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VOLUME I

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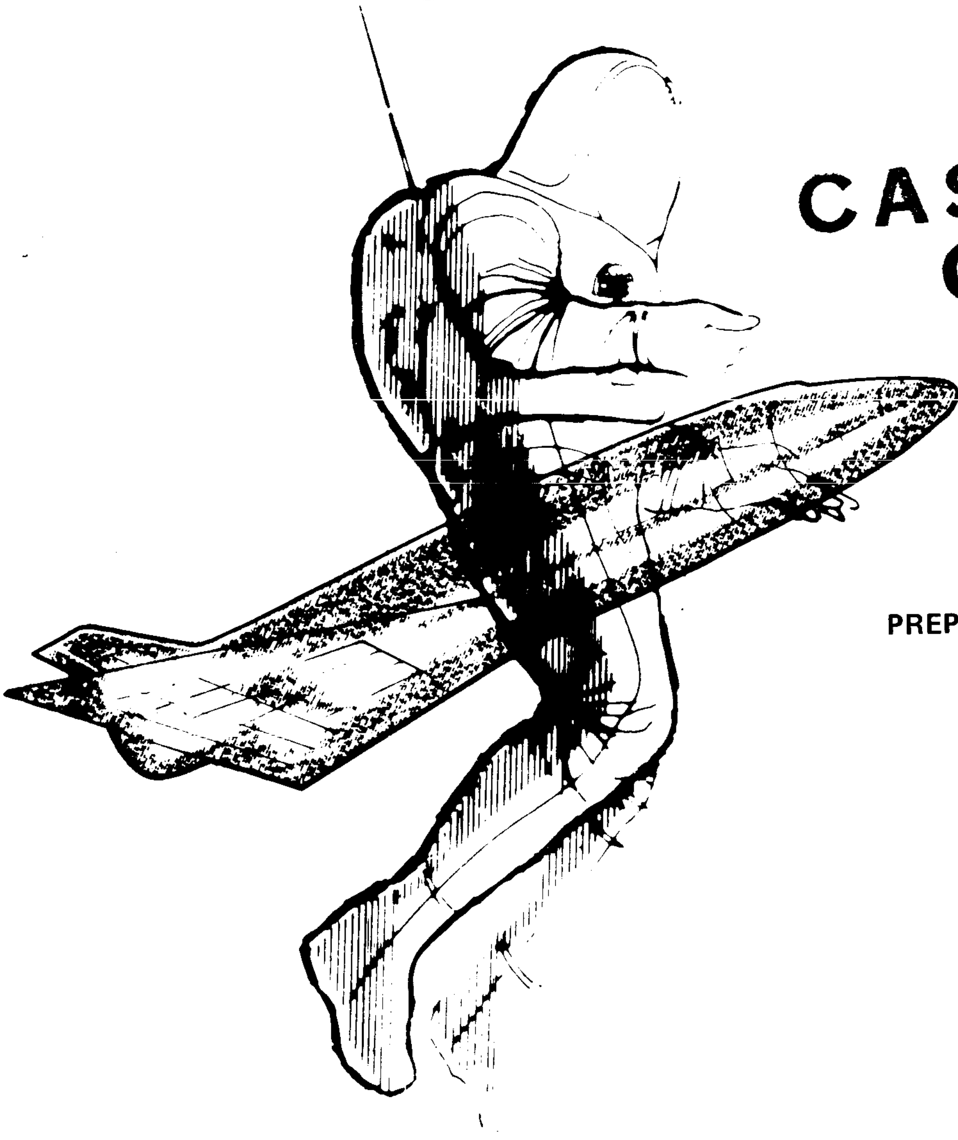
SPACE SHUTTLE EVA/IVA SUPPORT EQUIPMENT REQUIREMENTS STUDY



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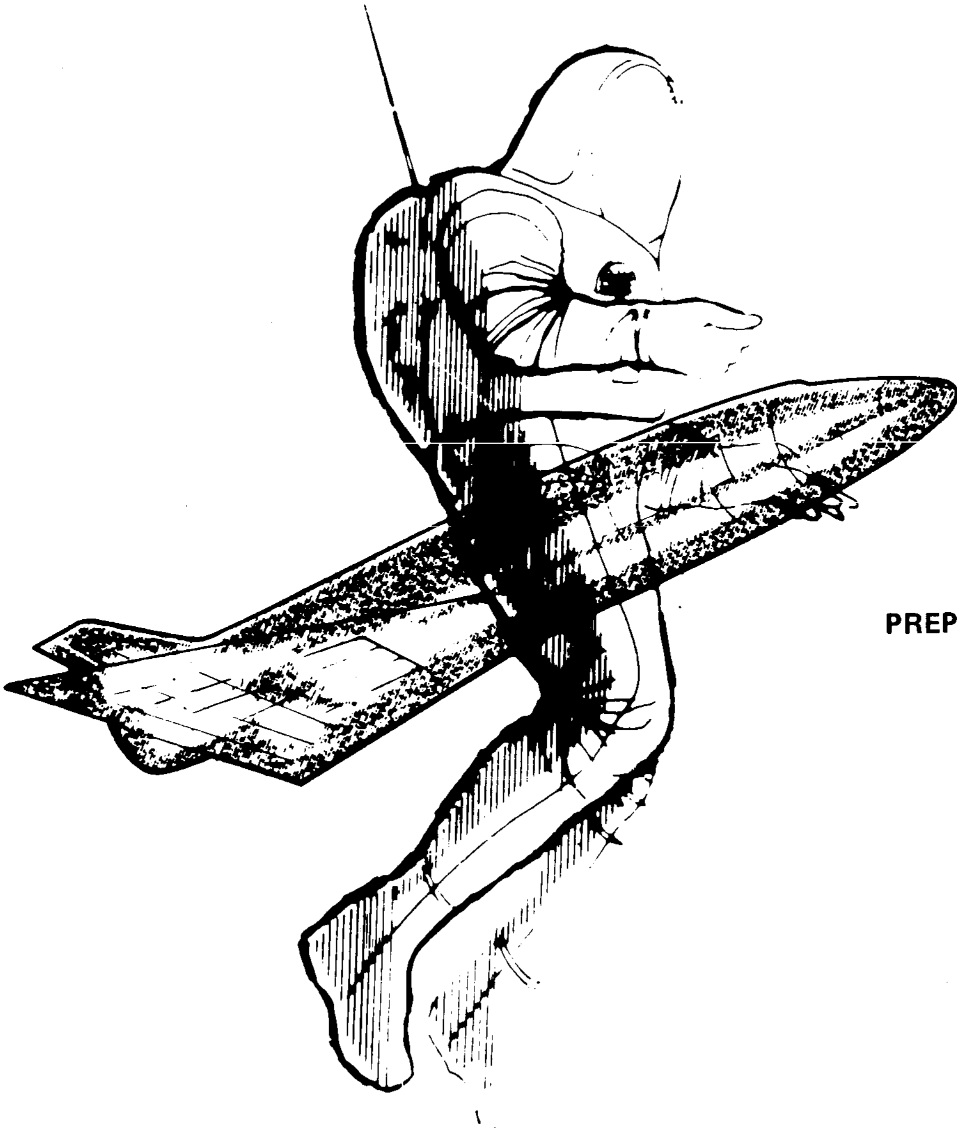
FINAL SUMMARY REPORT
PREPARED UNDER NASA CONTRACT
NO. NAS 9-12506

SP 01T73
VOLUME I

SPACE SHUTTLE EVA/IVA SUPPORT EQUIPMENT REQUIREMENTS STUDY



FINAL SUMMARY REPORT
PREPARED UNDER NASA CONTRACT
NO. NAS 9-12506

APRIL 30, 1973

FOREWORD

This is the Final Summary Report of the "Shuttle EVA/IVA Support Requirements Study". This effort was conducted by Hamilton Standard under NASA Contract NAS 9-12506 for the Lyndon B. Johnson Space Center of the National Aeronautics & Space Administration from March 14, 1972 to April 30, 1973. The principal contributors to this effort are listed in alphabetical order below:

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Special thanks are due to the Technical Contract Monitor, Mr. Donald L. Boydston, Crew Systems Division of the NASA Lyndon B. Johnson Space Center, for his advice and guidance.

This total report is contained in two (2) volumes as listed below:

Volume I	Final Summary Report
Volume II	Appendix

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SECTION 1.0

INTRODUCTION

1.0 INTRODUCTION

The primary objective of the Space Shuttle Program is to provide a new space transportation capability that will reduce substantially the cost of space operations, and provide a future capability designed to support a wide range of scientific, defense and commercial uses. An integral part of this future capability is man. Manned participation will certainly add new dimensions to the useful applications of space technology. The Space Shuttle will be capable of transporting safely and comfortably up to ten (10) scientists, technicians and astronauts into orbit while delivering payloads. This permits the direct participation in space experiments and observations by men and women who are leaders in their respective fields and no longer limits space flight to intensively trained astronauts.

The crew and passengers will be directly involved in three (3) new, important and different types of activities: (1) on-orbit placement and recovery of payloads; (2) on-orbit service and repair of satellites; and (3) operation of Shuttle-borne laboratories. In the first type of activity, manned on-robit checkout and activation of delivered satellites will assure effective systems are placed in orbit, and manned on-orbit command and control will enable capture and return of payloads to earth for reuse. Manned service and maintenance of satellites on-orbit will significantly increase the return of information and extend the useful life of the systems. In addition, replacements of satellite equipment that updates instrumentation, replaces degraded or failed parts, or provides additional materials consumed in operation will also significantly increase the utility of satellite developments.

