1). This configuration represents a way to accommodate celestial/earth viewing, Vehicle Accommodations, and microgravity requirements. The figure shows the current location of the Propulsion Modules. The modules are used for orbit reboost and backup attitude control.

The Space Station configuration is intended to have growth capability. Figure 3.5.2-2 shows the FOC Dual Keel configuration expected by 10 years after IOC. As can be seen in this figure, the power subsystem has been enlarged (more solar dynamic collectors) and more pressurized modules were added for crew habitation and labs. At FOC, orbital transfer vehicles will be based at Space Station so Vehicle Accommodations, which at IOC serviced Orbital Maneuvering Vehicles and transient satellites, will grow to accommodate these large reusable upper stages.

Space Station orbital decay can be described as a function of atmospheric density (a function of solar activity and altitude) and Space Station's configuration drag profile. Space Station configuration effects on orbit decay is tracked by its ballistic coefficient or beta (3) which is W/C_DA where,

W = Weight of Space Station;
C_D = Drag Coefficient of Space Station;
A = Frontal Area of Space Station.

The higher the value of beta, the lower the Space Station's orbital decay rate and vice versa.



ISOMETRIC VIEW

FIGURE 3.5.2-1 SPACE STATION BASELINE PERMANENTLY MANNED CONFIGURATION

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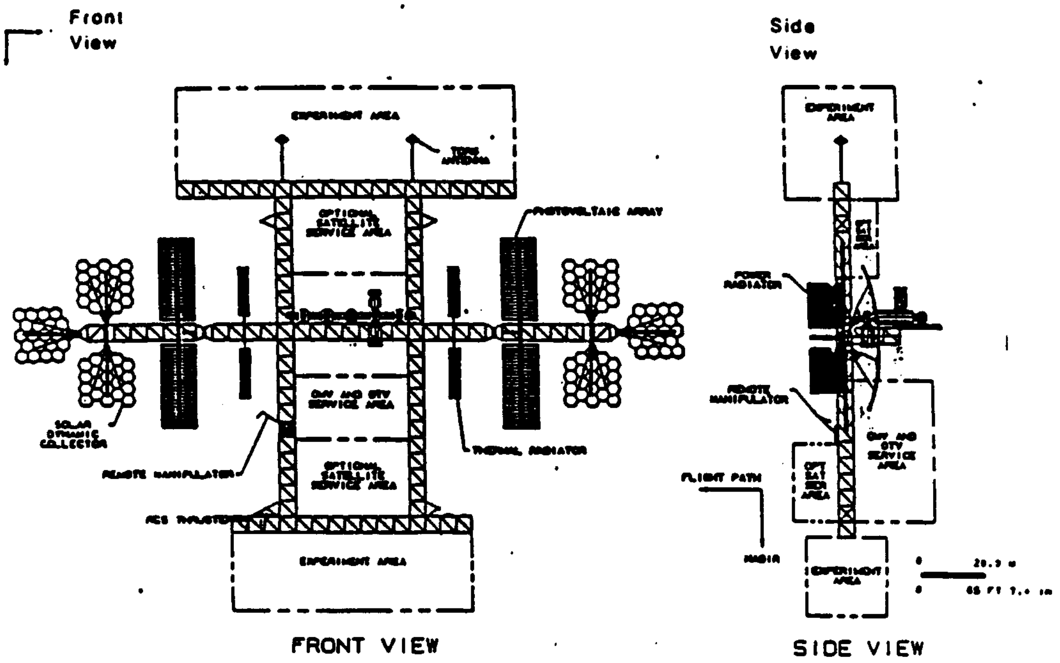

FIGURE 3.5.2-2 MARTIN MARIETTA MODIFIED REFERENCE CONFIGURATION (GROWTH)

3.5.2.1 Structure and Mechanisms

3.5 2.1.1 OMV Reboost Platform - The only effect of reboost on structures and mechanisms is with the optional OMV reboost platform (Figure 3.5.2-3), consisting of structural truss similar to the Space Station truss. Mechanical latches will be used to attach the structure to the Space Station truss at the node points (4). Physical attachment of the OMV to the reboost platform will be provided by standard FSS latches, and a grapple fixture will accommodate the MRMS for manipulation of the structure on the Space Station from storage to the center of mass for reboost. Trade study A040, summarized in Appendix A and the IRR trade studies volumes, describes this in detail. Note, baselining reboost of the Space Station using the OMV is not recommended at this time. However, the OMV reboost may be very attractive as a contingency/emergency mode. We recommend further study after SRR.

3.5.2.1.2 Impacts of Vehicle Accommodations - The baselined version of the Vehicle Accommodations enclosed the entire volume in a micrometeor protective shell. An option, now being considered, provides micrometeor protection only around selected storage canisters for vehicles and equipment. This results in an overall reduction of the mass associated with the vehicle accommodations by eliminating the protective walls. Sunscreening is provided by a thin film of material enclosing the accommodations volume, however, this sunscreen may not need to be deployed at all times. When the sunscreen is required, the ballistic coefficient (W/C_DA) of the Space Station decreases, because, while the overall accommodations mass decreases, the reference area remains unchanged. This lowering of the ballistic coefficient (relative to the old configuration) results in greater drag effects which causes the Space Station to require more frequent or larger reboosts to counter the accelerated orbit decay. If the sunscreen is not required, the reduction in reference area promoting aerodynamic drag offsets the reduction in accommodations mass and results in an increased ballistic coefficient. This results in reduced drag, slower orbit decay, and hence, reduced impulse and propellant requirements for reboost.

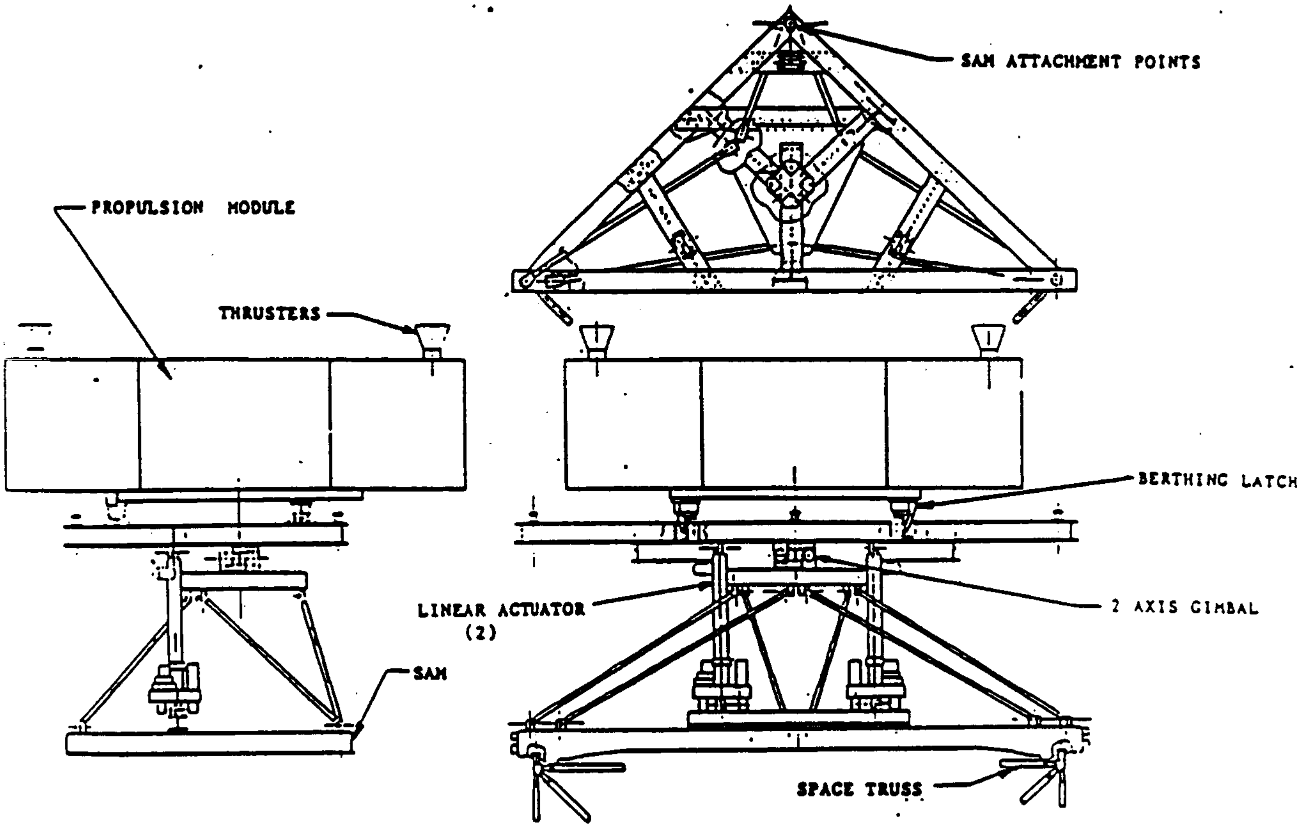

FIGURE 3.5.2-2 REBOOST PLATFORM

3.5.2.2 On-Orbit Operations

On-orbit operations for reboost can be split into three categories; (1) pre-boost, (2) boost, and (3) post-boost.

Pre-boost operations would consist of first receiving boost parametrics and system control data from the Space Station Operations Center (SSOC) and storing that data in the Space Station reboost database. After this, an automated series of checks would be initiated by the onboard crew to verify that the propulsion system is ready. During these operations the crew would also begin shutdown of all non-essential operations and systems including experiments.

Boost operations would consist of initiating the reboost sequences and monitoring all systems involved. During reboost, it may be possible to schedule meals, exercise, physiology experiments, etc, that are not G-level dependent.

Post-boost operations would consist of propulsion system shut down and safing. Experiments and other scheduled operations would resume.

These operations are depicted on the typical timeline shown on Figure 3.5.2-4

90 DAY TIMELINE RESOURCES	DAY	0		1		2		3		4		5		6		7		8		9		10		11		12		13		14	
	SHIFT	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
STATION SPECIALIST 1			SECOND HALF OF STS RESUPPLY MISSION									SPACE STATION REBOOST	SLEEP	A	SLEEP	OMV OPS	SLEEP	DAY OFF	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	DAY OFF	SLEEP
MISSION SPECIALIST 1													SLEEP	DAY OFF	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	DAY OFF	SLEEP	P/L OPS	SLEEP	SS MONT	SLEEP
MISSION SPECIALIST 2													SLEEP	SS MONT	SLEEP	DAY OFF	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	DAY OFF	SLEEP	P/L OPS	SLEEP
STATION SPECIALIST 2												SLEEP	OMV OPS	SLEEP	A	SLEEP	B	SLEEP	DAY OFF	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	SS MONT	SLEEP	DAY OFF
MISSION SPECIALIST 3												SLEEP	SS MONT	SLEEP	DAY OFF	SLEEP	P/L OPS	SLEEP	SS MONT	SLEEP	MRMS MNT	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	DAY OFF	SLEEP	P/L OPS	SLEEP	P/L OPS
MISSION SPECIALIST 4												SLEEP	DAY OFF	SLEEP	SS MONT	SLEEP	C	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	P/L OPS	SLEEP	DAY OFF	SLEEP	SS MONT

A - OMV OPS/SV MAINT
B - OMV OPS/SS MONITOR
C - SS MONT/PAYLOAD OPS

START OF OMV SATELLITE RETRIEVAL SERVICE AND REBOOST

START OF 28 DAY PAYLOAD MICRO "G" TIMELINE

MRMS MAINTENANCE (6 HOURS EACH WEEK)

FIGURE 3.5.2-4 REBOOST OPERATIONS - DAY 5 OF THE 90 DAY CYCLE

3.5.2.3 Safety and Radiation

Safety efforts in the reboost area related to IRR were primarily in the area of radiation protection. It was shown for RUR-2 that increased altitudes significantly increased the radiation environment to the point that providing the required protection for one-year continuous occupancy was not possible with the current Space Station concepts.

The trade study addressing this issue, IM10, "Define and Evaluate the Radiation Protection Requirements Relative to One Year Continuous Occupancy," has been updated with enhanced modeling. A three dimensional model of the Space Station configuration was developed. A program that determines doses received from 528 different directions was used with this model and with an enhanced astronaut model. The results showed a reduction in doses when compared to the previously used flat - plate geometry due to these enhancements and due to the use of a different solar minimum to correspond to the JSC modeling approach.

The study, contained in its entirety in SSP-MMC-00033, again concludes that the current Space Station configuration does not provide the required protection to allow one-year continuous occupancy. The study shows the doses received at an average 463.25 km (250 nm) orbit exceed the limits and appear to require enhanced protection. Evaluation of potential solutions showed that besides relaxing the requirement, further reductions in altitude would provide the least impacts.

Therefore, the input provided to the altitude trade study is that 463.25 km (250 nm) or lower average altitudes are needed from a radiation protection requirements standpoint.

3.5.2.4 Reboost Contamination

Evaluation of contamination associated with reboost was conducted under Study A003, "Define Contaminants from Space Station Propellants", and is documented in SSP-MMC-00033, Section 3.2.2.4j. A detailed discussion of Space Station propulsion contamination is provided in DR-02 Book 5, the Propulsion and Fluids End Item Data Book.

3.5.2.4.1 Periodic Reboost Contamination - Propulsion events generally produce enough gas to disturb instrument observation. Periodic reboost allows the propulsion events to be infrequent and schedulable, so that instruments may be deactivated (no loss of data) or protected. A secondary concern is the deposition of water from the hydrogen/oxygen propulsion system on very cold insensitive surfaces. This ice could be a source of particles or water vapor at some time subsequent to the reboost. The temperatures which such surfaces could achieve are being investigated. Protective measures for this secondary problem include passive or active thermal control of potentially cold surfaces, and thruster location selection.

3.5.2.4.2 OMV Contingency Reboost Contamination - in the event of a Space Station propulsion system failure, an option is to use the OMV for reboost propulsion. This presents an additional contamination problem since bipropellant engines produce exhaust products condensable at relatively high temperatures (at least 30°C). The most likely position to mount an OMV for reboost is aft of the Space Station C.G. This is an optimized location for bipropellant propulsion, since it places the engines aft of and directed away from Space Station surfaces. Analysis of the expected deposition from a single OMV reboost with the OMV located aft of the Space Station pressurized modules and C.G. indicates no detectable degradation of Space Station surfaces such as radiators and photovoltaic solar arrays.

3.5.2.5 Man-Tended and Growth Concepts

3.5.2.5.1 Man-Tended - The Man-Tended Concept is a viable, short duration, alternative to the permanently manned Space Station approach. This configuration will rely predominantly on ground based statusing/controlling/planning and automated onboard systems to meet Space Station functional requirements.

Operationally, at 90 day intervals, the Space Shuttle will be launched to resupply consumables for experiments and for the Shuttle crew to perform scheduled maintenance. The recommended duration of man-tended operations at Space Station is 14 days. The time frame when compared to a 7 day resupply on-orbit period is justified by an increase of 17.5% in available time for man-supported payload operations over 11 days. The 7 day stay time will only allow 2.5% of available time for man-supported payload operations in one mission day. The additional flexibility in scheduling crew tasks is also a major factor in the longer stay time. Following departure of the shuttle, the reboost of the MTA Space Station will occur. Table 3.5.2-1 lists the groundrules and assumptions used for the Martin Marietta preliminary Man-Tended assembly sequence studies. Figure 3.5.2-5 lists manifested weights for MTA flights, total weight of the Space Station after each flight (and at IOC and FOC), rendezvous and reboost altitudes for the flights listed, impulse required for each reboost (with estimated totals for the times between MTA & IOC and IOC & FOC), and the total impulse required for the Space Station.

The Man-Tended Configuration consists of two protovoltaic arrays, one laboratory, no logistics module, and no OMV hanger, although the structure is scarred to accept the hanger and additional modules and solar arrays, as a progression to realizing a permanently Manned Space Station.

3.5.2.5.2 Growth

Growth phase reboost operations would be the same as IOC with the exception that with growth will come increased levels of automation and crew involvement in reboost operations will decrease.

TABLE 3.5.2-1 MAN-TENDED ASSEMBLY AND REBOOST GROUNDRULES & ASSUMPTIONS

- o Initial flight 1/1/93
- o Man-Tended capability after flight 6
- o IOC manned capability after 4 years
- o FOC capability at IOC + 10 years
- o Flights 1-6 (assembly of man-tended station) on 45 day centers
- o All flights after flight 6 on 90 day centers
- o Assembly of man-tended station at 407.66 km (220 nm)
    - Boost to operating altitude of 463.25 km (250 nm) after flight 6

FLIGHT #	WEIGHT		SS/STS FINAL		REBOOST		REBOOST IMPULSE	
	[KG]	(LBS)	ALT. [KM]	(NM)	ALT. [KG]	(NM)	[N-SEC]	(LBF-SEC)
1 4/1/92	15,350	(33,840)	406.44	(219.34)	409.51	(221.00)	26,661	(5,994)
2	30,222	(66,627)	406.96	(219.62)	408.68	(220.55)	29,415	(6,613)
3	43,933	(96,854)	407.01	(219.65)	408.68	(220.55)	41,380	(9,303)
4	57,912	(127,673)	406.08	(219.15)	413.59	(223.20)	245,236	(55,134)
5	76,964	(169,673)	406.01	(219.11)	414.61	(223.75)	373,321	(83,930
6 MTA 10/18/92	91,021	(200,664)	405.99	(219.10)	416.00	(224.50)	513,691	(115,488)

FIGURE 3.5.2-5 IMP & ALTS FOR MAN-TENDED SS
ASSEMBLY SEQUENCE FLIGHTS (MMC-5/86)

3.5.2.6 Mass Properties

The potential variations in the Space Station mass properties (both weight and center of gravity) over the life of the Space Station were examined. The Space Station weights considered vary from 124,286 kg (274,000 lbs) to 475,826 kg (1,049,000 lbs); our current estimate of weight for the IOC Space Station is 181,440 kg (400,00 lbs). Figure 3.5.2-6 shows the variations in ballistic coefficient, altitude decay, and impulse requirements for 90 days for both nominal and worst quarter for several cases. The increase in the initial (IOC, no payloads) weight and updates of aerodynamic coefficients have accounted for an increase in ballistic coefficient from a RUR-1 value of 36.62 kg/m^2 (7.50 lbs/ft^2) to a synthesized value of 60.5 kg/m^2 (12.39 lbs/ft^2). This difference is reflected in a decrease in the altitude decay values from 15.75 km (8.5 nm) nominal (37.99 km (20.5 nm) for +2 sigma solar activity) to 5.56 km (3.0 nm) (27.80 km (15.0 nm) for +2 sigma solar activity) between RUR-1 and IRR. This, translated to total impulse requirements for a nominal atmosphere, reflects a 50% reduction in nominal impulse requirements (560,448 N-sec (126,000 lb$_f$-sec) from 1,089,760 N-sec (245,000 lb$_f$-sec)).

Similarly, for +2 sigma solar activity, this variation in ballistic coefficient causes a slight increase in total impulse value to 629,000 lb$_f$-sec (from 587,000 lb$_f$-sec). This increase, contradictory to the trend for nominal atmosphere is caused by the change in assumptions used for determining the worst quarter. For the synthesized configuration it was decided that constant values of F10.7 = 230 and a_p = 35 for 90 days would constitute the worst +2 sigma quarter. For all others, the worst quarter was the +2 sigma quarter at IOC, which is not as severe as the constant values of 230 and 35 for F10.7 and a_p respectively. Note, the 3/86 MMC revisory cases are for the worst quarter (October) of the year 1994, because it was assumed that this would be worse than the actual IOC date of 1/1/94.

SPACE STATION DESCRIPTION	IOC SS WEIGHT KG (LBS)	BALLISTIC COEFFICIENT KG/M^2 (LB/FT^2)	Δ ALTITUDE (NM)	90 DAY TOTAL IMPULSE (LBF-SEC)
NOMINAL WORST QUARTER				
NASA ATP NO P/L'S	124,545 (274,000)	36.62 (7.50)	15.7 (8.5)	1,090,250 (245,000)
NASA ATP WITH P/L'S	204,545 (450,000)	60.14 (12.32)	9.3 (5.0)	1,054,650 (237,000)
MMC REV. 3/86	202,273 (445,000)	41.84 (8.57)	7.0 (3.8)	792,100 (178,000)
SYNTHESIZED 12/85	181,818 (4000,000)	60.50 (12.39)	5.6 (3.0)	560,700 (126,000)
+2 SIGMA WORST QUARTER				
NASA ATP NO P/L'S	124,545 (274,000)	36.62 (7.50)	38.0 (20.5)	2,612,150 (587,000)
NASA ATP WITH P/L'S	204,545 (450,000)	60.14 (12.32)	25.9 (14.0)	2,937,000 (660,000)
MMC REV. 3/86	202,273 (445,000)	41.84 (8.57)	17.42 (9.4)	1,954,756 (439,271)
SYNTHESIZED	181,818 (4000,000)	60.50 (12.39)	27.8 (15.0)*	2,790,050 (629,000)

* F10.7 = 230 & AP = 35 ASSUMED FOR ENTIRE QUARTER

FIGURE 3.5.2-6 COMPARISON OF 90 DAY TOTAL IMPULSE REQUIREMENTS - IOC SS

3.5.2.7 Software

Applications software will properly configure the propulsion components required for each reboost. This includes automatic system checkout, propellant valve control, and thruster configuration. If a component failure is detected during a maneuver, propulsion software will automatically reconfigure active components to continue operations and, if necessary, invoke safing sequences to secure the system. The propulsion reboost software will interface with the GN&C System for the necessary orbit adjustment and attitude stabilization guidance parameters. For more detailed information, please refer to Section 3.4 (Propulsion).

3.6 VEHICLE ACCOMMODATIONS

This section will outline the recommended Vehicle Accommodations configuration based upon the results of several design analyses and trade 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, shown in Figure 3.6.1-2, is comprised of graphite epoxy thruss 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, seen in Figure 3.6.1-3, will contain the electrical load center which distributes power to the separate accommodations elements; the power conditioning unit which converts the space base 440 VAC, 20 kHz 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 vise versa; and the service aread controller which is the local area microcomputer that controls the accommodations operations such as latch actuation, umbilical operations, etc.

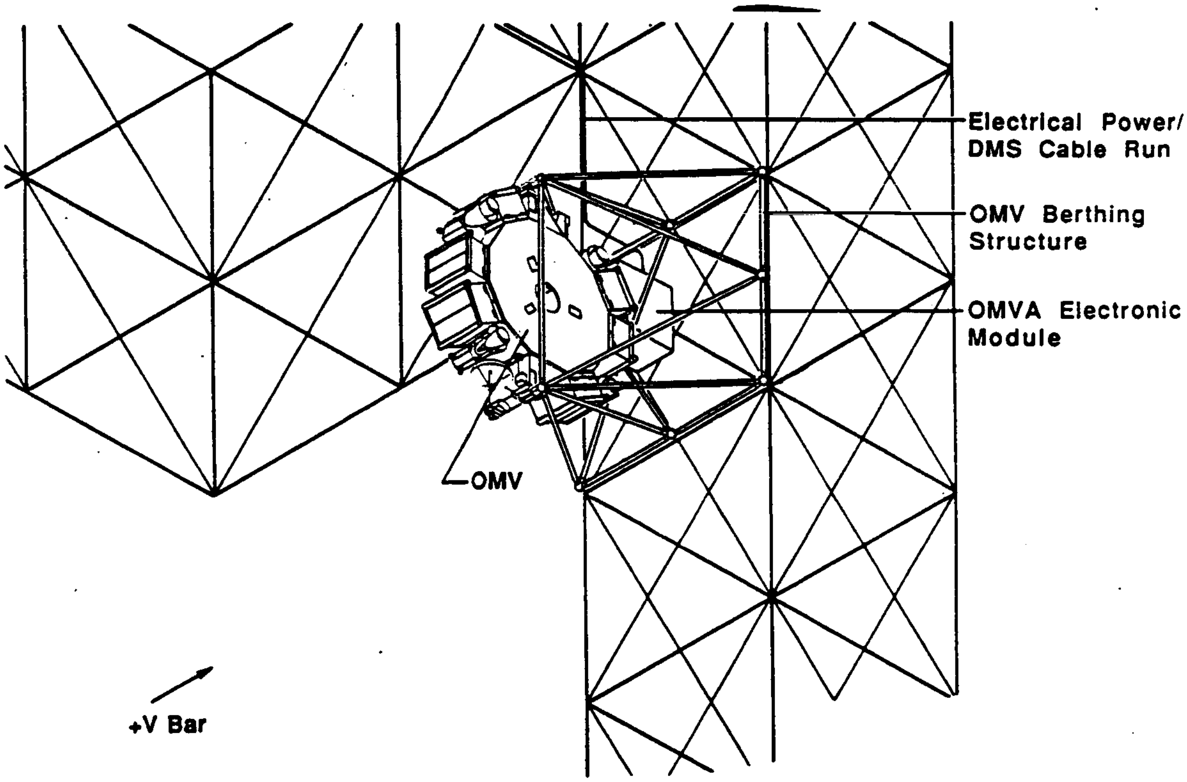

FIGURE 3.6.1-1 IOC - OMV ACCOMMODATIONS

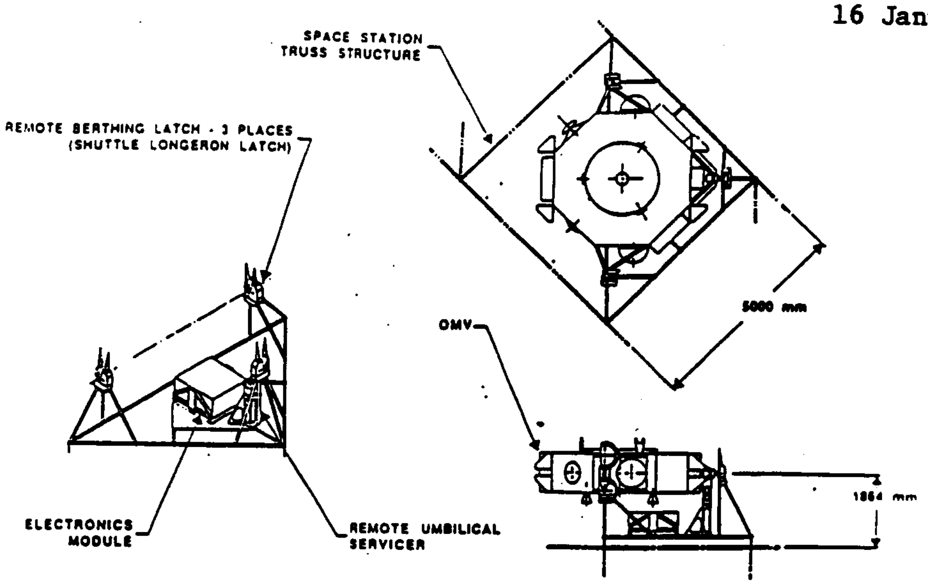

FIGURE 3.6.1-2 OMV BERTHING STRUCTURE

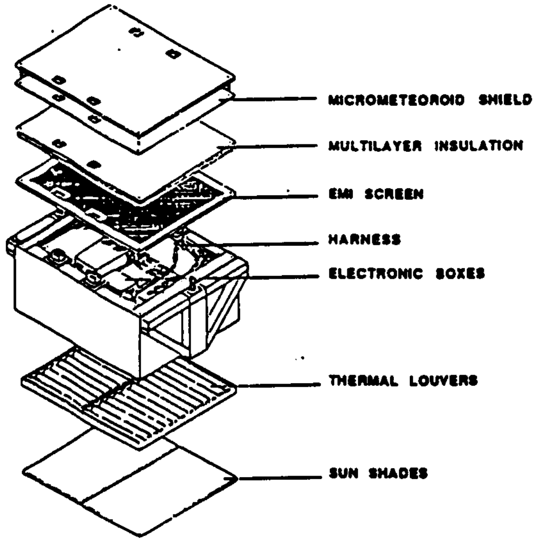

FIGURE 3.6.1-3 VEHICLE ACCOMMODATIONS ELECTRONICS MODULE

3.6.1.2 Growth Configuration

For the growth configuration, pictured in Figure 3.6.1-4, 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 book is extended in the -V bar direction, with a Spacecraft Positioning Unit (SPU) used to secure the entire stack until launch. The truss boom is also used to extend the MRMS reach envelope for greater retrieval capability.

