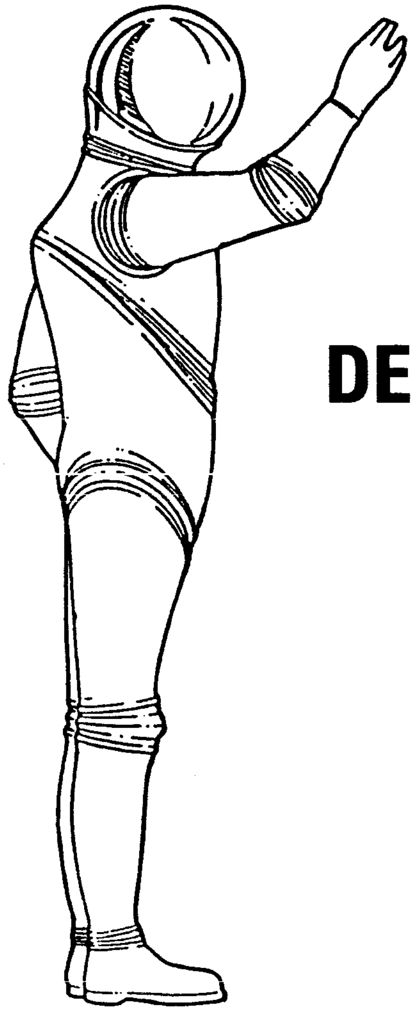
REPORT MDC W0070



ADVANCED EVA SYSTEM DESIGN REQUIREMENTS STUDY

EVAS/SPACE STATION SYSTEM INTERFACE REQUIREMENTS

NOVEMBER 1985

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-HOUSTON DIVISION

MCDONNELL DOUGLAS CORPORATION

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STUDY MANAGER

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1.0 INTRODUCTION

This report contains the definition of the EVA systems interface requirements and accommodations for effective integration of a production EVA capability into the Space Station program. It reflects the many interrelated considerations identified in the course of the MDAC-Houston Advanced EVA Systems Design Requirements Study Contract NAS 9-17299. Delivered as it is in support of the Space Station Phase B Interface Requirements Review, it is somewhat in advance of completion of the contract study and may be subject to some revision in the final report to be delivered in January 1986.

This report is organized in the following manner:

Section 2 provides a description of the EVA systems for which the Space Station must provide the various interfaces and accommodations. Systems descriptions and performance requirements are presented to the level of detail necessary to support an understanding of their attendant interface requirements.

Section 3 includes the discussions and analyses of the various SS areas in which EVA interfaces are required and/or from which implications for EVAS design requirements are derived. Roughly organized about the WBS for study Task 3, this section provides the rationale for all EVAS mechanical, fluid, electrical, communications and data system interfaces as well as exterior and interior requirements necessary to facilitate EVA operations. Results of studies supporting these discussions are presented in the appendix, which constitutes Appendix B of the Advanced EVA Systems Study.

Though they would appear somewhat out of context in this report, Section 2.2.8 describes candidate orbital experiments necessary to support advanced EVAS development. Assessment of these experiments is provided in Section 2.2.7, which identifies the EVAS technology risks associated with meeting the SS EVA requirements.

Philosophically, a very wholistic approach must be taken at all levels of the organization to the integration of the EVA capability into the SS program. EVA is no longer performed for its own sake, and our proven ability to extend man's natural abilities beyond the confines of his space habitat must be made as natural and routine as its unique environment allows. Concessions made "for the sake of EVA" cannot replace a keel up integration of EVA as a program resource--a resource proven to be just as important to mission success as electrical power, instrument pointing, heat transfer, etc. Therefore, the importance of proper integration of interface requirements and accommodations cannot be overemphasized. Essentially, end-to-end operational assessments supported by systems and subsystems performance testing provide the only true measure of successful integration prior to actual real-time use. Designing separate systems to individually derived sets of requirements leads to a high potential for expensive redesigns and recertification efforts and often to operational workarounds that adversely impact crew productivity. From the lessons learned in developing the EVA systems for the STS and from the data base amassed from ongoing STS extravehicular activity, NASA has the potential to provide a fully integrated and productive EVA capability that can be managed, along with other critical SS resources, to satisfy program objectives.

2.0 EVAS DESCRIPTION AND PERFORMANCE REQUIREMENTS

2.1 GENERAL

To specify EVAS/Space Station interface requirements, it is first necessary to briefly discuss functional requirements for the EVAS itself. Development/derivation of these requirements is the subject of SOW task 3.2.4, so only a minimal discussion will be provided here, with primary emphasis on the issues that drive the requirements. A more detailed explanation as to requirement derivation will be provided in the final report (DR-4).

2.2 OVERALL EVAS DRIVING ISSUES

2.2.1 Maintainability is considered to be the single most important element of the design requirements at this stage. While many other elements are very important, proper design of the EVAS will allow for choices to be made much later as to the exact approach to solve other design problems. Specifically, building in as much modularity as possible as early as possible provides:

1. ORU removal/replacement/repair capability
2. Growth by individual subsystem (or component) upgrades rather than block upgrades of the entire system
   a. Regenerables
   b. Smaller volume components
   c. Higher pressure gloves

3. Temporary fall-back position in the event of advanced technology funding cuts or technical problems (gloves, LiOH, PCM, etc., development)

2.2.2 Degree of function integration is a closely related and frequently competing issue to maintainability (i.e., a system that concentrates on functional integration like the STS PLSS can optimize volume, but sacrifices the ability to upgrade individual systems and components easily). Our STS experience has taught us that we are simply not smart enough to predict just which part of the system will eventually require modification, so every effort should be made now to group the functions to allow maximum modularity. In all likelihood, this means minimizing the functional integration of subsystems, regardless of the final physical arrangement of systems. It appears that the most appropriate breakdown of the functions is:

1. Life Support
   a. Pressurization/Pressure Control*
   b. Breathing Oxygen*
   c. Atmosphere Revitalization*
   d. Thermal Control*
2. Communication**
3. Data Management (including system monitoring)
4. Environmental Protection*
5. Mobility*

6. Propulsion*

7. Guidance, Navigation, and Control**

8. EVA Support Functions

*Denotes critical functions referred to in the following discussion.

**Denotes function that may or may not be designated as critical depending on the mission profile.

For convenience in this discussion, these functions will be grouped as the hardware has traditionally been configured. That is:

1. Life Support, Communication, and Data Management will be grouped under Life Support System (LSS).
2. Environmental Protection and Mobility will be grouped under Crew Enclosure.
3. Propulsion (translational and rotational) and Guidance, Navigation, and Control will be grouped under Propulsion System.
4. EVA Support Functions (tools, servicing equipment, etc.) will be discussed under the general title of Ancillary Equipment.