Lastly, manned operation of Shuttle-borne laboratories will provide an entirely new capability for investigation, development, evaluation, and application of space techniques and equipment. Discipline oriented nonastronaut personnel can utilize their laboratory skills in monitoring, control, calibration and repair of equipment, thus reducing complexity and cost of experimental development.

EVA/IVA operations are a key element of manned participation in the Shuttle program. The primary objectives of the Shuttle EVA/IVA Support Requirements Study are to establish a baseline EVA/IVA approach for Space Shuttle operations and to prepare specific system requirements for the EVA/IVA equipment required to support these operations.

This volume presents the Final Summary Report. General conclusions and recommendations resulting from this effort are presented in Section 2.0. A description of the study methodology utilized in the conduct of this program is found in Section 3.0. Section 4.0 contains the results of the EVA/IVA task identification and analysis effort, while the study guidelines and constraints are listed in Section 5.0. The suit pressure level determination is described in Section 6.0.

1.0 (Continued)

Sections 7.0 through 12.0 present the results of our EVA equipment requirements definition efforts and include the Primary Life Support System (PLSS), Emergency Life Support System (ELSS), Pressure Suit Assemblies, Restraints, Translation Aids, and Worksite Provisions, respectively. Emergency IV and development flights requirements are discussed in Sections 13.0 and 14.0. Vehicle interfaces are presented in Section 15.0.

SECTION 2.0

CONCLUSIONS AND RECOMMENDATIONS

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

General conclusions emanating from the Shuttle EVA/IVA Support Requirements Study effort are:

a. EVA/IVA Task Identification - The past history of the Gemini and Apollo EVA missions has demonstrated that EVA can be safely used for productive tasks. Based on this demonstrated capability and an evaluation of the Shuttle missions, their payloads, and the potential need for EVA/IVA, the following specific conclusions were drawn:

1. EVA/IVA may be required for on-orbit checkout prior to final deployment of a payload.

2. EVA/IVA operations are required for planned conduction of certain experiments.

3. EVA/IVA enhances overall Shuttle flexibility and capability for servicing payloads by providing the ability to conduct total maintenance.

4. EVA/IVA capability is required for unscheduled and contingency operations to prevent mission aborts and ensure crew safety.

b. EVA/IVA Task Analysis - Based on the results of the EVA/IVA task analysis effort, the following specific conclusions were drawn:

1. EVA mission duration required is four (4) hours.

2. The Shuttle Orbiter shall have the capability to support a maximum of six (6) dual EVA missions and 32 manhours of EVA.

3. Most planned and unscheduled EVA/IVA tasks require two (2) crewmen.

4. Emergency duration required is fifteen (15) minutes.

5. The manipulator assisted mode of translation is the selected mode for sixty-two (62) percent of the planned tasks; the manual mode of translation is the selected mode for eighty-three (83) percent of the unscheduled tasks.

6. The 8.0 psi Orbital EVA Space Suit Assembly RFP design goals are adequate for the Shuttle EVA missions.

2.1 (Continued)

7. Required worksite restraints are foot, waist and hand restraints, in various different combinations.

8. For flights carrying contamination sensitive payloads, the payload instrumentation shields must be closed during EVA operations. If this procedure is followed, an Apollo-type EVA system utilizing water as a thermal control evaporant and having a suit gaseous leakage rate of 100 scc/min is a useable system for performing Shuttle EVA missions.

c. Suit Pressure Level Determination - Optimum suit operating pressure level is 8 psia.

d. EVA Equipment -

1. The Primary Life Support System (PLSS) is a closed loop, self-contained system with the capability for liquid loop umbilical operation.

2. The Emergency Life Support System (ELSS) is an open loop, self-contained system.

3. The PLSS and ELSS should be structurally integrated to minimize weight and volume and to eliminate functional interfaces, and thus reduce the operational time required to stow, don/doff and recharge the equipment.

4. The Apollo ILC A7LB Suit is not adequate to meet the Shuttle EVA/IVA mobility requirements. Utilization of advanced state-of-the-art suit joints offer significant improvements in mobility and are less expensive to produce than the equivalent Apollo ILC A7LB suit joints.

5. It is possible to develop a suit sizing schedule such that selected off-the-shelf components could be assembled into one (1) unit for a particular crewman and thus provide the maximum possible mobility and comfort. It is expected that the number of sizes of each component can be reduced to a maximum of three (3) with the exception of the gloves which require six (6) sizes.

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2.1 (Continued)

6. A work platform located at the end of the Shuttle manipulator boom is a viable candidate to provide crewman translation and to permit the EVA crewman to service, maintain or repair payloads, and to assist in the conduct of experiments.

e. Emergency IV -

1. Lightweight, quick donning pressure suits are required for each of the crewmen for immediate donning in the event of loss of cabin pressure.

2. Portable one (1) hour rechargeable breathing systems are required for each of the crewmen for immediate donning in the event of a contaminated cabin.

3. On-board survival provisions should support the crew for up to ten (10) hours for mission aborts and for ninety-six (96) hours for completion of Shuttle-to-Shuttle rescue.

4. The capability for EVA transfer of the crew to a rescue Shuttle is required. A PLSS is used to support each crewman during the transfer. Additional PLSS's should be carried by the rescue Shuttle as required for each crewman.

f. Vehicle Interfaces -

1. EVA equipment should be stowed, donned/doffed and recharged in the lower crew compartment.

2. A suit ventilator is required during suit donning to provide crewman ventilation and cooling.

3. An RF hardline in the airlock is required to provide an RF link between the EVA crewman and the vehicle communications system while the crewman is in the airlock.

4. A vehicle liquid cooling system is recommended during the pressure integrity check and remains in use until activation of the PLSS thermal control subsystem.

5. The vehicle is required to provide PLSS recharge capability for water, oxygen and the battery, and for disposal of condensed water.

2.2 Recommendations

a. The baseline North American Rockwell breathing system, which is carried on board for each crewman, is an open loop system of ten (10) minutes duration. It is recommended that this system be modified to provide one (1) hour closed loop operation and be rechargeable.

b. Further study effort is required to evaluate candidate life support equipment concepts to provide emergency IV life support for on-board survival durations up to ninety-six (96) hours.

SECTION 3.0

STUDY METHODOLOGY

3.0 STUDY METHODOLOGY

The primary objectives of the Space Shuttle EVA/IVA Support Equipment Requirements Study were to establish a baseline EVA/IVA approach for Space Shuttle operations and to prepare specific system requirements. The general study approach consisted of:

a) Identification and analysis of representative Shuttle EVA/IVA tasks.

b) Establishment of study guidelines and constraints.

c) Determination of suit pressure level.

e) Establishment of life support systems requirements.

f) Establishment of translation requirements.

g) Establishment of restraint requirements.

h) Establishment of worksite provisions requirements.

i) Identification and analysis of emergency IV modes and establishment of emergency IV support requirements.

j) Establishment of Shuttle development flights support equipment requirements.

k) Establishment of vehicle support provisions requirements.

l) Preparation of the final report.

The study logic flow diagram is presented in Figure 3-1 to illustrate the approach utilized to achieve the objectives of this study program. The remainder of this volume presents the results of this study, in sequence, in accordance with the study logic flow diagram.

