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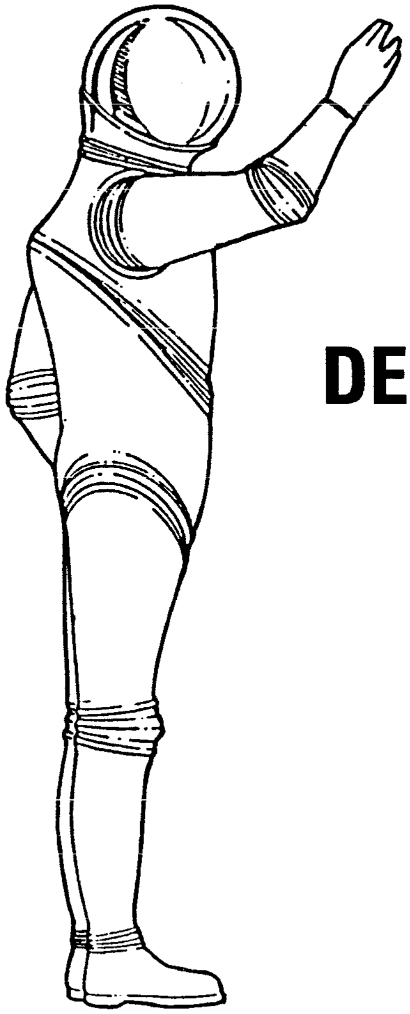

ADVANCED EVA SYSTEM DESIGN REQUIREMENTS STUDY

FINAL TECHNICAL REPORT

JANUARY 1986

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-HOUSTON DIVISION

MCDONNELL DOUGLAS
CORPORATION

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FINAL TECHNICAL REPORT

Prepared for the National
Aeronautics and Space Administration
Under NASA Contract NAS9-17299

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PREFACE

The Advanced EVA System Design Requirements study was a twelve month effort to identify specific criteria regarding Space Station EVA hardware requirements by analyses of EVA missions, environments, operations, procedures, and Space Station and STS interfaces. The study began in January of 1985 and was completed in January, 1986.

This final report has been prepared in accordance with the Statement of Work for the subject study, contract NAS9-17299, and contains the data and analyses from which all the study results were derived. A separate Executive Summary report has also been prepared for distribution as determined by the contract monitors.

The study results are intended to provide information and guidelines in a form that will assist NASA program managers in evaluating and substantiating EVA system requirements to support a productive EVA capability for the Space Station Program.

Questions and comments regarding this study or the material contained in this document should be directed to:

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SECTION 1

Introduction and Study Overview

Introduction

The purpose of this document is to report on the technical work accomplished on the Advanced Extravehicular Activity System Study, Contract NAS-9-17299. The study was performed to define and establish design requirements and criteria for the Space Station Advanced Extravehicular Activity System (EVAS) including crew enclosures, portable life support systems, maneuvering propulsion systems, and related EVA support equipment. The study considered EVA mission requirements, environments, and medical and physiological requirements, as well as operational, procedures and training issues.

1.1 Team Organization

The MDC EVAS Study Team was organized to take advantage of a unique mix of experience and expertise in defining and developing EVA systems, as well as in planning and conducting successful EVA operations. (Figure 1-1). The Houston Division of the McDonnell Douglas Astronautics Company provided overall study management and expert task leadership dedicated to incorporating in this study all the relevant lessons learned while helping NASA develop and exercise the NSTS EVA capability which has been so spectacularly demonstrated in recent years. To this invaluable understanding of EVA operations were added the skills and experience of the Huntington Beach division of MDAC (for physiology, productivity, system integration and compatibility with Space Station architecture); the Hamilton Standard Division of United Technologies (for life support system technologies); ILC-Dover (for crew enclosure, materials and ancillary equipment); and Martin Marietta (for maneuvering propulsion technologies). Corporate EVA experience bases dating back to Gemini IV were thus applied to the purpose of defining EVA system requirements for the Space Station.

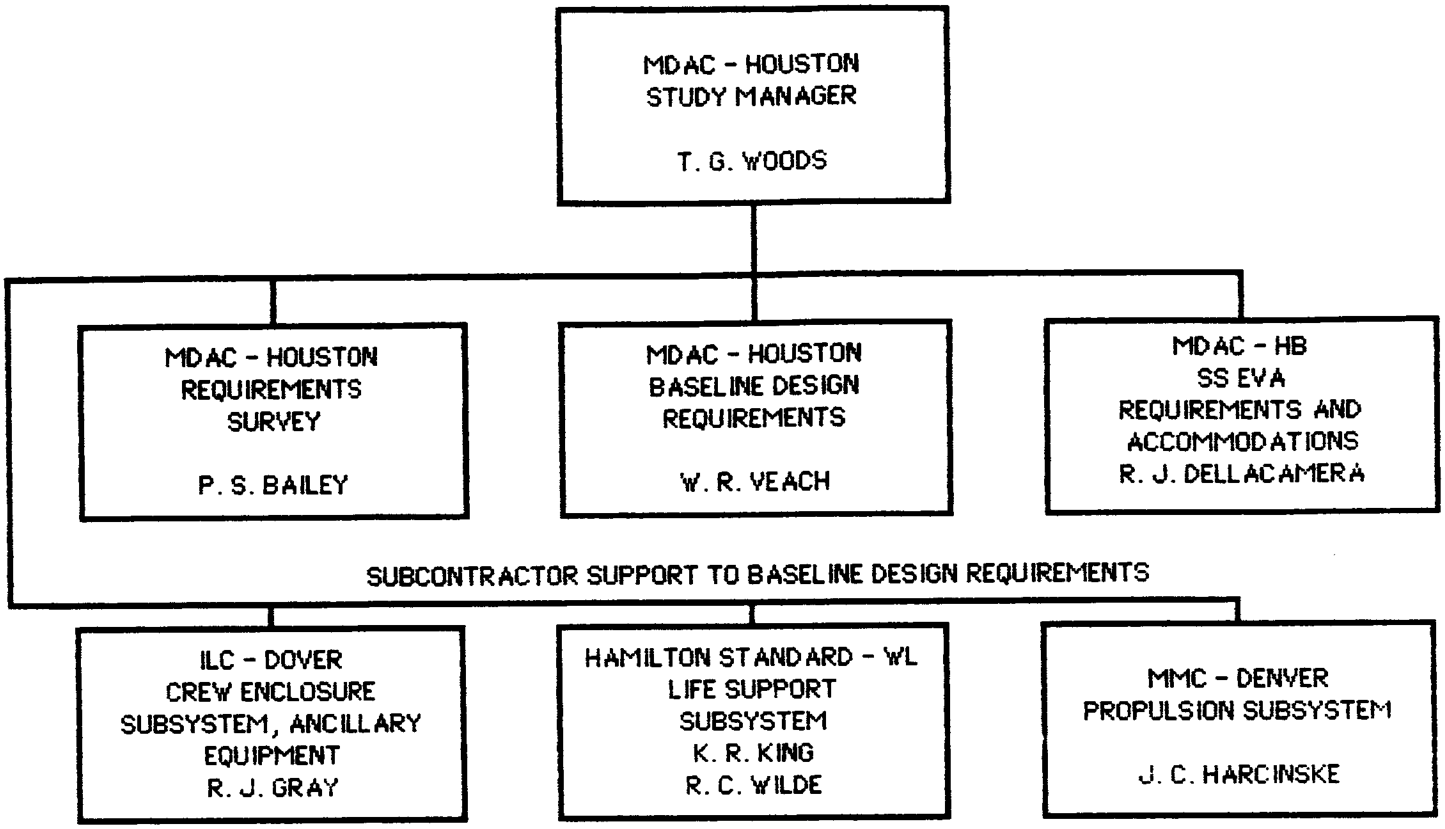


FIGURE 1-1
TEAM ORGANIZATION

1.2 Study Organization

The methodology chosen for this study was a classic Phase A approach of survey, analysis, synthesis and definition as shown in Figure 1-2.

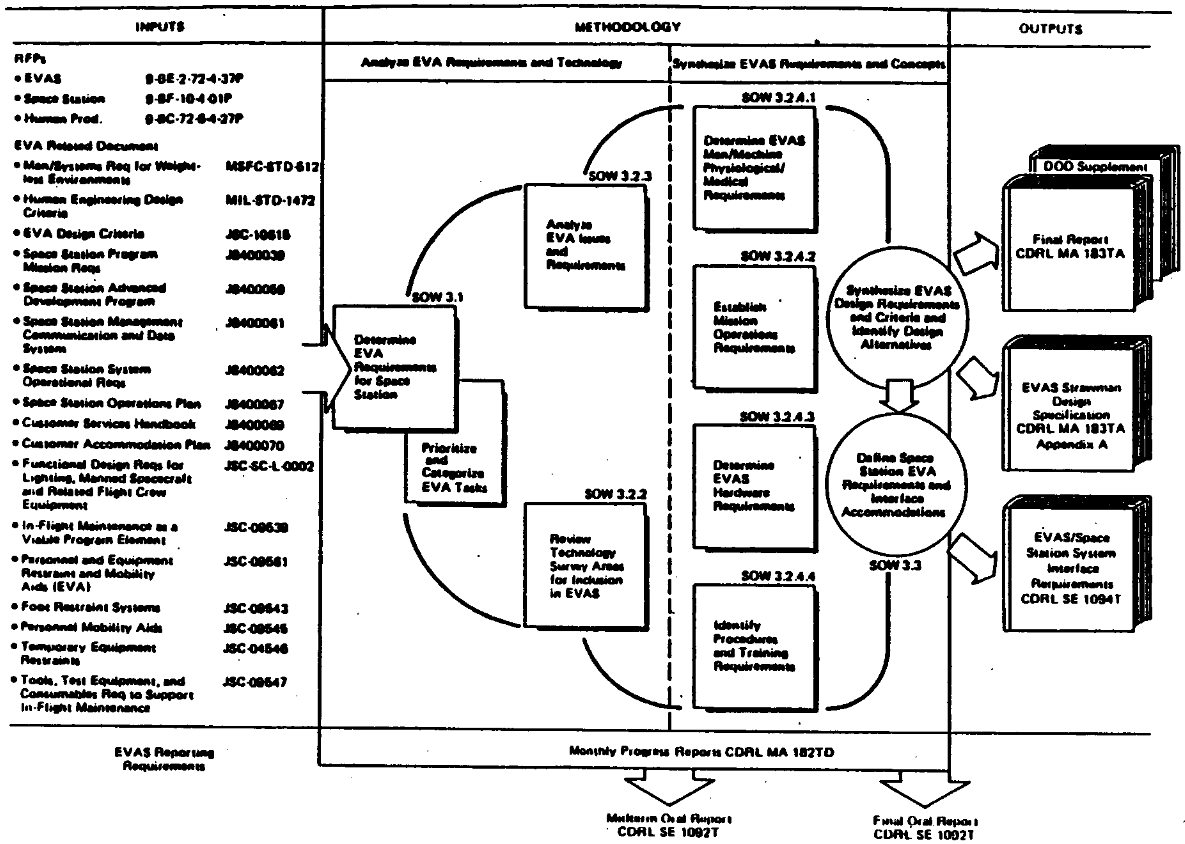


FIGURE 1-2
STUDY ORGANIZATION

The primary activity was organized into three major tasks corresponding to the contract Statement of Work (SOW). From numerous sources, the EVA Requirements Survey, Task 1, attempted to identify and quantify all the routine and contingency EVA mission requirements for assembly, servicing, maintenance, and repair, of satellites and attached payloads, as well as for the Space Station itself. Using the identified mission requirements as one of several inputs, EVAS Baseline Design Requirements and Criteria - Task 2, analysed numerous environmental, physiological, man/machine, operational and hardware considerations to identify specific design requirements for systems that would maximize human productivity in EVA. In Task 3, Space Station EVA Requirements and Interface Accommodations, we identified the EVAS interfaces and EVA peculiar accommodations and support requirements to be incorporated into the SS systems and architecture. The detailed Work Breakdown Structure (WBS) is illustrated in Figure 1-3.

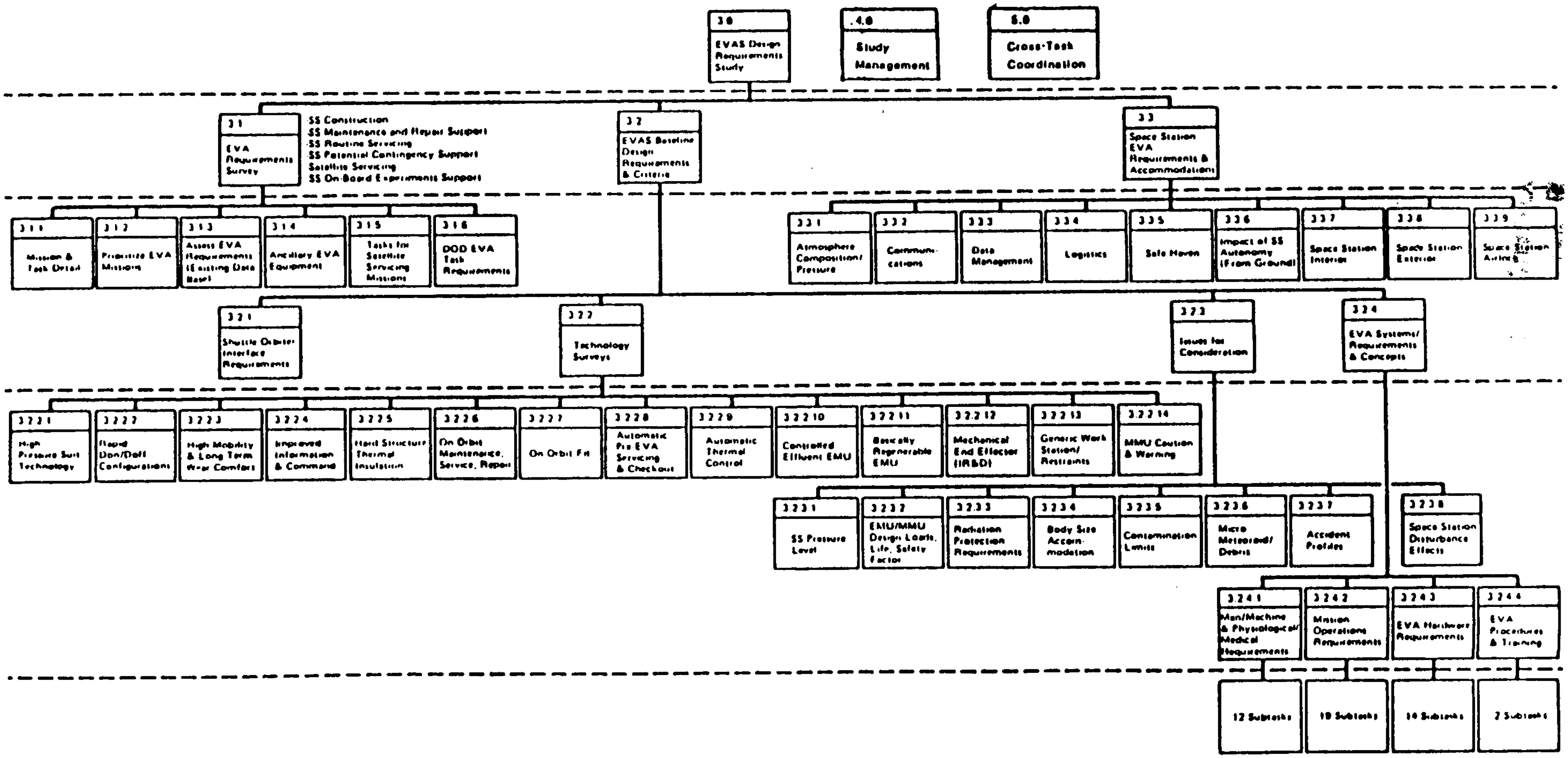


FIGURE 1-3
WORK BREAKDOWN STRUCTURE

1.3 Key Issues and Drivers

Specific EVA system requirements and their rationale are presented in the ensuing sections of this report. There were several issues and driving considerations developed in the course of the study that affected more than one system and which combined with some unique characteristics of the Space Station to effect many of the EVA design considerations.

1.3.1 Space Station Characteristics

When compared to previous programs, the Space Station crews will be routinely on-orbit for far longer periods, and the vehicle itself and many of its systems will be there virtually indefinitely. From this factor alone were derived several other key characteristics of the Space Station.

- **ORBIT STAY TIME GREATLY INCREASED OVER PREVIOUS PROGRAMS**
- **OPERATIONAL TEMPO RELATIVELY BENIGN**
- **MISSION PLANNING MORE LONG TERM, LESS PRE-MISSION DETAIL**
- **TRAINING MORE GENERIC, MORE TASK-ORIENTED, LESS MISSION SPECIFIC**
- **ON-ORBIT TRAINING REQUIRED FOR PROFICIENCY IN CONTINGENCY/ EMERGENCY SITUATIONS**
- **LONG VS SHORT TERM PHYSIOLOGICAL FACTORS AND ENVIRONMENTAL PROTECTION REQUIREMENTS**

FIGURE 1-4
UNIQUE SPACE STATION CHARACTERISTICS AFFECTING EVA

The tempo of operations will be relatively benign with regard to meeting most mission objectives in critical time periods. For instance, an EVA task that takes longer than anticipated can be rescheduled for completion in the next planned EVA event. This takes advantage of the more permanent nature of the manned presence than that afforded by the STS and also alleviates the potentially deleterious effect of less mission specific training available to SS crews. Mission planning itself will be more of a long-term nature on the ground with much less pre-mission daily detail than is required for Shuttle. For the same reasons, and due to the wide variety of EVA mission requirements, pre-mission training will enphasize development of the generic EVA skills that will be required to accomplish them. On-orbit EVA training opportunities will also be utilized to compliment limited ground simulations with an abundance of on the job training to achieve true proficiency. Additional on-orbit training requirements in emergency procedures and off-nominal EVA systems operations are required by the length of crew cycles and by the need to maintain proficiency in safety critical areas.

While much has been learned about adapting man to the orbital environment, there are new, different, and perhaps unknown risks associated with long term exposures. The statistical probability, however small, of a hazardous event or exposure occurring to a crewman takes on a whole new meaning when the opportunities are significantly increased. Thus, for Space Station there is special emphasis on such areas as bends risk, radiation exposure, and micrometeroid protection.

1.3.2 Key EVA Design Issues

With the considerations expressed above and with the key applicable lessons learned from the STS EVA experience, several issues emerged from the many considered in the study as having pervasive effects on EVAS design requirements. (Figure 1-5).

- **EVAS MAINTAINABILITY**
- **EVAS TECHNOLOGY READINESS**
- **EVA LSS VOLUME VS EVA TIME AVAILABLE**
- **SUIT PRESSURE/CABIN PRESSURE RELATIONSHIP AND PRODUCTIVITY EFFECTS**
- **EVA CREW AUTONOMY**
- **INTEGRATION OF EVA AS A PROGRAM RESOURCE**
- **STANDARDIZATION OF TASK INTERFACES**

FIGURE 1-5
KEY EVA DESIGN ISSUES

Maintainability is far and away the most important issue in EVAS design and the main reason why the STS EMU will not satisfy SS requirements.

Technology Readiness and risks associated with advanced EVAS technologies must be carefully considered in evaluating their benefits to EVA productivity. An assessment of technology readiness for the EVAS is provided in Section 4 of this report.

EVA LSS Volume vs EVA Time Available. There are several factors combining to drive the EVAS to an overall larger volume. While the STS constraints on volume are not expected to exist for Space

Station, this growth could be controlled by taking advantage of the Station's ability to provide dependent life support capability (i.e. via umbilicals) at remote worksites.

Suit Pressure/Cabin Pressure Relationship and Productivity Effects. Operating space suits at the pressure levels attendant to a sea level cabin with minimum prebreathe means that unless there is significant improvement in the glove technology the crewman will bear the brunt of having to perform manipulative tasks with very stiff hands. Recent tests have provided insufficient quantifiable data to back up this key feed back from our system operations. Further development efforts must concentrate on getting the technology up and/or the suit pressure down.

EVA Crew Autonomy is an issue which was found to affect many areas of the EVAS and the SS EVA interfaces and accommodations. To maximize the overall productivity of the crew they need to be provided with all the resources to operate independently from the ground, as well as to allow the EVA crew to operate independently from the IV crew. This issue affects EVAS design, including reliability and maintainability aspects, the Data Management System, the Communications System, provisioning, and training and makes a strong case for implementation of IVA automation and EVA robotics.

Integration of EVA as a Program Resource is no less important than integration of other SS user services such as heat transfer, power distribution, pointing accuracy or data handling. This program appears well on its way to achieving this critical perspective and it must be maintained during the SS development.

Finally the Standardization of Task Interfaces must be promoted to increase EVA productivity, enhance the probability of mission success and reduce the overhead burdens associated with performing EVA. If EVA is to be relied upon for SS assembly, maintenance, servicing, and repair and as a resource to be applied to user needs, then properly designed work interfaces are required.

1.4 Organization Of This Report

Sections 2 thru 6 and Appendices A, B, and C of this report contain the results of the work performed under this study contract.

Section 2 EVA Mission Requirements summarizes the results of the EVA requirements survey. For clarity and understanding it describes some of the intermediate results achieved in the process of developing the time phased SS EVA mission model which provided the scope for evaluating the technical issues in later sections. This section also identifies the support equipment requirements derived from the mission survey and the generic EVA task requirements.

In Section 3, an overview of SS EVA operations is presented. This material describes a typical EVA scenario in order to set the stage for the EVAS descriptions to follow as well as to tie together some of the operations-related systems concepts which were developed in the course of the study.

Section 4 covers the major effort of the study, the definition of the Advanced EVA Systems Baseline Design Requirements and Criteria, Task 2 of the contract statement of work (SOW). As required by the Data Requirements Description, the specific EVAS design requirements are also contained in Appendix A. If no requirement is stated, none is implied.

In Section 5 are presented the requirements definitions for the Space Station/EVAS Interfaces and EVA Accommodations, SOW Task 3. These requirements are also contained in Appendix B. This material is essentially the same as previously reported as required in DR3 of the contract.

In Appendix C are compiled various tables of supporting data which were either developed in the course of the study, or the results of other relevant studies or research. They are provided as more complete reference material than that which is discussed in the body of the report. This section also includes a bibliography of references consulted in the study and considered useful to readers of this report.

To assist the reader in tracing the study results to various SOW tasks, a cross reference is provided in Table 1-1 below.

TABLE 1-1
SOW to FINAL REPORT CROSS-REFERENCE

------SOW------- SECT	TITLE	FINAL REPORT SECTION(S)
3.1	EVA REQUIREMENTS SURVEY	
3.1.1	Greater Detail	2.1
3.1.2	Prioritized Listing	2.2
3.1.3	Assessment Around DB	2.3
3.1.4	ID Ancillary Equip	2.4
3.1.5	Satellite Serv Tasks	2.1, App C
3.1.6	DOD EVA Requirements	2.5
3.2	EVAS BASELINE DESIGN REQUIREMENTS AND CRITERIA	
3.2.1	Orbiter I/F Reqts	4.9
3.2.2	Technology Survey Areas	4.0.2.6
3.2.2.1	High Pressure Suit	4.0.2.1, 4.8.1
3.2.2.2	Rapid Don/Doff	4.8.2
3.2.2.3	Hi Mobility/Long Term Comfort	4.3.1, 4.8.3
3.2.2.4	Data Disp, Stor, Cmd	4.5, 4.8.4
3.2.2.5	Hard Struc Thermal Insu	4.8.5
3.2.2.6	Component Modularity	4.0.2.1, 4.8.6
3.2.2.7	On Orbit Fit/Resizing	4.3.2, 4.8.7
3.2.2.8	Auto Service & Checkout	4.8.8
3.2.2.9	Auto Thermal Control	4.8.9
3.2.2.10	Controlled Effluent EMU	4.8.10
3.2.2.11	Basically Regen EMU	4.8.11
3.2.2.12	Mech End Effector	4.8.12
3.2.2.13	Generic Work Sta, Restr	4.8.13
3.2.2.14	MMU C&W Interface	4.5, 4.6, 4.8.14
3.2.3	Issues For Consideration	Throughout Sections 3, 4, and 5
3.2.4	EVAS Systems/Requirements and Concepts	
3.2.4.1	EVA Man/Machine and Physiological/Medical Requirements	
3.2.4.1.1	duty cycles	3.0, 4.0.2.5
3.2.4.1.2	optimize duration	3.0, 4.0.2.5
3.2.4.1.4	human capabil.	4.0.1
3.2.4.1.5	integ. >2 cm	4.4
3.2.4.1.10	percep. acuity	4.5.2
3.2.4.1.13	radiation toler.	4.2.1
3.2.4.1.14	pers. hygiene	4.7
3.2.4.1.15	waste mgmt	4.7.2
3.2.4.1.16	EMU waste mgmt	4.7.2
3.2.4.1.17	food, water	4.7.1
3.2.4.1.19	biomed data	4.4, 4.5
3.2.4.1.21	medical care	4.7.3

TABLE 1-1
SOW to FINAL REPORT CROSS-REFERENCE (CONTINUED)

------SOW------- SECT	TITLE	FINAL REPORT SECTION(S)
3.2.4.2	Mission Operations Requirements	
3.2.4.2.1	ops scenario defn	3.3
3.2.4.2.2	EVA length	3.3.2, 4.0.2.5
3.2.4.2.3	EVA work period	3.3.2, 4.0.2.5
3.2.4.2.4	optimize duration	3.3.2, 4.0.2.5
3.2.4.2.5	prop capability	4.6
3.2.4.2.6	SS repair ops	2.1, 3.3.2, 4.6
3.2.4.2.7	work station ops	3.3.2, 4.6
3.2.4.2.8	EVA rescue capab.	4.6
3.2.4.2.9	EVA w/o resupply	5.4
3.2.4.2.10	resizing reqts	4.3.2
3.2.4.2.11	logistics reqts	5.4
3.2.4.2.12	maintainability	4.0.2.1
3.2.4.2.13	servicing	3.3, 3.5, 5.6
3.2.4.2.14	cleaning/drying	5.6
3.2.4.2.15	data mgmt	3.5.3, 4.5
3.2.4.2.16	c & w, checkout	4.5
3.2.4.2.17	communications	4.4
3.2.4.2.18	contam. (by EVAS)	4.8.10
3.2.4.2.19	decontamination	App B
3.2.4.3	EVA Hardware Requirements	
3.2.4.3.1	EVA tools	2.4
3.2.4.3.2	restr/work sta.	4.6, 5.7
3.2.4.3.3	communications	4.4
3.2.4.3.4	propulsion	4.6
3.2.4.3.5	propulsion system	4.6
3.2.4.3.6	exter. config	4.1, 4.2, 4.6
3.2.4.3.7	guidance & contrl	4.6
3.2.4.3.8	EMU/MMU/spt I/F	4.6
3.2.4.3.9	rescue equip	4.6
3.2.4.3.10	operational life	4.6, App A
3.2.4.3.11	worksite I/F	4.6, 5.7
3.2.4.3.12	sharp corn/impact	4.2.2, 4.6
3.2.4.3.13	meteoroid/debris	4.2.2
3.2.4.3.14	radiation envir.	4.2.1
3.2.4.4	EVA Procedures and Training	
3.2.4.4.1	simulators, tng	3.4
3.2.4.4.3	computer modeling	3.1, 4.5

TABLE 1-1
SOW to FINAL REPORT CROSS-REFERENCE (CONTINUED)

3.3 Space Station EVA Requirements and Interface Accommodations

3.3.1 Atmos. Composition/Press.	5.1
3.3.2 Communications	5.2
3.3.3 Data Management	5.3
3.3.4 Logistics	5.4
3.3.5 EVA Safety	5.5
3.3.6 Impact on EVA Cm autonomy	Section 3, 4.0.2.3
3.3.7 Space Station Interior	5.6
3.3.8 Space Station Exterior	5.7
3.3.9 Space Station Airlock	5.8

SECTION 2

MISSION REQUIREMENTS SURVEY

INTRODUCTION

In order to establish requirements for any type of system, it is first necesary to determine precisely what that system will be called upon to do. For the Space Station EVA System, the missions which the EVAS must support and the tasks it must perform provide that information. If any significant variation in these misions or tasks occurs with time, that time dependency must be established and accounted for. These objectives were accomplished in this portion of the Advanced EVA Systems Study. The approach and results are presented below.

2.1 MISSION AND TASK DETAIL

The study was begun by establishing as much detail as possible about the missions and tasks of the Space Station EVAS. This effort was hindered to some extent by the paucity of reliable information about missions which are 7 to 15 years in the future. Design details were usually sketchy or totally non-existant and quite often the viability of the actual mission was in doubt. Still, enough information existed to derive mission requirements for the Station EVAS.

Several different sources of information were consulted in the search for requirements. For detail on payload servicing missions Langley Data Bases dated March 1984 and May 1985 were consulted. These data bases began in 1991 and 1992, respectively, with the implied assumption that Space Station Initial Operational Capability (IOC) would occur on that initial date. While actual IOC is still unknown, the information derived from the Langley Data Bases should still provide reasonable estimates if referenced to IOC rather than a specific calendar date. As many as possible of the principal investigators or payload sponsors listed in the data bases were questioned. From the latest, perhaps more accurate, Langley Data Base it was determined that, of the 324 total missions, 141 would require some sort of EVA support. These were a mixture of domestic and foreign payloads. All American sponsors were contacted to verify and update the data in the data base. Generally it was found that the information was a sponsor's "best guess" at a very early date on what might fly. A supplement to the above data was a McDonnell Douglas study, the Space Station Customer Accommodation Study (MDC H1300), which provided some early detailed information on selected payloads before release of the current Langley Data Base.

For initial information on Space Station assembly, maintenance, and repair tasks the Space Station Reference Configuration Description and the Space Station Phase B Request For Proposal were consulted. Later, more detailed analyses were available from the McDonnell Douglas Space Station Phase B study organization.

Using the initial data on likely missions for the Space Station EVAS, a list of generic missions was generated which it was believed would describe the things the EVAS would be required to do and which would, by simplifying the analyses and reducing the data-to a manageable size, give a clear picture of those EVAS requirements. Fifteen such generic missions were identified. Table 2-1 lists them and provides further detail on each mission. Time estimates were made for each generic mission and these estimates were used to estimate times for each of the missions derived either from the Langley Data Bases or other Space Station documentation. This process was repeated as new mission data became available, and the Generic 15 Missions were updated as required on the basis of such new data. It should be noted that no significant updating was required as newer or more detailed data became available, indicating that the Generic 15 were both truly generic and complete.

TABLE 2-1
GENERIC EVA MISSIONS

			TIME
1.	ALIGNMENT OF XMITTER/RECEIVER ELEMENTS		0.5 HRS
	A.	OPTICAL ALIGNMENT TASKS	
	B.	RF ALIGNMENT TASKS	
	C.	THOSE REQUIRING EXTRA TOOLS	
	D.	THOSE DESIGNED FOR EVA	
	F.	FREE-FLYER BASED	
2.	DEPLOY/RETRACT SOLAR ARRAY		
	A.	MANUAL DEPLOY/RETRACT OF LINEAR STRUCTURE	0.25 HRS
	B.	CONTINGENCY DEPLOY/RETRACT	0.25
3.	TRUSS STRUCTURE CONSTRUCTION		0.1 HR/ TRUSS ELEMENT
	A.	ASSEMBLY OF TRUSSES TO FORM BOX STRUCTURE	
	B.	ASSEMBLY OF TRUSSES TO FORM FRAME STRUCTURE	
	C.	ASSEMBLY OF TRUSSES FOR SUPPORT POLES AND ASSEMBLY FIXTURES	

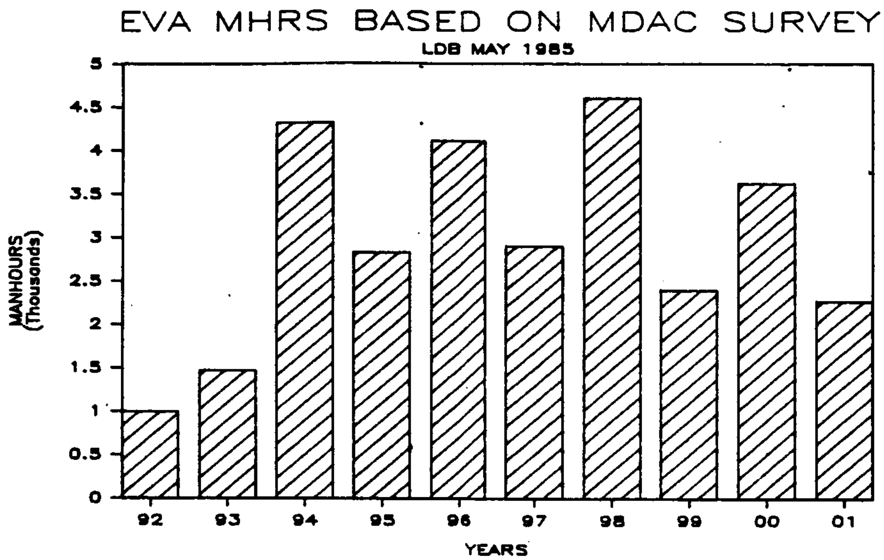
TABLE 2-1
GENERIC EVA MISSIONS (CONTINUED)

				TIME
4.	SATELLITE SERVICE TECHNOLOGY			
	A.	CONNECTOR CHANGEOUT (ELECTRICAL AND FLUID)		2 HRS
	B.	HINGE REPAIR		2 HRS
	C.	MECHANICAL ACTUATOR REPAIR		2 HRS
	D.	THERMAL INSULATION MANIPULATION		0.25 HR
	E.	IMPACT DAMAGE REPAIR		
		I	STRUCTURAL	1 HR
		II	RADIATOR	2 HRS
		III	SOLAR PANELS	2 HRS
	F.	FLUID LINE REPLACEMENT		1 OR 4 HRS
	G.	ELECTRICAL LINE REPLACEMENT		1 OR 4 HRS
	H.	TELESCOPE MIRROR REFINISHING		MULTIPLE DAYS
	I.	ELECTRONIC COMPONENT REPLACEMENT		5 HRS
		I	BLACK BOXES NOT DESIGNED FOR EVA	
		II	PORTIONS OVERLAP WITH I	
		III	INDIVIDUAL COMPONENT REPLACEMENT (SENSORS, DCB'S, PCB COMPONENT)	
	J.	INSPECTION		0.5 HR/SITE
	K.	CABLE ROUTING		75 FT/HR
5.	LARGE MODULES MANIPULATION			1 HR EACH WAY
	O	MODULES > 1 M**3, >250 KG		
	A.	TRANSPORT		
	B.	FINE POSITIONING		
	C.	SECURING		
	D.	EVA COMPATIBLE DESIGNS		
6.	SMALL MODULE MANIPULATION			0.25 HR EACH WAY
	O	MODULES < 1 M**3, <250 KG		
	O	OTHERWISE, SAME AS LARGE MODULE MANIPULATION		
7.	LARGE MIRROR CONSTRUCTION			0.1 HR/TRUSS 0.25 HR/ ELEMENT
	A.	SUBSET OF 5 OR 6		
	B.	MIRROR SUPPORT MAY FORCE SPECIAL HANDLING; I.E., MIRROR ELEMENTS MUST BE PLACED ON INTERIOR OF PARABOLA		
8.	CONSUMABLES RECHARGE VIA MODULE TRANSPORT			1 HR
	A.	SUBSET OF MEDIUM SIZE MODULE MANIPULATION		
	B.	MODULES (TANKS) ARE EMPTIED, NOT CHANGED		
		I	REQUIRE SPECIAL HANDLING TECHNIQUES/EQUIPMENT	
		II	TEMPORARY LINE ROUTING	

TABLE 2-1
GENERIC EVA MISSIONS (CONTINUED)

				TIME
9.	ORBIT LAUNCH OPERATIONS			
	A.	BOOSTERS/SATELLITE/LAUNCHER		
		I	STORAGE	1 HR
		II	ASSEMBLY	16 HRS
		III	CHECKOUT	4-8 HRS
	B.	SOLID AND LIQUID PROPELLANTS		
	C.	REUSEABLE OTV'S		
		I	REFURBISH/REFUEL	16 HRS
		II	ASSEMBLY/CHECKOUT	24 HRS
10.	SATELLITE OPERATIONS			
	O	<250 KG, FREE FLYERS		
	O	WITHIN 1 KM OF STATION		
	A.	DEPLOY		1 HR
	B.	RETRIEVAL		1 HR
	C.	OPERATION		AS REQUIRED
11.	SPACE STATION RADIATOR CONSTRUCTION (FROM ORBITER)			3 HRS/PANEL
	A.	SUBSET OF LARGE MODULE MANIPULATION (>1 M**3)		
	B.	HANDLING ELEMENTS WITH SENSITIVE SURFACES		
	C.	HANDLING OF LONG, THIN STRUCTURES		
12.	ORBITER SUPPORTED LARGE MODULE MANIPULATION			
	A.	TRUSS STRUCTURE MODULE HANDLING		0.5 HR
	B.	HABITABILITY MODULE HANDLING		0.1 HR
	C.	SUPPORTED ONLY BY ORBITER		
13.	ORBITER SUPPORTED TRUSS CONSTRUCTION/DEPLOYMENT			0.1 HR/TRUSS
	A.	ASSEMBLY		
	B.	DEPLOYMENT		
14.	RADIATOR CONSTRUCTION-FULL UP SPACE STATION			3 HRS/PANEL + 1 HR OVERHEAD
	A.	SAME AS 11, NO ORBITER		
	B.	TASK EXECUTION DIFFERENT		
15.	EVA RESCUE			
	A.	RETURN DISABLED CREWMAN TO INTERIOR OF STATION		0.3 HR
	B.	RETURN OF STRANDED FREE-FLYING ASTRONAUT TO STRUCTURES OF STATION		0.3 HR
	C.	TRANSFER OF PERSONNEL FROM DISABLED STATION TO ORBITER OR VICE-VERSA		0.3 HR/ CREWMAN

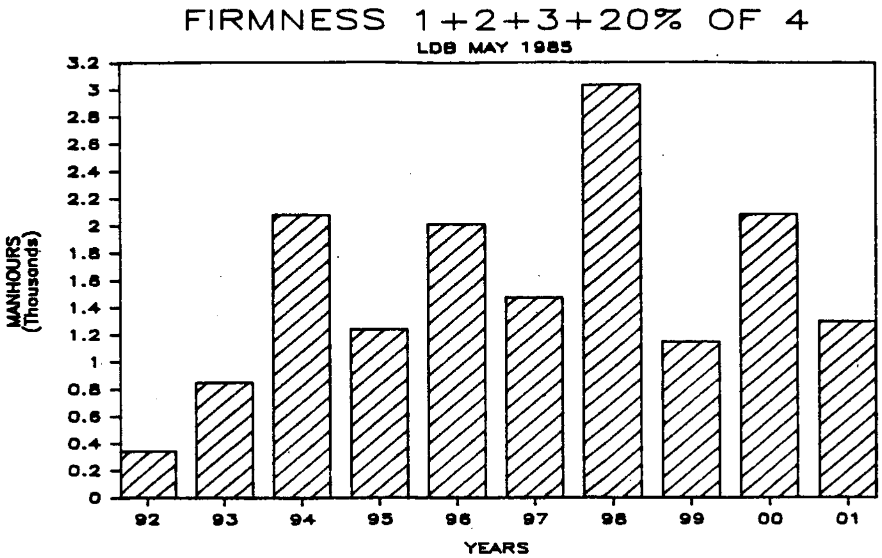
As noted above, the Generic 15 Missions were used to estimate EVA time required for each of the identified missions. These estimates were then summed to arrive at estimates of EVA time required per year for customer support. Figure 2-1 presents the results of this process.



YEAR	92	93	94	95	96	97	98	99	00	01
EVA MHRS/YR	1004	1476	4330	2836	4116	2904	4610	2400	3628	2270
EVA MHRS/WK	20	29	84	55	80	56	89	47	70	44

Figure 2-1
Total EVA Mission Manhour Requirements for the Space Station Program

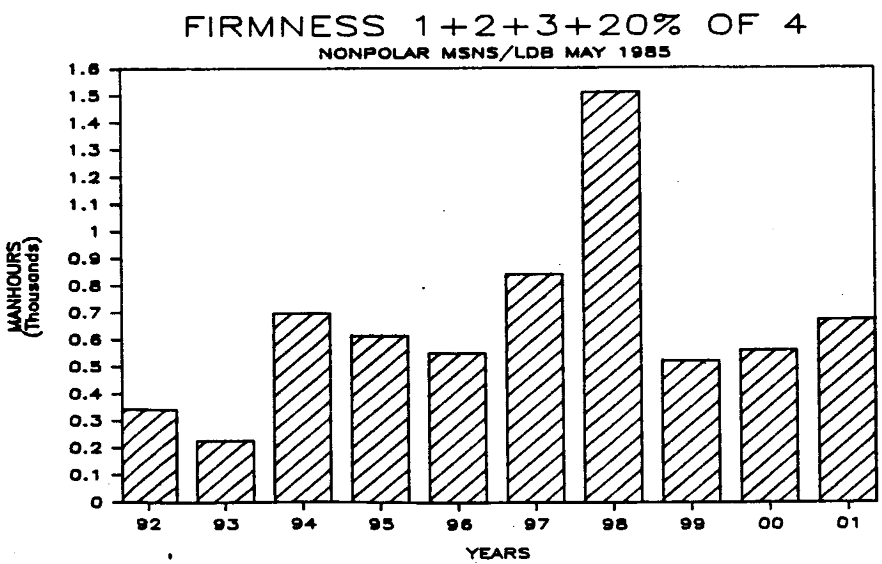
As the figure indicates, our analyses yield the information that a minimum of slightly more than 1000 manhours of EVA time per year will be required at Station IOC and that within two years approximately 4500 manhours of EVA time will be required per year. There are two problems with this estimate. First, it includes polar missions which probably will not be supported with EVA from the Station. Second, it includes many missions which have only a very low probability of flying. To address these problems, a ranking as to firmness, to be discussed in further detail below, was applied to the list of missions to determine which missions had a high and which missions had a low probability of flying. The missions were ordered on a scale from 1 to 5 with a 1 indicating a mission that was certain to fly and a 5 indicating a mission which would almost certainly not fly. A new sum of EVA manhours required per year was generated, this time including only those missions with a firmness rating of 1, 2, or 3 plus 20 percent of the time required for those missions with a firmness of 4. Results are presented in Figure 2-2.



YEAR	92	93	94	95	96	97	98	99	00	01
EVA MHRS/YR	349	856	2087	1246	2020	1480	3040	1150	2090	1300
EVA MHRS/WK	7	17	41	24	39	29	59	23	41	25

Figure 2-2
Estimated EVA Manhour Requirements Considering Firmness Ratings

Finally, all polar missions were removed from the estimates, yielding times as presented in Figure 2-3.



YEAR	92	93	94	95	96	97	98	99	00	01
EVA MHRS/YR	346	229	700	617	551	842	1512	522	562	674
EVA MHRS/WK	7	5	14	12	11	17	30	10	11	13

Figure 2-3
Estimated EVA Mission Manhour Requirements for Space Station Core

As indicated, 346 manhours of EVA time are estimated to be required in the first year of Space Station operation, increasing to a maximum of 1512 manhours required in the seventh year of Station operation. Two cautions go with these estimates. First, these are only estimates, heavily dependent on guesswork about missions as far as fifteen years in the future. Second, related to the first caveat, a "tail-off" phenomenon exists after the third year of Station operation, indicating that few experimenters and payload sponsors wish to guess about events so far in the future. This yields what is probably a false tail-off in required EVA hours in the latter years covered by the estimates and causes such estimates as exist to consist heavily of firmness 4 missions, yielding a further reduction due to our weighting procedure.

Space Station construction time estimates were derived by assigning times based on the Generic 15 Missions to construction tasks and plans presented in the Space Station Reference Configuration Description (JSC 19989) and to tasks and plans developed by MDAC Phase B Space Station personnel for the dual-keel configuration. The RCD scenario with associated time estimates is shown in Table 2-2 while the dual-keel scenario, with time estimates, is presented in Table 2-3. While Station construction may have significant impacts on Space Shuttle EVA support requirements, it does not seem to drive Space Station EVAS requirements, except to the extent of possibly driving the point at which the Station airlock is brought up for assembly with the rest of the Station. Otherwise there is insufficient data to properly integrate SS construction with the time phased SS EVA mission requirements.

TABLE 2-2
SPACE STATION ASSEMBLY EVA HOURS

	MDAC	RCD
FLIGHT 1		
1) ERECT BERTHING STRUCTURE, INSTALL PORT		
- 12 STRUTS X 0.1 HR	1.2	0.67
- 1 LARGE MODULE MANIP.	0.5	
2) INSTALL RADIATOR PANELS		
- 2 PANELS X 3.0 HRS	6.0	4.33
3) INSTALL MRMS		
- 2 LARGE MODULE MANIP. X 0.5 HR	1.0	1.67
4) CHECKOUT MRMS	0.5	0.5
TOTAL	9.2	7.2
FLIGHT 2		
1) ERECT KEEL EXTENSION BAYS		
- 92 ELEMENTS X 0.1 HRS	9.2	2.79
- 1 LARGE MODULE MANIP. (MRMS)	2.0	
2) INSTALL RADIATOR PANELS		
- 1 PANEL X 3.0 HRS	3.0	0.51
3) ATTACH KEEL EXTENSION PACKAGE TO RAILS		
- 1 LARGE MODULE MANIP. (MRMS)	2.0	3.65
4) ATTACH KEEL PACKAGE TO TRANSVERSE BOOM	0.5	1.0
TOTAL	16.7	7.95
FLIGHT 3		
1) ATTACH HM1 TO KEEL	1.0	2.67
2) INSTALL AIRLOCKS		
- LARGE MODULE MANIP. X 2 X 0.5 HRS	1.0	0.0
TOTAL	2.0	2.67
FLIGHT 4		
1) ATTACH NEW MODULE	1.0	2.65
2) MOVE AIRLOCK	0.5	0.0
3) INSTALL UPPER KEEL		
- LARGE MODULE MANIP.	2.0	2.17
TOTAL	3.5	4.82

TABLE 2-2
SPACE STATION ASSEMBLY EVA HOURS (CONTINUED)

	MDAC	RCD
FLIGHT 5		
1) INSTALL SOLAR ARRAY PACKAGE - 2 X LARGE MODULE MANIP. (MRMS)	4.0	5.07
2) ATTACH NEW MODULE	1.0	0.25
TOTAL	5.0	5.32
FLIGHT 6		
1) ATTACH NEW MODULE	1.0	2.5
TOTAL	1.0	2.5
FLIGHT 7		
1) ATTACH NEW MODULE	1.0	2.58
TOTAL	1.0	2.58
IN ADDITION, 42 MORE RADIATOR ELEMENTS MUST BE INSTALLED BETWEEN FLIGHTS THREE AND FIVE, INCLUSIVE, FOR A TOTAL OF 21 ADDITIONAL HRS SPREAD OVER THOSE FLIGHTS.	21.0	3.57
IOC TOTAL (HRS)	59.4	36.6

TABLE 2-3
EVA MANHOURS REQUIRED FOR DUAL KEEL POWER TOWER CONSTRUCTION
9 FOOT DEPLOYABLE

FLIGHT 1	
1) INSTALL RADIATOR PANELS	
- POWER SYSTEM (1 PANEL)	6.0
- OVERHEAD	2.0
- GIMBAL, BOOM INSTALLATION	2.0
2) ATTACH PACKAGE TO TRUNNIONS	
- 1 LARGE MODULE MANIPULATION (SRMS)	0.5
3) INSTALL DEPLOYMENT RAILS	1.0
4) ATTACH OUTBOARD ARRAYS	
- 8 STRUTS (0.2 MHRS/STRUT)	1.6
- 1 LARGE MODULE MANIPULATION (SRMS)	0.5
5) OBSERVATION/INSPECTION TASKS (3 MIN/BAY)	
- ALL AUTO DEPLOY SEQUENCES	3.9
- INSPECT 21 DEPLOYABLE BAYS	1.1
6) UTILITY TRAYS (45 TRAYS)	
- 5 TRAYS (1.0 MHRS/TRAY)	5.0
TOTAL	23.6
FLIGHT 2	
1) INSTALL MRMS	
- 2 LARGE MODULE MANIPULATIONS (SRMS)	1.0
- ATTACH MANIPULATOR BOOM	1.0
- CHECKOUT	4.0
2) ATTACH KEEL PACKAGES TO TRANSVERSE BOOM	
- 2 LARGE MODULE MANIPULATIONS (MRMS)	4.0
- 16 STRUTS	3.2
3) OBSERVATION/INSPECTION TASKS	
- INSPECT 32 DEPLOYABLE BAYS	1.6
4) INSTALL RCS MODULES	
- 1 MODULE (5.0 MHRS/MODULE)	5.0
5) UTILITY TRAYS (45 FT TRAYS)	
- 2 TRAYS	2.0
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
TOTAL	23.8

TABLE 2-3
EVA MANHOURS REQUIRED FOR DUAL KEEL POWER TOWER CONSTRUCTION
9 FOOT DEPLOYABLE (CONTINUED)

FLIGHT 3	
1) ATTACH MODULE TO STRUCTURE	
- 8 STRUTS	1.6
- CONNECT UTILITIES	0.5
2) INSTALL RCS MODULES	
- 1 MODULE (5.0 MHRS/MODULE)	5.0
3) UTILITY TRAYS (45 FT TRAYS)	
- 5 TRAYS	5.0
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
4) INSTALL RADIATOR PANELS (1.0 MHRS/ELEMENT)	
- MAIN (7 ELEMENTS)	7.0
- OVERHEAD	2.0
TOTAL	23.1
FLIGHT 4	
1) ATTACH UPPER & LOWER BOOM PACKAGES	
- 2 LARGE MODULE MANIPULATIONS (MRMS)	2.0
- 16 STRUTS	3.2
2) OBSERVATION/INSPECTION TASKS	
- INSPECT 13 DEPLOYABLE BAYS	0.7
3) UTILITY TRAYS (45 TRAYS)	
- 2 TRAYS	2.0
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
4) INSTALL ANTENNA BOOMS & ANTENNAS	
- 12 STRUTS	2.4
- 2 SMALL MODULE MANIPULATIONS (MRMS)	2.0
- DEPLOY BOOMS (2)	1.0
- MOUNT/ALIGN 9 ANTENNAS (1.0 MHRS/ANTENNA)	9.0
5) INSTALL RADIATOR PANELS (1.0 MHRS/ELEMENT)	
- MAIN (6 ELEMENTS)	6.0
- OVERHEAD	2.0
TOTAL	31.4
FLIGHT 5	
NO PLANNED EVA'S	
TOTAL	0.0
FLIGHT 6	
NO PLANNED EVA'S	
TOTAL	0.0

TABLE 2-3

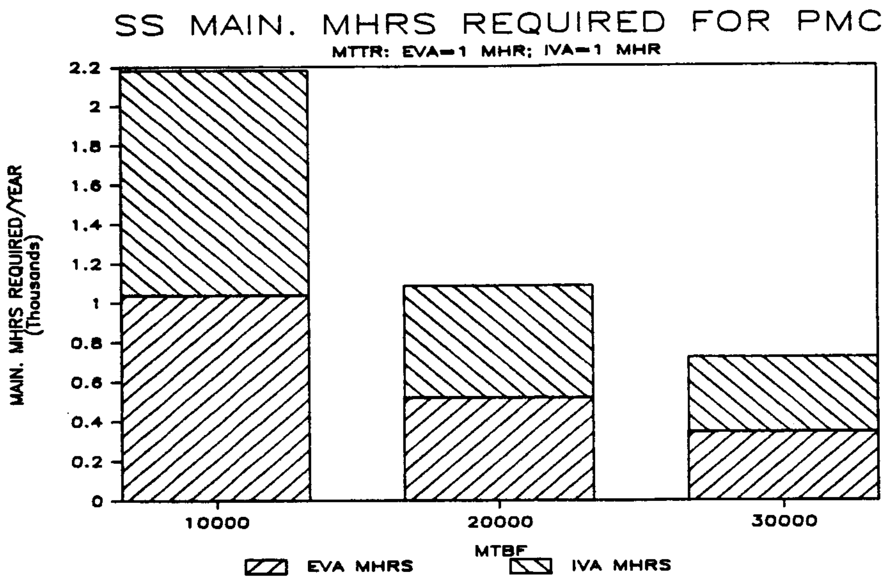
EVA MANHOURS REQUIRED FOR DUAL KEEL POWER TOWER CONSTRUCTION
9 FOOT DEPLOYABLE (CONTINUED)

FLIGHT 7	
1) INSTALL RADIATOR PANELS	
- POWER SYSTEM (1 PANEL)	6.0
- OVERHEAD	2.0
- GIMBAL, BOOM INSTALLION	3.0
2) REMOVE FLT 1 DOCKING MECHANISM	1.0
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
3) ATTACH OUTBOARD ARRAYS	
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
- 8 STRUTS	1.6
4) CONNECT TRANSVERSE BOOM HALVES	
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
- 8 STRUTS	1.6
5) OBSERVATION/INSPECTION TASKS	
- INSPECT 19 BAYS	1.0
6) UTILITY TRAYS	
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
- 5 TRAYS	5.0
TOTAL	29.2
FLIGHT 8	
1) ATTACH KEEL PACKAGES TO TRANSVERSE BOOM	
- 2 LARGE MODULE MANIPULATIONS (MRMS)	4.0
- 16 STRUTS	3.2
2) OBSERVATION/INSPECTION TASKS (3 MIN/BAY)	
- INSPECT 31 DEPLOYABLE BAYS	1.6
3) INSTALL RCS MODULES	
- 2 MODULES (5.0 MHRS/TRAY)	10.0
4) UTILITY TRAYS (45 FT TRAYS)	
- 4 TRAYS (1.0 MHRS/TRAY)	4.0
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
5) ATTACH MODULE SUPPORT STRUCTURE (AFT)	
- 16 STRUTS	3.2
- 8 STRUTS (MODULE #3)	1.6
6) INSTALL RADIATOR PANELS (1.0 MHRS/ELEMENT)	
- MAIN (16 ELEMENTS)	16.0
- OVERHEAD	2.0
TOTAL	47.6

TABLE 2-3
EVA MANHOURS REQUIRED FOR DUAL KEEL POWER TOWER CONSTRUCTION
9 FOOT DEPLOYABLE (CONTINUED)

FLIGHT 9	
1) ATTACH MODULE TO STRUCTURE	
- 8 STRUTS	1.6
- CONNECT UTILITIES	0.5
2) ATTACH UPPER & LOWER BOOM PACKAGES	
- 2 LARGE MODULE MANIPULATIONS (MRMS)	4.0
- 16 STRUTS	3.2
3) OBSERVATION/INSPECTION TASKS (3 MIN/BAY)	
- INSPECT 14 DEPLOYABLE BAYS	0.7
4) UTILITY TRAYS (45 FOOT TRAYS)	
- 8 TRAYS (1.0 MHRS/TRAY)	8.0
- 1 LARGE MODULE MANIPULATION (MRMS)	2.0
5) INSTALL RADIATOR PANELS (1.0 MHRS/ELEMENT)	
- MAIN (4 ELEMENTS)	4.0
TOTAL	24.0
FLIGHT 10	
1) INSTALL ANTENNA BOOMS & ANTENNAS	
- 12 STRUTS	2.4
- 2 SMALL MODULE MANIPULATIONS	1.0
- DEPLOY BOOMS (2)	1.0
- MOUNT/ALIGN 9 ANTENNAS	9.0
2) INSTALL RADIATOR PANELS (1.0 MHRS/ELEMENT)	
- MAIN (10 ELEMENTS)	10.0
TOTAL	24.4
FLIGHT 11	
1) ATTACH MODULE TO STRUCTURE	
- 8 STRUTS	1.6
- CONNECT UTILITIES	0.5
2) INSTALL RADIATOR PANELS (1.0 MHRS/ELEMENT)	
- MAIN (15 ELEMENTS)	15.0
TOTAL	17.1
FLIGHT 12	
NO PLANNED EVA'S	
TOTAL	0.0
IOC TOTAL (MHRS)	241.2

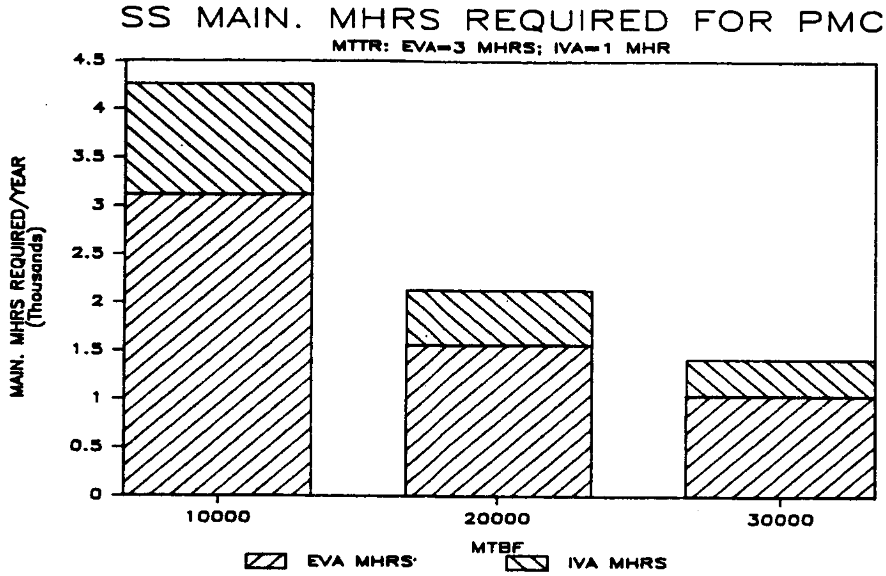
Station EVA maintenance requirements were derived in part from ongoing Phase B studies of on-orbit maintenance requirements. Estimates of ORU quantities were made for each SS work package, including allocations of both IVA and EVA ORU's. Estimates of Mean Time Between Failure (MTBF) of 10,000, 20,000, and 30,000 hours were then assumed in order to determine the frequency of required maintenance activity if all systems were operated to failure. The Mean Time To Repair (MTTR) for a properly designed EVA ORU was then defined to be one hour which resulted in the unscheduled maintenance requirements shown in Figure 2-4.