2.2.3 <u>Redundancy</u> of critical systems should be considered in place of backup systems used in past EVA systems (e.g., two (or even three) primary oxygen systems in place of an SOP) to provide not only a limited fail-ops capability, but also to reduce complexity of spares logistics. In any case, no single credible failure should result in loss of a critical function (even though it may possibly result in degradation of function and/or termination of EVA), and no two related failures should cause an immediately life-threatening situation.

2.2.4 Radiation exposure allowed/allowable is considered to be an issue encompassing much more than only EVA. For instance, regardless of the amount of protection built into the Crew Enclosure, common sense dictates that we still try to schedule EVA to avoid the South Atlantic Anomaly; therefore, our approach in designing the EVAS should be to provide as much protection as possible without restricting mobility (in no case less than that provided by the STS EVAS). This will allow overall radiation exposure philosophy to be developed on an informed basis by the appropriate agency while continuing to apply NASA's policy of As Low As Reasonably Achievable (ALARA).

2.2.5 The weighting given to LSS volume vs. time available for EVA warrants careful consideration. Generally, while smaller volume will always increase productivity by some amount, it is not the absolute constraint it was during STS EVAS development (e.g., requirement for passage of an EMU through the shuttle interdeck access no longer exists). Alternatively, deletion or drastic reduction of prebreathe penalty may make extended EVA time capability unnecessary by reducing the overhead time associated with each EVA, thereby allowing more frequent, shorter EVA's with a smaller volume LSS.

2.2.6 Acceptable physiological risks as regards decompression sickness should not be a consideration at this stage of the design process. Rather, these issues should be addressed by the medical community while our engineering efforts should be focused on the goal of eliminating these risks for nominal operations (R = 1.2 or less). In the event we are unable to meet this goal initially, we can fall back to higher risk pressure combinations and/or procedural workarounds using prebreathing to reduce the likelihood of problems.

2.2.7 Technology readiness assessment

During development of the EVAS requirements, it has been necessary to keep an eye on certain aspects of technological reality. Several technology advancement programs promise significant enhancement in EVA productivity and decreased logistics requirements, and we have assumed that progress will continue at a pace allowing their incorporation into EVAS design at IOC. Unfortunately, as with all such programs, they are subject to various degrees of risk from two sources: technical problems and funding cuts. Therefore, where possible, we are stating requirements so as not to preclude use of current technology (with its associated operational impacts) in the interim, with subsequent upgrades as the technology matures. Table 1 shows the most promising of these technology areas, their potential benefits and drawbacks, and the perceived degree of technical risk in bringing them to maturity by IOC.

2.2.8 Space Station Experiments Necessary For EVA Support

The present Shuttle environment offers many opportunities to test and evaluate EVA systems concepts prior to committing to full development for later use on the SS. For any hardware or system design, especially those involving critical new technologies, taking advantage of such test and demonstration opportunities may contribute to minimizing the overall technical risk to the program. This is especially true for those technologies or design concepts most affected by the zero gravity environment, since that is the area in which it is the most difficult to provide an end-to-end simulation in ground-based facilities.

Based on our understanding of the orbital environments and the development needs of the advanced EVA systems, we have assembled the following preliminary list of candidates for orbital experiments.

A. Crew Enclosure Experiments

1. Suit donning/doffing evaluation - fly device similar to laboratory evaluation stand in the middeck to evaluate various closure concepts, various scye/neck/closure orientations, and impact of arm/glove fit of providing a hand-in capability. Adjustment of device should allow for test by entire manifested STS crew to maximize data return and, if able to be pressurized, could validate reliability of on-orbit re-sizing concepts.

2. Suit material exposure tests - provide "witness plate" type samples of suit materials on multiple STS missions and in various locations to evaluate effects of radiation, atomic oxygen abrasion, extremes of temperature, micrometeoroid impacts, contamination, etc. While some of these environment influences can be simulated or produced on the ground, no single facility can produce the combined effects of all of them.

3. Suit loading data - provide a set of EMU crew enclosure sensors and wiring and recording devices to develop true design loading factors from actual EVA unmasked by one-g effects and possibly relieve those found to be too conservative.

B. Life Support System Experiments

1. In-flight maintenance proof-of-concept demonstration - provide test LSS or high fidelity mockup to assess orbital maintenance capability for advanced PLSS. LSS could be disassembled down to required ORU level, or beyond, then reassembled. Test would validate procedures and designs, and subsequent ground test would verify post-maintenance systems integrity and performance.

2. Efficiency of regenerative LSS components - on-orbit tests of regenerative C02 removal, humidity removal, and heat-absorbing devices could be provided in Get Away Special (GAS) type experiments that would reveal any problems or peculiarities associated with zero gravity operation in their intended environments.

Other candidates of lesser importance could benefit from realistic orbital tests either in the Space Station or the Shuttle and could be piggy-backed onto other more critical ones. It is strongly recommended that full advantage be taken of the opportunities afforded by the STS program to enhance the ability of the selected EVA systems to satisfy the demands of the SS EVA requirements.

2.3 REQUIREMENTS

Table 2.2 contains the requirements as they appear to be taking shape. As mentioned above (Section 2.2.2), they are grouped into:

1. Life Support System
2. Crew Enclosure
3. Propulsion System
4. Ancillary Equipment

TABLE 2.1. TECHNOLOGY ASSESSMENT

TECH AREA	BENEFITS	DRAWBACKS	TECH RISK	FALLBACK POSITION	COMMENTS
REGEN CO_2 SCRUBBING	LOGISTICS IMPACTS << LIOH	VOLUME > LIOH	MED	LIOH (STS)	EMPHASIS ON WP-01 SELECTED SYSTEM
HIGH-PRESSURE GLOVES	INCREASED MOBILITY AT ANY PRESSURE REDUCED PREBREATHE REQTS		MED-HI	OPERATE AT LOWER PRESSURE, PRE-BREATHE (STS) VARIABLE PRESSURE (USSR) MECHANICAL END-EFFECTOR (PROSTHESIS)	
NON-VENTING THERMAL CONTROL SYSTEM	LOGISTICS LESS PAYLOAD IMPACTS	VOLUME > SUBLIMATOR	LOW	SUBLIMATOR	

TABLE 2.1. TECHNOLOGY ASSESSMENT (Continued)