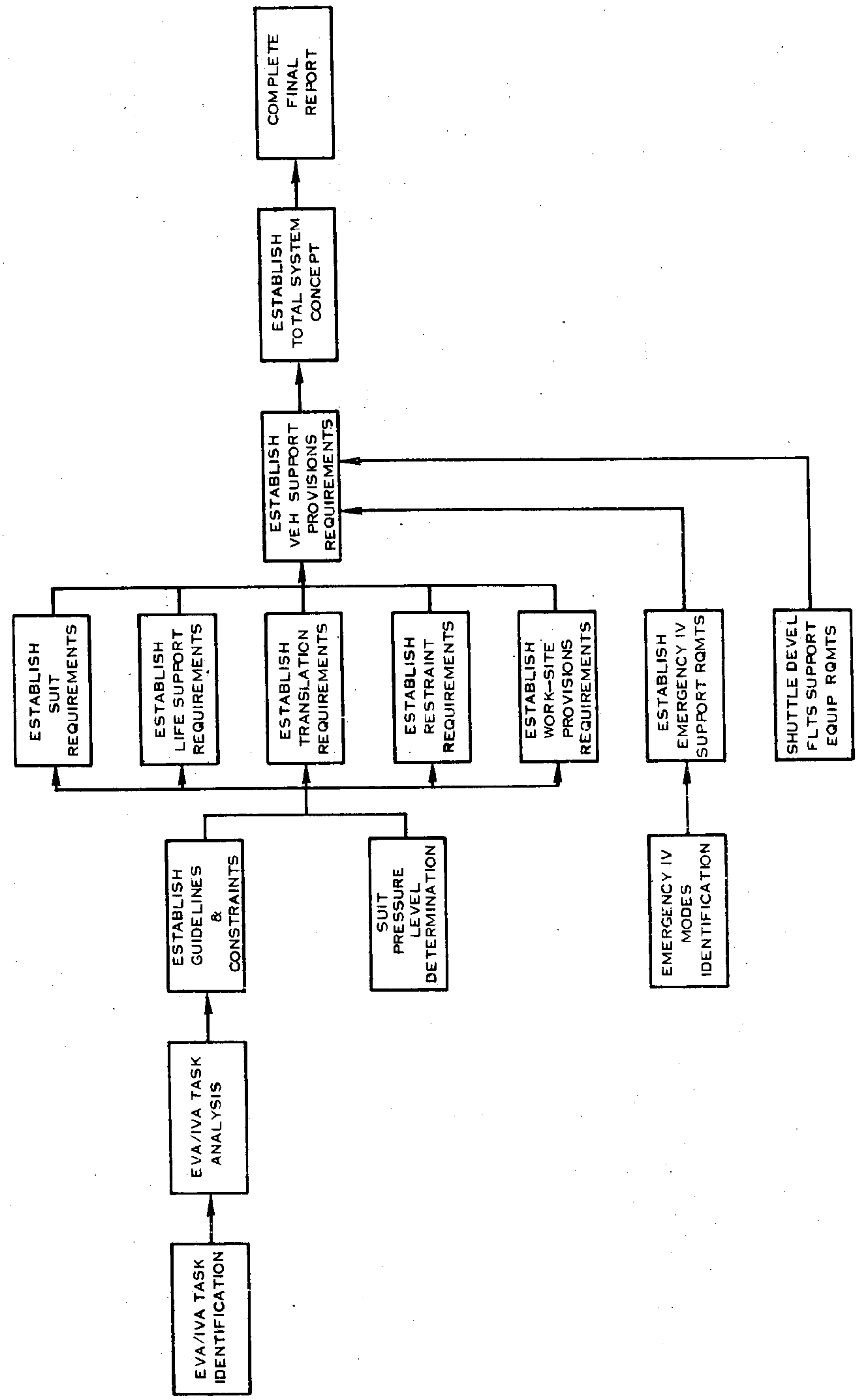


FIGURE 3-1 STUDY LOGIC FLOW DIAGRAM

SECTION 4.0

EVA/IVA TASK IDENTIFICATION AND ANALYSIS

4.0 EVA/IVA TASK IDENTIFICATION AND ANALYSIS

4.1 EVA/IVA Task Identification

4.1.1 General

In order to establish a baseline EVA/IVA approach to Space Shuttle operations, it was first necessary to identify the Space Shuttle EVA/IVA tasks. Utilizing the NASA/DOD Earth Orbit Shuttle Traffic Model (NASA MSC Internal Note Number 72-FM-71, March 21, 1972) as a basis, potential Shuttle EVA/IVA tasks were identified and evaluated. As depicted in Figure 4-1, Hamilton Standard was supported in this effort by three of the four potential Shuttle Orbiter Prime Contractors (NR, GAC and MDAC), numerous NASA personnel at both the Manned Spacecraft Center and the Marshall Space Flight Center, and the results of studies such as the GD/Convair Research and Applications Modules (RAM) study, and the NR Orbital Operations Study (OOS). In addition, the NASA Blue Book (reference Earth Orbital Research and Applications Investigations, NHB 7150.1, Volumes 1-8, January 15, 1971) was utilized to provide experiment descriptions and procedures.

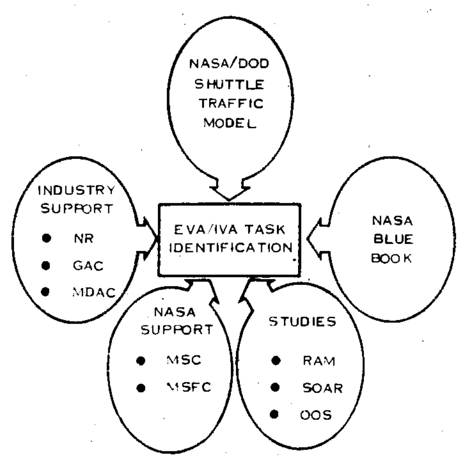


FIGURE 4-1. EVA/IVA TASK IDENTIFICATION

Each Shuttle payload on each Shuttle flight in the 1979 - 1990 time period was evaluated and the potential need for EVA/IVA support was determined. The results of this effort are presented in detail in Sections 1.0, 2.0 and 3.0 of Appendix A, Volume II of this report. Section 4.0 of Appendix A discusses how the Shuttle might be utilized to service or retrieve satellites which are presently operating in orbit or have been deactivated. The Shuttle EVA/IVA tasks identified as a result of this effort were classified into the following three (3) categories and are summarily described in the remainder of this section.

4.1.1 General - Continued

a. Planned
b. Unscheduled
c. Contingency

4.1.2 Planned Tasks

Planned tasks are defined as those tasks that are performed as the primary means of accomplishing Shuttle mission objectives. The general philosophy is that EVA/IVA shall be utilized for planned Shuttle operations only as required by the Shuttle payload(s). Although Shuttle payload deployment and retrieval operations are presently baselined so as not to require EVA/IVA operations, EVA/IVA is required for the conduct of some of the candidate Shuttle experiments and to support payload servicing and maintenance operations, and may be required to provide on-orbit checkout prior to final deployment of a payload.

4.1.2.1 Experiment Conduction

In the area of experiment conduction, the Shuttle Traffic Model defines two (2) specific payloads (reference Nos. 47 and 49) that are EVA experiments; the Manned Work Platform (MWP) is scheduled for flight in 1981 and the Astronaut Maneuvering Unit is scheduled for flight in 1980. An artist's concept of the MWP is presented in Figure 4-2. The objective of both of these experiments is to develop an understanding of and a control over problems associated with utilization of self-powered maneuvering equipment to perform specified tasks in orbit. In addition, numerous Sortie lab experiments proposed for Space Shuttle missions will require EVA.

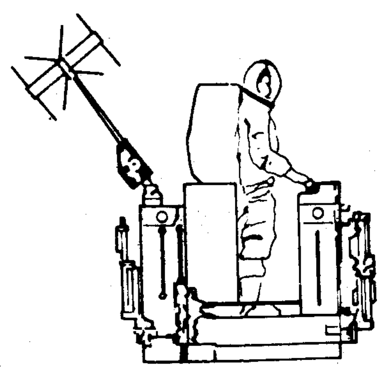


FIGURE 4–2. MANNED WORK PLATFORM

4.1.2.1 Experiment Conduction - Continued

The following examples were identified in Volume II - technology of the NASA Blue Book:

	Experiment Title	Reference Paragraph
a.	Real Time Contamination Measurements	1.4.2
b.	Surface Degradation Experiment	1.4.3
c.	Contaminant Cloud Composition Measurement	1.4.4
d.	Integrated Real-Time Contamination Monitor: Optical Module Evaluation	1.4.6
e.	Active Cleaning Technique Evaluation	1.4.7

EVA is required in support of these experiments for deployment and retrieval of exposure samples, in situ measurements of contamination effects, and for actual conduction of the active cleaning experiments. Another representative set of examples were identified in Volume VII - technology of the NASA Blue Book:

	Experiment Title	Reference Paragraph
a.	Oxygen Recovery and Biowaste Resistojet	4.4.1
b.	Thermal Coating Refurbishment in Space	4.4.3
c.	Leak Detection and Repair	4.4.5
d.	Maintainable Attitude Control Propulsion System	4.4.6
e.	Space Exposure Effects on Material Bulk Properties	4.4.10

EVA is required in support of these experiments for installation, inspection and maintenance of experiment equipment which is located external to the spacecraft.

4.1.2.2 Service and Maintenance

The second area in which planned EVA/IVA is required is for payload servicing and maintenance. The basic service and maintenance functions required by payloads and to be provided by the Shuttle Orbiter are:

a. Inspection

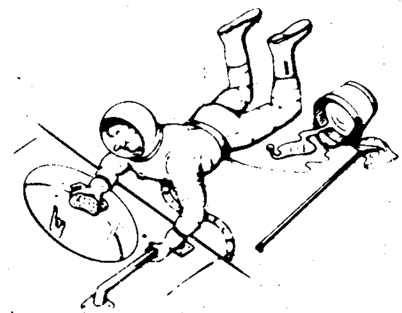
b. Cleaning

c. Replacement of Malfunctioning items

d. Replacement of life-limited items

e. Updating of instrumentation

f. Recharging of expendables



As shown in Table 4-1, the Shuttle Traffic Model indicates there are a total of 62 revisits planned to the following payloads in the 1979 to 1990 time period. This indicates the importance attached to payload servicing and maintenance:

PAYLOAD	NUMBER OF REVISITS
High Energy Astronomy Observatory (HEAO)	22
Large Space Telescope (LST)	17
Large Solar Observatory (LSO)	13
Large Radio Observatory (LRO)	10
Total	62

TABLE 4-1. REVISIT MISSIONS

4.1.2.2 Service and Maintenance - Continued

There are five (5) basic payload service and maintenance mode options available for Shuttle operations:

a. Ground Refurbishment - Ground refurbishment consists of payload retrieval in orbit and return to Earth. All service and maintenance operations are then performed in a controlled environment on Earth. Upon completion of these operations, the payload is then launched and placed in orbit once again. While this mode permits the most complete service and maintenance of the payload, it also appears to be the most costly.

b. On-Orbit, Pressurized (Figure 4-3) - On-Orbit pressurized service and maintenance of large payloads such as the LST require deployment of a resupply module and then docking of the payload to the resupply module. When possible, systems or equipment required to support maintenance operation will be stored in the resupply module. However, a limited amount of maintenance-related equipment can be pre-installed in the support systems module (SSM) to reduce crew time requirements or increase crew safety. The major advantage of this approach is that it allows the crewman to work in a shirt sleeve environment, thus allowing him to perform at his maximum efficiency. However, this mode has disadvantages in that it does not permit access to external items, it opens up the payload, especially the Scientific Instrument Package (SIP), to the "unclean" Shuttle environment, and it may be hazardous for refueling operations (i.e., - hydrazine).