		CORRECTIVE <-----10000----->			SCHED.	GRAND TOTAL	CORRECTIVE <-----20000----->			SCHED.	GRAND TOTAL	CORRECTIVE <-----30000----->			SCHED.	GRAND TOTAL
WP NO	ORU'S NO	EVA	IVA	TOTAL			EVA	IVA	TOTAL			EVA	IVA	TOTAL		
1	500	188	249	437	500	937	94	124	218	500	718	63	83	146	500	646
2	875	362	403	764	875	1639	181	201	382	875	1257	121	134	255	875	1130
3	750	197	459	655	750	1405	98	229	328	750	1078	66	153	218	750	968
4	375	295	33	328	375	703	147	16	164	375	539	98	11	109	375	484
	2500	1042	1144	2184	2500	4684	520	570	1092	2500	3592	348	381	728	2500	3228

Figure 2-4
Total Eva Manhours Required for ORU Replacement

A second estimate was performed with MTTR defined as three hours. The results are shown in Figure 2-5.

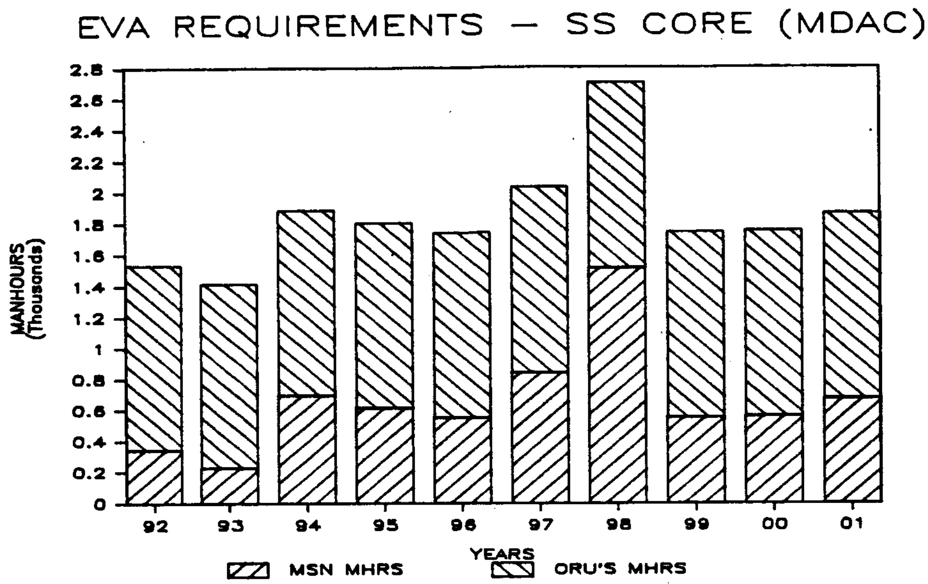


WP NO	NO ORU'S	CORRECTIVE 10000 EVA	IVA	TOTAL	SCHED.	GRAND TOTAL	CORRECTIVE 20000 EVA	IVA	TOTAL	SCHED.	GRAND TOTAL	CORRECTIVE 30000 EVA	IVA	TOTAL	SCHED.	GRAND TOTAL
1	500	563	249	812	500	1312	282	124	406	500	906	188	83	271	500	771
2	875	1085	403	1488	875	2363	542	201	744	875	1619	362	134	496	875	1371
3	750	590	459	1048	750	1789	295	229	524	750	1274	197	153	349	750	1099
4	375	885	33	917	375	1292	442	16	459	375	834	295	11	306	375	681
	2500	3123	1144	4265	2500	6766	1561	570	2133	2500	4633	1042	381	1422	2500	3922

Figure 2-5
Total Eva Manhours Required for ORU Replacement

The number finally chosen to allocate yearly for EVA maintenance, however, was based on estimating an average of one hour per EVA ORU per year to reflect the use of scheduled or planned EVA maintenance to enhance SS maintainability overall. Until system definition and development proceeds much nearer to completion, and a more accurate determination including actual failure history can be made of systems maintenance requirements, the allocation of 1192 EVA manhours yearly is a very realistic estimate for SS maintenance requirements.

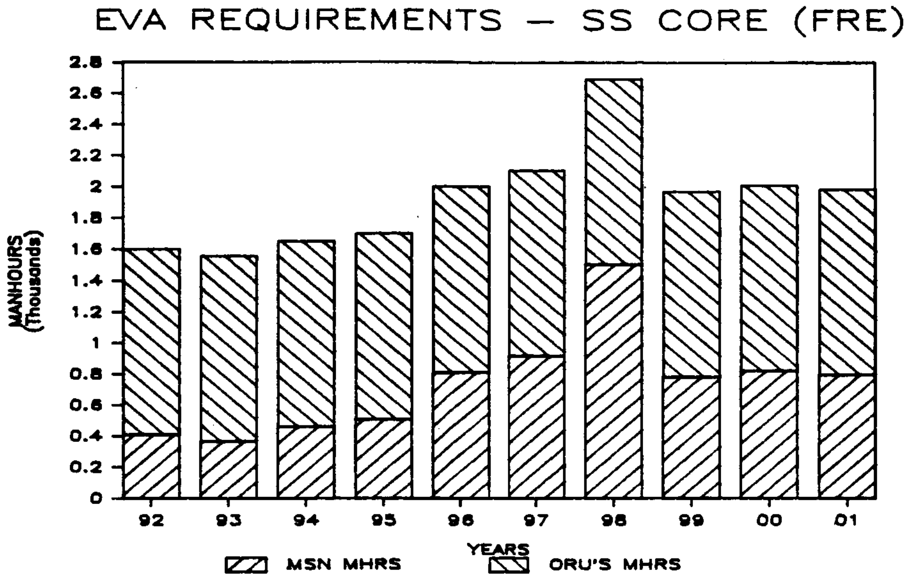
Total required EVA manhours per year were estimated by combining the above Station maintenance hours with the payload EVA mission hours presented in Figure 2-3. The result is presented in Figure 2-6.



YEAR	92	93	94	95	96	97	98	99	00	01
EVA USER MSN MHRS	346	229	700	617	552	842	1512	552	562	674
EVA ORU'S MAINT.	1192	1192	1192	1192	1192	1192	1192	1192	1192	1192
EVA TOTAL MHRS/YR	1538	1421	1892	1809	1744	2034	2704	1744	1754	1866
EVENTS/YR	129	119	158	151	146	170	225	146	147	156
EVA MHRS/WK	30	28	37	35	34	40	52	34	34	36
EVA EVENTS/WK	3	3	4	3	3	4	5	3	3	3

Figure 2-6
Total EVA Missions Plus ORU Manhours

It shows that a minimum requirement of about 1400 manhours per year in the neighborhood of IOC grows to a requirement for approximately 2700 manhours per year at IOC + 6. Compare this with the Functional Requirements Envelope (FRE) defined by NASA in a letter dated 23 May 1985 and presented in Figure 2-7.



YEAR	92	93	94	95	96	97	98	99	00	01
EVA USER MSN MHRS	412	368	462	509	810	915	1504	780	820	794
EVA ORU'S MAINT.	1192	1192	1192	1192	1192	1192	1192	1192	1192	1192
EVA TOTAL MHRS/YR	1604	1560	1654	1701	2002	2107	2692	1972	2012	1986
EVENTS/YR	134	130	138	142	167	176	225	165	168	166
EVA MHRS/WK	31	30	32	33	39	41	52	38	39	39
EVA EVENTS/WK	3	3	3	3	4	4	5	4	4	4

Figure 2-7
Total EVA Missions Plus ORU Manhours

The FRE corresponds closely to our estimates and either should suffice to define EVA manhour requirements given current knowledge. The most significant preliminary conclusion to be drawn from our EVA manhour requirements data (or the FRE) is that, even with the stated caveats, the required amount of EVA will far exceed that which could be provided by the current Shuttle EVAS. In fact, it quickly approaches EVA crew physiological limits as defined both by the RCD and by past (Shuttle) EVA experience. This will be discussed further, below.

2.2 MISSION PRIORITIZATION

As noted above, all customer support missions were prioritized with respect to firmness of the mission, that is, the probability that it would actually fly. These estimates of firmness were derived from conversations with the mission sponsors, in general, and were usually either equal to a firmness of 3, indicating a funded misssion in very early stages of development, or a 4, indicating a customer with a mission, no money, but with some chance of obtaining money. Some priority 1 and 2 missions were also noted, indicating operational missions or those scheduled for launch.

Missions were also prioritized according to maturity, that is, maturity of technology required to support that mission. The prioritization was once again on a scale of from 1 to 5 with a 1 indicating a low level of technological maturity, hence high risk and much required development, and a 5 indicating operational technology with no particular (technological) risk associated with it's use.

Originally, the intention was to sum the above two prioritizations for each mission to arrive at a single paramater to be used in ranking the missions from top to bottom. A mission with a low combined priority number would thus receive the greatest attention since it had the highest probability of actually occuring but required the greatest technology development. The lack of firmness in the mission estimates rendered the contemplated process useless since most missions had such a low (4 or sometimes 3 rating) probability of flying. Resources should not be allocated to missions which may never fly. The dilemma of resource allocation was resolved when the mission analyses and particularly the Generic 15 Tasks were assessed with respect to our existing data base of EVA knowledge.

2.3 ASSESS REQUIREMENTS AGAINST AN EXISTING DATA BASE

The Space Station EVAS requirements were compared on a task-by-task basis with current Shuttle EVAS capabilities. The general conclusion was that all requirements were well within the capabilities of a suited crewmember to perform. That is, no specific EVAS hardware requirements or capabilities were driven by the information on missions and tasks which were obtained. Thus, any reasonable crew enclosure and life support system would probably provide the crewmember with the capability to perform any single identified EVA task.

Difficulties arose, however, when the EVAS capabilities were considered in light of likely 90 day mission models consisting of many EVA tasks arranged in some probable time schedule. Two basic problem areas were identified.

First, EVA operational impacts to Shuttle flights could not be tolerated on the Space Station. This was particularly true in the case of three specific impacts. The frequent large pressure changes in cabin atmosphere incurred as a normal part of Shuttle EVA's could not be tolerated on the Station with its sensitive scientific experiments. Similarly, all Station operations could not be driven by EVA support requirements as they are on the Shuttle. EVA must be a routine, minimum impact part of day-to-day Station operations, not a special case requiring maximum attention from all hands. Finally, the heavy task-specific prelaunch training encountered in preparing Shuttle crews for EVA tasks will not be possible for Station crewmembers. Too many nominal and far too many contingency tasks are possible during the course of a 90 day mission to specifically train for them on the ground prior to flight. These operational impacts, then, require different handling on Space Station than they did on Shuttle.

The second major difficulty arising from considering the entire EVA mission model instead of just individual tasks is the problem of EVAS maintenance. Currently, all EVA equipment undergoes a maintenance cycle after every flight. For most equipment this involves an extensive tear-down, test, and component replacement with subsequent reassembly and complicated test and certification for re-flight. Such procedures are not possible on the Space Station due to time, personnel, operational, and material limitations. A stronger emphasis on maintainability in the design philosophy is thus called for, leading to an EVAS which requires very little maintenance per hour of operation, fails in a safe manner when it does fail, and which can be easily and quickly repaired or serviced when required.

The actual hardware impacts associated with these findings will be discussed in depth in Section 4 of this report, but the above considerations constitute the drivers for the requirements embodied therein.

2.4 ANCILLARY EQUIPMENT REQUIREMENTS

Partly as a result of the assessment of EVAS requirements against an existing database of EVA experience and knowledge, and partly as a result of a dedicated analysis effort based on the Generic 15 Missions and the various mission models, a list of approximately 120 pieces of EVA ancillary equipment was derived. Table 2-4 lists the ancillary equipment as it is currently defined. While this list is felt to be reasonably complete, it will, no doubt, undergo further refinement as Space Station systems themselves become more refined and should in any case be a dynamic, continually evolving list.

Two broad categories of equipment, Generic Equipment and Special Equipment were included in the list. Generic Equipment would be provided as a normal part of the EVAS in standard equipment/tool kits, arranged most likely into a nominal tool kit and supplementary kits. Special Equipment would be provided by individual payload sponsors as required to service their particular payloads, assuming that equipment from the generic kits would not suffice.

TABLE 2-4
ANCILLARY EQUIPMENT

GENERIC ANCILLARY EQUIPMENT
- TOOLS
  - POWER TOOLS
  - MANUAL WRENCHES
  - SOCKET SETS
  - FORCEPS/PLIERS
  - SCREWDRIVERS
  - SCREW EXTRACTOR
  - NUT HANDLER
  - ALLEN WRENCHES
  - HAMMERS
  - TORQUE WRENCHES
  - SAW WITH DEBRIS COLLECTING BAG
  - NIBBLER - POWER OR SHEAR
  - CABLE CUTTERS
  - BOLT CUTTERS
  - SURFACE COATING APPARATUS
    - PAINTING
    - MIRROR REFINISHING
  - DRILL AND BITS
  - WELDING/SOLDERING/BRAZING EQUIPMENT
  - THERMAL BLANKET CUTTING DEVICE
  - TUBE CUTTER
  - PORTABLE HEATER
  - TUBE BENDERS
  - SANDER/LARGE GRINDER
  - SMALL GRINDER
  - FILES
  - PRYBAR
  - GEAR PULLER
  - RIVET GUN
  - "AIRCRAFT LINE" CUTTER
  - LINE SPLICING KIT
  - CONNECTOR TOOLS
    - ALIGNMENT AID
    - CONNECTOR PULLER
    - PIN STRAIGHTER
  - DIAGONAL CUTTERS
  - DE-GAUSSER
  - CONNECTOR REPLACEMENT KIT
    (FOR ELECTRICAL, FLUID LINES)
  - ELECTRICAL SPLICING KIT
  - WIRE STRIPPERS/CUTTERS
  - PIN REPLACEMENT KIT

TABLE 2-4
ANCILLARY EQUIPMENT (CONTINUED)

RESTRAINTS/HANDLING AIDS
FOOT RESTRAINT & POSITIONER
PAYLOAD RETENTION DEVICE
RESTRAINT STRAPS
MANIPULATOR FOOT RESTRAINTS
ATTACHABLE/DETACHABLE TETHER POINTS
ATTACHABLE/DETACHABLE HANDRAILS
TETHERS
MODULE TRANSPORT DEVICE
EQUIPMENT TRANSFER BOOM
TEMPORARY STOWAGE FIXTURES
"CAPTURE NET" FOR TUMBLING SATELLITIES
STRUCTURAL CLAMPS & BRACES
GUIDE RAILS FOR POSITIONING
MATERIALS
GUY WIRES
ADHESIVE TAPE
THERMAL INSULATION KIT (BLANKETS & SPRAY-ON)
THERMAL COVER REPLACEMENT KIT
SUN SHADES FOR TANKS
GASKET & SEAL MAKING KIT
TIE WRAP KIT
CABLE RESTRAINT TAPE
ID TAGS FOR CABLES
STRAIN RELIEF MOUNT EQUIPMENT
TEFLON TAPE
POTTING COMPOUND
ACCESSORIES
TOOL BOARD
GARBAGE BAGS
LIGHTS - HELMENT & FLOODLIGHTS
COVERALL/APRONS & GLOVE PROTECTORS
MAGNIFIER
CARRYALL BAG
CLOTH WIPES/RAGS
"DROP CLOTH" FOR WELDING/INSTRUMENT PROTECTION
CONTAMINATION CLEANUP KIT
HEAT SINK

TABLE 2-4
ANCILLARY EQUIPMENT (CONTINUED)

- SENSORS
  - INSPECTION/CRACK DETECTION EQUIPMENT
    - "DYE PENETRANTS", X-RAY
    - UV LIGHTS
    - BORE SIGHTS & INSPECTION MIRRORS
  - TV CAMERAS, HELMET & PORTABLE
  - VIBRATION & THERMAL SENSORS
  - STILL CAMERAS
  - LEAK DETECTOR
  - ELECTRICAL TEST INSTRUMENTS

SPECIAL ANCILLARY EQUIPMENT

- TOOLS
  - WALDOES FOR RADIOISOTOPE HANDLING
  - SPECIFIC MODULE SERVICING TOOLS
  - JAM JACK
  - LINE PURGE KIT
  - GASKET & SEAL MAKING KIT
  - TOXIC SUBSTANCE FILL KIT
  - FLUID SAMPLE COLLECTION KIT

- RESTRAINTS/HANDLING AIDS
  - SATELLITE FSS W/TURNTABLES PLUS POWER & MANUAL CRANKS
  - HANDLING FIXTURES (FOR RADIATORS,ETC)
  - GRAPPLE DEVICE FOR SATELLITE PICKUP

- MATERIALS
  - SPACE QUALIFIED "LOCTITE"
  - LUBRICANTS
  - JOINT UNFREEZER "LIQUID WRENCH"
  - STRUCTURAL/MECHANICAL REPAIR KIT
    - INCLUDING COMPOSITES REPAIR KIT
  - EPOXIES
  - STRUCTURAL FITTING REPLACEMENT
  - FABRIC PATCH KIT
  - ALIGNMENT MAKER
  - VENT LINES/PORTABLE PLUMBING
  - LINE CAPS
  - LEAK PATCH KITS
  - CLEANERS
    - SPRAY ON
    - PREPREG
    - WIPES
  - ELECTRICAL INSULATION MATERIAL

- SENSORS
  - ALIGNMENT INSTRUMENTATION
    - (FOR OPTICS, ANTENNAS, ETC)
  - HYDRAZINE/TOXIC SUBSTANCE DETECTOR
  - PRESSURE GAUGES/PRESS INTEGRITY CHECK KIT

It should be noted that the ancillary equipment list currently contains both off-the-shelf hardware and hardware requiring various amounts of development. Often a significant portion of such hardware development consists solely of making an otherwise off-the-shelf item compatible with EVA operations. As a general guideline in EVA operations design, it is desirable to minimize new hardware development by avoiding the use of Special Equipment and by maximizing the use of the Generic Equipment already provided. However, the primary emphasis should be on minimizing all loose equipment (Generic or Special) by proper design of the subject equipment's interface with the EVAS. For instance, use of captured butterfly latches on access ports is much to be preferred over the use of bolts or screws requiring wrenches or screwdrivers. While wrenches and screwdrivers are very much off-the-shelf equipment, the butterfly latch dispenses with all loose equipment (insofar as it's own operation is concerned) and is therefore better than bolts and screws requiring tools to operate them.

2.5 DOD EVA REQUIREMENTS

DOD EVA requirements were coordinated through the USAF Space Division in El Segundo, California. The DOD has no current mission specific EVA requirements but it is expected that such requirements will arise in the future. Instead, the DOD has expressed twelve "concerns" which it believes must be addressed by the EVAS in order for it to be usable on defense-related missions. These twelve concerns are detailed in Table 2-5. Eleven of these concerns are already included as considerations in the Space Station EVA study. The twelth concern - an expressed desire for a two minute EMU don/doff capability - is not a requirement for the Space Station EVAS. If this is an actual DOD requirement, it may necessitate a separate crew enclosure design and possibly a separate life support subsystem design from that envisioned for the Space Station. It was suggested that this capability for rapid don/doff might be used in conjunction with a transatmospheric vehicle for scramble and launch from a conventional runway. If this is so, it should be noted that the Space Station EMU has no requirement to bear multiple-g loading and may be unsuitable for such activities.

TABLE 2-5
DOD SPACE SUIT ISSUES STATEMENT

MOBILITY
GLOVE/SUIT MOBILITY AND TACTILE SENSITIVITY MUST BE SIGNIFICANTLY IMPROVED

MAINTAINABILITY
THE SUIT SHOULD BE CAPABLE OF USE ON EXTENDED DURATION ORBITAL MISSIONS, TO INCLUDE EASE OF MAINTENANCE AND RAPID RESIZING

RADIATION PROTECTION
EVA CREW MEMBERS SHOULD BE OFFERED AT LEAST THE SAME PROTECTION AGAINST RADIATION AS THE CREW MEMBERS WHO REMAIN INSIDE

STATIC CHARGING HAZARD
SUITS MUST BE RESISTANT TO THE EFFECTS OF SUDDEN ELECTROSTATIC DISCHARGES ENCOUNTERED IN HIGH INCLINATION ORBITS AND NOT BE SUBJECT TO STATIC CHARGE BUILDUP

IMMEDIATE EVA CAPABILITY
NEITHER AN EXTENDED PERIOD OF REDUCED CABIN PRESSURE NOR PROTRACTED PREBRETHING SHOULD BE REQUIRED PRIOR TO EVA

CONTAMINATION
THE EVA SYSTEM SHALL NOT BE A SOURCE OF CONTAMINANTS

SIZING
RESIZING SHALL BE RAPID AND SIMPLE AND SHALL BE ACCOMPLISHED VIA MINIMUM OF COMPONENT SIZES

HEADS-UP DISPLAY (HUD)
THE EMU SHOULD BE EQUIPPED WITH A HEADS UP DISPLAY FOR PRODUCTIVITY ENHANCEMENT

MICROMETEOROID PROTECTION
PROTECTION FROM MICROMETEORIOD IMPACTS SHOULD BE AN INHERENT FEATURE OF THE SUIT

COMFORT
THE SUIT SHOULD PROVIDE TEMPERATURE, HUMIDITY, FIT AND FUNCTIONAL COMFORT

CONTINGENCY TRANSLATION AIDS
A CONTINGENCY TRANSLATION AID AS AN INHERENT SUIT FEATURE FEATURE COULD CONTRIBUTE TO REDUCTION OF THE NEEDS FOR TETHERS

DONNING AND DOFFING
SPACE SUITS FOR DOD MISSIONS SHOULD BE DONNABLE IN LESS THAN TWO MINUTES

CONCLUSIONS

The central conclusion of the mission requirement survey is that, while mission data base detail is insufficient for accurate determination of specific task requirements, all EVA mission requirements can be described in terms of the Generic 15 EVA Missions. Because of this, it is felt that the capability to accomplish the 15 Generic EVA Missions is mandatory and should be the focus of future work until such time as greater mission specific detail is available.

A second key conclusion is that, while individual tasks can be accomplished by any suited crewmember, the current Shuttle EVAS would not be satisfactory when examined in the light of the overall mission model. Current EVAS impacts on shuttle operations could not be tolerated on the Space Station, both in the area of EVA operations and in the area of EVAS servicing and maintenance. Therefore, a much improved EVA System must be provided for the Space Station.

A final conclusion, based on the overall mission model, is that, while a two man EVA crew will suffice for the first years of Space Station operations, within four to six years of Station IOC a four man EVA crew will be required.

RECOMMENDATIONS

1. The EVAS should be designed so that EVA time is crew limited, not hardware limited.

2. The capability should be developed to perform all 15 Generic Missions including development of all Generic Ancillary Equipment.

3. The EVAS must be maintainable on-orbit with continuous operations for 90 days on a 50% duty cycle as a minimum.

4. All payload sponsors should be made familiar with the JSC 10615A document and be encouraged to to use it in their design efforts. For time estimate purposes, they should be made familiar with the Generic 15 Missions.

5. All payload sponsors should be provided with a Generic Tool Kit description and a Specialized Tool Kit description. They should be encouraged to use a design requiring minimal loose equipment with such equipment as required being chosen from the Generic Tool Kit if possible. They should be encouraged to identify any required specialized tools as quickly as possible.

SECTION 3

EVA OPERATIONS OVERVIEW

INTRODUCTION

In order to develop realistic design requirements, a general understanding of EVA operations is necessary. EVA by its very nature provides the flexibility to change the way we operate in space on a day-to-day basis, but certain functions are required to be performed regardless. The following discussion covers what we believe to be the key elements of any EVA operation from a mature Space Station. The details are, of course, subject to change as the design and operating philosophy mature, but these key elements will remain in one form or another.

3.1 PLANNING/SCHEDULING: EVA tasks to be performed are scheduled by the master crew scheduling system, along with any other (IV) tasks to be performed for a particular day. Tasks are prioritized according to criticality, proximity to one another, launch windows, etc., then a group of tasks is selected to be performed in the course of an EVA event. EVA is nominally scheduled to be conducted during the 9 orbits/day which do not pass through the South Atlantic Anomaly in the Van Allen radiation belts. At least two crewmembers on each shift have been trained to perform EVA, allowing mission planners maximum flexibility.

3.2 EVAS HARDWARE: Each EVA crewmember normally is assigned an Extravehicular Manned Unit (EMU) consisting of a Life Support System and Crew Enclosure, and is responsible to insure that all required checks have been performed on his unit prior to EVA, whether manually or automatically. On-orbit resizing capability is required in order to permit changes in crewmember/EMU assignment, changes in sizing preference, and maintainability (modularity) of the EMU crew enclosure joints, but resizing is not normally accomplished on a routine basis. Four complete EMUs (1/crewmember, 2 crewmembers/shift) will provide the flexibility and redundancy needed to support the number of EVA hours predicted.

3.3 TYPICAL EVA SCENARIO: Table 3-1 presents a typical EVA timeline with events and event times listed. Major divisions of the EVA scenario/timeline are discussed in greater detail below.

3.3.1 PRE-EVA: The EVA crewmember dons his cooling garment and waste collection device(s) in his personal quarters, much as a workman on earth decides when he gets up whether to wear work clothes or a business suit for a particular day's activities. The day's mission is reviewed among the crew and/or ground support personnel. Checks equivalent to preflight inspection of an aircraft are performed on the EMU. These checks consist primarily of confirmation of completion of servicing (battery recharge, CO2 media regeneration or replacement, heat sink regeneration or recharge, and oxygen recharge), followed by a visual inspection of the hardware. Each EMU has an associated "logbook" in the Station Data Management System (DMS) which keeps track of accumulated time on the EMU components as well as any minor anomalies which do not preclude system operation, but may possibly cause degraded performance of one or more subsystems. This "logbook" is also reviewed as a part of the checks. Functional checks are performed in conjunction with system donning and activation, assuming no major maintenance has been performed since the last use. If any of these checks reveal a condition which cannot be corrected on the spot, the EVA is postponed unless it is time-critical, in which case a spare EMU is utilized for that particular EVA event, with the failed unit being restored to an operational condition in one duty cycle or less (approximately two days initially, one day or perhaps even one shift as the tempo of operations picks up in later years).

3.3.2 EVA: The conduct of the EVA consists of some amount of overhead--translation to worksite, trash stowage, etc.--and performance of some combination of the generic EVA tasks/missions identified in section 2 for a total time at reduced pressure up to 7 hours, with up to 6 hours of that being dedicated to useful EVA tasks. (An additional hour of reserve capacity is available from the Life support System, but this capability is not normally used except in an emergency.) Translation requirements can be satisfied by a number of approaches (hand-over-hand, propulsion, "dumbwaiter" or trolley concepts, etc.); flexibility can be most enhanced by not precluding any of these methods. For example, a trolley is likely the most efficient means of translation along a keel, while access to solar panels or the like for inspection, and especially rendezvous with/retrieval of free-fliers will require some sort of maneuvering propulsion. Upon arrival at the worksite, restraint is required for the crewmember and for any tools or other ancillary equipment in use. Permanent workstations will be provided in areas of intensive EVA activity, probably along with Station services such as power, hardline communications, and cooling. Some sort of portable, temporary workstation will be required which attaches to most any part of the Station, probably to the truss structure, for use in areas which do not have prepared worksites.

3.3.3 POST-EVA: After repressurization of the airlock and EMU doffing, the crewmember initiates recharge and performs a visual inspection of the EMU. The recharge systems located in the airlock automatically shut off upon completion of the recharge. Optionally, this recharge can be accomplished by module replacement to enable rapid turnaround of the EVAS.

TABLE 3-1
EVA TIMELINE

ITEM	TITLE	DURATION		
A	PRE-BRIEF AND EQUIP PREP (INCL. RECHARGE VERIFICATION)	60 MINUTES		
B	SUIT DONNING, CHECKOUT & PURGE(5)	15		NOTE 4 (B–I)
C	PREBREATHE(2) AND COMMUNICATIONS CHECKS	30(2)		
D	(ENTER AIRLOCK) CLOSE HATCH	2		
E	DEPRESS AIRLOCK (INCL. LEAK CHECK)	10	NOTE 3 (E–P)	
F	OPEN OUTER HATCH	2		
G	EGRESS AIRLOCK	2		
H	TRANSLATE TO EQUIP STOWAGE	5		
I	UNSTOW EQUIPMENT, CHECKOUT	15		
J	EVA TIME AVAILABLE TO USERS(6)	360 MINUTES		
K	RESTOW EQUIPMENT	15		NOTE 4 (K–R)
L	(EG MISCELLANEOUS STO TRASH)	10		
M	TRANSLATE TO AIRLOCK	5		
N	ENTER AIRLOCK	5		
O	CLOSE HATCH	2		
P	REPRESS AIRLOCK	5		
Q	DOFF SUITS	15		
R	STOW EQUIPMENT, INITIATE RECHARGE	30		
	TOTAL	528		

NOTES:
1. ALL TIMES IN MINUTES TO BE MULTIPLIED X 2 FOR MAN-MINUTES WITH POSSIBLE EXCEPTION OF ITEMS A & R.
2. PREBEATHE TIME VARIABLE, DEPENDS ON EMU OPERATING PRESSURE.
3. TOTAL TIME AT REDUCED PRESSURE IS 481 MIN (8 HRS) (INCLUDES ADD'L TIME ON 100% O2 WHICH TOTALS 8.55 HRS).
4. TOTAL GENERIC OVERHEAD TIME/EVA EVENT IS 168 MIN (81 MIN + 87 MIN) (2.8 HRS).
5. OXYGEN PURGE WILL BE PERFORMED TO NORMOXIC LEVEL (NOT NECESSARILY 100% O2).
6. SIX HOURS/MAN IS CONSIDERED DELIVERABLE FOR USERS, SS MAINT., ETC.

3.4 TRAINING CONCEPTS

Considering the sheer number of EVA hours required annually and the necessity of devising operational techniques and procedures between infrequent Shuttle flights, the impact of extensive mission-specific ground training associated with STS EVA clearly cannot be tolerated for Station operations. The following training philosophy is therefore recommended.

3.4.1 GENERIC TRAINING (ground): EVA crewmembers receive training roughly equivalent to that provided for STS flights without a planned EVA. This is currently broken into two distinct areas:

- o System operation fundamentals such as activation and troubleshooting of the Primary Life Support Subsystem (PLSS), donning/doffing of the Space Suit Assembly (SSA), and activation, piloting techniques and troubleshooting of the Manned Maneuvering Unit (MMU). Normal servicing and maintenance tasks are taught as a logical outgrowth of this training.

- o Performance of certain identified contingency EVA tasks required for safe return of the Orbiter after a given set of failures. Corrective actions for these failures, however credible, provide practice in the required basic skills such as position maintenance, translation, teamwork, and tether protocols, as well as familiarization with mobility limitations associated with pressure suits.

3.4.2 TASK SPECIFIC TRAINING: This training will be conducted on-orbit, primarily by the use of OJT. Unusually complex tasks may require special augmentation via video/CAI presentations, but for the most part rely on an awareness of EVA considerations during the design of the component/payload or during mission planning to enable application of generic training to the particular task.

3.4.3 RECURRENT TRAINING: Emergency procedures and system refresher training will need to be conducted regularly in order to ensure maximum crewmember proficiency and safety. This is partially a subset of task-specific training, in that rescue of an incapacitated EVA crewmember, for instance, differs only in criticality, not in task performance, from the translation of any large object or module. System emergency procedures training could best be accomplished by use of the EVAS DMS in concert with the Station DMS to simulate various system failures.

3.5 MAINTENANCE CONCEPTS

On-orbit maintenance of the EVAS is, for all practical purposes, completely new ground for the U. S. space program. The relatively short duration of missions to date, along with the relatively small number of EVA hours required and the philosophy that EVA is a backup to other methods of mission accomplishment, have relegated on-orbit maintainability to the status of an unnecessary luxury, one that we could ill afford in an era of decreasing NASA budgets. With the dependence expected to rightfully be placed on EVA for mission accomplishment in the Station environment, on-orbit maintainability ceases to be a luxury and becomes instead an absolute necessity. Incorporation of maintainability features in the EVAS at the outset not only increases the probability of success for any payload exterior to the pressurized compartments of the Station, but provides a built-in capability to upgrade the system as will inevitably be required after well-meaning (and in all likelihood, necessary) budget cutting at the front end of the program forces acceptance of a less than optimum initial configuration. This issue is discussed in more detail in 4.0.2.1 MAINTAINABILITY.

3.5.1 SCHEDULED MAINTENANCE: For STS, scheduled maintenance has consisted of approximately 3000 hours of ground turnaround between each mission. This will have to be reduced to no more than annual refurbishment of systems, and ideally to repairing only inoperative components. There is no apparent reason why the hardware should not continue to operate indefinitely, just as aircraft continue to provide reliable service after many years of operation.

3.5.2 UNSCHEDULED MAINTENANCE: Provisions will have to be made aboard the Station to troubleshoot the EVAS and to isolate failures to the ORU level. Definition of this level is premature at this point, as it is circularly dependent on system design, which in turn depends on ORU level definition. This iterative process is best accomplished during the preliminary design phase. Considerations will include tool requirements for disassembly of components, cleanliness requirements, crew training, and many others. As a general rule, design of any system should not preclude any subcomponent being designated as an ORU unless this unnecessarily complicates design or increases cost (procurement or operations).

3.5.3 MAINTENANCE DOCUMENTATION:

The Documentation System ("logbooks") has access terminals at all maintenance locations (primarily the airlock).

The EVAS components (crew enclosure, life support system, propulsion system, and support equipment) are subdivided into ORUs, at which level all maintenance documentation will be recorded.

The data compiled on the ORUs will be:

- o Date of initial use
- o Operating hours since last maintenance
- o Maintenance performed/date/operating hours
- o Performance capability

  GREEN = Spec or better
  AMBER = Degraded but adequate for use
  RED = Terminate use till repaired

- o Comments relative to ORU performance.
- o Next scheduled maintenance

SECTION 4

EVAS BASELINE DESIGN REQUIREMENTS AND CONCEPTS

INTRODUCTION

4.0.1 BACKGROUND

The basic configuration of the EVAS is driven by the environment. That is, any configuration developed will have to provide life support environmental protection, and probably propulsion.

The configuration and system sizing are driven by operational considerations. The intent of this portion of the study was to provide traceability of design requirements to these operational considerations. This proved to be a much more difficult task than we originally thought, and research indicates that this has traditionally been the case at this stage of a program.

- For Space Station, the missions listed in the Langley Mission Data Base are ill-defined (understandably so considering their level of maturity).

- Similar studies for STS predicted one or two EVAs a year. As seen in 1984 and 1985, these predictions turned out to be much lower than what was actually conducted, primarily because the flexibility and utility of EVA was recognized and applied, often on short notice, with a near-perfect success rate.

- For Skylab, these studies predicted a total of about 28 hours of EVA, then the actual numbers turned out to be approximately triple that. Again, the flexibility and utility of EVA was responsible for many unforeseen mission enhancements as well as the initial saving of the Skylab vehicle itself.

It has been shown then that the advantage of manned EVA is not expressed as some quantifiable number, but is primarily the presence of man, enabling the following tasks to be performed more efficiently than with present-day machines:

- O Sense/detect minimum amounts of visual and acoustical stimuli
- O Recognize/interpret patterns of light and sound
- O Improvise and use flexible procedures
- O Store large amounts of information over long periods and recall relevant facts at appropriate times
- O Reason inductively
- O Exercise judgment

4.0.2 KEY ISSUES

In trying to maximize the advantage from having a man present, we must enhance his flexibility at every opportunity. In doing this, several issues come to light. They issues cross functional lines and as such will be discussed as overall EVAS issues.

4.0.2.1 MAINTAINABILITY: Modularity and accessibility of EVAS components may not in itself be the most important factor in design, but when one considers the flexibility and capability provided, they move immediately to the top of the priority list.

- O Provides for ORU removal and replacement as required by the RFP and by an analysis of the sheer quantity of EVA required between resupply.
- O Allows for growth by individual subsystem or component upgrades:

  - o The area of most concern with respect to technology readiness is the development of pressure suit gloves which can operate at the higher pressures anticipated for Space Station EVA operations while still providing acceptable mobility. The interface between the gloves and the suit arms has long been standardized and as such permits easy incorporation of any concepts developed. This example could apply equally well to the various large suit joint development programs by deciding early to standardize the interfaces. (The design of each particular joint should be determined by the Phase B/C/D contractor.)

  - o While regenerable CO_2 removal system technology may very well have problems achieving the required level of maturity in order to be incorporated in the EVAS at IOC, the logistics advantages leave little doubt that provisions should be made for its eventual incorporation. This would consist of allowing sufficient volume clearance in the Life

Support System and standardizing interfaces--inlet, outlet, instrumentation, cooling, power--between the EVAS LSS and whatever CO_2 removal system is employed.

o Regenerable heat storage/rejection systems are relatively simple by comparison to CO_2 removal, but they still require more volume than a sublimator of equal capacity. Advances in this technology will probably result in components of lesser mass and volume for the same or increased capability. If a conductive interface is provided from the heat transport system to the heat sink, upgrading the system would be as simple as replacing a defective module, or inserting a freshly recharged module to allow EVA with short turnaround.

O Allows temporary fall-back position in the event of funding cuts or technical problems in any of the advancing technologies mentioned by simply incorporating current technology (LiOH, sublimator, gloves, etc.).

4.0.2.2 DEGREE OF SUBSYSTEM FUNCTIONAL INTEGRATION: This issue is closely related to maintainability and frequently competes with it. In most cases, it seems that maintainability is the key issue and should take priority.

NOTE: This applies to the functional breakdown, not necessarily the physical arrangement. For instance, in all likelihood, the communications system will be located in a backpack, but will have no functional interface with the LSS also resident in the backpack.

The most appropriate functional breakdown appears to be:

O Life Support--discussed in section 4.1

O Environmental Protection--discussed in section 4.2

O Mobility--discussed in section 4.3

O Communication--discussed in section 4.4

O Data Management--discussed in section 4.5

O Propulsion--discussed in section 4.6

O Crewmember Support Functions--discussed in section 4.7

4.0.2.3 AUTONOMY: Autonomy of the EVA crewmember from the Station and of the Station from the ground carries a host of benefits to productivity, along with some challenges to maintain safety and reliability of the crewmembers and systems.

Generally, autonomy of the EVA crewmember from the Station relieves the IV crewmember of his traditional EVA support role, increasing his productivity by freeing him to perform other (unrelated) tasks.

Autonomy of the Station from the ground reduces cost and manpower expenditures associated with providing real-time ground support. It also eliminates orbit track dependence to enable ground communications coverage during EVA, allowing operations schedulers to plan EVA for the time optimum to the task and crew schedule.

4.0.2.4 ACCEPTABLE PHYSIOLOGICAL (BENDS) RISK: Much has been said in recent months about what constitutes acceptable cabin/EVAS pressure combinations. Unfortunately, the fact remains that little is known about the phenomenon of altitude bends other than it seems to be related to the ratio of alveolar nitrogen partial pressure to final EVAS pressure. One study even suggests that intermediate prebreathe times (less than 3 hours) have no practical effect on ppN2 in the connective tissues normally responsible for limb bends, with 4-5 hours required to achieve complete protection. This is because the blood flow through these tissues is intermittent, not continuous as with muscle and other tissues. Even less is known about the long-term effects of regular exposure to pressure changes over the course of years. Because of the lack of hard data in this area, the risk should be minimized to the point of excluding the possibility of bends during nominal EVA operations. For the sea level pressure selected during the Phase B RUR process, this would mean an EVAS pressure > 65 kPa (9.5 psi).

For productivity's sake, suit pressure and cabin pressure should both be as low as possible commensurate with fire hazards, experiment requirements, etc.

Regardless of the cabin pressure and ppN2/p(EVA) ratio selected, zero prebreathe should be the operational baseline, again for the sake of productivity, but primarily because any other prebreathe requirement depends on analysis which is inexact at best.

4.0.2.5 NOMINAL AND MAXIMUM LENGTH OF EVA: Consideration was given to physiological and psychological, operations, and hardware design considerations in defining these requirements. Anticlimactically, the capabilities and constraints listed in the Phase B RFP and Reference Configuration seem to be as nearly accurate as any we were able to develop through literature searches, human factors analyses, and interviews with past EVA crewmembers. Table 4-1 shows the recommended requirements.

TABLE 4-1
EVA HOURS REQUIREMENTS FOR EVAS SYSTEM DESIGN

SCHEDULING/PLANNING MAXIMUM	6 hours available to users per crewmember per EVA event 3 EVA events per week (human limits)
CONTINGENCY DAILY MAXIMUM	8 hours total EVA per crewmember (recommended hardware limit includes reserve capacity--i.e., only contingency life support functions are left after 8 hours of nominal EVA)
LOGISTICS PLANNING	3 two-man EVA events per week until further definition of mission requirements is available

4.0.2.6 ADVANCED TECHNOLOGY: Many areas of EVAS design and operations stand to benefit greatly from high technology programs under way by NASA and industry. However, we must not lose sight of the fact that the program is committed to permanently man a Space Station (including the EVAS) within budget, which eliminates use of Space Station funds to advance technology for its own sake. Thorough analysis is being performed by a number of organizations, including this study, to identify needs and requirements; we must use this analysis to assist in properly prioritizing advanced technology programs for the Space Station era to best use the limited funds available. A discussion of specific technology areas and recommendations is in Section 4.8.

4.0.3 SUMMARY

It appears that the correct approach to defining EVAS design requirements is not to try to trace the design requirements to specific mission requirements, but to strive to provide the maximum flexibility in order to enable future operations planners, design engineers, and most of all EVA crewmembers to apply the advantages of human presence with minimum restrictions. The remainder of this section will be based on this premise.

4.1 LIFE SUPPORT REQUIREMENTS

The Life Support System (LSS) must provide pressurization, pressure control, breathing oxygen, atmosphere revitalization, and thermal control to support a crewmember in Low Earth Orbit (LEO) space vacuum during performance of tasks identified in Section 2.

KEY ISSUES:

The following issues apply to all LSS subsystems.

REDUNDANCY: Volume and weight constraints have traditionally precluded extensive application of redundancy in EVA systems design. Relaxation of these constraints to some degree for the Space Station suggests that this philosophy be reexamined. For instance, it may be prudent to provide two or more primary oxygen systems instead of a backup (not redundant) secondary oxygen system.

In any case, no single, credible failure should result in the loss of a critical function (though it may possibly result in function degradation and/or premature termination of EVA). For this discussion, critical functions consist of all life support functions, environmental protection, mobility, and possibly (depending on particular mission profile) communication, data management, and propulsion.

VOLUME VS. TIME AVAILABLE: While a smaller LSS volume will always increase EVA productivity by some amount, the dimensions are not the absolute constraint they were for STS (i.e., requirement for the STS EVAS to fit through the Shuttle interdeck access passage), allowing incorporation of a larger volume backpack for Station if required.

Alternatively, operation of the EVAS at the higher suit pressures contemplated reduces overhead time associated with each EVA event, and therefore could allow decreasing EVA time available (volume) without significant penalty.

These options should be traded by the Phase B contractors to determine the optimum duration for EVA, but from a purely productivity standpoint it appears that the additional volume required is well worth the operational flexibility gained from extending potential EVA time available, so productive EVA time should not be limited to less than 6 hours without recharge (does not include system time requirements for generic overhead or contingency reserve. See Table 4-1).

4.1.1 PRESSURIZATION/PRESSURE CONTROL REQUIREMENTS

The most important single function provided by the EVAS is maintenance of pressure consistent with physiological requirements. This means that the pressure must be maintained at a level high enough to minimize possibility of decompression sickness without requiring much (ideally, zero) prebreathe. At the same time, ppO2 must not exceed established oxygen toxicity limits and total suit pressure must allow for adequate suit mobility. The range of physiologically acceptable pressures ranges from 26 kPa (3.7 psi) of pure oxygen to 101 kPa (14.7 psi) of air. With the Space Station Program decision to baseline the cabin at 101 kPa (14.7 psi), we feel the best compromise between mobility and decompression sickness prevention is to nominally operate the EVAS at 66 kPa (9.5 psi), with an initial ppO2 of 22 kPa (3.2 psi). Capability should be provided for on-orbit adjustments of this pressure down to 30 kPa (4.3 psi) to allow increased mobility/tactility with prebreathing. The pressure would then be maintained by introducing O2 to make up for metabolic use and leakage. As shown in Figure 4-1 below, this results in a slow buildup of oxygen partial pressure during the course of EVA, but a survey of experts in the field indicates that these ppO2 profiles represent a minimal danger to the EVA crewmember considering the limited exposure (6-8 hours, three times a week).

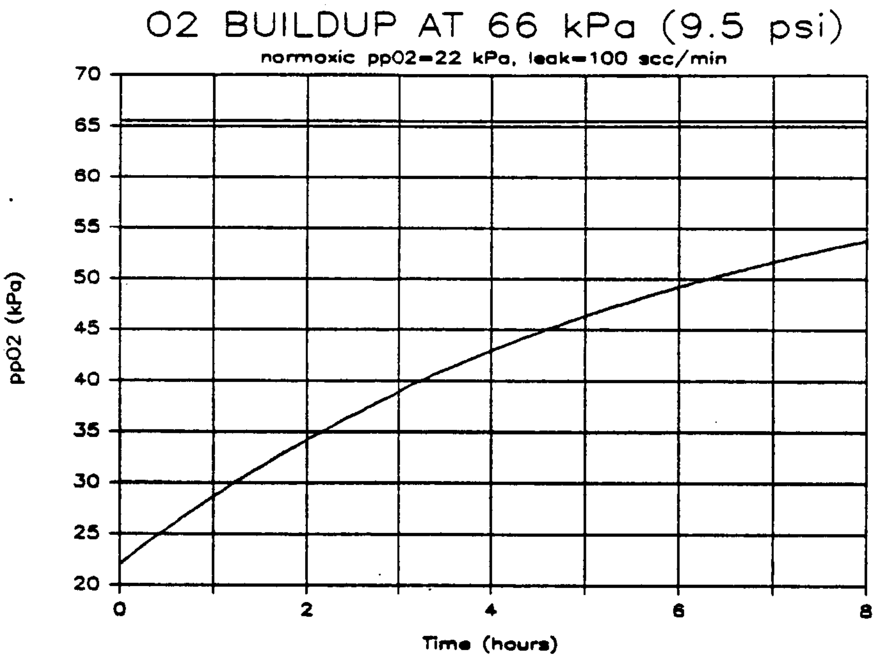


FIGURE 4-1
O2 BUILDUP USING A PASSIVE TWO-GAS PRESSURE CONTROL SYSTEM

Loss of pressure produces an immediate life-threatening situation; as such, some level of redundancy is mandatory. The most logical approach is one similar to the Shuttle vehicle which uses two automatic, parallel, redundant systems along with the capability of manually manipulating the configuration. A simple, reliable backup could then be provided which would permit the crewmember to manually regulate the pressure as long as the LSS has pressurant available. See Figure 4-2.

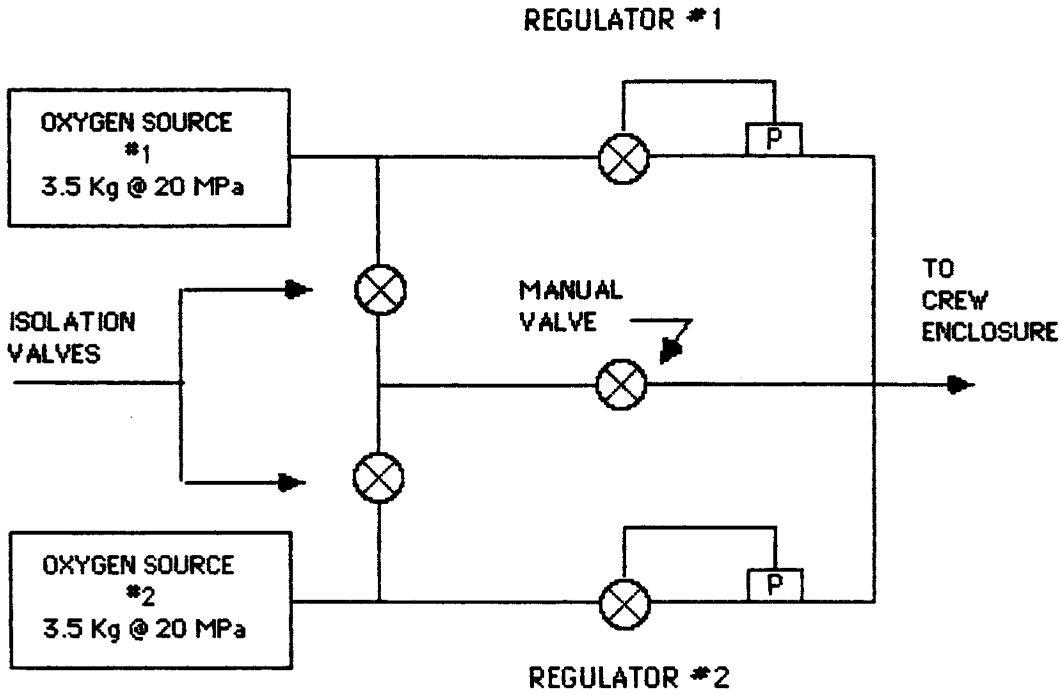


FIGURE 4-2
PRESSURE CONTROL SYSTEM

Complete loss of one of the automatic systems would no doubt require the termination of the EVA due to operational considerations, but would not endanger the crewmember.

4.1.2 BREATHING OXYGEN REQUIREMENTS

Breathing oxygen must be provided to support six hours of productive EVA, plus two hours of overhead/reserve, plus contingency return to a pressurized module within 45 minutes with a leak rate of 6 kg/hr (approximate flow rate through a Shuttle EMU DCM purge valve with a back pressure of 66 kPa).

Storage of this oxygen at 6 MPa (900 psi) as in the STS primary oxygen system would require an exorbitant amount of volume. At the same time, the 40 MPa (6000 psi) used in the STS Secondary Oxygen Pack is best avoided due to safety and processing concerns.

By storing the oxygen at an intermediate pressure such as 20 MPa (3000 psi), volume of such a system can be kept to roughly the combined volume of the primary and secondary oxygen systems of the Shuttle EMU. This is roughly the pressure and volume used in most modern SCUBA systems, whose technology is too mature to be dismissed out of hand.

4.1.3 ATMOSPHERE REVITALIZATION REQUIREMENTS

The LSS must control CO_2, humidity, odor, and particulates to acceptable levels.

CO_2: The logistics advantages of regenerable systems make their eventual inclusion highly desirable, so provisions should be made to not preclude solid amine or electrochemical regeneration systems. Standard interfaces will easily enable the use of LiOH (much smaller volume) in the interim if necessary.

HUMIDITY: Depending on the CO_2 control media selected, this may or may not be a separate concern. For example, the Solid Amine module also serves as a desiccant. Until such an approach is selected, however, the humidity removal system should be treated separately in keeping with the philosophy espoused in 4.0.2.2, DEGREE OF SUBSYSTEM FUNCTIONAL INTEGRATION. This will probably mean at least provisions for condensation and mechanical (centrifugal) humidity removal as in the Shuttle EMU.

ODOR: Odor is best controlled by use of activated charcoal in a replaceable filter module. This module is envisioned to be a subcomponent of the CO_2 removal module. If LiOH is used, the filter is changed after each EVA along with the LiOH. If a regenerable system is used, the charcoal bed will need to be changed out separately on a regular basis, or regenerated using a separate system.

PARTICULATES: Employ a mechanical filter module in the same manner as the odor filter, possibly as a combined module.

4.1.4 THERMAL CONTROL REQUIREMENTS

The system must collect, then store and/or reject metabolic, system-generated, and environmental heat loads. Sufficient LSS volume should be allocated to permit use of a Phase Change Module (PCM), with a conductive interface to the heat transport system which does not preclude use of a sublimator in the interim.

Post flight comments from several EVA crewmembers recently have indicated that a heating capability would be desirable in addition to the cooling provided. Since the Station environment is generally colder than the Shuttle payload bay environment, additional study should be performed by the Phase B contractors to ascertain the correct values for environmental heat loads, and if favorable, consideration should be given to allowing heat to leak out of the crew enclosure, then transport excess LSS heat to the crew enclosure instead of transporting it from the crew enclosure to the LSS for storage/rejection.

4.2 ENVIRONMENTAL PROTECTION

In order to allow for effective EVA operations from the Space Station, the EVA crewmember must be protected from the surrounding environment:

- RADIATION: The EVAS must provide adequate radiation protection to allow the EVA crewmember to remain within total exposure limits for Space Station. Section 4.2.1.

- MECHANICAL DANGERS: The EMU must provide reasonable protection against micrometeoroids, space debris, and impacts with sharp corners and edges. Section 4.2.2.

- ATOMIC OXYGEN: The EVAS must protect itself from the material degradation effects of atomic oxygen. Section 4.2.3.

- STATIC CHARGING: The EVAS must protect itself and the crewmember from static charging effects. Section 4.2.4.

4.2.1 RADIATION

Space radiation is a key factor in the consideration of EVA operations from the Space Station. The majority of the radiation exposure accumulates during vehicle passage through the South Atlantic Anomaly (SAA). Figure 4-3 shows the location of the anomaly in the southern hemisphere between South America and South Africa. The isodose lines represent equal particle flux in terms of protons per square centimeter per second at a representative altitude.

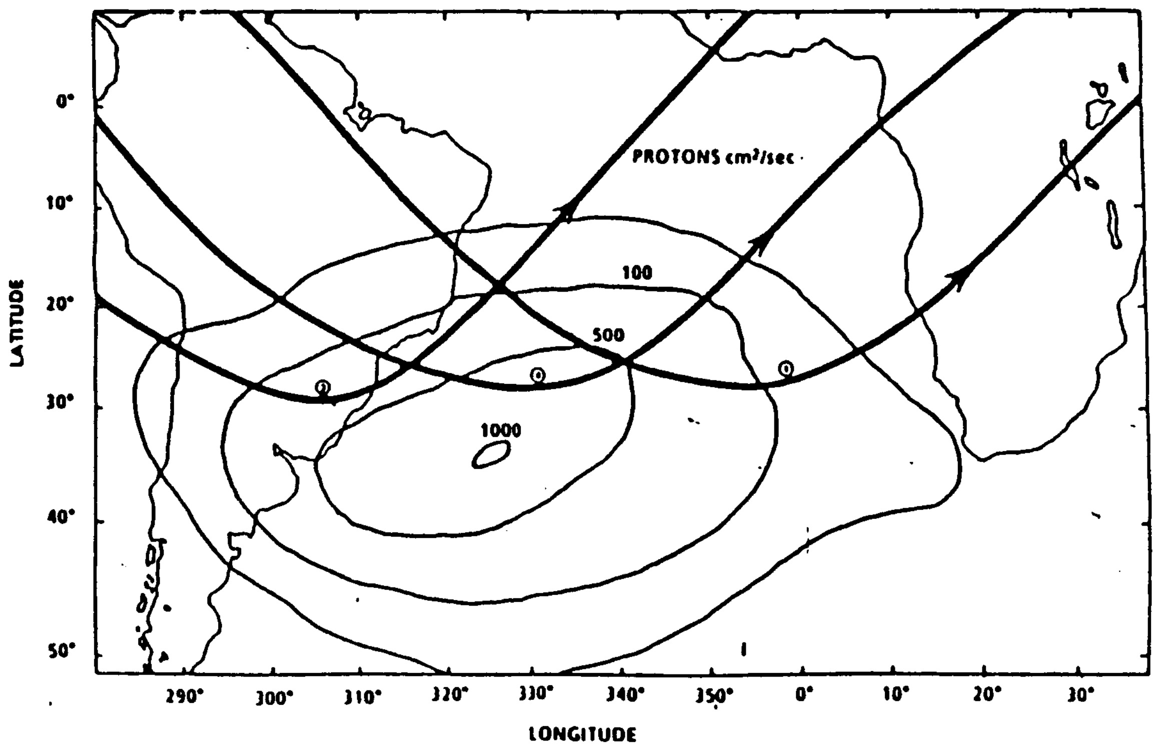


FIGURE 4-3
LINES OF EQUAL DOSE RATES IN THE SOUTH ATLANTIC ANOMALY

The flux gradient is steep and Figure 4-4 illustrates the time history of orbit traces in the anomaly and shows the radiation dose to an astronaut's eye, the limiting exposure factor. The chart is for the indicated altitude and wall density at the period of maximum radiation activity - Solar minimum.