TECH AREA	BENEFITS	DRAWBACKS	TECH RISK	FALLBACK POSITION	COMMENTS
SUIT SIZE RANGE CAPABILITY 5% OR FEM TO 95% ILE AM. MALE	WIDER CHOICE FOR CREW SELECTION	COMPROMISE FIT FOR SIZE EXTREMES HIGH COST TO DEVELOP SMALL GLOVES	HIGH	LIMIT SIZE RANGE FOR TO BE ACCOMODATED	RECOMMEND REQUIREMENT BE RESTATED
ON-ORBIT RESIZING CAPABILITY	LESS CREW TIME TO RESIZE		LOW	N/A	RECOMMEND BASELINE ORTMAN COUPLINGS
HIGH-PRESSURE JOINTS (OTHER THAN GLOVES)	INCREASED PRODUCTIVITY DUE TO LOWER TORQUES		LOW	FABRIC JOINTS	BOTH SWL AND HARD JOINTS LOOK FEASIBLE

TABLE 2.1. TECHNOLOGY ASSESSMENT (Continued)

TECH AREA	BENEFITS	DRAWBACKS	TECH RISK	FALLBACK POSITION	COMMENTS
K-BAND COMM SYS	COMMONALITY WITH REST OF SS COMM	VOLUME > STS UHF	LOW-MED	N/A	UHF REQUIRES EXTENSION OF WAIVERS GRANTED FOR STS (INTER-NATIONAL FREQUENCY ALLOCATION AGREEMENT)
DATA	HIGHER DATA RATES	POWER REQTS UHF			
VOICE	ACCESS TO SS DMS				
DMS FEATURES					
FULL SCREEN DISPLAY	INCREASED INFO AVAILABLE TO CREWMEMBER	POWER REQD	CRT: MED-HI (POWER) LCD: LOW-MED	LCD OR LED ALPHANUMERIC	
LOW POWER					

TABLE 2.1. TECHNOLOGY ASSESSMENT

TECH AREA	BENEFITS	DRAWBACKS	TECH RISK	FALLBACK POSITION	COMMENTS
INCREASED MEMORY	MORE USER-FRIENDLY SOFTWARE		MINIMAL	N/A	COMMERCIAL TECHNOLOGY MOVING VERY RAPIDLY
COMPUTATION SPEED	MORE COMPLEX				
EEU	INCREASED MANEUVERING CAPABILITY (ΔV)/ UTILITY	COST	MINIMAL	UPRATED MMU	MMU CANNOT BE UPRATED PRACTICALLY TO EQUAL EEU
	BUILT-IN TARGET-ING AND THRUST GUIDANCE	COST	MINIMAL	UPRATED MMU	LOWERS MMU PERFORMANCE IN FALL-BACK
	BETTER HANDLING OF LARGER CARGOS	COST	MINIMAL	UPRATED MMU	UPRATED MMU LESS EFFICIENT

TABLE 2.1. TECHNOLOGY ASSESSMENT (Concluded)

TECH AREA	BENEFITS	DRAWBACKS	TECH RISK	FALLBACK POSITION	COMMENTS
	ROBOTIC CONTROL POSSIBLE	COST	MINIMAL	NO ROBOTICS	NO ROBOTICS ENTAILS LESSENING PRODUCTIVITY

TABLE 2.2. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
1.0 LSS	Life support for 8 hours in LEO space vacuum
1.1 STRUCTURE	Mounting points for crew enclosure, propulsion system, and required ancillary equipment
1.2 VENTILATION SYSTEM	Breathing oxygen
	C02 control system allowing use of developing regenerable technologies or LiOH (emphasis on medium selected for Station C02 control by Phase B WP-01 team)--inlet, outlet, cooling, and instrumentation connections provided by LSS
	Humidity control
	Odor control

TABLE 2.2. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM (CONTINUED)

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
1.3 THERMAL CONTROL SYSTEM	Storage and/or rejection of metabolic, system-generated, and environmental heat loads Conductive interface and instrumentation should be provided that does not preclude any of the following approaches: Phase Change Module (PCM) Venting (sublimator) Radiator Augmented (umbilical)
1.4 PRESSURIZATION SYSTEM	Constant pressure of TBD ± TBD (see para 2.2.6) Regulators, orifices capable of adjustment or replaceable as ORU's
1.5 POWER	Storage, distribution system to allow 8 hours of EVA

TABLE 2.2. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM (CONTINUED)

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
1.6 DATA MANAGEMENT	Real-time systems monitoring
	Data base access
	Navigation
1.7 COMMUNICATIONS	Data (biomedical, systems, navigation)
	Voice
2.0 CREW ENCLOSURE	Pressure vessel to protect from vacuum, radiation, mechanical dangers
	Material, joint design TBD by Phase B
2.1 TORSO	Structural interface for legs, arms, restraints
	Negative pressure protection (hard upper torso or relief valve)
	Size range accommodated TBD (goal is to maximize number of people accomodated by minimum hardware.)

TABLE 2.2. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM (CONTINUED)

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
	Shoulder-to-crotch
	Shoulder width
2.2 LEGS	Mobility $\geq$ STS EMU
	Restraint interface to structures
	Joint types TBD; certification of Ortman coupling or similar technology allows later selection between:
	Hard "stove pipe"
	Toroidal single wall laminate (SWL)
	Rolling convolute SWL
	Tucked fabric

TABLE 2.2. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM (CONTINUED)

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
2.3 ARMS	Mobility ≥ STS EMU
	Mounting provisions for ancillary equipment --tools, restraints, etc.
	Joint types TBD; certification of Ortman coupling or similar technology allows later selection between:
	Hard "stove pipe"
	Toroidal SWL
	Rolling convolute SWL
	Tucked fabric
2.4 GLOVES	Mobility ≥ STS EMU--must accommodate sizes as small as TBD
	Tactility ≥ STS EMU

TABLE 2.2. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM (CONTINUED)

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
	Joint types TBD--Gloves are already ORU's on STS EVAS; any technology is easy to add later merely by specifying the interface the gloves must meet (wrist disconnect)--candidates include:
	Tucked fabric
	Hinge (metacarpal)
	Bearing (thumb)
	Bellows (finger)
	NOTE: Heavy-duty "work gloves", if used, do not necessarily have to meet the mobility and tactility requirements stated above
	NOTE: On-orbit resizing capability is not a requirement (custom-fit acceptable)
2.5 HELMET	Visibility
	UV, IR protection

TABLE 2.2. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM (CONTINUED)