Table 3.6.1-1 lists all of the vehicles/elements requiring accommodations through the space station growth phases.

TABLE 3.6.1-1 ELEMENTS REQUIRING ACCOMMODATIONS

IOC	BASELINE o 1 SHUTTLE-BASED OMV o OMV BATTERY RECHARGE SYSTEM
IOC-1	SPACE BASED OMV o 1 SPACE-BASED OMV o 1 SMART FRONT END - 1 TELEROBOTIC SYSTEM - 1 FLUID RESUPPLY SYSTEM - OMV ORU STORAGE - TOOLS AND HANDLING EQUIPMENT - MISSION KITS
IOC-2	SPACE BASED OMV - STAGE 2 o ALL ELEMENTS INCLUDED IN IOC-1 PLUS: o 1 ADDITIONAL SPACE-BASED OMV o ADDITIONAL OMV ORU STORAGE
FOC-1	SPACE BASED OTV o ALL ELEMENTS INCLUDED IN IOC-2 PLUS: o 1 SPACE-BASED OTV o 1 OTV PROPELLANT MODULE o OTV TOOLS AND HANDLING EQUIPMENT
FOC-2	SPACE BASED OTV-STAGE 2 o ALL ELEMENTS INCLUDED IN FOC-1 PLUS: o 1 ADDITIONAL SPACE-BASED OTV o ADDITIONAL OTV ORU STORAGE o 1 ADDITIONAL OTV PROPELLANT MODULE

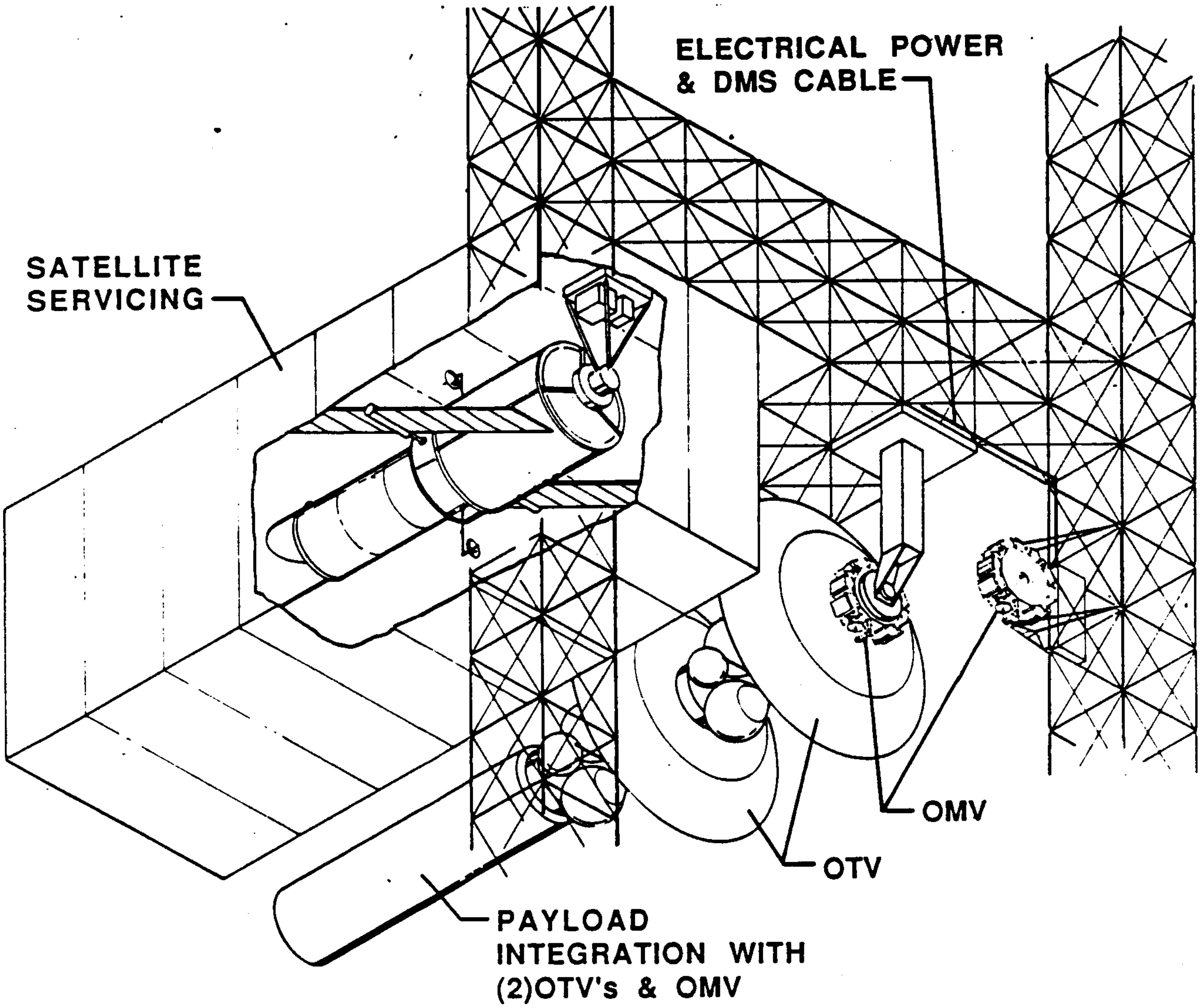

FIGURE 3.6.1-4 VEHICLE ACCOMMODATIONS - GROWTH

Functional schematic diagrams of both the IOC and the growth vehicle accommodations are shown in Figures 3.6.1-5, 6, 7. These outline the interfaces between the pressurized and unpressurized portions of the accommodations, the space station itself and the berthed vehicle.

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 wesre included in the studies that produced the recommended configuration shown in Figure 3.6.1-1.

Following, in Table 3.6.2-1, is a summary of the major trade studies and design analyses performed, which shows the description, objectives, and results of each study. 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.

TABLE 3.6.2-1 TRADES STUDIES AND ANALYSES SUMMARY

Description	Objective	Results
Space Based OMV vs. Ground/ Shuttle Based OMV	Determine Most Economical Basing Approach	Space Basing of OMV Results in Lower Operational Costs Within First Year
In-Situ Servicing vs. Space Based Servicing of Satellites	Deterine Most Economical Servicing Approach	In-Situ Servicing Pays Back Higer Initial Cost Within Two Years
OMV/Large Payload Proximity Ops Control Techniques	Assess V-bar and R-bar Approach Techniques; Recommended Piloting Techniques; Gather Time and Propellant Usage Data	Study Report
OMV Hand Controller Trade Study	Recommend 6-DOF Hand Controller System for OMV Proximity Ops at SS	MMU Type Hand Controllers Recommended
OMV Proximity Ops Piloting Aids Study	Recommend Display and Control Features Required By OMV Proximity Ops Pilot	Study Report
Location to Retrieve and Deploy Vehicles and Payloads	Locate OMV Deploy/Retrieve Area to Minimize Ops Perturbations on Micro-G	Locate Near Center-of Mass Oriented Toward Minus V-bar
Vehicle and Payload Retrieval Methods	Identify Best Approach For Retreiving OMV & Payloads	Retrieve OMV/Payload Using MRMS
Proximity Operations Control, Ground vs. Space Based	Choose the Optimal OMV Control Base for Prox Ops (Within 20 NMi of SS)	Space Based Control
Vehicle Accommodations Configuration & Location	Locate OMV Accommodations To Optimize Operations Activities and Minimize Perturbations to Lab Environments	Integrated Storage & Servicing Facility Most Cost Effective; Optimal Location at CG
Meteoroid/Debris Protection, Local vs. Facility Protected	Recommend the Best Approach for Shielding Sensitive Elements	Localized Shielding of Hardware Most Cost Effective
OMV Resupply and Servicing, On-Orbit vs. Ground	Determine Most Economical Approach to Resupply and Servicing	On-Orbit Servicing Has One Year Pay-Back For Limited Mission Model

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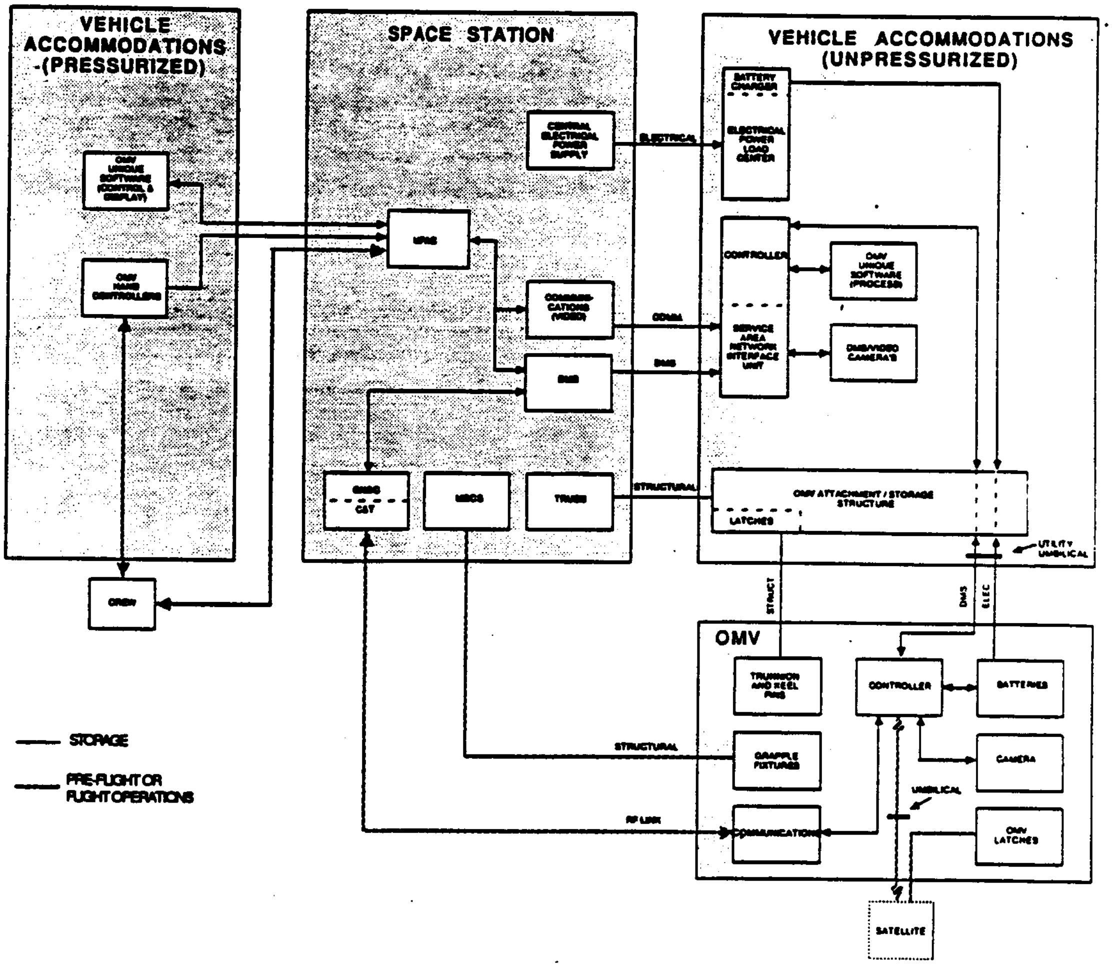

FIGURE 3.6.1-5 IOC OMV ACCOMMODATIONS INTERFACE SCHEMATIC

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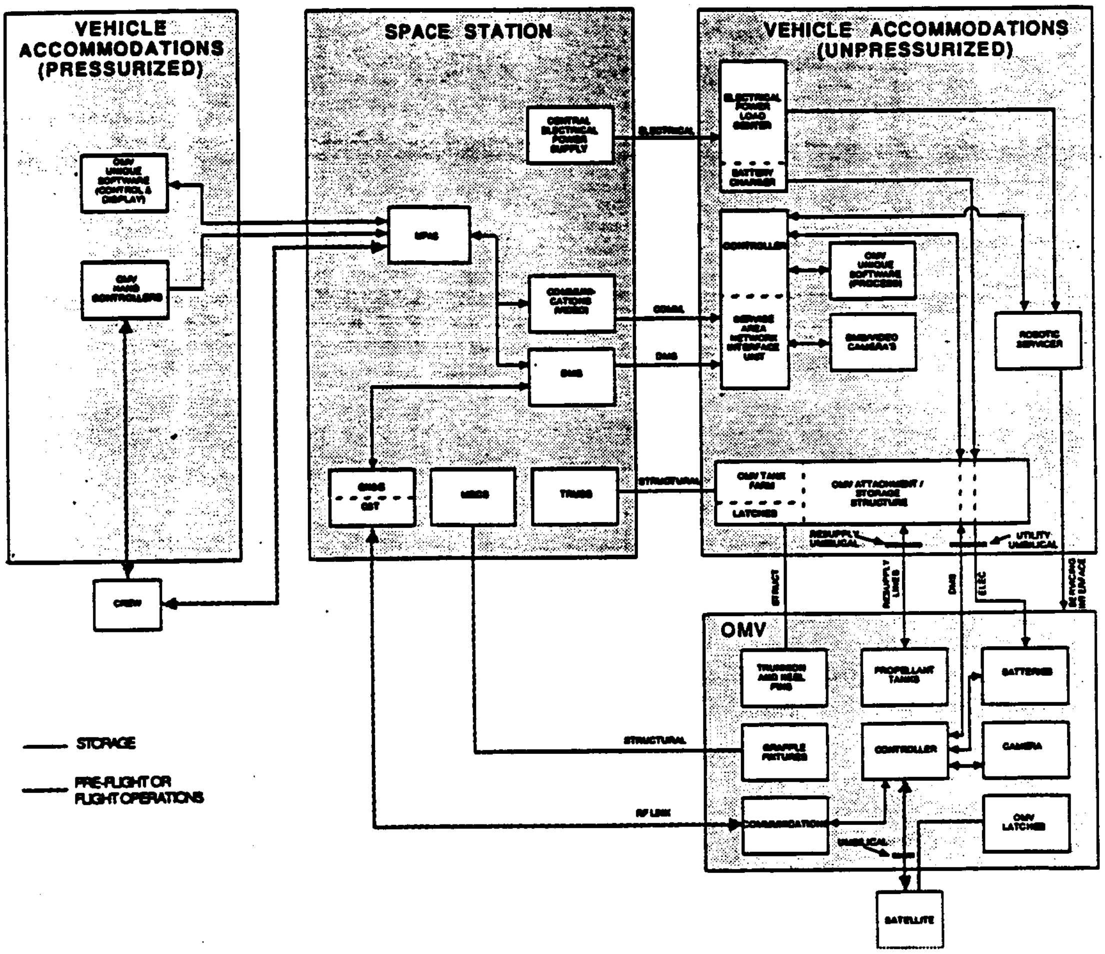


FIGURE 3.6.1-6 GROWTH OMV ACCOMMODATIONS INTERFACE SCHEMATIC

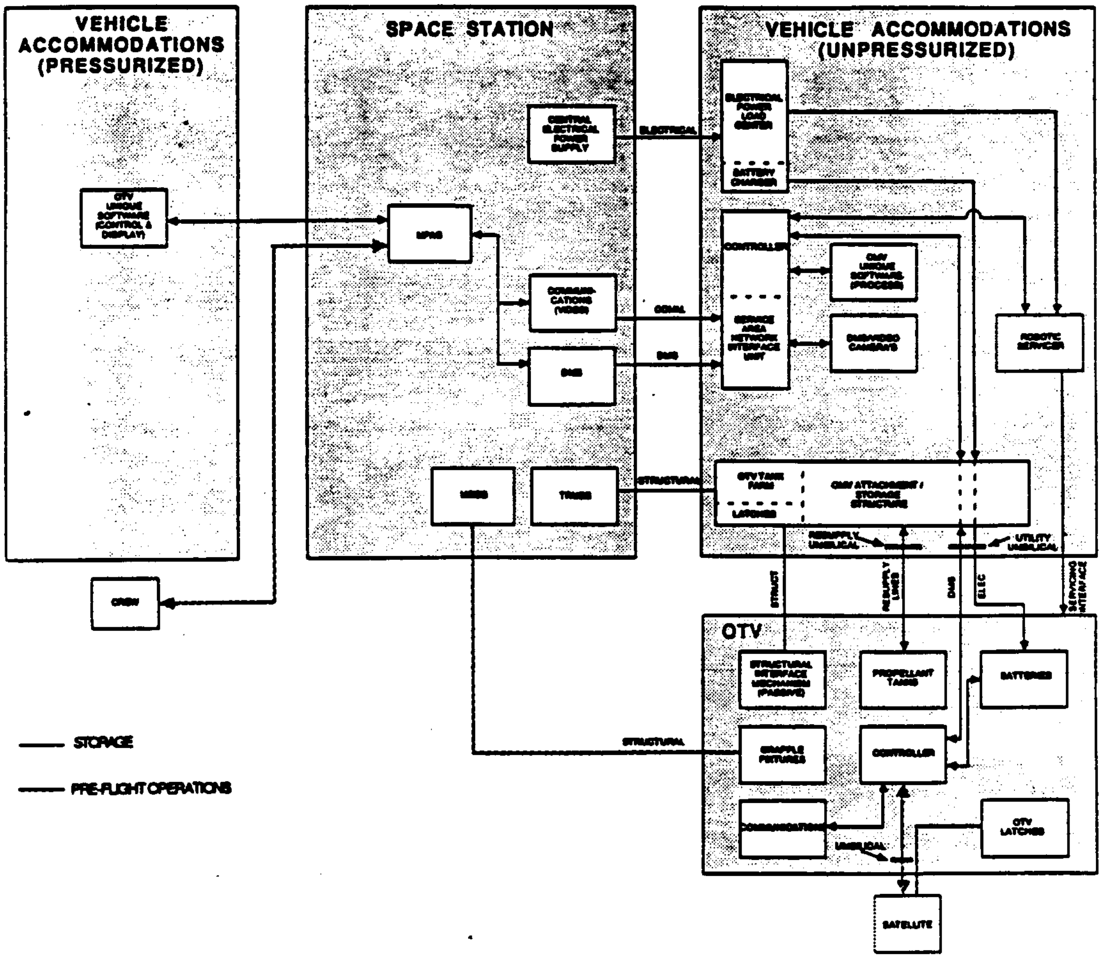


FIGURE 3.6.1-7 GROWTH OTV ACCOMMODATIONS INTERFACE SCHEMATIC

3.7 SMART FRONT END DESIGN

The Smart Front End consists of three basic elements, the Telerobotic System (TS), an ORU Carrier, and a Fluid Resupply System (FRS). At SS IOC, the SFE will be capable of performing satellite and payload servicing, Station assembly, and other ORU replacements and EVA assistance tasks. The growth SFE will add the ORU Carrier and FRS, and will be transported by the OMV, becoming capable of servicing satellites in-situ. In addition, the FRS could be used for fluid resupply at SS. The SFE will also provide test bed functions for technology evolution as more dexterous end effectors, force and tactile feedback systems, and artificial intelligence capabilities become available.

The primary mode of mobility at IOC for the TS will be the Mobile Servicing Center (MSC), which will also provide communication and power services to the TS.

The primary mode of transportation at growth for the TS, ORU Carrier, and the FRS will be the OMV, which will also provide basic communications and power.

Present SFE configurations require greater resources than the OMV provides, making it necessary to develop kits to supplement the OMV power and communications capabilities. In addition, future missions will require other special purpose kits for particular missions.

3.7.1 Telerobotic System

The TS is a remotely-controlled, teleoperated robotic system. The TS baseline configuration is shown in Figures 3.7.1-1 and 3.7.1-2. It consists of two 7-degree-of-freedom manipulators and one 7-degree-of-freedom stabilizer arm mounted to the work effector base. The vision system is attached to the top of the base, and contains stereo cameras and lights on a pan/tilt assembly. Initially the TS will be remotely controlled via teleoperation with the operator located at the SS. In-situ operations at growth will be controlled from the ground.

The TS will evolve with the development of technology to become an intelligent semi-autonomous system, capable of a multitude of tasks. It will achieve this capability in a progressive manner, evolving from teleoperation (man providing high-level control intelligence) to greater levels of supervisory control with the incorporation of artificial intelligence to handle high-level control functions.

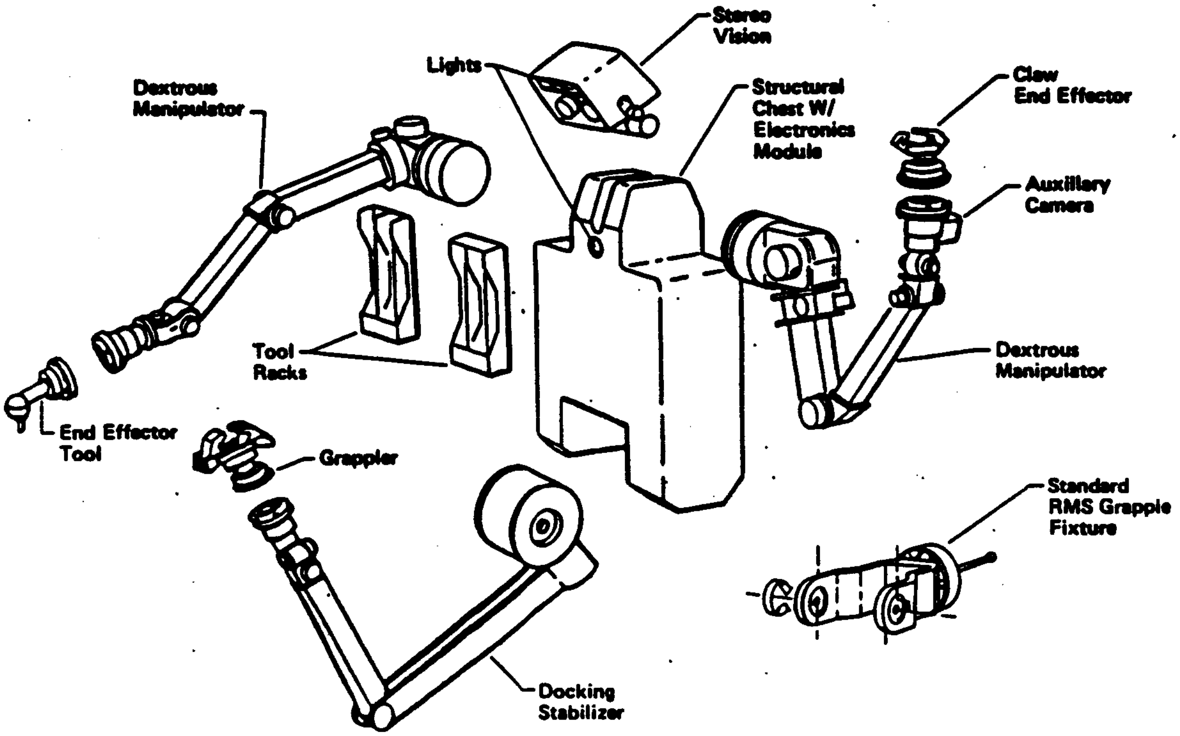


FIGURE 3.7.1-1 TS COMPONENTS

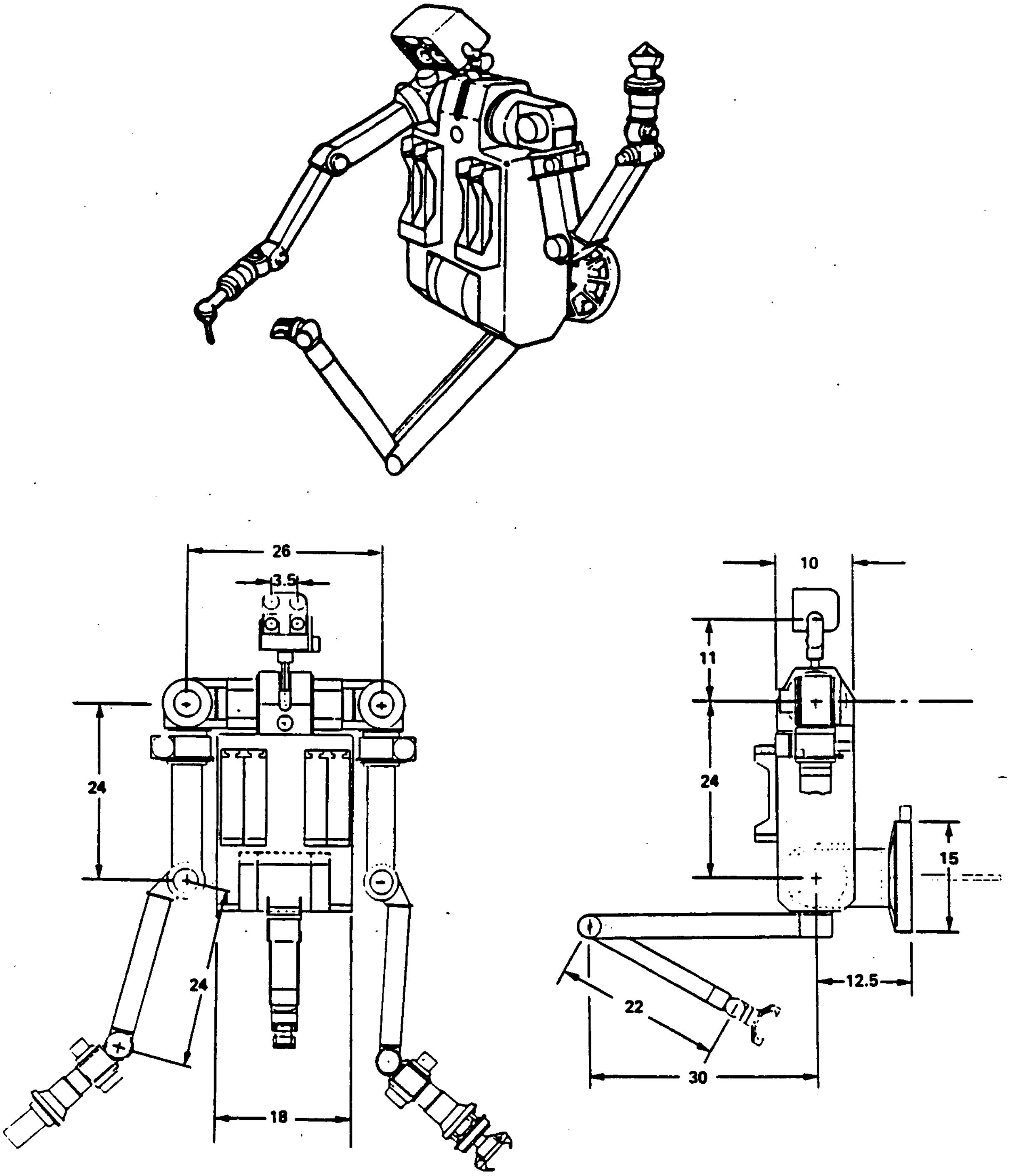


FIGURE 3.7.1-2 TS CONFIGURATION

3.7.1.1 Structures and Mechanisms

3.7.1.1.1 Manipulator Arms - The dual manipulators and vision assembly are anthropomorphically located on the TS structure. Thus control is simplified to movements proportional to those of man.

The TS utilizes 7-DOF general purpose arms which are also anthropomorphically configured. The arm is designed with shoulder drives, an upper arm segment, an elbow joint, a lower arm segment, and a three-DOF wrist. The reach envelope of the arm has a direct relationship to the task and its orientation to the serviceable object. The manipulator arms are ORUs which detach at the shoulder interface, allowing complete reconfiguration of the manipulator system.

The modular design is capable of changing manipulator length to accommodate a desired configuration by modifying its reach. As a consequence, it changes the torque requirements for each drive and the total arm weight. Table 3.7.1-1 sizes three different arm lengths for a 33 kg (15 lb) top force. The torque requirements doubles at the elbow and shoulder when changing from a 91.4 cm (3 ft.) to and 2.44 m (8 ft.) arm length.

The OMV-compatible TS (growth) uses a dual arm concept, which is required for conduct of EVA functionally-equivalent operations, and a single stabilizer arm. Each arm is mounted on the perimeter of a T-shaped section which is attached to a centrally-mounted docking mechanism, and is counterbalanced by a tool rack. The manipulators have the ability to rotate about the centerline of the docking mechanism. Affixed above the center of the T-section is the stereo vision system and located just behind the manipulator is the ORU Carrier which interfaces directly to the OMV.