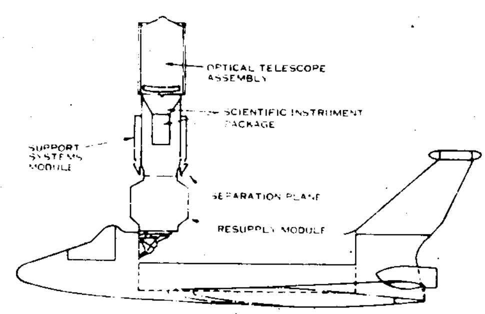


FIGURE 4—3. ON ORBIT, PRESSURIZED MAINTENANCE OPTION

c. On-Orbit, Unpressurized with IVA - The on-orbit, unpressurized with IVA mode is similar to the on-orbit, pressurized mode except that servicing is performed in the unpressurized payload, and the crewman is suited. This mode helps to minimize the potential cleanliness problem mentioned in b. above. However, the payload must be designed to permit a suited IVA crewman to perform maintenance operations within the payload.

4.1.2.2 Service and Maintenance - Continued

d. On-orbit, unpressurized with IVA and/or EVA - This maintenance mode option is similar to the mode described in c. above except that the additional capability of EVA maintenance has been added. This capability provides access to the external equipment for servicing.

e. On-Orbit, Unpressurized (Figure 4-4) - The on-orbit, unpressurized maintenance option permits total maintenance of the payload on each revisit, requires minimum maintenance time, and has a minimum of Shuttle interfaces. In addition, this concept permits ground calibration and test of spares and provides maximum flexibility for payload redesign. Although the crewman is suited and pressurized for this mode, it is anticipated that he would still have the required mobility and dexterity to successfully complete his mission. The major disadvantage of this concept is it requires module replacement (versus component replacement), thus requiring mandatory replacement of many non-life-limited items and more elaborate storage provisions in the Shuttle payload bay.

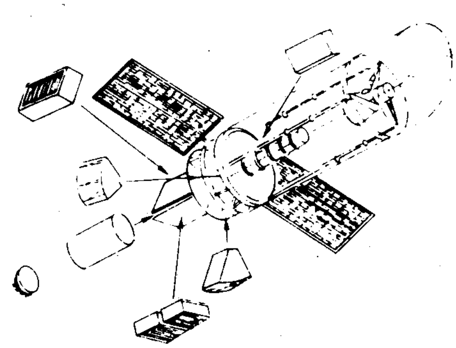


FIGURE 4-4. ON ORBIT, UNPRESSURIZED MAINTENACE OPTION

Note that the majority of these options require an EVA/IVA capability to support payload servicing operations. As mentioned in paragraph 4.1.2.1, the NASA Blue Book identified an experiment in which an EV crewman evaluates a cleaning unit. It is anticipated that an EV crewman can operate a similar cleaning device to clean critical payload equipment such as telescope lenses and mirrors, camera lenses, sensitive instrumentation, solar panels, etc. An artist's sketch representing an EV crewman preparing to clean the star tracker at the end of the LST is presented in Figure 4-5 as an example of payload servicing and maintenance. In this concept, the crewman mounts a work station at the end of the manipulator and the manipulator is used to translate the crewman from the airlock to the worksite.

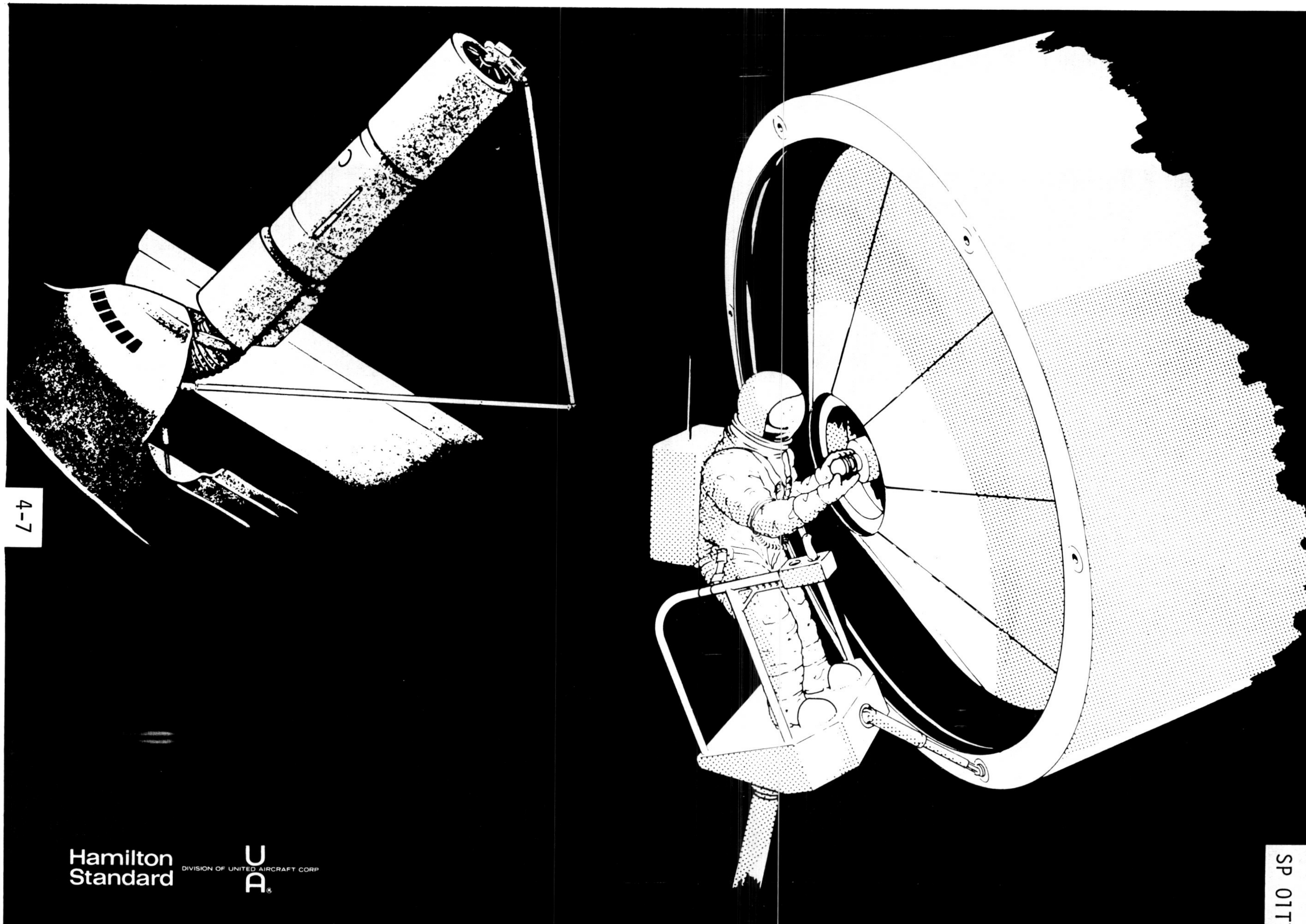


FIGURE 4–5. PAYLOAD SERVICE AND MAINTENANCE

4.1.2.2 Service and Maintenance - Continued

The crewman operates the manipulator from his work station. Dutch shoes and a waist tether are provided to restrain the crewman. The manipulator is attached to the LST by way of a telescoping connection to secure it to the worksite and thus prevent excessive flexure or bending of the manipulator boom due to crewman work forces.

4.1.2.3 On-Orbit Checkout

Approximately 50% of payload anomalies and failures associated with payloads launched with expendable boosters appear during the launch phase. Due to this high degree of "infant mortality", it might be very desireable to provide an on-orbit EVA capability for checkout prior to final deployment of a payload by the Shuttle. Besides decreasing the "infant mortality" rate of payloads, an on-orbit EVA checkout capability could also result in relaxed design and testing requirements for payloads and thus lower total payload cost.

4.1.3 Unscheduled Tasks

Unscheduled tasks are defined as those tasks performed as an alternate means of accomplishing Shuttle mission objectives, usually preceded by a malfunction of the primary means. The NASA Space Shuttle Orbiter Request for Proposal (RFP Number 9-BC421-67-2-40P) stated that the primary objective of the Space Shuttle Program is to provide a new space transportation capability that will:

a) Reduce substantially the cost of space operations.

b) Provide a future capability designed to support a wide range of scientific, defense and commercial uses.

In order to achieve this primary objective, the Shuttle must be capable of successfully performing the functions of deployment, retrieval, and servicing and maintenance of various types of payloads. In the event that any of the remotely-controlled electromechanical devices which perform these functions does malfunction, unshceduled EVA/IVA may be required to prevent a mission abort and successfully complete the mission. Since mission aborts cannot be tolerated due to the cost involved (approximately $10 mission per flight) and the loss of public confidence incurred, a backup EVA/IVA capability is required.

Sample sequential listings of the remotely-controlled automated steps required to deploy, retrieve and service payloads are presented in Figures 4-6, 4-7 and 4-8 respectively. EVA/IVA is capable of backing up each of these functional steps in the event of a malfunction. However, these systems must be designed to be compatible with the crewman in order to ensure successful implementation of EVA/IVA as a backup capability.