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
2.6 WATER	Sufficient for 8 hours of EVA
	Options include:
	• Dedicated container
	From LSS
2.7 FOOD	Sufficient for 8 hours of EVA
2.8 WASTE COLLECTION	Urine collection
	Fecal collection (containment)
	Emesis collection (containment)
3.0 <u>PROPULSION SYSTEM</u>	
3.1 PROPULSION	Delta-V capability of TBD
	Non-contaminating

TABLE 2.2. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM (CONTINUED)

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
3.2 CONTROL	Manual control--translation and rotation
	Automatic control--rotation (and translation)
	Teleoperation
	Artificially intelligent "smart front end"
3.3 POWER	Storage, distribution system to allow 8 hours of operation
3.4 STRUCTURE	Mounting provisions for LSS, crew enclosure, payloads, ancillary equipment
4.0 <u>ANCILLARY EQUIPMENT</u>	
4.1 EVAS SUPPORT EQUIPMENT	
4.1.1 <u>Checkout Equipment</u>	Perform system checkout during nominal operations with minimal human intervention

TABLE 2.1. EVAS FUNCTIONAL REQUIREMENTS BY SUBSYSTEM (CONCLUDED)

SYSTEM/SUBSYSTEM	FUNCTIONAL REQUIREMENT
4.1.2 Service/Maintenance/ Repair Equipment	Perform nominal servicing between EVA's, ORU changeout, and ORU repair capability
4.2 STATION/PAYLOAD SUPPORT EQUIPMENT (GENERIC)	Perform routine maintenance and servicing of the Station and experiments and unscheduled repair tasks as needed; i.e., provide the capability to perform each of the generic EVA missions
4.2.1 <u>Station Driven</u>	(tasks) identified in Section 3.1 of this study
4.2.2 <u>Payload Driven</u>	
4.3 PAYLOAD SUPPORT EQUIPMENT (SPECIAL)	Equipment not covered by 4.2 (above), which is required by one or more particular payload(s), will normally be provided by the user, and as such the only Station requirement is to provide services (power, comm, environmental control, etc.) as required by the equipment

3.1 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 composed 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 a 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 at 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 considerations 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. With maximizing crew productivity as our prime concern, we will make appropriate recommendations regarding such options and identify the necessary SS interfaces and accommodations in our final report.

3.2 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 any and 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.

COMMUNICATIONS

Basic needs for communication are voice communication, telemetry, and television.

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 then 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.

MAINTAINABILITY

The requirement for high maintainability of the EVAS and all associated systems must be kept in mind. Emphasis should be placed on ruggedness and reliability of design, and the philosophy of testing by using should be implemented everywhere possible. Eliminating unnecessary maintenance tasks, checks, and tests is the goal with an "if it's not broken don't fix it" attitude.

RECOMMENDATIONS

Continue to study EVAS comm requirements to more accurately define them as system parameters become more well defined.

Continue to study EVAS comm options to support further design efforts as they occur.

Design strawman comm system, including as much of the space station DMS as necessary, to satisfy operational requirements as defined in the technical discussion above. This is a job for communications and data systems experts.

3.3 DATA MANAGEMENT

The EVAS Data Management System (DMS) will be critical to the success, optimization of tasks and efficiency, and safety for 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.

Problems relative to the EVAS DMS capabilities may develop because of constraints imposed on it by the design and architecture of the EVAS resident microprocessor and memory and by the limited interface capability of the EVA crewmember.

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 in an efficient and expeditious manner.

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, using 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 the development of 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. EVAS 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.
also perform 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 HUD whether 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 optimally minimize their demands on the EVAS processor and memory.

To minimize the possibility of data loss during any operation and to preclude possible erroneous critical functions being performed, 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.

As an added safety feature for EVAS DMS operations within the EVAS, design residency of all life- and mission-critical applications shall, wherever possible, be in firmware.

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.

3.4 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 1 lists EMU spares, Table 2 lists EEU spares, and Table 3 lists spares for tools and ancillary equipment.

TABLE 1. PROJECTED EMV 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)
CO_2 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)
CO_2 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 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	0.2
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 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	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

ITEM	QTY	TOTAL MASS (KG)	TOTAL VOLUME (CC)
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	.75	1600
Cleaner Material Prepreg Clothes	200	15	72000
Electrical Insulation Material	1	1.0	1000

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 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 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 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 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	.79	24115 (3500)/GAS
		302.75	1.91	.77	31005 (4500)/GAS
		403.67	1.43	.7	41340 (6000)/GAS
		470.69	1.23	.66	55120 (8000)/GAS
		521.13	1.11	.65	68900 (10000)/GAS
		791.31	.8	.64	LIQUID/CRYO
180	1160.5	338.33	4.16	.99	74115 (3500)/GAS
		302.75	3.83	.97	31005 (4500)/GAS
		403.67	2.87	.88	41340 (6000)/GAS
		470.69	2.46	.83	55120 (8000)/GAS
		521.13	2.22	.83	68900 (10000)/GAS
		791.31	1.61	.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

CASE 2 (REFER TO TEXT)

90	1405	278.72	5.04	1.06	24115 (3500)/GAS
		302.75	4.64	1.03	31005 (4500)/GAS
		403.67	3.48	.93	41340 (6000)/GAS
		470.69	2.98	.89	55120 (8000)/GAS
		521.13	2.69	.88	68900 (10000)/GAS
		791.31	1.95	.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 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 4 indicates, two methods of storing the propellant are available. The gaseous state storage requires a greater volume than the liquid storage, but is less complex than 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 warm. 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 MDTSCO 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 two of three 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.

3.5 SAFE 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.

The passage of the South Atlantic Anomaly consists of six orbits that pass-through the intense radiation field and then followed by nine orbits that miss. The SAA pass-through consumes 15 minutes of time per each affected orbit. This, of course, will not affect the EVA crewmember if the EVA is done during the nine orbits that do not pass-through the SAA. A normal 6-hour EVA lasts approximately four orbits. The first day of EVA could begin just after the last pass-through of the SAA. If the EVA starts at the same time every-day, the SAA period could be retreating back from the EVA start time by 15 minutes each day. At the same time, the other edge of the SAA would be creeping up on the EVA time at the end of the day. At the end of approximately 9 weeks, the SAA encounter period would approach the EVA stopping time. The EVA schedule could then be shifted to again begin just after the last SAA pass-through, i.e., one work shift earlier. Therefore, it appears that an EVA safe haven is not required for any radiation protection purposes.

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 air-lock.

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 safe 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 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 lower end of the keel), a crewmember can be approximately 400 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 safe 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 obviously need for it. The opposite is also true. A decision must await further EVAS hardware definition to allow better accident/failure prediction and further safe haven definition to allow prediction of safe haven costs.