An important feature of this system concept is a telescoping mechanism in the stem of the T-section between the shoulders and the docking fixture, which together with the carriage, rolls about the work effector centerline. This telescoping mechanism and the 400 degree pitch of the shoulders enables the arms to reach around the 4.57 m (15 ft.) diameter of a serviceable craft as well as working on the OMV itself. Figure 3.7.1-3 shows the dual arm concept for the OMV transported TS. The 2.44 m (8 ft.) arms could very easily be converted to longer of shorter arms if different reaches become necessary.

3.7.1.1.2 Stabilizers - A stabilizer is needed to rigidize the TS to the work site. A frame of reference can be established to enable the manipulators to do precision work. The stabilizer requires several degrees of freedom to enable positioning at general work sites. Therefore, for redundancy in parts and modularity, the 7-DOF manipulator was selected for the stabilizer.

3.7.1.1.3 End Effectors - Numerous end effector designs are available in the commercial market and at various research laboratories. The final end effector design will be selected after detailed ORU task analyses have been completed. The baseline end effector is shown in Figure 3.7.1-4. This end effector is designed to accept EVA standard tools with proper mechanical interfaces. For example, a ratchet receives its rotary power from a power takeoff which is built into the end effector to eliminate the need for a motor for each tool.

3.7.1.1.4 Docking-Berthing Adapters - The growth OMV-TS combination will dock with the repairable satellite. Past and present satellites lack common docking hardware, so the TS will be capable of docking with an RMS grapple fixture, EVA handrails, or similar structures.

3.7.1.1.5 Vision and Lighting Mechanisms - Most of the TS functions are controlled and viewed with the aid of the vision and lighting assembly. The assembly consists of a pair of CCD cameras mounted approximately 8.89 cm apart. The cameras are equipped with auto-focus and auto-zoom capabilities. Accompanying the cameras are two work lights. Dual lights reduce shadows and provide redundancy. The dual cameras and lights are enclosed in a package that can be rotated in two degrees-of-freedom, pan and tilt.

3.7.1.2 Electrical Power

The TS operates on 28 Vdc power, and accepts power from the host vehicle redundant 28 Vdc busses or from a battery kit. Average power draw for the TS is 1.2 kW (not including end effector tools or serviced payload requirements). The DC-to-DC Converter selects the source of power according to commands from the DMS depending on mission power profiles, host vehicle power capabilities, and the battery kit charge state. The DC-to-DC Converter also provides isolation to prevent ground and power loops between the host vehicle, the TS kit , and the serviced payload.

TABLE 3.7.1-1 ARM TORQUES AND WEIGHTS

ITEM		TORQUE N-m (LB-FT)			RATE RAD/SEC	ACCEL RAD/SEC^2	WEIGHT Kg (LBS)		
		3'	5'	8'			3'	5'	8'
WRIST	ROLL	13.56 (10)	13.56 (10)	13.56 (10)	0.1	0.1	1.8 (4)	1.8 (4)	1.8 (4)
	PITCH	20.34 (15)	20.34 (15)	20.34 (15)	0.1	0.1	2.3 (5)	2.3 (5)	2.3 (5)
	YAW	20.34 (15)	20.34 (15)	20.34 (15)	0.1	0.1	2.3 (5)	2.3 (5)	2.3 (5)
ELBOW	YAW	54.23 (40)	75.93 (56)	105.8 (78)	0.2	0.2	6.8 (15)	8.2 (18)	10.4 (23)
SHOULDER	YAW	85.42 (63)	126.1 (93)	187.1 (138)	0.1	0.1	8.6 (19)	11.3 (25)	15.0 (33)
	PITCH	85.42 (63)	126.1 (93)	187.1 (138)	0.1	0.1	8.6 (19)	11.3 (25)	15.0 (33)
						TOTAL	30.4 (67)	37.2 (82)	46.7 (103)

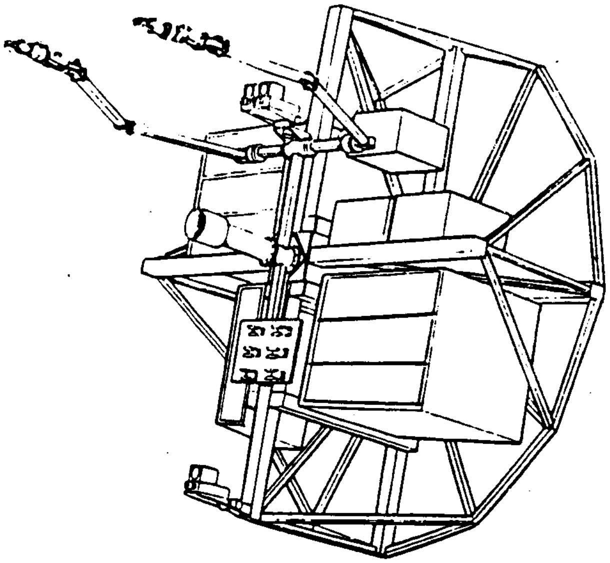


FIGURE 3.7.1-3 IN SITU SERVICING TS CONFIGURATION

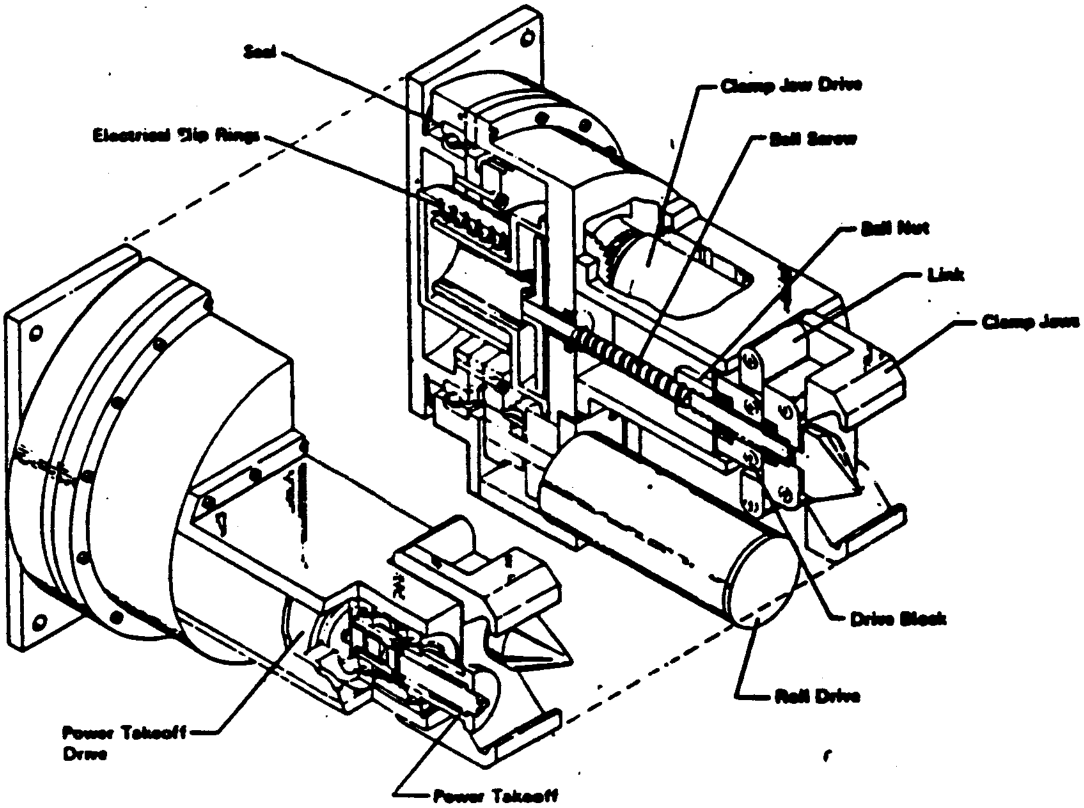


FIGURE 3.7.1-4 END EFFECTOR WITH A POWER TAKE-OFF

The Power Distribution Assembly functions as a load center to protect and control internal TS loads which include joint motors, TV cameras, lights, controller and instrumentation. A dc power subsystem was selected for direct compatibility with battery power, host vehicle power, and the TS loads. The power budget for the TS is shown in Table 3.7.1-2. Figure 3.7.1-5 shows the power distribution system schematic for the TS.

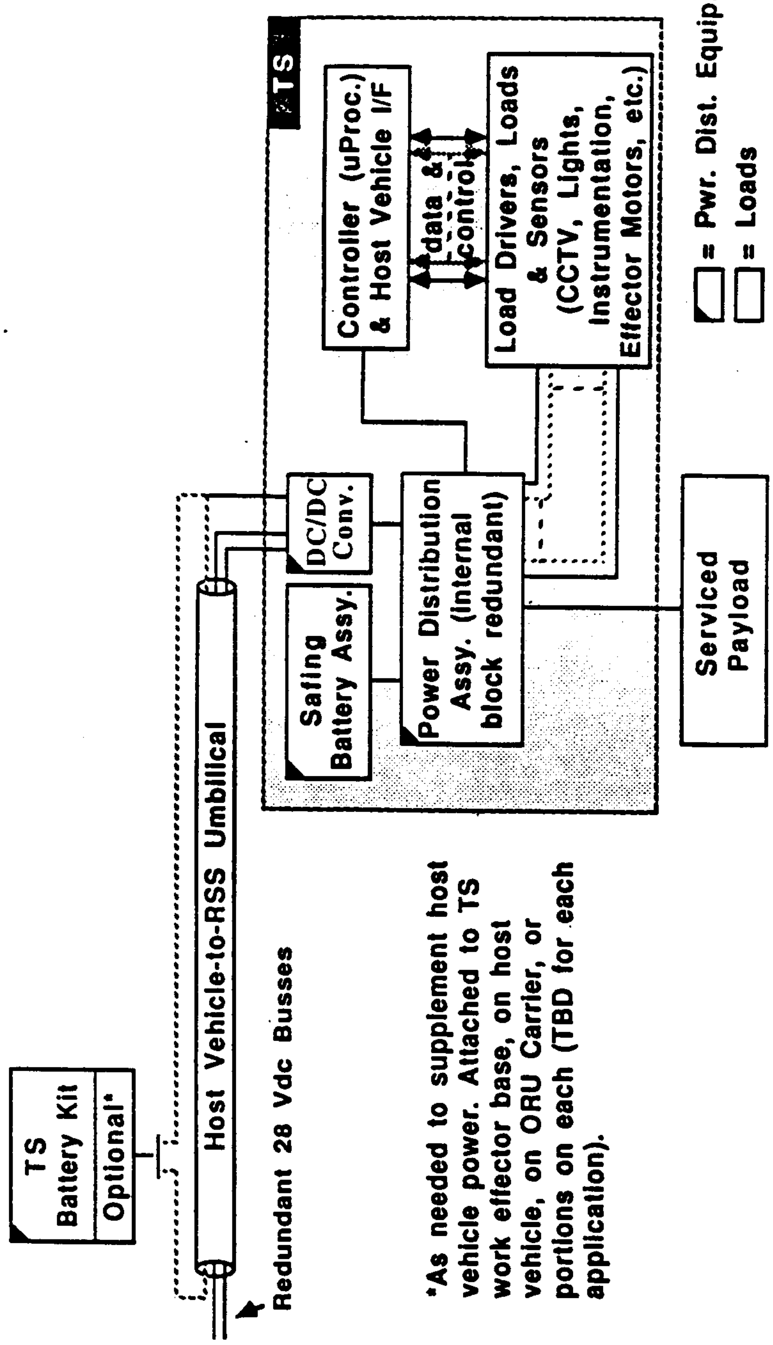
The safing battery assembly provides reduced power for 30 minutes to provide a safe shutdown of the TS and serviced payload in the event of a power failure. Batteries comprising the battery kit and the safing battery assembly are of rechargeable silver-zinc technology because of a good combination of reliability, relatively low size and weight, and cost impacts.

TABLE 3.7.1-2 POWER BUDGET

	Average Power, Watts
- Manipulator Arms (2)	500
- Stabilizer*	(200)
- End Effectors	50
- Waist Pitch	60
- Pan/Tilt	50
- Cameras	30
- Lighting	200
- Heaters	100
- Processors	150
- Other Electronics	100

1240 Total Watts

*Stabilizer Operates Exclusively
As One of the Manipulators



*As needed to supplement host vehicle power. Attached to TS work effector base, on host vehicle, on ORU Carrier, or portions on each (TBD for each application).

FIGURE 3.7.1-5 TELEROBOTIC SYSTEM POWER DISTRIBUTION

3.7.1.3 Thermal Control

The electronics components are packaged to minimize adverse thermal effects on the system.

The overall approach for the thermal control of the SFE will be to use thermal control coatings which will produce temperatures below the upper limit during extreme hot conditions. In cold case conditions electric heaters will be employed in order to maintain the temperatures above the minimum. Thermal insulation will be used to minimize the heater power requirements and electronic thermostats will be used to control the heaters.

3.7.1.4 SFE On-board Data Management and Control

The TS internal DMS is intrinsically tied to the control of the system as described below. The TS control system consists of three primary subsystems: (1). manipulator control, (2). vision/lighting positioning control, and (3). control processing/data management.

3.7.1.4.1 Manipulator Control - Control tasks for IOC are: positional, rate, and compliant control plus algorithmic path planning. The initial command mode will use a combination of man-in-the-loop and autonomous techniques. Man-in-the-loop mode will be capable of using rate, position, and compliance modes. A conventional autonomous mode would also be available on a limited basis.

Each DOF in the manipulator subsystem has a separate servo loop, and all servo loops are interfaced to the System Control Processor via a serial line. Digital control will be used for all servo loops. Therefore, joint stability compensation is performed by a microprocessor rather than an analog controller. There are two basic reasons for using digital control: (1). The digital controller will aid in decreasing the burden on the System Control Processor. Joint engineering parameters (e.g. joint position and velocity, motor current) can be sampled, converted, and formatted by the joint processor. These can then be transmitted to the System Control Processor via serial link. (2). Digital control provides more flexibility with regard to the control algorithm that can be implemented. For IOC, fixed gain control loops are anticipated. With the digital processing, however, the capability exists for gain scheduling, steady-state optimal or adaptive algorithms. Another attractive growth possibility that exists is that multivariable control algorithms could be implemented using the System Control Processor as a master controller.

3.7.1.4.2 Video and Lighting Positioning Control - Video commands are separated into two categories: internal (focus, zoom, etc.) and external (camera orientation). All camera functions can be independently controlled via console inputs. An automatic camera positioning control will hold the camera stationary for a given field of view. When the manipulator reaches a preset limit within the field of view, the camera will be recentered on the end-effector through a reset operation.

3.7.1.4.3 Control Processing/Data Management - The data system on-board the SFE must interface with mobility systems (e.g. OMV, MSC) and the SFE control station. It also processes and handles data for camera control, manipulators, end-effectors and lighting. At growth, it must support processing for AI planning, machine vision/perception, multi-manipulator control and CAD database utilization as these technologies mature. A distributed architecture for the on-board data system will provide the resources needed to meet requirements for real time control as well as for fault management and extensibility.

3.7.1.4.3.1 IOC Capabilities - The basic on-board computer architecture is presented in Figure 3.7.1-8. The components which will be present at IOC are shaded in Figure 3.7.1-8. These components will support telepresence and perhaps limited supervisory control through microprocessors dedicated to robot arm/hand control and to stabilizer/docking probe control. These controllers have direct access to force, torque, proximity and acceleration end-effector sensors. Experience has shown that multi-microprocessor systems provide sufficient processor bandwidth for the implementation of such real-time servoloops. Adequate floating point processing bandwidth must be provided for the coordinate transformations required for arm/hand control.

Stereo vision, alternative viewpoint mono vision, and end-effectors local vision imaging sensors will provide visual data to the SFE control station. There will be no on-board image processing at IOC, so the video data indicated as passing through the video switch may be routed directly to the communications system interface for transmission the the SFE control station.

The muilti-functional processing requirements in the telepresence mode are limited to dual-arm coordination and algorithmic path planning to support limited supervisory capabilities. It can be expected that conventional microprocessors will provide adequate processing power for these functions.

At IOC, the primary performance requirement on the processor interconnection network is for minimal latency to support real-time arm/hand control. Video data will not be transmitted through this network. All networks should be designed to be extensible for the addition of sensors, processors and devices.

On-board mass storage is probably not required at IOC, although on-board storage could be used to record command sequences for repetition in a supervisory mode. A more attractive alternate is to store such sequences at the SFE control station.

A dedicated processor to control a specialized servicing task (e.g. propellant transfer) may be provided on board at IOC. Alternatively, a multifunctional processing element could be dedicated to such tasks.

3.7.1.4.3.2 Growth Capabilities - For the growth SFE, additional processing, data storage, and data communication capabilities must be provided, as expert systems, AI planning, and machine vision/perception are introduced to enhance SFE autonomy. Such capabilities may be partitioned between on-board and control station resources with less time-critical functions (e.g. high level planning) assigned to remote sites. It is envisioned in Figure 3.7.1-6 that planning and control functions move on-board as supporting technologies mature.

A high-speed video switch supports real-time interconnection with the image processing system and with the communication system for remote viewing and back-up teleoperations. The multifunction processors will execute programs for overall systems control, AI planning, high-level vision, knowledge based, expert systems, and the communications between all processing systems.

The mass storage system will contain the CAD database, a priori knowledge base, and system programs. During autonomous operation, the mass storage system will perform event logging (audit trail/history), software checkpointing, and record some image data.

Robotic mobility, mission goal commands, telemetry data, teleoperator mode and ground links will be handled through the communications system link to the attached mobility system.

System evolution can be facilitated by the use of standards. Device-independent programs can be implemented in ADA and Common Lisp with OSI standard interprocess communications. Standard data representation, protocols and hardware interfaces will be used for the CAD/CAM database, iconic information and interprocess/interprocessor communications.

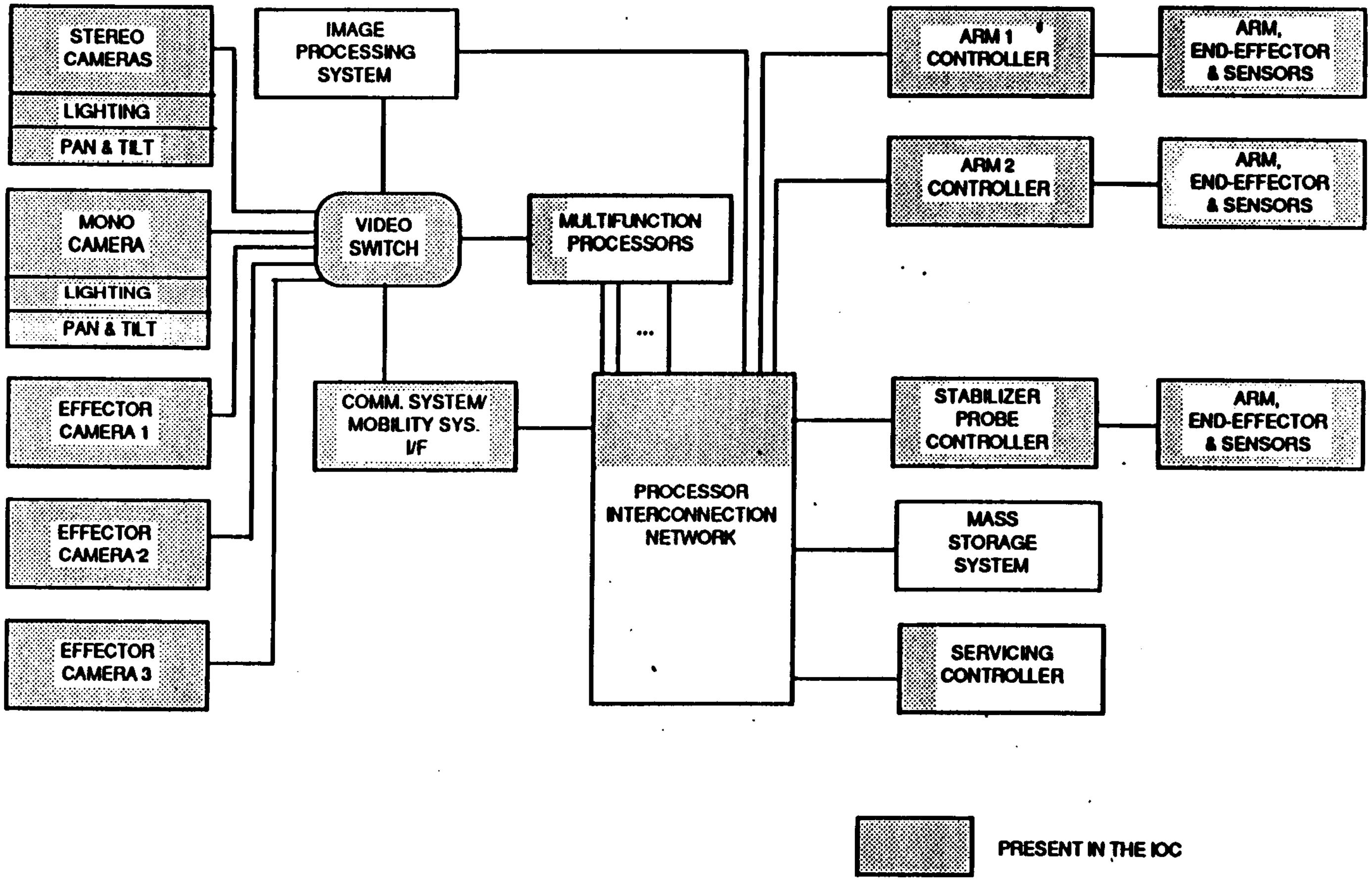


FIGURE 3.7.1-6 SFE ON-BOARD COMPUTER ARCHITECTURE

3.7.1.5 SFE Communications

The SFE Communications and Tracking system must have the following capabilities:

a. Provide for transmission, reception, distribution, signal processing, and controlling of telemetry, commands, video, and tracking data.

b. Capable of using umbilicals to the OMV C&T system (growth), and for an independent system when not berthed to the OMV or as a backup.

c. Provide for real time processing of control commands for servicing operations.

d. Provide CCTV and lighting for visual monitoring of SFE operations. Cameras shall have +/- 90 degree tilt and +/- 180 degree pan capabilities. Lighting shall provide 60 foot candles +/- 50% at a nominal distance of 1.52 m (5 ft.).

e. Provide video capabilities to read lettering a minimum of 3 mm (.12 in.) in height at a distance of 71.1 cm (28 in.), and alignment marks a minimum length of 7.62 mm (.30 in.) and width of 3.2 m (.125 in.).

f. Include provisions to prevent unauthorized access to communication links.

g. Provide 2 kbps transmission and 1 kbps reception rates for commands and up to 3 mpbs video transmission (stereo vision and a wrist camera) at IOC.

3.7.1.5.1 System Characteristics - The SFE Communications system will provide the following video characteristics at IOC:

a. Resolution: 1/16 in.

b. Scene area: 30.5 x 30.5 cm (12 in. x 12 in.)

c. Array sizing: 488 x 380 pixels for monoscopic display, and 1/8 th resolution for the second (stereo) display.

d. Gray levels: 4-bit quantization (16 gray levels)

e. Data compression: none

Figure 3.7.1-7 presents the growth SFE communications system functional flow, assuming the OMV as the carrier vehicle. Servicer commands are routed to a remote unit which provides the interfacing with the OMV data bus. The servicer provides all subsequent decoding and routing. Telemetry data is routed to the data handling system of the carrier vehicle where it is treated the same as the data from any other subsystem.

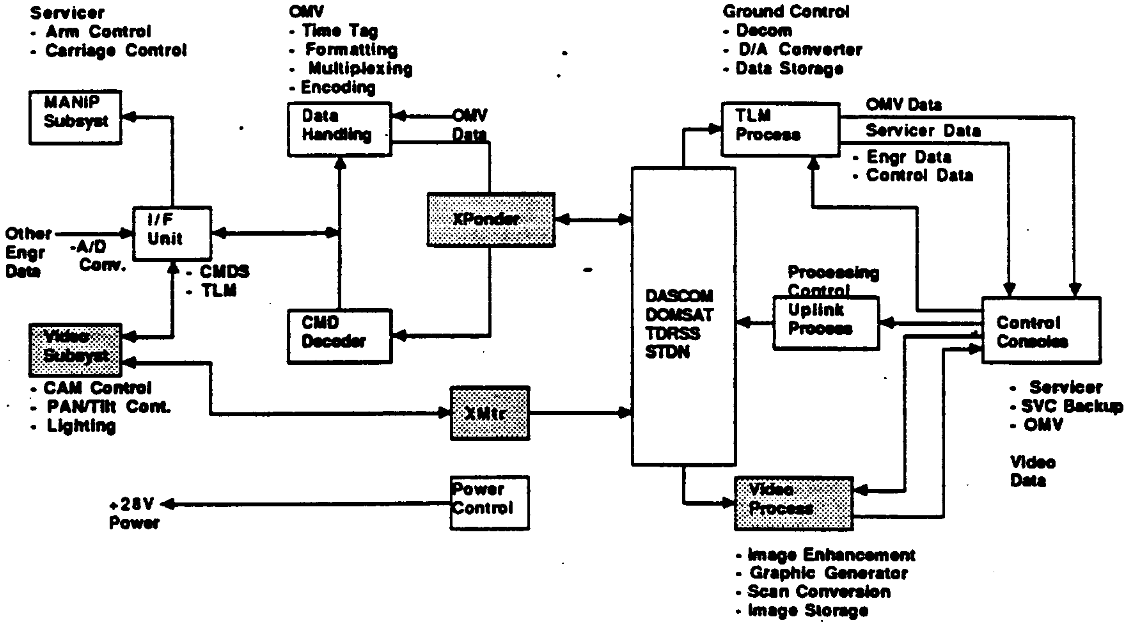


FIGURE 3.7.1-7 GROWTH COMMUNICATION SYSTEM FUNCTIONAL FLOW

The telemetry and video data are relayed from the carrier vehicle to the ground control center using TDRS (or STDN) and NASCOM ground lines or domestic satellite. Servicer data is stripped from the carrier vehicle data stream, processed and selected data input to the control console. The carrier vehicle (OMV) data is routed to the appropriate control center for that vehicle. Video data is processed as required and drives the display in the control console. The operators at the control consoles control both the telemetry and video processing.

Command functions generated at at the control consoles are processed and formatted into the required command bit structure for transmission back to the servicer.

3.7.2 ORU Carrier

The ORU Carrier is a system which will carry ORUs when the OMV/SFE conducts in-situ satellite/platform servicing. It will carry ORUs which vary in size and shape from a few inches on a side to telephone booth size, and provides space for the SFE kits.

3.7.2.1 Structures and Mechanisms

The ORU Carrier structure is sized similar to the OMV, 4.5m (14.7 ft.) diameter. It will interface with the OMV payload latches and the SFE structure, and will accommodate payload-unique ORU latch kits for each mission. A large ORU exchange mission might have two or more ORU carriers stacked to increase its ORU capacity. Figure 3.7.2-1 shows an ORU Carrier.