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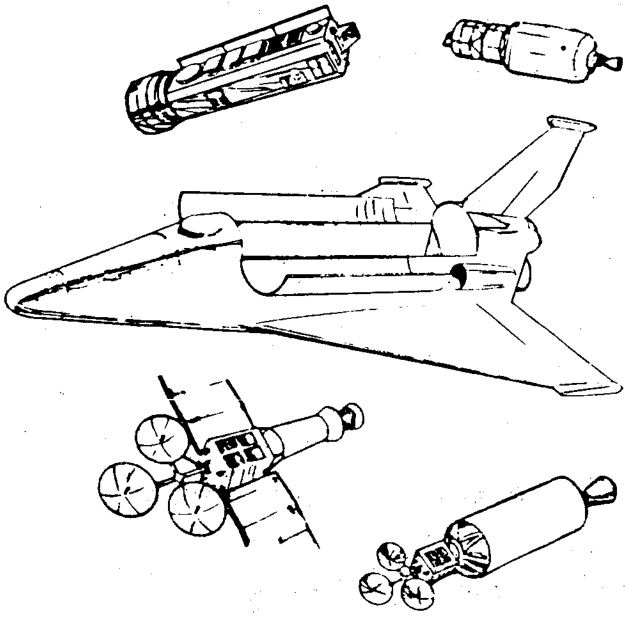
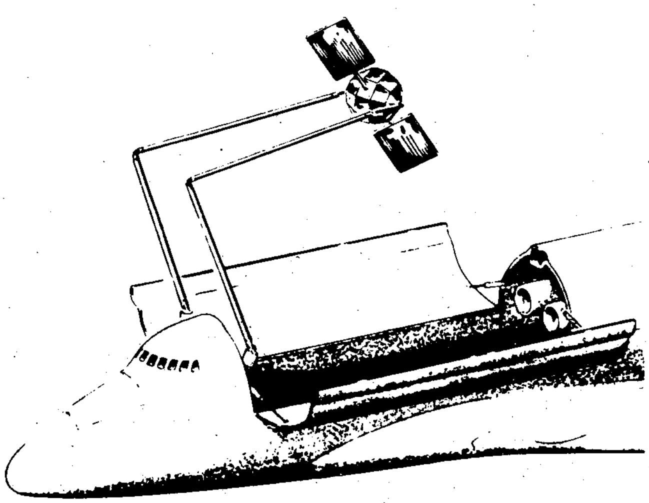
4.1.3 Unscheduled Tasks - Continued



- OPEN PAYLOAD BAY DOORS
- DEPLOY RADIATOR
- RELEASE MANIPULATOR
- ENGAGE PAYLOAD
- RELEASE PAYLOAD TIEDOWNS
- RAISE PAYLOAD FROM BAY
- RELEASE PAYLOAD
- SECURE MANIPULATOR

FIGURE 4–6. ORBITER OPERATIONS – DEPLOYMENT



- OPEN PAYLOAD BAY DOORS
- DEPLOY RADIATOR
- RELEASE MANIPULATOR
- LOCATE AND GRAPPLE PAYLOAD
- TRANSFER PAYLOAD INTO PAYLOAD BAY
- SECURE PAYLOAD
- RELEASE PAYLOAD FROM MANIPULATOR
- SECURE MANIPULATOR
- DEFUEL PAYLOAD

FIGURE 4–7. ORBITER OPERATIONS – RETRIEVAL

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4.1.3 Unscheduled Tasks - Continued

- OPEN PAYLOAD BAY DOORS
- DEPLOY RADIATOR
- RELEASE MANIPULATOR
- ENGAGE SERVICE MODULE WITH MANIPULATOR
- RELEASE SERVICE MODULE TIEDOWNS
- RAISE SERVICE MODULE FROM BAY
- DOCK SERVICE MODULE TO FRONT AIRLOCK
- CONDUCT SERVICING OPERATIONS
- UNDOCK SERVICE MODULE AND TRANSFER BACK TO PAYLOAD BAY
- SECURE SERVICE MODULE
- RELEASE SERVICE MODULE & SECURE MANIPULATOR

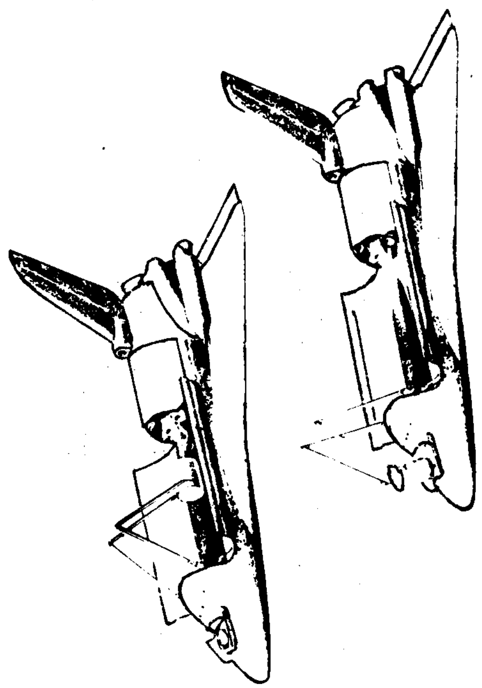

FIGURE 4–8. ORBITER OPERATIONS – SERVICING

4.1.4 Contingency Tasks

Contingency tasks are defined as those tasks performed to alleviate or cope with a condition which could affect the safety of the Shuttle crew, or the crew of another spacecraft. Contingency modes were classified into three categories:

a. Emergency IV - Emergency IV modes include all failure conditions affecting crew safety where operations performed by the crew are conducted within the Shuttle Orbiter. Examples of such failure conditions include fire, explosion, contamination and loss of pressure.

b. Emergency EV - Emergency EV modes include all failure conditions affecting crew safety where operations performed by the crew are conducted in an EV mode. Examples of such failure conditions include inability to undock from a payload, inability to close the payload bay doors and inability to stow the radiator. All of these failure conditions could prevent the Shuttle from returning to Earth unless alleviated.

c. Rescue - Rescue modes include all operations associated with the recovery and transfer of a crewman or crewmen from a potentially hazardous area to a safe area. Examples of such situations include an incapacitated EV crewman, who has lost his tether, or the inability to alleviate an emergency EV condition which prevents the Shuttle from returning to Earth. In the event the Shuttle is not able to return to Earth, another Shuttle is required to rescue the stranded crewmen. Figure 4-9 depicts a Shuttle rescue mission which is required due to the inability of the stranded Shuttle vehicle to undock from the payload which it was servicing. Note that in this situation, an extravehicular space transfer of the stranded crew is required.

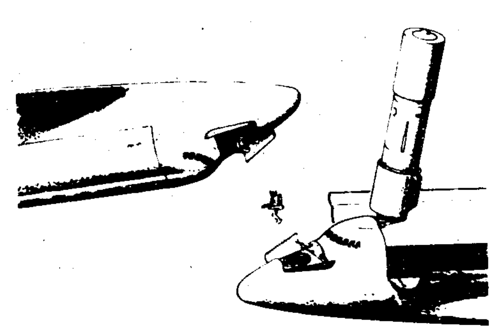

FIGURE 4-9. SHUTTLE TO SHUTTLE RESCUE

4.1.5 Conclusions

The past history of the Gemini and Apollo EVA missions has demonstrated that EVA can be used safely for productive tasks. Based on this demonstrated capability and an evaluation of the Shuttle missions, their payloads, and the potential need for EVA/IVA, the following major conclusions were drawn:

a. EVA/IVA operations are required for planned conduction of certain experiments.

b. EVA/IVA enhances overall Shuttle flexibility and capability for servicing payloads by providing the ability to conduct "total" maintenance.

c. EVA/IVA might be required for on-orbit checkout prior to final deployment of a payload.

d. EVA/IVA capability is required for unshceduled and contingency operations to prevent mission aborts and ensure crew safety.

4.2 EVA/IVA Task Analysis

4.2.1 General

Once the potential Shuttle EVA/IVA tasks have been identified, the next logical steps were to analyze these tasks in detail and generate meaningful statistical information to aid in the determination of EVA equipment requirements. The logic utilized in the EVA/IVA task analysis effort is presented in Figure 4-10.

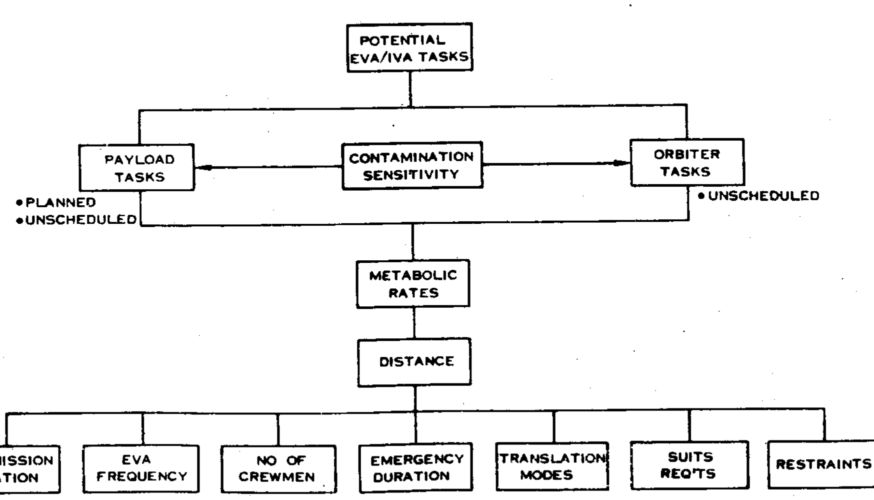

FIGURE 4—10. EVA/IVA TASK ANALYSIS LOGIC

4.2.1 General - Continued

The groundrules used in this analysis effort were:

a. One (1) man EVA/IVA's are used where tasks can be performed easily by one man and when a short duration is required to complete the tasks.

b. Two (2) man EVA/IVA's are used where possible to reduce on-orbit operational times and the number of airlock depressurizations per Shuttle flight. However, dual EVA's are only considered where both crewmen could be fully productive for the majority of the EVA mission.

c. During revisit missions for payload service and maintenance, 1/4 to 1/3 of serviceable equipment will be serviced.