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OF POOR QUALITY

3.6 Impact of EVA Crewman Autonomy From Space Station And Ground For EVA Tasks

The degree to which the EVA crew and their supporting systems can operate autonomously from the Space Station and/or the ground has a direct bearing on how productive the EVA crew can be. Costs of performing EVA, heavily considered in program planning and a factor in many design decisions, are also affected by the amount of burdening support costs. The Space Station operational environment is at the same time both more demanding than previous programs were for an autonomous EVA capability and potentially more conducive to reaching that goal.

With regards to EVA, autonomy has several key aspects, each of which results in important design considerations for the EVAS and their SS interfaces. The most apparent drawback of the Shuttle EVA capability with regards to crewman autonomy is the heavy dependence of the EVA crewmen on their designated IV assistant. IV1, as he is designated in the checklists, provides assistance in EMU donning, procedural assistance in monitoring of prebreathe protocols, and general coordinating of EVA preparation activities with parallel Orbiter activities, monitoring and integration of crew activities during EVA for both mission success and crew safety, and assisting the crew on management of LSS consumables and monitoring status of the EMU. The more complex the integration of the EVA activities, the more demanding are the chores of the IV helper.

Prior to STS launch, during the mission planning period, considerable resources are expended in mission specific procedures and hardware development and in crew training to achieve the level of confidence necessary to ensure mission success within the limited capabilities of a single STS mission. This iterative and costly process, the magnitude of which is directly proportional to the complexity of the EVA mission, results in the detailed, integrated checklist procedures and crew timelines that are used to orchestrate the real time EVA activities.

During the EVA mission, a significant amount of ground-based resources are held in a standby mode to assist the crew in responding to anomalous or unplanned conditions in a timely fashion to further ensure crew safety and/or mission success. Additionally, due to design limitations of the Orbiter/payload interfaces, some critical procedural integration activities must be performed by ground-based personnel, which levies additional requirements for the scheduling of EVA tasks during ground communication coverage periods. This was especially true during the Solar Max Repair Mission on STS 41-C where EVA activities had to be scheduled around the ground's capabilities to monitor and configure the spacecraft systems.

So far the factors cited above illustrate the need to improve EVA productivity by lessening the dependency of the EVA crew on the IV crew and on the ground for the accomplishment of their EVA mission. These cases serve to indentify design requirements primarily on-board SS systems, real-time access to procedural data by the EVA crew, and independence from ground support requirements for the monitoring and configuration of SS and payload systems. To maintain EVA productivity over sustained periods, on-orbit requires an additional emphasis on machine autonomy from ground-based maintenance requirements not only through improved orbit life and reliability of design but also through the inclusion of on-board performance monitoring, fault detection isolation and recovery (FDIR) capability, and proper provisioning of critical spares components.

An additional demand for autonomy from the ground, unique to the SS operational environment, results from the need to provide some EVA crew training capability on-board. The ability to perform detailed mission specific training that covers all anticipated mission needs for any given crew cycle will simply not exist. SS crew task training will emphasize development of generic EVA skills and techniques that are combined on-orbit to accomplish specific tasks. Any mission specific aspects will be developed as part of the EVA planning function, supported by on-board data bases and planning aids, to acquaint the crew with sequence critical steps and necessary integration of steps with other payload or SS system considerations. EVAS systems training performed on the ground will be continually and frequently reinforced in performance of routine EVA. Proficiency maintenance training on off-nominal and emergency systems procedures, however, will have to be supported, likely in a part-task fashion, by computer aided instruction (CAI) capabilities of the SS DMS, accessed through the standard crew workstations. Such a system will provide refresher training and proficiency maintenance training over all critical EVA systems.

The above requirements would most likely be implemented as follows. To relieve an IV crewmember of the burden of acting as EVA monitor, an expert system EVA monitor would be required, most likely resident in the SS DMS. This expert system would monitor EVA crewmember health, EVAS system status, and associated space station and payload status and take appropriate action as determined by the system programmers. For instance, it would sound alarms for out of tolerance conditions and in some instances begin the proper response for dealing with such conditions by displaying proper procedures for affected crewmember and/or possibly taking limited independent action. The expert system EVA monitor would also interface with the EVA crewmembers to provide required data or limited actions during the course of an EVA. The data could be procedures, payload system status parameters, and information processing services. Actions could be limited station or payload hardware operation on command of the EVA crewmember, software reconfiguration, or similar task performance.

Closely related to the expert system EVA monitor would be an expert system EVA planner. This entity would be used to relieve ground support personnel of the task of planning EVAS and could be used both for immediate day-to-day planning and for longer range "strategic" planning and scheduling. It could be used to generate timelines and equipment lists, and together with the expert monitor, it could keep track of logistics data and other EVA operational data as required.

To further relieve ground support personnel of the burden of EVA support, an expert system diagnostician capable of being programmed with the characteristics of all payload, space station, and EVAS hardware deemed appropriate should be constructed. This system would take the place of the ground-based systems expert and would relieve the training requirements on the crew by allowing them to service equipment without becoming virtual experts on the system.

All of the above systems are postulated on the basis of a space station DMS organized and constructed in such a way as to make all checklists, mission aids (such as photographs of hardware under consideration or specifications of that same hardware), and any expert system or other software help as required immediately available to the EVA crewmember. It is assumed that proper research and testing would be performed to ensure that everything required for autonomous operation was indeed available and reliable.

Beyond the software and data management realms described above, certain hardware or mixed hardware/software requirements exist.

For productive EVA operation with minimal IV crew impact, a self-contained EVAS automated servicing, checkout, and troubleshooting capability is required. The EVA crewmember should be able to doff the EEU or EMU, possibly make some umbilical connections manually, and then leave the automated servicer to check the equipment for malfunctions, troubleshoot any found and take other appropriate action, and service consumables or regenerables as required.

In conjunction with the above automatic servicer, the EVAS must be designed for easy on-orbit checkout, servicing, and maintenance. This is especially true with regards to relieving the requirements for massive checks and tests currently performed by ground support personnel after every use of the equipment. The servicer, above, will perform all nominal checks automatically without needing to disturb any crewmember. Any off-nominal conditions requiring crewmember intervention should be handled quickly and easily, based on troubleshooting also performed automatically by the servicer.

Another area of EVAS autonomy impact is that of EMU donning and doffing. The EMU should possess a truly self-donning/doffing crew enclosure, meaning that the individual EV crewmember should be able to don or doff the EMU without outside help. This will relieve the IV crew of providing such help and, with the other systems above, enable totally autonomous EVA operations.