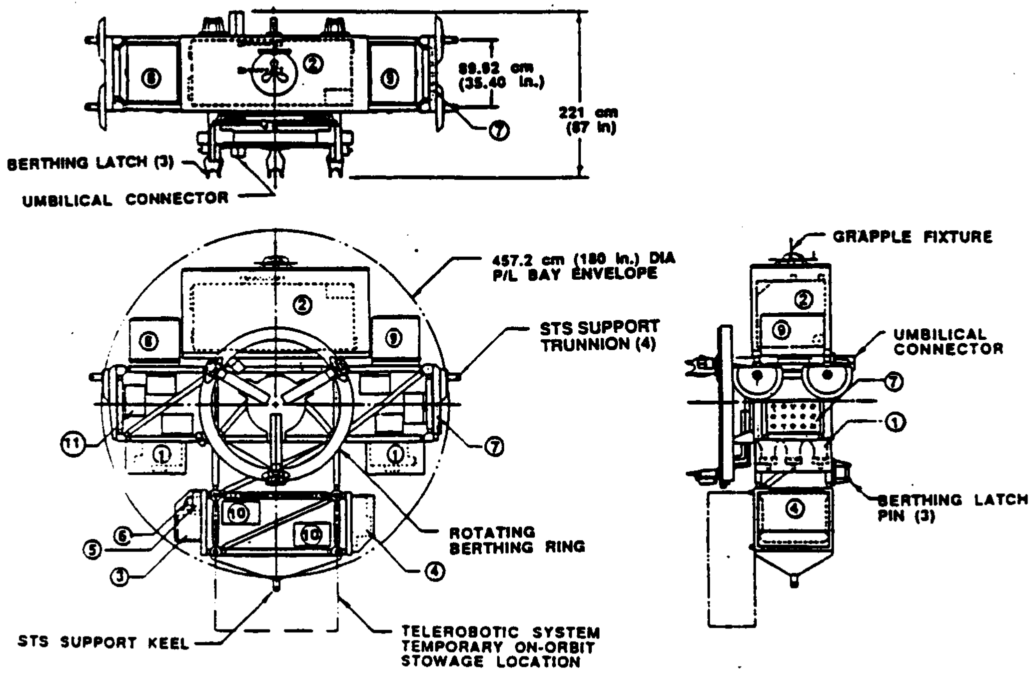


FIGURE 3.7.2-1 ORU CARRIER

3.7.2.2 Electrical Power

The electrical power requirements for the ORU Carrier are yet TBD. Because of the diverse electrical needs of the ORU's which will be carried, it is anticipated that the electrical power system will consist primarily of kit elements which will be assembled to meet the specific needs of the particular ORU's being transported. However, permanent wiring harness components are expected to be installed. See Section 3.7.4 b. for additional descriptions of the electrical power kit components.

3.7.2.3 Thermal Control

It is expected that the ORU's being transported by the ORU Carrier will generally supply unique thermal control subsystems. However, the ORU Carrier will provide electrical power to support those thermal control systems.

3.7.2.4 Data Management and Control

The ORU Carrier will supply interface ports to pick up status information from ORU's being transported and will interface it with the SFE Communications system as required.

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. These tanks are currently in production and are Shuttle qualified.

Two OMV pressurization spheres are included for pressurant supply for the FRS tanks and for resupply. The pressurant spheres could contain nitrogen or helium or one of each depending on the configuration of the system to be resupplied.

The FRS configuration is shown in Figure 3.7.3-1. The FRS plumbing layout is shown in Figure 3.7.3-2. The arrangement is similar to the OMV tank farm with the tanks plumbed in series to allow more flexible propellant transfer operations. The Olympus tanks contain screen-type surface tension propellant management devices allowing the same tank design to be used for both a hydrazine FRS and a storable bi-propellant FRS. A similar vent system is also employed on the FRS for those systems that require evacuated fillings.

The FRS will be as autonomous as possible during the fluid resupply processes, but will always allow for operator override of a specific procedure or control of an entire process. The fluid flow rate from the FRS to the servicing equipment will be controlled by adjusting valve openings. Temperature, flow rate, and pressure will be monitored to determine when the fluid resupply process has been completed.

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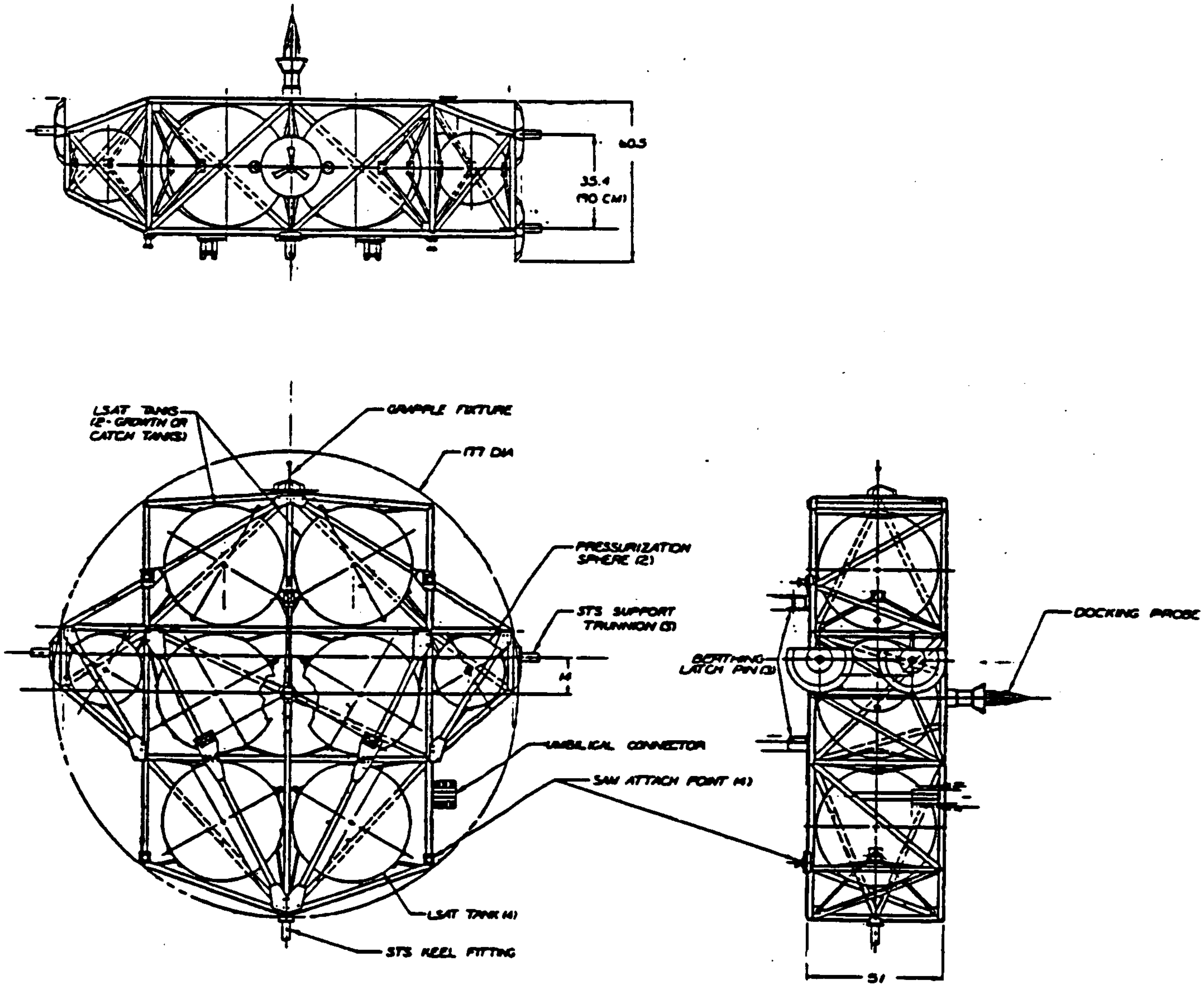

FIGURE 3.7.3-1 FRS CONFIGURATION

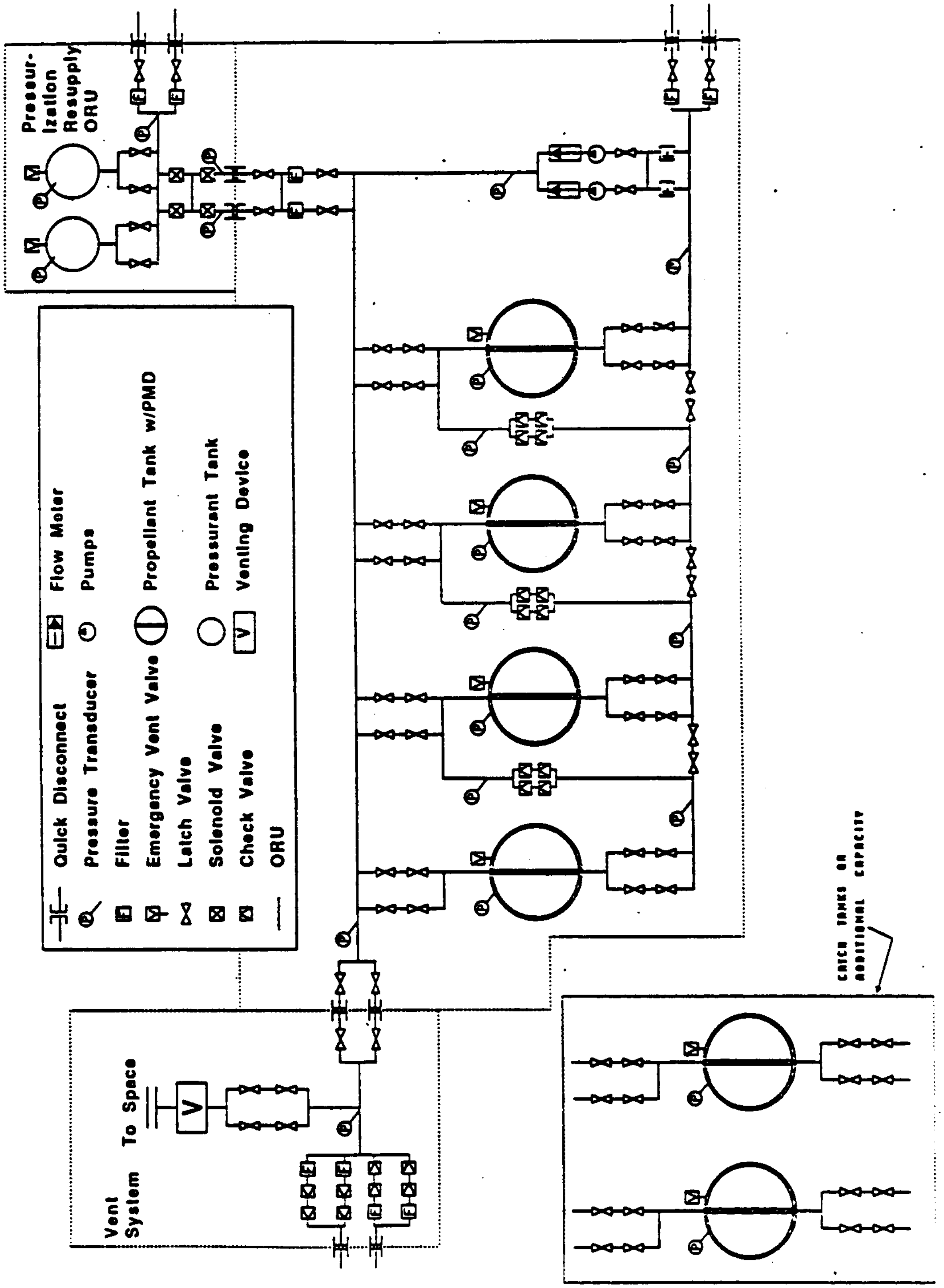

FIGURE 3.7.3-2 FRS PLUMBING LAYOUT

3.7.3.1 Structures and Mechanisms

The FRS has a structural envelope which is similar to the OMV, and is equipped with trunnion supports for interfacing with the STS and a grapple fixture for interfacing with the MSC. Three latching pins are provided on the aft end of the FRS for structural mating with the OMV. The front face of the FRS requires a docking mechanism to attach to the spacecraft to be serviced, as well as a common fluid umbilical panel equipped with automatic quick disconnects for both pressurant and liquids. Development of a common structural attachment and fluid umbilical panels are required for remote servicing of this type to be accomplished.

The FRS can hold up to 17,600 kg (8000 lbm) of storable propellants. Automatic remote fluid umbilical connectors will interface, either automatically at docking or with the aid of the TS, with compatible connectors on the receptor spacecraft. The structure is designed to allow for the removal or addition of two of the tanks for additional capacity or for use as catch tanks for refueling systems that require evacuated fillings. The FRS will be capable of structurally interfacing with the OMV, MSC, and the Orbiter payload bay.

The FRS will be expected to operate normally with umbilicals which will connect automatically upon hard docking with the vehicle to be serviced. 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 perform a hard connection with the satellite or platform fluid umbilical. Verification, fluid transfer, and disconnect steps would be similar to those performed by the hard docking and automatic umbilical connection process.

A third scenario would have the TS and FRS used independently to perform ORU exchange and fluid servicing on the same vehicle. These operations would be conducted in series since simultaneous operations could produce contamination or safety concerns.

3.7.3.2 Electrical Power

Figure 3.7.3-3 shows the power distribution for the FRS. 28 Vdc power is accepted from either of the host vehicle redundant busses or from a battery kit. The DC-to-DC converter provides isolation to prevent ground and power loops between the host vehicle, FRS kit, and serviced payload. The DC-to-DC converter also selects one of the host vehicle redundant busses.

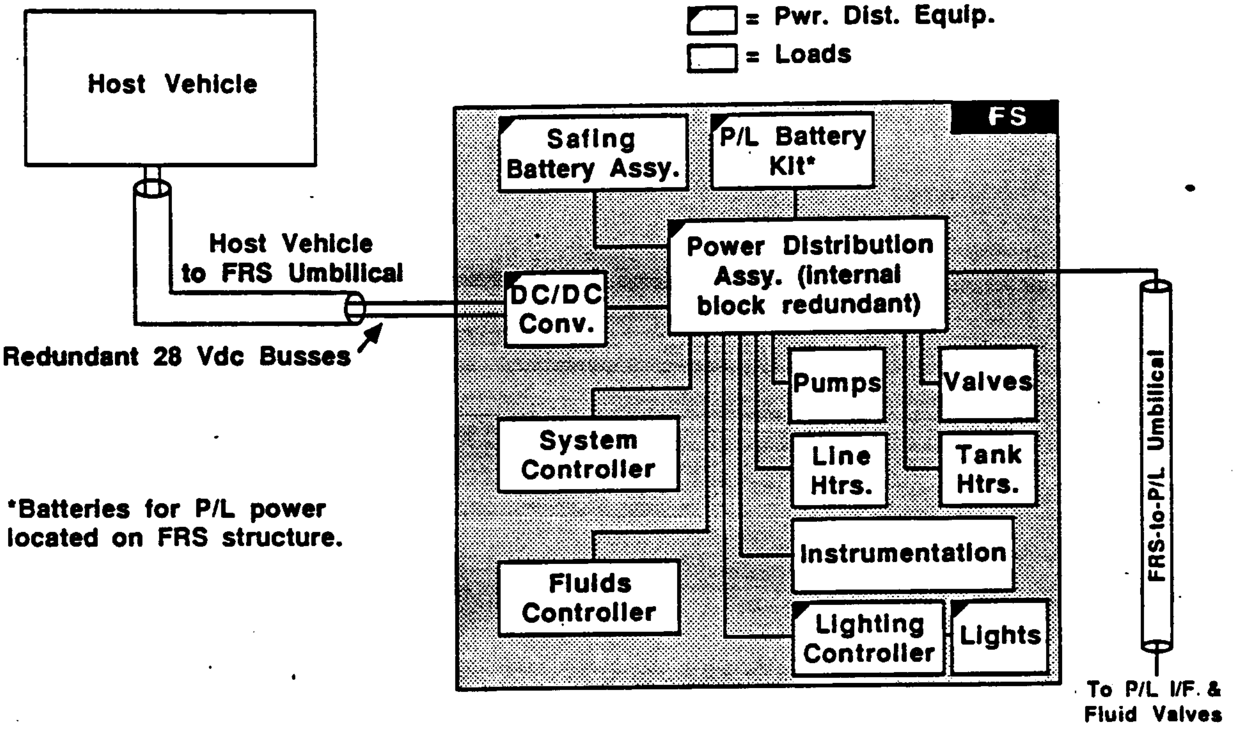

FIGURE 3.7.3-3 FRS POWER DISTRIBUTION

The Power Distribution Assembly selects the source of power (host vehicle or battery kit) according to commands from the DMS depending on host vehicle power capabilities and the battery kit charge state. The power Distribution Assembly also functions as a load center to protect and control the FRS loads which include pumps, valves, latches, heaters, controllers, instrumentation, lighting, and serviced payload interfacing. A dc power subsystem was selected for direct compatibility with battery power, host vehicle power, and the FRS kit loads.

Average power draw for the FRS is TBD W. The battery kit uses the same type batteries as the TS, and is sized to supply the FRS needs. The safing battery assembly provides power for 30 minutes to provide a safe shutdown of the FRS and serviced payload in the event of a power failure.

3.7.3.3 Thermal Control

The FRS thermal control system details are TBD. However, techniques such as thermal isolation, use of thermal paints, multilayer thermal blankets, thermostaticly controlled heaters on tanks, and avionics heat rejection to components inside insulation are expected to be used.

3.7.3.4 Data Management and Control

The FRS Data Management and Control system detail are TBD. The system will be required to provide the following:

a. electrical interfaces
b. power distribution and control
c. valve control and monitoring
d. mechanism control and monitoring
e. instrumentation
f. data display
g. data interface to downlink
h. caution and warning data

3.7.4 SFE Mission Kits

The SFE mission (or function) kits are those items which may be attached to the SFE to enable it to perform functions beyond those for which the basic SFE elements are capable, or provide support beyond the capabilities of the SFE mobility 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. Evaluation of these servicing mission types resulted in the following list of functional kits for IOC. Figure 3.7.4-1 relates the kits to mission types.

	NEAR-TERM MISSION TYPE			
FUNCTION KIT	MODULE REPLACEMENT	INSPECTION, REPAIR, & SERVICE	RETRIEVAL	PRODUCT RETURN
DOCKING/BERTHING KIT	✓	✓	✓	✓
ELECTRICAL POWER KIT	✓	✓	✓	✓
DATA COMMUNICATIONS KIT	✓	✓		

FIGURE 3.7.4-1 FUNCTION KITS BY MISSION TYPE

a. Docking/Berthing Kit. This kit will provide the non-standard docking or berthing interfaces between the SFE and the payload, satellite, or platform upon which the OMV/SFE is to perform servicing tasks.

b. Electrical Power Kit. This kit will be necessary if the basic power capability of the host mobility system is insufficient for a particular mission. It is expected that it will consist of batteries, solar panels, or both, depending upon the specific requirements.

The battery kit is reconfigured and sized according to requirements (i.e. host vehicle power capabilities) for each application of the TS. As an example, it is anticipated that power available from OMV as host vehicle for the TS would be limited to 5 kWh with maximum instantaneous draw of 1 kW. Therefore, when powered by an OMV for an 8 hour mission (resulting in 9.6 kWh total TS energy dissipation) the battery kit would need to be configured for 5 kWh to supplement the limited OMV power capabilities. In applications where total mission power is available directly from the host vehicle, such as on Space Station, no battery kit would be required. In some satellite servicing applications, the SFE will pass through power supplied by the host vehicle (up to 3 kW) for "keep alive" and/or battery charging while the satellite's solar array is disabled during servicing.

Because of limited volume internal to the TS work effector base, the battery kit will be externally located. Further study is needed to determine where the battery kit is to be located (mounted on the TS, on the ORU Carrier, or on the host vehicle, or portions on each) for the several possible applications.

c. Communications/DMS Kit. This kit would provide data transfer and communications capabilities beyond those normally available through the OMV. It is expected that it may be needed to accommodate SFE video data rates as well as handling diagnostics and experiments data transmission back to the Space Station. It will be necessary to consider encryption devices or other means of obtaining secure data as some company proprietary data may be involved.

3.7.5 SFE Software

The SFE requires software data services for health and monitoring, fluids transfer and servicing operations. Control of the TS will be through space or ground-based control station(s) and will require tailored data displays and menus. Manual override of all automatic functions will be available for contingency operations.

The TS will be controlled via hand controls at the control station. These hand control signals will be translated into robotic commands and transmitted through the communications system to the TS. The TS will also provide physical contact information and any other sensory perception information. This information will provide force feedback data to graphic displays, confirm camera information, produce information for graphics, and allow for growth from a teleoperational system. The operator will determine manipulator control modes and control tool selection and use while performing a mission.

The TS software will monitor TS subsystems and operations, compare actual data to standards stored in the TS data base, and produce conditions reports to the operator via the communication system. In the case of an extremely anomalous or hazardous condition, the TS software will be capable of detecting the condition, and arresting TS operations pending manned override instructions.

SS software will control the power consumption of TS and monitor the thermal system. The thermal environment of the TS may be controlled by passive and/or active means. Communication links from the TS will include digital data or TS status and video from TS cameras. The data link from SS to TS may include commands for robotic movements, invocation of software packages, selection of camera positions, and hand control directed commands that represent robotic movements.

The FRS requires software data for mating, monitoring, and fluid resupply operations. The Fluid resupply operation will normally be an automated sequence both for fluid loading and detanking, but will provide for operator override of a specific procedure or control of an entire process. Pressure, temperature, and flow rate sensors will be fed to the operator control station. A growth option to allow for non-standardized fluid supply equipment would be to add a robotic umbilical, which would permit the TS manipulator to access the fluid resupply areas.

Sensory feedback will also determine when mating between elements has been completed. This information will be used for automatic latch shutdown and for operator display. Software tests will be made after demating for determination of proper separation.

The SFE application software shown in Figure 3.7.5-1, required to support the accommodations and servicing are focused in the following areas:

IOC	ADDED AT GROWTH
TS Proximity Operations	FRS Fueling Procedures
TS Servicing	FRS Servicing
TS Robotics Operations	FRS Robotics Operations

The software is expected to be fairly complex due to proximity and robotics operations. The entire software set is estimated to be thirty to thirty-five thousand lines of code.

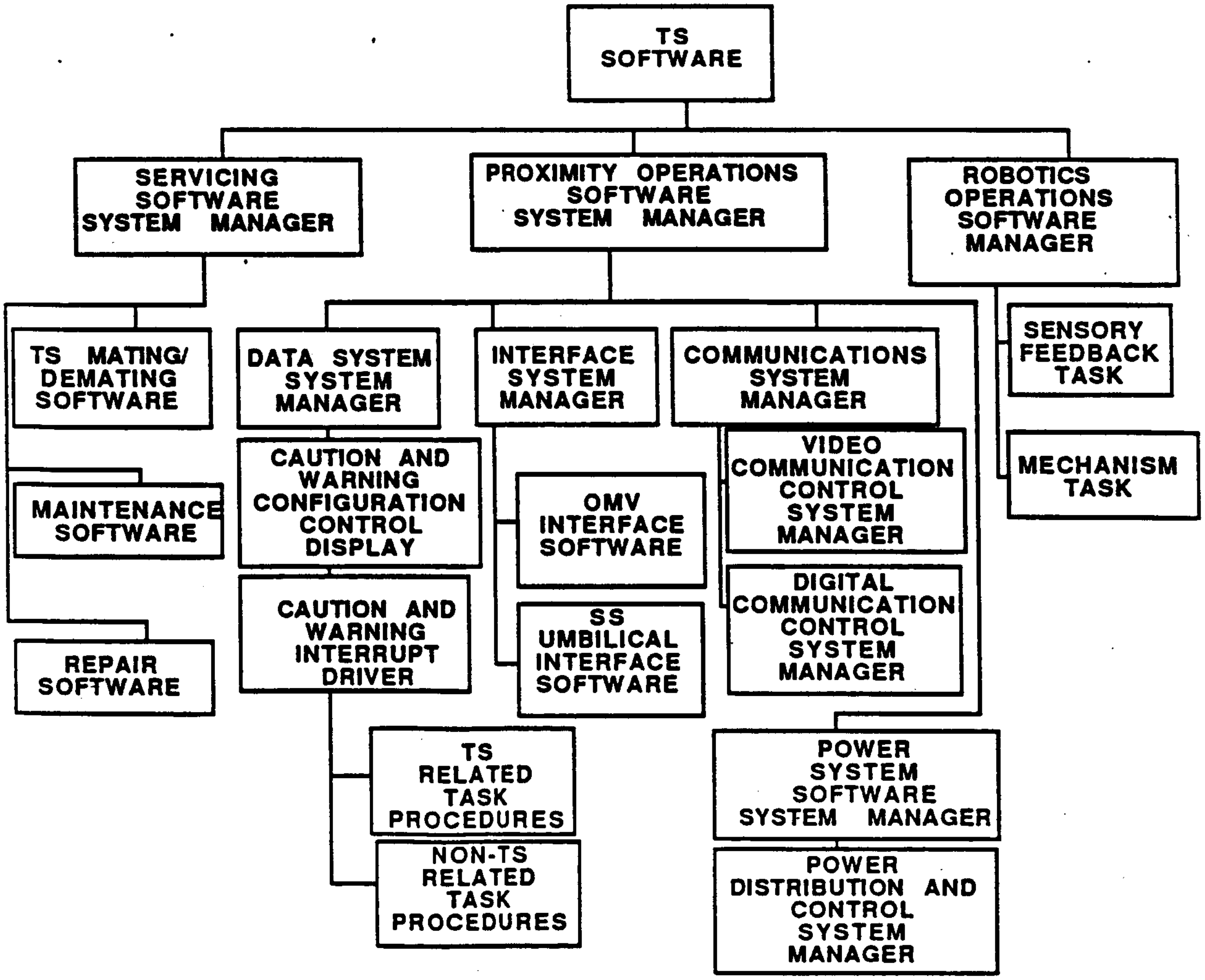

FIGURE 3.7.5-1 TS OPERATIONS SOFTWARE

3.7.6 SFE Control Station

Development of a teleoperated robotic servicer requires a close evolution with that of the control station from which it will be controlled. In order to define an integrated SFE control and display station for operating a remote on-orbit servicing system in conjunction with a remote mobility system, numerous configuration constraints were established. A functional analysis was performed to identify top level constraints. The analysis considered all servicer subsystems along with a minimum set of transporter vehicle subsystems. The primary emphasis was on visual displays and manipulator control elements. The findings are summarized in Table 3.7.6-1.

A preliminary listing of components (sensors), functions, C&D elements, and operator interactions is shown in Table 3.7.6-2.

The control station was broken down into various subsystems and major components as shown in Table 3.7.6-3.

A typical SFE control panel layout is presented in Figure 3.7.6-1.