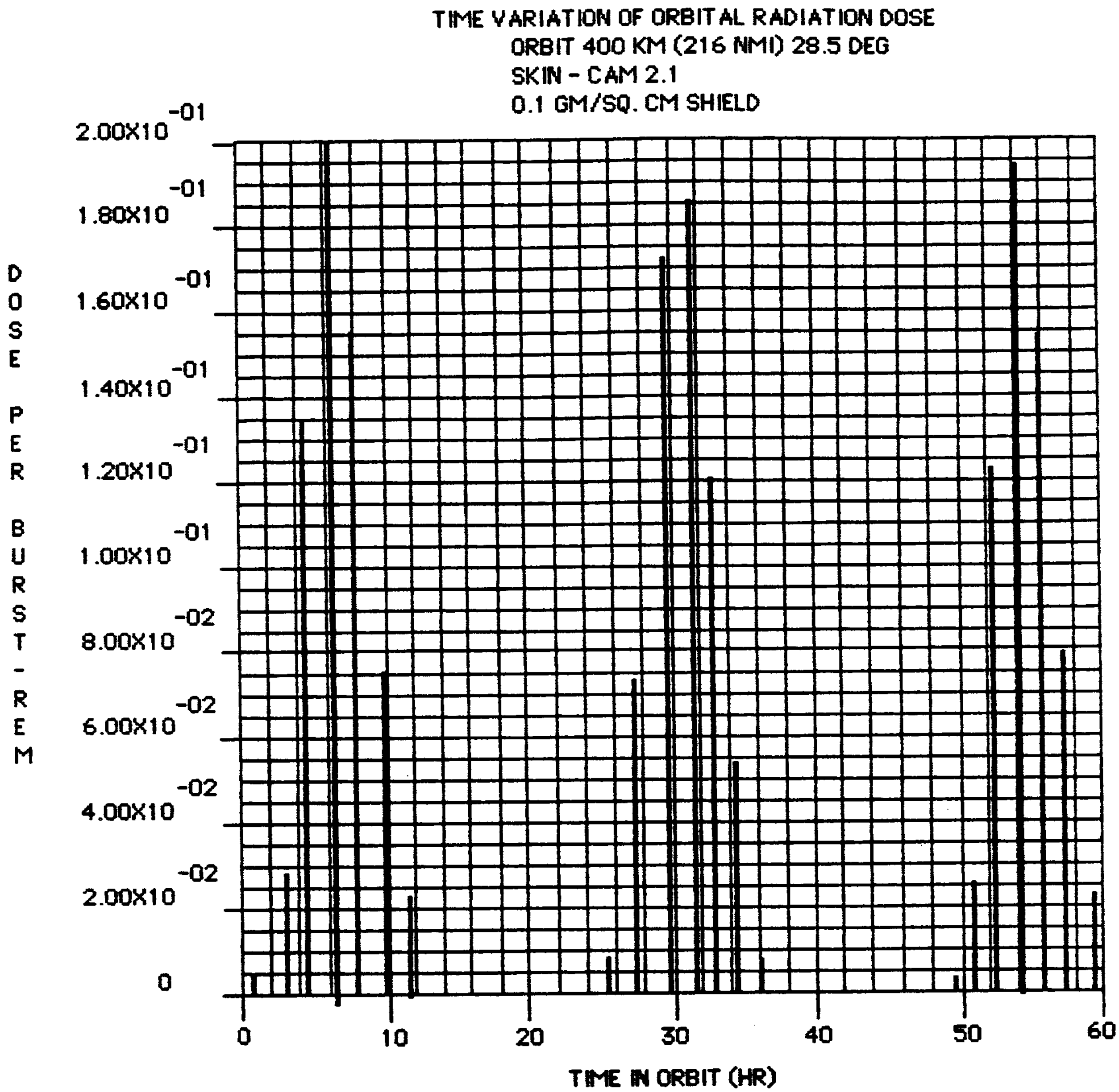


FIGURE 4-4
RADIATION DOSE TO THE EYE OVER TIME

Astronaut exposure depends on the orbit altitude, shielding from Station materials, the duration of the astronaut's time in orbit, and most importantly - the amount of atmosphere above the Station. Atmosphere effects are governed by the solar cycle. Maximum atmosphere heating and expansion occurs at the time of maximum solar activity due to solar radiation absorbed in the atmosphere. This condition provides the maximum "free" radiation shielding - that which comes from the atmosphere. The residual atmosphere removes and limits the lower edge of the Van Allen radiation belt, but it also increases the Station's drag. Thus, higher altitudes are necessary during solar maximum conditions. Conversely, at minimum solar activity, the atmosphere cools and contracts so that more radiation reaches the Station/Astronauts. Shielding is provided by the modules, tunnels, nodes, and airlock structures during IVA and by the EVA suit materials when outside the Station and is needed primarily during passage through the SAA. Figure 4-4 illustrates the radiation exposure bursts associated with passage through the anomaly and the radiation drop-off outside the anomaly, e.g. it changes by three orders of magnitude or more.

Table 4-2 shows the aluminum equivalent protection of the current Shuttle EMU. Analysis performed in association with the McDonnell Douglas Phase B Space Station contract indicate these shielding levels to be more than adequate if EVAs are scheduled around the SAA.

TABLE 4-2
ALUMINUM EQUIVALENT PROTECTION OF CURRENT SHUTTLE EMU MATERIALS

MATERIAL COVERINGS	DENSITY (gms/cm**2)	THICKNESS (in.)
ARMS & LEGS		
THERMAL MANAGEMENT GARMENT (TMG)	0.091	0.053
RESTRAINT BLADDER FABRIC	0.035	0.020
LIQUID COOLED VENTILATION GARMENT (LCVG)	0.039	0.0295
TOTAL	0.165	0.1025
APPROX. ALUM. EQUIV.	~0.2	
UPPER TORSO		
TMG	0.091	0.053
FIBERGLASS SHELL	0.354	0.075
LCVG	0.039	0.0295
TOTAL	0.484	0.158
APPROX. ALUM. EQUIV.	~0.5	
EYE SHIELD		
HELMENT (BUBBLE)	0.182	0.06
PROTECTIVE VISOR	0.182	0.06
SUN VISOR	0.190	0.06
CENTER EYESHADES	0.067	0.07
SIDE EYESHADES	0.238	0.125
TOTAL	0.859	0.375
APPROX. ALUM. EQUIV.	~0.9	

Timeline analysis, Figure 4-5, indicates no problem in scheduling around the SAA, since the worst case still has > 8 consecutive hours of non-SAA exposure for one shift or the other.

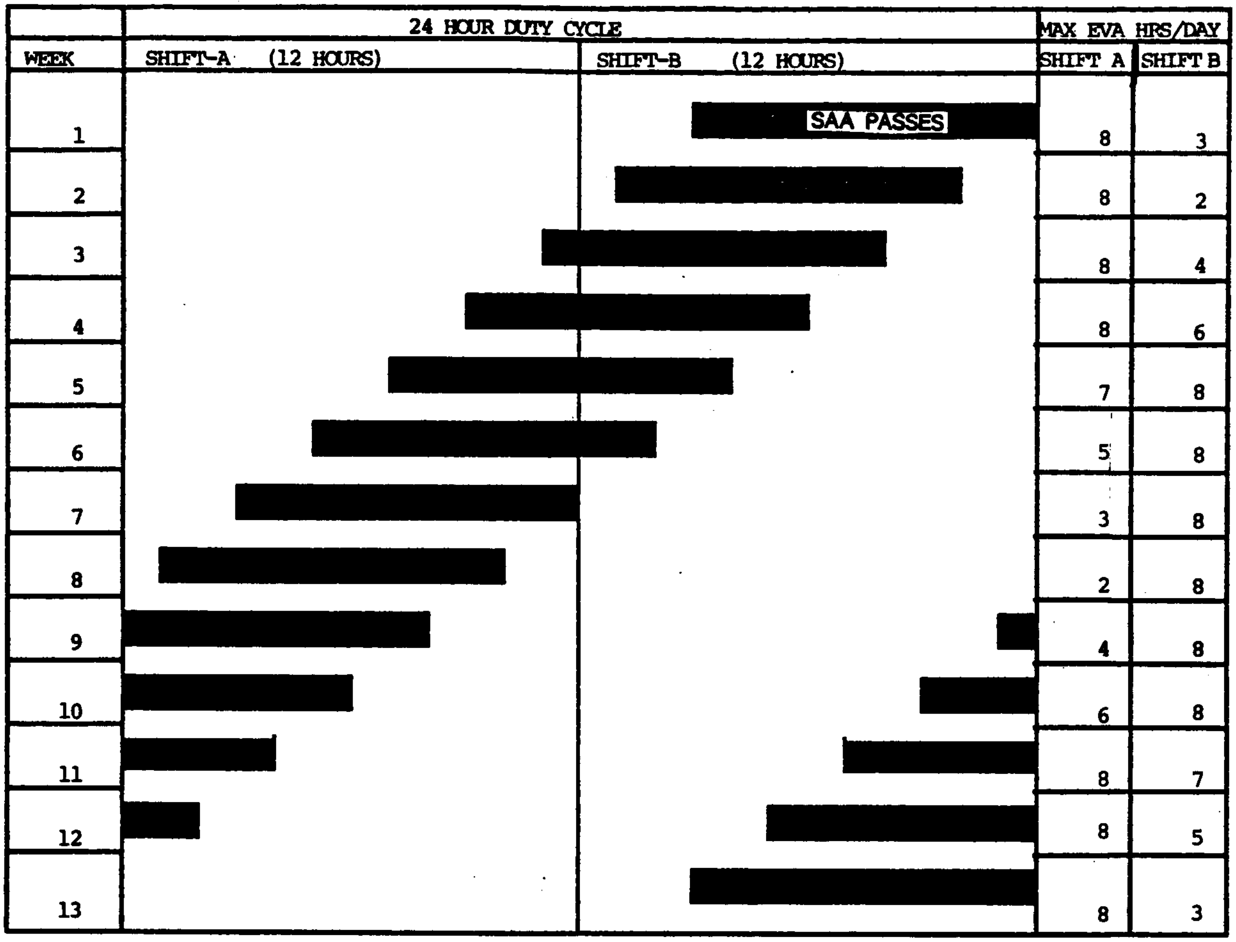
If operations are to be extended to polar and/or GEO, increased radiation shielding will be required. GEO is the harsher of the two and as such would be the driver for shielding requirements. We feel that to impose this shielding requirement on the EVAS would unnecessarily restrict nominal Station EVA operations by causing the EMU to be too cumbersome and massive, and so recommend that the problem be solved by applying prudent operational philosophies, such as limiting time of exposure to these high-risk areas and considering the total (IV + EV) dose, not just the EV dose.

The Langley Mission Data Base used for this study does not identify any requirements for GEO EVA capability, but other studies have examined this capability and have postulated mission times as long as a month. If this is considered reasonable, the minimum total shielding requirement is an average of at least 2 g/cm**2 of Al.

A different radiation problem concerns possible degradation of the EVAS by ultraviolet radiation (UV). Analysis indicates the only sensitive area of the Shuttle EMU to be the polycarbonate (Lexan) of the helmet. A UV-resistant material would be one solution, but in light of the excellent optical and pressure-retention characteristics of polycarbonates (such as Lexan), a more likely approach is to provide an on-orbit replaceable protective visor, which would absorb the UV effects and thus protect the polycarbonate visor. This protection scheme is used on the Shuttle EMU, except the visor requires significant technician support for replacement.

Recommended radiation-related requirements are:

- All non-emergency EVAs are scheduled around the SAA.
- Time in high-risk profiles is minimized--polar, GEO, SAA.
- The Space Station EMU-crew enclosure provides at least the radiation protection of the Space Shuttle EMU Space Suit Assembly for all areas of the crewmember's body.
- Provide an easily replaceable protective visor to shield the EVAS helmet from UV radiation.



1 Exact length of bars and amount/direction of weekly time shift is highly dependent on orbital altitude - example shown is roughly equivalent to 500 km (270 nm).
2 Intensity of radiation exposure within the period affected by passes through the SAA varies considerably from low levels near the ends to peak values during the middle of the period.
3 Assumes no EVA exposure to SAA. In reality, EVA during the first or last pass is only marginally worse than EVA outside the SAA.

FIGURE 4-5
TIMELINE ANALYSIS

4.2.2 MECHANICAL DANGERS

Mechanical dangers may be divided into two basic categories; micrometeoroid/space debris, and sharp corners/edges.

According to "Natural Environment Design Criteria for Space Station Definition and Preliminary Design" (NASA Technical Memorandum TM-86460), space debris is the "driver". It is also less understood than micrometeoroids, but work is continuing to define it. The requirement should be to meet, at a minimum, a 95% probability of safety as stated in the Technical Memorandum.

Survivability data based on the current micrometeoroid and space debris model and the ZPS space suit are presented for reference in Table 4-3, which shows probabilities of not receiving a leak-causing impact. These probabilities are based on 936 hours of use (approx. one year) and the current micrometeoroid/debris models. When this data is extrapolated to provide a ten-year projection, as shown at the bottom of the table, we see that the ZPS suit materials, by themselves, cannot meet the 95% criteria. In fact, the ten-year probability is closer to 80%.

Tests indicate that shielding the materials with a fabric layup similar to the Thermal/Micrometeoroid Garment (TMG) used on the Shuttle EMU can substantially decrease the probability of an impact causing a leak. Thus, regardless of the joint design selected, the crew enclosure will require the addition of a protective fabric layer.

Sharp corner/edges requirements involve safety from puncture or other damage for the EVAS operating around the Space Station. Two points are pertinent: the Shuttle EMU and MMU will be used in the Space Station vicinity (especially during assembly), and any Space Station EVAS should be required to be at least as resistant to impact as the Shuttle EMU and MMU. Taking these two points into account, NASA Document JSC-10615A requirements for sharp corners/edges should be used as an initial baseline and be considered minimum requirements.

A manned EVAS with maximum consumables should survive an impact with a stationary object at a velocity of .6 m/s (2 ft/s) with only cosmetic damage.

TABLE 4-3
MICROMETEOROID/DEBRIS PUNCTURE HAZARD ASSESSMENT
(Probability of no leak for 936 hours of operation)

SUIT ELEMENT	AREA m**2	MATERIAL	THICKNESS cm	PROBABILITY (400 km)	PROBABILITY (500 km)
LOWER LEGS	0.17	6061-T6	0.47	0.999978	0.999981
UPPER LEGS	0.03	6061-T6	0.47	0.999995	0.999996
LOWER ARMS	0.05	6061-T6	0.47	0.999993	0.999994
UPPER ARMS	0.03	6061-T6	0.47	0.999997	0.999997
ANKLES	0.10	LAMINATE	0.07	0.998757	0.998784
KNEES	0.25	LAMINATE	0.07	0.996908	0.996976
THIGHS	0.08	LAMINATE	0.07	0.999019	0.999041
ELBOWS	0.19	LAMINATE	0.07	0.996677	0.998526
WAIST	0.16	LAMINATE	0.07	0.997299	0.998090
SHOULDERS	0.08	LAMINATE	0.07	0.998950	0.998972
GLOVES	0.16	LAMINATE	0.07	0.998834	0.998077
BOOTS	0.22	LAMINATE	0.07	0.997233	0.997294
SHOULDERS	0.16	ST. STEEL	0.08	0.999920	0.999943
THIGHS	0.38	ST. STEEL	0.08	0.999851	0.999871
HARD UPPER TORSO	0.55	FIBER GLASS	0.19	0.999920	0.999864
HELMET	0.25	LEXAN	0.19	0.993467	0.993525
CUMULATIVE PROBABILITY FOR ONE YEAR (1)				0.976166	0.979116
CUMULATIVE PROBABILITY FOR TEN YEARS (2)				0.785663	0.809732

NOTES:
1. One year probability based on product of all probabilities
2. Ten year probability based on one year probability raised to tenth power

4.2.3 ATOMIC OXYGEN

According to "A Consideration of Atomic Oxygen Interactions with Space Station" (AIAA-85-0476), Shuttle EMU materials are not particularly reactive to atomic oxygen with the exception of the polycarbonate of the helmet.

The requirement should be to use these existing materials wherever possible and to replace them only with materials of equal or greater resistance.

The helmet polycarbonate erosion problem could be solved if a more atomic oxygen resistant replacement material were to be found. However, as stated in section 4.2.1, the visor materials provide excellent optical quality and pressure retention, so a more likely solution is the use of an easily replaceable protective visor. This would also provide needed protection from UV radiation and mechanical wear and tear. Thus, the replacement visor is likely the best solution.

4.2.4 STATIC CHARGING

Static charging of the Space Station EVAS does not appear to be a problem for the orbits considered for the Space Station (400 to 500 km and 28.5 degree inclination). During the first rendezvous operations in the Gemini program, all attempts to measure the charging effects resulted in off-scale low readings. EVA has been performed from the Shuttle from approximately these and less benign (57 deg) orbits with no problems encountered.

Since the Space Station EVAS may well have to support EVA operations in both polar and, eventually, geosynchronous orbits; static charging must be considered.

"Testing EVA Equipment for Polar Orbit Operations" (SAE 851330) states that levels of charging do not present a direct threat to the crewmember. However, it does reach levels that could affect sensitive electronic equipment in the EMU and EEU. The requirement, therefore, is to shield and ground all EVAS electronics in order to not preclude their eventual use at polar inclinations and eventually at GEO altitudes. Also, a proper ground path must be provided between all EVAS components (EMU to EEU, arms to gloves, etc.) in order to preclude buildup of such a charge in the first place. As with aircraft refueling operations, a ground strap or cable should be the first thing to make contact with any item which has a possible charge with respect to the EVAS.

4.3 MOBILITY AND ANTHROPOMETRIC SIZING

Mobility and anthropometric sizing are related issues in crew enclosure design. Mobility involves the range of motion, torques involved in motion, and clearances needed for motion in operating the EMU-Crew Enclosure. Anthropometric sizing involves the range of crew size to be accommodated by the crew enclosure.

Mobility considerations produce a requirement for an anthropomorphic suit with maximum torque and minimum range equivalent to a Shuttle EMU at 4.3 psi.

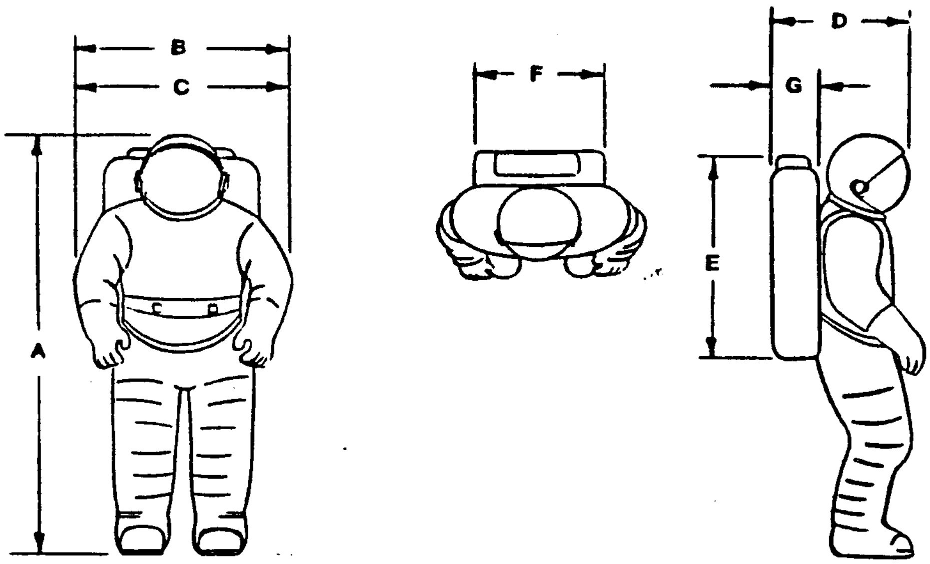
Range of crew size to be accommodated should be specified so as to fit the largest possible percentage of the target population with the minimum number of components. Attempts to fit some arbitrary range of male and female percentiles for STS resulted in a system which cost far too much, compromised fit for all but a few, and ultimately failed to fit the specified range due to the technology required to build gloves for the small end of the anthropometric range while retaining sufficient mobility to allow the crewmember to perform useful tasks.

4.3.1 MOBILITY

Mobility of the crew enclosure involves ranges of motion of the crew enclosure joints, torques required to achieve these ranges, and clearances required for the complete EMU.

A major consideration in establishing and meeting the mobility requirements for the EVAS is whether the crew enclosure is to remain anthropomorphic or is to evolve into a semi-anthropomorphic (man-in-a-can) or a fully non-anthropomorphic (pod-like) shape. Semi- and non-anthropomorphic crew enclosures offer some advantages such as packaging of LSS components and some relief from custom sizing requirements. However, they do not provide the crewmember with the capability to quickly and efficiently adapt to the variety of tasks and required physical orientations to work interfaces as does the fully anthropomorphic suit. Although pressure suits are certainly an encumberance and they decrease crewmember productivity when compared with shirt-sleeve performance, observations of experienced astronauts and test subjects during orbital EVA and/or underwater neutral-bouyancy exercises show that all the human motor skills are continuously utilized to the maximum for maneuvering, positioning, stability, reacting work forces/torques, etc. This is consistent with the findings of commercial undersea diving advocates who, with strong profit motives, have developed advanced anthropomorphic diving systems with the goal of achieving the manipulative ability of an ambient pressure system (such as SCUBA). As long as the goal of EVA systems remains to get the human astronaut as close to the work interface as possible so he can apply his natural skills and abilities to productive endeavors, advancing the technologies required for anthropomorphic space suits should continue to be emphasized, even if this requires a reduction of efforts aimed at semi- and non-anthropomorphic systems development. Similar to the diving systems, our goal should be to attain shirt-sleeve mobility.

Clearance required for an anthropomorphic EMU will vary with specific design. Figure 4-6 presents an example using dimensions of the ZPS suit and an estimated LSS volume of 183 liters (6.4 ft**3).



SUIT DIMENSIONS	SIZE RANGE cm(in) 5TH PERCENTILE FEMALE	95TH PERCENTILE MALE
A - HEIGHT	143.3 (56.4)	191.8 (75.5)
B - MAXIMUM BREADTH AT ELBOWS (ARMS DOWN)		84.8 (33.4)
C - MAXIMUM BREADTH AT ELBOWS (ARMS FOLDED OR UP)		66.0 (26.0)
D - MAXIMUM DEPTH WITH LSS	66.0 (26.0)	68.6 (27.0)

LIFE SUPPORT SYSTEM DIMENSIONS

E - HEIGHT	107 (42)
F - BREADTH	61 (24)
G - DEPTH	28 (11)

FIGURE 4-6
DIMENSIONS FOR ADVANCED EMU

4.3.2 ANTHROPOMETRIC SIZING

Operationally, the approach to establishing a policy for anthropometric sizing should be to fit the largest percentage of the target population, with cost considerations (design and procurement) suggesting the minimal possible number of different size components.

The selection of a target population will be affected by the size and strength of the individuals and the ability to build crew enclosure components to fit the individual. For example, the ability to build gloves for individuals with small hands is limited. For purposes of this study, it is felt that operational productivity and flexibility would be most enhanced by the selection of the total population (men and women) as the target population.

A list of key sizing dimensions has been developed, and a series of target points within the population selected. A grouping of sizing philosophies was then tested against them. The following definitions are necessary to understand the philosophies:

Accommodate = Size the crew enclosure such that at its largest or smallest it will fit the specified percentile.

Optimize = Size the crew enclosure such that at the middle of its size range it will fit the specified percentile.

The top number in each box in Table 4-4 is the range (in centimeters) accommodated by each philosophy for each critical dimension. The bottom number represents the percentage of the total population accommodated. By selecting the proper combinations of options a crew enclosure sizing option that will fit the largest percentage of the total population can be derived.

TABLE 4-4
SIZING PREDICTIONS--CURRENT SSA W/HORIZONTAL CLOSURE

CRITICAL DIMENSION (OPTIMUM FIT TOLERANCE)	ACCOMMODATE 95% MALE	OPTIMIZE TO 50% MALE	OPTIMIZE TO 50% TOTAL POPULATION	OPTIMIZE TO 50% FEMALE	ACCOMMODATE 5% FEMALE
CHEST BREADTH (± 0.75 in.)	12.9-14.4 in. 14%	12.2-13.7 in. 33%	11.2-12.7 in. 66%	10.3-11.8 in. 44%	9.5-11.0 in. 8%
INTERSCYE-MAX (± 0.75 in.)	23.5-25 in. 2%	22-23.5 in. 16%	20-21.5 in. 41%	18.8-20.3 in. 29%	17.3-18.8 in. 10%
CHEST CIRCUMFERENCE (± 1.0 in.)	41.1-43.1 in. 3%	37.7-39.7 in. 20%	35.6-37.6 in. 28%	34-36 in. 23%	32.1-34.1 in. 18%
SHOULDER CIRCUMFERENCE (± 1.5 in.)	47.2-50.2 in. 4%	42-45 in. 48%	41.9-44.9 in. 49%	37.9-40.9 in. 17%	36.5-39.5 in. 4%
ELBOW TO WRIST (± 0.5 in.)	10.5-11.5 in. 24%	10.1-11.1 in. 46%	9.6-10.6 in. 58%	8.7-9.7 in. 24%	8.3-9.3 in. 10%
ELBOW TO ELBOW (± 0.5 in.)	39.4-40.4 in. 4%	36.9-37.9 in. 18%	35.8-36.8 in. 24%	32.9-33.9 in. 4%	30.9-31.9 in. 4%
CROTCH HEIGHT (± 0.5 in.)	35.2-36.2 in. 2%	33-34 in. 12%	31.1-32.1 in. 22%	28.8-29.8 in. 12%	26.8-27.8 in. 1%
KNEE HEIGHT (± 1.5 in.)	18-21 in. 65%	18-21 in. 65%	17-20 in. 85%	15.6-18.6 in. 54%	15.8-18.8 in. 61%
ACROMIAL HEIGHT (± 1.0 in.)	58.9-60.9 in. 4%	56.2-58.2 in. 21%	54.1-56.1 in. 34%	50.9-52.9 in 15%	48.4-50.4 in. 2%
VTD (TORSO LENGTH) (± 0.5 in.)*	24.7-25.7 in. 7%	23.2-24.2 in. 30%	22.7-23.7 in. 37%	22.1-23.1 in. 28%	20.8-21.8 in. 9%

* VTD OR TORSO LENGTH RESULTS ARE FOR REF. ONLY

It should be noted that actual sizing optimization is very design specific. The example given is for the current Shuttle suit. The optimum sizing would be achieved by selecting the critical dimension ranges, in line with a reasonable number of components, that will fit the maximum reasonable range of the population. This problem would be eased considerably by selection of a closure technique other than horizontal plane; for instance, JSC and ARC rear-entry concepts allow a considerably larger range of fit for a given torso size.

On orbit sizing and maintenance can be achieved by use of Ortman couplings, Figure 4-7. This will allow easy resizing and make suit components into ORUs.

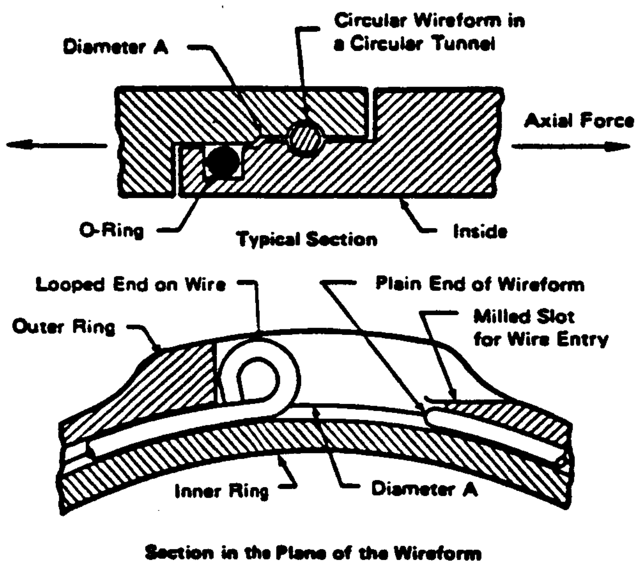


FIGURE 4-7
ORTMAN COUPLING

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4.4 COMMUNICATION REQUIREMENTS

In order to satisfy the goals of flexibility and autonomy, communication requirements far exceeding those levied on previous EVA systems will need to be met. Fortunately, this is an area where the commercial sector has made great strides in recent years; witness the state of the art in miniature sound systems, microprocessors, and video equipment.

Background:

The STS EVAS provides for full duplex voice communications between two EVA crewmembers, the Orbiter, and Mission Control. This is accomplished by a conferencing system of UHF-AM transmitters and receivers on the EVAS and Orbiter, tied through the vehicle communications system to the air-to-ground (A/G) transceiver aboard the vehicle (very similar to the system employed for Apollo lunar EVA). Figure 4-8 shows the nominal mode of operation, which requires one transmitter and two receivers to be powered within each EVAS and aboard the Orbiter. More than two crewmembers can only be accommodated by giving up the duplex capability as shown in Figure 4-9.

An additional capability of providing an EKG signal for downlink to Mission Control is achieved by adding a 1.5 kHz subcarrier to the UHF signal. This has recently been augmented to allow time multiplexing of EVAS LSS parameters with the biomed signal, a system which not only eliminates a portion of the EKG signal, but provides a minimum insight into the operating health of the LSS, since the low frequency utilized by the data subcarrier is only capable of sending a complete data stream approximately once/minute.

4.4.1 VOICE COMMUNICATION REQUIREMENTS

For obvious operational reasons, full duplex voice capability is required between all parties at all times during EVA. This includes EVA crewmembers (up to at least four and possibly more), any or all IV crewmembers, and ground personnel. EVA crewmembers need to be able to deselect any distracting communication, but

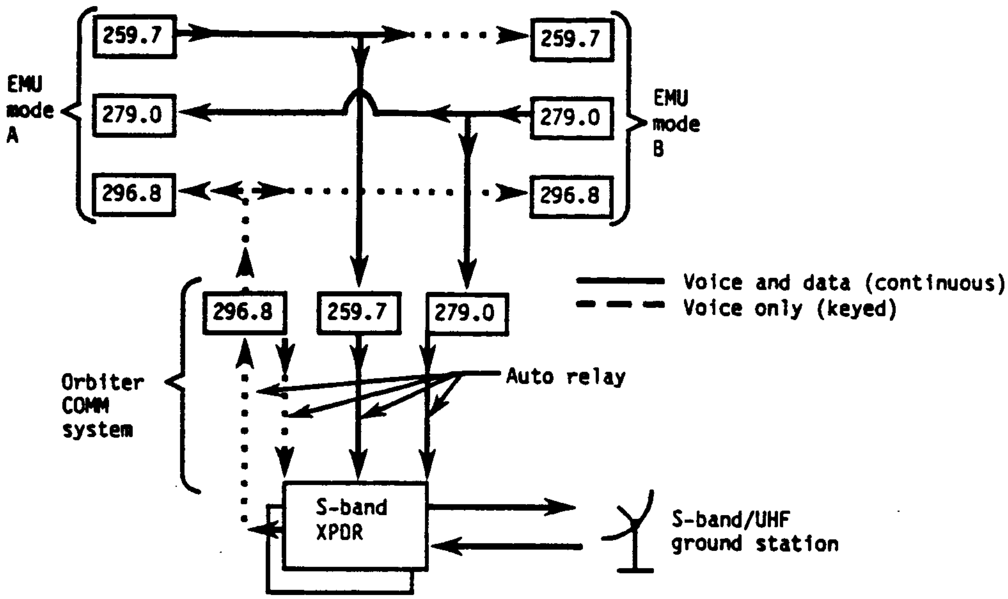
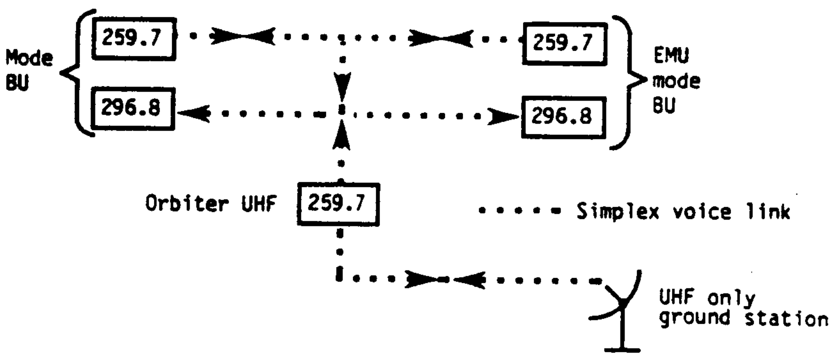


FIGURE 4-8
NOMINAL (FULL DUPLEX) COMMUNICATIONS DURING STS EVA



- As many EMUs can be added as desired, only impact is frequency crowding
- No biomed data
- No auto relay between EV and ground
- EV crewmembers probably will not hear ground
- Ground will not hear EV crewmembers

FIGURE 4-9
OFF-NOMINAL (SIMPLEX) COMMUNICATIONS CONFIGURATION AVAILABLE FOR ACCOMODATION OF >2 CREWMEMBERS DURING STS EVA

that party needs to be able to get through even when deselected by using a "call-up" capability.

It is envisioned that this voice signal will be digitized, then multiplexed with the data signal, thus becoming a subset of data communications requirements. As such, the requirements will not be discussed here, but in Section 4.4.2

4.4.2 DATA COMMUNICATION REQUIREMENTS

In order to minimize crew time expenditure, the function of tracking and recording system and biomedical data should be automated to the maximum extent possible. The most straightforward way to accomplish this is to send a data stream from the EVAS to the Station Data Management System (DMS), which will record and analyze it, alert the crew to anomalies, and make recommendations as to course of action to be followed. This does not include simple C & W functions such as out-of-limits or low consumables alerts. These will be handled by the EVAS DMS and are discussed in section 4.5.2.

Data transfer from the Station DMS to the EVAS will be required as a means to reduce dependence on paper checklists which must be developed and transported to orbit for each unique task--a massive logistics impact. This would also imply that some data transfer would be required from the EVAS to the Station to enable commands to display the Station data base information. An ill-defined but very possible additional requirement for data transfer from the Station to the EVAS is to enable system commands to be transmitted (for instance, control inputs to an unmanned propulsion system).

The most obvious approach to allow more than two crewmembers to pass such data between themselves and the Station is to allot a discrete two-way digital channel to each crewmember, then have the Station communications system distribute signals as appropriate, much like the digital voice distribution network aboard the Shuttle. This would normally by accomplished via RF link, but could use hardwire in special circumstances; i.e., contingencies, RF sensitive instruments, overload of RF spectrum, etc.

4.4.3 VIDEO COMMUNICATION REQUIREMENTS

Video requirements are the most difficult to quantify of the communication requirements, but frequently are the most valuable by a large margin--to a remote observer, a picture is frequently worth several thousand words. Preliminary concepts for Station video involve digitizing the video signal from the EVAS, then multiplexing this with the normal data stream. While this certainly meets the operational requirements, tying up a broadband data channel continuously during EVA is very inefficient in its use of the limited frequency spectrum. A more reasonable approach might be to use Station CCTV (hardline) for nominal EVA video, augmented by UHF or S-band analog video on the occasions that require full-motion TV from the perspective of the EVA crewmember. Still pictures--"freeze-frame"--would be available via the nominal two-way data link at all times for transmission of diagrams, schematics, close-up view of worksite, etc. at a rate of around one picture per second without using the broadband signal required for high-resolution full-motion digital video.

4.5 DATA MANAGEMENT

The primary requirements for the EVAS Data Management System (DMS) are to maximize:

- EVA crewmember safety
- EVA and IVA crewmember productivity and, therefore, mission success
- Level of reliability and maintainability both for design and operation
- Capability for expansion and upgrade as new tasks and technologies are developed.

Requirements for the EVAS DMS will be broken down into three functions:

- Input/Output (I/O) Data Handling--Section 4.5.1
- Systems Management--Section 4.5.2
- Applications Programs--Section 4.5.3

The EVAS DMS will be composed of software and firmware resident in a hardware microprocessor and shall interface directly with the EVAS, the EVA crewmember, and the EVAS Display System, and indirectly (through the EVAS data communication system) with other data management systems external to the EVAS (primarily the Space Station Information and Data Management System (IDMS)).

4.5.1 I/O DATA HANDLING

The I/O Data Handling function integral to the EVAS DMS shall provide the EVAS DMS those interfaces necessary for systems management, data reception and transmission, and command and control. See Table 4-5.

TABLE 4-5
I/O DATA HANDLING INTERFACES

INTERFACE	INTERFACE TYPE	I/O	DATA TYPE
EVA Crewmember	Voice	I	Voice recognition
	Mechanical Sw.	I	Analog, discrete and/or digital
	Audio	O	Voice synthesis/alarms
EVAS Display	Data	O	Analog and/or digital
	Video	O	Analog and/or digital
EVAS Systems (including EEU)	Biomed data	I	Analog and/or digital
	Systems data	I	Analog and/or digital
	Commands	O	Discrete
EVAS Communications	Data	I/O	Digital
	Video	I/O	Analog and/or digital

To service these interfaces, the I/O Data Handling function will require the capability of voice pattern recognition (applicable only to the EVA crewmember interface), receipt of digital and analog data, and transmission of digital data. The technologies necessary to perform these tasks are presently in existence.

To increase the productivity and efficiency of the EVA and IVA crewmembers while simultaneously optimizing EVA crewmember safety and system reliability, I/O Data Handling shall include the tasks and features discussed below.

To provide for future growth and the necessary flexibility to handle the various data types (status information, command and control, caution and warning, and freeze frame pictures) envisioned for EVAS operations, I/O Data Handling shall require the capability of transmission and receipt of serial, variable length, alphanumeric data strings on a synchronous and asynchronous basis.

EVAS DMS PROTOCOL STRUCTURE
(ACTUAL BIT ASSIGNMENTS AND TOTAL LENGTH TBD)

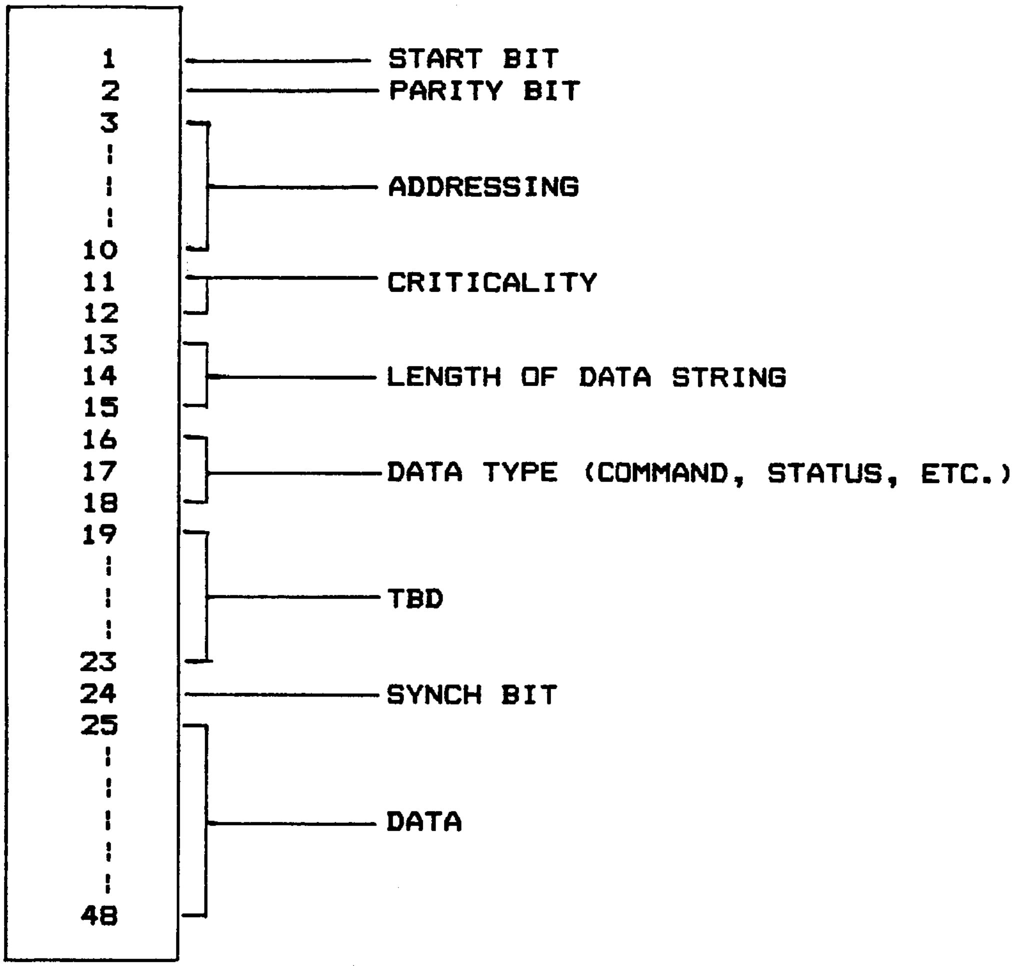


FIGURE 4-10
SAMPLE EVAS DMS DATA STRING

Additionally, due to possible loss or mutation of data during the communications process and its possible impact on crewmember safety and mission success, the I/O Data Handling shall perform validation tests on all data received via the data communications system. The severity of the validation test imposed upon received data will depend on the criticality of the data to crewmember safety and mission success. This criticality will be obtained primarily from header words on all data strings. The protocol structure used to determine criticality will also evaluate and provide information on data string addressing, length, type, and architecture.

Since the bi-directional data communications capability between the EVAS and the Space Station is critical to EVA mission success and crewmember productivity, and impacts EVA crewmember safety, I/O Data Handling shall transmit a "keep-alive" signal on a synchronous basis to the Space Station. The loss of this "keep alive" signal will indicate failure of data transmission capability and will instruct the EVA and IVA crewmembers to initiate appropriate corrective action.

At present, the design and architecture of the EVAS resident microprocessor and its associated memory are not sufficiently defined to identify possible impacts to the EVAS DMS I/O Data Handling capability or to determine the level of sophistication available to such a system. It is envisioned that I/O Data Handling will be significantly dependent upon the EVAS resident processing capabilities to satisfy the requirements imposed upon it.

4.5.2 SYSTEMS MANAGEMENT

The Systems Management function of the EVAS DMS shall perform all EEU and EMU Systems data accumulation, evaluation, and manipulation tasks and those EEU and EMU systems operations automated by design to maximize the safety and productivity of the EVA crewmember. Additionally, the Systems Management function must be available for autonomous EVAS operations to preclude a communications or like failure from jeopardizing the EVA crewmember.

The Systems management function will be further divided into four operating systems each of which will interface with the others but shall not be dependent upon the others to operate. These four operating systems are:

- o Monitoring and Control
- o System Operations
- o Displays Management
- o EEU Guidance and Control

Also, to support EVA crewmember productivity and system efficiency, Systems Management shall perform all information and data management operations while concurrently making the most efficient use of memory. Memory management features shall also be required within the Systems Operations.

o Monitoring and Control will be responsible for sampling all biomed, EMU, and EEU instrumentation and the delivery of this data to I/O Data Handling for transmission to the Space Station, to Systems Operations, or to Displays Management. Some Caution and warning capabilities may also be included in the Monitoring and Control function but will be limited in scope to those parameters sampled by it. All EVAS and EEU command and control operations shall be via the Monitoring and Control functions.

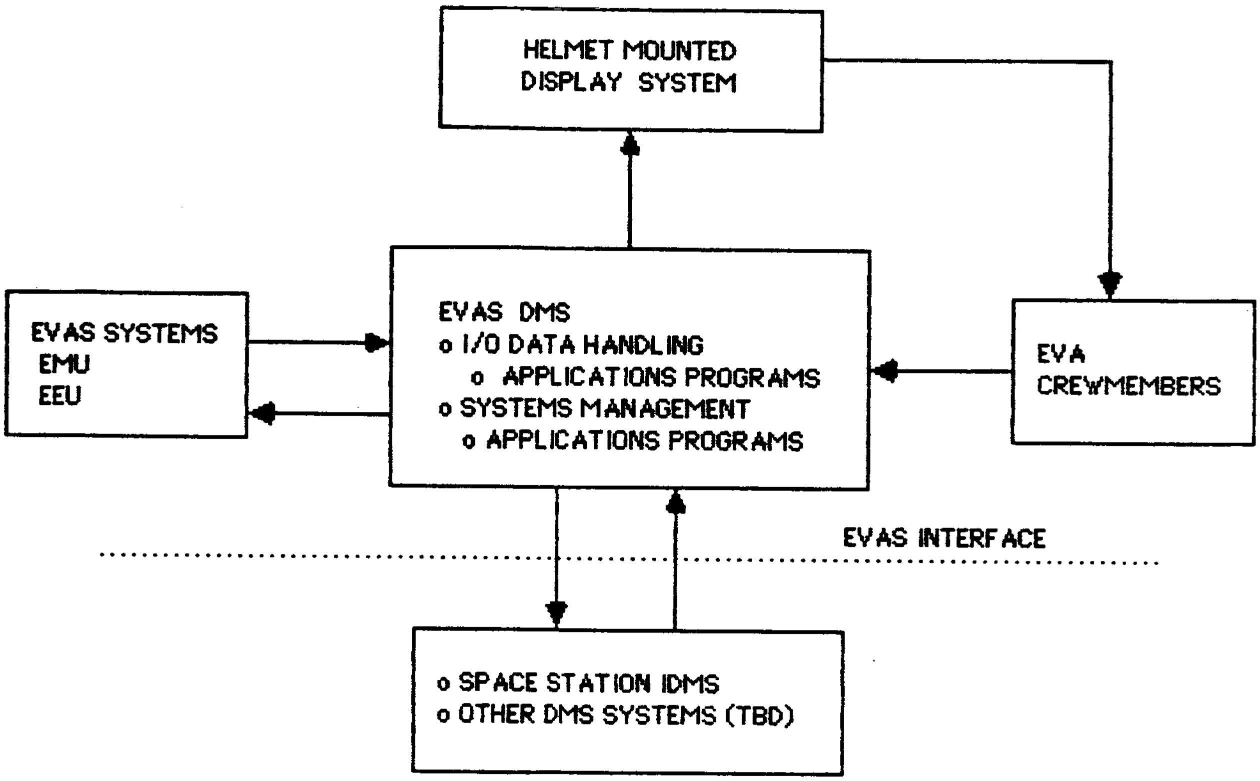


FIGURE 4-11
EVAS DMS INTERFACES

o System Operations will be responsible for the determination of EMU and EEU systems health and mission status, and all caution and warning functions derived from these.

o Displays Management shall be required to process all necessary data and/or pictures for use by the Helmet Mounted Display (HMD). Requirements for the HMD will be broken into hardware and display design.

- o HMD hardware design must minimize power requirements while providing an easily readable display which does not in trude on the crewmembers' normal vision. This suggests that a heads-up display may not be the optimal solution, rather a display just below or above the normal line of sight. Light levels should be in accordance with accepted industrial and MIL-SPEC standards for similar displays. Collimation should be adjustable from close-up to optical infinity. The capability to recall prior displays is desirable.

- In design of the displays, first a selection must be made between visual and auditory information transmittal. Any message which is short, simple, and/or time-critical should be presented aurally. If the information is to be presented visually, the choice becomes pictorial (video, graphics, etc.), symbolic (words, dials, digital parameters), or some combination (flowcharts, schematics, etc.). The following guidelines are based on the perception acuity of the EVA crewmember and should be taken into account:

  - The content should be limited to what is necessary to perform specific actions or make decisions.
  - The information should be displayed only to the necessary precision.
  - The format should be in a directly usable form, so the operator does not need to transpose, compute, interpolate, or translate into other units.
  - Redundancy in displayed information should be avoided.
  - Failure of a display or display circuit should be immediately apparent.
  - Unrelated information (e.g., trademarks) should not be displayed on a panel face.

- EEU Guidance and Control is another required operation. Further discussion on it can be found in section 4.6.

4.5.3 APPLICATIONS PROGRAMS

Applications programs necessary to support the operations and functions defined in sections 4.5.1 and 4.5.2 shall be wholly resident in the EVAS. To maintain a high level of system reliability and EVA crewmember safety, only those application programs determined to be non-critical to EVAS operations or EVA crewmember safety will be permitted software-only residency, the rest shall require firmware.

Additionally, all program standards and specifications defined for these Applications Programs shall whenever possible be the same as those used for the Space Station IDMS. The use of like standards for the Space Station IDMS and EVAS DMS will provide for a high level of reliability and ease of upgrade in the future. Also, standardizing the crewmember interface to these programs between the Station and the EVAS will minimize crew training requirements. It is recognized that this interface cannot be completely standardized when the programs have different functions, but a goal should be a level of standardization similar to that found between various applications programs within the new generation of integrated software packages for personal computers.

4.6 PROPULSION REQUIREMENTS

The Generic Fifteen EVA Missions identified in Section 2 and the potential accident profiles developed in support of task 3.2.3.7 (Appendix C) were analyzed to determine those missions either requiring or benefiting from EVA maneuvering propulsion. Five missions were so identified and analysis of these missions yielded basic hardware requirements for an MMU-class vehicle subsequently termed an Extravehicular Excursion Unit (EEU) and also requirements for an OMV-class vehicle termed a Tug. The latest Langley Data Base material on Space Station payload service requirements was analyzed to determine maneuvering propulsion sorties required per year and related logistics requirements were derived. While the only hard requirement for EEU use was for EVA crewmember rescue, it was apparent that an EEU would be very useful for many other tasks and would provide great flexibility in mission operations.

Based on the assumption that maneuvering propulsion will be provided, we proceeded to develop hardware requirements. Various propulsion techniques were examined as were alternate methods of propellant storage. On-orbit servicing and maintenance requirements were examined in some detail since the current MMU has only minimal on-orbit servicing capabilities and is virtually impossible to maintain on-orbit. External configuration of propulsion hardware together with interfaces with other equipment were examined. Guidance, navigation, and control of the EEU class vehicle was examined at length. The above analyses are discussed at greater length below. Propulsion hardware impacts on Space Station interior and exterior are discussed in section 5.6 and 5.7 of this report.

4.6.1 MISSION ANALYSIS

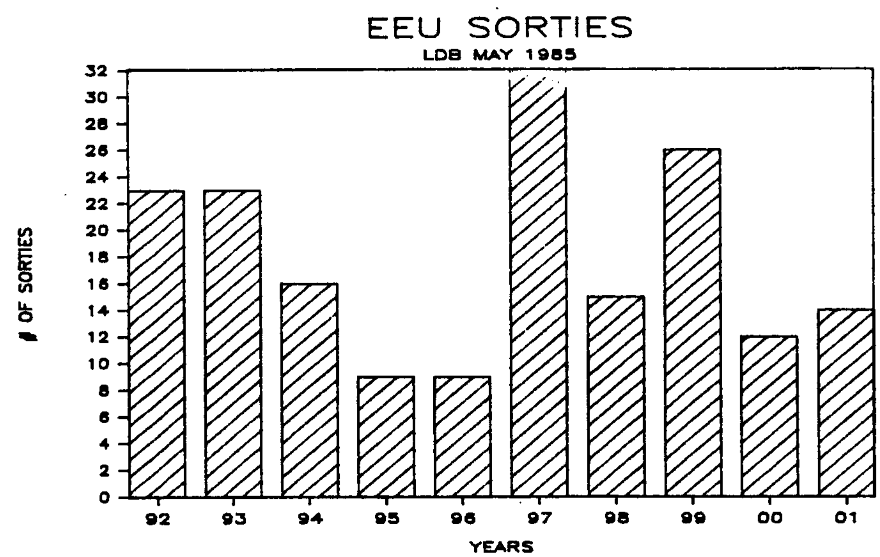
The Fifteen Generic Missions identified in the Mission Requirements Survey were examined to determine those missions that either required or that would benefit from maneuvering propulsion. Five such missions were identified, constituting all or part of five of the Generic Missions. They are:

- Translation to Space Station Worksites
- Translation to Free Fliers
- Space Station or Free Flier Inspections
- Module and Equipment Transfers
- EVA Crewmember Rescue Operations

These missions were then analyzed further to assess contamination constraints, plume impingement constraints, maneuvering precision requirements, hardware interface requirements, and instrumentation and control requirements. Estimates of time and consumable requirements for each of the five missions were obtained using the Martin Marietta Space Operations Simulator and overhead requirements were derived for each mission. The above process resulted in basic specifications, derived from mission requirements, for the EEU. A larger "Tug" type vehicle was also suggested by some of the simulations, due to its greater efficiency as compared to the EEU in manipulating larger classes of modules and objects, and it was included in subsequent analyses.

The Langley Data Bases were analyzed in light of the above selected five generic missions to determine EEU and Tug sorties per year. Very few missions required a sortie though many would benefit from use of maneuvering propulsion. Therefore, the number of "possible" EEU and Tug sorties per year was determined and formed the basis for subsequent analysis. Possible sorties were defined as those resulting from a requirement by a mission for a maneuvering propulsion sortie or a benefit by a mission from such a sortie.

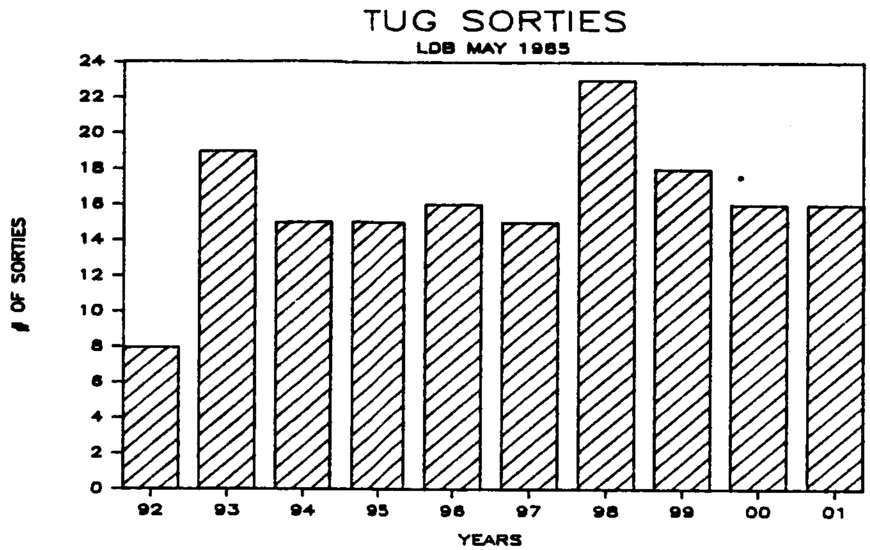
Figure 4-12 is a graph of possible EEU sorties per year, ranging from a low of 8 sorties per year to a high of 32.



YEAR	92	93	94	95	96	97	98	99	00	01
NO. OF SORTIES	23	23	16	9	9	32	15	26	12	14

FIGURE 4-12
POSSIBLE EEU SORTIES BY YEAR

Figure 4-13 shows possible Tug sorties per year, ranging from a low of 8 to a high of 23 possible sorties.



YEAR	92	93	94	95	96	97	98	99	00	01
NO. OF SORTIES	8	19	15	15	16	15	23	18	16	16

FIGURE 4-13
POSSIBLE TUG SORTIES BY YEAR

These estimates are only as good as the Langley Data Base estimates, and depend heavily on our estimate of a real benefit from maneuvering propulsion use. Also, the fact that such a benefit may actually exist does not mean that the payload sponsor or mission planner will necessarily require the use of maneuvering propulsion. Still, we believe that these are the best estimates possible at this time and recommend their use until better estimates become possible. One final note: No sorties are included for Space Station maintenance missions, but EEU flights for Station exterior inspections and other Station maintenance related missions are very possible. This might increase the possible sorties, but no reliable estimate of numbers of such sorties is possible given current information.

Propellant required per year of operation was estimated using the above sortie estimates, together with the basic vehicle specifications. Defining an EEU sortie as three round trips along a single-keel power tower and a Tug sortie as one such round-trip yielded propellant required per sortie. Total propellant required per year was then obtained by multiplying sorties by propellant per sortie in the appropriate category. For the EEU, from 288-1152 kg (8-32 sorties) of propellant were required per year while for the Tug the requirement was for from 272-782 kg (8-23 sorties) of propellant per year.

4.6.2 PROPULSION TECHNIQUES

Alternative methods of propulsion were assessed to determine relative attributes and suitability for use in the candidate missions identified earlier. The evaluation criteria included the following:

- The propulsion media must fulfill the total impulse requirements identified in the mission analyses.
- The propellant media should not be contaminating in the event of leakage or spillage during vehicle recharge or resupply. Further, the products output from the thrusters should minimize hazards and damage to payloads and EVA crewmembers.
- The propellant media should maximize efficiency to minimize the quantity (mass and volume) required both on-board the maneuvering vehicle and in the Space Station bulk storage facility.
- The amount of vehicle electrical power required to operate the propulsion system should be minimized.
- The propellant media should be safe and easy to handle in order to increase crew safety and reduce overall system design costs.

Several different propulsion techniques were evaluated using the preceding criteria. These techniques were cold gas, augmented cold gas, hot gas, ion, and nuclear. The results of the evaluation, summarized in Table 4-6 indicated that cold gas is the best approach.

TABLE 4-6
PROPULSION APPROACH EVALUATION MATRIX

	MEET SPECIFIC IMPULSE REQUIREMENTS	NON CONTAMINATING PLUMES	MINIMIZE PROPELLANT	MINIMIZE VEHICLE POWER	MINIMIZE PROPELLANT STOWAGE VOLUME	SYSTEM SAFE AND EASY TO HANDLE
COLD GAS	YES	SOME YES	SOME YES	YES	SOME YES	SOME YES
AUGUMENTED	YES	SOME YES	SOME YES	NO	SOME YES	SOME YES
HOT GAS	YES	NO	YES	YES	YES	NO
ION	YES	NO	YES	NO	YES	NO
NUCLEAR	YES	NO	YES	NO	YES	NO

A further evaluation of different gases suitable for propellant was conducted. The results of this evaluation are summarized in Table 4.6.2. Helium and nitrogen were the best two gases, with nitrogen preferred because it is less susceptible to diffusion losses due to fitting leakage.