Another area of autonomy impact on the EVAS is the requirement for stranded crewmember rescue. If a crewmember loses contact with the space station structure and becomes stranded away from it, the EVAS must possess the capability to rescue that crewmember. A line-thrower fired by the stranded crewmember or a free-flying rescue vehicle on the order of the EEU have been proposed as solutions to this problem, but much more work is required for a resolution.

Certain risks are associated with the above requirements. Artificial intelligence is a relatively new and unexplored field. Therefore, the exact characteristics and capabilities of the required expert systems are difficult to define currently. It seems reasonable that they should be within the state of the art when needed for space station operation, but actual events could prove otherwise. Furthermore, unanticipated events or sequences of events during actual operations could lead to hazardous situations with which the autonomous system could not cope, thus endangering the crew. The problem would arise if the autonomous system either did not recognize a harzardous condition or responded inappropriately, causing or allowing the situation to deteriorate to an unacceptable degree. Some measure of safety can be obtained by operating the autonomous system only in the presence of human monitors for the first few months of operation, but this would not ensure that all difficulties had been resolved before the autonomous system became truly autonomous.

3.7 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.

3.8 SPACE STATION EXTERIOR

This study was undertaken to identify interface requirements for IOC 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 (read extremely costly) 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), or EVA umbilical as it is usually called, 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 many pieces of 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 a nightmare. In zero-g they act as an incredible drag and entanglement and are to be avoided unless there is no alternative. A DLSS support network should 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, based on a linear station model. 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. The equipment also must be capable of tolerating extended (perhaps several years) exposure to vacuum. 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.

3.9 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).

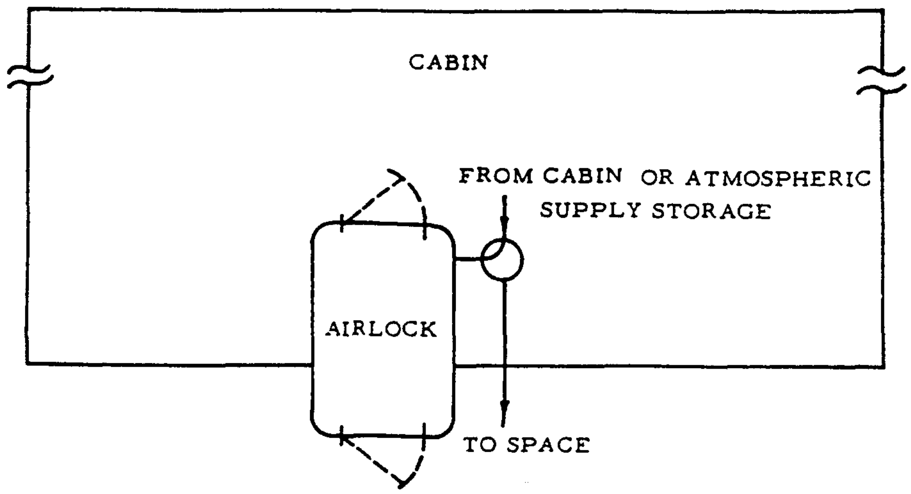
To move men and equipment safely beween the pressurized area of a space craft and the vacuum of space, an airlock is needed. The airlock permits entering and exiting of the space vehicle without subjecting the entire crew and equipment to the vacuum of space. During this process, the airlock atmospheric 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.

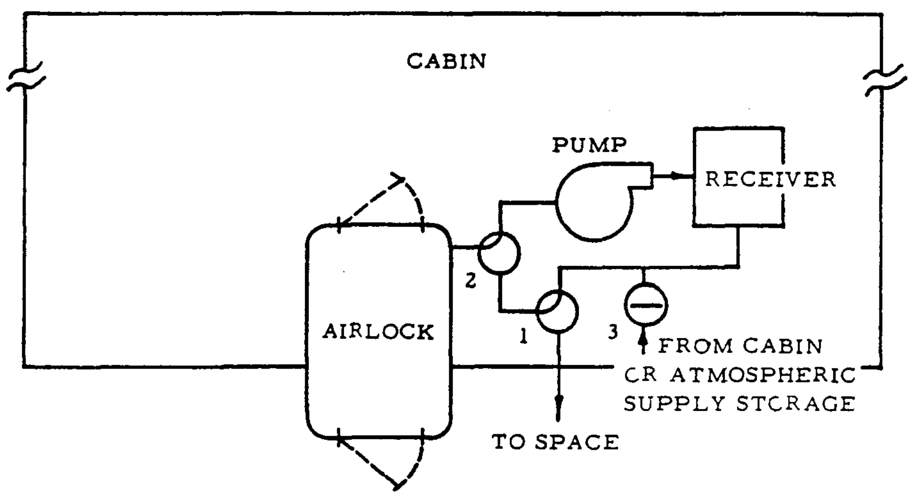
The second method recovers the airlock atmosphere by pumping most of the gases into a separate receiver for re-use (Figure 2). This receiver can be the main cabin, a second airlock, a high pressure container located elsewhere, or a second area of the airlock module. This pump-down to receiver concept 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 diagram provides an idea of these two basic methods.



EXPENDABLE GAS SYSTEM - SINGLE AIRLOCK



PUMP-DOWN FROM AIRLOCK TO RECEIVER

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.

ADVANCED EVA SYSTEMS DESIGN REQUIREMENTS STUDY

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 <u>RELIABILITY/MAINTAINABILITY</u>

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 the Advanced EVA System Study.

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.

2.2.0 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 <u>EVAS SPARE PARTS REQUIREMENTS</u>

3.1.1 EMU spare part requirements are shown in Table 1.

3.1.2 EEU spare part requirements are shown in Table 2.

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

3.2.0 <u>EVAS CONSUMABLES REQUIREMENTS</u>

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 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 CO_2 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 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)
CO_2 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)
CO_2 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 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	0.2
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 3. PROJECTED ANCILLARY EQUIPMENT SPARES REQUIREMENTS