TABLE 3.7.6-1

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 6-DOF position controllers	Limits operating envelope at console, keeps operator's hands committed
- Two Arms		
Camera Assy Control:	Pan/Tilt joy stick auto follow or voice	Keep joy 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

TABLE 3.7.6-2 SUMMARY OF C&D STATION ELEMENTS

SUBSYSTEM	C&D FUNCTION	OPERATOR INTERACTION* OPS	C/C	CAU ALERT	DATA STOR	SUPT. OPER.	CONTROL CONSOLE HARDWARE
Manipulators	Power/On-Off	X				X	Guarded Toggle Switch
	Control Mod Select	X					Guarded Toggle Switch
	Right Arm Control	X					6-DOF Hand Control
	Left Arm Control	X					6-DOF Hand Control
	Actuator Status		X	X	X	X	Motor Current and Rate
	Force Ration(C)	X					Rotary Pot (1 to 5)
	Spatial Ratio	X					
	Wrist Torque Ratio	X			X		Rotary Pot (1 to 5)
	Joint Angles			X	X	X	Lights and Sound
	Joint Brakes (Master Button)	X		X		X	6 Push Button Matrix, Status Lights
	End Eff. Open/ Close	X	X				Rocker Switch on controller
	Grip Force	X				X	Force Meter
	Auto Modes	X					Push Button Matrix (software program)
	Assembly Rotate	X			X	X	Rotary Pot and Location Ind.
	Teach/Playback	X			X	X	Toggle Switch
Power (from OMV)	Main Power/On-Off	X				X	Guarded Toggle Switch
	Power Status	X	X	X	X	X	Lights and Sound Call-up/ Monitor
	Bank Select	X					3-Way Toggle Switch
	Capacity Remaining	X		X		X	Comp Generator call-up/ Monitor
ORU Storage Rack	Power/On-Off	X				X	Guarded Toggle Switch
	Mounting Status	X	X	X	X	X	Keyboard Select, Call-up
	Latch/Release	X					Optional/Pushbutton Matrix
Spacecraft	Alignment	X			X	X	Stereo/Mono Wrist
	Attachment	X	X			X	Special EE, Wrist/TV
	Collision Avoidance	X		X	X	X	Force Feedback, Controller/ Meter, Predictive Simulations Displays
Visual (Main) Stereo Camera Assembly	Power/On-Off	X	X		X	X	Guarded Toggle Switch
	Camera Select (Power)	X	X			X	3-Way Toggle Switch
	200 m (Far-Near [40%])	X				X	Switch, Toggle
	Iris (Open-Close)	X				X	Switch, Toggle
	Focus (Far-Near)	X				X	Switch, Toggle
	Auto Light Cont. (ALC)	X				X	Switch (Ave-Peak)
	Camera Adjust					X	Switch (Dist Adjust)

TABLE 3.7.6-2 SUMMARY OF C&D STATION ELEMENTS (Continued)

SUBSYSTEM	C&D FUNCTION	OPERATOR INTERACTION*					CONTROL CONSOLE HARDWARE
		OPS	C/O	CAU ALERT	DATA STOR	SUPT. OPER.	
Mono Camera Assembly	Power/On-Off	X	X		X	X	Guarded Toggle Switch
	Same as for Stereo	X				X	(see above)
Monitors (2) (Auxiliary)	Mon.Select (Power)	X				X	3-Way Toggle Switch
	Split Screen on Monitor	X	X			X	3-Way Toggle Switch
	Data Select on Monitor	X	X		X	X	3-Way Toggle Switch
	Brightness	X				X	Rotary Pot
	Contrast	X				X	Rotary Pot
	Vertical	X				X	Rotary Pot
	Horizontal	X				X	Rotary Pot
	Automatic Fine Control	X				X	Toggle Switch (Optional)
Lights	Power/On-Off	X	X			X	Toggle Switch
	Light Source Select(Beam & Diffuse)	X	X			X	3-Way Toggle Switch
	Light Intensity	X				X	Rotary Pot
Fresnel Lens	Stereo Display Top Monitor	X				X	Manual Operation
Camera Positioning	Power/On-Off	X	X			X	Guarded Toggle Switch
	Mode Select	X			X	X	3-Way Toggle Switch
	Camera LOS (Manual)	X	X			X	2-Axis, 4 Position Joy Stick
	Actuator Status		X	X	X	X	Comp. Source Call-up/Monitor
	Position Ind. Pan ± 180 Deg.	X		X	X	X	Position Meter
	Position Ind. Tilt ± 90 Deg.	X		X	X	X	Position Meter
	Release/Stow	X			X	X	Toggle Switch
Docking	Power/On-Off	X				X	Guarded Toggle Switch
	Probe Extend/Ret	X	X			X	Toggle Rocker Switch
	Docking Status	X		X	X	X	Lights, Sound
	Actuator Data	X	X	X		X	Contact, Torque, Force, Current
	EE: Latch Index	X				X	Rotary Pot
C&DH	Communications	X					Comm Link Select Switch
	Power/On-Off	X				X	Guarded Toggle Switch
	Interface Status	X		X	X	X	Data Call-up
	Data Record	X			X		Push Button
	Video Record	X			X	X	Push Button
	Special Compute	X			X	X	Keyboard/Multifunctional Display
	Instructions(Comp)	X			X	X	Keyboard/Monitor
	Task Times	X			X	X	Timer & Reset
Thermal	Power/On-Off	X	X			X	Guarded Toggle Switch
	Temp Status			X	X	X	Lights & Data Call-up
	Temp Select	X		X	X	X	Auto Heater Control

C-4

TABLE 3.7.6-3 MAJOR CONTROL STATION COMPONENTS

C&D COMPONENTS	PRIMARY FUNCTION
Hand Controller	Provide Man-in-loop Hand Control
Primary Video Display	Provide Screen for Stereo Display
Auxiliary Video Displays	Provide Screens for mono & Graphic Displays
Operator's Keyboard	Provide Standard Input Devices
Multifunctional Display	Provide Quick Response Output Devices with Reconfigureability
Computer Control	Provide Central Processing Capability for System Supervision & Control Algorithms
Data Storage:	
Hard Disk	Provide Data Storage for Operations
Video Tape	Provide Video Storage Capability
Voice Commands	Provide Backup Command Mode
Other Controls & Displays	Units, Rotary/Toggle Switches, Back Lights, etc.

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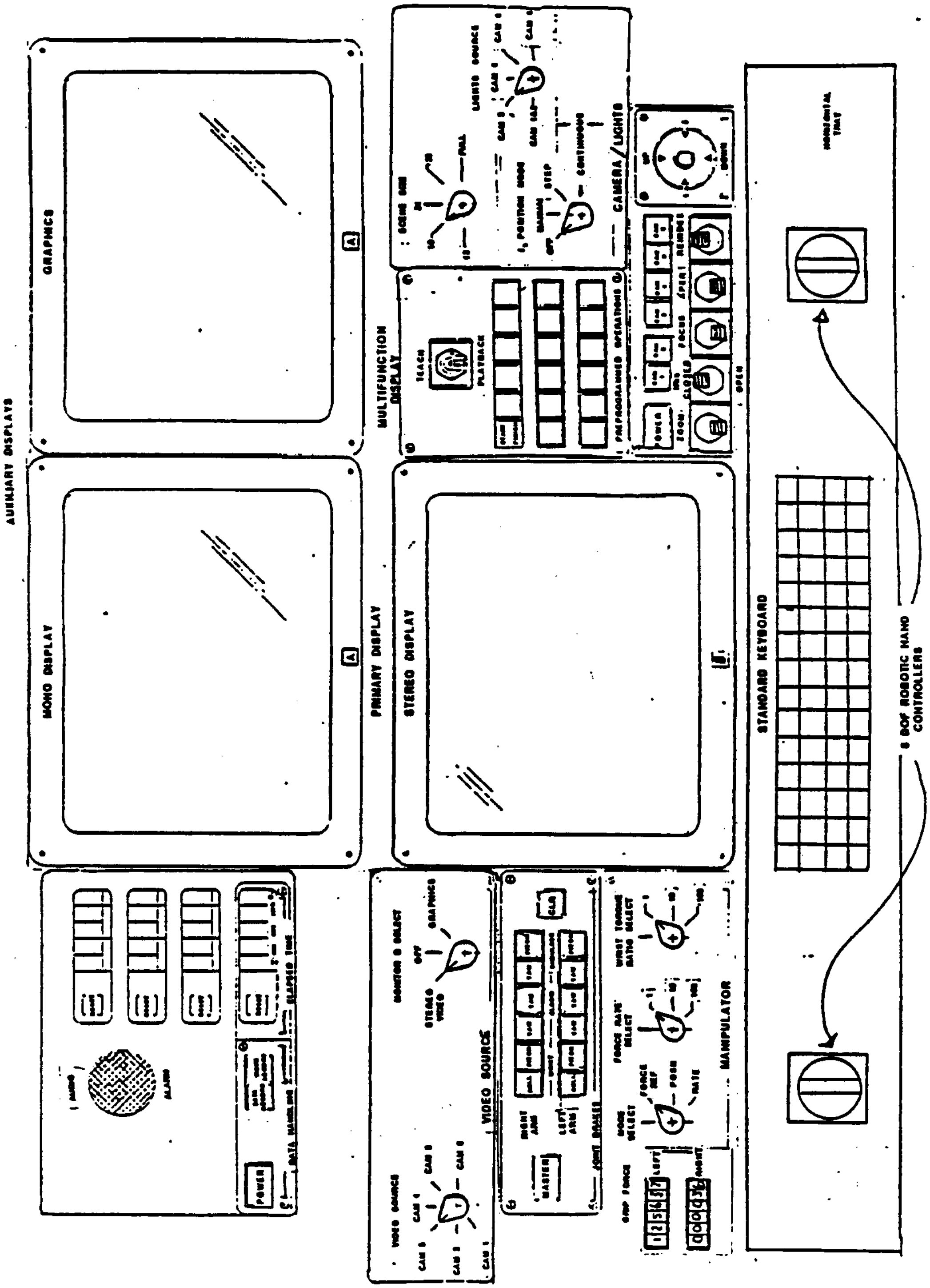


FIGURE 3.7.6-1 CONTROL STATION LAYOUT

4.0 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.

Appendix E was deleted, by MSFC direction, from the June 1986 submission and is therefore omitted from this summary.

4.1 PRIMARY DOCUMENT

4.1.1 Introductory Material

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

- Ground Rules and Assumptions
- Inter/Intra-WP Operations
- Operations Issues
- Space Station Operations
- KSC Operations
- International Elements
- 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 4.1-1, and include hardware/software elements and subsystems, as well as system level responsibilities.

TABLE 4.1-1 WORK PACKAGE ONE, SUMMARY DEFINITION

- WP-01-MSFC
  - SE&I Support
    - ECLSS Analysis
    - Logistics Analysis
    - OMV/OTV Interface Analysis*
    - Common Module Commonality Analysis
    - Propulsion Analysis*
    - Reboost Analysis*
    - Laboratory Analysis
    - Common Workstation

- Hardware/Software
  - Common Module
  - Structure
  - Distribution for:
    - DMS*
    - Power*
    - ECLSS
    - Thermal
    - Communications

  - ECLS System
  - Propulsion System*
  - Laboratory Module Outfitting (1)
  - Logistics Module Outfitting (2 or 3)
  - OMV/OTV Accommodations
  - Applications Software*

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

4.2 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.

4.2.1 KSC Space Station Project Plan

The Kennedy Space Center (KSC) Space Station Project Plan Overview is illustrated by Figure 4.2-1. The plan presents the schedule for the planning, implementation, and activation of the launch site facilities and systems required to support the Space Station program milestones. The plan describes the use of those facilities and systems.

4.2.2 Ground Operations

The Space Station launch site operations is to prepare all Space Station hardware for installation into the NSTS orbiter as integrated cargos for delivery to orbit. This appendix, however, concentrates only on the WP-01 element hardware. Processing of WP-01 Space Station hardware at the launch site will be consistent with NSTS payload processing concepts and philosophy. The diversity of the WP-01 elements results in varied launch site processing flows tailored to the specific element requirements for assembly, checkout, test and prelaunch servicing and postlanding deservicing, disposal, or refurbishment and turnaround. These launch site operations encompass the activities required to process and launch the IOC and follow-on operations capability (FOC) WP-01 hardware, as well as the recurring efforts associated with the cyclic WP-01 hardware, e.g., Logistics modules, propellant resupply modules/pallets.

The ground operations provided for in this plan are those which are necessary to satisfy all the levels A, B, and C program requirements. Level A requirements provide program policy direction and top level requirements. Level B requirements are developed by the National Aeronautics Space Administration (NASA) lead center and consist of Space Station system, operational, and mission requirements. Level C requirements are those developed by the NASA project centers to implement the Level A and Level B requirements. This plan documents the Level C prelaunch operations requirements for WP-01. This plan illustrates a minimum launch site test and verification approach consistent with the WP-01 overall test and verification philosophy utilizing a cost effective approach.

Figure 4.2.2-1 summarizes the launch site operations flows of the WP-01 elements. The hardware traces through this diagram represent our preliminary determination of the operations required for each WP-01 element and assembly. The location for outfitting the MTL and Logistics module has considerable impact on the scope of the required launch site operations as well as the level of outfitting of the USL which will be completed on-orbit.

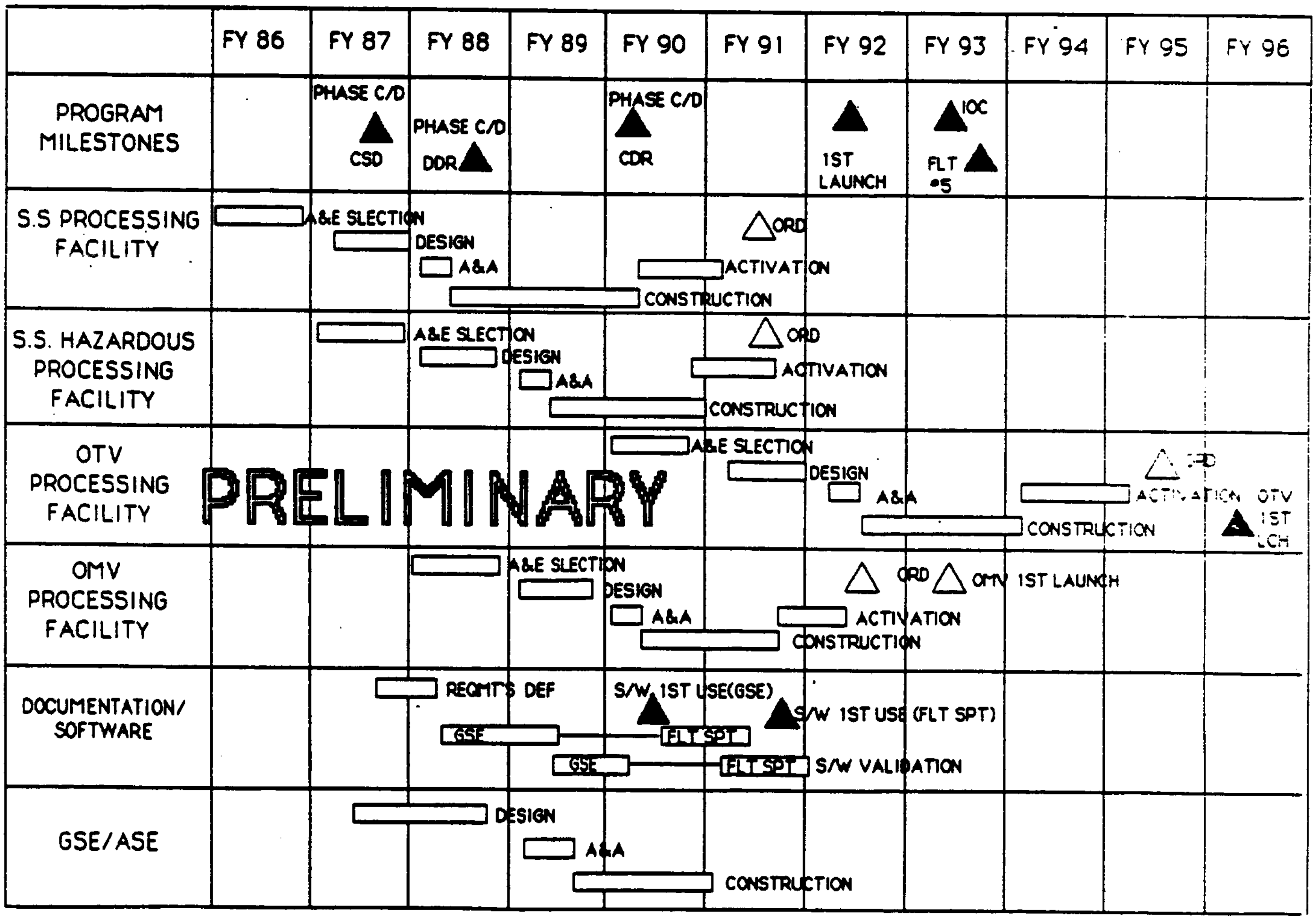


FIGURE 4.2-1 SPACE STATION PROJECT PLAN OVERVIEW

Complete outfitting of the USL and Logistics module prior to delivery to the launch site provides for minimal launch site processing and checkout activities. These activities would include receiving/inspections, performance of remove/install before flight operations, prelaunch system configuration checks, and element/NSTS interface integrity verification.

Outfitting of the USL or Logistics module at the launch site remains a program consideration and selection of this option would result in more extensive launch site testing as indicated in Figure 4.2.2-1. Launch site outfitting would also dictate that any program level requirement for integrated element testing would logically be implemented at the launch site.

4.2.2.1 IOC Processing and Resupply Functions

In addition to processing assembly related elements, this appendix includes a detailed discussion on IOC (or nominal) ground processing. The prime areas covered are:

a. IOC Support/Buildup to Growth
b. Growth Configuration Support
c. Resupply Requirements
d. Hazardous Processing
e. WP-01 Element Testing

Preliminary prelaunch operational processing flows and timelines are presented and discussed, starting with top level functional flows as shown in Figure 4.2.2.1-1. Figures 4.2.2.1-2 and 4.2.2.1-3, which reflect the OMV refueling and propellant transfer facility activities are examples of the specific functional flows and timelines which are illustrated throughout this appendix.

The same level of illustrations, accompanied by detailed explanations and discussions on selected approaches, are presented for the other four areas covered in this section.

4.2.2.2 Ground Facilities

In addition to the processing of WP-01 elements, the ground processing facilities are also addressed for (1) capability, (2) availability and (3) processing requirements, policies, and procedures. The operational plan presented in this appendix covers the integration of Space Station assembly, IOC, and growth support requirements on the ground processing facilities. The current KSC support facilities, such as the NSTS facilities, OPF, etc, are discussed along with options of expanding existing facilities and/or providing additional facilities to support Space Station required operations. Figure 4.2.2.2-1 illustrates the general approach while Table 4.2.2.2-1 examines more specific issues and requirements. The plan then matches program requirements with facility capabilities and proposes methods and procedures for accomplishing the program objectives and goals.

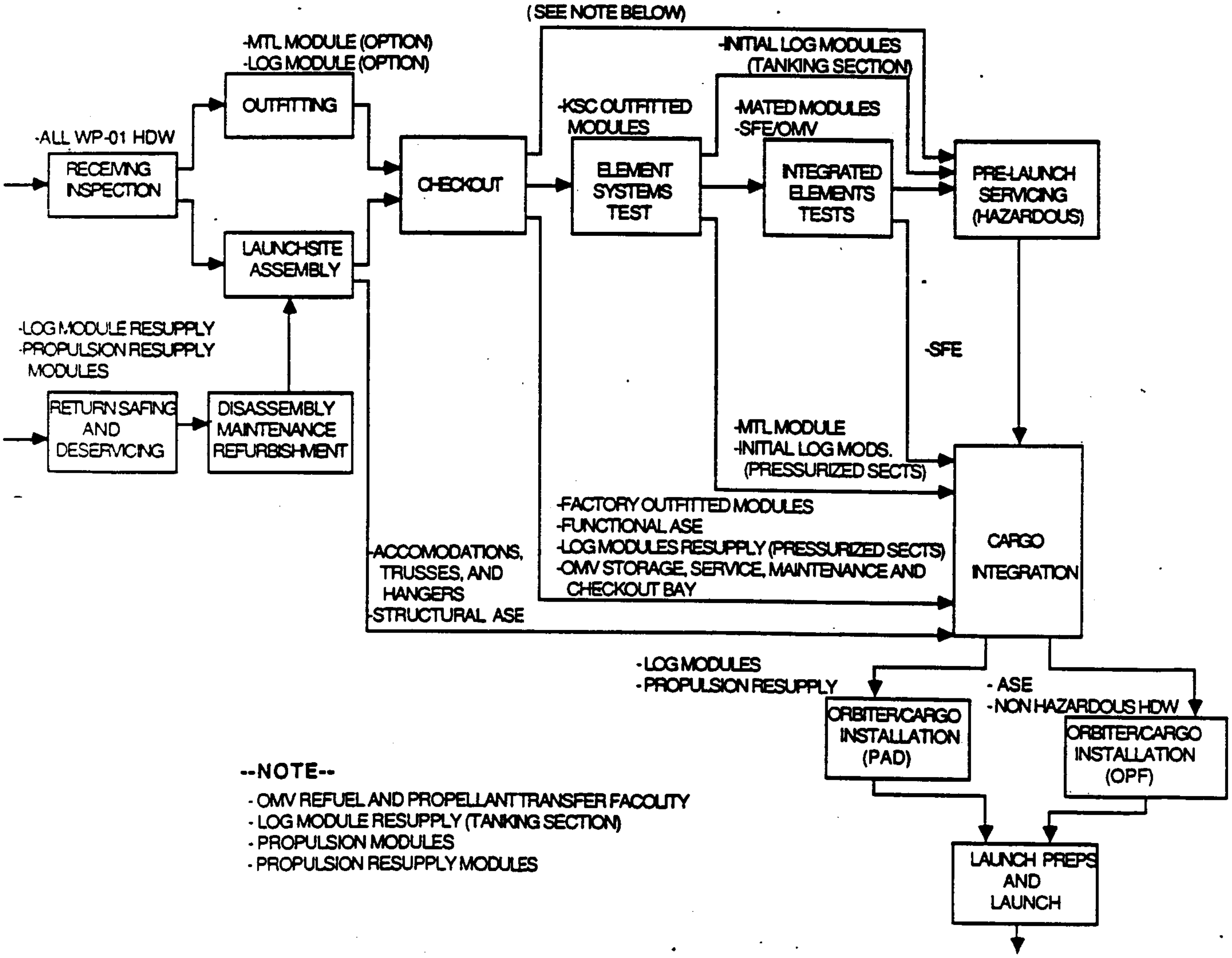


FIGURE 4.2.2-1 LAUNCHSITE OPERATIONS FLOW

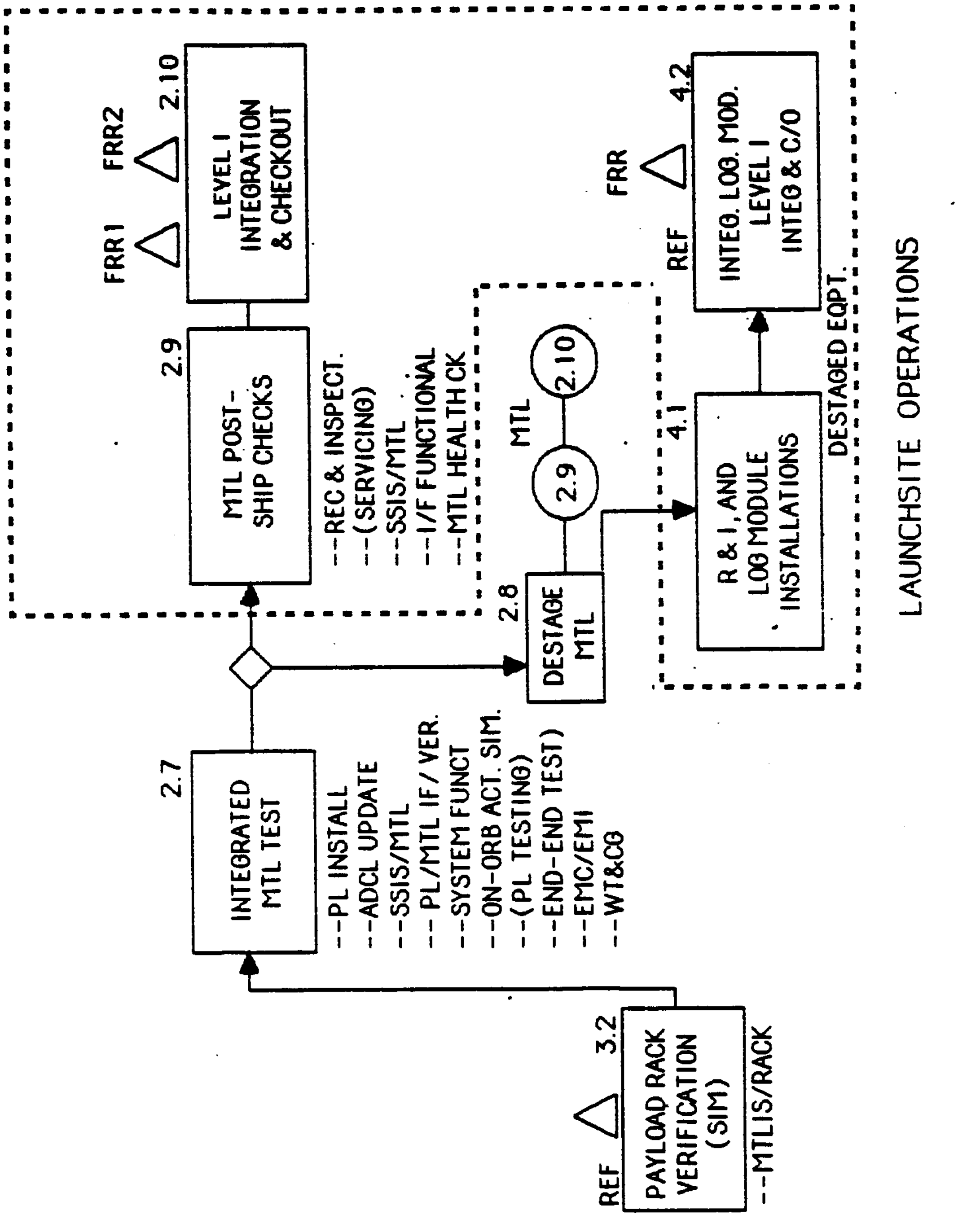


FIGURE 4.2.2.1-1 PRELIMINARY TOP LEVEL FUNCTIONAL FLOW

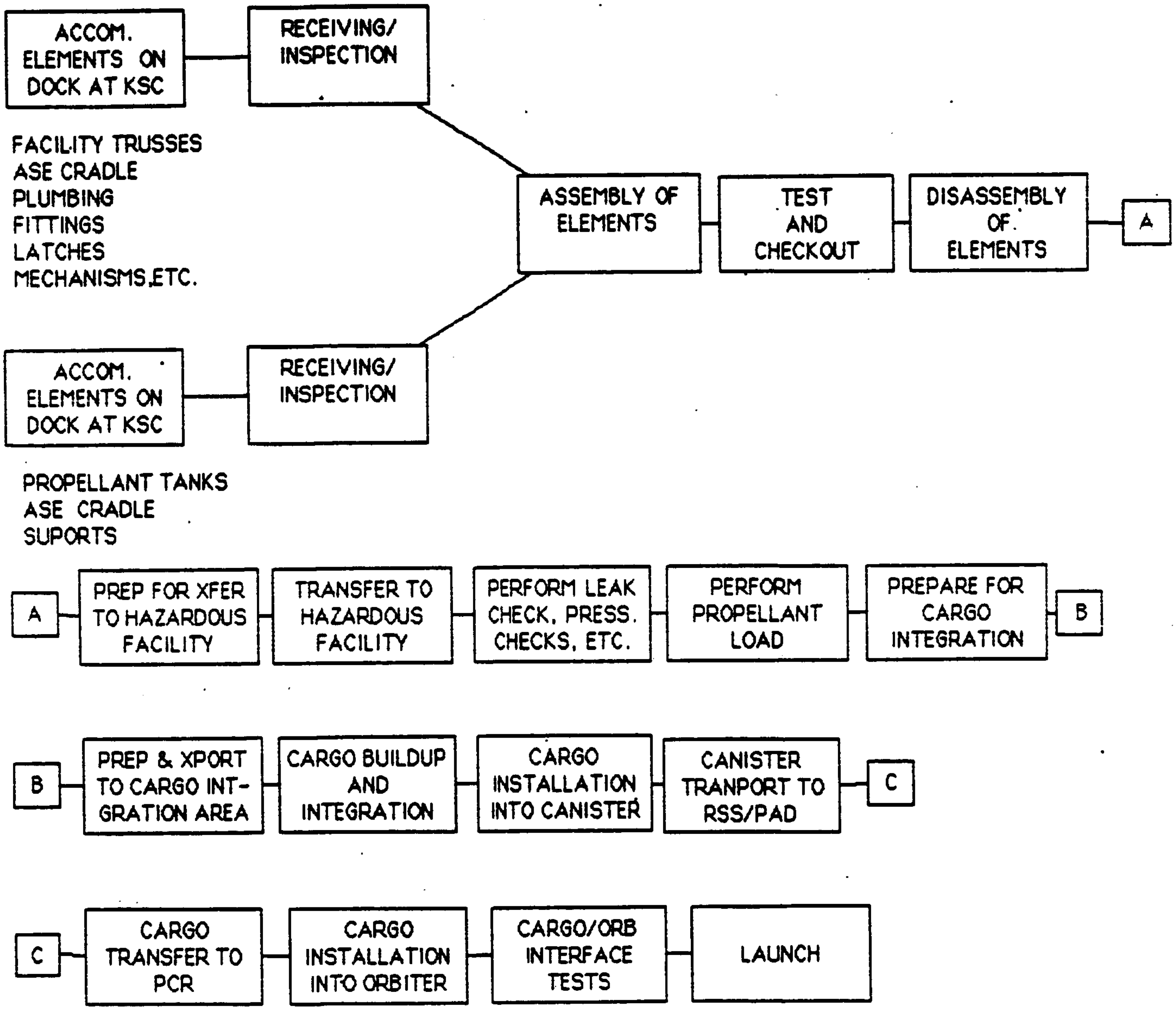
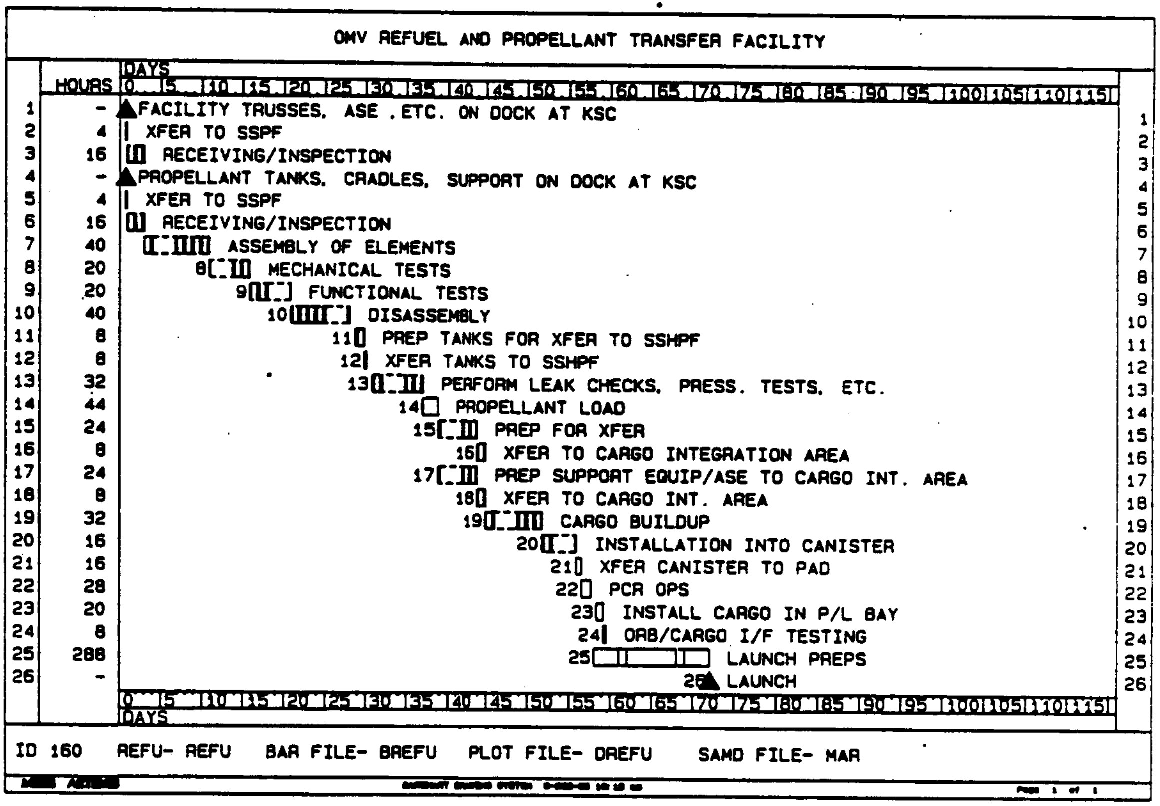