TABLE 4-7
COLD GAS PROPELLANT EVALUATION MATRIX

	SPECIFIC IMPULSE	NON CONTAMINATING PLUME	MINIMIZE PROPELLANT	MINIMIZE STOWAGE VOLUME	PROPELLANT SAFE AND EASY TO HANDLE	COST
HYDROGEN	287	NO	YES	NO	NO	LOW
HELIUM	172	YES	YES	NO	NO	HIGH
METHANE	112	NO	YES	NO	NO	LOW
NEON	77	YES	YES	YES	YES	HIGH
NITROGEN	76.8	YES	YES	YES	YES	MEDIUM
FREON 14	62	NO	NO	YES	YES	MEDIUM
ARGON	54	YES	NO	YES	YES	HIGH

4.6.3 LOGISTICS

Several aspects of Space Station logistics were addressed; propellant transport and bulk storage, spare parts volume and weight for on-orbit maintenance, and support equipment volume and weight. Differing approaches to all three aspects were evaluated using the following criteria:

- o Weight requirements
- o Volume requirements
- o Resupply intervals
- o System complexity

Propellant transport and storage via cryogenic means consumes the least volume for a given mass. Further, if the cryogenic method is used, it may be feasible to resupply propellant at one-year intervals, freeing Orbiter payload bay volume and weight in three of four annual resupply missions.

However, cryogenic storage and transport entails increased system complexity, boil-off problems, and slosh during launch and orbital maneuvering. In comparison, high-pressure gaseous-state storage requires a slightly greater volume, does not involve slosh problems, and can be implemented as a relatively simple system. The recommendation, therefore, is to use high-pressure gaseous systems for propellant storage.

Using MMU ground servicing experience as a general guideline, a list of EEU and Tug spares was compiled. This list may be found in Section 5.4, LOGISTICS. Estimates of volume and mass for the spares are included in the list, with totals of 0.3 cubic meters (10.6 cubic feet) and 177 kilograms (390.1 pounds) required for the maneuvering propulsion spares and equipment servicing expendables. These totals could possibly be reduced as a result of failure analyses which would pinpoint (and, where possible, eliminate) failure prone parts, allowing such parts to be stockpiled while avoiding over-stocking of more reliable components. The mass and volume totals could also be reduced by encouraging a high degree of commonality between EEU and Tug parts, allowing contingency repair parts to be stocked only once instead of having separate EEU and Tug components. Of course, higher reliability in all components will minimize the spares mass and volume.

Support equipment for EEU and Tug maintenance, such as maintenance work stands and associated tools, was considered in the logistics analysis to determine the supply support requirements for such equipment and, hence, the total logistics "cost" of maneuvering propulsion. In general, it is believed that very little, if any, truly dedicated maneuvering propulsion support equipment is necessary and that logistics requirements can be made to be sensibly negligible by the use of standard Space Station workbenches, tools, etc. Dedicated storage and nominal servicing stands will, of course, be necessary for the EEUs and Tugs, but logistics requirements for these, if properly designed, should be minimal.

4.6.4 SERVICING

EVA maneuvering vehicle servicing operations are defined as propellant recharge, battery check and/or changeout, and vehicle checkout. The criteria used to assess servicing operations and equipment include minimizing the time required to perform the operations, minimizing the involvement of the EVA crewmember, and maximizing the levels of crewmember safety and confidence.

This analysis concluded that some EVA time can be saved by using an automatically mating connector for propellant recharge, battery recharge, and vehicle Airborne Test Equipment (ATE) checkout. A connector of this type currently exists, but it is not yet flight qualified, and reliability data is not yet known.

Another savings in time results if the vehicle batteries have sufficient capacity to support the vehicle for the duration of an operation. In the case of the EEU, the nominal duration is eight hours. By using this type of battery, the need to change out batteries during the EVA is eliminated. Crewmember confidence and safety are also enhanced because the batteries are less likely to cause the vehicle to become stranded.

Prior to commencing the EVA, the vehicle should be thoroughly checked out with ATE to eliminate the need for contingency planning during EVA time. During EVA servicing operations, a "quick ATE check" of vehicle health should be performed to ascertain if any potential problems exist.

The final conclusions pertinent to servicing encompass the propellant recharging system. Maximum flow rates from the bulk storage facility to the vehicle are necessary to minimize recharge time. Flow rates can be maximized by locating the storage tank close to the recharge station and by connecting the two with straight lines using a minimum number of fittings.

4.6.5 MAINTENANCE, MAINTAINABILITY

The maintenance and maintainability analysis defined criteria for performance of on-orbit maintenance such as microgravity constraints, crew time, and tool and support equipment requirements. Using the present MMU as a basis, design changes required to perform on-orbit maintenance were also defined.

This analysis concluded that a modular design approach is desirable to reduce diagnosis and repair times. Electrical and fluid connectors (rather than welds) should be used to reduce repair times and improve repairability. Bonded heaters should be provided on spare components as required to eliminate adhesive curing times. The ATE should be able to isolate faults to the lowest level orbital replacement unit (ORU) in order to minimize diagnostic times. Maintenance activities can be minimized by using high reliability components, and by performing maintenance on an "as required" basis. Periodic maintenance requirements should be eliminated or minimized.

4.6.6 EXTERNAL CONFIGURATION

The intent of this analysis was to ascertain preliminary physical maneuvering vehicle characteristics such as size and mass.

The analysis concluded that several factors influence the future size and weight. Among these factors is on-orbit maintenance, and where maintenance will be performed. Designing the maneuvering vehicles for compatibility with on-orbit maintenance constraints will result in larger vehicles to improve access to interior components. Also, if the vehicle or a component thereof is to be maintained inside Space Station, the airlock hatch must be large enough to safely pass either the entire vehicle or the largest module to be maintained.

Other factors influencing the size and weight include the Life Support System (LSS), which latches into the EEU. If a regenerable LSS is used, it is expected to be significantly larger than the present unit. Additions to basic vehicle equipment, such as navigation aids, rescue interfaces, larger batteries and propellant tanks, and more electronics also increase vehicle weight and size.

In summary, the size and weight of the EEU and Tug cannot be determined until decisions concerning other related equipment and concepts are firm. However, for performance estimation purposes, a mass of 820 kg was assumed for an EEU "stack" (crewmember + EEU + EMU + PAYLOAD) and a mass of 7700 kg was assumed for a Tug "stack" ("OMV" + PAYLOAD). The EEU stack mass was estimated by assuming upgrades from current equipment while the Tug stack mass was estimated by assuming an OMV-class vehicle.

4.6.7 GUIDANCE, NAVIGATION, AND CONTROL

This analysis considered two vehicle subsystems: the vehicle control system and the vehicle rendezvous and targeting systems. The control system alternatives considered included direct and proportional rate systems as well as automatic control of translations and rotations. Two rendezvous and targeting techniques were assessed: proportional navigation and Clohessy-Wiltshire equations. The following paragraphs provide details of the above analyses.

Manual direct control of an orbital, free-flying maneuvering vehicle is accomplished simply by turning thrusters off or on in response to a hand controller input. One constant acceleration rate is provided by the thrusters and vehicle translation and rotation rates increase (or decrease) as long as the manual command is provided. Manual direct control is used on the current Manned Maneuvering Unit vehicle. It has proven to be highly satisfactory in all respects, yielding precise, straightforward, convenient vehicle control by the pilot without mentally or physically fatiguing him and without distracting him from the task at hand. Before the MMU, manual direct control was used experimentally on the Skylab M509 vehicle and found to be highly satisfactory there. The M509 also was equipped with two proportional rate control modes for proportional control of vehicle rotations. While these were found to provide generally satisfactory results, some crewmember fatigue was evinced during long slow rotations (since the hand controller input must be held in order to maintain a rate) and the overall conclusion was that direct control of both rotations and translations was the preferred method. Based on these results and the outstanding performance of the MMU to date, direct manual control of any Space Station EVA maneuvering propulsion vehicles is recommended.

Automatic control of an EVA maneuvering vehicle can be provided for both rotations and translations. In evaluating probable missions it was found that attitude and position hold, rather than non-zero rate maintenance or programming, would be the desired features. Further analysis combined with experience from the MMU program indicated that, while a position hold capability would be useful, it would be much too costly in terms of propellant use for any practical system. The required capability, therefore, is for an automatic attitude hold feature. In use on the MMU, this capability has proven to be useful and, for some missions, nearly indispensable in lessening the pilot's workload while simultaneously conserving propellant. It has also found great use in some classes of malfunction handling, rendering otherwise uncontrollable malfunctions relatively harmless. One shortcoming of the present MMU attitude hold system becomes apparent when it is used during translations with large vehicle center of gravity offsets. The amplitude and rate of deadband oscillation are increased during translational thruster firing, resulting in a "chattering" effect which is both unpleasant for the pilot and wasteful of propellant. A simple CG offset compensation feature has been proven in simulations to resolve the problem and will be implemented on the MMU in the future. Such a feature will be a necessity for any Space Station EVA maneuvering propulsion. Implementation of the attitude hold feature can be with thruster firings or with Control Moment Gyros. Given the size of the contemplated EEU and Tug vehicles, and the range of expected rotational rates, thruster implemented attitude control is the preferred method since it provides the greatest range of control with the least mass and power requirements. CMGs provide smoother control than thrusters within their saturation limits, but usually require the use of thrusters to bring large rates into those limits.

In summary, it is recommended that an automatic attitude hold capability, implemented via thruster firings, be provided on Space Station EVA maneuvering vehicles, and that the control system be equipped with an automatic center of gravity offset compensator.

In analyzing rendezvous navigation and targeting requirements for EVA propulsion, it is best to examine targeting methods first since these drive the navigation requirements. Two practical methods for EVA rendezvous targeting exist: proportional navigation and Clohessy-Wiltshire equation navigation. Proportional navigation uses two parabolic curves drawn on a range versus range-rate plot to implement the rendezvous control law, as shown in Figure 4-14 (overleaf).

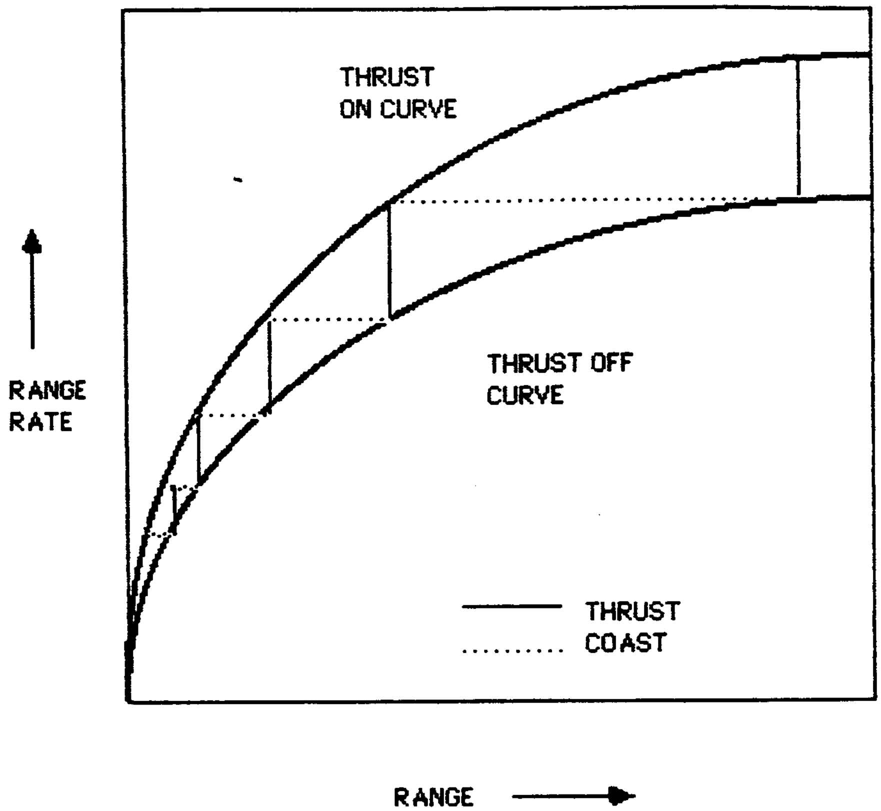


FIGURE 4-14
PROPORTIONAL NAVIGATION CURVES

On a log-log plot these curves are drawn as straight lines and represent lines of constant deceleration. Both curves intersect the 0,0 point, which corresponds to a completed rendezvous. Thrusting is always performed directly along the line-of-sight to the target vehicle so that the upper curve is defined as the "thrust on" curve and the lower curve as the "thrust off " curve. By following the zig-zag pattern of thrusting and coasting illustrated in the figure, the spacecraft are driven to rendezvous. Curves are drawn based on the desired "gain" (deceleration bandwidth) of the control system and in such a way as to cover expected initial dispersions of the two vehicles. Navigation requirements for this method consist only of range and range-rate information and of the ability to see the target or determine a line-of-sight to it. Computational requirements are limited to the ability to determine vehicle position on the range, range-rate plane with respect to the two curves. The technique can also be implemented simply by drawing the curves on a card for crewmember reference.

Clohessy-Wiltshire equations are simply equations of relative motion, linearized for proximate (less than about 10 km.) vehicle ranges. They provide rendezvous targeting information by taking terminal conditions (rates and displacements equal to zero, time some specified value), and initial position and yielding initial velocities necessary to obtain the specified terminal conditions. Delta-velocity, or required rendezvous thrusting, can then be solved for by subtracting actual velocity at the initial conditions from the desired velocities. Navigation requirements are for instrumentation to determine relative position (X, Y, and Z coordinates) and velocity between target and active vehicle and instrumentation to monitor thrust targets for delta-v implementation. Computational requirements are for the ability to solve the three linearized equations of motion.

Of the two methods, the proportional navigation scheme is simple to implement, the least sensitive to navigation errors, and requires the least equipment. The CW navigation scheme is the more accurate of the two schemes, assuming accurate navigation equipment (position to less than 10 meters, angles to less than one degree accuracy), and theoretically requires only the initial thrusting to accomplish rendezvous. However, it probably requires an inertial platform on the maneuvering vehicle for delta-v monitoring during thrusting, either to provide a thrust pointing angle while monitoring delta-v or to provide separate delta-v readings for each axis. It is therefore recommended that proportional navigation be implemented for Space Station EVA propulsion targeting. This will provide good targeting performance with the least amount of equipment on board the maneuvering vehicle, increasing overall performance.

In pursuit of the goal of maximizing overall maneuvering vehicle performance, it is desirable to implement navigation and tracking by placing the minimal amount of equipment (whether used to determine range and range-rate or velocity and displacement components) on the vehicle itself and as much equipment as possible on the Space Station. It is also desirable to place any necessary computational facilities on the Station, if possible, and simply to have output displayed at the maneuvering vehicle. If, in fact, all tracking and navigation functions were resident on the Station, with only a transponder or similar device on the EVA crewmember, then this system would provide an excellent basis for adrift crewmember rescue navigation and targeting. It is therefore recommended that navigation and targeting functions be resident on the Space Station and that each and every EVA crewmember be equipped only with such equipment as is required to interface with the Station equipment, such as a transponder and such data reception and display equipment as is required for maneuvering propulsion operations.

4.6.8 INTERFACES

Many different interfaces were identified in this analysis. These interfaces are:

Attachment to payloads.
Attachment at a maintenance/repair site
EVA rescue
Vehicle servicing
Vehicle storage
Test, checkout (ATE)
Man/machine (operator controls, displays)
EEU/EMU

Specific interface requirements are listed in Appendix B. In general, this analysis found that costs, volumes, weights, and crew times could be minimized by using universal interfaces that are modular for repairability, and require minimal maintenance. The man/machine interface should be designed to maximize crewmember confidence and safety, while minimizing the amount of initial and ongoing training required to operate the vehicle.

4.6.9 OPERATIONAL LIFE ANALYSIS

The operational life analysis assumed a baseline interval of one year on-orbit between ground depot maintenance operations. Based on our previous estimate of sorties per year, the EEU can expect to be operational for a minimum of 8 6-hour sorties and a maximum of 32 6-hour sorties per year. As a minimum, then, the EEU will be operational for 48 hours in one year or about 0.5% of the time. As a maximum, it can be expected to be operational for 192 hours or about 2.2% of the time. The Tug has very similar use figures. The conclusion to be derived from this analysis is that both maneuvering propulsion vehicles will spend nearly all of their on-orbit lives in storage.

Based on the above conclusion and upon general considerations of vehicle use and maintenance, it is felt that maneuvering propulsion operational life will be maximized by proper design of the storage facility, specifically:

- o A storage facility that protects the vehicles from thermal extremes, micrometeoroids, radiation, and debris.
- o A simple design using high-reliability components that require minimal or no periodic maintenance.
- o A modular design reducing repair times.
- o Redundant propulsion and control systems to increase crew safety and confidence.
- o Tolerance of normal wear and tear with minimal degradation of protection or capabilities.
- o A design requiring minimal initial and ongoing operator training.

Additional discussion can be found in Section 5.7.

4.7 CREWMEMBER SUPPORT REQUIREMENTS

Accomodation of the crewmembers' regular anatomical functions (food, water, and waste management) is necessary to support routine accomplishment of EVA missions. Additionally, the potential need for in-suit medical care must be considered.

4.7.1 FOOD AND WATER

The EVA Medical/Physiological Requirements document (SSCN JJ020011) states that minimum food and water requirements for an eight hour EVA are 1.2 liters (40 oz.) of water and 750 Calories of food. While these figures are somewhat more than the 0.62 liters (21 OZ) and 200 calories provided by the Shuttle system, they are not believed to represent an unreasonable extension of the current Shuttle suit technology.

Water and food, in the current system, are provided by an in-suit drink bag and a food bar (wrapped in edible rice paper). Both are accessed, at the crew enclosure neck ring, by use of the mouth, unassisted by the hands. Inclusion of a hand-in capability in the EMU-Crew Enclosure design would make the use of whatever specific designs are designs are decided upon much more convenient.

4.7.2 WASTE MANAGEMENT

Waste management involves urine, fecal, and vomitus containment and/or collection.

Urine collection systems have been developed for both men and women.

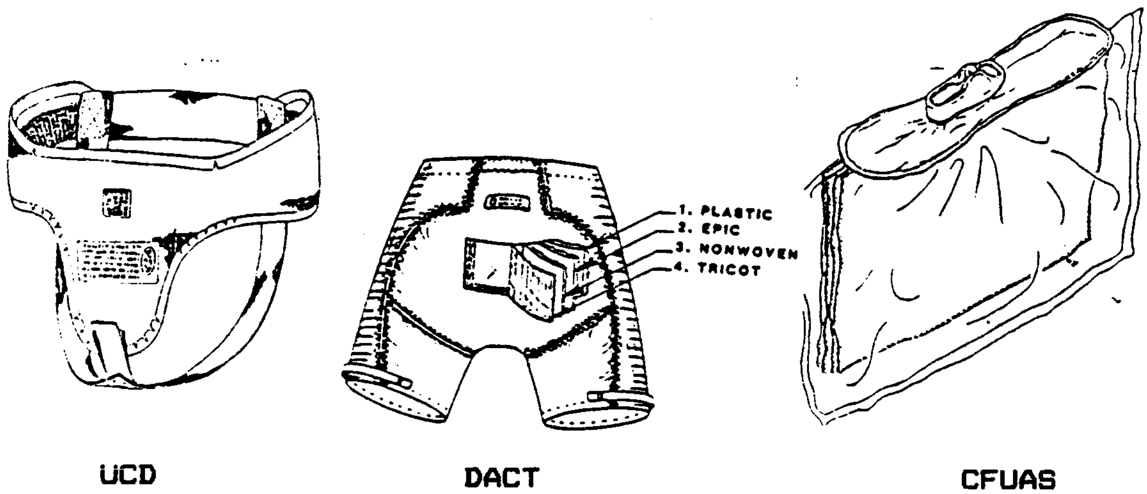


FIGURE 4-15
URINE COLLECTION SYSTEMS

The device for males, the Urine Collection Device (UCD), is basically a bag with a size selectable interface for the crewmember. The device for females, the Disposable Absorption Containment Trunk (DACT), is essentially a large diaper and has disadvantages in its bulk and changes in fit due to crewmember physical changes. A Contingency Female Urine Absorbent System (CFUAS), which operates simlarly to the UCD, has been developed but never flown.

With either the UCD or the CFUAS, problems with interface fit can cause serious hygiene problems. The inclusion of a hand-in capability could greatly reduce this problem.

The EVA Medical/Physiological Requirements document (SSCN JJ020011) requires the urine collection systems to have capacities of 1000 cc. This is comparable to the current UCD and should present no design problems.

Fecal containment can best be accomplished by control of diet and personal habits in order to negate the need for a collection system. In case of an "accident" the liquid cooling garment inner liner will serve as a temporary containment system.

Attempts to develop vomitus containment systems have been largely unsuccessful due to the reflexive nature of the muscle contractions involved. It makes it difficult to keep the mouth enclosed on an entry way. While some work should continue in this area, emphasis should be given to prevention rather than containment. Again, a hand-in capability would greatly simplify implementation of such a system.

4.7.3 MEDICAL CARE

A survey was performed to determine the medical problems that could be induced by or associated with performance of EVA. Facilities, equipment, and procedures for prevention diagnosis, and treatment were identified.

The most likely problems were:

- Barotrauma
- Evolved gas dysbarism
- Gas embolism
- Conditions resulting from inadequate environmental control
- Mechanical trauma
- Oxygen toxicity

As detailed in Appendix C, treatments for these conditions, other than medication such as analgesics and decongestants, require return of the crewmember to the Station. In-suit medication use would be greatly facilitated by inclusion of a hand-in capability in the crew enclosure.

4.8 TECHNOLOGY ASSESSMENT

The following paragraphs summarize the results of our analysis in SOW task 3.2.2. A complete listing of the readiness status of the various approaches can be found in Appendix C, and most of these approaches are discussed in Sections 4.0-4.7 of this report.

4.8.1 HIGH PRESSURE SUIT TECHNOLOGY

The pressure of the crew enclosure must be high in order to minimize the risk of decompression sickness. There is a direct relationship between suit pressure and joint torques. The high pressure required for physiological reasons thus creates a requirement for technology development to increase mobility at these higher pressures. The easiest way to do this is to develop joints which have a constant volume during flexion and therefore do not have a "preferred" orientation or set point. Also, since a true constant volume joint is difficult to achieve, some joint friction is necessary to resist it's tendency to seek the set point. Obviously, this further increases the torque required to manipulate the joint. Technology for gloves is so much different from that for the large joints that it requires separate discussion.

- Gloves: Glove mobility is generally considered to be the most important element in EVA productivity. Unfortunately, it has also been the most difficult to provide at an acceptable level. The main problem has been the adaptation of manufacturing techniques employed with the larger joints to the small scale required for gloves. The problem becomes more acute as attempts are made to accommodate the smaller end of the target size range. Three concepts are being pursued to enable higher pressure operation with little or no degradation in torques and ranges. Two are "soft" (tucked fabric finger joint) concepts and the other uses a system of metal bellows and rigid knuckle sections very similar in concept to the toroidal convolutes under development for elbow and knee joints. The "Link-net" soft glove concept being developed by the David Clark Company has had prototype tests (Level 6), while the ILC soft glove and the NASA/ARC hard glove are at the conceptual design stage (Level 3). Any of the three could reach full operational capability (Level 8) in time for IOC. We recommend continued pursuit of all three concepts.

- Joints other than gloves: The current Shuttle suit uses a minimum number of bearings, with tucked fabric used for joint construction. While this provides acceptable mobility at Shuttle EMU operating pressures, it is very pressure-dependent and rapidly degrades productivity during extended high-pressure operation. Four types of constant volume joints are being investigated, along with improve -ments to fabrics and construction techniques for tucked fabric joints.

The constant volume joint types are:

- o Variable geometry hard sections/bearings (stove-pipe)
- o Rolling convolute Single Wall Laminate (SWL)
- o External linkage, toroidal convolute SWL
- o Internal linkage, toroidal convolute SWL

The mechanical constant volume joints show much greater promise of achieving the mobility and operational life requirements than improvements to tucked fabric technology. The four mechanical joints have all had prototype/engineering models tested in a relevant (manned, pressurized) environment (Level 6), and could be at Full Operational Capability (Level 8) by Space Station IOC. Emphasis should be placed on the stove-pipe and rolling convolute SWL concepts.

4.8.2 CONFIGURATIONS PROVIDING RAPID DON/DOFF WITHOUT ASSISTANCE

For productivity's sake, it is highly desirable to have the capability for a person to don and doff the crew enclosure without assistance in a minimum time. The horizontal plane closure currently in use on the Shuttle EMU does not meet this criteria. While the suit can be donned and doffed unassisted, to do so is difficult and time-consuming.

Other closure concepts being examined include diagonal (AX-1), bi-planar (Manned Orbiting Laboratory), and rear-entry (AX-5, ZPS, Soviet Salyut). The bi-planar and diagonal closures have had prototypes tested (Level 6). The rear-entry closure is operational (Level 8) in the Salyut suit and is at the conceptual design stage (Level 3) for the AX-5 and ZPS suits. Any of the three closures could be at Level 8 in time for IOC. We recommend continued effort on the bi-planar and rear-entry closure, with primary emphasis on the rear-entry method.

4.8.3 HIGH MOBILITY AND LONG TERM WEAR COMFORT

For productivity during routine operations, maximum comfort and mobility must be provided with minimum torque/effort required. The technology required for low-torque joints is discussed in Section 4.8.1.

Shuttle EMU experience has shown that the use of pads to increase comfort is an individual exercise for each astronaut, but basic concepts have been developed and pure O2-compatible materials selected which will be applicable to the Space Station EVAS.

A further recommendation regarding comfort is to continue development of crew enclosures which permit a hand-in capability in minimum external volume.

4.8.4 IMPROVED INFORMATION DISPLAY, STORAGE, AND COMMAND

Improving the information processing capability of the EVAS allows increased autonomy for the EVA crewmember to perform his assigned tasks without requiring the constant support of one or more IV crewmembers or the ground. A system is envisioned for the EVAS which not only monitors systems and alerts the crewmember to anomalies, but actually manages the systems while providing the capability for a crewmember to access the Space Station IDMS while EVA. This appears to be completely feasible by utilizing current technology developed primarily for the commercial and home electronics markets. The only remaining decisions are between types of technological solutions for each element of the system. The recommended course of action is to allow the development pace to continue without significant NASA R&D funds being committed, then simply select and certify the appropriate systems when required.

- Display systems are getting smaller, lighter, more capable, more reliable, less power-hungry, and most of all, LESS EXPENSIVE by the month. The choice between CRT, liquid crystal, and a host of other mature technology should be based on which approach most exceeds the requirements for the least money. We feel that this will most likely result in incorporation of one or more high-resolution liquid crystal displays (LCD) in the helmet. Of course, any visual display will be augmented by some sort of audio alerts in the event the crewmember is not looking at the display when a warning occurs. Mature technology here ranges from bells and buzzers to voice synthesis. Studies have shown that the optimum audio alert is a synthesized voice with a quality somewhat less than completely human-sounding, which gets the crewmember's attention, but allows him to discriminate readily between synthesized and human voices.

- Like display systems, storage systems unimaginable a few years ago are today within the budgetary reach of millions of homes, and their development is accelerating, not just advancing. This report contains much more information than would be envisioned to be used during the course of an EVA, and is contained on two 5-1/4" floppy disks which will soon be obsolete due to their "low" volume and mass efficiency in storing large quantities of data. Read/write capabilities for laser disks, for example, may soon increase this capability by two or three orders of magnitude. The use of rotating memories (diskettes,etc.) should not be ruled out, particularly for task or mission specific data such as timelines, procedures, etc. Random access memory technology is sufficiently advanced that it should not be considered as a constraint of any kind for processing or manipulating data.

- EVAS DMS control systems, up until now, have consisted of electromechanical switches on a Displays and Controls Module (DCM) on the front of the EMU. Voice recognition technology will probably never do away with this long-proven actuation method, but certainly promises to augment it in order to greatly enhance productivity in two ways. Not only can the crewmember concentrate on the task at hand during actuation of the DMS, but the necessity for a DCM which intrudes on his optimum work area has been eliminated since this would no longer be the primary interface with the DMS. Virtual control techniques (coupling a visual display with hand-position sensing in order to manipulate a virtual switch) now being developed for military aircraft applications are not as mature as voice recognition, and even if they were, have certain peculiarities which limit their application to an EVAS. For instance, the normal method of allowing the EVA crewmember to move his head about in the helmet introduces the additional variable of eye position, significantly complicating the application.

4.8.5 HARD STRUCTURE THERMAL INSULATION

Most concepts for higher pressure crew enclosures involve some type of hard structures as opposed to the soft suit materials used for EVA systems to date. The Thermal/Micrometeoroid Garment (TMG) used for the Shuttle EMU is unsuitable for these hard materials, and anyway cannot meet the anticipated cycle life requirements for Station, without further development.

Three types of solutions are being examined

- o Fabric or composite thermal insulation as on STS EMU
- o Gold coatings
- o Aluminum coatings

All three of these concepts are at the conceptual design stage (Level 3) and could easily reach full operational capability (Level 8) by IOC. We recommend continued development on all these concepts with emphasis on fabric/composite insulation due to the additional advantage of extra micrometeoroid/debris protection capability.

4.8.6 ON-ORBIT MAINTENANCE, SERVICE, REPAIR, REPLACEMENT (COMPONENT MODULARITY)

The need for on-orbit repair capability is obvious as stated in Section 4.0.2.1. The primary challenge to providing this capability is designing modular components with easy access and few loose parts.

- o Crew Enclosure: The use of Ortman coupling technology, Figure 4-7, with some combination of mechanical joints makes maintenance and repair of the crew enclosure simple and straightforward. Relevant prototype testing has been conducted on these concepts (Level 6), and they could be operational (Level 8) by IOC.

- Life Support System: All filters, motors, valves, orifices, regulators, and electrical functions should be modularized along with the obvious batteries, CO_2 scrubbing system, and heat sink. Implementation of this requires mainly access and captive fasteners, and could easily advance from its current level of critical function tested (Level 4) to full operational capability (Level 8) by IOC.

- Propulsion System: Same concept as LSS. This modularity is only at the level of basic principles observed and reported (Level 1), but no problem is perceived in achieving operational status, especially considering the benign operating environment (no requirement to withstand launch/landing loads in operational configuration), which allows much less rigid construction, along with ease of access to components.

4.8.7 ON-ORBIT FIT CHECK, RESIZING

Because of the criticality of proper glove fit, we feel that the use of custom gloves is justified.

On-orbit resizing of the remainder of the crew enclosure is accomplished identically to crew enclosure maintenance, namely, through the use of Ortman coupling technology to insert/remove sizing elements from the suit segments corresponding to long bones (Level 6 now, Level 8 at IOC).

4.8.8 AUTOMATIC SERVICE AND CHECKOUT

Automating any routine function will obviously contribute to enhancing overall productivity. However, in this instance, the functions simple to automate have already been automated, while the remainder will require a visual inspection anyway after performance, and so provide a rapidly diminishing return. Specifically:

- Regeneration of the CO_2 scrubbing module is the most likely candidate for automation, involving either the connection of a regenerating umbilical to the EMU or the removal and replacement of the CO_2 module with a fresh one, then initiation of recharge. Termination of recharge would then be automated based on a predetermined set of parameters. Verification would be by the EVA crewmember during pre-EVA activities.

- If humidity removal is not combined with CO_2 removal, this will involve draining an accumulator, a function easily and quickly accomplished manually. Automation of this function is simple, but would provide only a minimal enhancement.

- Battery and fluid (oxygen, nitrogen) recharge automatically stop after the potential (pressure or voltage) is equalized, so that only initiation and verification is required.

- Cleaning and sterilization of the crew enclosure can easily be performed during a visual inspection for damage after EVA; minimal effort should be expended toward automating this function.

- Automatic checkout of systems is best accomplished during EMU donning and activation, consisting of built-in tests similar to those in use on the STS EMU (electronic self-test at start-up, continuous system monitoring during operation). The only time more complete checks would be required would be after ORU replacement or maintenance and would not be automated, unless they are to be performed frequently.

4.8.9 AUTOMATIC THERMAL CONTROL

From a hardware standpoint, this is easily achievable using current technology. The only obstacle is development of an algorithm which provides comfortable control of temperature with minimum crewmember involvement. Since nominal temperature control is envisioned to be accomplished by electronic manipulation of valves, the implementation of this technology at any point in the development cycle should be all but transparent to the user or the designer. Provisions should be made for its incorporation, with research continuing to develop the proper algorithm.

4.8.10 CONTROLLED EFFLUENT EMU

While no absolute requirement was identified for protection of sensitive payloads from EVAS effluents, it stands to reason that minimizing these effluents can only enhance observations by such instruments as the SIRTF (SAAX 0004). A bigger impact has been identified in the field of logistics. Use of a sublimator, such as in the STS EMU, requires resupply of around .5 kg (1 lbm) per EVA man-hour. This penalty can be eliminated by use of a regenerable heat sink, a system allowing heat leakage in the cold Space Station environment, or some combination of these. Sufficient volume should be allocated in the LSS to enable inclusion of such a heat sink, whether or not it is a part of the design at IOC. An alternative approach is to use dependent life support for these limited applications as an augmentation to the independent life support provided by the LSS.

4.8.11 BASICALLY REGENERABLE EMU

The regeneration of LSS functions as opposed to using consumables has the obvious advantage of reducing logistics requirements, but also carries the not-so-obvious disadvantage of increasing LSS volume for a given number of hours of life support. As stated in 4.1, we feel regeneration technology should be pursued at the expense of LSS volume. In the event the technology is not ready in time for IOC, consumable systems can easily bridge the gap until it is ready. All that is required is to standardize the interfaces at the LSS:

- O The cooling system interface should provide a conductive surface and instrumentation. Primary emphasis should be placed on simple phase-change systems (without radiators) augmented as required by umbilical cooling and proper use of the environment to allow heat to escape from the crew enclosure. As with CO2 systems, the Phase B contractor must trade these systems against the logistics impacts, smaller volume, and payload contamination impacts of heat rejection through a sublimator. Implementation of such a regenerable cooling system should receive a higher priority than regenerable CO2 removal.

- O The CO2 scrubbing system interface should provide inlet, outlet, cooling, instrumentation, and electrical power interfaces. All current efforts should be continued toward developing a regenerable system. Priority should go to the hollow-fiber membrane approach and to whatever approach is selected for Station cabin CO2 regeneration by NASA in the course of Phase B WP-01. The Phase B contractor must make an informed recommendation based on a trade between the logistics advantages of such a system against the lower development cost and lesser LSS volume provided by LiOH systems.

- O The electrical interface should accept whatever standard power is provided by the Station (400 Hz, 20 kHz) and convert it to whatever is required by the EVAS systems. This should itself be standardized, if not to the same as the Station power system, at least to 28 vdc as used on aircraft systems. Efforts should continue toward increasing the number of recharges acceptable for EVAS energy storage devices; batteries, fuel cells, mechanical (flywheel).

4.8.12 MECHANICAL END-EFFECTOR

This task was descoped during contract negotiations. A copy of the MDAC-HB IR&D status report is being provided under separate cover.

4.8.13 GENERIC WORKSTATION

No technology issues were identified in the development of a generic workstation. The operational needs must, however, continue to be refined. At some point, preferably by the Phase B Interface Requirements Review (IRR), these needs should be frozen to allow preliminary design work to be conducted on a workstation which will then itself define the interface to be met by the remainder of the Station systems and payloads.

4.8.14 MMU CAUTION/WARNING

Several techniques were identified which would permit passing of MMU (or EEU, as defined in Section 4.6) data to the EVAS DMS within the EMU. The most promising approach is to use the optical data link capability envisioned for the Shuttle EMU. In addition to being more mature than RF or hardware linkage (Level 5 vs. Level 4), this makes the most efficient use of the mechanical interface envisioned between the EMU and EEU. It also presents a simpler problem for the design engineer.

4.9 EVAS/STS INTERFACES

A survey was performed to determine requirements for operating the Space Station EVAS in conjunction with the Space Shuttle Orbiter. Two scenarios were developed: the first assumed that the EVAS would not be operated out of the Orbiter but would only be used for rescue missions or EVA from the Station in the Orbiter cargo bay--Section 4.9.1. The second scenario assumed that the Station EVAS would be operated out of the Orbiter with all attendant support functions provided by it--Section 4.9.2. A final point of interest between the Station EVAS and the STS is that Station EVAS technology might be applicable to an STS EVAS, assuming that they are not the same system. This is discussed in Section 4.9.3.

4.9.1 STATION SUPPORTED EVA

If all EVA using the Space Station EVAS is supported only from the Station, then Orbiter interface requirements are limited to two: communications and hatch size. The EVA crewmembers must be able to communicate directly with the Orbiter crew in a straightforward fashion, preferably without having to process such communication through the Station. Communications frequencies, data types, and power levels must then be compatible between the Orbiter and the Station EVAS. For rescue scenarios, the Station EMU must be capable of fitting through an Orbiter airlock hatch. This imposes a size limitation on the Station EMU to be small enough to fit through the present hatch, in order to avoid requiring a new and larger Orbiter hatch.

4.9.2 ORBITER SUPPORTED EVA

If the Station EVAS is to be operated out of the Orbiter the following requirements must be met. First, the Orbiter must provide storage volume for three EMUs and such support equipment as is deemed necessary. The Orbiter must be capable of securely storing the potentially much more massive (compared to current) Station EMUs through launch and landing loads, requiring more heavy-duty mountings than are currently used, and attendant modifications to the airlock and/or Orbiter middeck area. The Orbiter must be capable of recharging consumables used by the Station EVAS. Both the EMU and EEU (required because the Station EVAS LSS will not interface with the current MMU) require battery recharge so the Orbiter must supply properly regulated power through correct connectors to them. The Orbiter must also supply correct power either to the EMU or to adjacent EMU support equipment for carbon dioxide control regeneration and heat sink resupply or regeneration, or provide storage space for spare regenerable units. Correct connections through airlock or middeck umbilicals must also be supplied. The Orbiter must supply gaseous oxygen to the EMU for life support recharge and gaseous high pressure nitrogen to the EEU for propellant recharge through the proper lines and connections. Finally, the Orbiter software must interface with the EMUs and EEUs for automatic checkout and servicing.

4.9.3 STATION EVAS TECHNOLOGY APPLICATION TO SHUTTLE EVAS

Even if a separate NSTS EVAS is used, some of the Station EVAS technology could be employed in it to good advantage. The regenerative consumables technology would probably not be used since the Orbiter would be able to support the consumables use requirements easily but would be severely impacted, as noted above, by regenerable support. While other pieces of Station EVAS technology may find use on the NSTS EVAS, the prime area of technology which could and should be transferred is high pressure suit technology. This would would favorably impact Shuttle EVA operations by eliminating or minimizing prebreathe requirements and by providing easily sized, easily maintained crew enclosures. Most of all, the mobility and torque enhancements required in order to implement higher pressure suits have a major positive impact on productivity no matter what operating pressure they are used with. Other maintenance ideas and design philosophy from the Station EVAS may be employed in the NSTS EVAS to provide a more reliable, easier to service and maintain, cheaper to operate system than the current one.

SECTION 5

SPACE STATION EVA REQUIREMENTS AND INTERFACE ACCOMMODATIONS

5.1 ATMOSPHERIC PRESSURE AND COMPOSITION

The issue of Space Station cabin pressure and atmosphere composition as it relates to EVA involves a complex interrelationship among human physiological factors, space suit technology limitations, and complexity of EVA life support systems. The basic issue includes the following considerations:

1. Suit pressure relationship to EVA productivity
2. Physiological relationship of suit pressure to cabin pressure for reduction of the crewmember's bends risk
3. Space suit technology readiness for EVA operations at higher pressures, particularly in regards to gloves
4. The degree to which EVA requirements for cabin pressure selection can be imposed over global program issues

Suit Pressure Relationship To EVA Productivity

It has been previously reported, in the Midterm Review Presentation (DR2) of this study, that the EVA crewmember's joint mobility and dexterity vary inversely with the suit pressure level. Constant volume, or near constant volume, type joints are required in the crew enclosure to eliminate, or at least reduce this sensitivity. The tucked fabric type joints currently in use are most sensitive to changes in operating pressure. The crewman's overall productivity in accomplishing EVA tasks will be enhanced by having as low suit pressure as possible.

Physiological Relationship Of Suit Pressure To Cabin Pressure

Reduction of bends risk for crewman about to go EVA has been the subject of intense study for the STS, and ongoing tests have further defined this critical relationship. The ratio ("R value") of the crewman's tissue nitrogen to the total suit pressure determines acceptable combinations of suit/cabin pressure with the associated risks determined by the R value selected. The crewmember's tissue nitrogen level is a variable that can be controlled by introduction of various prebreathing protocols, all of which have attendant systems requirements and productivity penalties associated with them.

Suit Technology Readiness For High Pressure Operation

In the course of the technology surveys conducted early in this study, it was our assessment that the highest reasonable pressure level for operation of a suit incorporating advanced joint designs was around 8 psid. While recent testing indicates that this number may be somewhat conservative for most joints, the gloves remain the most sensitive to pressure level. Since they are also the most critical elements in the ability of the crewman to perform useful work and since there is a good deal of technical risk still associated with enhanced gloves, the need to operate a space suit at the lowest reasonable pressure must continue to be emphasized.

Global Considerations For Selecting SS Pressure Level

The aforementioned factors that strongly suggested a cabin pressure selection of 10.2 psi were duly considered by the SS program managers along with other driving issues affecting many areas of concern. Their recent decision to baseline a 14.7 psi Earth normal atmosphere for the SS shifts the impacts of the EVA requirements fully onto the EVA systems themselves and away from their SS interfaces and accommodations. It must be noted, however, that further studies by the SS phase B contractors, in attempting to bridge the gap of cabin/suit pressure incompatibility due to space suit technical limitations, may result in protocol options that do have impacts on SS architecture and SS/EVAS interfaces to maximize overall crew productivity. These may include methods such as use of intermediate pressure levels in the EVA preparation areas for the suit donning activities or even for the entire prebreathe period.

5.2 COMMUNICATIONS REQUIREMENTS

Communication of information to and from the EVA crewmembers will be of utmost importance during the Space Station era due to the multiplexity, complexity, and flexibility of EVA tasks to be performed. Proper communications will optimize productivity, increase reliability, and improve operational safety for all EVA missions.

Communications include voice communication, telemetry, freeze-frame TV, and full motion TV. Part of the communication problem is how the data is displayed, since a good display will communicate well the information contained therein while a poor display may not communicate at all.

For voice communication, the fundamental requirements are that any crewmember who needs to be heard can be heard and that all communication should be smooth, easy, and prompt, with no "noise" if possible. Noise as used here can be simple electronic noise or other communications of a non-germane nature. To meet this requirement, the equivalent of two channels of voice communications are needed for every pair of EVA crewmembers. In this fashion, each crewmember can transmit on one channel and receive on the other. The Space Station itself must be capable of receiving each channel and of transmitting either on each channel or on its own separate channel to each EVA team. The EVAS must then receive the Station's transmission.

It is anticipated that for IOC, the EVAS must be capable of supporting EVA by two crewmembers at once with the requirement to support EVA by four crewmembers working in teams of two within 6 years. This means the equivalent of four channels of voice communication will be required with a possible station channel constituting a fifth and sixth channel. In addition, an "All Call" channel will be required for emergency or off-nominal operations, for a total of seven channels required.

The major function of telemetry in support of the EVAS will be to provide IV crewmembers, ground monitors, and a possible on-orbit expert system EVA monitor with data on crewmember health status and EVAS hardware status.

Health monitoring will include EKG and respiration readouts for each crewmember. While outputs from each crewmember can probably be multiplexed so that each crewmember has only a single biomedical output, each crewmember will require that one output so that at IOC two channels will be necessary for this monitoring with four channels for growth.

Hardware system status can probably be treated like crewmember biomedical monitoring with a single, higher data rate channel for each EMU with EEU status information multiplexed into the signal as required. Payload systems may additionally require telemetered monitoring by the ground or an IV crewman. Whether this requires a separate channel or can be multiplexed with the EVAS hardware data is unknown. The EVAS hardware data may be amenable to multiplexing with the crewman biomedical data, reducing the required number of channels, but this has not been determined yet.

Two distinct types of television will be required. One type will constitute a single freeze-frame transmission from the station DMS to an individual crewman or to a team of crewmen. The second type of television will consist of normal-motion transmission from the EVA crew to the Space Station.

In freeze-frame television use, each team of crewmembers could receive the same picture. Additionally each crewmember of a team could receive different pictures simultaneously. Source of the transmission could be electronically stored data in the DMS (a satellite maintenance manual for instance), a diagram placed on a camera table in the Space Station, or similar transmissions relayed from the ground.

In normal-motion television, each team should be able to transmit one channel of data to the Space Station for simultaneous display, recording, or transmission to the ground.

In all, then, two channels of freeze-frame television transmission/reception will be required for IOC and four for growth. One channel of normal-motion television will be required for IOC and two channels for growth.

It is not clear as yet exactly how EEU targeting will be performed for the long (approximately 1 kilometer) translations from the Space Station. If all data taking and targeting functions are handled within the EEU itself, no communications functions with the Space Station, other than a possible transponder on the station, will be required. However, if tracking and targeting are handled by the Station with data relay to the EEU, then provision must be made for that data relay. This would require two channels for both IOC and growth with currently envisaged EEU manifesting.

Provisions must further be made for communicating with teleoperators and robotic devices. These may be attached or free-flying. Examples are the MRMS or OMV in teleoperator mode and the OMV or EEU with FIDO package in robotic mode. Command data must be transmitted by the station and received by the device, and systems and status data, probably including television, must be transmitted by the device and received by the station. Provisions must be made for all of the above functions, but insufficient detail exists to estimate number of channels or all types of data.

5.3 DATA MANAGEMENT

The EVAS Data Management System (DMS) will be critical to the success, optimization of tasks and efficiency, and safety of all Space Station EVA missions, planned or unplanned.

The EVAS DMS will consist of various software and firmware packages that, depending on their application, are resident in the EVAS, the Space Station, or both. The EVAS DMS will permit the EVAS to receive, access, or transmit data from or to the Space Station Information and Data Management System (IDMS) via RF or hardline communications. It will also enhance the EVA crewmember's EVAS system monitoring capability, enhance the Space Station's EVA monitoring capability, support EVAS memory management, and optimize the use of the EVAS and Space Station resources to provide real-time support to the EVA mission crewmember. Additionally, the EVAS DMS will be capable of recognizing partial or complete data communications failure and will be capable of providing support, on an autonomous basis, to an EVA crewmember in a critical failure to achieve a safe return or safe haven. The fundamental requirements to be imposed on the EVAS Data Management System (DMS) are the provision of Input/Output (I/O), Data Handling, and Systems Management capabilities and the allocation of these capabilities to software or firmware within the EVAS, the Space Station, or both.

To provide the necessary interface between the EVAS processor, the Space Station processor, and their corresponding full-duplex telemetry communications systems, an I/O Data Handling capability is warranted. During an EVA, telemetry data can consist of commands, status, software loads, alarms, and other data types necessary for mission success and safety. To most efficiently use the communications system and maximize data transmission and reception capability, the I/O system shall be capable of handling serial, variable length, alphanumeric data strings. Additionally, because certain data can be critical or routine, the transmission and reception capability should extend to asynchronous or synchronous communications.

During an EVA, it is considered probable that the quality or completeness of a data sequence in the transmission or reception phase of communications may degrade or experience signal loss for brief periods. Therefore, to preclude such a failure from causing any possible erroneous action or possible processing failures due to the received communications telemetry, the I/O Data Handling system shall impose a validity test on all communications. For those data sequences considered life or mission critical, a unique validity test sequence shall be performed. Variations in data type, length, criticality, and priority are expected to exist within any EVA telemetry communications scenario. To support these communications variations and to optimize processing, unique telemetry data formats, with the judicious use of header words, are considered a necessary requirement on the I/O Data Handling system. During transmission or reception, telemetry data shall be formatted or unformatted so that necessary data characteristics are identified for processing.

During an EVA, it is desirable to maximize the processing capability of the EVAS and the Space Station processor, while simultaneously reducing the probability of telemetry data loss due to the receiving processor being utilized for other operations. To achieve such a goal, the EVAS DMS shall be required to use communications protocol techniques that will direct the receiving I/O system to prepare for receipt of data. Additionally, such techniques, when developed, will permit an EVAS or Space Station processor that is not being addressed to continue its normal operations with the exception of an "ALL CALL" signal intended for reception at all processors other than the transmitting unit.

Due to synchronization of signal and processing requirements inherent to synchronous communications of telemetry data, the EVAS resident DMS shall require a timing synchronization signal from the Space Station on a periodic basis. However, it should be noted, that the loss of such a timing signal shall not prohibit the EVAS resident DMS from performing in an autonomous manner.

Because the capability to communicate data bi-directionally between the EVAS and the Space Station is a safety concern, it is prudent to require that the EVAS DMS use bi-directional Keep-Alive signals. These Keep-Alive signals shall be incorporated within the telemetry data communications on a periodic basis to identify to the receiving processor the continued communications health of the transmitting system. Absence of the Keep-Alive over some predefined number of periods shall result in an alarm being issued to the resident IVA or EVA crewmember and appropriate action taken. Although loss of telemetry data communications is the only immediate failure that can be deduced for such a signal loss, other failures such as a massive power failure or extreme damage to the EVAS warrant the incorporation of a Keep-Alive into the EVAS DMS.

In addition to performing those I/O operations necessary to support telemetry communications during an EVA, the EVAS DMS must provide the EVAS and the Space Station the capability to perform those operations necessary for the efficient and safe performance of the EVAS during its mission. To achieve such a goal, the EVAS DMS shall be required to provide a complete Systems Management operations environment via software or firmware. This Systems Management operations environment shall, as a minimum, include the following operating systems:

1. EVAS Monitoring and Control - provides the EVAS DMS and the Space Station the direct interface to all EVAS and EEU instrumentation and command/control hardware for data samples, statuses, command/control operations, fault determination and annunciation, and all EVAS resident caution and warning functions.

2. EVA Systems - provides the EVAS DMS the capability to determine systems health and status of mission-related parameters for update to the EVA crewmember or the Space Station. This operating system shall also contain all necessary memory.

3. EEU Guidance and Control - provides the EVAS DMS the capability to perform all EEU operations necessary for mission success and safety.

4. Displays Management - interfaces all EVAS DMS operations to the HMD whether they are EVAS or Space Station initiated.

For the purpose of future growth and updates, the above identified operating systems shall be required to be modular. They shall also use, where feasible, data base techniques identical to those used on Space Station to reduce interface impacts and to permit program loads to most efficiently use both the EVAS and Space Station processors. Because the EVAS system processor will be more limited in its capabilities than those available on the

Space Station, only those functions considered critical to EVAS and EEU operations for EVA crewmember safety shall be required to be permanently resident in protected memory within the EVAS in the event autonomous EVAS operations become necessary. Also, all operations, whether permanent or non-permanent in EVAS residency, shall be capable of being loaded into the EVAS by the Space Station and shall be required to minimize their demands on the EVAS processor and memory.

To minimize the possibility of data loss during any operation and to preclude critical functions being performed erroneously, the EVAS DMS shall be required to be fault tolerant and to be designed with an automatic error recovery feature. An internal mechanism or design feature shall also be required to prioritize and control all processing operations within the EVAS to maximize safety critical performance objectives and mission success objectives.

RELIABILITY/MAINTAINABILITY

To permit ease of update and increase the efficiency of operations, the EVAS DMS shall be required to be developed within those TBD standards for the Space Station Information and Data Management System; however, those standards that adversely impact the EVAS' processing capability shall be identified and considered for exception.

5.4 LOGISTICS

INTRODUCTION

EVAS logistics can be considered under three broad categories: EMU logistics, EEU logistics, and tool and ancillary equipment logistics. Our approach to examining these areas is to generate an overall logistics philosophy, including a definition of five generic categories of spare parts, and to apply this philosophy to the specific systems to estimate spares and general resupply requirements. The result is a preliminary estimate, based heavily on current experience with similar shuttle systems, of station EVAS logistics requirements.

DISCUSSION

The following analysis assumes that two crewmembers will be performing EVA each day within the bounds of an 18-hour workweek for each crewmember. It is assumed that this will be implemented via two complete airlocks supporting four separate EMU's and two EEU's, with EVAS performed by at least four separate crewmembers.

In defining an overall logistics philosophy, it is first necessary to define categories of spare parts. Support in orbit requires the following categories of ORU's:

1. Scheduled maintenance items
2. Regenerable ORU's to support quick turnaround for contingency EVA's
3. Single use and/or low MTBF items
4. Select, damage-prone items
5. Select, random failure items

Scheduled maintenance ORU's are items with scheduled replacement intervals to ensure proper equipment operation. Spares are maintained at a level to ensure that EVA to support a 90-day mission will not be curtailed by running out of these ORU's. Examples of this equipment include filters, gas traps, chemical beds, and mechanisms that must be replaced or actuated to ensure item integrity. They are not usually life critical, but could delay scheduled mission plans if not maintained.

Regenerable items are items that after operation require regeneration to ensure peak operation. Spares in this category include batteries, carbon dioxide removal modules, and heat sink modules.

Here spares are maintained to ensure that 1-hour turnaround can be effected when contingency EVA is required within the normal 12-hour regeneration period. Regenerated modules are returned to inventory after servicing is completed.

Single use/low MTBF items can be considered personal and/or expendable. These items are usually life-limited or crew-preferred items, such as urine collection devices, undergarments, gloves, and sizing elements.

Selected damage-prone items are items that through experience or anticipation are spared for potential damage occurrences that could affect the mission. Examples of this equipment include thermal garments, lower torso assemblies or elbow joints that have no history of failure, but under adverse conditions could sustain undesirable damage and require replacement.

Selected random failure items are EMU and service equipment items that must be replaced in the event of failure. Items in this category include sensors, service equipment, solenoids, and communication equipment. Generally these are not life-critical items, but malfunction would result in EVA sortie abort. On-orbit replacement is expected to be quick and cost-effective.

As mentioned above the Space Station will maintain four operational EMU's and two operational EEU's supported by the following spares:

1. Sufficient spares to satisfy EVA crew personnel sizing elements every 90 days.
2. Sufficient spares to replace expendables and low reliability items (less than 0.999) for a 90-day cycle.
3. Four SCU assemblies.
4. Sufficient quick turnaround recharge/regenerable items to ensure emergency conditions will be met if normal recharge/regeneration cycle cannot support contingency mission needs.
5. Sufficient spares to support service equipment while on-orbit. All items must be considered in the 90-day resupply to account for unscheduled maintenance problems that occurred in the previous 90-day period.

Batteries are considered resupply items because of their usually low shelf life. All the batteries, including spares, will probably have to be replaced every 90 days.

The suit parts are considered resupply items because sizing considerations will require an inventory revision, including spares every 90 days.

The spares list assumes that a set of resupply items is provided prior to the first 90-day period and resupplied thereafter.

ORU's may be components or modules depending on the capability of the subsystem instrumentation to isolate the fault. Failure detection for each ORU will require added instrumentation and information processing in the EMU Caution and Warning System.

Applying these definitions to specific systems yields the spares lists as described in the accompanying tables. Table 5-1 lists EMU spares, Table 5-2 lists EEU spares, and Table 5-3 lists spares for tools and ancillary equipment.