A summary of the results of the EVA/IVA task analysis effort is presented in Table 4-2 and indicates that 242 of the 407 NASA Shuttle flights require planned EVA, and these 242 flights require a total of 486 planned EVA missions.

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	TOTAL
TOTAL FLIGHTS	21	20	29	25	29	27	47	37	48	38	49	37	407
FLIGHTS REQUIRING EVA	0	5	8	11	9	13	37	30	33	32	37	27	242
NO. OF EVA S	0	23	37	39	35	44	63	54	45	34	52	40	486

TABLE 4-2. POTENTIAL PLANNED EVA MISSIONS

The remainder of this section presents the detailed results of the EVA/IVA task analysis effort.

4.2.2 Metabolic Rates

Metabolic rates for accomplishment of discrete elements of EVA/IVA tasks which were common to most EVA/IVA missions were estimated and the results are presented in Table 4-3.

4.2.2 Metabolic Rates - Continued

TASK	METABOLIC RATE (BTU/HR)	TASK	METABOLIC RATE (BTU/HR)
OPEN AND CLOSE AIRLOCK HATCH	800	MAINTENANCE, SERVICE OR REPAIR	
OPEN AND CLOSE ACCESS PANELS, SHROUDS, ETC.	1000-1400	A) USING HAND TOOLS	1000
MANUAL CREWMAN TRANSLATION		B) USING POWER TOOLS	700-800
A) MORE THAN 10 FEET	900	PAYLOAD REFUELING	800
B) LESS THAN 10 FEET	800	MONITOR OR TROUBLESHOOT ORBITER OR PAYLOAD	600-800
POWERED TRANSLATION		CALIBRATE, ADJUST OR REPOSITION EXPERIMENT OR ORBITER EQUIPMENT	600-700
A) WORK PLATFORM OR AMU	700	INSTALL OR REMOVE DATA PACKAGES	900-1000
B) HANDHELD MANEUVERING UNIT	800	REPLACE FAILED OR EXPENDED COMPONENTS	1000-1400
C) MANIPULATOR/WORK STATION	700	MANUAL DEPLOYMENT OR RETRIEVAL OF PAYLOADS	1000-1400
INGRESS/EGRESS TO CREW STATION, OR WORKSITE	900	DATA ACQUISITION	
ATTACHMENT OR RELEASE OF CREWMAN RESTRAINTS	900	A) ACTIVE ROLE	800
RESTRAIN OR RELEASE WORKSITE TOOLS	700-800	B) PASSIVE ROLE	500
GENERAL WORKSITE HOUSEKEEPING	800	VEHICLE OR EXPERIMENT ASSEMBLY OR CONSTRUCTION	1200-1600
DESIGNATED REST PERIOD	400	RESCUE TASKS	
STOW AND UNSTOW CARGO	1000	A) SELF-RESCUE, UNASSISTED	1800-2400
TRANSFER EQUIPMENT INTO AND OUT OF AIRLOCK OR HATCHES	900	B) SELF-RESCUE ASSISTED (AMU OR CREW MEMBER)	1400-1800
MANUALLY TRANSPORT CARGO		C) RESCUE TEAM MEMBERS	1600-2000
A) SMALL (LESS THAN 100 LBM)	800-1000		
B) LARGE (MORE THAN 100 LBM)	1000-1600		

TABLE 4-3. METABOLIC RATE AS A FUNCTION OF EVA/IVA TASK

4.2.3 Distances

The 486 potential planned EVA tasks were operationally analyzed and the maximum distance traveled from the airlock was determined. In addition, 1148 potential unscheduled EVA tasks were also identified and operationally analyzed to determine the maximum distance traveled from the airlock. The results of both of these analyses are presented in Figure 4-11. As an example, 29% of the planned tasks and 72% of the unscheduled tasks require that the crewman travel a maximum distance of between 50 to 60 feet to complete his mission. The maximum estimated distance from the airlock for both planned and unscheduled tasks is 100 feet, except for the AMU and MWP experiments referenced in the Shuttle Traffic Model and described in detail in the NASA Blue Book.

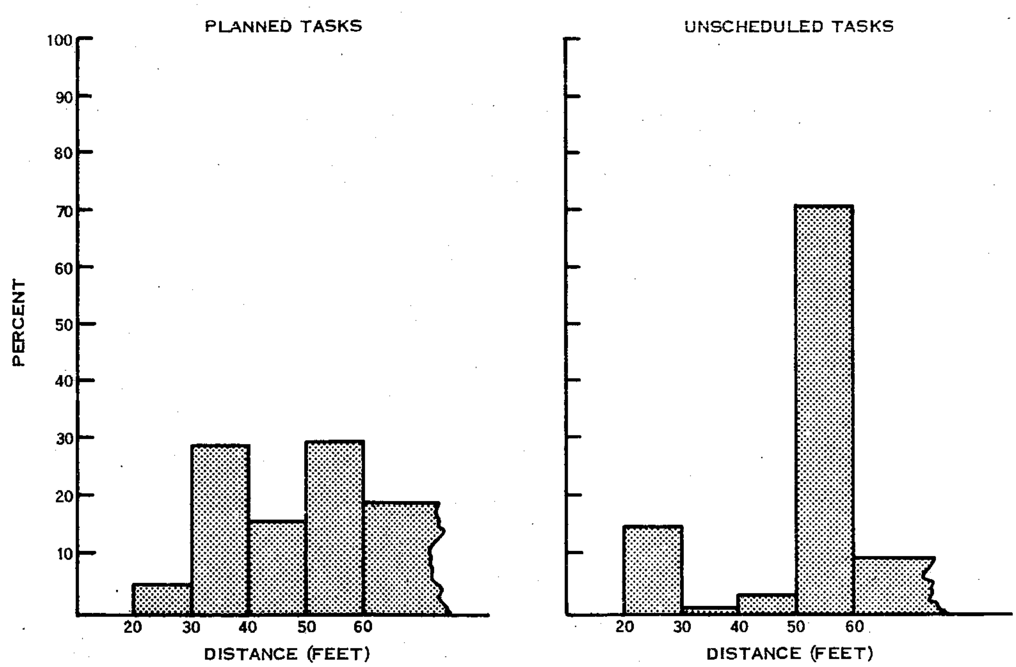

FIGURE 4–11. TASKS AS A FUNCTION OF DISTANCE FROM AIRLOCK

4.2.4 EVA Mission Duration

The 486 potential planned EVA tasks identified were analyzed and a duration for each was determined based on a single crewman EVA. In an effort to reduce on-orbit EVA time and the number of airlock depressurizations, dual EVA's were considered where both crewman could be fully productive for the majority of the EVA mission. The results of this effort are presented in Figure 4-12. Note that only 3.5% of the EVA missions require an EVA equipment duration capability in excess of four (4) hours and these are the AMU and MWP experiments.

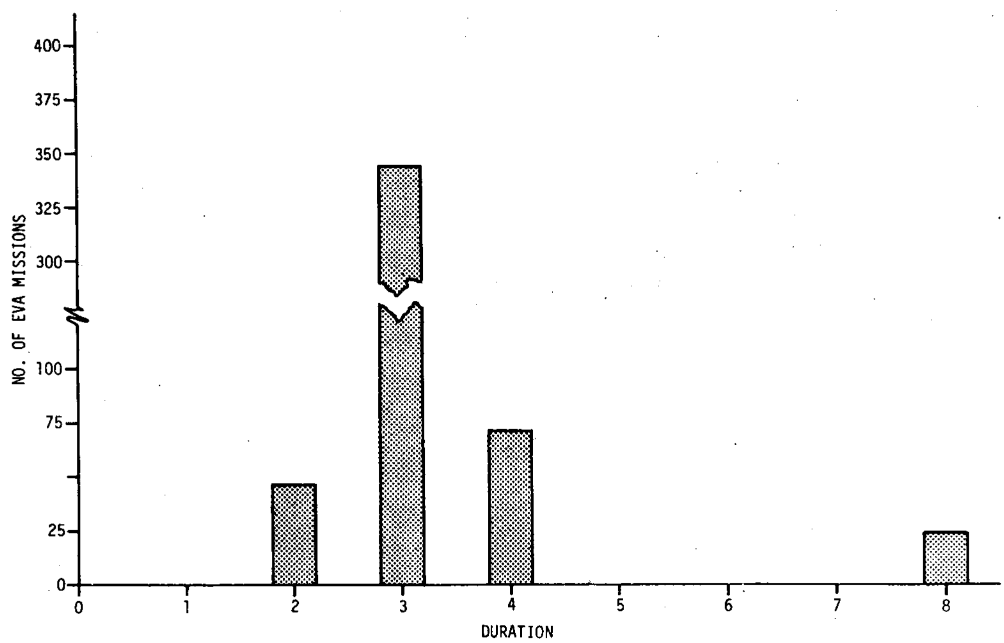

FIGURE 4-12. EVA DURATION—PLANNED TASKS

4.2.4 <u>EVA Mission Duration</u> - Continued

A representative timeline for a 4-hour, dual EVA depicting servicing of a LST is shown in Figure 4-13.