FIGURE 4.2.2.1-2 PRELIMINARY OMV REFUEL AND PROPELLANT TRANSFER FACILITY FUNCTIONAL FLOW

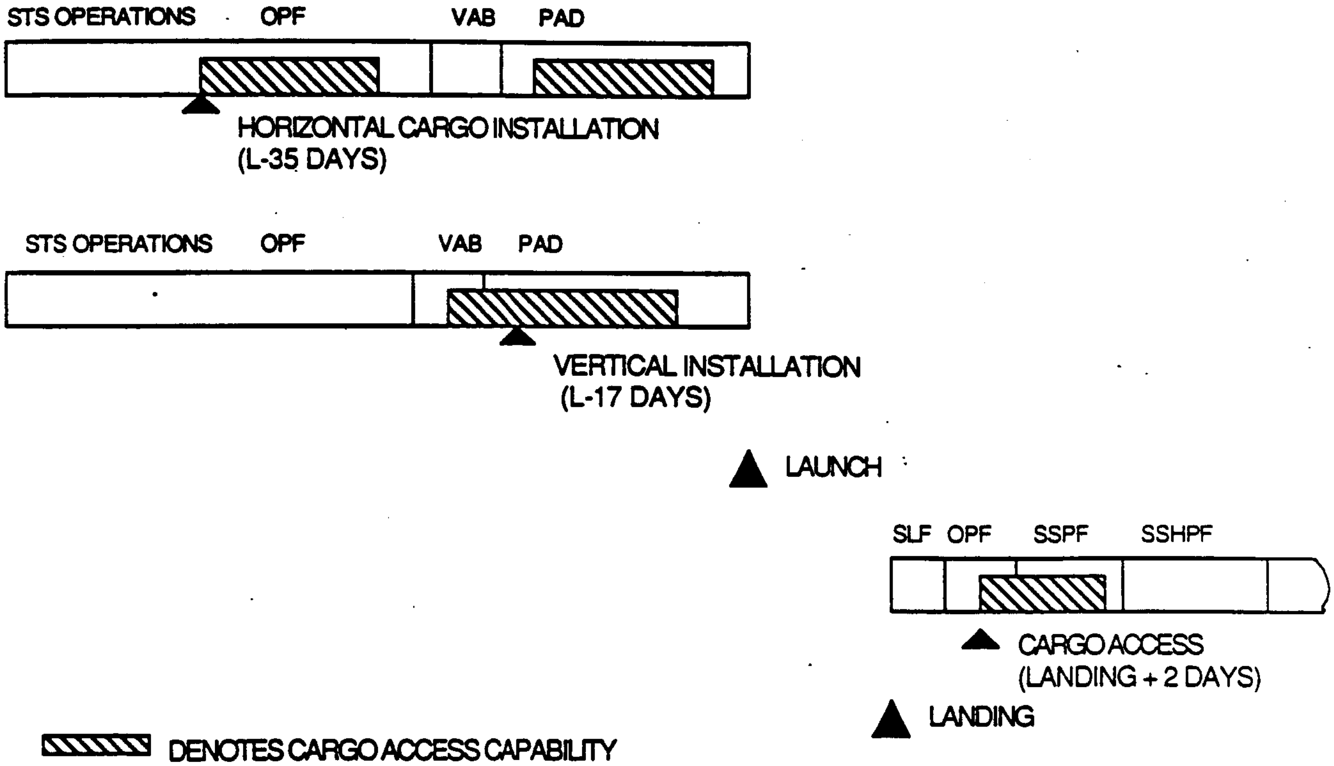


OMV REFUEL AND PROPELLANT TRANSFER FACILITY

	HOURS	
1	-	FACILITY TRUSSES, ASE, ETC. ON DOCK AT KSC
2	4	XFER TO SSPF
3	16	RECEIVING/INSPECTION
4	-	PROPELLANT TANKS, CRADLES, SUPPORT ON DOCK AT KSC
5	4	XFER TO SSPF
6	16	RECEIVING/INSPECTION
7	40	ASSEMBLY OF ELEMENTS
8	20	MECHANICAL TESTS
9	20	FUNCTIONAL TESTS
10	40	DISASSEMBLY
11	8	PREP TANKS FOR XFER TO SSHPF
12	8	XFER TANKS TO SSHPF
13	32	PERFORM LEAK CHECKS, PRESS. TESTS, ETC.
14	44	PROPELLANT LOAD
15	24	PREP FOR XFER
16	8	XFER TO CARGO INTEGRATION AREA
17	24	PREP SUPPORT EQUIP/ASE TO CARGO INT. AREA
18	8	XFER TO CARGO INT. AREA
19	32	CARGO BUILDUP
20	16	INSTALLATION INTO CANISTER
21	16	XFER CANISTER TO PAD
22	28	PCR OPS
23	20	INSTALL CARGO IN P/L BAY
24	8	ORB/CARGO I/F TESTING
25	288	LAUNCH PREPS
26	-	LAUNCH

ID 160 REFU- REFU BAR FILE- BREFU PLOT FILE- DREFU SAMD FILE- MAR

FIGURE 4.2.2.1-3 OMV REFUEL AND PROPELLANT TRANSFER FACILITY PROCESSING TIMELINE (PRELIMINARY)



▨ DENOTES CARGO ACCESS CAPABILITY

NOTES: 1) FOR VERTICAL CARGO INSTALLATION, CARGO DELIVERED TO PAD TWO DAYS PRIOR TO ORBITER ARRIVAL.
2) PAYLOAD BAY DOORS ARE CLOSED A MINIMUM OF TWO DAYS PRIOR TO LAUNCH.

FIGURE 4.2.2.2-1 STS INTEGRATED OPERATIONS

TABLE 4.2.2.2-1 LOGISTICS MODULE FACILITY REQUIREMENTS

FACILITY REQUIREMENTS	NON-HAZARDOUS STANDALONE PROCESSING	HAZARDOUS STANDALONE PROCESSING	CARGO INTEGRATION CANISTER INSTALLATION
WORK AREA	5400 SQ. FT.	2700 SQ. FT.	3200 SQ. FT.
CEILING HEIGHT	30 FT.	30 FT.	60 FT.
STORAGE SPACE	TBD	TBD	N/A
POWER	28 VDC 120/480 VAC 3PH	28 VDC 120/480 VAC 3 PH	28 VDC 120/480 VAC 3 PH
DOOR DIMENSION	30' W x 25' H	30' W x 25' H	40'W x 35'H
DATA MGMT SYS.	YES	NO	NO
ENVIRONMENTAL CONTROL	CLEANLINESS 100K TEMP 86 - 77 F HUMIDITY 45+/-5 RH.	CLEANLINESS 100K TEMP 68 - 77 F HUMIDITY 45 +/-5 RH	CLEANILESS 100K TEMP 68-77 F HUMIDITY 45 +/-5 RH
COMMODITIES H20,AIR CO2,GN2,GHE	 YES YES	 YES YES	 YES YES
SAFETY FEATURES	N/A	HAZ GAS DETECTORS (MMH,N2O4,N2H4) WATER DELUGE	HZA GAS DETECTORS (MMH, N2O4,N2H4) WATER DELUGE
CRANE CAPACITY	20 TON	20 TON	20 TON

4.3 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 4.3-1 illustrates the Space Station operations support system architecture presented in this appendix/operations plan.

4.3.1 Assembly Phase

This section of the appendix discusses the process for assembling the Space Station. The areas addressed are:

a. Assembly Altitude Profile
b. Launch Sequences
c. Checkout and Activation of SS Elements
d. Crew Size Requirements
e. Automation Applications

In addition, as an operations concept document, it was important to note that most of the initial assembly activities for the Space Station will be unique and performed for the first time in space. In order to accomplish the assembly of the Space Station, an integrated and consistently changing approach has to be adopted. That is, the assembly operations will initially be based from the Shuttle Orbiter and later from the available Space Station elements in conjunction with the Orbiter. Ground control will be the primary management authority for the assembly process, providing most of the monitoring, checkout, verification, and technical guidance. The on-orbit crew will provide control of the assembly process. These functions differ significantly from previous manned space activities and the post assembly operations described in this operations plan.

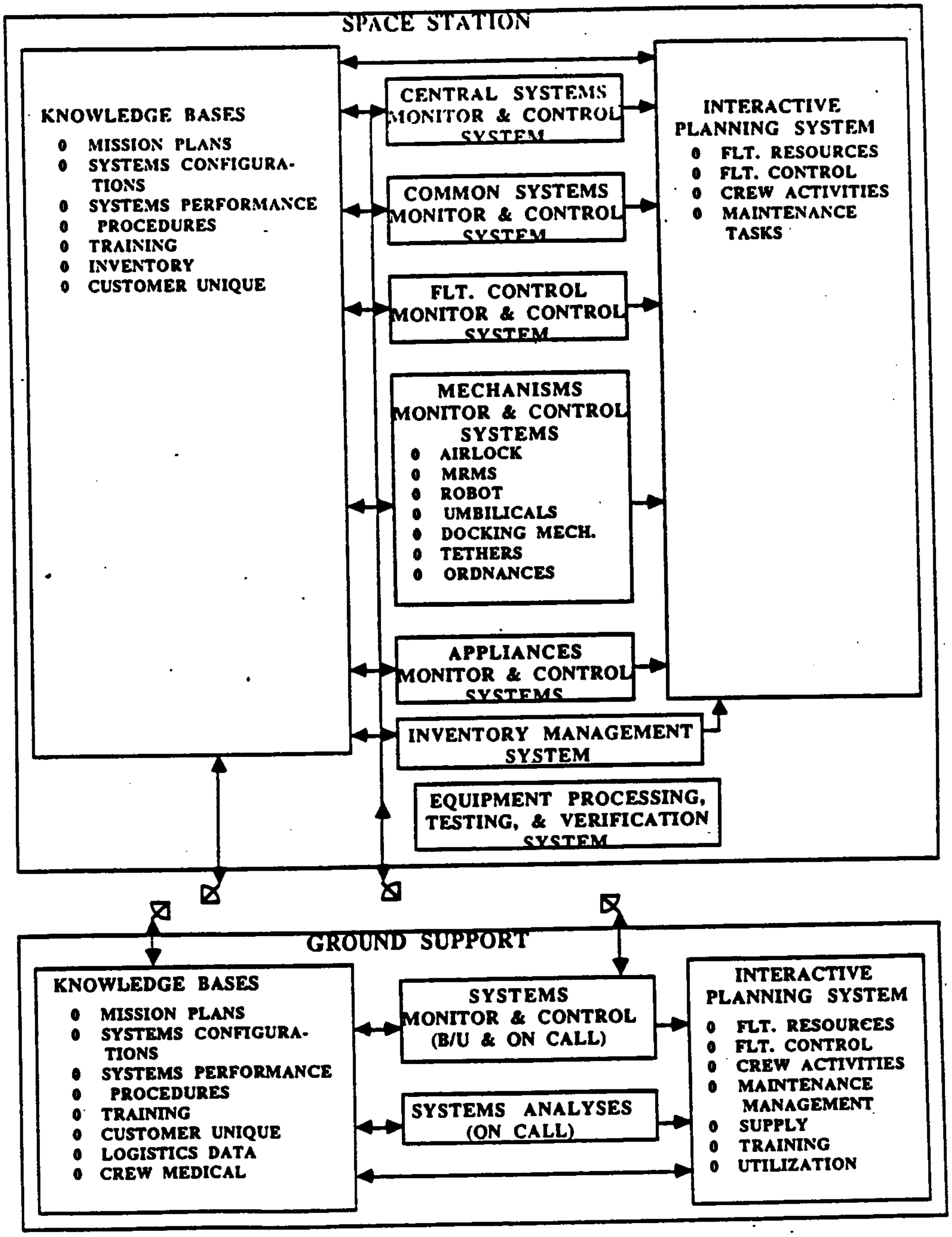


FIGURE 4.3-1 SPACE STATION OPERATIONS SUPPORT SYSTEMS CONCEPT

4.3.2 IOC Phase

A majority of the appendix was devoted to IOC Operations, although both man-tended and growth operations were included in the general discussions. As the baseline for presenting an IOC concept and approach to developing more detailed operations plans, the Martin Marietta RUR-2 Space Station Configuration illustrated in Figure 4.3.2-1 was used.

The primary areas addressed for operational development are listed in Table 4.3.2-1.

TABLE 4.3.2-1 SPACE STATION OPERATIONAL CONCEPTS

SUBJECT	ITEM
1. Ground Support	1. Ground Support Complex 2. System Monitoring 3. Flight Design 4. Operations Planning 5. Operations Management 6. Space/Ground Systems Interfaces 7. SSP Interfaces and Operations 8. Customer/User Operations
2. On-Orbit Operations	1. Station Crew 2. Operations Planning 3. On-Orbit Management 4. Systems Management 5. Maintenance 6. IVA/EVA Operations 7. Proximity Operations 8. Payload/User Operations 9. Contingency Operations 10. Systems/Elements Interfaces 11. Automation & Robotics 12. Flight Control
3. Man-Tended	1. See Above
4. Growth	1. See Above
5. Program Phase Deltas	1. See Above

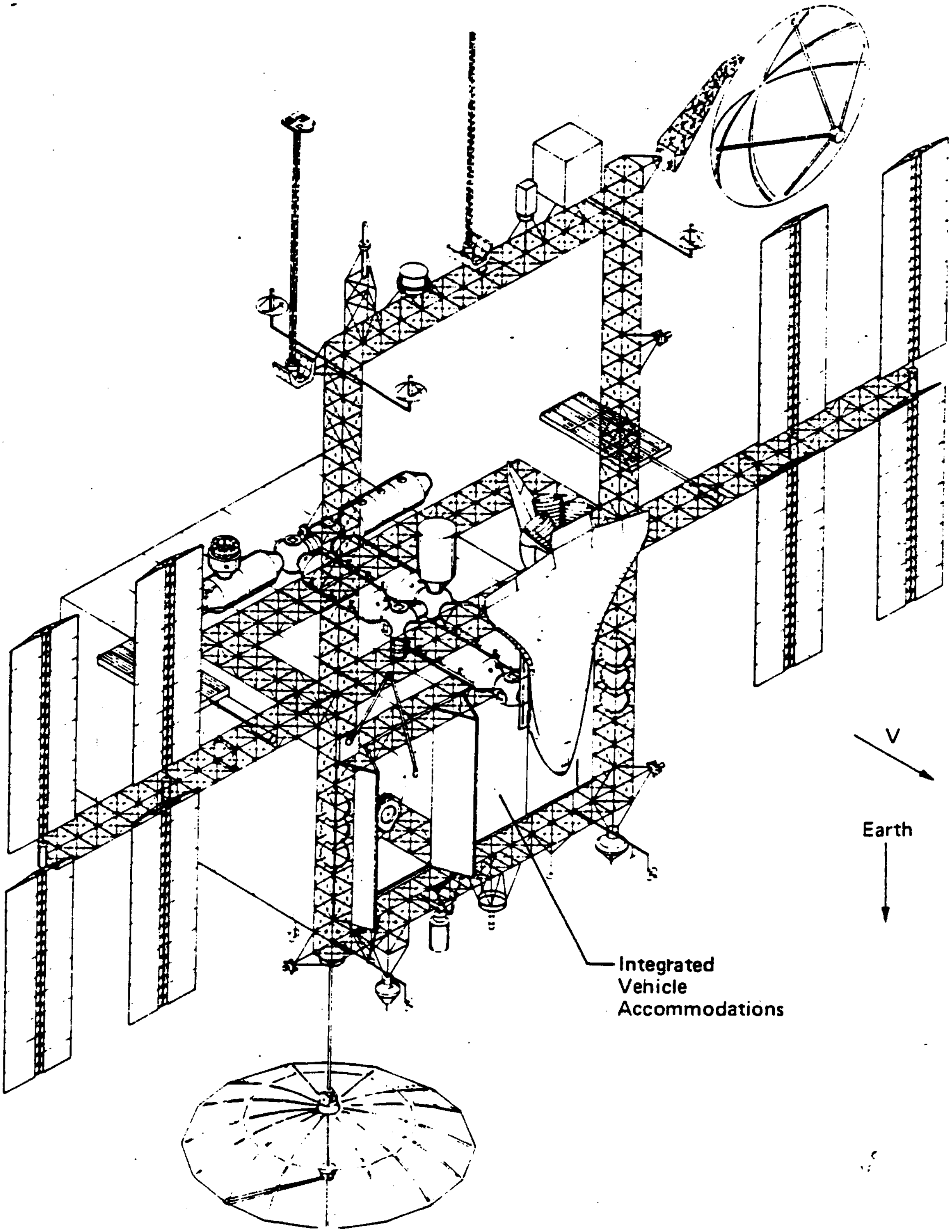


FIGURE 4.3.2-1 IOC SPACE STATION CONCEPT

4.3.2.1 Ground Support Operations

This section provides a conceptual description of the operational functions to be performed by the ground elements, in support of the Space Station, during the IOC timeframe. Emphasis is placed on the roles and responsibilities, interfaces, and ground support daily activities. The concept was developed in conjunction with the section on on-orbit operations to ensure consistent conceptual definition.

The concept includes the following features: a streamlined approach to customer payload operations and extensive use of software routines to reduce ground crew workload.

The scope of ground support operations will change as the Space Station progresses through each program phase.

4.3.2.1.1 Program Phases - During each phase of the Space Station development (man-tended to growth), station functions will be reallocated between the space and ground segments. The reallocation process will assign a given function to that operational element which provides the most efficient support during that specific development phase. It is expected that single functions will be transferred between the ground and space segments several times during the program lifetime.

The ground operations staffing levels will shift from a ground support intensive effort during the man-tended phase to a system where minimal ground support is required during the growth phase.

a. Man-tended

During the man-tended phase, the ground support system will be performing all of the station system monitoring functions. The level of ground support personnel performing these functions will be high due to the lack of maturity of expert systems and the nature of the tasks. The functional allocation indicates a high level of ground control and monitoring functions and a limited number of similar functions performed on the Space Station during the man-tended era.

The Space Station configuration for the man-tended phase is illustrated in Figure 4.3.2.1-1.

b. Growth

The growth version of the Space Station will require less real time ground support. During this phase, most system monitoring functions will be automated at either the ground or on the station. The ground support will consist of a small crew providing assistance in contingency situations and

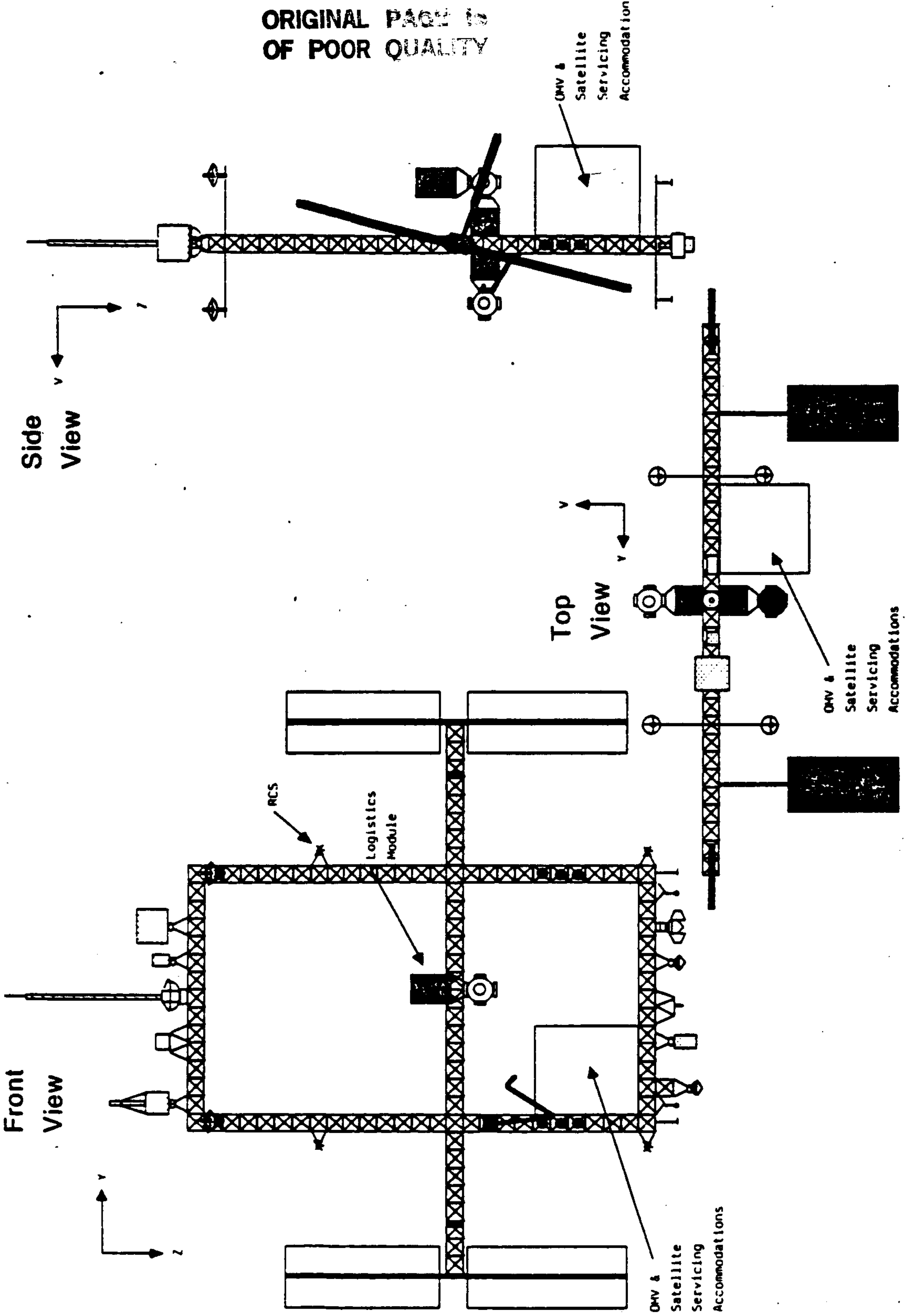


FIGURE 4.3.2.1-1 SPACE STATION MAN-TENDED OPTION CONCEPT

performing long range planning and trend analysis on the subsystems and automated software package operation. Figure 4.3.2.1-2 shows the conceptual design used for operational concept discussions during the Space Station growth phase.

4.3.2.2 On-Orbit Operations

This section provides a description of the IOC operational functions to be performed by the flight crew, hardware and software usage, and the Space Station subsystems operation. Emphasis is placed on the system interfaces and crew activities that take place within the architecture established by Martin Marietta. The concept presented also includes extensive use of software routines for reducing the crew workload, cross training requirements for all crew members, and the effects that EVA activities have on the availability of crew time.

As in the above summary of the ground operations, the scope of on-orbit operations will change as the Space Station matures and goes through each of its program phases.

4.4 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 4.4-1 provides an overview of the approach Martin Marietta has taken in the Operations Plan (DR-07).

4.4.1 Organizational Level Maintenance

Organizational level maintenance may be either preventative or scheduled in nature and may consist of either corrective or unscheduled maintenance. Organizational level maintenance shall be performed either on-orbit and/or at a ground based station, which ever facility is necessary to accomplish the task.

a. On-orbit organizational maintenance consists of scheduled orbital replaceable unit (ORU) removal/replacement action to prevent a failure, or as a result from an unscheduled failure which has been fault detected and fault isolated by a built in test of Space Station systems. On-orbit maintenance is limited to the removal and replacement of ORUs, the associated inspection, and the test and verification of all affected systems.

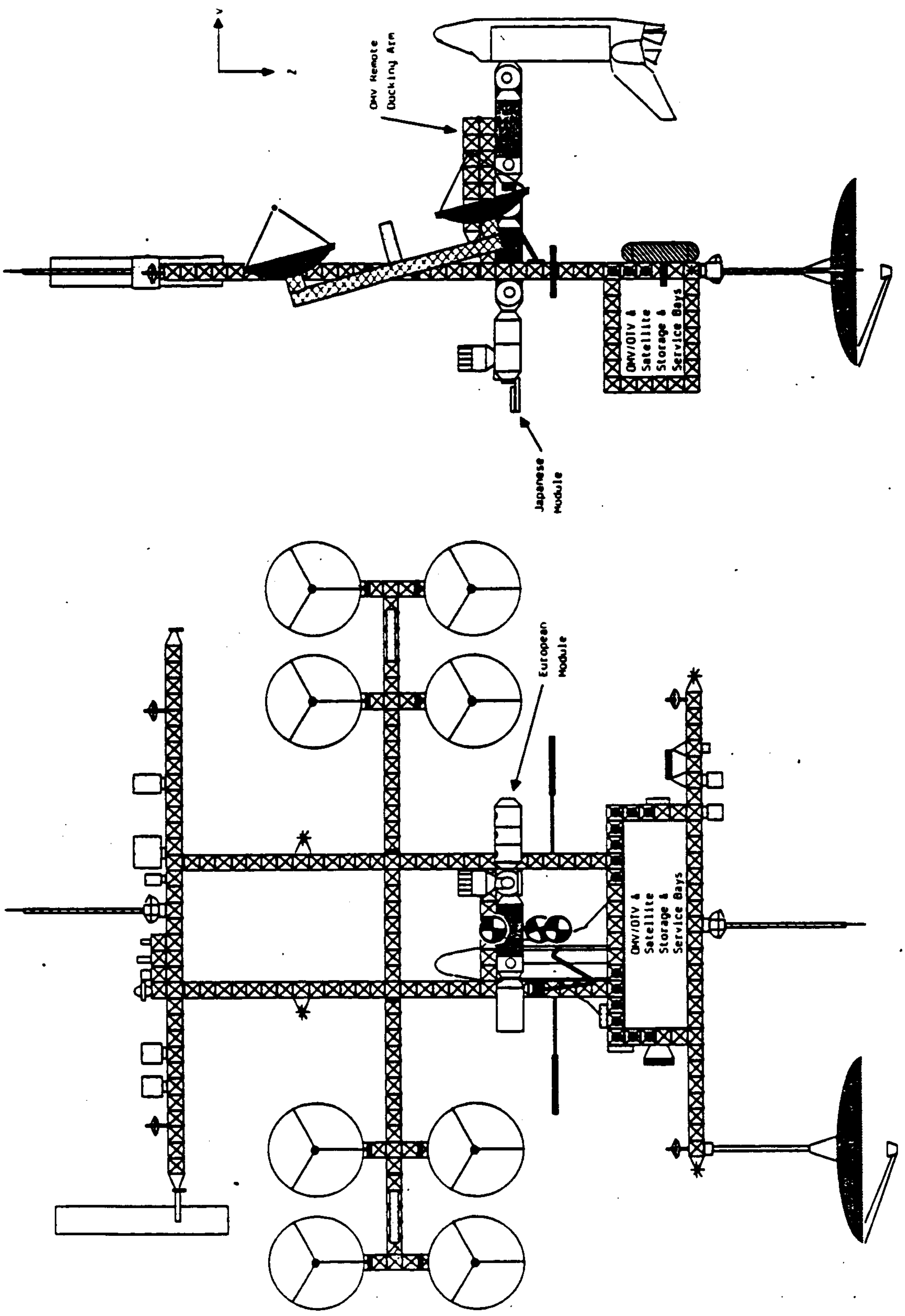


FIGURE 4.3.2.1-2 GROWTH VERSION CONCEPT FOR THE SPACE STATION

b. Ground-based organization maintenance consists of all organizational level defined maintenance as indicated in Table 4.4-1.