TABLE 5-1
PROJECTED EMU SPARES REQUIREMENTS

ON-ORBIT EMU SPARES - One time delivery; replenish as required

ITEM	QUANTITY	MASS kg (lbm)	VOLUME liters (ft**3)
EMU LSS	2	378(834)	382(13.5)
SCU	2	10(22)	57(2.0)
Phase Change Heat Exchanger	2	20(43)	28(1.0)
CO2 Removal Canister	2	98(216)	76(2.7)
CWS	1	2(5)	3(0.1)
DCM	1	7(15)	6(0.2)
EVC	1	5(11)	3(0.1)

EMU RESUPPLY 90 DAYS - Size sensitive, damage prone, and limited life items

ITEM	QUANTITY	MASS kg (lbm)	VOLUME liters (ft**3)
SSA (less LCVG, CCA, UCD/ DFXT, IDB)	2	161(354)	312(11.0)
Filters	1 Set	.5(1)	6(0.2)
Batteries	8	218(480)	142(5.0)
CO2 Sensors	2	1(2)	6(0.2)
Gloves	10	34(75)	71(2.5)
Suit Components	As Required	79(175)	127(4.5)
UCD	32 Max	8(17)	57(2.0)
DACT	32 Max	7(16)	142(5.0)
Vomitus Collector	4	1(2)	3(0.1)
IDB	2	.5(1)	14(0.5)

TABLE 5-1
PROJECTED EMU SPARES REQUIREMENTS (CONTINUED)

ON-ORBIT SERVICE EQUIPMENT SPARES - One time delivery; replenish as required

ITEM	QUANTITY	MASS kg (lbm)	VOLUME liters (ft**3)
Pump/Separator	1	5.0(10)	6.0(0.2)
Power Supply/Battery Charger	1	23.0(50)	14.0(0.5)
Fan	1	5.0(10)	6.0(0.2)
Fan/Separator	1	5.0(10)	6.0(0.2)
Solenoid Valves	2	0.5(1)	0.3(0.01)
Compressor Head	1	5.0(10)	1.4(0.05)
Communicaton/Data Interface Equipment	1	0.2(0.5)	0.6(0.02)
Regulator	1	2.0(4.0)	0.6(0.02)
Controller	1	1.0(3.0)	6.0(0.2)
Filters Miscellaneous	1 Set	0.5(1.0)	6.0(0.2)

SERVICE EQUIPMENT RESUPPLY 90 DAYS - Limited life items

ITEM	QUANTITY	MASS kg (lbm)	VOLUME liters (ft**3)
Filters	1 Set	.3(0.6)	6(0.2)

TABLE 5-2
PROJECTED EEU/FSS SPARES REQUIREMENTS
SPARES REQUIRED PER YEAR

ITEM	QTY	UNIT VOL (CC) (1,2)	UNIT MASS (KG) (1,2)	TOTAL VOL (CC) (1,2)	TOTAL MASS (KG) (1,2)
Central Electronics Unit (3)	2	33000	9.1	66000	18.2
Regulator	2	1500	0.4	3000	0.8
Isolation Valve	2	1400	1.3	2800	2.6
Thruster Triad (2 RH & 2 LH)	4	3000	1.4	12000	5.6
Quick Disconnect Fittings	2	500	0.5	1000	1.0
EMU/MMU Interface (3)	1	1000	0.9	1000	0.9
Control Arms with Handcontrollers	2	15500	4.6	31000	9.2
Locator Lights	2	500	0.3	1000	0.6
Lap Belt	2	500	0.5	1000	1.0
Small Hardware Set (3)	2	1100	1.0	2200	2.0
Batteries (3) (4)	4	7900	6.8	31600	27.2
Paint (3)	1	500	0.5	500	0.5
Velcro	1	500	0.5	500	0.5
Lubricant (4)	1	500	0.5	500	0.5
Service and C/O Connectors (3)	2	500	0.5	1000	1.0
Internal Electrical Connectors (3)	4	135	0.3	540	1.2
Internal Fluid Connectors (3)	2	270	0.3	540	0.6
Propellant Filters (4)	80	7	0.1	560	8.0
Circuit Breakers	2	135	0.1	270	0.2
Switches	2	135	0.1	270	0.2
PLSS Latch (3)	2	2800	1.0	5600	2.0
FSS Latch (3)	2	550	1.0	1100	2.0
Battery Latch (3)	2	550	1.0	1100	2.0
Wire (3)	3	1650	0.3	4950	0.9
Propellant Line Repair Mat'ls (3)	2	260	0.7	520	1.4
Propellant Vessel (3)	2	10000	18.0	20000	36.0
Totals		84392	51.9	190550	125.1

1. Volumes and masses are based on presently used MMU components.

2. Volumes and masses are for components only and do not include packing material and containers.

3. Item definition not sufficiently precise for an exact volume and mass; therefore, volumes and masses are rough estimates.

4. Resupply item.

TABLE 5-3
PROJECTED ANCILLARY EQUIPMENT SPARES REQUIREMENTS
SPARES REQUIRED PER YEAR

ITEM	QTY	TOTAL MASS (KG)	TOTAL VOLUME (CC)
Saw Blades	10	1.0	60
Trash Bags	200	10.0	72000
Nibbler Bits	10	0.5	30
Surface Coating Materials	1	5.0	4500
Drill Bits - Set	1	1.0	450
Welding Rods - Assortment	1	2.0	650
Brazing Rods	1	1.5	650
Grinder Pads - Assortment	1	1.0	3600
Rivets - Assortment	1	1.0	2000
Fluid Connectors - Assortment	5	0.5	3000
Electrical Connectors - Assortment	5	0.5	5000
Adhesive Tape - Rolls	2	1.5	3200
Thermal Insulation Material	1	2.0	20000
Gasket/Seal Material	1	0.1	250
Tie Wrap Assortment	1	0.25	500
ID Tags	1	0.1	50
Teflon Tape - Roll	2	0.1	100
Potting Compound - Can	1	1.0	1000
Coveralls (EVA)	8	2.0	72000
Glove Protectors	16	2.0	55000
Fluid/Gas Sample Collection Vial	50	0.3	500
Lubricant	1	0.5	500
Epoxies	4	0.5	2000
Structural Repair Materials	1	1.0	20000
Fabric Patch Material	1	2.0	20000
Leak Patch Material	1	0.75	1600
Cleaner Material Prepreg Clothes	200	15.0	72000
Electrical Insulation Material	1	1.0	1000
Totals			

All items are spares - resupply as required.

In addition to the above logistics requirements, it will also be necessary to resupply propellant for EVA maneuvering propulsion. Two alternatives are possible, as defined in the midterm report.

The first alternative assumes two different maneuvering vehicles, the EEU and an OMV-class vehicle (TUG). The maximum projected propellant use for each vehicle was given in the midterm report as 1152 kilograms per year and 782 kilograms per year, respectively. A 20% overhead was added to account for residuals not available for use. The resulting volumes required for 90-day, 180-day, and 360-day supplies of propellant are listed in Table 5-4 under "Case 1" for five different gaseous state storage pressures and for cryogenic liquid storage.

The second alternative vehicle complement, Case 2 in Table 5-4, assumes that the EEU is the sole maneuvering vehicle. The maximum propellant consumption per year for this case is estimated to be 4680 kilograms per year. With the 20% overhead for residuals, this figure becomes 5620 kilograms. Table 5-4, Case 2, lists the volume and spherical radius parameters for this mass of fuel. The larger amount of propellant required for the EEU-only vehicle complement is mainly attributable to the relative inefficiency of a small vehicle handling bigger payloads, as borne out in SOS simulations. In these simulations, the larger thrust moment arms of a larger vehicle (the TUG) were more efficient in controlling vehicle rotations in the attitude hold mode and also provided more control authority and higher maneuvering precision than the smaller thrust moment arms of the smaller vehicle (the EEU).

TABLE 5-4
PROPELLANT STORAGE REQUIREMENTS (1)

DAYS SUPPLY	MASS REQUIRED (KG) (2)	DENSITY (KG/M3)	VOLUME (M3) (3)	SPHERICAL RADIUS (M) (3)	PRESSURE/ STATE KPA (PSI)
CASE 1 (REFER TO TEXT)					
90	580.25	278.72	2.08	0.79	24115 (3500)/GAS
		302.75	1.91	0.77	31005 (4500)/GAS
		403.67	1.43	0.7	41340 (6000)/GAS
		470.69	1.23	0.66	55120 (8000)/GAS
		521.13	1.11	0.65	68900 (10000)/GAS
		791.31	0.8	0.64	LIQUID/CRYO
180	1160.5	338.33	4.16	0.99	74115 (3500)/GAS
		302.75	3.83	0.97	31005 (4500)/GAS
		403.67	2.87	0.88	41340 (6000)/GAS
		470.69	2.46	0.83	55120 (8000)/GAS
		521.13	2.22	0.83	68900 (10000)/GAS
		791.31	1.61	0.81	LIQUID/CRYO
360	2321	278.72	8.32	1.25	24115 (3500)/GAS
		302.75	7.66	1.21	31005 (4500)/GAS
		403.67	5.74	1.1	41340 (6000)/GAS
		470.69	4.93	1.05	55120 (8000)/GAS
		521.13	4.45	1.04	68900 (10000)/GAS
		781.31	3.22	1.01	LIQUID/CRYO

TABLE 5-4
PROPELLANT STORAGE REQUIREMENTS (1) (CONTINUED)

CASE 2 (REFER TO TEXT)

DAYS SUPPLY	MASS REQUIRED (KG) (2)	DENSITY (KG/M3)	VOLUME (M3) (3)	SPHERICAL RADIUS (M) (3)	PRESSURE/ STATE KPA (PSI)
90	1405	278.72	5.04	1.06	24115 (3500)/GAS
		302.75	4.64	1.03	31005 (4500)/GAS
		403.67	3.48	0.93	41340 (6000)/GAS
		470.69	2.98	0.89	55120 (8000)/GAS
		521.13	2.69	0.88	68900 (10000)/GAS
		791.31	1.95	0.86	LIQUID/CRYO
180	2810	278.72	10.08	1.33	24115 (3500)/GAS
		302.75	9.28	1.29	31005 (4500)/GAS
		403.67	6.96	1.18	41340 (6000)/GAS
		470.69	5.96	1.12	55120 (8000)/GAS
		521.13	5.39	1.12	68900 (10000)/GAS
		791.31	3.9	1.08	LIQUID/CRYO
360	5620	278.72	20.16	1.67	24115 (3500)/GAS
		302.75	18.56	1.63	31005 (4500)/GAS
		403.67	13.92	1.48	41340 (6000)/GAS
		470.69	11.93	1.41	55120 (8000)/GAS
		521.13	10.78	1.41	68900 (10000)/GAS
		791.31	7.81	1.36	LIQUID/CRYO

1. GASEOUS STATE DATA ASSUMES NITROGEN AT ZERO DEGREES CENTIGRADE.

2. BASED ON PROPELLANT CONSUMPTION ESTIMATES PRESENTED IN THE MDTSCO MIDTERM REPORT, WITH 20% ADDED FOR RESIDUALS.

3. LIQUID STATE VOLUMES AND RADII COMPUTED FOR 110% OF PROPELLANT VOLUME TO ACCOUNT FOR VAPOR SPACE.

Note that the spherical radii given in Table 5-4 are inside dimensions. The total volume occupied by the container requires the addition of the container wall dimension, insulation, and outer containers, as required. Research indicates that cryogenic containers can normally only be filled to 90% of maximum capacity, due to vapor space. Therefore, the volumes for the cryogenic media have been increased by 10% to allow for the vapor space. The corresponding radii reflect this increase in volume.

As Table 5-4 indicates, gaseous state storage requires a greater volume than liquid state storage, but is less complex than the cryogenic storage systems. Another consideration is the tendency of cryogenic liquids to return to the gaseous state ("boil off") as the temperature of the outer layers of liquid in the container increases. The boil off phenomenon is normally dealt with in one of two ways. The first, allowing the gasified media to escape, is wasteful in the Space Station application, especially with an estimated rate of loss of 1 to 3% of the stored mass per day. The second method, recycling the gaseous boil off (reconverting it to a liquid and returning it to the cryogenic tank), is expensive in terms of system complexity and power consumption. A third alternative may be feasible, using the boil off to pressurize a separate gas container for vehicle recharging and recycling the excess back into the cryogenic tank. The quantity of boiled off gas may not be sufficient to charge the gas holding tank rapidly, however. An analogy may be found in the Orbiter Power Reactant Storage Assembly (PRSA), wherein boil off from cryogenic oxygen and hydrogen storage containers is used to supply the fuel cells. In the orbiter, heaters are used inside the cryogenic storage tanks to speed the liquid-to-gas conversion process to supply the required gas flow rates to the fuel cells. The same approach could be used on-orbit if the Space Station uses cryogenic storage to facilitate conversion of the cryogenic propellant to a gaseous state.

In addition to the boil off during storage on-orbit, a problem may exist during the period from installation of the charged cryogenic container in the orbiter payload bay until arrival at the station. If the time is greater than a few days, the quantity of gas in the container could significantly increase the pressure inside the container, if it is not allowed to escape. Simply allowing the boil off to escape inside the closed payload bay could adversely affect other payloads in the bay. Additionally, the problem of slosh in the partially full container during launch could have adverse effects on the launch guidance and control systems. A system to recycle the boil off during pre-launch storage and launch would consume large amounts of power for the pumps and compressors needed to re-liquify the gas. Furthermore, additional volume is required to store the cooling agent used to re-liquify the gaseous propellant boiled off. Since these coolants are normally cryogens that are converted to gases in the cooling process, this technique raises the problems of storage and what to do with the used coolant.

In considering the above, the best approach appears to be transporting the propellant as a high pressure gas. The relatively simple storage requirements and lack of propellant slosh are the primary advantages. On-orbit storage could use either the cryogenic/gaseous state storage discussed earlier or a simple high-pressure gaseous state storage. Again, the relative merits of system complexity and power requirements must be traded off against volume constraints.

If it can be assumed that two vehicles will be used (Case 1) and if the MDAC estimates for cold gas propellant consumption are accurate, then it appears feasible to transport a 1-year supply of gas to the station at a time. The relative merits of this philosophy include more payload bay volume and more available payload weight for other uses on three of four 90-day resupply sorties and a potential reduction in the amount of time required for the orbiter to be on-site for the resupply operation.

5.5 SAFETY HAVEN

At the nominal Space Station altitude and inclination, an EVA crewmember may be exposed to fairly high levels of particle radiation as the station passes through the South Atlantic Anomaly (SAA) in the Van Allen Radiation Belts. These exposures can quickly reach safe limits if EVA is performed during this time frame. Similarly, Solar Flares may occasionally present a radiation hazard to an EVA crewmember. Furthermore, if an EVA crewmember suffers a catastrophic failure of his EVAS at some distance from the pressurized portion of the Space Station, he may be at a great hazard. An EVA safe haven pressurizable volume has been proposed as a solution to the catastrophic problems. The following discussion examines the issues in more detail.

In the presence of a very intense Solar Flare (e.g., 1000 rad), EVA must be aborted and the crewmember must retreat to a safe haven with shielding of at least 10 gm/cm2. There is at least a 30- to 60-minute warning before such a Solar Flare would reach the station. This type of activity only occurs one or two times in an 11-year cycle and generally lasts several days. Intense radiation is limited to a few hours. Most of the time, the crewmember would be able to reach the safety of the station before the effects of the flare would be felt. Therefore, no safe haven appears to be necessary in this case.

As discussed earlier in section 4.2.1, EVA operations can be scheduled around the South Atlantic Anomaly radiation hazard. Therefore, no safe haven is required for protection from this or any other radiation hazard.

In case of a catastrophic failure such as the suit becoming torn or punctured, the crewmember needs to reach a safe location quickly. In this case it needs to be a pressurized safe haven that has all the necessary provisions where the crewmember can either repair the suit or be brought back to the Station airlock.

In the case of an incapacitated crewmember due to space adaptation syndrome, induced nausea, or some other major medical problem, a few minutes difference in getting help could be enormously important. The crewmember's partner may need this time to get him to some pressurized safe haven location where he can receive immediate treatment.

An independent safety haven, however, may not be required, depending on what type of translation system is available. The crewmember needs a fast means of transportation so that he can reach the Station airlock quickly in an emergency. This transportation system can range from a "dumbwaiter", which is permanently mounted along the keel, to an EEU, which would have to be worn at all times. Another possibility is to ride the MRMS, but this would be too slow in an emergency so it should be ruled out.

Based on the current reference configuration of the Space Station (modules and airlock located at the one end of the keel), a crewmember can be approximately 200 feet away from the Station pressurized volume at the time of an accident or emergency. Depending on the exact accident profile or emergency condition, he may only have a very short amount of time to reach a pressurized area. With this time factor being critical, even with a rapid translation device such as a dumbwaiter, he may not be able to reach the Station interior in time. Therefore, a pressurizable safe haven must be as close as possible to the worksite. It must have the capability to be pressurized very quickly. The crewmember might receive ear damage due to this rapid pressurization, but he will have a much improved chance of surviving. If the safe haven is portable via the RMS, then it can be brought from the worksite to mate with the station docking module with the crewmember in a safe environment inside. Therefore, hatch interface should be developed to dock with the Station airlock and/or the Shuttle docking port so that the crewmember can transfer to the Station interior from the safe haven while remaining pressurized.

Utility of the EVA safety haven must be considered. If the failures it is designed to protect against are considered to be so unlikely that the risk incurred in not having the safe haven is acceptable, then there is no requirement for it. The opposite is also true. A decision must await further EVAS hardware definition to allow better accident/failure prediction and further safety haven definition to allow prediction of safety haven costs.

5.6 SPACE STATION INTERIOR REQUIREMENTS

Space Station interior requirements refers to accommodations for the EVAS, interior to the Space Station pressurized volume. This is considered, for purposes of this evaluation, to be separate from the airlock and the logistics module. Thus any services or stowage supplied by the airlock or logistics module should not be duplicated in the Space Station interior.

Space Station support requirements fall into the following major categories:

1. Servicing
2. Maintenance
3. Checkout
4. Prep and Post
5. Stowage (of EVAS spares)

For purposes of this report, the Space Station can provide these functions in three areas:

1. Airlock
2. Logistics Module
3. Space Station Interior (Common Modules)

There is considerable possible overlap in how these functions can be allocated to the possible locations. The first step then is to perform the suggested allocation:

1. Airlock
   a. Servicing
   b. Checkout
   c. Prep and Post
2. Logistics Module
   a. Stowage (of EVAS Spares)
3. Space Station Interior
   a. Maintenance

The maintenance functions to be performed in the Space Station interior involve standard scheduled maintenance and repair of any components found necessary by checkout in the airlock. The major divisions of the EVAS on which this maintenance is to be performed are:

1. Crew Enclosure
2. Life Support System
3. Propulsion System
4. EVA Tools

Maintenance and repair equipment for the Life Support System, Propulsion System, and EVAS tools involves that equipment needed for evaluation and repair of electrical/mechanical systems. This equipment includes: screwdrivers, clamps, am meters, volt meters, and soldering equipment. If proper design work is done in advance, much, if not all, of this equipment can be common with IV tools and equipment. In addition, any extra equipment for safing of high pressure systems while working on them IV will be needed.

Both the Life Support and Propulsion Systems will require mounting positions to secure them while they are worked on. These mountings should allow easy access to the units from all pertinent angles.

Cleanliness levels for both the Life Support and Propulsion Systems are only generally clean (as for the crew enclosure and EVA tools). The exception to this will be on the Life Support System oxygen subsystem. Here a cleanliness of 10,000 will be required whenever pressurization above 500 psi is accomplished.

Maintenance and repair of the crew enclosure will involve bearing and lock maintenance and repair/replacement of any leaking suit components. Again, use of standard IV screwdrivers and other tools should be possible.

In discussing the crew enclosure, it should be noted that the most difficult problem could be isolating the source of a leak. Procedures currently in use include leak teck, halogen detector, and individual pressure test on suit components. These methods are used on the ground only and are either not suitable or ineffective for Space Station use. Leak teck involves use of a soapy liquid applied over the area of a suspected leak. It is effective only if the area in which the leak is located is already known.

Halogen detectors can be used only if freon is pumped into the suit. The detector reacts to the freon setting off a loud noise at the point of the leak. Use of freon in the closed environment of the Station, however, would have to be extremely restricted.

Pressure testing of components (arms, legs, etc.) is effective but requires a test stand and equipment (mounting fixtures, test plugs, etc.). This equipment has penalties in terms of power, volume, and mass. This procedure would also consume a good deal of IV crew time.

To circumvent these problems, a new approach to leak detection in the crew enclosure is suggested. Since the oxygen pumped into the suit for leak checks will be at least subtly different in temperature from ambient in the airlock, an infrared detection system for leak detection should be practical. The detector could be either a scope or video camera, and the leak isolation could be done in the airlock don/doff area.

5.7 SPACE STATION EXTERIOR

This study was undertaken to identify interface requirements for Space Station exterior operations. The objective of this study is to define the operational requirements that should be considered prior to design of the Station exterior, EVA workstation, and mobility aids.

STS experience has demonstrated that on-orbit repair, servicing, and maintenance of spacecraft is more cost effective than returning the vehicle to the ground for work. In the case of the Space Station and other satellites in orbit during that time frame, routine and contingency repairs, maintenance, and servicing will be accomplished on-orbit. To facilitate on-orbit servicing and repair, subsystem and component design and the overall design of the Space Station and other orbiting vehicles should be compatible with EVA in general and with EVA servicing in particular.

This section discusses Space Station exterior design for interface with the EVAS system, an area where compatibility is of great concern. This area can be broken up into five subcategories:

1. EVA Access Requirements
2. EVA Workstation Design
3. Dependent Life Support Subsystem
4. EVA Storage
5. External Safety Requirements

The following sections address each of the five categories in turn.

EVA Access Requirements

EVA operations should have access to all exterior areas of the Space Station for Station and spacecraft assembly or servicing. Handholds and handrails will be required for translation to and positioning at any location on the exterior of the Space Station. Provision of an effective means of transporting the crewmember to and from his worksite will mean less time spent on unproductive translation activities and more time for task performance. More than one type of such mobility hardware may be required to enable efficient transport of small and large items. Handrails constitute the basic provision, as stated above, but other aids similar to the current Shuttle EVA slidewire or more sophisticated devices, possibly motor-driven, such as "clothesline" or "dumbwaiter" concepts, will be necessary for rapid, efficient translation over major Space Station distances. It should be noted that free-flying translation via the EEU was considered as a possible solution to this last question, but was dismissed because it required large amounts of propellant for nominal translations.

EVA Workstation Design

A satellite servicing workstation will be required to manipulate, position, and service said spacecraft while in EVA and can be used to service other large modules, as required. The workstation should have standard interfaces that accommodate required tools and EVA mobility and positioning aids (such as a portable foot restraint) to maximize EVA crew productivity. The work station will provide its own restraints, either fixed or portable, as well as provisions for storing and restraining tools, spare parts, and vehicle components during the maintenance/repair activity.

The workstation must, as a minimum, accommodate servicing of the Hubble Space Telescope at the large end of the spectrum, but be capable of restraining an EEU Central Electronics Unit for maintenance at the small end. It must allow maximum flexibility in positioning and restraining the item under repair.

The workstation should interface with automatic test equipment resident in the Station (probably the station DMS) for spacecraft and component diagnosis, test, and checkout.

Dependent Life Support Subsystem

A Dependent Life Support Subsystem (DLSS), via EVA umbilical, is justified on two accounts. First, it may be necessary to extend an EVA beyond the capability of the EMU's self-contained life support subsystem. This situation could especially arise if a regenerable system were down-sized to limit the volume of the outer shell of the LSS, making the EMU less cumbersome and bulky but also lowering the allowable independent EVA time. It is still debatable as to whether or not such a down-sizing will be necessary, but if it is, a dependent life support capability, via an umbilical, will certainly be necessary. The second justification for a DLSS is that it can be made to be fully self-contained, that is, without any effluents, so that it would not contaminate any sensitive payloads or instruments while operating. If the EMU LSS is fully self-contained anyway, then the DLSS may not be an advantage over it. Beyond this, there is a good deal of concern that the normal leak rate of the EMU Crew Enclosure may be such that it alone provides more contamination than some sensitive equipment can tolerate.

Further design details or, rather, more maturity of the Space Station EMU is required before a decision for a DLSS is made. Provisioning for a DLSS, though, should be relatively simple. Length of the actual umbilical should be based on the maximum length that is operationally tolerable. "Tolerable" is certainly the correct word, since from an operational standpoint umbilicals are encumbrances. In zero-g they act as a drag and entanglement and are to be avoided unless there is no alternative. A DLSS support network would have to be emplaced throughout the Station exterior with "junction boxes" for umbilical interface as necessary to allow EVA access to all parts of the Station while using the DLSS. The basic spacing between the junction boxes would be equal to two times the length of the tolerable umbilical. This, again, would allow access to all portions of the Station.

EVA Storage

The optimum storage location for most EVA equipment would be outside the Space Station pressurized volume. Outside storage reduces wear and tear incurred during translation through the airlock, maximizes available airlock volume for suit don and doff and necessary storage, and maximizes the availability of equipment to the EVA crewmembers. The disadvantages of outside storage are the requirements imposed by the environment. Protection must be available to minimize damage to equipment caused by thermal extremes, micrometeoroids, and radiation. An EV storage facility to stow all possible tools and equipment outside while providing the necessary protection from the environment should, then, be provided. This facility should be located near the EVA airlock (perhaps on its exterior surface) to minimize the time and effort required to acquire or stow tools and equipment during EVA.

External Safety Requirements

Sharp corner/edge, impact, and general design safety requirements for equipment interfacing with the Shuttle EVAS are covered in JSC document 10615A, "EVA Description and Design Criteria." A similar document detailing design criteria for equipment interfacing with the Space Station EVAS will be required and is assumed. This document should be standard for safety-related requirements as well as for general EVA interface requirements. One area that JSC 10615A does not address is that of an EVA safe haven, which would provide radiation protection and a pressurizable volume for emergencies. Normally this subject would be included in this section, but because of its magnitude, it is discussed separately in this document.

Some sort of autonomous rescue capability - autonomous to the Station - must be provided to rescue stranded, free-floating crewmembers. The crewmember may have been the victim of a malfunctioning EEU and possibly be as much as 1 kilometer away from the Station, or he may simply have experienced a broken tether and so, probably, be quite close to the station. In either case, the capability to rescue him must exist.

In the first situation, besides being some distance from the Station, the crewmember may also have a signficant opening rate with respect to it. In this case, a free-flying rescue vehicle is necessary. This vehicle would be similar to an EEU and could be manned, robotic, or teleoperator controlled from within the vehicle. Since time is of the essence in a rescue situation such as this, the latter two options are favored. They would allow immediate initiation of the rescue, whereas the manned vehicle option would require waiting for a second EVA crewmember to arrive at the vehicle storage site and performing subsequent checkout procedures (though abbreviated, of course) before rescue initiation. The robotic/teleoperator vehicle could be a unit designed to plug into an EEU, and in fact, such a vehicle has been proposed as an EVA astronaut assistant. This vehicle should be pursued because of its importance as a rescue device and because of its added usefulness to the EVA astronaut. If it is adopted, provision for this device must be made on the exterior of the Station. This will probably be an automated storage facility and, if the EEU is used, will simply be the EEU FSS.

If the stranded astronaut is in reasonably close proximity to the Station structure, he may be able to rescue himself with some sort of self-contained line-thrower. Several devices to perform this function have been proposed, but no detailed concepts exist. This is considered to be a prime area for experimentation on Shuttle flights prior to Station construction. Depending on the design adopted, if one is, special interface requirements on the exterior of the Space Station may or may not be imposed. For instance, one concept proposes the use of a large net on the Station exterior that would provide a large target for a stranded crewmember's line-thrower. It should be noted that a small propulsion unit integral to the EMU could also be used in this case, but may be impractical due to EMU LSS sizing and cost considerations.

5.8 AIRLOCK FUNCTIONAL DEFINITION

The intent of this section is to provide a definition of an EVA airlock system for Space Station operations. The goal is to present feasible airlock concepts that might be considered prior to incorporating such a system into the final Space Station configuration. This study will reflect the current convergence of operational conditions that are considered to be design drivers for an effective EVA support airlock system. Although the following discussion on airlock requirements is in no way inclusive, it does represent issues that support a preliminary design concept. References for this section were obtained from the following sources: the Request for Proposal (RFP), the Reference Configuration Document (RCD), Data package 2.3 Phase B, and the Science Division EVA requirements for Space Station Technical Status Review (TSR).

To move men and equipment safely beween the pressurized area of a space craft and the vacuum of space, an airlock is needed. The airlock permits entering and exiting of the space vehicle without subjecting the entire crew and equipment to the vacuum of space. During this process, the airlock atmospheric pressure must be equal to that of the cabin pressure before a suited crewman can enter the airlock from the cabin. After entering the airlock and before exiting into space, the crewman must reduce the airlock pressure to nearly equal that of space. After the EVA has been completed and the crewman wishes to re-enter the cabin, the process must be reversed. This procedure can be accomplished using two basic methods, the gas expendable method or the gas recovery method. The simplest airlock pressurization method is an expendable gas system, whereby all or the greater portion of the airlock atmosphere is expended overboard for each airlock use, as in the current shuttle airlock system, (Figure 1). The major penalties associated with this type of method, however, are the cost of resupplying lost gases and providing storage areas for replacement gases. This process, then, is reasonable only when a small number of EVA's are planned for a given mission.

The second method recovers the airlock atmosphere by pumping most of the gases into a separate receiver for re-use (Figure 2). This receiver can be the main cabin, a second airlock, a high pressure container located elsewhere, or a second area of the airlock module. This pump-down to receiver concept is considered optimal for high use rates where the less complex expendable gas systems would discard an amount of gases greater than the total pump-down cost penalty (e.g., pump weight, pump power cost, and storage).

This pump-down to receiver method is considered the method of choice for the Space Station configuration because of the large number of EVA excursions expected for Station operation. There are, however, penalties associated with this method of gas recovery. Two of the most important cost penalties are pump-down power and time. Depending on the airlock volume and number of EVA's, this operational cost penalty could be substantial. To reduce the impact of this cost, it is recommended that the ingress and egress area of the airlock be kept as small as possible, without jeopardizing crew safety. This would reduce the time needed for gas pump-down and allow for the use of a smaller pump-down compressor. For this reason, we recommend that the airlock be designed with two separate chambers. One larger chamber could be used for an EVA equipment and service area, while the smaller chamber could serve as an egress and ingress pathway. The larger service area could also serve as a special airlock chamber for large equipment when necessary.

The following Figure 5-1 provides an idea of these two basic methods.

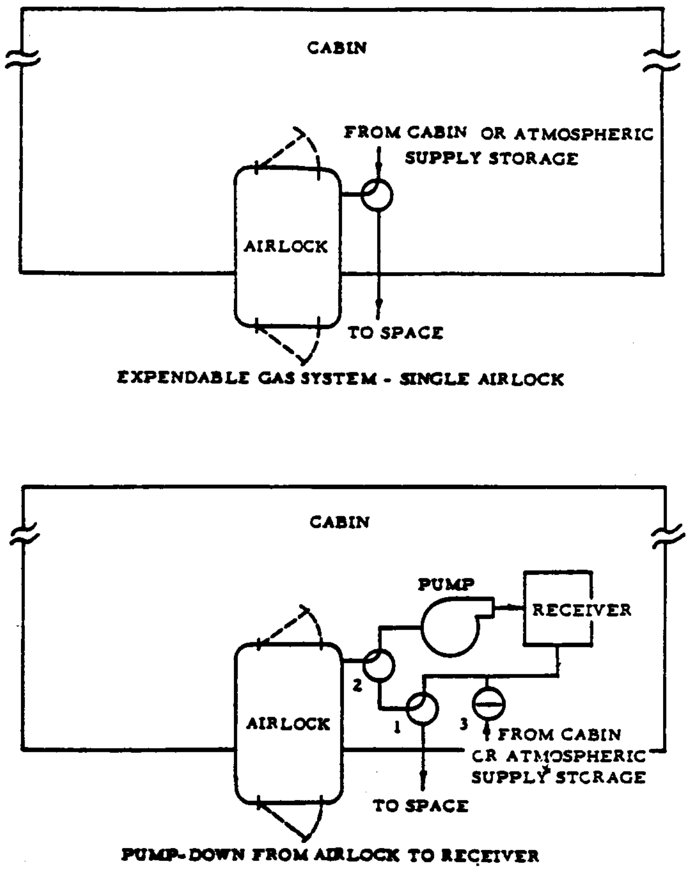


FIGURE 5-1
AIRLOCK CONFIGURATIONS

Still another pressure/volume related design driver for airlock architecture is the requirement for hyperbaric capability. At least one airlock must be capable of achieving and holding pressures of up to six atmospheres for the treatment of rapid decompression illness. This illness is caused by the infusion of gases into the blood while at pressure. If these gases are then allowed to expand, as in a rapid decompression, they might cause damage to the crewman that could be fatal in some extreme cases. For most practical applications, however, the hyperbaric chamber will be used to treat the effects of bends, which occur when nitrogen bubbles form in the skeletal joints. The recommended treatment for these pressure-related contingencies is to repressurize the subject as soon as possible to approximately five times the pressure at sea level and to bring the pressure down in controlled increments. This procedure allows the blood to disseminate the gases from the circulatory system without causing further distress. Therefore, the airlock will require the proper controls and displays to aid in the biomedical monitoring of the affected crewman. The airlock controls and displays will be required to monitor and assist in the regulation of parameters such as blood gas levels, heart rate, chamber pressure, chamber temperature, and chamber gas composition.

For the reasons stated above, the airlock architecture should include in its design ample room for the transfer of men and equipment through all hatchways, which would include both the ingress/egress chamber and the main service chamber. While the size is yet to be determined, it is suggested that the airlock hatchways be sized to accommodate a standard equipment rack or the return of an incapacitated EVA crewman. It is further recommended that an additional small service airlock be incorporated into the airlock. This pass-through airlock would be used to support routine EVA's for tool and equipment requirements and to provide an emergency passageway in case of medical equipment needs. This small pass-through airlock should be installed in the airlock hatchway that separates the main service chamber and the egress/ingress chamber. The use of this small pass-through airlock could be expected to save a substantial amount of airlock cycle time.

Because of the difficulty in anticipating the equipment needs of the EVA crewmen, it is important to store as much EVA hardware as possible in areas that will complement the EVA mission requirements. Therefore, we suggest that all EVA equipment that is compatible with a space environment be located in storage areas external to the airlock, but in close proximity to the airlock hatchway. For the EVA hardware that requires service, such as the MMU's, an external service area that can be operated from inside the airlock would conserve IV space and localize EVA systems controls. Additional EVA equipment service and checkout could be accomplished in the main airlock chamber. Localization of this equipment within the airlock service area will ensure a quick turnaround time for scheduling flexibility. Because of the small volume of the airlock service area, however, we recommend that only required tools and equipment needed in support of EVA activities be stored inside the airlock area. All other equipment should be supplied, as needed, from the Space Station common modules. In addition to localization of EVA service equipment, it is important to conserve as much room as possible inside the airlock area. For this reason it is suggested that as much of the EVA support equipment as possible be equipped with automatic checkout capabilities. This would reduce the need for crew involvement in equipment turnaround and improve the reliance on automatic systems.

SECTION 6

HUMAN PRODUCTIVITY STUDY CROSS TASK COORDINATION - TASK 5

INTRODUCTION

The study contract mandated that an allocation of study resources be made to coordinating with the Space Station Human Productivity Study sponsored by the NASA-JSC, Manned Systems Division. NASA defined, coordinated, and authorized the effort associated with this task.

6.1 REQUIREMENTS AND ISSUES REVIEW

Approximately midway through this study, a set of preliminary elements and issues related to EVA were provided for review and comment. As the definition of purely EVA productivity issues had been left to the EVAS Phase A studies, most of the review items concerned elements of IVA/EVA interfaces. The material was reviewed for consistency with EVAS study findings to date and applicable lessons learned from the STS and previous programs experience base.

In addition to providing comments on all EVA related requirements and issues the critical assumption of baselining pressure suited operations for the SS Man-Tended Approach (MTA) configuration was analyzed and various impacts addressed as follows:

- o Design requirements would be imposed on all EVA crew interfaces to accommodate EVA; such as access, layout/spacing of switches, etc., for operation by pressure suited crewmembers as well as overall volumetric requirements of the EMU (reference JSC 10615A).

- o It would limit all (IVA & EVA) MTA crew operations to the maximum EVA time available from NSTS; namely, two six-hour, two-man EVAs, for a maximum of 24 man-hours of crew time. Additional time could possibly be made available by providing additional EVA consumables, primarily nitrogen for more airlock repressurization cycles. In-module EVA time could possibly be extended by providing umbilicals (which do not now exist) for dependent life support from Shuttle; however, CO_2 removal remains an independent life support function and could be a limiting factor. (LiOH cartridges provide a minimum of 7 hours of CO_2 removal but have tested consistently for longer periods).

- o Even with extended life support capability, operations in a pressure suit are generally more fatiguing than in shirt sleeves and would be significantly less productive.

- o Unless additional EMUs are provided above the two baselined, use of EMUs by multiple crewmembers (e.g., to support two-shift operations) would require selecting crewmembers of comparable anthropometry since Shuttle EMUs have a very limited on-orbit resizing capability. Providing more EMUs than the two baselined carries a significant weight and volume penalty, with no current or planned capability to stow more than a total of three.

- o It was recommended that EVA not be baselined for MTA IV operations. EVA has too many encumbrances associated with its use to be acceptably productive in the cabin. EVA is a limited resource in itself and the EVA mission requirements for the baseline MTA payloads already exceed the NSTS capabilities to deliver.

- o If EVA must be considered for IV operations as a contingency requirement, as it should be, then trade studies must be performed to determine the optimum degree of imposition of EVA design requirements, with weighting given to those activities necessary to reestablish a pressurized environment.

During the course of the review several elements such as 303 Maintainability were found to be generically applicable to the EVA systems and the guidelines were considered in formulating the design requirements for the EVAS. Our inputs to the SS Human Productivity Study were conveyed in our letter HAD-1.0-4947 dated 26 July 1985.

6.2 REVIEW OF PROGRAM PLAN FOR HUMAN PRODUCTIVITY DATA BASE

Late in the course of this study, a copy of the program plan for development of the Human Productivity Data Base was reviewed. With the level of detail provided it was not apparent how useful the data base would be in the EVA area and an illustrative example was requested which would in part satisfy the following concerns:

- o How would the user identify the underlying assumptions for various requirements?

- o Can the data base be manipulated by, for instance, altering a critical assumption, and then can all the ramifications of such a change be readily displayed for assessment of impacts?

- o Can the data base be accessed in plain English words or must the user have specialized knowledge of its architecture, interrelationships, and vocabulary?

- After delivery to NASA, who will exercise control over the content of the data base, particularly with regard to standardization of requirements for consistency with the evolving SS systems design definition?

As the schedule for the SS Human Productivity Data Base runs well beyond that of this study, it is not anticipated that these issues will be resolved by contract end.

SECTION 7

SUMMARY

7.1 STUDY OBJECTIVES ACHIEVED

As they were defined by the Statement of Work, our study objectives were achieved by survey and research, analyses and trade studies. We have developed what we consider to be a comprehensive set of design requirements for the Space Station EVAS and its interfacing and supporting systems.

In addition to the study contract objectives, the McDonnell-Douglas team had several other objectives in mind. First, we were determined to assist NASA in justifying a productive EVA capability for the Space Station program. As adamant EVA advocates we were strongly motivated to see that EVA and its attendant systems and accommodations received the programmatic attention they deserved. Secondly, we were fresh from our experiences in developing and conducting the STS EVA missions and eager to apply the lessons learned to the Space Station development effort. We were confident that as a continuing part of the NASA-led SS development team, we would share in the downstream benefits of a strong front end effort. Finally, and taking our cue from a theme consistent throughout the SOW, we wanted to make sure that all EVA system definition and development efforts were sensitive to human productivity aspects and impacts which are so often expressed in non-quantifiable terms.

Our first objective was shown to have been naively conceived as our mission requirements survey resulted in an EVA mission model which demands EVA services on a sustained and routine basis. Even with peak needs exceeding 3000 manhours in a year, the model must be considered conservative, since the SS maintenance, servicing, and repair requirements are poorly defined at this time and there is virtually no data to support the unplanned or contingency requirements which have been responsible for so much of the STS recent EVA requirements. We must continue to recognize that our mission model, as well as those we are aware of being utilized in SS Phase B trade studies, are indeed conservative and may not represent the full scope of EVA requirements for the Space Station.

Throughout the study we were careful to apply the lessons learned from the STS EVA experience base to our analyses and trade studies and found this background useful in identifying truly useful advancements, in weighting trade-off criteria or in assessing all the ramifications of a new requirement or concept. Extrapolating from this base also enabled us to characterize the key differences in EVA capabilities and limitations between the STS and the SS. While we feel we were thus successful in meeting our second objective we recognize that there is a continuing need for NASA and the Space Station contractors to pursue this goal in the development of EVA systems.

With regards to the emphasis placed on human productivity aspects of EVA designs, we made a concerted effort to bias our trades in favor of productivity, even to the point of ignoring development cost as a discriminator between design options. So far, our conviction that maximizing the use of the crew as the most critical SS resource was the highest priority is being borne out by the EVAS cost trades being performed in the Phase B arena. We will have a continuing concern, though, that there will be productivity impacts resulting from priorities established for distributing limited SS development funds and minimizing those impacts will be a major challenge to the program. The savings in operational costs will be the future dividend of that effort.

7.2 AREAS REQUIRING FURTHER STUDY

Phase B studies will continue to refine EVAS requirements during the SS preliminary design phase, and both contractor and NASA Advanced Development programs will continue to develop the necessary technologies. We strongly recommend that emphasis be placed in the following areas as the program advances (Figure 7-1).

7.2.1 KEY ISSUES

The SS program has already recognized the importance of the radiation exposure issue as it affects the SS as a whole. We feel that this is the proper perspective to take considering the frequency, duration, and dose rate of the possible crew exposures, both IV and EV.

So long as space suit mobility remains affected by suit pressure, we must look for ways to improve the technology or lower the suit pressure. This is especially true for the gloves where even a technology breakthrough would be enhanced even further by lowering the operating pressure. However difficult it is to measure the impacts of this problem on overall EVA productivity, we are convinced that it will significantly affect the productive utilization of EVA as a valuable program resource.

While we are convinced that a maneuvering propulsion capability should be a part of the advanced EVAS, we recognize that the justification for it is not as firmly rooted in mission requirements as are the justifications for other systems. The cost of providing this capability should be carefully balanced against

KEY ISSUES

- O RADIATION EXPOSURE LIMITS
- O GLOVE DEXTERITY/SUIT MOBILITY REQUIREMENTS VS TECHNOLOGY LIMITS
- O EEU JUSTIFICATION
- O IMPLEMENTATION OF ROBOTICS

DESIGN TRADE STUDIES FOR PHASE B/C/D CONTRACTORS

- O HAND-IN-SUIT CAPABILITY FOR CREW ENCLOSURE VS SUIT FIT, DEXTERITY, EVAS VOLUME IMPACTS
- O CREW ENCLOSURE JOINT DESIGN SELECTION
- O BODY SIZE ACCOMMODATION RANGE VS COST OF IMPLEMENTATION
- O DUAL PRESSURE EMU
- O EXTENDED EVA DURATION VS EVAS VOLUME GROWTH
- O THERMAL CONTROL SYSTEM PERFORMANCE

FIGURE 7-1
AREAS REQUIRING FURTHER STUDY

prioritized program needs, regardless of the benefits of having it. Maneuvering propulsion does remain the only practical solution to the potential problem of crew rescue.

We have identified a number of areas which would benefit from advancing technologies in expert systems, teleoperations and other automation or robotic-type applications. While the implementation of such advances is still premature in many cases, the productive benefits warrant continued emphasis.

7.2.2 DESIGN TRADES

The hand-in-suit capability, while offering some significant benefits for crew health and comfort, must be evaluated for the potential impacts to suit fit in general, and especially to the critical glove fit relationship to hand dexterity. The overall crew enclosure may also tend to grow which may also be a problem.

While actual selection of the joint designs was not a Phase A issue, several concepts were evaluated and appear workable. To prevent development from being hindered, premature selection of one concept should be avoided. The modularity afforded by all the current design concepts supports this.

Just as it was for the STS program, the actual crew size range to be accommodated by the SS program, regardless of the range accommodated by the EVAS design, will have to be a carefully considered decision,based heavily on program cost.

A dual pressure EMU must be considered as an option until the suit pressure can be maintained at a level that satisfies both human physiological and productivity considerations. Our requirement for a variable suit pressure reflects the current dilemma posed by the sea level cabin. This will definitely require further study.

Several factors (maintainability, regenerative system efficiency, reliability) continue to conspire to increase the overall volume of the EVAS. This concern may result in a need to reduce the LSS volume allocated for time dependent functions which must be traded off against allowable independent life support time.

The EVAS thermal control system, which was overdesigned for the STS environment, should benefit even more from the more thermally benign SS environment, and thus reduce its volume as the performance requirements are relieved.

There are numerous other design options to be considered as EVA systems and subsystems develop. As cost driven compromises have an effect on crew productivity, continuing effort must be applied to carefully assess those effects to be sure that negative impacts are properly justified.

APPENDIX A

EVAS BASELINE DESIGN REQUIREMENTS

1 LIFE SUPPORT

1.1 PRESSURIZATION/PRESSURE CONTROL

1.1.1 The Pressure Control System (PCS) shall maintain pressure at 30-66 kPa (4.3-9.5 psi) through the use of gaseous oxygen make-up to a closed-loop Atmosphere Revitalization System (ARS). This pressure shall be selectable on-orbit within 10 minutes. Capability to vary/adjust pressure during EVA is desirable. Selected pressure shall be maintained plus or minus 3 kPa (0.4 psi) at flow rates ranging from 0-6 kg/hr.

1.1.2 The PCS shall continue to operate nominally with any single credible failure including failure of a pressure regulator.

1.1.3 The PCS shall permit safe return of the EVA crewmember to a pressurized module after any two credible failures.

1.2 BREATHING OXYGEN

Sufficient breathing oxygen shall be provided to permit 6 hours of useful work at an average rate of 300 watts (1000 BTU/hr) with a leak rate of 100 scc/min, plus two hours of combination overhead/reserve at this rate, plus 45 minutes of contingency operations with a leak rate of 6 kg/hr.

1.3 ATMOSPHERE REVITALIZATION

1.3.1 CO2 CONTROL

CO2 partial pressure (ppCO2) shall be maintained below 3.8 torr for the first seven hours and below 7.6 torr at all times during EVA. During periods of metabolic activity > 450 watts (1500 BTU/hr), ppCO2 will be permitted to rise as high as 15 torr, but must return to normal levels upon cessation of the high metabolic rate.

1.3.2 HUMIDITY CONTROL

Relative humidity shall be maintained between 40 and 70 percent. During periods of metabolic activity > 450 watts (1500 BTU/hr), relative humidity may rise to > 70 percent, so long as helmet fogging is prevented, but must return to normal levels upon cessation of the high metabolic rate.

1.3.3 TRACE CONTAMINATE CONTROL

Particulates, organic compounds, and other contaminates shall be controlled to physiologically acceptable levels as specified below:

TABLE A-1
MAXIMUM LEVELS FOR CONTAMINATES

CONTAMINANT	MAXIMUM LEVEL (mg/m**3)
Any particulates	0.1
Families of compounds	
Alcohols	10
Aldehydes	0.1
Aromatic hydrocarbons	3
Esters	30
Ethers	3
Halocarbons	
Chlorocarbons	0.2
Chlorofluorocarbons	24
Fluorocarbons	12
Hydrocarbons	3
Inorganic acids	0.08
Ketones	29
Mercaptans	2
Oxides of nitrogen	0.9
Organic acids	5
Organic nitrogens	0.03
Organic sulfides	0.37
Specific compounds	
Ammonia	17
Carbon monoxide	500
Hydrogen cyanide	1

1.4 THERMAL CONTROL

1.4.1 COOLING

The crewmember must be able to maintain thermal comfort at metabolic rates up to 450 watts (1500 BTU/hr), with an average rate of 300 watts (1000 BTU/hr). Above 450 watts (1500 BTU/hr), some overheating of the crewmember is to be expected, but the system must accept metabolic heat loads at rates up to 600 watts (2000 BTU/hr). Automatic temperature control is desirable. If automatic temperature control is implemented, capability for crewmember selection of set point is mandatory.

1.4.2 HEATING

The crewmember must be able to maintain thermal comfort at metabolic rates as low as 100 watts (340 BTU/hr) during the night portion of orbits. Automatic temperature control is desirable. If automatic temperature control is implemented, capability for crewmember selection of set point is mandatory.

1.5 INSTRUMENTATION

Appropriate transducers, gauges, and/or other sensors shall be provided to permit the EVA crewmember, the IV crew, or the ground to ascertain correct functioning of the systems described above.

1.6 ELECTRIC POWER

The system shall accept unconditioned power from the Space Station electrical system (currently planned at 400 Hz) for EVAS power system recharge.

2 ENVIRONMENTAL PROTECTION

2.1 RADIATION

2.1.1 IONIZING

2.1.1.1 The EVAS shall provide sufficient protection from proton radiation to maintain the crewmembers' total mission dose at or below the allowable dose for the Space Station program. The level of protection provided shall in no case be less than that provided by the Shuttle EMU. All non-emergency EVA shall be scheduled so as not to coincide with passes through the South Atlantic Anomaly in the inner Van Allen radiation belt.

2.1.1.2 RF radiation protection will be provided by operational restrictions on Station antenna selection, pointing, and power levels during EVA; as such, no specific requirement is placed on the EVAS.

2.1.2 NON-IONIZING

2.1.2.1 The crewmembers' eyes shall be protected from UV radiation. Intensity of ultraviolet radiation admitted to the crew enclosure shall be no more than that admitted by the Shuttle helmet/visor assembly, including the gold visor.

2.1.2.2 If a polycarbonate is used for the helmet pressure shell, it shall be protected from the degradation effects of UV radiation. The preferred method of protection is to use an easily replaceable protective visor, as this would also provide protection from mechanical dangers.

2.2 MECHANICAL DANGERS

2.2.1 MICROMETEOROIDS AND SPACE DEBRIS

The EVAS shall provide > 95% probability of safety from puncture for a ten year operational life at 936 hours/year, using the best available space debris model for hazard assessment.

2.2.3 IMPACTS WITH SHARP CORNERS/EDGES

The EVAS (EMU + EEU + crewmember + maximum consumables) shall survive an impact with a 1 mm (.04 in) radius corner on the Station with a relative velocity of .6 m/s (2 ft/s) with no more than cosmetic damage.

2.3 ATOMIC OXYGEN

Materials used on the EVAS shall be at least as resistant to the effects of atomic oxygen as those of the Shuttle EMU. If a polycarbonate is used for the helmet, it shall be shielded from atomic oxygen impingement.

2.4 STATIC CHARGING

2.4.1 CREWMEMBER PROTECTION

The levels of static charging encountered in LEO, Polar, and GEO are not sufficient to present a direct threat to the EVA crewmember.

2.4.2 EVAS/PAYLOAD PROTECTION

All EVAS/payload electronics shall be properly shielded and grounded. Proper ground paths shall be provided between any mechanically interfacing EVAS components and between the EVAS and payloads, in order to prevent buildup of charges to potentially damaging levels.

3 MOBILITY/ANTHROPOMETRIC SIZING

3.1 MOBILITY

3.1.1 The range of motion provided shall be no less than that provided by the Shuttle EMU Space Suit Assembly (SSA).

3.1.2 The torques required to operate the joints of the crew enclosure shall be no greater than those required to operate the corresponding joints of the Shuttle SSA.

3.2 ANTHROPOMETRIC SIZING

The crew enclosure shall accommodate the maximum possible number of people, with the capability of accommodating a 95th percentile Caucasian male.

4 COMMUNICATIONS

Encryption capability is required for all RF links.

4.1 VOICE COMMUNICATIONS

Full duplex voice capability is required between all parties at all times during EVA. This includes up to six EVA crewmembers, any or all IV crewmembers, and Mission Control. EVA crewmembers must have the capability to deselect transmit and/or receive functions for any party(s)--including Mission Control, but a deselected party must be able to re-establish communication with the EVA crewmember if required by using a "call-up" capability.

4.2 DATA COMMUNICATIONS

4.2.1 UPLINK (Station to EVAS)

4.2.1.1 A relative state vector (range, range rate) update is required once/second during untethered operations.

4.2.1.2 Procedural text and graphics (NTSC resolution) is required at a rate of one screen every 5 seconds.

4.2.2 DOWNLINK (EVAS to Station)

4.2.2.1 Complete system status must be transmitted at least once/second.

4.2.2.2 A continuous carrier ("keep-alive") signal is required.

4.3 VIDEO COMMUNICATIONS

4.3.1 UPLINK (Station to EVAS)

4.3.1.1 RF Link: One NTSC-resolution screen is required every 5 seconds.

4.3.1.2 Hardline Link: An interface is required on the EVAS to permit full-motion video from the Station CCTV system, hand-held cameras, etc.

4.3.2 DOWNLINK (EVAS to Station)

4.3.2.1 Nominal (attached operations in designated work areas) video services are provided by the Station CCTV system and/or hardline hand-held cameras.

4.3.2.2 NTSC-resolution full-motion video is required from the EVAS during EEU free-flight.

5 DATA MANAGEMENT

5.1 I/O DATA HANDLING

5.1.1 Interfaces shall be provided from the EVAS Data Management System (DMS) to the EVA crewmember, the EVAS display, the EVAS systems (LSS, EEU), and the EVAS communication system as specified in Table 4-5.

5.1.2 Capability shall be provided to transmit and receive serial, variable length alphanumeric data strings.

5.1.3 Validation tests shall be performed on all received data with the severity of the test dependent on the criticality of the data, as determined primarily by header words on data strings.

5.2 SYSTEMS MANAGEMENT

5.2.1 Monitoring and Control: The EVAS DMS shall sample all biomedical, EMU, and EEU instrumentation and deliver the data to the I/O Data Handling function (for transmission to the Space Station), to the Systems Operations function, and to the Displays Management function.

5.2.2 Systems Operations: The EVAS DMS shall determine the health and mission status of all EMU and EEU systems, and provide appropriate Caution and Warning functions.

5.2.3 Displays Management: This function shall process all necessary data and/or video for use by the Helmet Mounted Display. The capability to recall prior displays is desirable.

5.2.4 EEU Guidance and Control is performed by the Systems Management function. Detailed requirements are found in this Appendix, 6.3.1.

5.3 APPLICATIONS PROGRAMS

5.3.1 Applications programs necessary to support the functions above shall be wholly resident in the EVAS DMS, in software and/or firmware. Only non-safety critical programs are permitted software-only residency.

5.3.2 Standards and specifications for these programs shall be as similar as possible to those applied to the Space Station IDMS, in order to permit greater portability of programs.

5.3.3 The crewmember interface to applications programs shall be standardized to the maximum extent possible, with a goal of providing a level of standardization such as provided between various applications programs within the new generation of integrated software packages for personal computers.

6 MANEUVERING PROPULSION REQUIREMENTS

6.1 MISSION REQUIREMENTS

MMU-class propulsion capability (Extravehicular Excursion Unit) is required to support adrift EVA crewmember rescue operations. It is highly desirable for support of routine mission operations.

OMV-class propulsion capability (Tug) is highly desirable due to its greater efficiency at large object manipulation and transfer in support of EVA missions.

6.2 PROPULSION SYSTEM

6.2.1 Cold nitrogen gas shall be used as the EEU propellant and as the Tug propellant for proximity operations.

6.2.2 Sufficient propellant shall be provided on board the EEU to insure a minimum of 50 meters/second (150 feet/second) delta velocity capability with an EMU-suited 90 kg (200 lbm) crewmember piloting the EEU.

6.2.3 Thruster force shall be sized so as to yield the same thrust to mass ratio on the EEU as is currently provided on the MMU (acceleration = .09 meters per second per second). Thruster moments shall be adjusted to provide the same rotational control authority on the EEU as is currently provided on the MMU (6 degrees per second per second).

6.2.4 Two completely redundant propulsion systems shall be provided by the EEU so that, in the event of catastrophic failure of one system, the remaining system will provide full maneuvering capability to ensure a safe return to the Space Station structure.

6.3 INSTRUMENTATION

6.3.1 The following information shall be provided to the EEU/Tug pilot via appropriate sensors and displays:

1. Vehicle health and status data
2. Cautions and warnings
3. Navigation/targeting information sufficient to perform rendezvous with a Circular Error Probable of 10 meters at ranges of up to 2 kilometers and precision maneuvering to a predetermined position and attitude at up to 2 kilometers range. Maneuvering precision limits shall be those adequate to perform the specified rendezvous.
4. Malfunction procedures at time of occurrence of malfunction.

6.3.2 Built-In Test Equipment (BITE) shall be provided to determine vehicle operational status with interfaces to Space Station IV displays and to EV crewmember displays. A complete check shall be performed automatically as a part of initial power-up, with continuous monitoring of key parameters during operation.

6.4 CONTROLS

6.4.1 Manual control of EEU/Tug translations and rotations shall be provided, with the same control authority as the current MMU.

6.4.2 An Automatic Attitude Hold (AAH) capability shall be provided with selectable axis inhibit of up to two axes.

6.4.3 Selectable center-of-gravity offset compensation shall be provided to allow more efficient rotational control with large attached masses.

6.4.4 Except for hand controller handles, all portions of the EEU and Tug control systems shall be fully redundant so that, in the event of catastrophic loss of one system, the remaining system shall provide full maneuvering capability in order to enable a safe return to Space Station structure.

6.4.5 The capability shall exist to attach a robotic and/or teleoperator control device to the EEU so that it may be controlled by that robot or by a teleoperator while operating unmanned.

6.5 INTERFACES

6.5.1 EEU/PAYLOAD

6.5.1.1 A universal attachment fixture capable of grappling/attaching to all requisite EVA serviced payloads is highly desired. The fixture should support all module manipulations including satellite retrieval. It should require minimum effort to attach to or remove from the EEU and minimum effort to operate in grappling a payload. The fixture should maximize rigidity of the EEU/payload interface while minimizing loads transmitted to EEU structure and fittings. It should minimize interference with pilot visibility and access to EEU controls. It should also minimize vehicle center-of-gravity offsets when a payload is attached. It should require minimal maintenance/servicing between uses.

6.5.1.2 An EVA crewmember rescue interface shall be provided on the EEU such that an adrift crewmember, with or without an attached EEU, can be attached to a functioning EEU and returned safely to Space Station structure.

6.5.1.3 A workstation interface shall be provided to allow attachment of a generic EVA workstation to the EEU and its use by the crewmember while it is still attached. Attachment/detachment of the workstation shall be easily accomplished by a suited EVA crewmember. The workstation, with or without attached configuration modules, shall provide minimum interference with pilot vision and access to EEU controls and shall maximize work volume and envelope at the worksite while minimizing required effort. It shall allow doffing of the EEU at the worksite and egress and ingress of the combined workstation/EEU there. It shall transmit minimal loading to EEU structure and fittings while providing maximum rigidity during flight and tolerance of collision and work loads.