SPARES REQUIRED PER YEAR

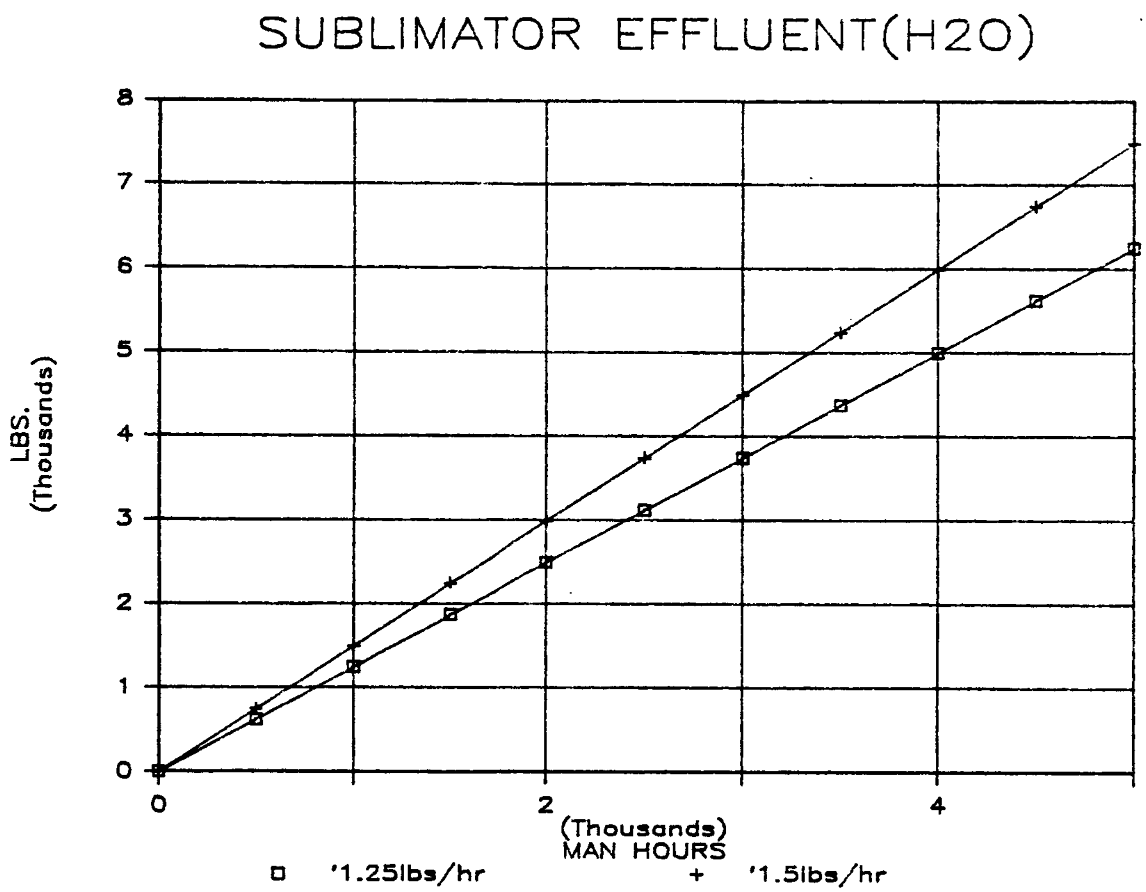
ITEM	QTY	TOTAL MASS (KG)	TOTAL VOLUME (CC)
Saw Blades	10	1.0	60
Trash Bags	200	10.0	72000
Nibbler Bits	10	0.5	30
Surface Coating Materials	1	5.0	4500
Drill Bits - Set	1	1.0	450
Welding Rods - Assortment	1	2.0	650
Brazing Rods	1	1.5	650
Grinder Pads - Assortment	1	1.0	3600
Rivets - Assortment	1	1	2000
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

C-2

ITEM	QTY	TOTAL MASS (KG)	VOLUME (CC)
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	.75	1600
Cleaner Material Prepreg Clothes	200	15	72000
Electrical Insulation Material	1	1.0	1000

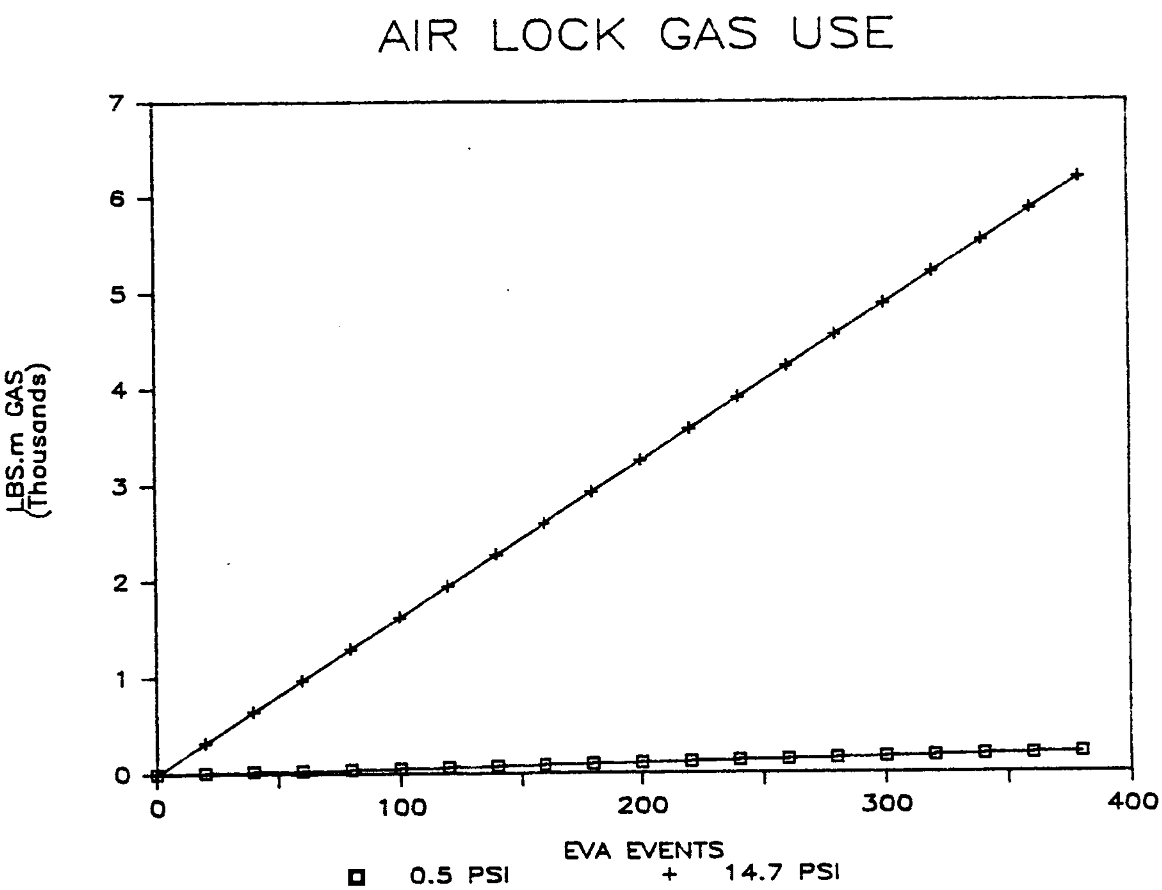
All items are spares - resupply as required.