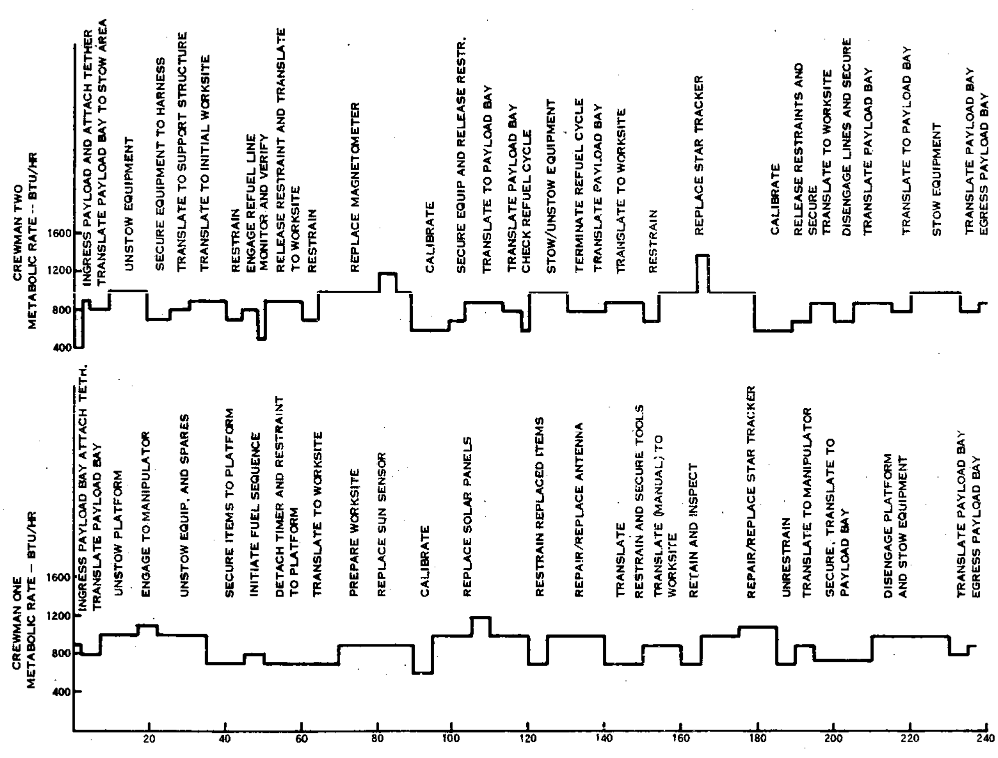

FIGURE 4—13. REPRESENTATIVE DUAL EVA MISSION TIMELINE— LST SERVICING

A similar effort was conducted to determine EVA duration of unscheduled tasks. The 1148 potential unscheduled EVA tasks were analyzed, a determination of single versus dual crewman EVA was conducted, and a duration for each unscheduled EVA task was determined. The results of this effort are presented in Figure 4-14. Note that 83.5% of these tasks require an EVA duration of four (4) hours or less. It was determined

4.2.4 EVA Mission Duration - Continued

that the remaining 16.5% of these tasks could be accomplished by two dual EVA's with the crewmen returning to the vehicle after the first EVA, recharging their equipment, and then returning to the worksite to complete their mission.

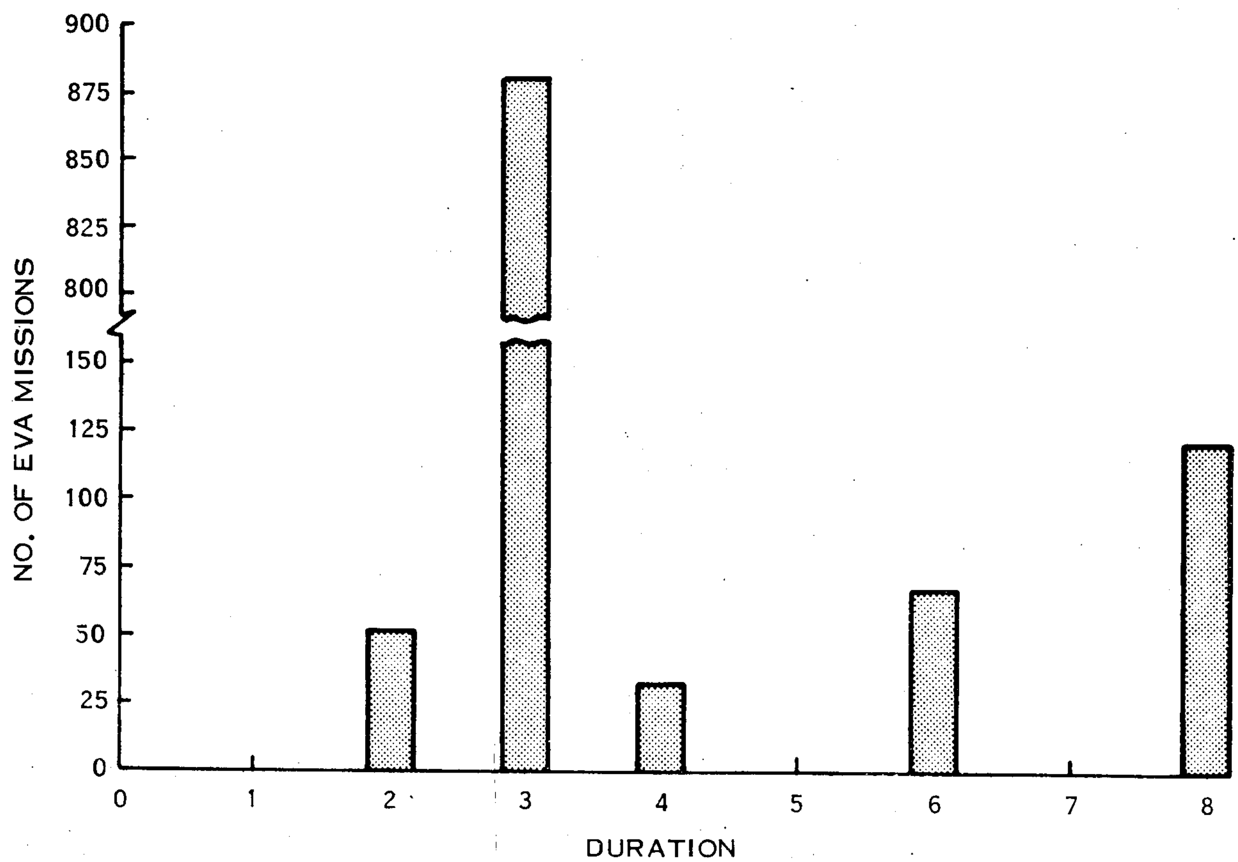

FIGURE 4—14. EVA DURATION—UNSCHEDULED TASKS

The conclusion emanating from this effort is that the EVA equipment shall be capable of supporting four (4) hour EVA mission duration.

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4.2.5 Planned EVA Frequency

Figure 4-15 depicts the number of NASA Shuttle flights as a function of potential planned airlock depressurizations per flight. Note that 240 of the 242 flights which require EVA will require six (6) or less airlock depressurizations. The remaining two (2) flights are those which carry the AMU and MWP experiments and additional payload provisions could be carried on these flights to accomodate the increased number of airlock depressurizations required.

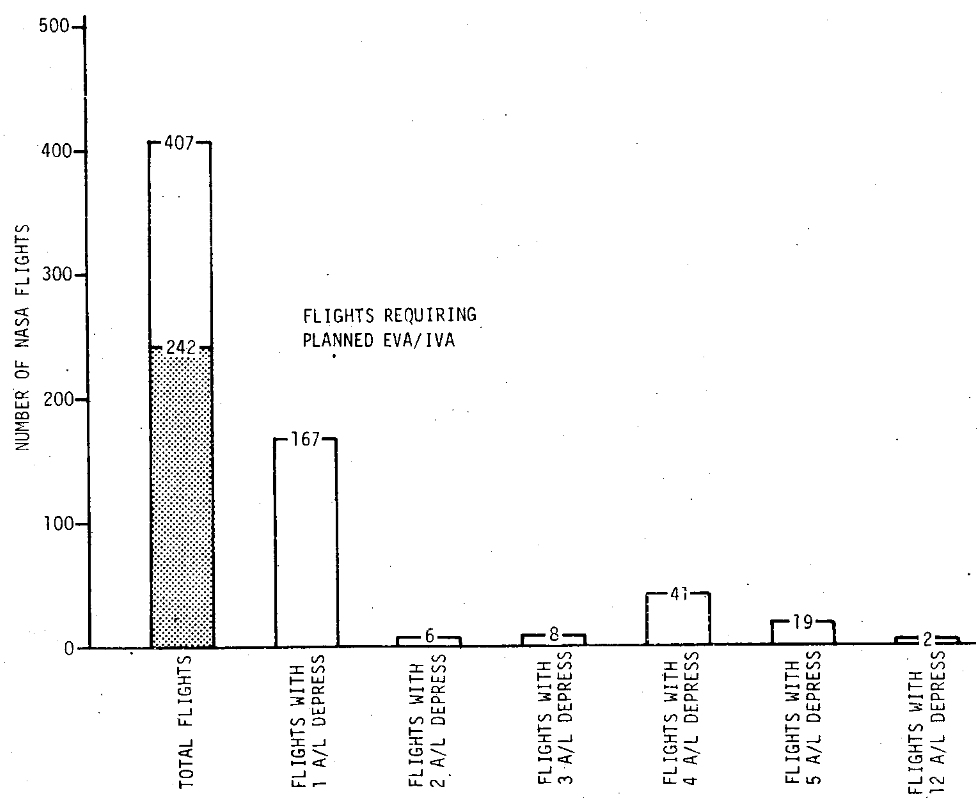

FIGURE 4–15. PLANNED EVA FREQUENCY

4.2.5 Planned EVA Frequency - Continued

Figure 4-16 presents the total planned EVA/IVA man-hours per flight as a function of airlock depressurizations (or EVA excursions). Results indicate, except for the unique AMU and MWP experiment missions, that a maximum of 32 man-hours of EVA/IVA capability is required. Therefore, if the EVA equipment flies charged, the Shuttle Orbiter has to provide 24 man-hours of recharge capability. For the two (2) flights which carry the AMU and MWP experiments, additional EVA equipment recharge capability could be carried to accomodate the increased EVA recharge requirements or the scope of the experiments could be reduced.