6.5.1.4 Thruster plume impingement on attached payloads, workstations, and the Space Station exterior should be minimized through the use of careful interface design, and proper thruster positioning. Canted thrusters and variable thruster select logic should also be employed, where and if appropriate, to minimize such plume impingement effects.

6.5.1.4 A worksite interface shall be provided to allow removal and "parking" of the EEU at a remote worksite.

6.5.2 EEU/STORAGE AND SERVICING FACILITY

6.5.2.1 A storage facility shall be provided to allow safe on-orbit storage of the EEU. The facility shall provide protection from the on-orbit environment including thermal, radiation, micro-meteoroid, debris, atomic oxygen, and impact threats.

6.5.2.2 The storage facility shall be equipped with interfaces to allow automatic servicing and checkout of the EEU and to allow monitoring of such tasks as well as general EEU status by IV and EV crewmembers. Connections between the EEU and such interfaces shall either be automatic with EEU docking or shall be quickly and easily made and unmade by a suited EV crewmember. The interfaces shall be designed to minimize servicing/recharge times.

6.5.2.3 The storage facility shall be provided with positioning aids such as handrails, tether points, and foot restraints so as to allow EV crewmembers to be properly restrained and positioned during EEU and storage facility servicing, repair, and donning and doffing.

7 CREWMEMBER SUPPORT FUNCTIONS

While alternate design solutions can no doubt be found, the inclusion of a hand-in capability in the crew enclosure greatly simplifies accomplishment of all crewmember support functions. This capability also has a positive psychological effect on the crewmember, and as such is highly desirable.

7.1 FOOD/WATER

7.1.1 FOOD

The EVAS shall provide the crewmember with 750 Calories of food accessible during EVA.

7.1.2 WATER

The EVAS shall provide the crewmember with 1.2 liters (40 oz) of water accessible during EVA.

7.2 WASTE MANAGEMENT

7.2.1 URINE

The EVAS shall provide a hygienic method of collecting up to 1.5 liters (51 oz) of urine for male and female crewmembers. A hand-in capability is highly desirable in order to enhance hygiene.

7.2.2 FECES

Fecal control shall be be accomplished through control of diet and personal habits. A hand-in capability is highly desirable, in which case appropriate containers shall be provided to enable collection; otherwise, no requirement should be imposed.

7.2.3 VOMITUS

Conditions leading to sickness in the crew enclosure shall be avoided. A hand-in capability is highly desirable, in which case appropriate containers shall be provided to enable collection; otherwise, no requirement should be imposed.

7.3 MEDICAL CARE

A hand-in capability is highly desirable to enable the in-suit use of medication.

8 MISCELLANEOUS

8.1 MAINTENANCE/MAINTAINABILITY

8.1.1 EVAS design shall be conducive to on-orbit maintenance by the use of modular designs employing easy access provisions and quick disconnect connectors for fluid and electrical lines, as well as for access panel fasteners and other mechanical fasteners. All fasteners shall be captured fasteners. EVAS design shall be according to the constraints of microgravity servicing requirements, with the guiding constraint being to minimize the time for on-orbit repair of the system.

8.1.2 The use of periodic or preventive maintenance and testing shall be minimized and a maintain as required philosophy will be substituted, backed-up both by a fail-safe design allowing safe return to a pressurized environment in the event of a malfunction, and by Automatic Test Equipment enabling early diagnosis of any impending system faults.

8.1.3 An IV maintenance workstation shall be provided for EVAS repair and servicing. The workstation shall include provisions for equipment restraint and positioning, module, tool, and part restraint, restraint and positioning aids for two crewmembers, and interfaces to fluid, electrical, and electronic lines as required. This includes interfaces to instrumentation and automatic test equipment.

8.1.4 An EVA maintenance stand shall be provided, either as a separate work area or as an integral part of the EEU or Tug storage facility. The stand shall provide positioning and restraint functions for the vehicle under repair, fluid, power, and electronic interfaces as required by the repair process, tool storage and restraint, crewmember restraint and positioning for two crewmembers, and part and module restraint. If the vehicle must be moved to the interior of the station for whatever reason, provision shall be made for draining propellants to safe levels.

8.2 SERVICING

8.2.1 Routine servicing of the EVAS shall be automated to the maximum extent practical. Daily reservice shall require no more than 15 minutes (post-EVA) for activation, 5 minutes (<12 hours later) for deactivation, and 10 minutes (pre-EVA) for verification. Capability shall be provided to replace modules (vs. recharge/regeneration) in < 30 minutes to support rapid turnaround.

8.2.2 If regenerable LSS systems are used, in-place regeneration is desirable.

8.3 LOGISTICS

8.3.1 Sufficient consumables and spare parts shall be stored aboard the Station to enable three two-man, 8-hour EVAs/week for 120 days.

8.3.2 It is highly desirable to have the capability to store a one year supply of propellant in the form of high pressure (nitrogen) gas in order to minimize transportation costs of the propellant.

8.3.3 Quantities of spare parts required shall be minimized by the use of rugged, high reliability parts, commonality of design where applicable (as between Tug and EEU), and the use of failure history analyses to correctly size inventories.

8.3.4 Use of specialized support equipment shall be minimized by the use of generic tools and modular design to facilitate repair. Generally, the requirement for any tools for maintenance should be minimized.

8.4 OPERATIONAL LIFE

8.4.1 The EVAS shall be capable of a minimum on-orbit use time of one year between ground depot servicings.

8.4.2 EVAS design shall emphasize simple, rugged components designed for maximal operational life. Component mass shall be a secondary consideration, and other performance parameters should be compromised as appropriate in order to achieve high reliability with acceptable performance.

8.4.3 Design of mechanical and electrical hardware as well as procedural design shall be such as to minimize component operational cycles and thus maximize component operational life.

8.4.4 EVAS components shall be selected and/or designed to require a minimum amount of servicing and maintenance.

8.4.5 Vehicle design should maximize protection from EVA environmental hazards such as thermal extremes, radiation, micrometeoroids and debris, atomic oxygen, and impacts encountered during EEU or Tug operation.

8.5 CHECKOUT

Nominal checkout of all EVAS systems shall be automatic, and shall be in conjunction with nominal system donning and activation. More extensive checkout shall only be performed after ORU replacement/repair.

8.6 EXTERNAL CONFIGURATION

8.6.1 The crew enclosure shall be anthropomorphic.

8.6.2 When sized for a 95th percentile Caucasian male, the EMU shall pass through a Shuttle airlock hatch.

8.6.2 The EEU shall accommodate a Shuttle EMU-suited crewmember.

APPENDIX B

EVAS/SPACE STATION SYSTEM INTERFACE REQUIREMENTS

1. REQUIREMENTS FOR SPACE STATION/EVAS COMMUNICATIONS INTERFACE

1.1.0 COMMUNICATIONS

1.1.1 VOICE COMMUNICATIONS

1.1.1.1 All EVA crewmembers should have full duplex voice communications capability with sufficient channel selection available to permit non-interference communication between any two crewmembers and/or the Station.

1.1.1.2 An "All Call" capability shall exist so that any EVA crewmember or the Station will be able to contact all EVA crewmembers and the Station simultaneously. This capability shall exist in both transmit and receive functions.

1.1.1.3 The Station shall be able to receive all crew transmissions simultaneously.

1.1.1.4 The Station shall be capable of two separate transmissions simultaneously to any combination of EVA crewmembers as selected by Station personnel.

1.1.2 TELEMETRY

1.1.2.1 One channel of telemetry per EVA crewmember shall be required for biomedical monitoring.

1.1.2.2 One channel of telemetry per crewmember, either discrete or multiplexed with the biomedical signal, is required for EVA systems monitoring.

1.1.2.3 The Station communications and data management system shall be capable of receiving, demultiplexing, processing, displaying, recording, and re-transmitting to the ground all EVA telemetry.

1.1.3 TELEVISION

1.1.3.1 The Station shall be capable of transmitting a separate freeze-frame television picture to each individual EVA crewmember simultaneously.

1.1.3.2 Each EVA crewmember shall be capable of receiving and displaying freeze-frame television transmitted to him on his individually assigned channel or on another crewman's assigned channel.

1.1.3.3 The Space Station DMS shall provide the picture for freeze-frame transmission to the EVA crewmembers and shall be capable of providing separate pictures to each crewmember simultaneously.

1.1.3.4 Each EVA crewmember shall be capable of transmitting one channel of normal-motion television (NTSC Resolution).

1.1.3.5 The Station shall be capable of simultaneously receiving, displaying, recording, and transmitting to ground all normal-motion television from each EVA crewmember.

1.1.4 TARGETING

1.1.4.1 The Station shall support free-flying EVA navigation and targeting.

1.1.5 TELEOPERATOR/ROBOT CONTROL

1.1.5.1 The Station shall support control/communications required in association with teleoperator/robotic operations.

1.2.0 RELIABILITY/MAINTAINABILITY

1.2.1 The Station and EVAS communication systems shall be designed in accordance with the General Requirements for Reliability and Maintainability as set forth in Appendix A of this report.

2. DATA MANAGEMENT SYSTEM REQUIREMENTS

2.1.0 EVAS DATA MANAGEMENT SYSTEM (DMS)

2.1.1 INPUT/OUTPUT (I/O) DATA HANDLING

2.1.1.1 The EVAS DMS, at the Space Station and the EVAS communications interfaces, shall be capable of the transmission and reception of serial, variable length, alphanumeric data on a synchronous or asynchronous basis depending on the particular data type.

2.1.1.2 The EVAS DMS shall validate all data received or transmitted and shall use a unique validation sequence to verify the integrity of all data defined as life or mission critical.

2.1.1.3 The EVAS DMS shall provide for the formatting and unformatting of all transmitted and received data, respectively, and shall make effective use of header words in these operations to further define the data type, length, and criticality.

2.1.1.4 The EVAS DMS shall use protocol techniques for all transmitted and received data to minimize the probability of data loss and to optimize the processing capabilities of the processor in which it is resident.

2.1.1.5 The EVAS DMS shall output, on a periodic basis, a Keep-Alive signal that shall be used by the receiving DMS as a verification of communications capability, and the loss of the signal over time shall result in an alarm being issued to both the EVA and IVA crewpersons.

2.1.1.6 The EVAS DMS shall require a time synchronization signal to be transmitted from the Space Station and received in the EVAS to maintain I/O time synchronization.

2.1.1.7 The EVAS DMS resident in the Space Station shall interface the EVAS voice communications channel and use a minimal voice recognition capability to respond to any of a predefined set of life- or mission-critical messages from the EVA crewperson.

2.1.2 SYSTEMS MANAGEMENT

2.1.2.1 The EVAS DMS shall use advanced data base management techniques to maximize the efficient use of the EVAS memory and to prioritize and control all processing operations within the EVAS.

2.1.2.2 The EVAS DMS shall provide a Monitoring and Control Operating System, resident within the EVAS, to periodically sample and store in digital form all biomedical, EVAS system, and EEU system parameters available from the EVAS instrumentation; additionally, EVA crewmember initiated discretes shall be monitored and the appropriate response initiated.

2.1.2.3 The EVAS DMS shall require an EVAS Systems Management Operating System resident in both the Space Station and EVAS processors to acquire, process, and evaluate biomedical, EVAS system, and EEU system data obtained by the Monitoring and Control Operating System.

2.1.2.4 An EEU Guidance and Control Operating System shall be required to be resident for both the EVAS and the Space Station to support, as needed, EEU navigation and targeting on a joint integrated or autonomous EVAS basis.

2.1.2.5 The EVAS DMS shall provide the EVAS with Displays Management Operating System, which shall support efficient HMD display generation via a minimal set of geometric entities.

2.1.2.6 The EVAS DMS shall provide automatic error recovery capability and fault tolerant processing to minimize possible data loss or loss of critical processing within the EVAS.

2.1.2.7 As a minimum, the EVAS DMS shall provide the EVA crewmember with the capability for autonomous EEU and non-EEU operations to attain a safe haven in the event of a total communications failure.

2.1.3 FIRMWARE AND SOFTWARE

2.1.3.1 The EVAS DMS shall make optimal use of EVAS resident firmware for those applications considered critical to EVA operations.

2.2 RELIABILITY/MAINTAINABILITY

2.2.1 The EVAS DMS shall be required to comply with those standards TBD for Space Station software and firmware development except for those standards that, when identified, reduce the efficiency or capabilities of the EVAS processor.

3. EVAS LOGISTICS REQUIREMENTS

3.1.0 EVAS SPARE PARTS REQUIREMENTS

3.1.1 EMU spare part requirements are shown in Table B-1.

3.1.2 EEU spare part requirements are shown in Table B-2.

3.1.3 Ancillary equipment spare part requirements are shown in Table B-3.

3.2.0 EVAS CONSUMABLES REQUIREMENTS

3.2.1 EMU consumables requirements are met by nominal IV usage requirements except as noted below.

3.2.1.1 If a sublimator is used, 1.5 lbm of water (max) per EVA man-hour is required for sublimator operations. (See Figure B-1.) A minimum of 2250 lbm and a maximum of 6000 lbm of water should be provided.

3.2.1.2 Airlock make-up gas as indicated in Figure 2 shall be provided to make up for gas vented overboard during airlock depress.

3.2.1.3 If LiOH is used for CO2 scrubbing in the EVAS, LiOH and Oxygen as per Figure 3 must be supplied.

3.2.2 EEU consumables requirements are 2400 kg of gaseous nitrogen per year, pressurized to 4500 psia at the supply outlet.

3.2.3 Ancillary equipment consumables requirements are covered under 3.1.3, Spare parts.

TABLE B-1
PROJECTED EMU SPARES REQUIREMENTS

ON-ORBIT EMU SPARES - One time delivery; replenish as required

ITEM	QUANTITY	MASS kg (lbm)	VOL. liters (Ft3)
EMU LSS	2	378(834)	382(13.5)
SCU	2	10(22)	57(2.0)
Phase Change Heat Exchanger	2	20(43)	28(1.0)
CO2 Removal Canister	2	98(216)	76(2.7)
CWS	1	2(5)	3(0.1)
DCM	1	7(15)	6(0.2)
EVC	1	5(11)	3(0.1)

EMU RESUPPLY 90 DAYS - Size sensitive, damage prone, and limited life items

ITEM	QUANTITY	MASS kg (lbm)	VOL. liters (Ft3)
SSA (less LCVG, CCA, UCD/ DFXT, 1DB)	2	161(354)	312(11)
Filters	1 Set	.5(1)	6(0.2)
Batteries	8	218(480)	142(5)
CO2 Sensors	2	1(2)	6(0.2)
Gloves	10	34(75)	71(2.5)
Suit Components	As Required	79(175)	127(4.5)
UCD	32 Maximum	8(17)	57(2)
DACT	32 Maximum	7(16)	142(5)
Vomitus Collector	4	1(2)	3(0.1)
IDB	2	.5(1)	14(0.5)

ON-ORBIT SERVICE EQUIPMENT SPARES - One time delivery; replenish as required

ITEM	QUANTITY	MASS kg (lbm)	VOL. liters (Ft3)
Pump/Separator	1	5(10)	6(0.2)
Power Supply/Battery Charger	1	23(50)	14(0.5)
Fan	1	5(10)	6(0.2)
Fan/Separator	1	5(10)	6(0.2)
Solenoid Valves	2	.5(1)	.3(0.01)
Compressor Head	1	5(10)	1.4(0.05)
Communicaton/Data Interface Equipment	1	.2(0.5)	.6(0.02)
Regulator	1	2(4)	.6(0.02)
Controller	1	1(3)	6(0.2)
Filters Miscellaneous	1 Set	.5(1)	6(0.2)

SERVICE EQUIPMENT RESUPPLY 90 DAYS - Limited life items

ITEM	QUANTITY	MASS kg (lbm)	VOL. liters (Ft3)
Filters	1 Set	.3(0.6)	6(0.2)

TABLE B-2
PROJECT EEU/FSS SPARES REQUIREMENTS
SPARES REQUIRED PER YEAR

ITEM	QTY	UNIT VOL (CC) (1,2)	UNIT MASS (KG) (1,2)	TOTAL VOL (CC) (1,2)	TOTAL MASS (KG) (1,2)
Central Electronics Unit (3)	2	33000	9.1	66000	18.2
Regulator	2	1500	0.4	3000	0.8
Isolation Valve	2	1400	1.3	2800	2.6
Thruster Triad (2 RH & 2 LH)	4	3000	1.4	12000	5.6
Quick Disconnect Fittings	2	500	0.5	1000	1.0
EMU/MMU Interface (3)	1	1000	0.9	1000	0.9
Control Arms with Handcontrollers	2	15500	4.6	31000	9.2
Locator Lights	2	500	0.3	1000	0.6
Lap Belt	2	500	0.5	1000	1.0
Small Hardware Set (3)	2	1100	1.0	2200	2.0
Batteries (3) (4)	4	7900	6.8	31600	27.2
Paint (3)	1	500	0.5	500	0.5
Velcro	1	500	0.5	500	0.5
Lubricant (4)	1	500	0.5	500	0.5
Service and C/O Connectors (3)	2	500	0.5	1000	1.0
Internal Electrical Connectors (3)	4	135	0.3	540	1.2
Internal Fluid Connectors (3)	2	270	0.3	540	0.6
Propellant Filters (4)	80	7	0.1	560	8.0
Circuit Breakers	2	135	0.1	270	0.2
Switches	2	135	0.1	270	0.[illegible]
PLSS Latch (3)	2	2800	1.0	5600	2[illegible]
FSS Latch (3)	2	550	1.0	1100	2.0
Battery Latch (3)	2	550	1.0	1100	2.0
Wire (3)	3	1650	0.3	4950	0.9
Propellant Line Repair Mat'ls (3)	2	260	0.7	520	1.4
Propellant Vessel (3)	2	10000	18.0	20000	36.0
Totals		84392	51.9	190550	125.1

1. Volumes and masses are based on presently used MMU components.

2. Volumes and masses are for components only and do not include packing material and containers.

3. Item definition not sufficiently precise for an exact volume and mass; therefore, volumes and masses are rough estimates.

4. Resupply item.

TABLE B-3
PROJECTED ANCILLARY EQUIPMENT SPARES REQUIREMENTS
SPARES REQUIRED PER YEAR

ITEM	QTY	TOTAL MASS (KG)	TOTAL VOLUME (CC)
Saw Blades	10	1.0	60
Trash Bags	200	10.0	72000
Nibbler Bits	10	0.5	30
Surface Coating Materials	1	5.0	4500
Drill Bits - Set	1	1.0	450
Welding Rods - Assortment	1	2.0	650
Brazing Rods	1	1.5	650
Grinder Pads - Assortment	1	1.0	3600
Rivets - Assortment	1	1.0	2000
Fluid Connectors - Assortment	5	0.5	3000
Electrical Connectors - Assortment	5	0.5	5000
Adhesive Tape - Rolls	2	1.5	3200
Thermal Insulation Material	1	2.0	20000
Gasket/Seal Material	1	0.1	250
Tie Wrap Assortment	1	0.25	500
ID Tags	1	0.1	50
Teflon Tape - Roll	2	0.1	100
Potting Compound - Can	1	1.0	1000
Coveralls (EVA)	8	2.0	72000
Glove Protectors	16	2.0	55000
Fluid/Gas Sample Collection Vial	50	0.3	500
Lubricant	1	0.5	500
Epoxies	4	0.5	2000
Structural Repair Materials	1	1.0	20000
Fabric Patch Material	1	2.0	20000
Leak Patch Material	1	0.75	1600
Cleaner Material Prepreg Clothes	200	15.0	72000
Electrical Insulation Material	1	1.0	1000

All items are spares - resupply as required.

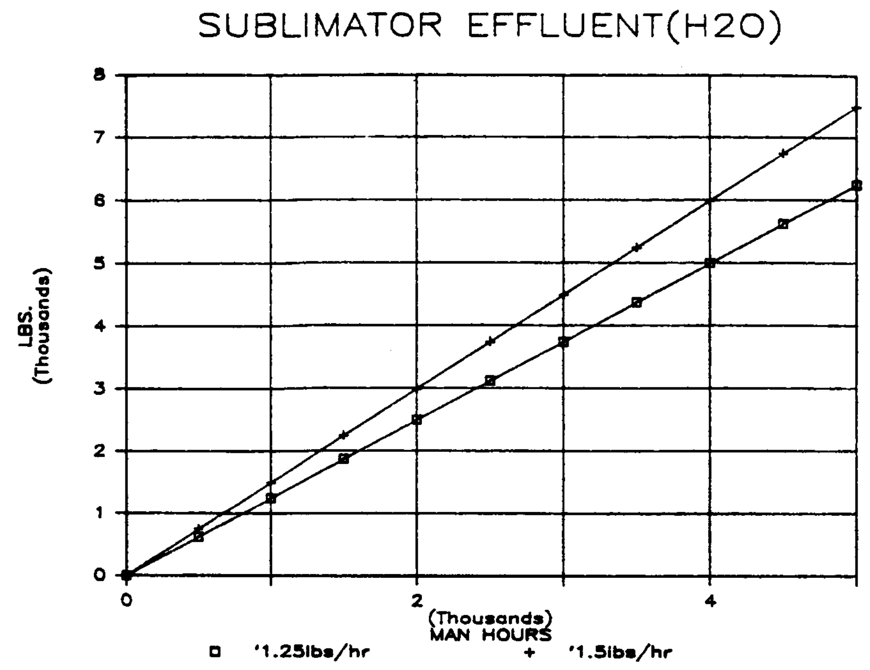


FIGURE B-1
SUBLIMATOR EFFLUENT (H2O)

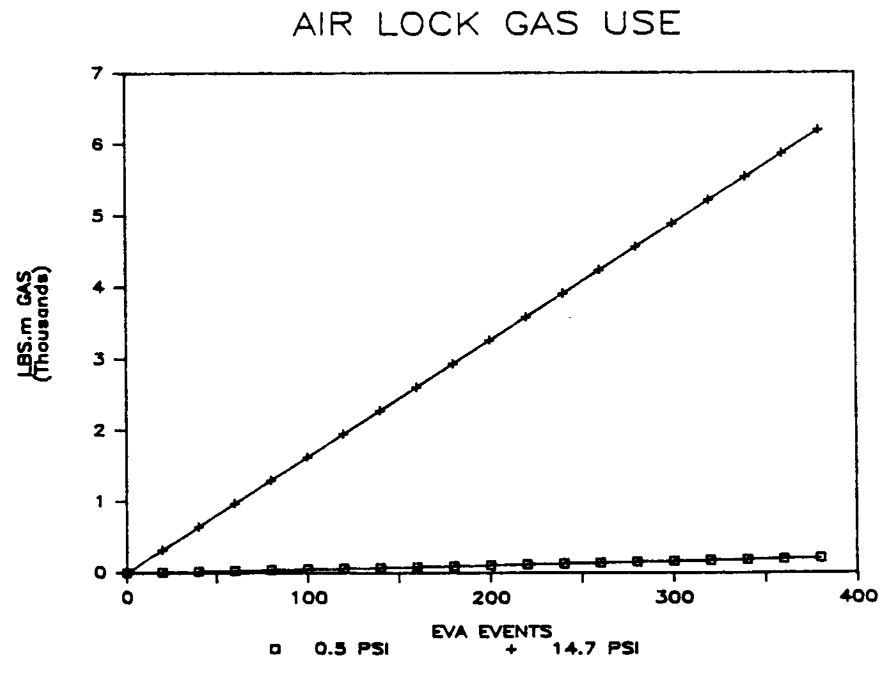
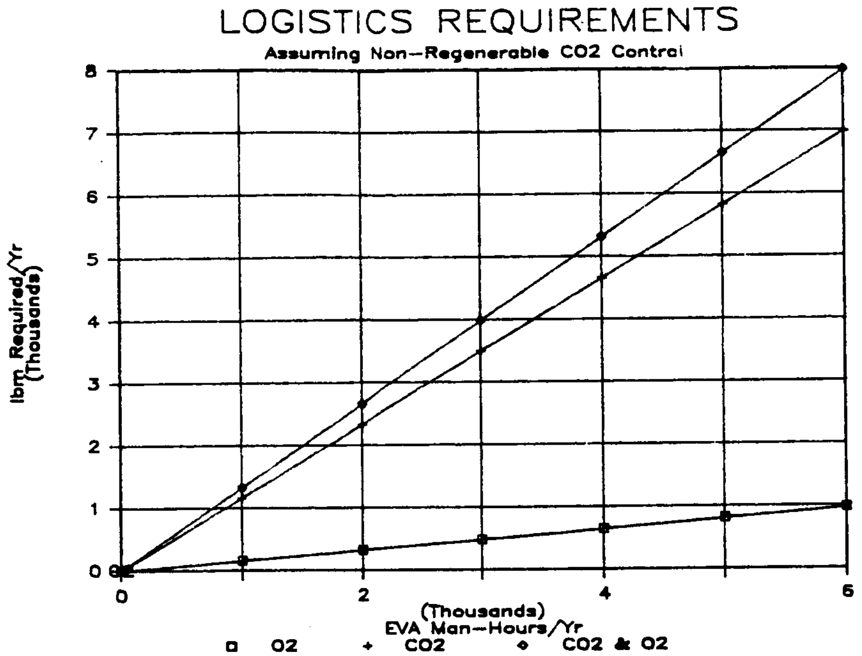


FIGURE B-2
AIRLOCK GAS USE



Assumptions:

Use STS EMU LiOH cartridges (7 lbm, 9 kBTU capacity)
Average EVA 6 kBTU (6 hrs, 1 kBTU/hr)
LiOH cartridges not refilled on-orbit
Therefore, approx. 1/3 of capacity unused
Non-regenerable CO2 means O2 also becomes consumable
(0.1634 lbm/hr @ 1 kBTU/hr)

FIGURE B-3
LOGISTICS REQUIREMENTS

4. SPACE STATION SAFETY HAVEN REQUIREMENTS

4.1.0 An EVA safety haven shall be provided.

4.1.1 The safety haven shall be portable via MRMS to remote worksite.

4.1.1.1 The safety haven shall be secured to Station structure near the workstation.

4.1.2 The safety haven shall be pressurizable.

4.1.2.1 The safety haven shall be pressurizable to 4.0 psia 100% O_2 in less than 10 seconds.

4.1.2.2 The safety haven shall be pressurizable to 14.7 psia in less than 5 minutes.

4.1.2.3 The safety haven atmosphere shall be 21% O_2 minimum - 30% O_2 maximum and the remainder of N_2 at 14.7 psia.

4.1.2.4 The safety haven shall have enough O_2 for two crewmembers for 2 hours.

4.1.3 The hatch size shall accommodate two crewmen.

4.1.3.1 The hatch shall be designed to dock with airlock or docking module hatch with interface seal to maintain pressure.

4.1.4 The safety haven shall have lighting equal to 50 footcandles to illuminate the interior for up to 2 hours.

4.1.5 The safety haven shall have a basic medical kit installed in the interior.

4.1.6 The safety haven shall have handholds on interior walls for positioning.

4.1.7 The safety haven shall have restraints to hold incapacitated crewmember.

4.1.8 The safety haven shall have the capability to communicate via voice comm with IV crewmembers.

5. SPACE STATION INTERIOR REQUIREMENTS

5.1 CLEANLINESS

5.1.1 A 10,000 class clean room is required for work on life support system oxygen subsystem.

5.2 SAFETY

5.2.1 Safing equipment in the form of restraints for high pressure components of EVAS oxygen and nitrogen systems is required.

5.3 WORKSTANDS

5.3.1 Workstands to restrain and position EVAS components while they are being maintained are required.

5.3.1.1 Workstands shall be equipped with such tools as are necessary to maintain the EVAS.

5.3.1.1.1 The EVAS shall be designed so that standard IV tools can be used to accomplish as much maintenance and servicing as feasible.

6. SPACE STATION EXTERIOR REQUIREMENTS

6.1 TRANSLATION AIDS

6.1.1 EVA translation aids shall be provided to allow EVA access to all portions of the exterior of the Space Station and any attached payloads.

6.1.2 The basic translation aid shall be a system of hand rails arranged to give the crewmember access to all exterior areas of the Space Station.

6.1.3 A supplemental translation aid shall be provided that will provide transportation for the crewmember and a module of less than 250 kg mass and less than 1 cubic meter volume from one extremity of the Space Station to the other in under 5 minutes.

6.1.3.1 The supplemental translation aid shall be controllable by either the crewmember riding it or another EV or IV crewmember.

6.1.4 A supplemental translation aid shall be provided that shall be capable of transporting any size module encountered in a Space Station EVA from one extremity of the Space Station to another.

6.1.4.1 The translation aid shall be capable of limited fine positioning via a self-contained manipulator arm.

6.1.4.1.1 The arm shall use a standard RMS end effector interface.

6.2 RESTRAINTS

6.2.1 A system of tether points shall accompany the translation aids, allowing the EVA crewmember to be tethered at all times while performing EVA.

6.2.1.1 A TBD mobile tether system shall be used to allow the astronaut to be tethered continuously while translating, without interfering with that translation or requiring continuous shifting of tethers.

6.2.2 Workstations shall be provided where and as necessary to restrain equipment under repair and associated tools and spare parts. If these are not fixed, the Station shall provide interfaces as necessary to restrain portable workstations.

6.2.2.1 Workstations shall provide restraint as necessary to position and hold EVA crewmembers while they are performing work.

6.2.2.2 A workstation shall be provided that is capable of holding and positioning a satellite for repair or servicing.

6.2.2.2.1 The workstation shall be able to accommodate spacecraft up to the size of the Hubble Space Telescope.

6.3 STORAGE

6.3.1 External storage shall be provided for all EVA tools and for a TBD amount of spare parts and equipment for Space Station and satellite servicing and repair.

6.3.1.1 The external storage facilities shall provide such protection as required by the stored equipment from the on-orbit environment.

6.3.1.2 The external storage facilities shall be located in proximity to the EVA airlock.

6.4 LIGHTING

6.4.1 All areas of the Space Station exterior should have provisions for lighting to the 50 footcandle level.

6.4.1.1 The lighting should be selectable on/off by EV or IV personnel.

6.5 TELEVISION

6.5.1 Closed-circuit television (CCTV) cameras shall be mounted at TBD locations on the exterior of the Station.

6.5.1.1 The CCTV's shall be IV controllable in azimuth, elevation f-stop, and zoom.

6.6 DEPENDENT LIFE SUPPORT SUBSYSTEM

6.6.1 A Dependent Life Support Subsystem shall be provided, allowing crewmembers dependent life support while they are located at any point on the Space Station exterior.

6.7.0 External Safety Requirements

6.7.1 Space Station and all external equipment design, including spacecraft to be serviced by EVA crewmembers, shall conform to a TBD EVA Design Criteria document similar to the current JSC 10615A document.

6.7.2 The Space Station personnel shall be capable of carrying out an independent, autonomous rescue of a free-floating, stranded crewmember with initial distance and velocity of up to 1 kilometer and 1 foot per second opening.

7. AIRLOCK REQUIREMENTS

A set of working requirements has been compiled to serve as design and performance guidelines for airlock subsystems. The following list represents what we feel to be, at this time, the most important Space Station sensitive of these areas.

7.1 GENERAL AIRLOCK DESIGN REQUIREMENTS

7.1.1 The EVA airlock shall provide a controlled rate of depressurized and pressurization. The nominal rate experienced by the crewman inside the EMU shall not exceed 689 N/m2-sec2 (.1 psi/sec). The maximum rates are not to exceed 6896 N/m2-sec (1 psi/sec).

7.1.2 As a design goal, 90% of the airlock gas shall be recovered during depressurization.

7.1.3 Control of depressurization and pressurization shall be possible from inside the Space Station and inside and outside the airlock.

7.1.4 The airlock design shall accommodate the transfer of a standard equipment rack or the return of an incapacitated EVA crewmember.

7.1.5 Two EVA airlocks shall be provided to ensure redundant egress/ingress capability.

7.1.6 Each airlock hatchway shall be sized to accommodate the transfer of two suited crewmen.

7.1.7 The EMU shall be capable of being resized inside the airlock service area.

7.1.8 The airlocks shall be sized to accommodate donning/doffing the EMU by an unaided crewman.

7.2 EMU SUPPORT REQUIREMENTS

7.2.1 Stowage of the EMU's in the airlock versus in the Space Station is required to allow for automatic checkout of the EMU's during depressurization and for reconnection of life support for contingencies while at vacuum.

7.2.2 The Space Station shall provide the IVA service, repair, and maintenance operations for the EMU. These operations include power, N2 purge and purge verification, cooling, IV pressure regulation, suit integrated check, airlock depressurization/

repressurization, and service lines connection/disconnection.

7.2.3 The EMU will normally be reserviced as an assembly in the airlock.

7.2.4 Automatic servicing and performance checkout of the EMU includes expendables regeneration, such as O2 and N2 resupply, and the regeneration of time dependent processes, such as CO2 and H2O removal, heat rejection, and power storage.

7.2.5 The service station will automatically dry the suit.

7.2.6 The entire normal servicing will be accomplished in 12 hours with the minimum human intervention.

7.2.7 A non-standard, short notice time TBD, reservicing capability shall be provided.

7.2.8 Servicing capabilities shall be based on 10 EMU reservices per week initially and on 20 EMU reservices per week for the growth Station.

7.2.9 Cleanliness levels of the EMU shall meet the requirements in NHB 8060.1b (J8400003) and microbiological contamination levels shall meet the requirements of "STS Microbial Contamination Plan" (J8400084).

7.2.10 A capability shall be provided for decontamination of the EMU after a chemical spill. Verification of safe contamination levels shall be made.

7.2.11 The cooling garment (extracted from the EMU) shall be removed in the Space Station and washed or replaced.

7.2.12 The EVA suit must be kept biologically and chemically clean, and the cleaning agent must not present toxic hazards. Periodic microbiological sampling of the suit areas will be performed at regular intervals TBD.

7.2.13 The Space Station shall accommodate the disposal of EMU waste. The containers shall be easily cleaned or disposable.

7.2.14 The EMU shall be capable of being fully maintained in the Space Station.

7.3 EEU SUPPORT, STOWAGE

7.3.1 Stowage of the EEU's outside the airlock is required to centralize the EVA servicing equipment and to localize the EVA hardware. This localization also allows for easier relocation of the equipment for flexibility for growth phases.

7.3.2 Micrometeoroid protection for the stored EEU (shall be provided).

7.3.3 Automatic servicing and performance checkout of the EEU includes expendables regeneration, such as N2 resupply, and the regeneration of time dependent processes, such as heat rejection and power storage.

7.3.4 The Space Station shall support recharge of the EEU propellant by supplying gaseous nitrogen at least 300 x 105 N/m2 (4500 psia) to the flight support station.

7.3.5 The Space Station shall provide recharge of the EEU batteries while installed in the EEU.

7.3.6 Power for thermal control (of the EEU) shall be provided.

7.3.7 The entire normal servicing will be accomplished in 12 hours without human intervention.

7.3.8 A non-standard, 1-hour, reservicing capability shall be provided.

7.3.9 Servicing capabilities shall be based on 10 EEU reservices per week initially and on 20 EEU reservices per week for the growth Station.

7.3.10 The Space Station shall provide spare parts to the EEU.

7.3.11 The EEU shall be maintained outside the Space Station to at least the ORU level.

7.4 EVA EQUIPMENT

7.4.1 Provisions for EVA equipment and spares stowage shall be provided inside the Space Station and outside the EVA airlock.

7.4.2 External storage facilities with appropriate handrails and supports for work restraints shall provide for storage of EVA tools and support equipment. The storage boxes shall be modularized with easy attach/detach capability for transport and worksite convenience.

7.5 MAINTENANCE

7.5.1 A functional capability shall be provided to bring internally located ORU's into the pressurized work area to conduct maintenance.

7.5.2 Maintenance and repair of all EVA equipment shall be performed inside the Space Station except EEU ORU replacement.

7.6 HYPERBARIC CHAMBER GENERAL REQUIREMENTS

7.6.1 One airlock shall have the capability of serving as a hyperbaric chamber for two crewmen.

7.6.2 The hyperbaric chamber shall be of sufficient size to accommodate two crewmen - one patient and one attendant.

7.6.3 The hyperbaric chamber shall be of sufficient size to allow the patient to be extended at full length and restrained on a hard surface so the attendant shall have access to all of the patient.

7.6.4 Large items of equipment that must be simultaneously accommodated include a mechanical cardiac massage unit, a cardiac defibrillator/pacemaker, a pulmonary ventilator/respirator, and an IV fluid system.

7.6.5 Other smaller units and kits required for examination and treatment of the patient include a physician's "black bag" and a trauma treatment kit.

7.6.6 In a hyperbaric chamber mode, the airlock pressure shall be raised to as high as 5.0 atmospheres above the ambient cabin pressure.

7.6.7 The chamber must be capable of attaining and holding the following pressures for the following minimum durations:

- 6 atmospheres for 2 hours

- 2.8 atmospheres for 4 hours

- 1.9 atmospheres for 5 hours

7.6.8 The chamber must be capable of the following rates of pressure increases.

- Nominal cabin pressure to 6 atmospheres at a rate of approximately 2 atmospheres per minute.
- Nominal cabin pressure to 2.8 atmospheres at a rate of 0.76 atmospheres (11 psi) per minute.

7.6.9 The chamber must be capable of the following rates of pressure decreases:

- 6 atmospheres to 2.8 atmospheres at a rate of 0.79 atmospheres (11.6 psi) per minute.

- 2.8 atmospheres to 1.9 atmospheres and 1.9 atmospheres to nominal cabin pressure at a rate of 0.03 atmospheres (0.45 psi) per minute.

7.6.10 The chamber shall be capable of one recycle from 6 atmospheres to 3 atmospheres and return to 6 atmospheres. This requirement would apply to the treatment of a pneumothorax in which air of 6 atmospheres had entered the chest cavity and become apparent only following a decrease in chamber pressure.

7.7 CHAMBER DISPLAYS AND CONTROLS

7.7.1 Chamber pressure shall be automatically controlled with manual override controls both inside and outside the chamber.

7.7.2 Total pressure, oxygen partial pressure, oxygen percent, carbon dioxide partial pressure, and temperature shall be continuously monitored and displayed both inside and outside the chamber. Out-of-tolerance values shall be indicated by both visual and auditory signals.

7.7.3 Elapsed and interval time shall be displayed both inside and outside the chamber in accordance with accepted hyperbaric operational procedures.

7.7.4 The airlock controls and displays shall include biomedical monitoring of heart rate (EKG), blood pressure, body temperature, blood gas levels (via audio monitoring or blood sample), and brain wave recording (ECG).

7.8 CHAMBER LIGHTING

7.8.1 The general level of illumination within the chamber shall be 50 footcandles.

7.8.2 Supplemental lighting with a level of 200 footcandles shall be available for illuminating selected areas.

7.9 MONITORING AND COMMUNICATIONS

7.9.1 Video monitoring of the chamber shall be provided to give outside close-up visual access to the anatomical parts of the patient.

7.9.2 Video cameras shall be adjustable and remotely controlled from outside the chamber.

7.9.3 A window shall be available for visual access to the inside of the chamber for back-up monitoring capability.

7.9.4 All video images shall be capable of being down-linked to ground observers.

7.9.5 Three lead EKG's shall be available for patient electrocardiographic monitoring. The EKG waveform shall be displayed both inside and outside the chamber and shall be capable of being down-linked.

7.9.6 A pass-through airlock between the hyperbaric chamber airlock and the airlock service area shall be provided for passing medication, food, and water.

7.10 CHAMBER ATMOSPHERE COMPOSITION AND BREATHING GAS PROVISIONS

7.10.1 The O2 concentration shall not exceed 30% for O2 toxicity reasons.

7.10.2 The chamber shall be pressurized with compressed air for all pressures and procedures.

7.10.3 Breathing oxygen (and masks) shall be provided for both the patient and the attendant.

7.10.4 A 7-hour oxygen supply shall be available for the patient for each treatment task.

7.10.5 A 90-minute O2 supply shall be available for the attendant for all operations.

7.10.6 A 2-hour supply of nitrox (50% N2; 50% O2) shall be available for patient breathing (via mask) when the chamber is being operated at 6 atmospheres.

7.11 CHAMBER TEMPERATURE

7.11.1 The normal operating temperature shall be 75t-80t. Degraded operating temperature shall be 70t-90t.

7.11.2 The temperature in the chamber following pressurization shall not exceed 120tF.

7.11.3 Following pressurization, the chamber temperature shall be reduced from the maximum to degraded operating temperature range within 15 minutes and to the nominal operating range within 30 minutes.

7.11.4 The chamber temperature shall not decrease below 70tF as a result of reducing chamber pressure.

7.11.5 Following a reduction in chamber pressure, the chamber temperature shall be returned to the normal operating range within 15 minutes.

7.12 SAFETY

7.12.1 The oxygen percentage in the chamber atmosphere shall not exceed 30% to be compatible with fire safety.

7.12.2 Rapid emergency EVA egress shall be possible with minimal EMU functional checkout.

7.12.3 The nominal rate of depressurization and pressurization experienced by the crewman inside the EMU shall not exceed 0.1 psi/sec.

7.12.4 The CO_2 concentration within the chamber atmosphere shall not be allowed to exceed 7.6 torr for nominal operations or 15 torr for emergency operations.

7.12.5 The O_2:N_2 ratio within the chamber shall be maintained at approximately that of cabin air, 21% O_2 and 79% N_2.

7.13 AIRLOCK LIGHTING

7.13.1 Floodlights shall be provided to aid EVA crew visibility in areas of high EVA activity such as the airlock.

7.14 AIRLOCK COMMUNICATIONS

7.14.1 The airlock shall have wireless voice communications that shall be capable of being down-linked.

7.15 DATA

7.15.1 The service data of EVA equipment shall be retained by the data system. Performance trend data shall be used to define the need for maintenance of the EMU and EEU.

7.16 EQUIPMENT AIRLOCK

7.16.1 An equipment airlock shall be provided for the transfer of tools, parts, and equipment without using the EVA airlock.

7.16.2 The equipment airlock can be located at any convenient location on the Space Station.

7.17 ECLSS INTERFACING

7.17.1 The ECLSS shall support the capability to service and checkout the regenerative EMU within the airlocks. The ECLSS shall also support servicing the EEU.

7.17.2 Life-support umbilical connectors shall be available outside the pressurized compartments to allow umbilical-supported EVA operations.

7.17.3 Checkout functions provided by the ECLSS service equipment, which are considered critical functions for EVA equipment operations, shall be continuously verifiable.

APPENDIX C

SUPPORTING DATA

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TABLE C-1

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE

BASED ON MDAC SURVEY

MISSIONS USA	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
SAAX 0004	SIRTF PLATFORM MISSION	-	-	-	-	-	48	50	-	-	-
SAAX 0005	TRANS. RAD & ION CAL	-	-	-	8	8	8	8	-	-	-
SAAX 0006	STARLAB	-	-	-	-	30	-	-	30	-	-
SAAX 0007	HI THROUGHPUT MISSION SERV	-	-	-	-	30	-	-	30	-	-
SAAX 0008	HIGH ENERGY ISO EXP	-	-	-	8	8	8	8	8	8	-
SAAX 0011	ASO II/POF + SOT	-	-	-	-	-	-	30	-	-	30
SAAX 0012	HUBBLE SPACE TEL SERV	-	-	-	100	-	-	100	-	-	-
SAAX 0013	GAMMA RAY OBSER SERV	-	-	-	16	-	-	16	-	-	16
SAAX 0016	SOLAR MAX MISSION SERV	20	-	-	20	-	-	20	-	-	20
SAAX 0017	AXAF SERVICING	-	-	-	86	-	-	86	-	-	86
SAAX 0020	LARGE DEPLOY REFLECTOR	-	-	-	-	-	450	-	50	-	100
SAAX 0021	SUPER COND MAG FAC	-	-	16	16	16	16	-	-	-	-
SAAX 0202	EARTH OBSER SYS	-	440	440	440	440	440	440	440	440	440
SAAX 0208	MOD RES IMAG SPECT	-	20	-	20	-	20	-	20	-	20
SAAX 0209	HIGH RES IMAG SPECT	-	20	-	20	-	20	-	20	-	20
SAAX 0210	HIGH RES MULTI MW RAD	-	20	-	20	-	20	-	20	-	20
SAAX 0211	LASER ATMO SOUNDER & ALT	-	20	-	20	-	20	-	20	-	20
SAAX 0212	SYNTHETIC APER RADAR	-	20	-	20	-	20	-	20	-	20
SAAX 0213	ALTIMETER	-	20	-	20	-	20	-	20	-	20
SAAX 0214	SCATTEROMETER	-	10	-	10	-	10	-	10	-	10
SAAX 0215	CORRELATION RADIOMETER	-	6	-	6	-	6	-	6	-	6
SAAX 0216	EARTH RAD BUDGET EXP	-	10	-	10	-	10	-	10	-	10
SAAX 0219	ENVIROMENTAL MONITORS	-	20	-	20	-	20	-	20	-	20
SAAX 0220	AUTOMATED DATA COLLECTION	-	20	-	20	-	20	-	20	-	20
SAAX 0221	LARGE MICROWAVE ANTENNA	-	-	-	-	-	-	-	-	16	16
SAAX 0222	INFRARED SOUNDING	-	-	-	-	-	-	-	-	16	16
SAAX 0223	LARGE IMAGER	-	-	-	-	-	-	-	-	16	16
SAAX 0225	SOLAR TERRES POLAR PLATFORM	-	-	-	-	-	48	-	-	-	-
SAAX 0227	CONTAINED PLASMA EXP	-	-	-	-	104	104	-	-	-	-
SAAX 0228	THERMAL IR MAPPING SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0229	CRYOGENIC INTERFER/SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0230	FABRY PEROT INTERFEROMETER	-	-	20	-	20	-	20	-	20	-
SAAX 0231	VIS/UV SPECTOMETER	-	-	-	-	20	-	20	-	20	-
SAAX 0232	MICROWAVE LIMB SOUNDER	-	-	-	-	20	-	20	-	20	-
SAAX 0233	SUBMILLIMETER SPECT	-	-	-	-	-	-	20	-	20	-
SAAX 0234	INTERFEROMETER/SPECT/UPPER ATM	-	-	-	-	20	-	20	-	20	-
SAAX 0235	UPPER ATM IR RADIOMETER	-	-	-	-	20	-	20	-	20	-
SAAX 0236	DOPPLER LIDAR	-	-	-	-	-	-	20	-	20	-
SAAX 0237	DIFFERENTIAL ABSORP LIDAR	-	-	-	-	-	-	20	-	20	-
SAAX 0238	NADIR CLIMATE INTERFER/SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0306	CELSS PALLET	-	-	-	32	32	32	32	-	-	-
SAAX 0309	SETI GEO ANTENNA MISSION	-	-	-	-	-	-	-	200	-	-
SAAX 0402	MICRO G VARIABLE "G" FREE FLYER	-	-	-	-	-	-	100	132	132	132
SAAX 0501	EXP GEO PLATFORM	-	-	-	-	-	-	720	-	-	-
SAAX 0502	SPACE BASED ANTENNA TEST RANGE	-	-	1152	1152	1152	1152	1152	1152	1152	1152

TABLE C-1

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE

BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
COMM 1304	OMV/TMS	160	60	-	-	-	-	-	-	-	-
COMM 1309	ORBITAL TRANSFER VEHICLE	-	-	126	-	-	-	-	-	-	-
TDMX 2011	SPACECRAFT MATERIAL & COATINGS	8	4	4	4	4	4	4	4	4	4
TDMX 2022	GROWTH OF COND SEMICOND CRYSTALS	32	32	-	-	-	-	-	-	-	-
TDMX 2061	LARGE SPACE STRUCTURES	228	48	-	-	-	-	-	-	-	-
TDMX 2062	SPACE STATION STRUCTURES	72	-	-	-	-	-	-	-	-	-
TDMX 2063	ON ORBIT SPACECRAFT ASSY/TEST	-	154	-	-	-	-	-	-	-	-
TDMX 2064	ADVANCED ANT ASS/PERFORM	-	-	-	-	-	250	-	-	-	-
TDMX 2071	FLIGHT DYNAMICS IDENTIFACTION	134	-	-	-	-	-	-	-	-	-
TDMX 2072	S/C STRAIN AND ACOUSTIC SENSORS	12	-	-	-	-	-	-	-	-	-
TDMX 2111	DEPLOY & TEST LARGE SOLAR CONCEN	32	-	-	-	-	-	-	-	-	-
TDMX 2121	TEST SOLAR PUMPED LASER	20	-	-	-	-	-	-	-	-	-
TDMX 2122	LASER-ELECTRIC ENERGY CONVERSION	30	-	-	-	-	-	-	-	-	-
TDMX 2132	ADVANCED RADIATOR CONCEPTS	16	16	-	16	10	-	-	-	-	-
TDMX 2152	LARGE SPACE POWER SYSTEMS	-	108	108	-	-	-	-	-	-	-
TDMX 2153	SOLAR DYNAMIC POWER	32	10	10	32	-	-	-	-	-	-
TDMX 2211	MULTI FTN SPACE ANTENNA RNG TECH	-	46	-	-	-	-	-	-	-	-
TDMX 2212	MULTI ANTENNA BEAM PATTERNS	-	44	-	-	-	-	-	-	-	-
TDMX 2213	MULTI FREQUENCY ANTENNA TECH	-	-	38	-	-	-	-	-	-	-
TDMX 2221	LASER COMM & TRACKING DEVELOP	-	-	18	-	-	-	-	-	-	-
TDMX 2224	DEEP SPACE OPTICAL DSN TERMINAL	-	28	-	-	-	-	-	-	-	-
TDMX 2261	SENSOR SYSTEMS TECHNOLOGY	-	-	-	48	48	48	48	48	48	48
TDMX 2263	CO2 LIDAR WIND AND TRACE GASES	-	-	-	8	8	-	-	-	-	-
TDMX 2265	SATELLITE DOPPLER METEROL RADAR	6	-	-	-	-	-	-	-	-	-
TDMX 2311	LONG TERM CRYO FLUID STORAGE	-	4	4	-	-	-	-	-	-	-
TDMX 2322	LASER PROPULSION	-	12	-	-	-	-	-	-	-	-
TDMX 2411	ADVANCED ADAPTIVE CONTROL	-	30	42	42	-	-	-	-	-	-
TDMX 2412	DISTRIBUTED ADAPTIVE CONTROL	-	-	16	-	-	-	-	-	-	-
TDMX 2413	DYNAMIC DISTURBANCE CONTROL	-	-	-	16	-	-	-	-	-	-
TDMX 2421	ACTIVE OPTIC TECHNOLOGY	78	78	-	-	-	-	-	-	-	-
TDMX 2431	ADVANCED CONTROL DEVICE TECH	-	-	24	-	-	-	-	-	-	-
TDMX 2441	GUIDED WAVE OPTICS DATA SYS EXP	8	8	8	8	8	-	-	-	-	-
TDMX 2462	TELEOPERATOR SENSOR EVAL & TEST	8	-	-	-	-	-	-	-	-	-
TDMX 2511	SPACE POWER SYS ENVIRO INT	-	104	104	-	-	-	-	-	-	-
TDMX 2542	TETHERED CONSTELLATION	-	-	616	-	616	-	616	-	616	-
TDMX 2543	TETHERED TRANSPORTATION	-	-	-	-	-	14	24	24	24	-
TDMX 2544	TETHERED FLUID STOWAGE TRANSFER	-	-	96	36	36	36	36	36	36	-
TDMX 2561	SATELLITE SERVICING & REFURB	12	-	-	-	-	-	-	-	-	-
TDMX 2562	SATELLITE MAINTENANCE & REPAIR	-	20	-	-	-	-	-	-	-	-
TDMX 2563	MATERIALS RESUPPLY	-	6	-	-	-	-	-	-	-	-
TDMX 2565	THERMAL INTERFACE TECHNOLOGY	24	-	-	-	-	-	-	-	-	-
TDMX 2571	OTV/PAYLOAD INTERFACING/TRANSFER	-	-	-	98	98	-	-	-	-	-
TDMX 2574	OTV MAINTENANCE TECHNOLOGY	-	-	40	-	-	-	-	-	-	-

TABLE C-1

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SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
ESA											
MAT 130	MICROGRAVITY	-	-	354	408	408	-	-	-	-	-
SPA 801	FAR INFRARED/SUBMM SPACE TEL	-	-	-	12	-	-	-	12	-	-
TOS 401	ADV TECH TEST SATELLITE	-	-	-	20	-	-	-	-	-	-
JAPAN											
C-002	LARGE COMM ANTENNA	-	-	10	-	-	-	-	-	-	-
C-003	ADV COMM & DATA HANDLING SYS	-	-	-	-	10	-	-	-	-	-
C-004	GRAV STABILD DEPLOY ANT TEST	-	-	-	-	-	-	-	12	-	-
E-001	LASER RANGING SYSTEM	4	-	-	-	-	2	-	-	-	-
E-002	TEST OF SENSOR TECHNOLOGIES	-	-	-	12	-	-	-	-	-	-
E-003	OBSERV OF UPPER ATMOSPHERE	-	-	-	-	-	24	-	-	-	-
E-005	DPS FOR EARTH OBSERVATION	-	-	2	2	-	-	-	-	-	-
S-001	ASTRONOMICAL PLATFORM	-	-	-	-	14	2	2	2	2	-
S-002	INFRARED TELESCOPE IN SPACE	-	-	2	-	2	-	-	-	-	-
S-005	LINE GAMMA DETECTION	-	-	-	2	-	-	-	-	-	-
S-006	X-RAY ASTRONOMY OBSERVATION	-	-	-	-	-	24	-	-	-	-
S-008	SPACE VLBI	-	-	-	-	-	-	-	-	24	-
S-009	SOLAR ACTIVITY MONITOR	-	-	-	-	-	-	-	26	-	-
S-010	SUBMILLIMETER TELESCOPE	-	-	-	-	-	-	24	-	-	-
T-002	LARGE ANTENNA SYS TECHNOLOGY	-	-	100	-	-	-	-	-	-	-
T-007	2D-SOLAR ARRAY MISSION	-	-	16	-	-	-	-	-	-	-
T-009	LIQUID PROPELLANT HANDLING	-	8	8	-	-	-	-	-	-	-
CANADA											
SAAX 4002	POLCATS	8	8	8	8	8	8	8	8	8	8
SAAX 4004	LONG BAS LINE ARRAY	4	-	-	-	-	-	-	-	-	-
SAAX 4006	UV ATMOSPHERIC LIMB SCANNER	16	16	16	-	-	-	-	-	-	-
TDMX 4006	SPACE STRUCTURES	40	6	6	-	-	-	-	-	-	-
NOAA											
NOAA 0001	GEO SYNTHETIC APERTURE RADAR	-	-	20	-	20	-	20	-	20	-
NOAA 0002	SEA SYNTHETIC APERTURE RADAR	-	-	20	-	20	-	20	-	20	-
NOAA 0003	MULTISPECTRAL LINEAR ARRY	-	-	20	-	20	-	20	-	20	-
NOAA 0004	SEARCH AND RESCUE	-	-	20	-	20	-	20	-	20	-
NOAA 0005	SPACE ENVIRONMENT MONITOR	-	-	20	-	20	-	20	-	20	-
NOAA 0006	ADV MICROWAVE SOUNDING UNIT	-	-	20	-	20	-	20	-	20	-
NOAA 0007	ADV MICROWAVE RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0008	MED RES IMAGING RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0009	RADAR ALTIMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0010	ALONG TRACK SCAN RAD MICROWAVE	-	-	20	-	20	-	20	-	20	-
NOAA 0011	HIGH RES IR RADIATION SOUNDER	-	-	46	-	46	-	46	-	46	-
NOAA 0012	N-ROSS SCATTEROMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0013	SPECIAL SENSOR MICROWAVE IMAGING	-	-	92	-	92	-	92	-	92	-
NOAA 0014	DATA COLLECTION SYSTEM	-	-	40	-	40	-	40	-	40	-
NOAA 0015	SPACE ENVIRONMENT MONITOR	-	-	24	-	24	-	24	-	24	-
NOAA 0016	SEARCH AND RESCUE	-	-	20	-	20	-	20	-	20	-
NOAA 0017	ADV MICROWAVE SOUNDINS	-	-	40	-	40	-	40	-	40	-
NOAA 0018	ADV MICROWAVE RADIOMETER	-	-	20	-	20	-	20	-	20	-

TABLE C-1

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
NOAA 0019	MED RES IMAGING RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0020	ALONG TRACK SCAN RAD MICROWAVE	-	-	20	-	20	-	20	-	20	-
NOAA 0021	HIGH RES IR RADIATION SOUNDER	-	-	46	-	46	-	46	-	46	-
NOAA 0022	RADAR ALTIMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0023	N-ROSS SCATTEROMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0024	SPECIAL SENSOR MICROWAVE IMAGING	-	-	92	-	92	-	92	-	92	-
NOAA 0025	DATA COLLECTION SYSTEM	-	-	40	-	40	-	40	-	40	-
NOAA 0026	GLOBAL OZONE MONITORING RADIOM	-	-	66	-	66	-	66	-	66	-
NOAA 0027	EARTH RADIATION BUDGET SENSOR	-	-	20	-	20	-	20	-	20	-
NOAA 0028	OCEAN COLOR IMAGER	-	-	20	-	20	-	20	-	20	-
	SUB TOTAL										
	USA										
	SAAX	20	626	1688	2064	1980	2492	2982	2228	2000	2210
	COMM	160	60	126	0	0	0	0	0	0	0
	TDMX	752	752	1128	308	828	352	728	112	728	52
	ESA	0	0	354	440	408	0	0	12	0	0
	JAPAN	4	8	138	16	26	52	26	40	26	0
	CANADA	68	30	30	8	8	8	8	9	8	8
	NOAA	0	0	866	0	866	0	866	0	866	0
	TOTAL	1004	1476	4330	2836	4116	2904	4610	2400	3628	2270