FIGURE 1.



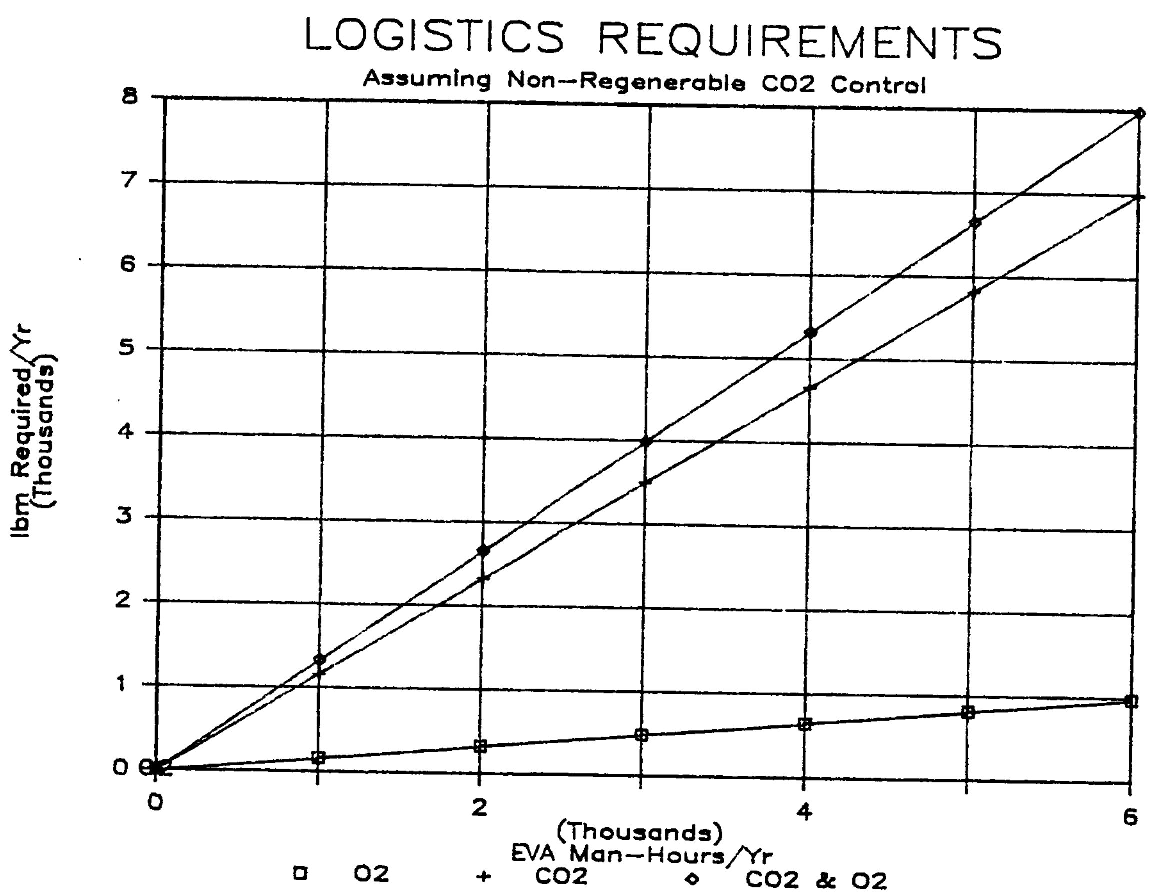
SUBLIMATOR EFFLUENT(H2O)
LBS.
(Thousands)
8
7
6
5
4
3
2
1
0
0
2
4
(Thousands)
MAN HOURS
'1.25lbs/hr
'1.5lbs/hr

FIGURE 2.



AIR LOCK GAS USE
LBS.m GAS (Thousands)
7
6
5
4
3
2
1
0
0
100
200
300
400
EVA EVENTS
0.5 PSI
14.7 PSI

FIGURE 3.



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
(.1634 lbm/hr @ 1 kBTU/hr)

4. SPACE STATION SAFE HAVEN REQUIREMENTS

4.1.0 An EVA safe haven shall be provided.

4.1.1 Save haven shall be portable via MRMS to remote worksite.

4.1.1.1 Safe haven shall be secured to station structure near workstation.

4.1.2 Safe haven shall be pressurizable.

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

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

4.1.2.3 Safe 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 Safe 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 Safe haven shall have lighting equal to 50 footcandles to illuminate the interior for up to 2 hours.

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

4.1.6 Safe haven shall have handholds on interior walls for positioning.

4.1.7 Safe haven shall have restraints to hold incapacitated crewmember.

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

5. SPACE STATION INTERIOR REQUIREMENTS

5.1.0 CLEANLINESS

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

5.2.0 SAFETY

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

5.3.0 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

6.1.0 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.

6.2.0 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.

6.3.0 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.

6.4.0 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.

6.5.0 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.

6.6.0 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.

7.1.0 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/m^2-sec_2 (.1 psi/sec). The maximum rates are not to exceed 6896 N/m^2-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.

7.2.0 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, N_2 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 O_2 and N_2 resupply, and the regeneration of time dependent processes, such as CO_2 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.

7.3.0 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 N_2 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 300×10^5 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.

7.4.0 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.

7.5.0 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.

7.6.0 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 at 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.

7.7.0 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).

7.8.0 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.

7.9.0 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.

7.10.0 CHAMBER ATMOSPHERE COMPOSITION AND BREATHING GAS PROVISIONS

7.10.1 The O_2 concentration shall not exceed 30% for O_2 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 O_2 supply shall be available for the attendant for all operations.

7.10.6 A 2-hour supply of nitrox (50% N_2; 50% O_2) shall be available for patient breathing (via mask) when the chamber is being operated at 6 atmospheres.

7.11.0 <u>CHAMBER TEMPERATURE</u>

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

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

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 70°F 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.

7.12.0 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 .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.

7.13.0 AIRLOCK LIGHTING

7.13.1 Floodlights shall be provided to aid EVA crew visibility in areas of high EVA activity such as the airlock.

7.14.0 AIRLOCK COMMUNICATIONS

7.14.1 The airlock shall have wireless voice communications that shall be capable of being down-linked.

7.15.0 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.

7.16.0 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.

7.17.0 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.