The on-orbit maintenance plan outlines the maintenance concept for accomplishing all levels of maintenance which can be performed on-orbit. This includes the removal and replacement of ORUs, and on-orbit servicing of Space Station systems. Table 4.4.4-1 indicates the major maintenance activities and other considerations covered in this section.

4.4.2 Intermediate Level Maintenance

Intermediate level maintenance consists of on-orbit limited-corrective maintenance functions and ground based corrective maintenance functions.

4.4.2.1 On-Orbit

On-orbit intermediate level maintenance is a proposed growth option not currently part of the maintenance plan. This option would provide for limited corrective maintenance governed by the available skills, test equipment and manpower. These activities will be conducted by the flight crew. The current on-orbit intermediate maintenance activities consist of off-line fault verification, fault isolation, verification of repair, and calibration as required.

4.4.2.2 Ground-Based

The maintenance activities at the intermediate level consist of fault verification and isolation of subassemblies, installation of hardware/software modifications, ORU repair, calibration, functional verification, hardware disposition, and failure analysis support.

4.4.3 Depot Level Maintenance

Depot level maintenance consists of only ground based corrective maintenance of ORUs by an off-line government, contractor or vendor shop. Trained and skilled repair technicians will conduct the ORU repair. The maintenance activities at this level will consist of fault verification and isolation at component levels, installation of hardware and software modifications, ORU repair calibrations, functional verification, assets disposition, manufacture of components and assemblies, overhaul/rebuild of ORUs, and failure analysis support.

TABLE 4.4-1 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

TABLE 4.4.4-1 ON-ORBIT MAINTENANCE CONSIDERATIONS

Type
Preventive Maintenance
Corrective Maintenance
Maintenance Criticality Levels (C-1 through C-3b)
Maintenance Documentation - Levels A through C
International Maintenance Interface
Procedures and Data Development
Maintainability, Maintenance, and Operational Requirements

4.4.4 On-Orbit Maintenance Plan

This section of the document (Appendix C) describes the details of the on-orbit maintenance plan and how the several levels of maintenance are achieved.

This plan addresses each of the following areas in order to accomplish on-orbit Space Station maintenance with the limited manpower resources available, there is a need for:

a. A high degree of maintainability to be built into the design for ease of access and removal tasks associated with the organizational level of repair.

b. A high degree of design for reliability (system and component redundancy coupled with design for operation in degraded modes), to allow for deferral of emergent maintenance tasks as necessary to gain maximum time-saving benefit from maintenance task "blocking" (minimize discrete "make ready" and "put away" times), as well as easing on-orbit spares requirements.

c. A high degree of commonality across Space Station elements to minimize logistics burdens associated with procedure items, tools and test equipment, and spares allowances carried, as well as maintenance related task familiarity/training times.

d. Optimal use of automation and robotics to support status monitoring fault detection and isolation, system reconfiguration, and maintenance task accomplishment.

e. A highly tailored logistics delivery system, which provides configuration specific logistics resources, and which accounts for planned growth (and associated alterations/modifications) of the Space Station platform capability.

4.4.5 Flight Operations

This section addresses the specific approaches, and activities necessary to carry out maintenance tasks, including crew and systems support during each Space Station development phase.

To support flight operations, the design approach for on-orbit maintenance calls for personnel to remove/replace ORU's by IOC. Personnel will also perform simple preventive maintenance tasks such as cleaning and servicing, which do not require comprehensive specialized diagnostic/system troubleshooting or maintenance disassembly. Capability for contingency repair will be provided at IOC. Tools, test equipment and procedures will be accessible on-orbit along with a two-way audio and video communications link for ground-based assistance.

4.4.5.1 Onboard Diagnostics Operational State and Maintenance Management Data Systems (MMDS)

The MMDS is an example of the subjects discussed in this section of the maintenance plan. The design of an MMDS will include and support both on-orbit and ground-based Space Station elements. Functional components of the on-orbit system defined include:

a. A Performance Monitoring Subsystem
b. A Maintenance Task Requirements ID and Scheduler Subsystem
c. A Maintenance Task Accomplishment/Maintainer Aids Subsystem
d. A Maintenance Task Accomplishment Logging Subsystem

See Figure 4.4.5.1-1

4.4.6 Logistics Operational Planning

In support of on-orbit maintenance, ground operations will integrate planning and scheduling of maintenance for each successive mission cycle (including integration of maintenance related resource requirements into resupply mission manifesting), monitor on-orbit system configuration and maintenance schedule status, up-link updates and/or additions to electronic media items (procedures and/or s/w mods) as required, and finally, standby to MSFC and render system engineering and/or maintenance/diagnostic assists/direction as required. Ground based maintenance support operations will be conducted from a ground based maintenance management support position and an operational support facility. The operational support facility will contain the necessary automated data processing (ADP), hot test bed, and mockup resources required to conduct daily operations support, mission planning, and database/system integrity and update tasks, as well as providing for accomplishment of contingency tasks related to real-time, two-way, audio-video comm-lined ground-based assists. A comprehensive maintenance data base (MDB) will be maintained by the ground based maintenance support operations. The MDB will be the primary planning tool used in the maintenance support operation. See Figure 4.4.6-1.

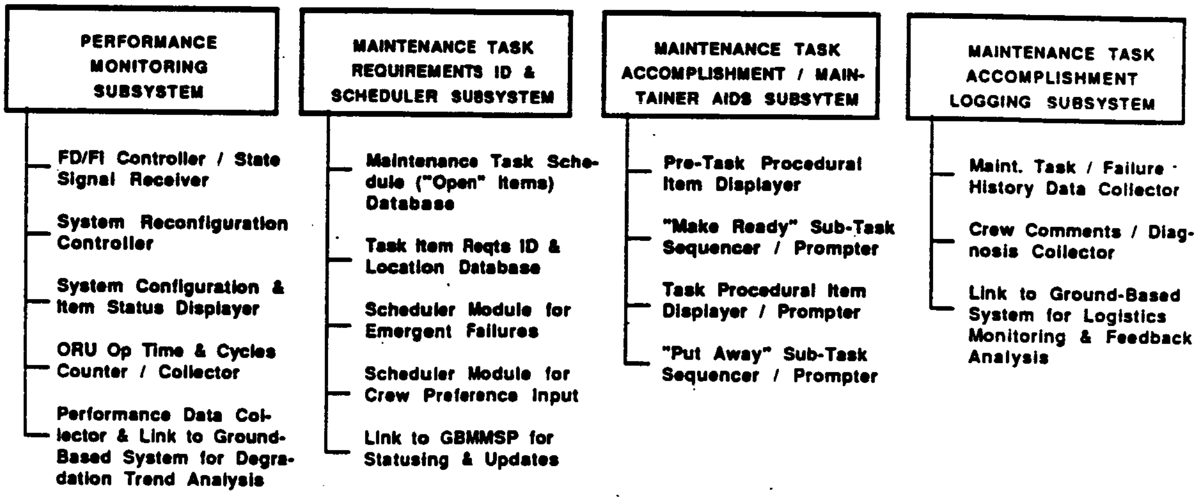


FIGURE 4.4.5.1-1 SPACE STATION MAINTENANCE MANAGEMENT DATA SYSTEM

4.4.6.1 Mission Planning

In order to integrate maintenance activities into the mission timelines, the ground based operations support facility will be responsible for development of a scheduled maintenance plan for each mission cycle. The scheduled maintenance plan will be broken into lower level schedule for task accomplishment during periods when both crews (the off-going and on-coming crews) are available, and a task plan for the remainder of the mission cycle. The schedule plan addresses a) maintenance not accomplished during the current cycle; b) maintenance deferred because of lack of availability on-orbit of required resources; c) alteration/modification installation tasks; d) calibration tasks which require shuttle provided artifact standards; e) planned or preventive maintenance tasks associated with alterations/modifications scheduled for installation tasks; d) calibration tasks which require shuttle provided artifact standards; e) planned or preventive maintenance tasks associated with alterations/modifications scheduled for installation; f) planned "remove-replace prior to failure" maintenance tasks; and g) planned or preventive maintenance tasks already scheduled relative to the on-orbit in-line configuration. The maintenance schedule plan also addresses required maintenance of any items in storage. Mission planning resources integrate maintenance schedule planning with procedural item update actions, and resupply mission manifesting (including statusing of pre-launch performance and installation verification testing status) as required to assure that resources will be available for accomplishment of both forecast failures and scheduled activities. Updates to the on-orbit schedule and resource requirements ID and location database will be uploaded to the on-orbit system in time to support task evolutions during resupply mission periods with the NSTS Orbiter berthed to the Space Station.

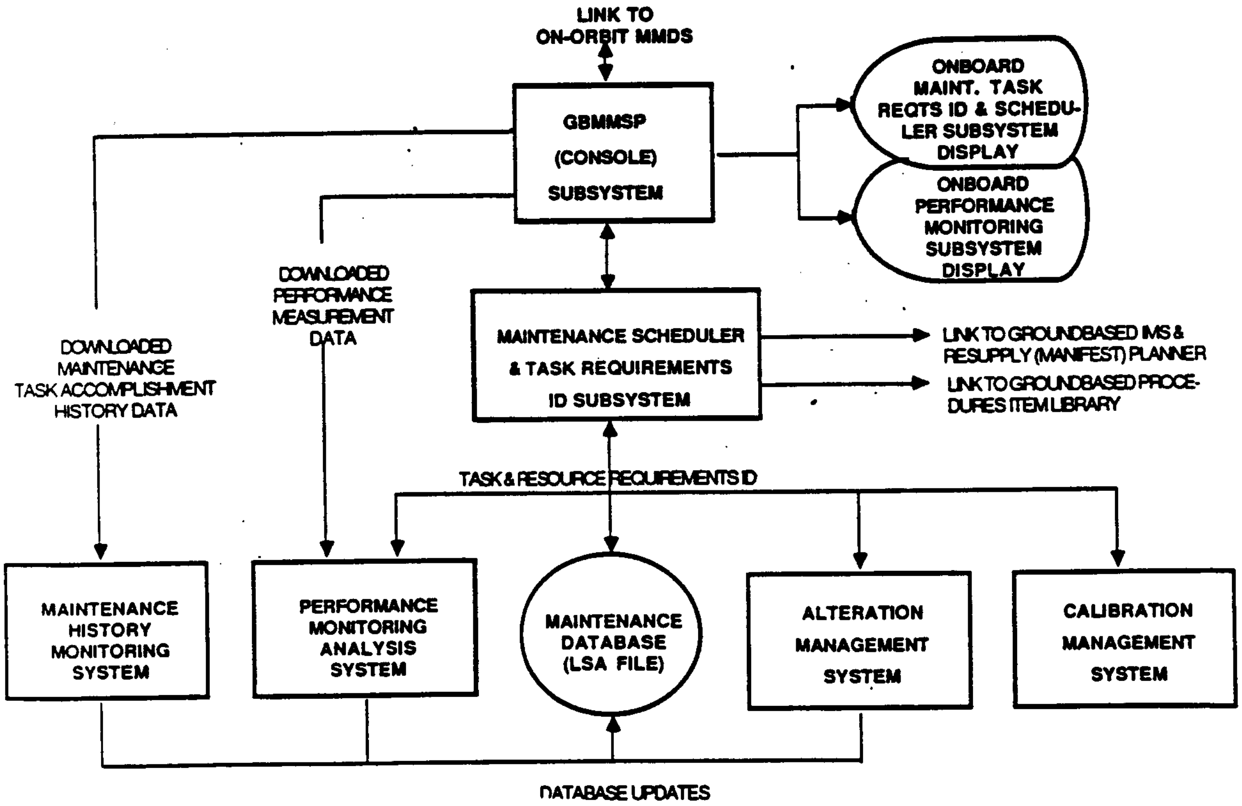


FIGURE 4.4.6-1 GROUND-BASED MAINTENANCE MANAGEMENT DATA SYSTEM

4.4.6.2 Maintenance Data Base (MDB)

Another critical element in the planning and implementation of the maintenance program is the maintenance data base (MDB). The MDB will be a life-cycle logistic support analysis (LSA) type database, maintained and updated over the life of the program. The MDB will be used to link Space Station configuration item identification to maintenance task requirements for all levels of maintenance. The MDB will also be used to link exact support resource requirements and expected periodicity statistics to each discrete task.

Data for the maintenance data base will initially be developed using an LSA process which would include: links to FMEA and reliability program outputs, maintenance engineering analysis, ORLA, systems requirements analysis, links to provisioning processes, aggregations and updates for tools and test equipment, and links back to design. Other data to be maintained in the MDB will include: a current application data base for ORUs by serial number, an ORU pedigree/maintenance/failure/degradation history data base also keyed to each ORU (by serial number); and a failure/degradation threshold value database for each in-line sensor. MDB maintenance will be linked to the configuration management program for update/change control of data in the file to reflect product engineering evolutions, alterations/modifications program planning and status, and procedural item and/or other logistic resource item changes resulting from operational feedback and/or maintenance and logistics history monitoring.

4.4.7 Procedures and Data Development

The next section of this appendix covers the role, applications, and requirements for developing maintenance procedures and data.

The on-orbit maintenance procedures and data development will be determined by implementation of the maintainability design guide (MDG) (TBD document) by all WP1 hardware and software design disciplines. Compliance with the design requirements of the MDG will ensure system and specific ORU maintainability features are incorporated early in the design process. The MDG requirements implemented by the design activities will determine the approach in development of maintenance procedures and data to support the Space Station both on-orbit and on the ground.

All task procedures and data will be determined as part of the LSA process and developed and stored in an electronic data format that can be transferred between system hardware suppliers, users, NASA centers, and between the on-orbit and ground Space Station activities.

Engineering data will be developed during each phase of the Space Station program. This data will be used in the development of task procedures and data to support program requirements. The program phases in which data will be developed are: a) definition; b) design/full scale development; c) production; and d) operations.

4.4.7.1 Engineering Design

The logistic support analysis (LSA) as outlined in the level B Logistics Support Analysis Plan will be performed during the design/full scale development phase to complement the basic system engineering design and development process in achieving the life-cycle cost (LCC) objectives. The results of the LSA shall be used in establishing and implementing the maintenance program. LSA will result in: a) establishing criteria for system design; b) influencing design alternatives; c) identifying and provisioning of logistic support elements; and d) assessment of system support capability.

The following areas are addressed, in order:

a. Mean Time Between Failures (MTBF)
b. Failure Mode and Effects Analysis (FMEA)
c. Degradation Window
d. System Interface and Specifications
e. Orbital Replacement Unit (ORU) Repair Definition
f. Diagnostic Procedures and Specifications

4.4.7.2 Procedures Demonstration

Procedures for ORU maintenance activity will be demonstrated in a realistic environment using protoflight-type subsystems and progressing from ground facilities to zero-g environments where possible. The following approaches are examples of environments to be used in demonstrating the procedures: a) test beds; b) zero-g aircraft; c) water tank; d) shuttle flight.

4.4.7.2.1 Verification

Procedures and data used for ORU maintenance and repair will be verified as outlined in the ILSP Technical Data and Documentation Plan by demonstration or simulation as applicable by NASA representatives. The verification team, comprised of NASA representatives, would demonstrate or simulate the procedures/data as appropriate, with the assistance of the respective equipment suppliers.

4.4.7.2.2 Verified Procedures and Data - Identification data relative to new/updated procedures and data will be electronically stored in the maintenance management data system (MMDS) subsequent to verification.

4.4.7.3 Documentation

The ILSP Technical Data and Documentation Plan establishes the requirements for development, implementation, and maintenance of the technical data and documentation required to support the Space Station on the ground and on-orbit. Technical data shall be prepared by many contractors and support subcontractors under the management of a designated integrator.

Documentation synergism shall be accomplished by using the best mix of approaches for development, storage, retrieval, reproduction and usability in the Space Station's unique environment.

4.4.7.4 Other Maintenance Considerations

The balance of this appendix discusses Extravehicular Activity (EVA) maintenance, Software Maintenance, and Maintenance Procedures Implementation.

These sections cover the application of EVA tools, procedures, and techniques such as using the Manned Maneuvering Unit (MMU), Remote Manipulator System (RMS), and the Orbital Maneuvering Vehicle (OMV) to support EVA maintenance. Other subjects include:

a. Software maintenance procedures and requirements for all on-board and ground operations via a consolidated software integration test facility.

b. Requirements for implementation and validation of maintenance and maintainability procedures.

c. The use of test facilities to validate on-board maintenance operation procedures.

d. Use of the Automatic Maintenance Management System (AMMS)/Maintenance Management Data System (MMDS) in support of real-time operations.

4.5 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.

4.5.1 Organizational Relationships and Responsibilities

This section of the appendix will define and describe the logistics functional and organizational relationships necessary to plan, schedule, and measure the ILS program/project performance.

4.5.2 Logistics Engineering Analysis (LEA)

Logistics Engineering Analysis (LEA) is the planned series of tasks which will be performed to examine all elements of Space Station (SS) systems/subsystems. The process will determine the logistics support required to keep the SS system/subsystems operational for their primary mission. The process will also influence design to the extent that the primary and logistics support system will be provided at an economical cost. This section will cover the description, application, and management of the LEA process. Figure 4.5.2-1 illustrates an approach to this process.

The LEA discussion continues with an outline of the major sub-tasks required to establish and executing an effective LEA program. The areas to be covered will include:

a. Logistics Support Analysis Plan (LSAP)
b. The Process of Logistics Engineering Analysis
c. LEA Output Products
d. Optimum Repair Level Analysis (ORLA)

Figure 4.5.2-2 demonstrates the LEA process flow, which indicates the sequence of the above functions. The ORLA decision process is discussed separately and shown in Figure 4.5.2-3.

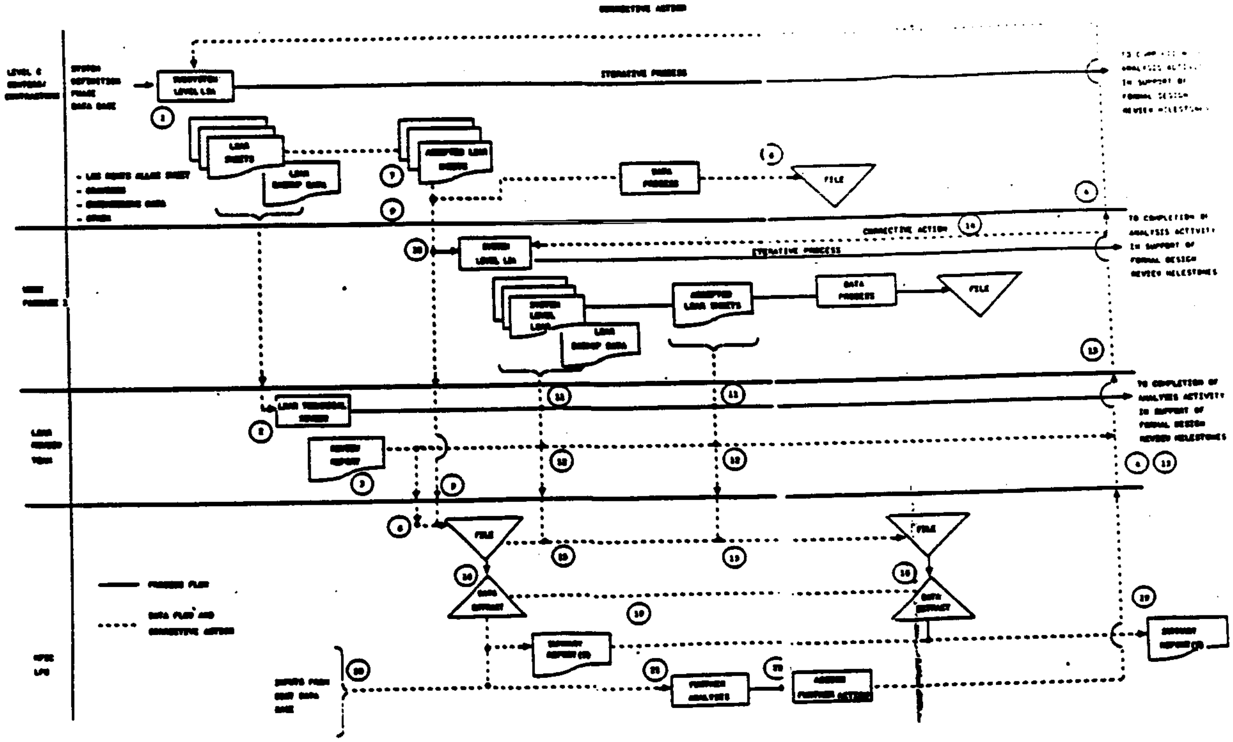


FIGURE 4.5.2-1 LEA INTEGRATION PROCESS OVERVIEW

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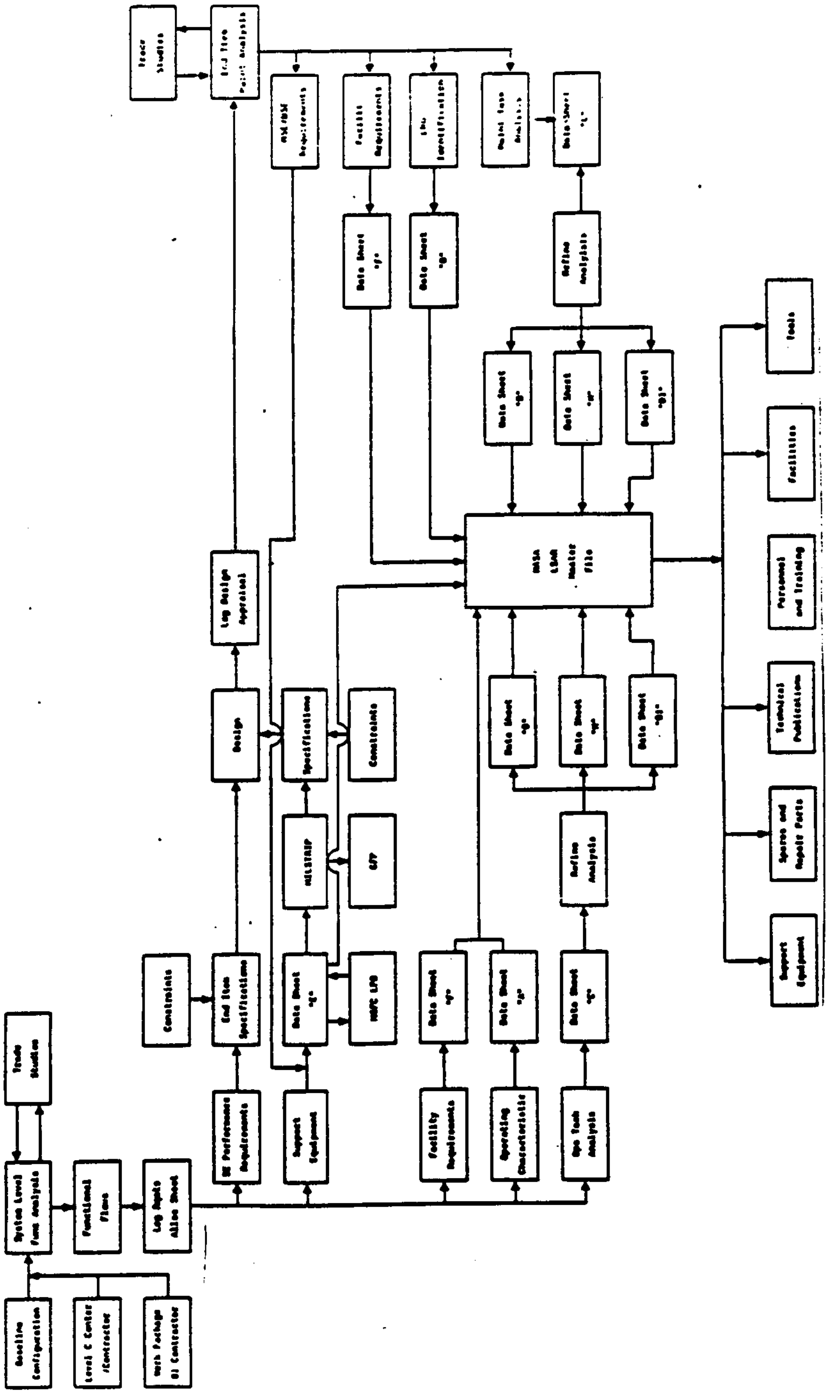

FIGURE 4.5.2-2 LEA PROCESS FLOW

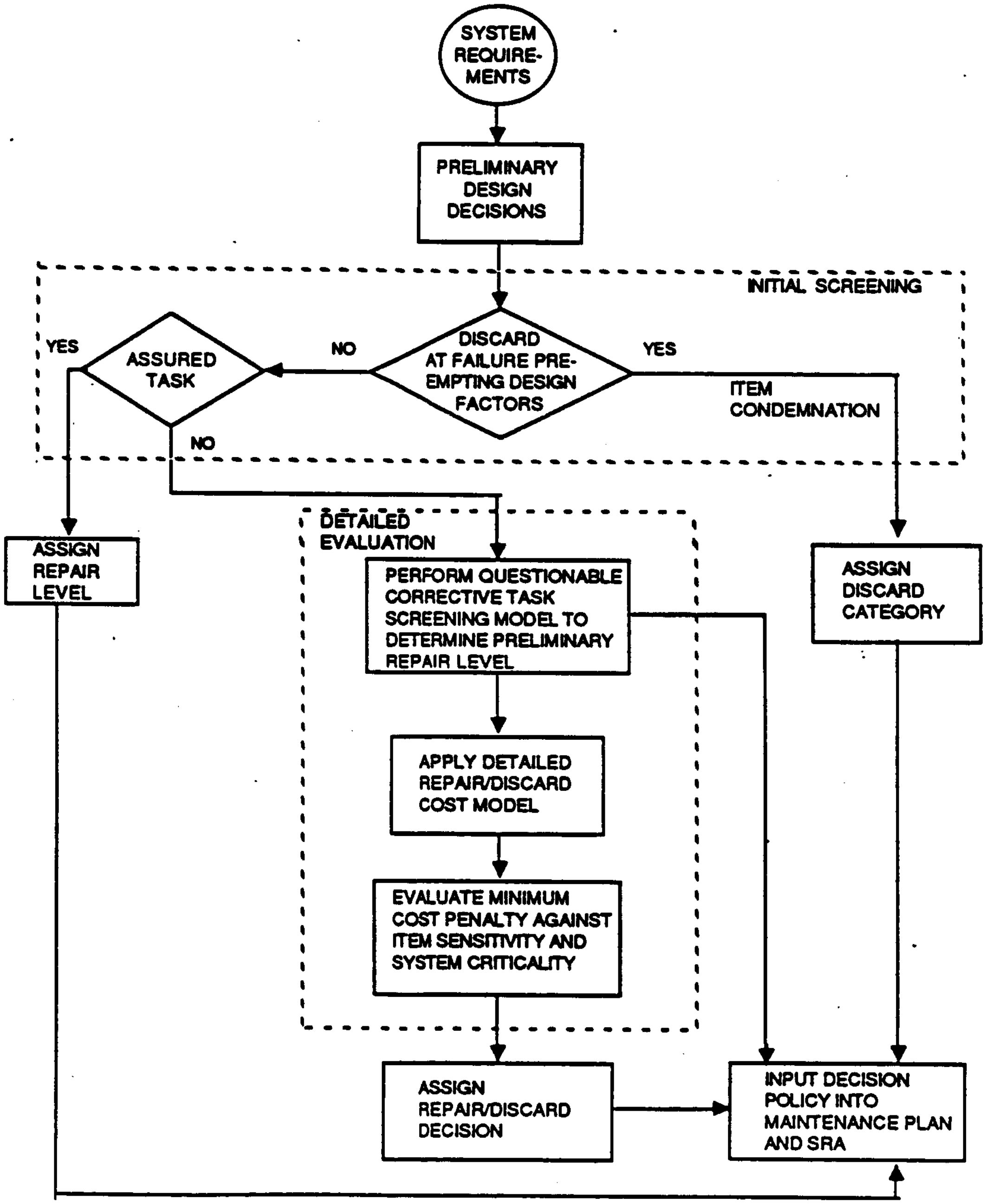

FIGURE 4.5.2-3 ORLA DECISION PROCESS

4.5.3 Logistics Elements

The primary logistics responsibility during the test/operations phase is the planning, coordination and integration of the resupply and return from orbit of spares, equipment, consumables and other materials in support of SS. Using actual consumption experience and predictor models, logistics must preplan each STS load to ensure the continued operation of the SS and its mission. Likewise, logistics must plan the retrograde movement of repairables, excess materials and waste products. Limited quantities of spares may dictate rapid turnaround of the repairables to support subsequent missions. Logistics is responsible to plan for and execute this requirement.