TABLE C-2

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE

STRAIGHT COUNT OF DATA BASE MHRS

MISSIONS USA	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
SAAX 0004	SIRTF PLATFORM MISSION	-	-	-	-	-	50	24	-	-	-
SAAX 0005	TRANS. RAD & ION CAL	-	-	-	8	8	8	8	-	-	-
SAAX 0006	STARLAB	-	-	-	-	30	-	-	30	-	-
SAAX 0007	HI THROUGHPUT MISSION SERV	-	-	-	-	30	-	-	30	-	-
SAAX 0008	HIGH ENERGY ISO EXP	-	-	-	8	8	8	8	8	8	-
SAAX 0011	ASO II/POF + SOT	-	-	-	-	-	-	30	-	-	30
SAAX 0012	HUBBLE SPACE TEL SERV	-	-	-	100	-	-	100	-	-	-
SAAX 0013	GAMMA RAY OBSER SERV	-	-	-	16	-	-	16	-	-	16
SAAX 0016	SOLAR MAX MISSION SERV	20	-	-	20	-	-	20	-	-	20
SAAX 0017	AXAF SERVICING	-	-	-	86	-	-	86	-	-	86
SAAX 0020	LARGE DEPLOY REFLECTOR	-	-	-	-	-	450	-	50	-	100
SAAX 0021	SUPER COND MAG FAC	-	-	16	16	16	16	-	-	-	-
SAAX 0202	EARTH OBSER SYS	-	440	440	440	440	440	440	440	440	440
SAAX 0208	MOD RES IMAG SPECT	-	20	-	20	-	20	-	20	-	20
SAAX 0209	HIGH RES IMAG SPECT	-	20	-	20	-	20	-	20	-	20
SAAX 0210	HIGH RES MULTI MW RAD	-	20	-	20	-	20	-	20	-	20
SAAX 0211	LASER ATMO SOUNDER & ALT	-	20	-	20	-	20	-	20	-	20
SAAX 0212	SYNTHETIC APER RADAR	-	20	-	20	-	20	-	20	-	20
SAAX 0213	ALTIMETER	-	10	-	10	-	10	-	10	-	10
SAAX 0214	SCATTEROMETER	-	10	-	10	-	10	-	10	-	10
SAAX 0215	CORRELATION RADIOMETER	-	6	-	6	-	6	-	6	-	6
SAAX 0216	EARTH RAD BUDGET EXP	-	10	-	10	-	10	-	10	-	10
SAAX 0219	ENVIROMENTAL MONITORS	-	20	-	20	-	20	-	20	-	20
SAAX 0220	AUTOMATED DATA COLLECTION	-	20	-	20	-	20	-	20	-	20
SAAX 0221	LARGE MICROWAVE ANTENNA	-	-	-	-	-	-	-	-	16	16
SAAX 0222	INFRARED SOUNDING	-	-	-	-	-	-	-	-	16	16
SAAX 0223	LARGE IMAGER	-	-	-	-	-	-	-	-	16	16
SAAX 0225	SOLAR TERRES POLAR PLATFORM	-	-	-	-	-	48	-	-	-	-
SAAX 0227	CONTAINED PLASMA EXP	-	-	-	-	-	-	-	-	-	-
SAAX 0228	THERMAL IR MAPPING SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0229	CRYOGENIC INTERFER/SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0230	FABRY PEROT INTERFEROMETER	-	-	20	-	20	-	20	-	20	-
SAAX 0231	VIS/UV SPECTOMETER	-	-	-	-	20	-	20	-	20	-
SAAX 0232	MICROWAVE LIMB SOUNDER	-	-	-	-	20	-	20	-	20	-
SAAX 0233	SUBMILLIMETER SPECT	-	-	-	-	-	-	20	-	20	-
SAAX 0234	INTERFEROMETER/SPECT/UPPER ATM	-	-	-	-	20	-	20	-	20	-
SAAX 0235	UPPER ATM IR RADIOMETER	-	-	-	-	20	-	20	-	20	-
SAAX 0236	DOPPLER LIDAR	-	-	-	-	-	-	20	-	20	-
SAAX 0237	DIFFERENTIAL ABSORP LIDAR	-	-	-	-	-	-	20	-	20	-
SAAX 0238	NADIR CLIMATE INTERFER/SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0306	CELSS PALLET	-	-	-	32	32	32	32	-	-	-
SAAX 0309	SETI GEO ANTENNA MISSION	-	-	-	-	-	-	-	200	-	-
SAAX 0402	MICRO G VARIABLE "G" FREE FLYER	-	-	-	-	-	-	140	140	140	140
SAAX 0501	EXP GEO PLATFORM	-	-	-	-	-	-	18720	18720	18720	18720
SAAX 0502	SPACE BASED ANTENNA TEST RANGE	-	-	1152	1152	1152	1152	1152	1152	1152	1152

TABLE C-2

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE

STRAIGHT COUNT OF DATA BASE MHRS

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
COMM 1304	OMV/TMS	160	60	-	-	-	-	-	-	-	-
COMM 1309	ORBITAL TRANSFER VEHICLE	-	-	126	-	-	-	-	-	-	-
TDMX 2011	SPACECRAFT MATERIAL & COATINGS	8	8	8	8	8	8	8	8	8	8
TDMX 2022	GROWTH OF COND SEMICOND CRYSTALS	24	24	-	-	-	-	-	-	-	-
TDMX 2061	LARGE SPACE STRUCTURES	138	48	-	-	-	-	-	-	-	-
TDMX 2062	SPACE STATION STRUCTURES	888	-	-	-	-	-	-	-	-	-
TDMX 2063	ON ORBIT SPACECRAFT ASSY/TEST	-	422	-	-	-	-	-	-	-	-
TDMX 2064	ADVANCED ANT ASS/PERFORM	-	-	-	-	-	250	-	-	-	-
TDMX 2071	FLIGHT DYNAMICS IDENTIFACTION	116	-	-	-	-	-	-	-	-	-
TDMX 2072	S/C STRAIN AND ACOUSTIC SENSORS	6	-	-	-	-	-	-	-	-	-
TDMX 2111	DEPLOY & TEST LARGE SOLAR CONCEN	56	-	-	-	-	-	-	-	-	-
TDMX 2121	TEST SOLAR PUMPED LASER	108	-	-	-	-	-	-	-	-	-
TDMX 2122	LASER-ELECTRIC ENERGY CONVERSION	598	-	-	-	-	-	-	-	-	-
TDMX 2132	ADVANCED RADIATOR CONCEPTS	8	16	-	16	8	-	-	-	-	-
TDMX 2152	LARGE SPACE POWER SYSTEMS	-	104	104	-	-	-	-	-	-	-
TDMX 2153	SOLAR DYNAMIC POWER	32	-	-	32	-	-	-	-	-	-
TDMX 2211	MULTI FTN SPACE ANTENNA RNG TECH	-	282	-	-	-	-	-	-	-	-
TDMX 2212	MULTI ANTENNA BEAM PATTERNS	-	320	-	-	-	-	-	-	-	-
TDMX 2213	MULTI FREQUENCY ANTENNA TECH	-	-	412	-	-	-	-	-	-	-
TDMX 2221	LASER COMM & TRACKING DEVELOP	-	-	102	-	-	-	-	-	-	-
TDMX 2224	DEEP SPACE OPTICAL DSN TERMINAL	-	50	-	-	-	-	-	-	-	-
TDMX 2261	SENSOR SYSTEMS TECHNOLOGY	-	-	-	48	48	48	48	48	48	48
TDMX 2263	CO2 LIDAR WIND AND TRACE GASES	-	-	-	4	4	-	-	-	-	-
TDMX 2265	SATELLITE DOPPLER METEROL RADAR	36	-	-	-	-	-	-	-	-	-
TDMX 2311	LONG TERM CRYO FLUID STORAGE	-	4	4	-	-	-	-	-	-	-
TDMX 2322	LASER PROPULSION	-	12	-	-	-	-	-	-	-	-
TDMX 2411	ADVANCED ADAPTIVE CONTROL	-	48	42	24	-	-	-	-	-	-
TDMX 2412	DISTRIBUTED ADAPTIVE CONTROL	-	-	48	-	-	-	-	-	-	-
TDMX 2413	DYNAMIC DISTURBANCE CONTROL	-	-	-	48	-	-	-	-	-	-
TDMX 2421	ACTIVE OPTIC TECHNOLOGY	96	84	-	-	-	-	-	-	-	-
TDMX 2431	ADVANCED CONTROL DEVICE TECH	-	-	24	-	-	-	-	-	-	-
TDMX 2441	GUIDED WAVE OPTICS DATA SYS EXP	8	8	8	8	8	-	-	-	-	-
TDMX 2462	TELEOPERATOR SENSOR EVAL & TEST	144	-	-	-	-	-	-	-	-	-
TDMX 2511	SPACE POWER SYS ENVIRO INT	-	104	104	-	-	-	-	-	-	-
TDMX 2542	TETHERED CONSTELLATION	-	-	744	-	744	-	744	-	744	-
TDMX 2543	TETHERED TRANSPORTATION	-	-	-	-	-	100	94	94	94	-
TDMX 2544	TETHERED FLUID STOWAGE TRANSFER	-	-	1195	1195	1195	1195	1195	1195	1195	-
TDMX 2561	SATELLITE SERVICING & REFURB	12	-	-	-	-	-	-	-	-	-
TDMX 2562	SATELLITE MAINTENANCE & REPAIR	-	734	-	-	-	-	-	-	-	-
TDMX 2563	MATERIALS RESUPPLY	-	6	-	-	-	-	-	-	-	-
TDMX 2565	THERMAL INTERFACE TECHNOLOGY	292	-	-	-	-	-	-	-	-	-
TDMX 2571	OTV/PAYLOAD INTERFACING/TRANSFER	-	-	-	4380	4380	-	-	-	-	-
TDMX 2574	OTV MAINTENANCE TECHNOLOGY	-	-	432	-	-	-	-	-	-	-

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TABLE C-2

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE

STRAIGHT COUNT OF DATA BASE MHRS

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
ESA											
MAT 130	MICROGRAVITY	-	-	384	384	384	-	-	-	-	-
SPA 801	FAR INFRARED/SUBMM SPACE TEL	-	-	-	24	-	-	-	24	-	-
TOS 401	ADV TECH TEST SATELLITE	-	-	-	20	-	-	-	-	-	-
JAPAN											
C-002	LARGE COMM ANTENNA	-	-	10	-	-	-	-	-	-	-
C-003	ADV COMM & DATA HANDLING SYS	-	-	-	-	10	-	-	-	-	-
C-004	GRAV STABILD DEPLOY ANT TEST	-	-	-	-	-	-	-	12	-	-
E-001	LASER RANGING SYSTEM	2	-	-	-	-	2	-	-	-	-
E-002	TEST OF SENSOR TECHNOLOGIES	-	-	-	20	-	-	-	-	-	-
E-003	OBSERV OF UPPER ATMOSPHERE	-	-	-	-	-	28	-	-	-	-
E-005	OPS FOR EARTH OBSERVATION	-	-	1	1	-	-	-	-	-	-
S-001	ASTRONOMICAL PLATFORM	-	-	-	-	24	24	24	24	24	-
S-002	INFRARED TELESCOPE IN SPACE	-	-	24	-	24	-	-	-	-	-
S-005	LINE GAMMA DETECTION	-	-	-	6	-	-	-	-	-	-
S-006	X-RAY ASTRONOMY OBSERVATION	-	-	-	-	-	24	-	-	-	-
S-008	SPACE VLBI	-	-	-	-	-	-	-	-	12	-
S-009	SOLAR ACTIVITY MONITOR	-	-	-	-	-	-	-	24	-	-
S-010	SUBMILLIMETER TELESCOPE	-	-	-	-	-	-	24	-	-	-
T-002	LARGE ANTENNA SYS TECHNOLOGY	-	-	100	-	-	-	-	-	-	-
T-007	2D-SOLAR ARRAY MISSION	-	-	16	-	-	-	-	-	-	-
T-009	LIQUID PROPELLANT HANDLING	-	21	21	-	-	-	-	-	-	-
CANADA											
SAAX 4002	POLCATS	6	6	6	6	6	6	6	6	6	6
SAAX 4004	LONG BAS LINE ARRAY	4	-	-	-	-	-	-	-	-	-
SAAX 4006	UV ATMOSPHERIC LIMB SCANNER	16	16	16	-	-	-	-	-	-	-
TDMX 4006	SPACE STRUCTURES	12	-	-	-	-	-	-	-	-	-
NOAA											
NOAA 0001	SEO SYNTHETIC APERTURE RADAR	-	-	-	-	-	-	-	-	-	-
NOAA 0002	SEA SYNTHETIC APERTURE RADAR	-	-	-	-	-	-	-	-	-	-
NOAA 0003	MULTISPECTRAL LINEAR ARRY	-	-	-	-	-	-	-	-	-	-
NOAA 0004	SEARCH AND RESCUE	-	-	-	-	-	-	-	-	-	-
NOAA 0005	SPACE ENVIRONMENT MONITOR	-	-	20	-	20	-	20	-	20	-
NOAA 0006	ADV MICROWAVE SOUNDING UNIT	-	-	20	-	20	-	20	-	20	-
NOAA 0007	ADV MICROWAVE RADIOMETER	-	-	-	-	-	-	-	-	-	-
NOAA 0008	MED RES IMAGING RADIOMETER	-	-	-	-	-	-	-	-	-	-
NOAA 0009	RADAR ALTIMETER	-	-	-	-	-	-	-	-	-	-
NOAA 0010	ALONG TRACK SCAN RAD MICROWAVE	-	-	-	-	-	-	-	-	-	-
NOAA 0011	HIGH RES IR RADIATION SOUNDER	-	-	46	-	46	-	46	-	46	-
NOAA 0012	N-ROSS SCATTEROMETER	-	-	-	-	-	-	-	-	-	-
NOAA 0013	SPECIAL SENSOR MICROWAVE IMAGING	-	-	92	-	92	-	92	-	92	-
NOAA 0014	DATA COLLECTION SYSTEM	-	-	40	-	40	-	40	-	40	-
NOAA 0015	SPACE ENVIRONMENT MONITOR	-	-	20	-	20	-	20	-	20	-
NOAA 0016	SEARCH AND RESCUE	-	-	-	-	-	-	-	-	-	-
NOAA 0017	ADV MICROWAVE SOUNDING	-	-	20	-	20	-	20	-	20	-
NOAA 0018	ADV MICROWAVE RADIOMETER	-	-	-	-	-	-	-	-	-	-

TABLE C-2

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE

STRAIGHT COUNT OF DATA BASE MHRS

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
NOAA 0019	MED RES IMAGING RADIOMETER	-	-	-	-	-	-	-	-	-	-
NOAA 0020	ALONG TRACK SCAN RAD MICROWAVE	-	-	-	-	-	-	-	-	-	-
NOAA 0021	HIGH RES IR RADIATION SOUNDER	-	-	46	-	46	-	46	-	46	-
NOAA 0022	RADAR ALTIMETER	-	-	-	-	-	-	-	-	-	-
NOAA 0023	N-ROSS SCATTEROMETER	-	-	-	-	-	-	-	-	-	-
NOAA 0024	SPECIAL SENSOR MICROWAVE IMAGING	-	-	92	-	92	-	92	-	92	-
NOAA 0025	DATA COLLECTION SYSTEM	-	-	40	-	40	-	40	-	40	-
NOAA 0026	GLOBAL OZONE MONITORING RADIOM	-	-	46	-	46	-	46	-	46	-
NOAA 0027	EARTH RADIATION BUDGET SENSOR	-	-	-	-	-	-	-	-	-	-
NOAA 0028	OCEAN COLOR IMAGER	-	-	-	-	-	-	-	-	-	-
	SUB TOTAL										
	USA										
	SAAX	20	616	1683	2054	1876	2380	20996	20946	20728	20528
	COMM	160	60	126	0	0	0	0	0	0	0
	TDMX	2570	2274	3227	5763	6397	1601	2089	1345	2089	56
	ESA	0	0	384	428	384	0	0	24	0	0
	JAPAN	2	21	172	27	58	78	48	62	36	0
	CANADA	38	22	22	6	6	6	6	6	6	6
	NOAA	0	0	482	0	482	0	482	0	482	0
	TOTAL	2790	2993	6101	8278	9193	4065	23621	22383	23341	20590

TABLE C-3

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE
TOTAL FIRMNESS
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
USA											
SAAX 0004	SIRTF PLATFORM MISSION	-	-	-	-	-	48	50	-	-	-
SAAX 0005	TRANS. RAD & ION CAL	-	-	-	8	8	8	8	-	-	-
SAAX 0006	STARLAB	-	-	-	-	30	-	-	30	-	-
SAAX 0007	HI THROUGHPUT MISSION SERV	-	-	-	-	30	-	-	30	-	-
SAAX 0008	HIGH ENERGY ISO EXP	-	-	-	8	8	8	8	8	8	-
SAAX 0011	ASO II/POF + SOT	-	-	-	-	-	-	30	-	-	30
SAAX 0012	HUBBLE SPACE TEL SERV	-	-	-	100	-	-	100	-	-	-
SAAX 0013	GAMMA RAY OBSER SERV	-	-	-	16	-	-	16	-	-	16
SAAX 0016	SOLAR MAX MISSION SERV	20	-	-	20	-	-	20	-	-	20
SAAX 0017	AXAF SERVICING	-	-	-	86	-	-	86	-	-	86
SAAX 0020	LARGE DEPLOY REFLECTOR	-	-	-	-	-	450	-	50	-	100
SAAX 0021	SUPER COND MAG FAC	-	-	16	16	16	16	-	-	-	-
SAAX 0202	EARTH OBSER SYS	-	440	440	440	440	440	440	440	440	440
SAAX 0208	MOD RES IMAG SPECT	-	20	-	20	-	20	-	20	-	20
SAAX 0209	HIGH RES IMAG SPECT	-	20	-	20	-	20	-	20	-	20
SAAX 0210	HIGH RES MULTI MW RAD	-	20	-	20	-	20	-	20	-	20
SAAX 0211	LASER ATMO SOUNDER & ALT	-	20	-	20	-	20	-	20	-	20
SAAX 0212	SYNTHETIC APER RADAR	-	20	-	20	-	20	-	20	-	20
SAAX 0213	ALTIMETER	-	20	-	20	-	20	-	20	-	20
SAAX 0214	SCATTEROMETER	-	10	-	10	-	10	-	10	-	10
SAAX 0215	CORRELATION RADIOMETER	-	6	-	6	-	6	-	6	-	6
SAAX 0216	EARTH RAD BUDGET EXP	-	10	-	10	-	10	-	10	-	10
SAAX 0219	ENVIROMENTAL MONITORS	-	20	-	20	-	20	-	20	-	20
SAAX 0220	AUTOMATED DATA COLLECTION	-	20	-	20	-	20	-	20	-	20
SAAX 0221	LARGE MICROWAVE ANTENNA	-	-	-	-	-	-	-	-	16	16
SAAX 0222	INFRARED SOUNDING	-	-	-	-	-	-	-	-	16	16
SAAX 0223	LARGE IMAGER	-	-	-	-	-	-	-	-	16	16
SAAX 0225	SOLAR TERRES POLAR PLATFORM	-	-	-	-	-	48	-	-	-	-
SAAX 0227	CONTAINED PLASMA EXP	-	-	-	-	104	104	-	-	-	-
SAAX 0228	THERMAL IR MAPPING SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0229	CRYOGENIC INTERFER/SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0230	FABRY PEROT INTERFEROMETER	-	-	20	-	20	-	20	-	20	-
SAAX 0231	VIS/UV SPECTOMETER	-	-	-	-	20	-	20	-	20	-
SAAX 0232	MICROWAVE LIMB SOUNDER	-	-	-	-	20	-	20	-	20	-
SAAX 0233	SUBMILLIMETER SPECT	-	-	-	-	-	-	20	-	20	-
SAAX 0234	INTERFEROMETER/SPECT/UPPER ATM	-	-	-	-	20	-	20	-	20	-
SAAX 0235	UPPER ATM IR RADIOMETER	-	-	-	-	20	-	20	-	20	-
SAAX 0236	DOPPLER LIDAR	-	-	-	-	-	-	20	-	20	-
SAAX 0237	DIFFERENTIAL ABSORP LIDAR	-	-	-	-	-	-	20	-	20	-
SAAX 0238	NADIR CLIMATE INTERFER/SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0306	CELSS PALLET	-	-	-	32	32	32	32	-	-	-
SAAX 0309	SETI GEO ANTENNA MISSION	-	-	-	-	-	-	-	200	-	-
SAAX 0402	MICRO G VARIABLE "G" FREE FLYER	-	-	-	-	-	-	100	132	132	132
SAAX 0501	EXP GEO PLATFORM	-	-	-	-	-	-	720	-	-	-
SAAX 0502	SPACE BASED ANTENNA TEST RANGE	-	-	1152	1152	1152	1152	1152	1152	1152	1152

TABLE C-3

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE
TOTAL FIRMNESS
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
COMM 1304	OMV/TMS	160	60	-	-	-	-	-	-	-	-
COMM 1309	ORBITAL TRANSFER VEHICLE	-	-	126	-	-	-	-	-	-	-
TDMX 2011	SPACECRAFT MATERIAL & COATINGS	8	4	4	4	4	4	4	4	4	4
TDMX 2022	GROWTH OF COND SEMICOND CRYSTALS	32	32	-	-	-	-	-	-	-	-
TDMX 2061	LARGE SPACE STRUCTURES	228	48	-	-	-	-	-	-	-	-
TDMX 2062	SPACE STATION STRUCTURES	72	-	-	-	-	-	-	-	-	-
TDMX 2063	ON ORBIT SPACECRAFT ASSY/TEST	-	154	-	-	-	-	-	-	-	-
TDMX 2064	ADVANCED ANT ASS/PERFORM	-	-	-	-	-	250	-	-	-	-
TDMX 2071	FLIGHT DYNAMICS IDENTIFACTION	134	-	-	-	-	-	-	-	-	-
TDMX 2072	S/C STRAIN AND ACOUSTIC SENSORS	12	-	-	-	-	-	-	-	-	-
TDMX 2111	DEPLOY & TEST LARGE SOLAR CONCEN	32	-	-	-	-	-	-	-	-	-
TDMX 2121	TEST SOLAR PUMPED LASER	20	-	-	-	-	-	-	-	-	-
TDMX 2122	LASER-ELECTRIC ENERGY CONVERSION	30	-	-	-	-	-	-	-	-	-
TDMX 2132	ADVANCED RADIATOR CONCEPTS	16	16	-	16	10	-	-	-	-	-
TDMX 2152	LARGE SPACE POWER SYSTEMS	-	109	108	-	-	-	-	-	-	-
TDMX 2153	SOLAR DYNAMIC POWER	32	10	10	32	-	-	-	-	-	-
TDMX 2211	MULTI FTN SPACE ANTENNA RNG TECH	-	46	-	-	-	-	-	-	-	-
TDMX 2212	MULTI ANTENNA BEAM PATTERNS	-	44	-	-	-	-	-	-	-	-
TDMX 2213	MULTI FREQUENCY ANTENNA TECH	-	-	38	-	-	-	-	-	-	-
TDMX 2221	LASER COMM & TRACKING DEVELOP	-	-	18	-	-	-	-	-	-	-
TDMX 2224	DEEP SPACE OPTICAL DSN TERMINAL	-	28	-	-	-	-	-	-	-	-
TDMX 2261	SENSOR SYSTEMS TECHNOLOGY	-	-	-	48	48	48	48	48	48	48
TDMX 2263	CO2 LIDAR WIND AND TRACE GASES	-	-	-	8	8	-	-	-	-	-
TDMX 2265	SATELLITE DOPPLER METEROL RADAR	6	-	-	-	-	-	-	-	-	-
TDMX 2311	LONG TERM CRYO FLUID STORAGE	-	4	4	-	-	-	-	-	-	-
TDMX 2322	LASER PROPULSION	-	12	-	-	-	-	-	-	-	-
TDMX 2411	ADVANCED ADAPTIVE CONTROL	-	30	42	42	-	-	-	-	-	-
TDMX 2412	DISTRIBUTED ADAPTIVE CONTROL	-	-	16	-	-	-	-	-	-	-
TDMX 2413	DYNAMIC DISTURBANCE CONTROL	-	-	-	16	-	-	-	-	-	-
TDMX 2421	ACTIVE OPTIC TECHNOLOGY	78	78	-	-	-	-	-	-	-	-
TDMX 2431	ADVANCED CONTROL DEVICE TECH	-	-	24	-	-	-	-	-	-	-
TDMX 2441	GUIDED WAVE OPTICS DATA SYS EXP	8	8	8	8	8	-	-	-	-	-
TDMX 2462	TELEOPERATOR SENSOR EVAL & TEST	8	-	-	-	-	-	-	-	-	-
TDMX 2511	SPACE POWER SYS ENVIRO INT	-	104	104	-	-	-	-	-	-	-
TDMX 2542	TETHERED CONSTELLATION	-	-	616	-	616	-	616	-	616	-
TDMX 2543	TETHERED TRANSPORTATION	-	-	-	-	-	14	24	24	24	-
TDMX 2544	TETHERED FLUID STOWAGE TRANSFER	-	-	96	36	36	36	36	36	36	-
TDMX 2561	SATELLITE SERVICING & REFURB	12	-	-	-	-	-	-	-	-	-
TDMX 2562	SATELLITE MAINTENANCE & REPAIR	-	20	-	-	-	-	-	-	-	-
TDMX 2563	MATERIALS RESUPPLY	-	6	-	-	-	-	-	-	-	-
TDMX 2565	THERMAL INTERFACE TECHNOLOGY	24	-	-	-	-	-	-	-	-	-
TDMX 2571	OTV/PAYLOAD INTERFACING/TRANSFER	-	-	-	98	98	-	-	-	-	-
TDMX 2574	OTV MAINTENANCE TECHNOLOGY	-	-	40	-	-	-	-	-	-	-

TABLE C-3

ORIGINAL PAGE IS OF POOR QUALITY

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE
TOTAL FIRMNESS
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
ESA											
MAT 130	MICROGRAVITY	-	-	354	408	408	-	-	-	-	-
SPA 801	FAR INFRARED/SUBMM SPACE TEL	-	-	-	12	-	-	-	12	-	-
TDS 401	ADV TECH TEST SATELLITE	-	-	-	20	-	-	-	-	-	-
JAPAN											
C-002	LARGE COMM ANTENNA	-	-	10	-	-	-	-	-	-	-
C-003	ADV COMM & DATA HANDLING SYS	-	-	-	-	10	-	-	-	-	-
C-004	GRAV STABILD DEPLOY ANT TEST	-	-	-	-	-	-	-	12	-	-
E-001	LASER RANGING SYSTEM	4	-	-	-	-	2	-	-	-	-
E-002	TEST OF SENSOR TECHNOLOGIES	-	-	-	12	-	-	-	-	-	-
E-003	OBSERV OF UPPER ATMOSPHERE	-	-	-	-	-	24	-	-	-	-
E-005	OPS FOR EARTH OBSERVATION	-	-	2	2	-	-	-	-	-	-
S-001	ASTRONOMICAL PLATFORM	-	-	-	-	14	2	2	2	2	-
S-002	INFRARED TELESCOPE IN SPACE	-	-	2	-	2	-	-	-	-	-
S-005	LINE GAMMA DETECTION	-	-	-	2	-	-	-	-	-	-
S-006	X-RAY ASTRONOMY OBSERVATION	-	-	-	-	-	24	-	-	-	-
S-008	SPACE VLBI	-	-	-	-	-	-	-	-	24	-
S-009	SOLAR ACTIVITY MONITOR	-	-	-	-	-	-	-	26	-	-
S-010	SUBMILLIMETER TELESCOPE	-	-	-	-	-	-	24	-	-	-
T-002	LARGE ANTENNA SYS TECHNOLOGY	-	-	100	-	-	-	-	-	-	-
T-007	2D-SOLAR ARRAY MISSION	-	-	16	-	-	-	-	-	-	-
T-009	LIQUID PROPELLANT HANDLING	-	8	8	-	-	-	-	-	-	-
CANADA											
SAAX 4002	POLCATS	8	8	8	8	8	8	8	8	8	8
SAAX 4004	LONG BAS LINE ARRAY	4	-	-	-	-	-	-	-	-	-
SAAX 4006	UV ATMOSPHERIC LIMB SCANNER	16	16	16	-	-	-	-	-	-	-
TDMX 4006	SPACE STRUCTURES	40	6	6	-	-	-	-	-	-	-
NOAA											
NOAA 0001	GEO SYNTHETIC APERTURE RADAR	-	-	20	-	20	-	20	-	20	-
NOAA 0002	SEA SYNTHETIC APERTURE RADAR	-	-	20	-	20	-	20	-	20	-
NOAA 0003	MULTISPECTRAL LINEAR ARRY	-	-	20	-	20	-	20	-	20	-
NOAA 0004	SEARCH AND RESCUE	-	-	20	-	20	-	20	-	20	-
NOAA 0005	SPACE ENVIRONMENT MONITOR	-	-	20	-	20	-	20	-	20	-
NOAA 0006	ADV MICROWAVE SOUNDING UNIT	-	-	20	-	20	-	20	-	20	-
NOAA 0007	ADV MICROWAVE RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0008	MED RES IMAGING RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0009	RADAR ALTIMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0010	ALONG TRACK SCAN RAD MICROWAVE	-	-	20	-	20	-	20	-	20	-
NOAA 0011	HIGH RES IR RADIATION SOUNDER	-	-	46	-	46	-	46	-	46	-
NOAA 0012	N-ROSS SCATTEROMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0013	SPECIAL SENSOR MICROWAVE IMAGING	-	-	92	-	92	-	92	-	92	-
NOAA 0014	DATA COLLECTION SYSTEM	-	-	40	-	40	-	40	-	40	-
NOAA 0015	SPACE ENVIRONMENT MONITOR	-	-	24	-	24	-	24	-	24	-
NOAA 0016	SEARCH AND RESCUE	-	-	20	-	20	-	20	-	20	-
NOAA 0017	ADV MICROWAVE SOUNDING	-	-	40	-	40	-	40	-	40	-

TABLE C-3

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE
TOTAL FIRMNESS
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
NOAA 0018	ADV MICROWAVE RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0019	MED RES IMAGING RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0020	ALONG TRACK SCAN RAD MICROWAVE	-	-	20	-	20	-	20	-	20	-
NOAA 0021	HIGH RES IR RADIATION SOUNDER	-	-	46	-	46	-	46	-	46	-
NOAA 0022	RADAR ALTIMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0023	N-ROSS SCATTEROMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0024	SPECIAL SENSOR MICROWAVE IMAGING	-	-	92	-	92	-	92	-	92	-
NOAA 0025	DATA COLLECTION SYSTEM	-	-	40	-	40	-	40	-	40	-
NOAA 0026	GLOBAL OZONE MONITORING RADIOM	-	-	66	-	66	-	66	-	66	-
NOAA 0027	EARTH RADIATION BUDGET SENSOR	-	-	20	-	20	-	20	-	20	-
NOAA 0028	OCEAN COLOR IMAGER	-	-	20	-	20	-	20	-	20	-

SUB TOTAL	92	93	94	95	96	97	98	99	00	01
USA										
SAAX	20	626	1688	2064	1980	2492	2982	2228	2000	2210
COMM	160	60	126	0	0	0	0	0	0	0
TDMX	752	752	1128	308	828	352	728	112	728	52
ESA	0	0	354	440	408	0	0	12	0	0
JAPAN	4	8	138	16	26	52	26	40	26	0
CANADA	68	30	30	8	8	8	8	8	8	8
NOAA	0	0	866	0	866	0	866	0	866	0
TOTAL	1004	1476	4330	2836	4116	2904	4610	2400	3628	2270

TABLE C-3-1

EVA MANHOURS BY FIRMNESS
FIRMNESS: OPERATIONAL (1)

BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	1992	93	94	95	96	97	98	99	00	01
SAAX 0016	SOLAR MAX MISSION SERV	20	-	-	20	-	-	20	-	-	20
SAAX 0211	LASER ATMO SOUNDER & ALT	-	20	-	20	-	20	-	20	-	20
NOAA 0003	MULTISPECTRAL LINEAR ARRY	-	-	20	-	20	-	20	-	20	-
NOAA 0004	SEARCH AND RESCUE	-	-	20	-	20	-	20	-	20	-
NOAA 0005	SPACE ENVIRONMENT MONITOR	-	-	20	-	20	-	20	-	20	-
NOAA 0007	ADV MICROWAVE RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0009	RADAR ALTIMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0010	ALONG TRACK SCAN RAD MICROWAVE	-	-	20	-	20	-	20	-	20	-
NOAA 0011	HIGH RES IR RADIATION SOUNDER	-	-	46	-	46	-	46	-	46	-
NOAA 0013	SPECIAL SENSOR MICROWAVE IMAGING	-	-	92	-	92	-	92	-	92	-
NOAA 0014	DATA COLLECTION SYSTEM	-	-	40	-	40	-	40	-	40	-
NOAA 0015	SPACE ENVIRONMENT MONITOR	-	-	24	-	24	-	24	-	24	-
NOAA 0016	SEARCH AND RESCUE	-	-	20	-	20	-	20	-	20	-
NOAA 0018	ADV MICROWAVE RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0020	ALONG TRACK SCAN RAD MICROWAVE	-	-	20	-	20	-	20	-	20	-
NOAA 0021	HIGH RES IR RADIATION SOUNDER	-	-	46	-	46	-	46	-	46	-
NOAA 0022	RADAR ALTIMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0024	SPECIAL SENSOR MICROWAVE IMAGING	-	-	92	-	92	-	92	-	92	-
NOAA 0025	DATA COLLECTION SYSTEM	-	-	40	-	40	-	40	-	40	-
NOAA 0027	EARTH RADIATION BUDGET SENSOR	-	-	20	-	20	-	20	-	20	-
NOAA 0028	OCEAN COLOR IMAGER	-	-	20	-	20	-	20	-	20	-
	TOTAL	20	20	620	40	620	20	640	20	620	40

TABLE C-3-2

EVA MANHOURS BY FIRMNESS
FIRMNESS: APPROVED (2)

BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
SAAX 0012	HUBBLE SPACE TEL SERV	-	-	-	100	-	-	100	-	-	-
SAAX 0013	GAMMA RAY OBSER SERV	-	-	-	16	-	-	16	-	-	16
NOAA 0006	ADV MICROWAVE SOUNDING UNIT	-	-	20	-	20	-	20	-	20	-
NOAA 0012	N-ROSS SCATTEROMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0017	ADV MICROWAVE SOUNDING	-	-	40	-	40	-	40	-	40	-
NOAA 0023	N-ROSS SCATTEROMETER	-	-	20	-	20	-	20	-	20	-
	TOTAL	0	0	100	116	100	0	216	0	100	16

TABLE C-3-3

EVA MANHOURS BY FIRMNESS
FIRMNESS: PLANNED (3)

BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
SAAX 0004	SIRTF PLATFORM MISSION	-	-	-	-	-	48	50	-	-	-
SAAX 0006	STARLAB	-	-	-	-	30	-	-	30	-	-
SAAX 0011	ASO II/POF + SOT	-	-	-	-	-	-	30	-	-	30
SAAX 0017	AXAF SERVICING	-	-	-	86	-	-	86	-	-	86
SAAX 0020	LARGE DEPLOY REFLECTOR	-	-	-	-	-	450	-	50	-	100
SAAX 0202	EARTH OBSER SYS	-	440	440	440	440	440	440	440	440	440
SAAX 0208	MOD RES IMAG SPECT	-	20	-	20	-	20	-	20	-	20
SAAX 0209	HIGH RES IMAG SPECT	-	20	-	20	-	20	-	20	-	20
SAAX 0210	HIGH RES MULTI MW RAD	-	20	-	20	-	20	-	20	-	20
SAAX 0212	SYNTHETIC APER RADAR	-	20	-	20	-	20	-	20	-	20
SAAX 0213	ALTIMETER	-	20	-	20	-	20	-	20	-	20
SAAX 0214	SCATTEROMETER	-	10	-	10	-	10	-	10	-	10
SAAX 0215	CORRELATION RADIOMETER	-	6	-	6	-	6	-	6	-	6
SAAX 0216	EARTH RAD BUDGET EXP	-	10	-	10	-	10	-	10	-	10
SAAX 0219	ENVIROMENTAL MONITORS	-	20	-	20	-	20	-	20	-	20
SAAX 0220	AUTOMATED DATA COLLECTION	-	20	-	20	-	20	-	20	-	20
SAAX 0221	LARGE MICROWAVE ANTENNA	-	-	-	-	-	-	-	-	16	16
SAAX 0222	INFRARED SOUNDING	-	-	-	-	-	-	-	-	16	16
SAAX 0223	LARGE IMAGER	-	-	-	-	-	-	-	-	16	16
SAAX 0228	THERMAL IR MAPPING SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0229	CRYOGENIC INTERFER/SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0230	FABRY PEROT INTERFEROMETER	-	-	20	-	20	-	20	-	20	-
SAAX 0231	VIS/UV SPECTOMETER	-	-	-	-	20	-	20	-	20	-
SAAX 0232	MICROWAVE LIMB SOUNDER	-	-	-	-	20	-	20	-	20	-
SAAX 0233	SUBMILLIMETER SPECT	-	-	-	-	-	-	20	-	20	-
SAAX 0234	INTERFEROMETER/SPECT/UPPER ATM	-	-	-	-	20	-	20	-	20	-
SAAX 0235	UPPER ATM IR RADIOMETER	-	-	-	-	20	-	20	-	20	-
SAAX 0236	DOPPLER LIDAR	-	-	-	-	-	-	20	-	20	-
SAAX 0237	DIFFERENTIAL ABSORP LIDAR	-	-	-	-	-	-	20	-	20	-
SAAX 0238	NADIR CLIMATE INTERFER/SPECT	-	-	20	-	20	-	20	-	20	-
SAAX 0402	MICRO G VARIABLE "G" FREE FLYER	-	-	-	-	-	-	100	132	132	132
SAAX 0501	EXP GEO PLATFORM	-	-	-	-	-	-	720	-	-	-
COMM 1304	OMV/TMS	160	60	-	-	-	-	-	-	-	-
COMM 1309	ORBITAL TRANSFER VEHICLE	-	-	126	-	-	-	-	-	-	-
SAAX 4006	UV ATMOSPHERIC LIMB SCANNER	16	16	16	-	-	-	-	-	-	-
NOAA 0001	GEO SYNTHETIC APERTURE RADAR	-	-	20	-	20	-	20	-	20	-
NOAA 0002	SEA SYNTHETIC APERTURE RADAR	-	-	20	-	20	-	20	-	20	-
NOAA 0008	MED RES IMAGING RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0019	MED RES IMAGING RADIOMETER	-	-	20	-	20	-	20	-	20	-
NOAA 0026	GLOBAL OZONE MONITORING RADIOM	-	-	66	-	66	-	66	-	66	-
	TOTAL	176	682	808	692	776	1104	1792	818	986	1002

TABLE C-3-4

EVA MANHOURS BY FIRMNESS
FIRMNESS: CANDIDATE (4)

BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
SAAX 0005	TRANS. RAD & ION CAL	-	-	-	8	8	8	8	-	-	-
SAAX 0007	HI THROUGHPUT MISSION SERV	-	-	-	-	30	-	-	30	-	-
SAAX 0008	HIGH ENERGY ISO EXP	-	-	-	8	8	8	8	8	8	-
SAAX 0021	SUPER COND MAG FAC	-	-	16	16	16	16	-	-	-	-
SAAX 0225	SOLAR TERRES POLAR PLATFORM	-	-	-	-	-	48	-	-	-	-
SAAX 0227	CONTAINED PLASMA EXP	-	-	-	-	104	104	-	-	-	-
SAAX 0306	CELSS PALLET	-	-	-	32	32	32	32	-	-	-
SAAX 0309	SETI GEO ANTENNA MISSION	-	-	-	-	-	-	-	200	-	-
SAAX 0502	SPACE BASED ANTENNA TEST RANGE	-	-	1152	1152	1152	1152	1152	1152	1152	1152
TDMX 2011	SPACECRAFT MATERIAL & COATINGS	8	4	4	4	4	4	4	4	4	4
TDMX 2022	GROWTH OF COND SEMICOND CRYSTALS	32	32	-	-	-	-	-	-	-	-
TDMX 2061	LARGE SPACE STRUCTURES	228	48	-	-	-	-	-	-	-	-
TDMX 2062	SPACE STATION STRUCTURES	72	-	-	-	-	-	-	-	-	-
TDMX 2063	ON ORBIT SPACECRAFT ASSY/TEST	-	154	-	-	-	-	-	-	-	-
TDMX 2064	ADVANCED ANT ASS/PERFORM	-	-	-	-	-	250	-	-	-	-
TDMX 2071	FLIGHT DYNAMICS IDENTIFACTION	134	-	-	-	-	-	-	-	-	-
TDMX 2072	S/C STRAIN AND ACOUSTIC SENSORS	12	-	-	-	-	-	-	-	-	-
TDMX 2111	DEPLOY & TEST LARGE SOLAR CONCEN	32	-	-	-	-	-	-	-	-	-
TDMX 2121	TEST SOLAR PUMPED LASER	20	-	-	-	-	-	-	-	-	-
TDMX 2122	LASER-ELECTRIC ENERGY CONVERSION	30	-	-	-	-	-	-	-	-	-
TDMX 2132	ADVANCED RADIATOR CONCEPTS	16	16	-	16	10	-	-	-	-	-
TDMX 2152	LARGE SPACE POWER SYSTEMS	-	108	108	-	-	-	-	-	-	-
TDMX 2153	SOLAR DYNAMIC POWER	32	10	10	32	-	-	-	-	-	-
TDMX 2211	MULTI FTN SPACE ANTENNA RNG TECH	-	46	-	-	-	-	-	-	-	-
TDMX 2212	MULTI ANTENNA BEAM PATTERNS	-	44	-	-	-	-	-	-	-	-
TDMX 2213	MULTI FREQUENCY ANTENNA TECH	-	-	38	-	-	-	-	-	-	-
TDMX 2221	LASER COMM & TRACKING DEVELOP	-	-	18	-	-	-	-	-	-	-
TDMX 2224	DEEP SPACE OPTICAL DSN TERMINAL	-	28	-	-	-	-	-	-	-	-
TDMX 2261	SENSOR SYSTEMS TECHNOLOGY	-	-	-	48	48	48	48	48	48	48
TDMX 2263	CO2 LIDAR WIND AND TRACE GASES	-	-	-	8	8	-	-	-	-	-
TDMX 2265	SATELLITE DOPPLER METEROL RADAR	6	-	-	-	-	-	-	-	-	-
TDMX 2311	LONG TERM CRYO FLUID STORAGE	-	4	4	-	-	-	-	-	-	-
TDMX 2322	LASER PROPULSION	-	12	-	-	-	-	-	-	-	-
TDMX 2411	ADVANCED ADAPTIVE CONTROL	-	30	42	42	-	-	-	-	-	-
TDMX 2412	DISTRIBUTED ADAPTIVE CONTROL	-	-	16	-	-	-	-	-	-	-
TDMX 2413	DYNAMIC DISTURBANCE CONTROL	-	-	-	16	-	-	-	-	-	-
TDMX 2421	ACTIVE OPTIC TECHNOLOGY	78	78	-	-	-	-	-	-	-	-
TDMX 2431	ADVANCED CONTROL DEVICE TECH	-	-	24	-	-	-	-	-	-	-
TDMX 2441	GUIDED WAVE OPTICS DATA SYS EXP	8	8	8	8	8	-	-	-	-	-
TDMX 2462	TELEOPERATOR SENSOR EVAL & TEST	8	-	-	-	-	-	-	-	-	-
TDMX 2511	SPACE POWER SYS ENVIRO INT	-	104	104	-	-	-	-	-	-	-
TDMX 2542	TETHERED CONSTELLATION	-	-	616	-	616	-	616	-	616	-
TDMX 2543	TETHERED TRANSPORTATION	-	-	-	-	-	14	24	24	24	-
TDMX 2544	TETHERED FLUID STOWAGE TRANSFER	-	-	96	36	36	36	36	36	36	-
TDMX 2561	SATELLITE SERVICING & REFURB	12	-	-	-	-	-	-	-	-	-
TDMX 2562	SATELLITE MAINTENANCE & REPAIR	-	20	-	-	-	-	-	-	-	-

TABLE C-3-4

ORIGINAL PAGE IS OF POOR QUALITY

EVA MANHOURS BY FIRMNESS
FIRMNESS: CANDIDATE (4)

BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
TDMX 2563	MATERIALS RESUPPLY	-	6	-	-	-	-	-	-	-	-
TDMX 2565	THERMAL INTERFACE TECHNOLOGY	24	-	-	-	-	-	-	-	-	-
TDMX 2571	OTV/PAYLOAD INTERFACING/TRANSFER	-	-	-	98	98	-	-	-	-	-
TDMX 2574	OTV MAINTENANCE TECHNOLOGY	-	-	40	-	-	-	-	-	-	-
MAT 130	MICROGRAVITY	-	-	354	408	408	-	-	-	-	-
SPA 801	FAR INFRARED/SUBMM SPACE TEL	-	-	-	12	-	-	-	12	-	-
TOS 401	ADV TECH TEST SATELLITE	-	-	-	20	-	-	-	-	-	-
C-002	LARGE COMM ANTENNA	-	-	10	-	-	-	-	-	-	-
C-003	ADV COMM & DATA HANDLING SYS	-	-	-	-	10	-	-	-	-	-
C-004	GRAV STABILD DEPLOY ANT TEST	-	-	-	-	-	-	-	12	-	-
E-001	LASER RANGING SYSTEM	4	-	-	-	-	2	-	-	-	-
E-002	TEST OF SENSOR TECHNOLOGIES	-	-	-	12	-	-	-	-	-	-
E-003	OBSERV OF UPPER ATMOSPHERE	-	-	-	-	-	24	-	-	-	-
E-005	OPS FOR EARTH OBSERVATION	-	-	2	2	-	-	-	-	-	-
S-001	ASTRONOMICAL PLATFORM	-	-	-	-	14	2	2	2	2	-
S-002	INFRARED TELESCOPE IN SPACE	-	-	2	-	2	-	-	-	-	-
S-005	LINE GAMMA DETECTION	-	-	-	2	-	-	-	-	-	-
S-006	X-RAY ASTRONOMY OBSERVATION	-	-	-	-	-	24	-	-	-	-
S-008	SPACE VLBI	-	-	-	-	-	-	-	-	24	-
S-009	SOLAR ACTIVITY MONITOR	-	-	-	-	-	-	-	26	-	-
S-010	SUBMILLIMETER TELESCOPE	-	-	-	-	-	-	24	-	-	-
T-002	LARGE ANTENNA SYS TECHNOLOGY	-	-	100	-	-	-	-	-	-	-
T-007	2D-SOLAR ARRAY MISSION	-	-	16	-	-	-	-	-	-	-
T-009	LIQUID PROPELLANT HANDLING	-	8	8	-	-	-	-	-	-	-
SAAX 4002	POLCATS	8	8	8	8	8	8	8	8	8	8
	TOTAL	764	768	2796	1988	2620	1780	1962	1562	1922	1212

TABLE C-3-5

EVA MANHOURS BY FIRMNESS
FIRMNESS: OPPORTUNITY (5)

BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
SAAX 0004	LONG BAS LINE ARRAY	4	-	-	-	-	-	-	-	-	-
TDMX 4006	SPACE STRUCTURES	40	6	6	-	-	-	-	-	-	-
	TOTAL	44	6	6	0	0	0	0	0	0	0

TABLE C-4

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE
NON-POLAR MISSIONS
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
SAAX 0004	SIRTF PLATFORM MISSION	-	-	-	-	-	48	50	-	-	-
SAAX 0005	TRANS. RAD & ION CAL	-	-	-	8	8	8	8	-	-	-
SAAX 0006	STARLAB	-	-	-	-	30	-	-	30	-	-
SAAX 0007	HI THROUGHPUT MISSION SERV	-	-	-	-	30	-	-	30	-	-
SAAX 0011	ASD II/POF + SOT	-	-	-	-	-	-	30	-	-	30
SAAX 0012	HUBBLE SPACE TEL SERV	-	-	-	100	-	-	100	-	-	-
SAAX 0013	GAMMA RAY OBSER SERV	-	-	-	16	-	-	16	-	-	16
SAAX 0016	SOLAR MAX MISSION SERV	20	-	-	20	-	-	20	-	-	20
SAAX 0017	AXAF SERVICING	-	-	-	86	-	-	86	-	-	86
SAAX 0020	LARGE DEPLOY REFLECTOR	-	-	-	-	-	450	-	50	-	100
SAAX 0021	SUPER COND MAG FAC	-	-	16	16	16	16	-	-	-	-
SAAX 0221	LARGE MICROWAVE ANTENNA	-	-	-	-	-	-	-	-	16	16
SAAX 0222	INFRARED SOUNDING	-	-	-	-	-	-	-	-	16	16
SAAX 0223	LARGE IMAGER	-	-	-	-	-	-	-	-	16	16
SAAX 0227	CONTAINED PLASMA EXP	-	-	-	-	104	104	-	-	-	-
SAAX 0306	CELSS PALLET	-	-	-	32	32	32	32	-	-	-
SAAX 0309	SETI GEO ANTENNA MISSION	-	-	-	-	-	-	-	200	-	-
SAAX 0402	MICRO G VARIABLE "G" FREE FLYER	-	-	-	-	-	-	100	132	132	132
SAAX 0501	EXP GEO PLATFORM	-	-	-	-	-	-	720	-	-	-
SAAX 0502	SPACE BASED ANTENNA TEST RANGE	-	-	1152	1152	1152	1152	1152	1152	1152	1152
COMM 1304	OMV/TMS	160	60	-	-	-	-	-	-	-	-
COMM 1309	ORBITAL TRANSFER VEHICLE	-	-	126	-	-	-	-	-	-	-
TDMX 2022	GROWTH OF COND SEMICOND CRYSTALS	32	32	-	-	-	-	-	-	-	-
TDMX 2061	LARGE SPACE STRUCTURES	228	48	-	-	-	-	-	-	-	-
TDMX 2062	SPACE STATION STRUCTURES	72	-	-	-	-	-	-	-	-	-
TDMX 2063	ON ORBIT SPACECRAFT ASSY/TEST	-	154	-	-	-	-	-	-	-	-
TDMX 2064	ADVANCED ANT ASS/PERFORM	-	-	-	-	-	250	-	-	-	-
TDMX 2071	FLIGHT DYNAMICS IDENTIFACTION	134	-	-	-	-	-	-	-	-	-
TDMX 2072	S/C STRAIN AND ACOUSTIC SENSORS	12	-	-	-	-	-	-	-	-	-
TDMX 2111	DEPLOY & TEST LARGE SOLAR CONCEN	32	-	-	-	-	-	-	-	-	-
TDMX 2121	TEST SOLAR PUMPED LASER	20	-	-	-	-	-	-	-	-	-
TDMX 2122	LASER-ELECTRIC ENERGY CONVERSION	30	-	-	-	-	-	-	-	-	-
TDMX 2132	ADVANCED RADIATOR CONCEPTS	16	16	-	16	10	-	-	-	-	-
TDMX 2152	LARGE SPACE POWER SYSTEMS	-	108	108	-	-	-	-	-	-	-
TDMX 2153	SOLAR DYNAMIC POWER	32	10	10	32	-	-	-	-	-	-
TDMX 2211	MULTI FTN SPACE ANTENNA RNG TECH	-	46	-	-	-	-	-	-	-	-
TDMX 2212	MULTI ANTENNA BEAM PATTERNS	-	44	-	-	-	-	-	-	-	-
TDMX 2213	MULTI FREQUENCY ANTENNA TECH	-	-	38	-	-	-	-	-	-	-
TDMX 2221	LASER COMM & TRACKING DEVELOP	-	-	18	-	-	-	-	-	-	-
TDMX 2224	DEEP SPACE OPTICAL DSN TERMINAL	-	28	-	-	-	-	-	-	-	-
TDMX 2261	SENSOR SYSTEMS TECHNOLOGY	-	-	-	48	48	48	48	48	48	48
TDMX 2263	CO2 LIDAR WIND AND TRACE GASES	-	-	-	8	8	-	-	-	-	-
TDMX 2265	SATELLITE DOPPLER METEROL RADAR	6	-	-	-	-	-	-	-	-	-
TDMX 2311	LONG TERM CRYO FLUID STORAGE	-	4	4	-	-	-	-	-	-	-
TDMX 2322	LASER PROPULSION	-	12	-	-	-	-	-	-	-	-

TABLE C-4

SPACE STATION PAYLOADS REQUIRING EVA SUPPORT (MHRS)
MAY 1985 LANGLEY DATA BASE
NON-POLAR MISSIONS
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	92	93	94	95	96	97	98	99	00	01
TDMX 2411	ADVANCED ADAPTIVE CONTROL	-	30	42	42	-	-	-	-	-	-
TDMX 2412	DISTRIBUTED ADAPTIVE CONTROL	-	-	16	-	-	-	-	-	-	-
TDMX 2413	DYNAMIC DISTURBANCE CONTROL	-	-	-	16	-	-	-	-	-	-
TDMX 2421	ACTIVE OPTIC TECHNOLOGY	78	78	-	-	-	-	-	-	-	-
TDMX 2431	ADVANCED CONTROL DEVICE TECH	-	-	24	-	-	-	-	-	-	-
TDMX 2441	GUIDED WAVE OPTICS DATA SYS EXP	8	8	8	8	8	-	-	-	-	-
TDMX 2462	TELEOPERATOR SENSOR EVAL & TEST	8	-	-	-	-	-	-	-	-	-
TDMX 2511	SPACE POWER SYS ENVIRO INT	-	104	104	-	-	-	-	-	-	-
TDMX 2542	TETHERED CONSTELLATION	-	-	616	-	616	-	616	-	616	-
TDMX 2543	TETHERED TRANSPORTATION	-	-	-	-	-	14	24	24	24	-
TDMX 2544	TETHERED FLUID STOWAGE TRANSFER	-	-	96	36	36	36	36	36	36	-
TDMX 2561	SATELLITE SERVICING & REFURB	12	-	-	-	-	-	-	-	-	-
TDMX 2562	SATELLITE MAINTENANCE & REPAIR	-	20	-	-	-	-	-	-	-	-
TDMX 2563	MATERIALS RESUPPLY	-	6	-	-	-	-	-	-	-	-
TDMX 2565	THERMAL INTERFACE TECHNOLOGY	24	-	-	-	-	-	-	-	-	-
TDMX 2571	OTV/PAYLOAD INTERFACING/TRANSFER	-	-	-	98	98	-	-	-	-	-
TDMX 2574	OTV MAINTENANCE TECHNOLOGY	-	-	40	-	-	-	-	-	-	-
MAT 130	MICROGRAVITY	-	-	354	408	408	-	-	-	-	-
SPA 801	FAR INFRARED/SUBMM SPACE TEL	-	-	-	12	-	-	-	12	-	-
TDS 401	ADV TECH TEST SATELLITE	-	-	-	20	-	-	-	-	-	-
C-002	LARGE COMM ANTENNA	-	-	10	-	-	-	-	-	-	-
C-003	ADV COMM & DATA HANDLING SYS	-	-	-	-	10	-	-	-	-	-
C-004	GRAV STABILD DEPLOY ANT TEST	-	-	-	-	-	-	-	12	-	-
E-002	TEST OF SENSOR TECHNOLOGIES	-	-	-	12	-	-	-	-	-	-
E-003	OBSERV OF UPPER ATMOSPHERE	-	-	-	-	-	24	-	-	-	-
E-005	OPS FOR EARTH OBSERVATION	-	-	2	2	-	-	-	-	-	-
S-001	ASTRONOMICAL PLATFORM	-	-	-	-	14	2	2	2	2	-
S-002	INFRARED TELESCOPE IN SPACE	-	-	2	-	2	-	-	-	-	-
S-005	LINE GAMMA DETECTION	-	-	-	2	-	-	-	-	-	-
S-006	X-RAY ASTRONOMY OBSERVATION	-	-	-	-	-	24	-	-	-	-
S-008	SPACE VLBI	-	-	-	-	-	-	-	-	24	-
S-009	SOLAR ACTIVITY MONITOR	-	-	-	-	-	-	-	26	-	-
S-010	SUBMILLIMETER TELESCOPE	-	-	-	-	-	-	24	-	-	-
T-002	LARGE ANTENNA SYS TECHNOLOGY	-	-	100	-	-	-	-	-	-	-
T-007	2D-SOLAR ARRAY MISSION	-	-	16	-	-	-	-	-	-	-
T-009	LIQUID PROPELLANT HANDLING	-	8	8	-	-	-	-	-	-	-
SAAX 4002	POLCATS	8	8	8	8	8	8	8	8	8	8
SAAX 4004	LONG BAS LINE ARRAY	4	-	-	-	-	-	-	-	-	-
SAAX 4006	UV ATMOSPHERIC LIMB SCANNER	16	16	16	-	-	-	-	-	-	-
TDMX 4006	SPACE STRUCTURES	40	6	6	-	-	-	-	-	-	-
	TOTAL	992	846	2940	2198	2638	2216	3072	1762	2090	1640

TABLE C-5

FIRMNESS AND MATURITY
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	FIRMNESS	MATURITY
USA			
SAAX 0004	SIRTF PLATFORM MISSION	3	4
SAAX 0005	TRANS. RAD & ION CAL	4	5
SAAX 0006	STARLAB	3	5
SAAX 0007	HI THROUGHPUT MISSION SERV	4	5
SAAX 0008	HIGH ENERGY ISO EXP	4	4
SAAX 0011	ASO II/POF + SOT	3	4
SAAX 0012	HUBBLE SPACE TEL SERV	2	4
SAAX 0013	GAMMA RAY OBSER SERV	2	4
SAAX 0016	SOLAR MAX MISSION SERV	1	5
SAAX 0017	AXAF SERVICING	3	4
SAAX 0020	LARGE DEPLOY REFLECTOR	3	4
SAAX 0021	SUPER COND MAG FAC	4	4
SAAX 0202	EARTH OBSER SYS.	3	3
SAAX 0208	MOD RES IMAG SPECT	3	3
SAAX 0209	HIGH RES IMAG SPECT	3	3
SAAX 0210	HI RES MULTI MW RAD	3	3
SAAX 0211	LASER ATMO SOUNDER & ALT	1	3
SAAX 0212	SYNTHETIC APER RADAR	3	3
SAAX 0213	ALTIMETER	3	3
SAAX 0214	SCATTEROMETER	3	3
SAAX 0215	CORRELATION RADIOMETER	3	3
SAAX 0216	EARTH RAD BUDGET EXP	3	3
SAAX 0219	ENVIRONMENTAL MONITORS	3	3
SAAX 0220	AUTOMATED DATA COLLECT	3	3
SAAX 0221	LARGE MICROWAVE ANTENNA	3	3
SAAX 0222	INFRARED SOUNDING	3	3
SAAX 0223	LARGE IMAGER	3	3
SAAX 0225	SOLAR TERRES POLAR PLAT	4	3
SAAX 0227	CONTAINED PLASMA EXP	4	3
SAAX 0228	THERMAL IR MAPPING SPECT	3	3
SAAX 0229	CRYOGENIC INTERFER/SPECT	3	3
SAAX 0230	FABRY PEROT INTERFEROMETER	3	3
SAAX 0231	VIS/UV SPECTOMETER	3	3
SAAX 0232	MICROWAVE LIMB SOUNDER	3	3
SAAX 0233	SUBMILLIMETER SPECT	3	3
SAAX 0234	INTERFEROMETER/SPECT/UPPER ATM	3	3
SAAX 0235	UPPER ATM IR RADIOMETER	3	3
SAAX 0236	DOPLER LIDAR	3	3
SAAX 0237	DIFFERENTIAL ABSORP LIDAR	3	3
SAAX 0238	NADIR CLIMATE INTERFER/SPECT	3	3
SAAX 0306	CELSS PALLET	4	4
SAAX 0309	SETI GEO ANTENNA MISSION	4	4
SAAX 0402	MICRO G VARIABLE "G" FREE FLYER	3	4
SAAX 0501	EXP GEO PLATFORM	3	4
SAAX 0502	SPACE BASED ANTENNA TEST RANGE	4	2

TABLE C-5

FIRMNESS AND MATURITY
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	FIRMNESS	MATURITY
COMM 1304	OMV/TMS	3	3
COMM 1309	ORBITAL TRANSFER VEHICLE	3	4
TDMX 2011	SPACECRAFT MATERIALS & COATINGS	4	5
TDMX 2022	GROWTH OF COND SEMICOND CRYSTALS	4	4
TDMX 2061	LARGE SPACE STRUCTURES	4	3
TDMX 2062	SPACE STATION MODIFICATIONS	4	3
TDMX 2063	ON ORBIT SPACECRAFT ASSY/TEST	4	4
TDMX 2064	ADVANCED ANT ASSY/PERFORM	4	3
TDMX 2071	FLIGHT DYNAMICS IDENTIFACTION	4	4
TDMX 2072	S/C STRAIN AND ACOUSTIC SENSORS	4	4
TDMX 2111	DEPLOY & TEST LARGE SOLAR CONCEN	4	3
TDMX 2121	TEST SOLAR PUMPED LASER	4	4
TDMX 2122	LASER-ELECTRIC ENERGY CONVERSION	4	5
TDMX 2132	ADVANCED RADIATOR CONCEPTS	4	5
TDMX 2152	LARGE SPACE POWER SYSTEMS	4	4
TDMX 2153	SOLAR DYNAMIC POWER	4	3
TDMX 2211	MULTI FTN SPACE ANTENNA RNG TECH	4	3
TDMX 2212	MULTI ANTENNA BEAM PATTERNS	4	3
TDMX 2213	MULTI FREQUENCY ANTENNA TECH	4	4
TDMX 2221	LASER COMM & TRACKING DEVELOP	4	4
TDMX 2224	DEEP SPACE OPTICAL DSN TERMINAL	4	4
TDMX 2261	SENSOR SYSTEMS TECHNOLOGY	4	3
TDMX 2263	CO2 LIDAR WIND AND TRACE GASES	4	4
TDMX 2265	SATELLITE DOPPLER METEROL RADAR	4	3
TDMX 2311	LONG TERM CRYO FLUID STORAGE	4	2
TDMX 2322	LASER PROPULSION	4	4
TDMX 2411	ADVANCED ADAPTIVE CONTROL	4	4
TDMX 2412	DISTRIBUTED ADAPTIVE CONTROL	4	4
TDMX 2413	DYNAMIC DISTURBANCE CONTROL	4	4
TDMX 2421	ACTIVE OPTIC TECHNOLOGY	4	2
TDMX 2431	ADVANCED CONTROL DEVICE TECH	4	4
TDMX 2441	GUIDED WAVE OPTICS DATA SYS EXP	4	5
TDMX 2461	STRUCT ASSEMBLY W/TELEOPERATOR	4	3
TDMX 2462	TELEOPERATOR SENSOR EVAL & TEST	4	4
TDMX 2511	SPACE POWER SYS ENVIRO INT	4	4
TDMX 2542	TETHERED CONSTELLATION	4	4
TDMX 2543	TETHERED TRANSPORTATION	4	3
TDMX 2544	TETHERED FLUID STOWAGE TRANSFER	4	3
TDMX 2561	SATELLITE SERVICING & REFURB	4	3
TDMX 2562	SATELLITE MAINTENANCE & REPAIR	4	3
TDMX 2563	MATERIALS RESUPPLY	4	2
TDMX 2565	THERMAL INTERFACE TECHNOLOGY	4	4
TDMX 2571	OTV/PAYLOAD INTERFACING/TRANSFER	4	2
TDMX 2574	OTV MAINTENANCE TECHNOLOGY	4	3

TABLE C-5

FIRMNESS AND MATURITY
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	FIRMNESS	MATURITY
ESA			
MAT 130	MICROGRAVITY	4	2
SPA 801	FAR INFRARED/SUBMM SPACE TELE	4	2
TOS 401	ADV TECH TEST SATELLITE	4	2
JAPAN			
C-002	LARGE COMM ANTENNA	4	3
C-003	ADV COMM & DATA HANDLING SYS	4	4
C-004	GRAV STABILD DEPLOY ANT TEST	4	3
E-001	LASER RANGING SYSTEM	4	4
E-002	TEST OF SENSOR TECHNOLOGIES	4	4
E-003	OBSERV OF UPPER ATMOSPHERE	4	4
E-005	DPS FOR EARTH OBSERVATION	4	4
S-001	ASTRONOMICAL PLATFORM	4	3
S-002	INFRARED TELESCOPE IN SPACE	4	3
S-005	LINE GAMMA DETECTION	4	4
S-006	X-RAY ASTRONOMY OBSERVATION	4	2
S-008	SPACE VLBI	4	3
S-009	SOLAR ACTIVITY MONITOR	4	2
S-010	SUBMILLIMETER TELESCOPE	4	3
T-002	LARGE ANTENNA SYS TECHNOLOGY	4	3
T-007	2D-SOLAR ARRAY MISSION	4	3
T-009	LIQUID PROPELLANT HANDLING	4	3
CANADA			
SAAX 4002	POLCATS	4	4
SAAX 4004	LONG BAS LINE ARRAY	5	3
SAAX 4006	UV ATMOSPHERIC LIMB SCANNER	3	4
TDMX 4006	SPACE STRUCTURES	5	4
NOAA			
NOAA 0001	GEO SYNTHETIC APERTURE RADAR	3	3
NOAA 0002	SEA SYNTHETIC APERTURE RADAR	3	3
NOAA 0003	MULTISPECTRAL LINEAR ARRAY	1	3
NOAA 0004	SEARCH AND RESCUE	1	3
NOAA 0005	SPACE ENVIRONMENT MONITOR	1	3
NOAA 0006	ADV MICROWAVE SOUNDING UNIT	2	3
NOAA 0007	ADV MICROWAVE RADIOMETER	1	3
NOAA 0008	MED RES IMAGING RADIOMETER	3	3
NOAA 0009	RADAR ALTIMETER	1	3
NOAA 0010	ALONG TRACK SCAN RAD MICROWAVE	1	3
NOAA 0011	HIGH RES IR RADIATION SOUNDER	1	3
NOAA 0012	N-ROSS SCATTEROMETER	2	3
NOAA 0013	SPECIAL SENSOR MICROWAVE IMAGING	1	3
NOAA 0014	DATA COLLECTION SYSTEM	1	3
NOAA 0015	SPACE ENVIRONMENT MONITOR	1	3
NOAA 0016	SEARCH AND RESCUE	1	3
NOAA 0017	ADV MICROWAVE SOUNDING UNIT	2	3
NOAA 0018	ADV MICROWAVE RADIOMETER	1	3
NOAA 0019	MED RES IMAGING RADIOMETER	3	3

TABLE C-5

FIRMNESS AND MATURITY
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	FIRMNESS	MATURITY
NOAA 0020	ALONG TRACK SCAN RAD MICROWAVE	1	3
NOAA 0021	HIGH RES IR RADIATION SOUNDER	1	3
NOAA 0022	RADAR ALTIMETER	1	3
NOAA 0023	N-ROSS SCATTEROMETER	2	3
NOAA 0024	SPECIAL SENSOR MICROWAVE IMAGING	1	3
NOAA 0025	DATA COLLECTION SYSTEM	1	3
NOAA 0026	GLOBAL OZONE MONITORING RADIOM	3	3
NOAA 0027	EARTH RADIATION BUDGET SENSOR	1	3
NOAA 0028	OCEAN COLOR IMAGER	1	3

FIRMNESS
1. OPERATIONAL
2. APPROVED
3. PLANNED
4. CANDIDATE
5. OPPORTUNITY

MATURITY
1. NEEDS DEVELOPMENT-HIGH RISK
2. NEEDS DEVELOPMENT-MODERATE RISK
3. NEEDS DEVELOPMENT-LOW RISK
4. STATE OF THE ART
5. WELL WITHIN CURRENT CAPABILITY

TABLE C-6

TYPES OF MANEUVERING
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

ORIGINAL PAGE IS
OF POOR QUALITY

MISSIONS	PAYLOAD NAME	MANEUVERING EEU	RMS	TUG
USA				
SAAX 0004	SIRTF PLATFORM MISSION	C	+	+
SAAX 0005	TRANS. RAD & ION CAL	C	+	–
SAAX 0006	STARLAB	–	+	C
SAAX 0007	HI THROUGHPUT MISSION SERV	–	+	C
SAAX 0008	HIGH ENERGY ISO EXP	?	+	–
SAAX 0011	ASO II/POF + SOT	–	C	–
SAAX 0012	HUBBLE SPACE TEL SERV	–	+	C
SAAX 0013	GAMMA RAY OBSER SERV	–	+	C
SAAX 0016	SOLAR MAX MISSION SERV	–	+	–
SAAX 0017	AXAF SERVICING	–	+	–
SAAX 0020	LARGE DEPLOY REFLECTOR	C	+	–
SAAX 0021	SUPER COND MAG FAC	C	+	–
SAAX 0202	EARTH OBSER SYS.	–	C	–
SAAX 0208	MOD RES IMAG SPECT	–	C	–
SAAX 0209	HIGH RES IMAG SPECT	–	C	–
SAAX 0210	HI RES MULTI MW RAD	–	C	–
SAAX 0211	LASER ATMO SOUNDER & ALT	–	C	–
SAAX 0212	SYNTHETIC APER RADAR	–	C	–
SAAX 0213	ALTIMETER	–	C	–
SAAX 0214	SCATTEROMETER	–	C	–
SAAX 0215	CORRELATION RADIOMETER	–	C	–
SAAX 0216	EARTH RAD BUDGET EXP	–	C	–
SAAX 0219	ENVIRONMENTAL MONITORS	–	C	–
SAAX 0220	AUTOMATED DATA COLLECT	–	C	–
SAAX 0221	LARGE MICROWAVE ANTENNA	–	?	–
SAAX 0222	INFRARED SOUNDING	–	–	–
SAAX 0223	LARGE IMAGER	–	–	–
SAAX 0225	SOLAR TERRES POLAR PLAT	–	–	–
SAAX 0227	CONTAINED PLASMA EXP	C	+	–
SAAX 0228	THERMAL IR MAPPING SPECT	–	–	–
SAAX 0229	CRYOGENIC INTERFER/SPECT	–	–	–
SAAX 0230	FABRY PEROT INTERFEROMETER	–	–	–
SAAX 0231	VIS/UV SPECTOMETER	–	–	–
SAAX 0232	MICROWAVE LIMB SOUNDER	–	–	–
SAAX 0233	SUBMILLIMETER SPECT	–	–	–
SAAX 0234	INTERFEROMETER/SPECT/UPPER ATM	–	–	–
SAAX 0235	UPPER ATM IR RADIOMETER	–	–	–
SAAX 0236	DOPLER LIDAR	–	–	–
SAAX 0237	DIFFERENTIAL ABSORP LIDAR	–	–	–
SAAX 0238	NADIR CLIMATE INTERFER/SPECT	–	–	–
SAAX 0306	CELSS PALLET	C	C	–
SAAX 0309	SETI GEO ANTENNA MISSION	C	C	–
SAAX 0402	MICRO G VARIABLE "G" FREE FLYER	C	+	C
SAAX 0501	EXP GEO PLATFORM	–	+	C
SAAX 0502	SPACE BASED ANTENNA TEST RANGE	C	?	C

TABLE C-6

TYPES OF MANEUVERING
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	MANEUVERING EEU	RMS	TUG
COMM 1304	OMV/TMS	-	C	-
COMM 1309	ORBITAL TRANSFER VEHICLE	-	C	-
TDMX 2011	SPACECRAFT MATERIALS & COATINGS	-	-	-
TDMX 2022	GROWTH OF COND SEMICOND CRYSTALS	+	-	-
TDMX 2061	LARGE SPACE STRUCTURES	-	-	-
TDMX 2062	SPACE STATION MODIFICATIONS	-	-	C
TDMX 2063	ON ORBIT SPACECRAFT ASSY/TEST	-	-	C
TDMX 2064	ADVANCED ANT ASSY/PERFORM	C	-	-
TDMX 2071	FLIGHT DYNAMICS IDENTIFACTION	-	-	-
TDMX 2072	S/C STRAIN AND ACOUSTIC SENSORS	-	-	-
TDMX 2111	DEPLOY & TEST LARGE SOLAR CONCEN	C	-	-
TDMX 2121	TEST SOLAR PUMPED LASER	C	-	-
TDMX 2122	LASER-ELECTRIC ENERGY CONVERSION	-	-	-
TDMX 2132	ADVANCED RADIATOR CONCEPTS	C	-	-
TDMX 2152	LARGE SPACE POWER SYSTEMS	-	-	C
TDMX 2153	SOLAR DYNAMIC POWER	-	-	?
TDMX 2211	MULTI FTN SPACE ANTENNA RNG TECH	-	-	C
TDMX 2212	MULTI ANTENNA BEAM PATTERNS	C	-	-
TDMX 2213	MULTI FREQUENCY ANTENNA TECH	C	-	-
TDMX 2221	LASER COMM & TRACKING DEVELOP	-	-	-
TDMX 2224	DEEP SPACE OPTICAL DSN TERMINAL	-	-	-
TDMX 2261	SENSOR SYSTEMS TECHNOLOGY	-	-	-
TDMX 2263	CO2 LIDAR WIND AND TRACE GASES	-	-	-
TDMX 2265	SATELLITE DOPPLER METEROL RADAR	-	-	-
TDMX 2311	LONG TERM CRYO FLUID STORAGE	-	-	-
TDMX 2322	LASER PROPULSION	-	-	-
TDMX 2411	ADVANCED ADAPTIVE CONTROL	-	-	-
TDMX 2412	DISTRIBUTED ADAPTIVE CONTROL	-	-	-
TDMX 2413	DYNAMIC DISTURBANCE CONTROL	-	-	-
TDMX 2421	ACTIVE OPTIC TECHNOLOGY	C	-	-
TDMX 2431	ADVANCED CONTROL DEVICE TECH	-	-	?
TDMX 2441	GUIDED WAVE OPTICS DATA SYS EXP	-	-	-
TDMX 2461	STRUCT ASSEMBLY W/TELEOPERATOR	-	-	-
TDMX 2462	TELEOPERATOR SENSOR EVAL & TEST	-	-	-
TDMX 2511	SPACE POWER SYS ENVIRO INT	?	-	-
TDMX 2542	TETHERED CONSTELLATION	-	-	-
TDMX 2543	TETHERED TRANSPORTATION	-	-	-
TDMX 2544	TETHERED FLUID STOWAGE TRANSFER	-	-	-
TDMX 2561	SATELLITE SERVICING & REFURB	?	-	?
TDMX 2562	SATELLITE MAINTENANCE & REPAIR	-	-	C
TDMX 2563	MATERIALS RESUPPLY	C	-	-
TDMX 2565	THERMAL INTERFACE TECHNOLOGY	-	-	-
TDMX 2571	OTV/PAYLOAD INTERFACING/TRANSFER	-	-	?
TDMX 2574	OTV MAINTENANCE TECHNOLOGY	-	-	?

TABLE C-6

TYPES OF MANEUVERING
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	MANEUVERING EEU	RMS	TUG
ESA				
MAT 130	MICROGRAVITY	C	?	+
SPA 801	FAR INFRARED/SUBMM SPACE TELE	–	+	–
TOS 401	ADV TECH TEST SATELLITE	–	C	–
JAPAN				
C-002	LARGE COMM ANTENNA	C	–	–
C-003	ADV COMM & DATA HANDLING SYS	–	–	–
C-004	GRAV STABILD DEPLOY ANT TEST	–	–	C
E-001	LASER RANGING SYSTEM	–	–	C
E-002	TEST OF SENSOR TECHNOLOGIES	–	–	–
E-003	OBSERV OF UPPER ATMOSPHERE	C	–	–
E-005	DPS FOR EARTH OBSERVATION	–	–	–
S-001	ASTRONOMICAL PLATFORM	–	–	+
S-002	INFRARED TELESCOPE IN SPACE	–	–	–
S-005	LINE GAMMA DETECTION	–	–	–
S-006	X-RAY ASTRONOMY OBSERVATION	–	–	–
S-008	SPACE VLBI	–	–	–
S-009	SOLAR ACTIVITY MONITOR	–	–	–
S-010	SUBMILLIMETER TELESCOPE	–	–	–
T-002	LARGE ANTENNA SYS TECHNOLOGY	–	–	–
T-007	2D-SOLAR ARRAY MISSION	–	–	–
T-009	LIQUID PROPELLANT HANDLING	–	–	–
CANADA				
SAAX 4002	POLCATS	–	+	–
SAAX 4004	LONG BAS LINE ARRAY	C	C	–
SAAX 4006	UV ATMOSPHERIC LIMB SCANNER	–	C	–
TDMX 4006	SPACE STRUCTURES	C	C	–
NOAA				
NOAA 0001	GEO SYNTHETIC APERTURE RADAR	–	–	–
NOAA 0002	SEA SYNTHETIC APERTURE RADAR	–	–	–
NOAA 0003	MULTISPECTRAL LINEAR ARRAY	–	–	–
NOAA 0004	SEARCH AND RESCUE	–	–	–
NOAA 0005	SPACE ENVIRONMENT MONITOR	–	–	–
NOAA 0006	ADV MICROWAVE SOUNDING UNIT	–	–	–
NOAA 0007	ADV MICROWAVE RADIOMETER	–	–	–
NOAA 0008	MED RES IMAGING RADIOMETER	–	–	–
NOAA 0009	RADAR ALTIMETER	–	–	–
NOAA 0010	ALONG TRACK SCAN RAD MICROWAVE	–	–	–
NOAA 0011	HIGH RES IR RADIATION SOUNDER	–	–	–
NOAA 0012	N-ROSS SCATTEROMETER	–	–	–
NOAA 0013	SPECIAL SENSOR MICROWAVE IMAGING	–	–	–
NOAA 0014	DATA COLLECTION SYSTEM	–	–	–
NOAA 0015	SPACE ENVIRONMENT MONITOR	–	–	–
NOAA 0016	SEARCH AND RESCUE	–	–	–
NOAA 0017	ADV MICROWAVE SOUNDING UNIT	–	–	–

TABLE C-6

TYPES OF MANEUVERING
MAY 1985 LANGLEY DATA BASE
BASED ON MDAC SURVEY

MISSIONS	PAYLOAD NAME	MANEUVERING EEU	RMS	TUG
NOAA 0018	ADV MICROWAVE RADIOMETER	-	-	-
NOAA 0019	MED RES IMAGING RADIOMETER	-	-	-
NOAA 0020	ALONG TRACK SCAN RAD MICROWAVE	-	-	-
NOAA 0021	HIGH RES IR RADIATION SOUNDER	-	-	-
NOAA 0022	RADAR ALTIMETER	-	-	-
NOAA 0023	N-ROSS SCATTEROMETER	-	-	-
NOAA 0024	SPECIAL SENSOR MICROWAVE IMAGING	-	-	-
NOAA 0025	DATA COLLECTION SYSTEM	-	-	-
NOAA 0026	GLOBAL OZONE MONITORING RADIOM	-	-	-
NOAA 0027	EARTH RADIATION BUDGET SENSOR	-	-	-
NOAA 0028	OCEAN COLOR IMAGER	-	-	-

KEY:
+ MUST HAVE
C CANDIDATE
? MAYBE REQUIRED
- DOES NOT REQUIRE

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS

- o SCENARIOS DEVELOPED IN THE FOLLOWING CATEGORIES
  - o EVAS FAILURES (LSS, CREW ENCLOSURE, PROPULSION SYSTEM)
  - o ENVIRONMENTAL HAZARDS
  - o HUMAN FACTORS
- o SCENARIOS ANALYZED TO DETERMINE DESIGN AND OPERATIONAL FACTORS TO BE CONSIDERED IN ORDER TO MINIMIZE THE PROBABILITY OF OCCURENCE

ACCIDENT PROFILE ANALYSES

- o EACH FAILURE SCENARIO WAS ANALYZED AS FOLLOWS:
  - o DEFINITION OF SCENARIO
  - o POTENTIAL CAUSES
  - o POTENTIAL RESULTS
  - o PREVENTIVE MEASURES (DESIGN, OPERATIONAL CONSTRAINTS)
  - o CORRECTIVE ACTIONS TO BE TAKEN
  - o LIKELIHOOD OF OCCURENCE*

* DEFINED, FOR PURPOSED OF THIS ANALYSIS, AS FOLLOWS:

0 = NOT CREDIBLE
1 = REMOTELY POSSIBLE
2 = PROBABLY WILL NOT OCCUR
3 = MAY OCCUR
4 = PROBABLY WILL OCCUR
5 = ALMOST CERTAIN TO OCCUR

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

EVA SYSTEMS FAILURES

- LIFE SUPPORT SYSTEM (LSS)
  - LSS PRESSURE NOT MAINTAINED BETWEEN LIMITS (HIGH OR LOW)
  - LOSS OF THERMAL/HUMIDITY CONTROL
  - LOSS OF DATA MANAGEMENT/COMM/DATA PROCESSING
  - LOSS OF CO_2 CONTROL
- PROPULSION SYSTEM
  - LOSS OF THRUST
  - LOSS OF CONTROL AUTHORITY
  - LOSS OF SYSTEM MONITORING CAPABILITY
- CREW ENCLOSURE SYSTEM
  - LOSS OF PRESSURE INTEGRITY
  - LOSS OF MOBILITY
  - LOSS OF PASSIVE THERMAL PROTECTION
  - LOSS OF VISIBILITY

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS-1:	EMU pressure is not maintained between limits (high or low)
Possible Causes:	Regulator shift/failure Depletion of supply O2 Loss of pressure integrity of crew enclosure (hole/tear)
Potential Results:	Hypoxia (low press. case) Decompression sickness (low press. case) O2 venting - - high use rate (high press. case) Structural failure of crew enclosure (high press. case)
Corrective Actions:	Recharge O2 tanks (primary) Activate back-up pressure control system Seek safe (pressurized) haven Relieve excess pressure
Likelihood:	3
Preventive measures:	Eliminate sharp edges Provide recharge stations in convenient locations Design redundant pressure control systems

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS-2: Loss of thermal/humidity control

Possible Causes: Saturation of heat sink
Failure of cooling loop

Potential Results: Mild discomfort
Overheating - - high 02 use rate
Loss of visibility (helmet visor fogging)
Moisture (perspiration) in ventilation loop/electronics

Corrective Actions: Minimize physical activity
Activate back-up heat sink/rejection system (purge, etc.)
Access station cooling (unbilical)

Likelihood: 4

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS-3: Loss of data management/comm/data processing

Possible Causes:
- Sensor failures
- Electrical component failure (shorts, etc.)
- Battery/power source discharge
- "Blockage" zones (comm)

Potential Results:
- Inability to communicate with other crewmembers
- Inability to monitor suit parameters
- Inability to access FDF documentation and other real-time data

Corrective Actions:
- Charge/recharge battery
- Access on external power source
- Monitor redundant sensors
- Hand signals (comm failure)
- Move to location having clear line-of-sight
- Access external comm (voice/data) connection

Likelihood: 3

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

SCENARIO # SYSTEMS-4: Inspired CO2 is not maintained within limits

POTENTIAL CAUSES:
- Saturation of CO2 removal media
- Failure of ventilation system

POTENTIAL RESULTS:
- Discomfort
- Incapacitation
- Asphyxiation

PREVENTIVE MEASURES:
- Design CO2 removal system and ventilation system with adequate safety margin/redundancy
- Limit physical workload

CORRECTIVE ACTION FOR OCCURENCE:
- Minimize physical activity
- Activate back up CO2 removal system (purge, etc.)
- Seek safe haven

LIKELIHOOD OF OCCURENCE: 4

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS- 5: Loss of propulsion system thrust (assume station maneuver to rescue not possible)

Possible Causes: Depletion of propulsion system fuel
Failure of propulsion system regulators
Total failure of propulsion system control electronics

Potential Results: Stranded crewmember with possible opening DV

Corrective Actions: EVA Rescue
Backup propulsion system activation

Likelihood: 2

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS- 6: Loss of populsion system control authority

Possible Causes: Failed on/off thrusters
Control electronics failures (failed "on"/"off" command)
Control system hardware failure (hand controller)

Potential Results: Damage to worksite equipment
Depletion of prop as a result of fighting/isolating failure
Damage to EVAS

Corrective Actions: Isolate failed on/off thruster
Use of backup thrust system
Redundant control paths

Likelihood: 4

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS- 7: Loss of propulsion system monitoring capability

Possible Causes: Loss of MMU CWS
Loss of power
Loss of sensors

Potential Results: Inability to monitor MMU status

Corrective Actions: Use of redundant sensors to monitor parameters (pressure, etc.)

Likelihood: 4

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS- 8: Loss of pressure integrity of crew enclosure

Possible Causes: Hole/tear in the crew enclosure

Potential Results:
- o Hypexia
- o Depletion of LSS O2 at a high rate
- o Decompression sickness

Preventive Measures:
- o Rip/tear puncture-resistant crew enclosure
- o Elimination of sharp edges at crew worksite
- o shielding from micrometeroids
- o Take special care around potential hazards

Corrective Actions:
- o Activation of secondary source of O2
- o "Repair" tear
- o Seek pressurized safe-haven

Likelihood: 3

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS- 9: Loss of mobility of crew enclosure

Possible Causes:
- o Mechanical (bearing or restraint) failure
- o Electrical or pneumatic failure (power-assisted joints, end effectors, etc.)

Potential Results:
- o Inability to translate to/from worksite
- o Inability to complete task
- o "Incapacitation" of crewmember

Preventive Measures: Preventive maintenance, pre-EVA checks of crew enclosure

Corrective Actions: EVA Rescue
Overpower frozen joints

Likelihood: 2

Scenario # SYSTEMS- 10: Loss of passive thermal protection afforeded the crew enclosure

Possible Causes:
- o Destruction of or damage to the thermal protection layer(s) of the crew enclosure
  - oo hot lights/sun
  - oo chemicals
  - oo tear/abrasion
- o Work in hostile thermal environments
  - oo Solar array focal points

Potential Causes: "hot spots" in the crew enclosure

Preventive Measures: Same as loss of pressure integrity

Corrective Actions:
- o Activate or increase active thermal protection from LSS
- o Don thermal gloves, blankets, protective covers
- o Get out of hostile environment

Likelihood: 4

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # SYSTEMS- 11: Loss of visibility from within crew enclosure

Possible Causes:
- o Fogging of visor or window (internal)
- o Contamination of visor or window (external)
- o (Thermally) Mechanically jammed sunshade or visor over inner visor
- o View restrictions associated with worksite

Potential Results:
- o Inability to accomplish task
- o inability to translate ("blind")

Corrective Actions:
- o Anti-fog and ventilation for internal fogging
- o Capability to wipe up dirt, chemicals, etc., which contaminate external surface
- o Tear-away visors

Likelihood: 4

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

HUMAN FACTORS-RELATED EVENTS
o ACCIDENTS INVOLVING AN INCAPACITATED OR SICK EVA CREW MEMBER
o EVA CREW MEMBER FREE-FLOATING
o EVA CREW MEMBER TRAPPED/ENTANGLED

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # HUMAN FACTORS-1: EVA Crewman becomes sick or incapacitated

Possible Causes:
- o Bends
- o Space sickness
- o High CO2/hypoxia

Potential Results:
- o Inability to reach safe haven/airlock
- o Loss of LSS functions (vomitus)

Preventive Measures: "Physical exam" prior to EVA

Corrective Actions:
- o Minimize physical activity
- o Rescue by other EVA crewmember

Likelihood: 2-3

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

SCENARIO # HUMAN FACTORS-2: EVA crewmember turns loose from Space Station

POSSIBLE CAUSES:
- Improper tether protocol
- Hardware (tether, foot restraint, etc.) failure

POTENTIAL RESULTS: Stranded crew member with possible opening delta-v with respect to SS

PREVENTIVE MEASURES:
- Lock-lock design on hardware
- Use of proper tether protocol

CORRECTIVE ACTIONS FOR OCCURENCE:
- Rescue by other EVA crew member
- "Push-off"
- MMU
- Lifeline
- Rescue by OMV/Teleoperator
- Rescue by Shuttle
- Rescur by MRMS
- "Life vest" MMU

LIKELIHOOD OF OCCURENCE: 2

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # HUMAN FACTORS-3: EVA crewmember becomes tangled or trapped

Possible Causes:
- o Exess safety tether
- o SS structure
  - oo trusses
  - oo cables/wires
  - oo "cracks and crevices"

Preventive Measures:

Corrective Actions:
- o Cut cable, wire, tethers
- o Rescue by other crewmen
- o "Pull out" using MRMS?
- o Decrease crew enclosure pressure to unwedge

Likelihood: 2

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

SPACE STATION ENVIRONMENTAL HAZARDS o RADIATION (RF, SOLAR, THERMAL, ETC.) o CHEMICAL CONTAMINATION o ELECTRICAL SYSTEMS o MECHANICAL SYSTEMS

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

SCENARIO # ENVIRONMENT-1: Exposure to dangerous levels of radiation in the SS environment (RF, thermal, solar, etc.)

POTENTIAL CAUSES:
- Inadequate UV protection in crew enclosure
- EVA crewmember crossing in front of transmitting antennas
- Solar flares

POTENTIAL RESULTS:
- Radiation sickness

PREVENTIVE MEASURES:
- Use of sun visors/UV protection in crew enclosure
- Proper shielding of antennas
- Operational constraints on use of antennas when crew member EVA
- Limit EVA during high solar activity
- Schedule EVA to avoid South Atlantic Anomaly

CORRECTIVE ACTIONS FOR OCCURENCE
- Seek safe haven/shielded area
- Medical attention

LIKELIHOOD OF OCCURENCE: 3

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # ENVIRONMENT-2: Chemical contamination in the SS environment

Potential Causes:
- o Hardware failure
  - oo leaking valves, thrusters on satellites
  - oo leaking fuel storage resovoirs
- o Operational errors
  - oo fuel transfer

Potential Results:
- o Damage to crew enclosure
- o Contamination of sensitive payloads
- o Contamination of airlock and pressurized SS environment

Preventive Measures: (design, operations)
- o Redundant valves
- o Leak detection systems (i.e., on fuel transfer umbilicals)

Corrective Action:
- o "Bake off" contaminants from crew enclosure
- o Purge airlock
- o Clear off payloads, optical surfaces, etc.

Likelihood: 3

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # ENVIRONMENT-3: Exposure of EVA crewmember to electrical hazards in the SS environment

Potential Causes:
- o Power sources in satellites being repaired
- o Static discharges
- o EVA activity in the aurural zones on night passes *
- o SS power sources and transmission time failures

Potential Results:
- o Electrical shock to crewmember
- o Loss of electronically-controlled components in LSS
- o Fire in crew enclosure

Preventive Measures:
- o Properly shield/ground power sources
- o Verify power sources safed/unpowered prior to repairs

Corrective Action:
- o Seek safe haven
- o Activate back-ups to failed components
- o Aid injured crewmember

Likelihood: 3

Table C-7
POTENTIAL EVA ACCIDENT SCENARIOS (CONTINUED)

Scenario # ENVIRONMENT-4: Exposure of EVA crewmember to mechanical hazards in SS environment

Potential Causes:
- o Run-away MRMS
- o Failure of SS structure
- o Airlock hatch problems?
- o Failure of stored mechanical energy systems (springs, flywheels, etc.)

Potential Results:
- o Damage to crew enclosure/LSS
- o Crew entrapment
- o Crew injury

Preventive Measures:
- o Design structure with factors of safety taking into account dynamics of crew activity around them (MMU, shuttle, etc.)
- o Redundant hatch sealing techniques

Corrective Action:

Likelihood:

TABLE C-8
3.2.2 TECHNOLOGY SURVEYS (SUMMARY)

SECTION	TITLE/APPROACH	LEVEL CURRENT	LEVEL IOC
3.2.2.1	HIGH PRESSURE SUIT GLOVES		
	A. SOFT GLOVES (DAVID CLARK)	6	8
	B. SOFT GLOVES (ILC)	3	8
	C. HARD GLOVES	3	8
	OTHER THAN GLOVES		
	A. VARIABLE GEOMETRY HARD SECTIONS W/BEARINGS	6	8
	B. ROLLING CONVOLUTE	6	8
	C. TOROIDAL-EXTERNAL LINKAGE	6	8
	D. TOROIDAL-INTERNAL LINKAGE	6	8
	E. SOFT JOINT TRIAXIAL MATERIAL	3	8
3.2.2.2	CONFIG PROVIDING RAPID DON/DOFF WITHOUT ASSISTANCE		
	A. DIAGONAL PLANE CLOSURE	6	8
	B. BI-PLANE CLOSURE	6	8
	C. HORIZONTAL SINGLE PLANE CLOSURE	8	
	D. REAR ENTRY CLOSURE	3	8
3.2.2.3	HIGH MOBILITY AND LONG TERM WEAR COMFORT	8	

TABLE C-8

3.2.2 TECHNOLOGY SURVEYS (SUMMARY) (CONTINUED)

SECTION	TITLE/APPROACH	LEVEL CURRENT	LEVEL IOC
3.2.2.4	IMPROVED INFORMATION/EVA DATA DISPLAY, STORAGE AND COMMAND SYSTEM		
	DISPLAY SYSTEMS		
	A. MINATURE CRT DISPLAY	5	8
	B. VISUALLY-COMPLED DISPLAYS	4	TBD
	C. AUDIO SYSTEMS	8	
	D. FIXED READOUT	7	8
	DATA STORAGE TECHNOLOGIES		
	A. BUBBLE MEMORY	5	TBD
	B. COMMAND STORAGE (READ ONLY)	8	
	C. RANDOM ACCESS	8	
	D. ROTATING MEMORIES		
	1. LASER DISK	4	TBD
	2. MAGNETIC	4	TBD
	COMMAND/CONTROL		
	A. VIRTUAL CONTROL (HAND POSITION SENSING)	2	TBD
	B. VOICE RECOGNITION	7	8
	DATA PROCESSING/INTEPRETATION TECHNOLOGIES		
	A. AUTOMATED CHECKLISTS	8	
	B. DIAGNOSIS/REPAIR PROCEDURES	8	
	C. EXPERT SYSTEMS	6	8
3.2.2.5	HARD STRUCTURE THERMAL INSULATION		
	A. OVERGARMENT	3	8
	B. GOLD COATING	3	8
	C. ALUMINUM COATING	3	8
3.2.2.6	ON ORBIT MAINTENANCE, SERVICE, REPAIR AND REPLACEMENT		
	A. CREW ENCLOSURE	6	8
	B. LIFE SUPPORT SYSTEM		
	REGENERABLES REPLACEMENT	8	
	SCHEDULED REPLACEMENT OF LIMITED LIFE ITEMS	4	8
	UNSCHEDULED REPLACEMENT OF LONG LIFE ITEMS	4	8
	CHANGE OUT OF ENTIRE LSS	4	8
	C. PROPULSION SYSTEM	1	8

TABLE C-8
3.2.2 TECHNOLOGY SURVEYS (SUMMARY) (CONTINUED)

SECTION	TITLE/APPROACH	LEVEL CURRENT	LEVEL IOC
3.2.2.7	ON ORBIT FIT CHECK/RESIZING	6	8
3.2.2.8	AUTOMATIC SERVICE AND CHECKOUT		
	EMU		
	CREW ENCLOSURE		
	CLEANING/STERILIZATION		
	A. MANUAL WIPING OF INTERIOR SURFACES	8	
	B. STEAM CLEANING	4	8
	DRYING		
	A. MANUAL DRYING OF INTERIOR SURFACES	8	
	B. FLEXIBLE DUCT	4	
	C. SAME AS B EXCEPT VENT TUBES INTEGRAL TO CREW ENCLOSURE	1	TBD
	LIFE SUPPORT SYSTEM		
	RECHARGE		
	OXYGEN (GASEOUS)	4	8
	OXYGEN (LIQUID)	3	8
	ENERGY STORAGE		
	BATTERY	8	
	FLY WHEEL	2	4
	AUTO CHECKOUT	4	8
	PROPULSION SYSTEM		
	BATTERY RECHARGE	8	
	PROPELLANT RECHARGE	4	8
	CHECKOUT	2	8

TABLE C-8
3.2.2 TECHNOLOGY SURVEYS (SUMMARY) (CONTINUED)

SECTION	TITLE/APPROACH	LEVEL CURRENT	LEVEL IOC
3.2.2.9	AUTOMATIC THERMAL CONTROL		
	A. THERMOSTATIC BYPASS OF COOLANT FLOW AROUND HEAT SINK USING REGULATION METHODS METHODS BELOW		
	B. VARIABLE SPEED COOLANT PUMP USING REGULATION METHODS BELOW		
	METHOD 1: CM SELECTS DESIRED LCG INLET TEMP CONTROL SETPOINT	4	8
	METHOD 2: SAME AS METHOD 1 EXCEPT CONTROL SETPOINT AUTOMA- TICALLY VARIES TO MAINTAIN COMFORT AS METABOLIC LOAD CHANGES	2	8
	C. VARIABLE THERMOELECTRIC LIFT BETWEEN LIQUID COOLANT LOOP AND HEAT SINK	2	8
3.2.2.10	CONTROLLED EFFLUENT EMU		
	A. THERMOELECTRIC ICE CHEST COUPLED VIA A VAPOR CYCLE TO A RADIATOR	2	8
	B. THERMOELECTRICALLY PUMPED LIQUID LOOP TO INTEGRATED, HIGH TEMPERATURE HEAT SINK AND RADIATOR	2	8

TABLE C-8
3.2.2 TECHNOLOGY SURVEYS (SUMMARY) (CONTINUED)

SECTION	TITLE/APPROACH	LEVEL CURRENT	LEVEL IOC
3.2.2.11	BASICALLY REGENERABLE EMU		
	HUMIDITY		
	A. CONDENSATION		
	METHOD 1: EXISTING HEAT SINK	8	
	METHOD 2: LOCAL HEAT SINK	1	1
	METHOD 3: COMPRESSION / EXPANSION	2	TBD
	B. ABSORPTION		
	METHOD 1: SILICA GEL	4	4
	METHOD 2: MOLECULAR SIEVES	8	
	METHOD 3: CHEMICAL (ETHYLENE GLYCOL)	4	5
	CO2		
	LIQUID SORBENTS		
	A. POTASSIUM CARBONATE	4	8
	B. CESIUM CARBONATE	4	8
	C. TETRA METHYL AMMONIUM CARBONATE	1	8
	D. ALKAZID M	3	8
	SOLID SORBENTS		
	A. SOLID AMINE, WATER	4	8
	B. SILVER OXIDE	3	8
	C. MAGNESIUM OXIDE	1	8
	D. ZINC OXIDE	2	8
	ELECTROCHEMICAL REMOVAL	2	2
3.2.2.12	MECHANICAL END-EFFECTOR	SEE MDAC IR&D	
3.2.2.13	GENERIC WORKSTATION		
	A. SHUTTLE MANIPULATOR FOOT RESTRAINT	8	
	B. ATTACH SHUTTLE PORTABLE FOOT RESTRAINT	8	
	C. HAMILTON STANDARD GENERIC WORK STATION	3	8
	D. VOUGHT MANEUVERING WORK PLATFORM	1	1
3.2.2.14	MMU CAUTION/WARNING SYSTEM WITH EMU INTERFACE		
	A. OPTICAL DATA LINK	5	8
	B. RADIO FREQUENCY LINK	4	8
	C. HARDWARE LINK	4	8

3.2.4.1.21 Medical Care. This section will address the medical conditions induced by or associated with EVA and will identify the facilities, equipment, and procedures required for their prevention, diagnosis, and treatment.

Medical Conditions Associated with EVA

Medical conditions that occur as a direct result of a crewman's involvement in EVA include the following:

A. Barotrauma - A condition which results from an expansion of gases trapped within a body cavity or unequal pressures across a tissue, produced by a significant pressure change in the crewman's environment. In the EVA situation, barotrauma would most likely occur when the pressure ambient to an EVA crewman is being reduced from cabin pressure (e.g., 14.7 psia) to EMU pressure (e.g. 43 psia) within the space station airlock; or in the reverse situation, increasing from EMU pressure to cabin pressure, also in the airlock. The most common locations of barotrauma include:

(1) Middle ear - The occurrance of middle ear barotrauma is almost completely restricted to increases in ambient pressure such as that which an EVA crewman would encounter when repressurizing from suit to cabin pressure in the airlock. Although cases have been reported which resulted from decreases in ambient pressure, these must be considered rare. Barotrauma of the middle ear may also occur in a delayed form, resulting from the reabsorption of O_2 from the middle ear some hours following prolonged breathing of 100% O_2 by a crewman.

(2) Sinuses - Sinus barotrauma results from a pressure differential between the inside and outside of a sinus cavity. Similar to but less common than middle ear barotrauma, sinus barotrauma may occur during either reductions or increases in ambient pressure but is more common during an increase. This condition can also be manifested in a delayed form.

(3) Alimentary Tract - Gases trapped within the stomach, large, or small intestine may expand and produce abdominal pain during reductions in ambient pressure.

(4) Other sites of barotrauma are significantly less common that the three identified above and may include air pockets in filled teeth and pulmonary blebs. These may usually be eliminated as potential sites by appropriate crew selection.

B. Evolved Gas Dysbarism - This condition is characterized by the formation of gas bubbles in the blood and tissue fluids. These bubbles result from nitrogen or other diluent gases in the crewman's breathing mixture. These biologically inert gases are dissolved in body fluids under normal cabin pressures and tend to come out of solution when the ambient pressure is sufficiently reduced. Various types of evolved gas dysbarism have been described relative to the location and severity of bubble formation. These include:

(1) Joint and Limb Pains (Type I Decompression Sickness) - More commonly referred to as "Bends", these pains are the most frequently observed manifestation of evolved gas dysbarism. Pain can range from a mild feeling of stiffness in the joint to a severe, debilitating distress. Grades of bends from I to IV have been defined for more easily assessing the severity of the symptoms.

(2) Pulmonary Disturbances (Type II Decompression Sickness) - Symptoms for this condition, also termed "Chokes", include substernal distress, a dry cough, and a restricted inspiratory capacity, are thought to result from irritation of pulmonary tissue when gas emboli cause obstruction of pulmonary arterioles and capillaries. Chokes must be considered a dangerous condition which may lead to neurocirculatory collapse.

(3) Central Nervous System Disturbances (Type III Decompression Sickness) - Central nervous system disturbances are manifested as visual field defects, disturbances of equilibrium and coordination, weakness of arm or leg, numbness, tingling, paralysis, disorientation, amnesia, dizziness, nausea, headache, and other general neurological symptoms.

There is a consensus that the occurrence of bubbles causing ischemic hypoxia is the actual mechanism. Central nervous system disturbances are viewed as serious symptoms.

(4) Skin Disturbances - Symptoms in this category include rashes, mottling, paraesthesia, and edema. Such disturbances most frequently occur in association with joint pains and probably signify the presence of gas emboli in vessels of the subcutaneous tissues, or an effect on the autonomic nervous system, or both. Although skin disturbances are usually not painful and do not appear as a threat to the patient, they should be considered dangerous symptoms.

C. Gas Embolism - Gas embolism is caused by the expansion of gas which has been taken into the lungs while breathing under a pressure and held in the lungs during a reduction in the ambient pressure. If enough gas is held, and if it expands sufficiently, the pressure will tend to force the gas through the alveolar walls and into the bloodstream and surrounding tissues. These gas bubbles may lodge in the arteries to the brain, cutting off blood circulation and producing convulsions, loss of consciousness, and, if not treated promptly, death. Gas embolism is a significant hazard in diving; it's occurrence in association with EVA operations should, however, be rare. Operations tending to expose a crewman to the danger of gas embolism include the following.

(1) EMU Pressure Tests in the Airlock - A pressure/leak check of the EMU after it has been donned and prior to reduction of airlock pressure will expose the crewman to the EMU pressure some 4.3 or more higher than airlock pressure. A sudden reduction in EMU pressure, such as that which may result from the loss of a glove, could produce air embolism if the crewman inadvertently held his breath during the transition from suit to airlock pressure.

(2) Loss of Suit Pressure During EVA - A sudden, catastrophic loss of suit pressure during EVA could potentially produce gas embolism in reducing the crewman's ambient pressure from EMU pressure to zero. In this situation, the greatest threat to the crewman's survival would, of

course, be exposure to vacuum rather than the development of gas embolism.

D. Conditions Resulting from Inadequate Environmental Control - Hypoxia, hypercapnia, hyperthermia and hypothermia are potential conditions that could potentially result from malfunctions or inadequate capabilities of the EMU environmental control system. These conditions have been addressed in Sections 3.2.4.1.6, 3.2.4.1.7, and 3.2.4.1.8 and will not be further discussed in this section.

E. Mechanical Trauma - Injuries, such as fractures, sprains, dislocations, and crushing injuries, suffered as a result of EVA accidents will require medical care. Rescue of an injured EVA crewman was discussed in Section 3.2.4.2.8 and rescue equipment requirements will be discussed in Section 3.2.4.3.9. Following rescue of the crewman and removal of the EMU, mechanical trauma resulting from EVA will be treated in an identical manner to that resulting from injuries resulting from intravehicular operations.

F. Oxygen Toxicity - This condition can result from the inhalation of oxygen at higher than normal partial pressures. The inspired gas may be pure oxygen or a gas mixture containing oxygen. The two most important factors which determine whether oxygen toxicity will occur are the magnitude of the oxygen partial pressure and the length of time that the gas is inhaled. As the oxygen pressure is increased, the permissible time of exposure is shortened. There are two forms of oxygentoxicity, a central nervous system (CNS) form which is manifest most commonly by convulsions, and a pulmonary form which is manifest by substernal distress, coughing, and breathing difficulty. CNS toxicity will usually require oxygen pressures about 1.5 atmospheres and will, consequently, be encountered in space only during hyperbaric treatment. At 2.8ATA, for example, the early signs of CNS involvement (facial twitching) will appear in about 30 minutes in persons breathing 100% O_2. Convulsions will usually occur shortly thereafter. For this reason, the inhalation of pure oxygen during hyperbaric treatment is limited to periods of 20 minutes duration, with 5 minute intervals of breathing chamber air between successive periods. CNS effects are not of concern at operational suit pressures and for practicable exposure times and symptoms of pulmonary oxygen toxicity will probably not be manifest at suit pressures anticipated for Space Station for periods up to six or seven hours a day, three days a week.

Health Maintenance Considerations for EVA - Associated Medical Conditions

The capabilities and approaches required for the prevention, diagnosis, and treatment of the various medical conditions, identified above, associated with EVA operations are addressed in this section.

A. Barotrauma

(1) Middle Ear Barotrauma

a. Prevention

- Selection of personnel with demonstrated ability to perform Valsalva maneuver with ease.
- Training in the performance of the "Valsalva" maneuver for middle ear repressurization.
- Avoidance of EVA operations by crewmen with upper respiratory infections.
- Use of nasal decongestants prior to EVA, when needed.
- Removal of EMU helmet in airlock during repressurization at approximately 10 psia in order to permit middle ear pressurization maneuvers to be conducted more easily.

b. Diagnosis

- Subjective report of symptoms of ear fullness or pain by the EVA crewman.
- Examination of tympanic membrane with otoscope

c. Treatment

- Assist/encourage crewman in "ear clearing" techniques (e.g., Valsalva maneuver, swallowing)
- Use of politzer bag (introduce pressure through nostril while patient is swallowing a sip of water)

- Use of airlock - reduce pressure until middle ear pressure equalizes, carefully return to normal cabin pressure, use pressure equalization procedures assisted by medical crewman

(2) Sinus Barotrauma

a. Prevention

- Judicious selection of crewmen without sinus abnormalities
- Abstaining from EVA during chronic or acute upper respiratory infections
- Use of nasal decongestants prior to EVA, as required

b. Diagnosis

- Complaint of pain in EVA crewman
- Identification of tenderness on pressure over frontal sinuses or over an antrum
- Radiological imaging of sinuses
- Relief of pain upon ascent in airlock

c. Treatment

- Use of nasal decongestants
- Ascent in airlock and treatment with decongestants
- Sinus lavage

(3) Delayed Middle Ear Barotrauma (O_2 absorption)

a. Prevention

- Use of diluent gas in EMU PLSS
- Removal of EMU helmet in airlock at approximately 10 psi during return to cabin pressure (14.7 psi). Middle ear will then be repressurized with O_2-N_2 mixture rather than pure O_2
- Frequent clearing of middle ear after return to cabin pressure to replace high O_2 concentrations in middle ear with air.

b. Diagnosis

- Same as that described in middle ear barotrauma

c. Treatment

- Same as that described in middle ear barotrauma

(4) Abdominal Barotrauma

a. Prevention

- Judicious dietary practices prior to EVA

b. Diagnosis

- Complaint of abdominal pain during airlock pressure reduction

c. Treatment

- Abdominal massage

B. Evolved Gas Dysbarism

(1) Joint and Limb Pains (Type I Decompression Sickness)

a. Prevention

1. Do not exceed on R value of 1.22 for EVA
   - Establish an EMU pressure high enough to achieve the required R value, or
   - Prebreathe sufficiently long to achieve the required R value
   - Equilibrate at a lower cabin pressure, low enough to produce the required R value

$$(R = P_o/P_{EMU})$$

where

P_o = tissue nitrogen pressure at initiation of EVA

P_{EMU} = EMU pressure

NOTE: An R value of 1.4, while not preventing bends, is currently considered to reduce the risk of bends to an acceptable level.

b. Diagnosis

- Subjective reports of joint pains during EVA
- Alleviation of pain upon return to cabin pressure
- Alleviation of pain upon inflation of pressure cuff over painful area
- Detection of bubbles in blood stream with doppler bubble detector

c. Treatment

1. Repressurization to normal cabin pressure
   - Terminate EVA mission and return crewman to the Space Station following initial report of joint or limb pains.
   - Immediately repressurize airlock to cabin pressure
   - If pain clears within 10 minutes of repressurization, place crewman on 100% O_2 by mask for two hours, follow this by 24 hours of close observation, and prohibit EVA or exercise for 72 hours
   - If pain persists after 10 minutes at cabin pressure, treat in hyperbaric treatment facility.

2. Hyperbaric treatment
   - Place crewman (patient) and medical observer in hyperbaric treatment facility (chamber)
   - Place patient on 100% oxygen by mask and medical observer on chamber air
   - Pressurize chamber to the pressure equivalent to 60 feet of sea water (approximately 2.8 ATA)
   - If pain clears within 10 minutes at 2.8 ATA, continue to treat in accordance with "Air Force Treatment Table 5", shown in Figure 3.2.4.1.21-1
   - If pain persists after 10 minutes at 2.8 ATA, continue to treat in accordance with schedule used for Type II decompression sickness.

2. Type II Decompression Sickness (CNS symptoms, pulmonary symptoms, collapse)

   a. Prevention
      - Utilize preventative procedures identical to those used for the prevention of Type I bends, joint and limb pains

   b. Diagnosis
      - Subjective reports of symptoms characteristic of Type II disturbances particularly when coupled with complaints of joint or limb pains

- Observation of signs characteristic of any of the Type II disturbances (e.g., collapse, poorly coordinated movements, respiratory difficulties)

c. Treatment

- Place crewman (patient) and medical observer in hyperbaric treatment facility (chamber)
- Place patient on 100% oxygen by mask and medical observed on chamber air
- Pressurize chamber to the pressure equivalent of 60 feet of sea water (approximately 2.8 ATA)
- Continue treatment in accordance with "Air Force Treatment Table 6", shown in Figure 3.2.4.1.21-2
- If symptoms persist after 70 minutes of treatment at 2.8 ATA, treatment at this pressure may be extended for a longer duration at the discretion of the senior medical supervisor involved in the treatment

C. Gas (Air) Embolism

(1) Air embolism without pneumothorax

a. Prevention

- Crew training to avoid breath holding during ambient pressure reduction

b. Diagnosis

- Collapse following a situation conducive to the development of air embolism

c. Treatment

- Remove EMU from collapsed crewman and place him in hyperbaric treatment facility with medical observer
- Rapidly pressurize chamber to the pressure equivalent of 165 feet of sea water (approximately 6.0 ATA)
- Continue treatment in accordance with "Air Force Treatment Table 6A", shown in Figure 3.2.4.1.21-3

- A breathing gas mixture of 50% oxygen/50% nitrogen administered to the patient upon reaching 6.0 ATA instead of chamber air has been used successfully at various hyperbaric treatment facilities. This treatment procedure has not, however, become a standard therapy
- The patient's ECG should be monitored as soon a the ECG leads can be feasibly applied
- As illustrated in Table 6A, 100% oxygen is not administered to the patient until the chamber pressure has been reduced to 2.8 ATA.
- Should the patient, while breathing 100% oxygen, develop symptoms of oxygen toxicity, he should be immediately switched from 100% O_2 to chamber air. The patient may be returned to 100% O_2 after the symptoms subside. This procedure should be followed for any of the specified hyperbaric treatment regimens (Tables 5, 6, and 6A)

(2) Air embolism with pneumothorax

a. Prevention

- Some training as in 1a, above.

b. Diagnosis

- Patient develops cardio-respiratory distress when hyperbaric chamber pressure is reduced from 6.0 ATA toward 2.8 ATA

c. Treatment

- Repressurize chamber to a level that alleviates patient's distress and insert a tube through the chest wall into the air accumulation

D. Conditions Resulting from Inadequate Environmental Control.

These conditions are addressed in Sections 3.2.4.1.6, 3.2.4.1.7 and 3.2.4.1.8.

E. Mechanical Trauma

(1) Prevention

a. Crew training in safety procedures

b. Design of EVA procedures to reduce safety hazards

(2) Diagnosis

a. Physical examination

(3) Treatment

a. Treatment identical to that used for mechanical trauma injuries occurring during intravehicular activities.

F. Oxygen Toxicity

(1) CNS toxicity

a. Prevention

- Restrict oxygen partial pressure in breathing mixtures to levels below 1.5 ATA

b. Diagnosis

- Convulsions and unconsciousness in affected crewman

c. Treatment

- Immediate removal of crewman from breathing mixture containing high oxygen partial pressure

(2) Pulmonary Toxicity

a. Prevention

- Restrict oxygen partial pressure in breathing mixtures to levels below ~~6.0~~ TBD psia
- Limit exposure time to TBD hrs/~~wk~~ day for oxygen partial pressures above 6.0 psia

b. Diagnosis

- Substernal pain reported by crewman
- Development of cough
- Respiratory distress
- Reduced vital capacity shown in pulmonary function tests

c. Treatment

- Restrict crewman from breathing mixture with oxygen partial pressures higher than 6.0 psia.

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