This section will describe the contractor's management of the Inventory Management System (IMS), and its application to the logistics elements which make up the following:

a. Spares (ORUs, SRUs and parts)

b. Maintenance tools, supplies and consumables

c. Fluids, gases and propellants

d. Raw materials

e. Software and documentation

f. Failed items (ORUs, SRUs, etc)

g. Processed materials

h. Waste/trash

4.5.3.1 Maintenance

The ground maintenance concept shall be to "remove and replace" to the functional Line Replaceable Unit (LRU) either on a scheduled basis as determined from design characteristics or on an unscheduled basis as determined from malfunction. "Repair in place" shall be permitted only when justified by support requirements analysis and time constraints. Maintenance shall be accomplished in a manner that will provide support for operational time constraints, prevent deterioration of inherent system/subsystem design levels of reliability and operating safety and accomplish this support at the minimum cost.

Pre-launch or post-flight maintenance activities for flight hardware, ORUs and logistics elements returned from, or going to, the Space Station will be performed by technicians functioning within three levels of maintenance.

4.5.3.2 Technical Data/Documentation

Technical data includes all operating and maintenance procedures, special test procedures, installation instructions, checklists, change notices and change procedures for prime equipment, support equipment, training equipment, transportation and handling equipment and facilities. Technical data covers all system operations and logistic support requirements on-orbit and on-the-ground. Technical data is updated as required to cover prime equipment modifications, revised maintenance policies and changes in the elements of logistic support.

4.5.3.3 Supply Support

Supply support includes support equipment, spares, repair parts, consumables, special supplies and related inventories needed to support SS prime mission equipment, software, test equipment, transportation and handling equipment, training equipment and facilities. Providing supply support includes the activities of provisioning, procurement, warehousing, distribution and logistics personnel support.

4.5.3.4 Personnel and Training

Manpower, Personnel and Training (MPT) provides determinations of the quality and quantity of manpower necessary to operate, maintain, and support the Space Station Program. It also provides the training resource requirements necessary to provide training and the content and materials necessary for training courses. MPT determinations are based on the equipment or system-specific tasks and skills for both Space Station on-orbit and ground operations/processing activities in their operational environment.

4.5.3.5 Support Equipment (SE)

This section will provide an approach to support equipment requisition.

5.0 PRODUCT ASSURANCE

5.1 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.

5.2 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 (See Table 5.2-1). 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.

TABLE 5.2-1

WP-01 HAZARD IDENTIFICATION BREAKDOWN

Hazard Level	Flight Hardware	Ground Support Equipment
Catastrophic	39	20
Critical	28	28
TBD	1	1
SUBTOTAL	68	49

Total Number of Identified Hazards: 117

A total of 426 new or derived requirements were also identified to control hazards.

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.

5.3 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.

A summary of criticalities 1, 1R and 2, 2R identified in the first submission follows:

Subsystem	Criticalities	No. of Failure Modes
Propulsion	1	-
	1R	-
	2	-
	2R	-
Thermal Control	1	-
	1R	-
	2	2
	2R	-
	TBD	10
Power Distribution	1	-
	1R	-
	2	-
	2R	-
	TBD	8

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.

A summary of criticalities 1, 1R and 2, 2R identified in the second submission of DR-12 follows.

Subsystem	Criticalities	No. of Failure Modes
Structures	1	7
	1R	-
	2	8
	2R	-
MTL Outfitting	1	26
	1R	2
	2	12
	2R	-
	TBD	10
ECLSS	1	4
	1R	14
	2	8
	2R	37

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.

The FMEA process will be continued in Phase C/D with detailed analysis at the ORU level and to the piece part level for critical items (1, 1R, 2). As additional critical items are identified they will be tracked and given special attention to insure acceptable solutions are presented.

6.0 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) (DR-08) 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 summarize the major sections of DR-10.

6.1 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.

6.1.1 Network Analysis

All networks and schedules were derived from a single data base which was developed by networking the individual elements to the lowest level of design maturity existing at that time. The element networks were then merged to create a single data base. The data base network was then integrated with "what if" situations considering risks, resources and critical paths resulting in several options from which to select our program planning approach.

Constrained by Level B PDR and CDR program milestones on the front end coupled with a later flight program, the option we selected resulted in the following programmatic guidelines for planning purposes:

6.1.1.A Utilize a "split target" float management scheduling approach which reflects early design and development (early start/finish) and a late start on outfitting and integrated testing (late start/finish). This guideline was selected to insure design maturity prior to production commitment to enhance producibility and minimize schedule/cost risk.

6.1.1.B Waterfall subassemblies and assemblies thru manufacturing on a continuous serial basis for resource leveling and facility/tooling considerations.

6.1.1.C Utilize CM-1 as a pathfinder for vertical and horizontal installation fixtures/facilities verification.

6.1.2 Critical Path

Our WP-01 critical path commences with ECLSS design thru procurement, mock-ups/test beds, development/certification tests, fabrication, assembly, test6 to the Common Module CM-1 (MTL) subsystem installation and checkout activity, thru MTL outfitting, integration/acceptance tests, KSC operations to flight #6. This critical path is not a schedule concern, however, in that we scheduled CM-1 for an "early finish"; and, in the event schedule recovery is required, it can be rescheduled for a later finish without affecting the MTL outfitting start date.

6.1.3 Work Breakdown Structure

The Work Breakdown Structure developed for DR-10 is our interim baseline for this DR-10 submittal. Levels 4, 5, and 7 reflect MSFC's WBS change request BM010027, Rev. A, and Level 7 under 1.1.1.3.16 has been added to align with the schedules submitted herein.

This WBS will be expanded by the WP-01 Phase C/D contractor and provide the framework for the performance management system and provide the basis for lower level planning, scheduling, schedule status, cost performance and technical performance management.

6.1.4 Schedule Integration

The Phase C/D WP-01 contractor data base will be compatible with and transmitted to the NASA data base to provide real-time status and information.

Vertical schedule integration is achieved by hierarchical schedule arrangements whereby program-critical milestones are assigned at the master schedule level and carried down through the derivation of detailed milestones and schedules that are used by the Level II and Level III managers to accomplish the contract requirements. Schedule integration and hierarchy also apply to subcontractors to provide a critical tool to the subcontractor(s) managers for analyzing performance progress. Planned subcontractor activities are integrated into all levels of schedules. These schedules then become the basis for the specific schedules that are developed for the individual subcontractor, included as a requirements document into their contract, and used for weekly status and monthly reporting.

Horizontal schedule integration is primarily accomplished by using Artemis planning systems in combination with IBM PC programs in the systematic development of logic and sequence flows and constraints that, when integrated with the major program milestones and detailed activity time spans, provides the critical path for the complete program period of performance. The critical path outputs and analyses are major elements of schedule control.

6.1.5 Government-Furnished Equipment

Martin Marietta will utilize the existing infrastructure of Buildings, Utilities, Services, Systems, and Equipment at the Michoud Assembly Facility to Design, Manufacture, Assemble, Test, Provision, and Outfit the Space Station WP-01 deliverable hardware.

GFE requirements to WP-01 includes the following distributed systems: Electrical Power, Data Management, Communications and Tracking, Thermal Control (Exterior), MTL/LOG User Equipment and Common GSE from KSC.

GFE management will be accomplished by using the property control system that has been approved by the Government and is in place at the Michoud Assembly Facility. The SS property control system will use an online computer system to track GFE from receipt through disposition. To reinforce the control of property on the SS program, we have dedicated property staffs at Denver Aerospace, the Michoud Assembly Facility, and the Marshall Space Flight Center. These dedicated personnel are at the disposal of MSFC and the SS project to lend assistance in working property-related matters.

Maintenance of GFE will be monitored and scheduled through the project's property control system. Necessary calibration, preventative maintenance, and periodic inspections will be performed on GFE as required by Martin Marietta standard procedure, vendor data, or sound industrial practice. Government equipment will be maintained in good working order.

Technical monitoring of GFE will be accomplished to assure that a configuration baseline exists and GFE is compatible with the SS. Changes or modifications to GFE will be submitted to the contracting officer for approval. After approval, the necessary changes will be accomplished to bring the equipment into SS compatible configuration.

6.1.6 Make-or-Buy Assumptions

It is the basic policy of Martin Marietta to assure that its Make-or-Buy decisions and plans are made in the best interest of the program involved, and that they comply with applicable contract requirements. We will examine the Make-or-Buy and reporting requirements of the RFP, and insure that our Make-or-Buy approach is totally responsive to the contract objectives of the Space Station (SS) Program.

In the implementation of our Make-or-Buy approach for the SS Program, the following factors will be considered:

6.1.6.A Extensive application of components of existing design;

6.1.6.B Competitive procurement;

6.1.6.C Geographic distribution of procurement dollars with emphasis on small and disadvantaged small business and labor surplus area businesses;

6.1.6.D Use of existing facilities, whether private or Government-owned, in the best interest of all concerned;

6.1.6.E Economic use of in-house capability.

6.1.6.F Selection of items estimated to cost less than one percent of the total estimated contract price, or $500,000.00 whichever is greater.

The Make-or-Buy Program will be implemented and managed by the SS Program Make-or-Buy committee, chaired by the planning manager for the program manager, and will be comprised of the membership identified on Figure 2-19. These SS program personnel will be supported by technical, business management, and socioeconomic specialists drawn from division central departments. The Make-or-Buy committee, using the equipment and software list developed by SS technical personnel, will conduct on-project meetings in which a comprehensive review will be conducted to properly categorize each item as either "make" or "buy".

The NASA approved make-or-buy decisions will be implemented by formal Operations Directive (OD) prepared by the Contracts organization and approved by the SS program manager.

6.1.7 Project Risk Assessment Plan

The Risk Management System Martin Marietta will implement for the design and development phase is a continued operational use of the risk analysis method employed on current contracts. To avoid technical risk, subsystem components with a high technical maturity level are selected. The Office of Aeronautics and Space Technology Scale for Technical Maturity is used to provide a basis for the identification of risk levels at the component level. High technical maturity and low risks will be key drivers in design and selection of subcontractors. Risk assessment, risk analysis and risk mitigation techniques will be employed to achieve this goal.

6.1.8 Management Systems

6.1.8.1 Performance Measurement

A Performance Measurement System (PMS) will be used to monitor, control, and report planned versus actual contract cost and schedule status of the Space Station Program. This system will integrate work authorization, scheduling, budgeting, cost accumulation, performance measurement, management reporting and analysis, and customer reporting through the work breakdown structure and organization structure.

Responsibility for major contract work breakdown structure (CWBS) elements will be assigned to individual task managers. Responsibility for the performance of all effort displayed on the work breakdown structure is assigned to functional organizations which plan, schedule, and status their efforts in smaller segments of work referred to as cost accounts. Cost account managers will be assigned to monitor their accounts.

Work to be performed on the Space Station Program will be initiated through a formal work authorization system. The Operations Directive (OD), the principal administrative instrument used to authorize effort, will be prepared by Contracts for approval for the Program Manager. The OD, in addition to providing authority to proceed with work, provides a statement of work, assigns functional responsibility, allocates budgets by organization and the designated control level of the CWBS, directs project schedule requirements and directs any project-peculiar practices not otherwise covered by company policies or procedures.

Performance Management and analysis of schedule and cost data will be the responsibility of the Business Management Group in direct support of the Program Director and his managers. Performance Measurement will be made at designated levels of the WBS, where schedules, time-phased resource plans, and actual costs are integrated.

Our Performance Management will be keyed to the major WBS Task Managers. They will be assigned the responsibility and necessary resources, and are held accountable for performance.

6.1.8.2 Financial Management

The Program Operating Plan (POP) is the document by which cost forecasting information is provided to the NASA Project Office. With a program the size of Space Station, NASA Management must have the visibility to determine how major program requirements will affect anticipated budget requests. Decisions on commencing, terminating, or changing long-range, large dollar value activities must be made far in advance of the anticipated occurrence. Our experience on the External Tank project shows the POP to be a major decision making document for both NASA and Contractor Management.

The POP will reflect the schedule, workscope, and economic groundrules as specified by the Project Office. The cost forecasts will be time phased by NASA recommended cost estimating and reporting categories. These categories are consistent with the way MMC forecasts cost projections in the 533 Series of reports and collects/statuses actuals against them.

The POP will be submitted and updated as required to support the NASA budgeting cycle. The POP submissions will be linked to the TMIS Network and transmitted electronically.

6.1.8.3 Technical and Management Information System (TMIS)

Martin Marietta will utilize the Martin Marietta Technical and Management Information System (TMIS) throughout the Space Station Program as the primary mechanism for routine data transfer between Martin Marietta and the MSFC TMIS and between Martin Marietta and its subcontractors. The Martin Marietta TMIS will be implemented using a phased approach paralleling the implementation of the MSFC TMIS. Data will be transmitted to MSFC in the MSFC prescribed formats to provide the MSFC end user the maximum freedom to access and process this data from personal workstations connected to either the MSFC DEC VAX or IBM mainframes. Data will be transmitted over either the existing 9600 baud dedicated line between Martin Marietta Data Systems Orlando Data Center and MSFC or via a 56 kilobaud line provided by NASA.

6.1.8.4 Procurement and Subcontract Management

The existing procurement management system in place at the Michoud Aerospace Facility will be utilized for our Space Station Effort. This system includes the necessary controls to assure performance and provide flexibility to meet the Space Station Program (SSP) requirements while following the guidelines established by government acquisition regulations. The system and procedures are reviewed annually. Approvals have been received from the cognizant government agency [Defense Logistics Agency (DLA), Defense Contract Administrative Services, Plant Representative Office (DCASPRO), N.O., LA] since the inception of the External Tank Program.

The level of subcontractor surveillance is determined by the criticality category associated with the procurement. We assess all procurements into 5 categories, depending upon the degree of risk associated with the design of the hardware, schedule needs, and type of contract. Categories 3, 4, and 5 (the most critical) provide for formal program plans and reporting to a formal work breakdown structure. These subcontracts are generally incentive and/or cost type.

Less critical Category 2 subcontracts include formal requirements similar to Categories 3, 4, and 5; however, task breakdowns do not use WBS format. Category 1 purchase orders are managed by schedule surveillance and buyer follow up through the use of mechanized reporting systems. Both Category 1 and 2 subcontracts generally use Fixed Price contractual agreements because of the limited risk associated with the design and availability of the hardware.

6.1.8.5 Configuration and Data Management

Our configuration and data management system provides for configuration identification, baseline management, change control, status accounting, and verification and acceptance.

The Space Station Project Manager is responsible for Configuration Management (CM) policies and direction for the Project. The Project CM Organization administers the implementation of these policies and direction. The functional organizations provide specialized capabilities to perform the Configuration Management functions in accordance with existing practices and procedures.

The Manager of CM has the responsibility and authority to implement and control all CM activities. He reports to the Space Station Business Director for functional and program direction and to the Michoud Aerospace Contracts Director for technical and administrative direction.

The following organizations implement CM functions as a result of project decisions: engineering, production operations, product assurance, material operations, and finance/planning and computer services. These organizations provide specialized information to CM and the Contractor CCB from their respective functional areas; participate in formulation of the CCB's change impact determination and recommendations; support the Project Director's impact assessment; and perform tasks to incorporate and to verify incorporation of changes to authorized requirements.

6.1.8.6 Engineering Systems

An engineering system project implementation plan for Phase C/D will be developed based on updating our existing validated systems. The basic systems are essentially the same as those being used at Michoud for the ET Project and Space Station Phase B. However, with mechanized data system technology improving daily, new improvements will be incorporated into the plan as required.

Technical engineering systems to aid design, analysis, and support will be updated and implemented. CAD/CAE computer tools will be utilized to analyze and manage the system engineering and integration function during the Space Station Program. CAD systems, already being used during Phase B, will be utilized for mechanical and electrical design. These data include 3-D wireframe models, sculptured surface models, solids models, 2-D drawings (design and as-built) and schematics. TRMS (Technical Requirement Management System), already in place on the ET project, will be used to provide planning and scheduling, parts data, document status, configuration verification and CEI requirements identification. CAE systems will be implemented to analyze the design data from the CAD data base. CAE tasks include stress analysis, loads and dynamics, thermal analysis, mass properties and electrical analyses.

Administrative engineering systems to handle scheduling, planning, and cost management will be updated from existing systems in use at Michoud. TRMS and ARTEMIS planning and scheduling systems will provide real-time capability to track and status all work identified with the program. Engineering cost management systems such as FORESIGHT will be updated to support Phase C/D. Office automation systems for word processing such as the WANG will continue to be used to provide engineering administrative support.

6.1.8.7 Manufacturing System

The production operation is supported by a sophisticated integrated manufacturing system, the Production Control Data System (PCDS). Subsystems within PCDS control all of the separate manufacturing functions. These manufacturing functions encompass scheduling, capacity planning, requirements control, order release and control, inventory control, serialization, traceability, order management, change control, and tool control. The Functional Cost Management System (FCMS) supports PCDS by monitoring all factory and support labor costs.

The Production Master Schedule is developed in the ARTEMIS project management system. The Master Schedule is used to drive the component schedule, test article build, end item deliveries and GSE/FSE milestones. The Master Schedule is used to develop and forecast resources and establishes the base for the performance measurement system.

PCDS is an integration of all Production Operations systems. In addition PCDS performs all forecasting, budget maintenance, staffing plan and performance reporting functions.

PCDS interfaces with the production schedules, the Manufacturing Accounting System (MAS) and the requirements module of the MPCS to automatically generate work orders and inventory pick lists. When the schedule determines that an order is to be released, PCDS automatically prints the order in the appropriate Shop Control Center. The work order is printed with bar code symbols to provide for the fastest and most accurate means of shop floor data collection. Other elements of the PCDS include material inventory management, as built hardware reporting system, manufacturing accounting system, and the tool status and accounting system.

6.1.8.8 Product Assurance

Product quality and integrity is assured through the use of proven management systems and techniques. These management tools are applied within the safety, reliability, quality and software product assurance disciplines. These management tools/systems include the Martin Anomaly Reporting System (MARS), the Corrective Action Problem Summary (CAPS), hazard reports, the safety analysis report system (SARS), failure modes and effects analysis (FMEA), the critical items list (CIL) and the software control system.

6.2 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. system 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 design and 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 efforts by assuring that end item requirements are satisfied by subcontractor products.

6.2.1 System Engineering

Martin Marietta's system engineering process includes the application of scientific and engineering efforts to (a) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design; and (c) integrate reliability, maintainability, safety, human engineering and other such factors into the total engineering effort to meet cost, schedule, and technical performance objectives.

Key tasks in the system engineering effort include system requirements, interface requirements, trade study performance, system design, systems support, and automation and robotics.

6.2.2 System Integration

System Design Integration will be performed to assure that all WP-01 elements are compatible technically and will function as an integrated system with the Space Station to provide the optimum technical performance, IOC cost and life-cycle-cost with an acceptable risk. An integration plan will be implemented through performing system synthesis of the WP-01 elements and the overall SS and analyses and trade to develop and maintain system level schematics and layouts.

The System Test Integration effort manages the development and implementation of system test requirements. Major tasks include identification of test and verification requirements and development of plans, verification compliance and the conduct of test and verification design reviews.

Logistics and Operations Engineering defines logistics requirements, develops a maintainability implementation plan, provides on-orbit assembly planning, accomplishes logistics support analysis and performs mission operations integration.

6.2.3 Systems Management

Martin Marietta will plan formal management and technical reviews and monthly contract status reviews per Standard Procedure (SP) 51.1 as significant steps in the program to summarize accomplishments, evaluate results, establish baselines, and plan subsequent program actions. Reviews will be conducted in a disciplined, timely manner to provide maximum assurance of a minimum risk system in terms of performance, cost, and schedule.

These formal reviews will be supplemented with smaller, less formal technical interchange meetings (TIM's) to support long-lead requirements and evaluate subsystem approaches for a more manageable milestone review. The subject of, and need for, these interchange meetings will be identified and scheduled during monthly status reviews.

Design reviews (DR's) as required by the contract will be conducted to determine the technical adequacy of WP-01 hardware and software designs, verify the compliance of the design with specifications and other systems requirements documentation, and establish a product baseline for production/fabrication/procurement. Design reviews include, but are not limited to, a preliminary design review and a critical design review.

The Systems Engineering organization, through the authority and responsibility of its Engineering Change Manager (ECM), plays an important role in the control of all changes processed on the program. The ECM has the responsibility to review and approve all changes processed on the program relative to the technical adequacy and accuracy of the contents of the change. In accordance with Martin Marietta's Standard Procedure (SP) 42.2, Internal Change Processing, the ECM chairs the coordination group meeting and oversees all change processing activities within engineering. It is his responsibility to coordinate and integrate the change within and between all engineering groups including Systems, Design, Logistics, Operations and appropriate support groups as applied to each of the elements within the program.

The data bases which form a part of the Systems Engineering effort, such as the requirements data base, the equipment list, and the mass properties data base will be formally controlled and maintained. Baselines will be established early in the Phase C/D effort, with MSFC concurrence. Changes to these baselines will be processed through the Engineering Change Control system so that complete visibility and coordination is achieved.

6.2.4 Technical Performance Management

Martin Marietta will develop a technical performance measurement (TPM) plan, which outlines the initial selection of parameters to be evaluated. This documentation will be used to status the system/subsystem compliance with requirements. The TPM process, consisting of measurement definition, prediction, status, and corrective action, will be conducted continuously for monitoring and comparing actual performance with the predicted and contractually required performance values. The TPM process will provide early identification of the system impact of technical problems and solutions and provides management with sufficient information to make timely decision to correct the problem.

6.3 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, test and verification requirements, and technology development status.

The major hardware elements include the core module and its associated subsystems such as thermal control and ECLSS, and its applications software; the manufacturing and technology laboratory; the logistics elements including the logistics module and the unpressurized cargo carrier; mechanisms such as berthing hardware, hatches and umbilicals; and resource nodes.

6.4 MANUFACTURING

Our manufacturing plan has as its objective to produce the various end items for 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, 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.

6.4.1 Project Plan and Schedules

Space Station Project plans shall be developed to allow sufficient time during the early phase of the program to complete tool planning, technology, and producibility studies before commitment to detail tool design and hardware development. This shall minimize the project start-up costs and eliminate premature expenditure of project funds.

At ATP, the Production Operations activities include:

6.4.1.A Preproduction planning and producibility studies with Design Engineering.

6.4.1.B Development of production planning and tooling.

6.4.1.C Production test planning.

6.4.1.D Process development.

6.4.1.E Development of facilities requirements.

6.4.1.F Skill training and certification planning.

6.4.1.G Operations planning.

6.4.1.H Support of supplier source evaluation.

6.4.1.I Preparation of criteria and specifications for subcontracted tooling effort.

These activities will continue until about PDR, at which time increased emphasis will be placed on final design producibility, manufacturing process planning, tooling and test equipment design.

6.4.2 Manufacturing Master Schedule

The Manufacturing Master Schedule has been assessed and major milestones have been established. The Master Schedule is built from Space Station Program Baseline Phase C/D Integrated Schedule Rev. 5 dated 3 April 1986. The Master Schedule depicts all end item units to be produced including test articles.

6.4.3 Manufacturing Technology

Existing manufacturing technology will be applied to meet structural, functional and environmental stability requirements. Full or subscale development demonstrations will be performed when necessary to verify the selections made for major processing methods. Emphasis will be placed on producing the structures designed to meet the stringent requirements of the extended lifetime, meteoroid/debris penetration resistance and damage control. The small number of articles to be manufactured dictates that flexible or existing tooling and facilities be utilized for as many major operations as possible.

Manufacturing development and/or demonstrations may be necessary to support fabrication by both subcontractors and in-house Production Operations in the areas described in more detail in DR-10.

6.4.4 Tooling

The production requirements for the various end items for WP-01 shall be accommodated by a flexible tooling approach that will be the most economical at very low start-stop-start type production rates. Tooling shall be designed based upon other current programs (i.e., External Tank) to incorporate the degree of producibility incumbent with these mature programs.

The tooling approach shall also consist of designing like-structures and systems of each end item to have as many common parts as possible to reduce the number of tools and increase number of operations on a single tool.

Master tooling shall be required to provide interface for the docking mechanisms on the WP-02 tower structure, orbiter attach points, berthing port mechanism, feed-throughs on the module end cones. The master tools and their coordinated working tools shall be maintained by existing MMC-NASA interface controlled documents (ICD).

6.4.5 Facilities

Martin Marietta Aerospace will integrate production of Space Station Work Package 01 items with External Tank production operations at the Michoud Assembly Facility. Integration of the Space Station and External Tank production operations will allow maximum effective use of the existing infrastructure of buildings, utilities, and support services.

Space Station production activities will take place in Buildings 103, 110, 114, 131, and 451. Space Station office personnel will be integrated into office areas at MAF.

6.4.6 Long-Lead Items

Long-Lead items shall be evaluated on an individual basis utilizing complexity, technical risks, and program plan requirements as the criteria. A procurement program plan shall be developed from this assessment, scheduling release of requirements with adequate lead time to accomplish all phases of the procurement cycle in support of the Space Station program plan.

6.4.7 Producibility

Producibility Trade Studies are being conducted during the Phase B proposal effort. These trade studies shall continue throughout the Phase C/D. An integrated team has been established for the studies with representatives from the following groups:

- Design Engineering
- Manufacturing Engineering
- Tool Design
- Test Engineering
- Industrial Engineering
- Advanced Manufacturing Technology
- Facilities
- Materiel
- Quality Assurance
- Program Planning
- Safety and Reliability Assurance

Trade studies have been selected from promising production alternatives that were identified through detailed analysis of the design elements. Design concepts are prepared for the alternative approaches in sufficient depth to permit development of manufacturing plans and identification of critical production processes. Tool concepts are developed and production test requirements and special facility needs are identified. The alternative approaches are evaluated against subcontractor capabilities and Make or Buy evaluations are made considering lowest cost approach and schedule and capacity requirements. Cost and schedule impacts are identified. A final assessment is made of study results to determine the relative cost of alternative approaches and identify the lowest cost producible design.

6.5 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.

6.6 PRODUCTIVITY

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