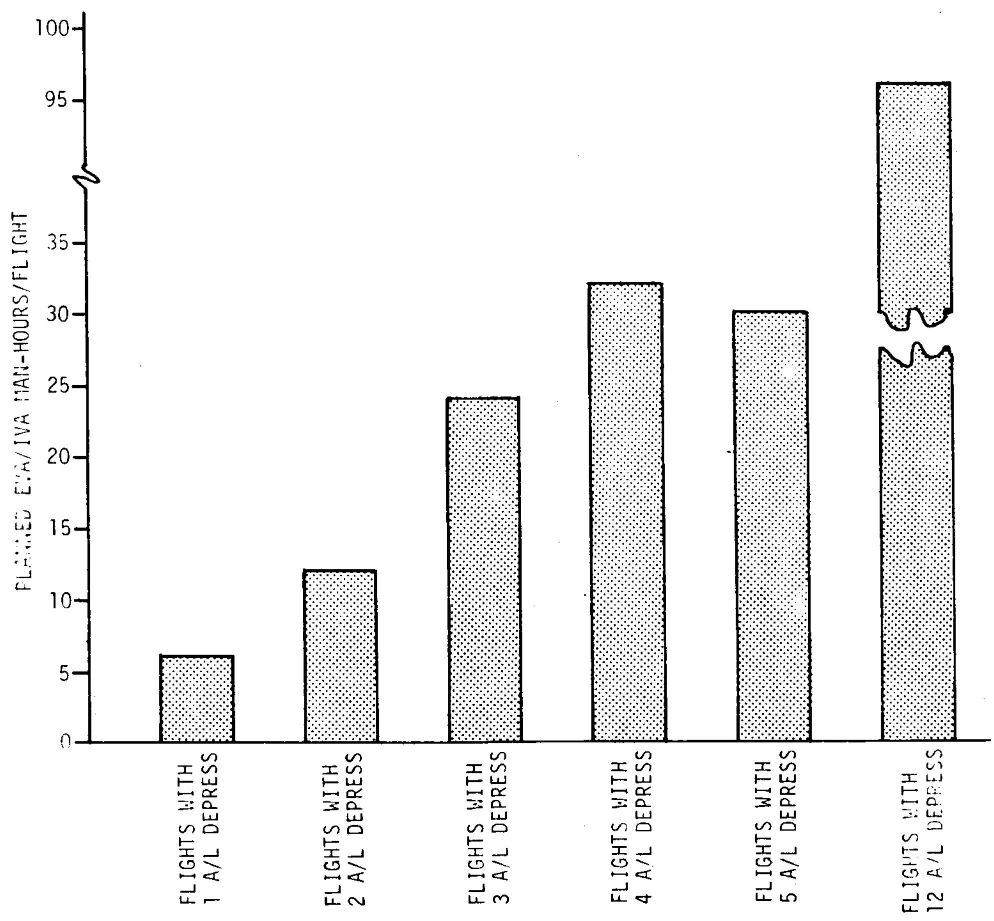

FIGURE 4-16. EVA/IVA MAN-HOURS PER FLIGHT

4.2.6 Number of Crewmen

An assessment of the number of crewmen required to perform the potential planned and unscheduled EVA tasks was conducted and the results shown in Table 4-4. Eighty-three (83) percent of the potential planned EVA tasks and ninety-seven (97) percent of the potential unscheduled EVA tasks require dual crewmen EVA's.

	SINGLE	DUAL	TOTAL
PLANNED	83	403	486
UNSCHEDULED	35	1113	1148

TABLE 4-4 NUMBER OF CREWMEN REQUIRED FOR EVA

4.2.7 Emergency Duration

The logic utilized to establish the EVA Emergency Life Support System (ELSS) duration requirement is depicted in Figure 4-17.

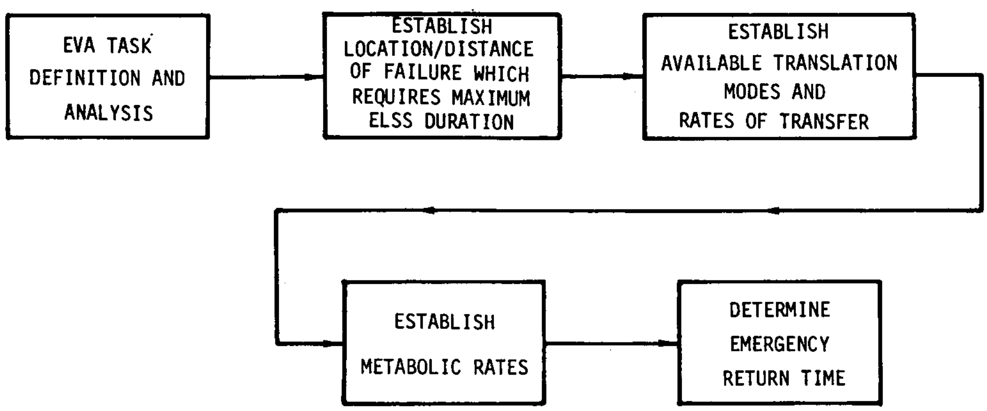

FIGURE 4—17. EMERGENCY LIFE SUPPORT SYSTEM DURATION REQUIREMENTS LOGIC DIAGRAM

All of the planned EVA tasks were evaluated to determine the worst case emergency duration tasks. The six (6) planned EVA tasks that appeared to require the greatest EVA emergency duration requirement (in the event an emergency situation occurs requiring the crewman to activate his ELSS) were

4.2.7 Emergency Duration - Continued

selected. The metabolic rates assumed for emergency EVA operations were 1500 Bty/hr. nominal with a peak rate of 2000 Btu/hr for five minutes maximum. Based upon the metabolic rates, distance from the airlock and mode and rate of translation available, emergency return times were estimated for these six (6) planned EVA tasks. Results of this evaluation are presented in Table 4-5. Note that the longest estimated return time was 11.7 minutes for the MWP experiment.

ACTIVITY/TASK	ASSUMPTIONS: DISTANCE FROM AIRLOCK (FT)	MODE OF TRANSLATION	RATE OF TRANSLATION (FPS)	FAILURE VERIFICATION DURATION (SEC)	AIRLOCK REPRESS RATE (PSI/SEC)	EMERGENCY RETURN TIME (MINUTES)
SERVICING/MAINTENANCE						
HEAO, LST, LSO, LRO	100	MANUAL	1.0	180	0.1	9.3
	100	MANIP./MAN.	2.0	180	0.1	8.5
	100	POWER-ASSIST	6.0	180	0.1	5
AMU EXPERIMENT	200	AMU	1.0	180	0.1	7.7
MWP EXPERIMENT	6600	MWP	15.0	180	0.1	11.7

TABLE 4—5. EVA EMERGENCY DURATION

A representative emergency mode timeline for a failure occurring during servicing of the LST is shown in Figure 4-18. The mode of translation for this timeline is manipulator-assisted/manual.

4.2.7 Emergency Duration - Continued

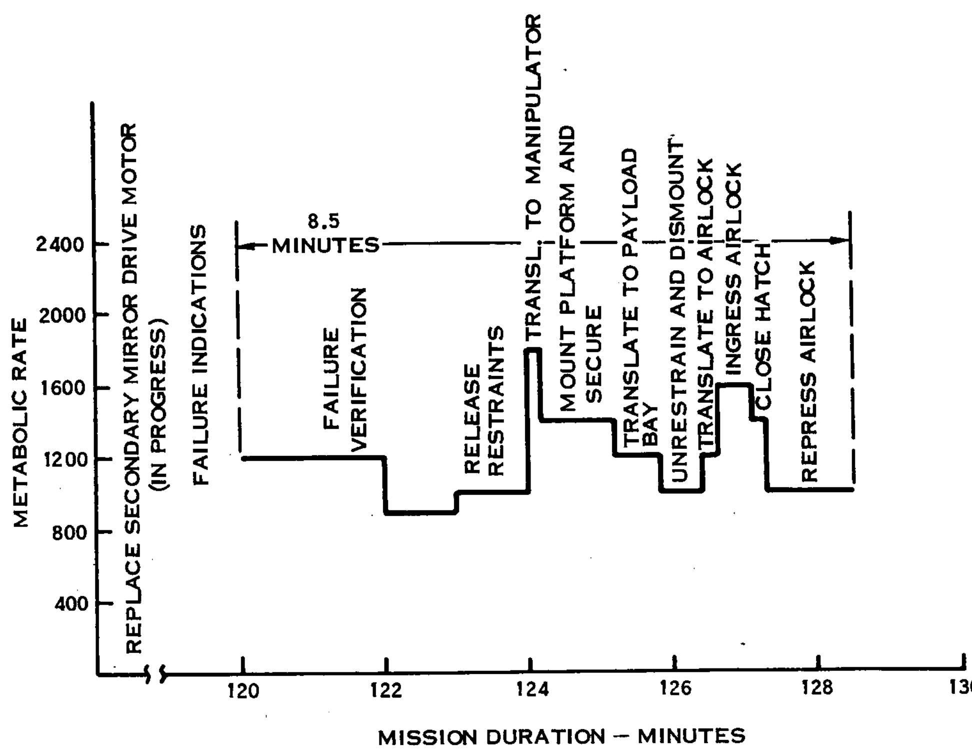

FIGURE 4–18. EMERGENCY MODE TIMELINE

4.2.8 Translation Modes

The logic utilized to select the optimum translation modes for the potential planned and unscheduled EVA tasks is presented in Figure 4-19.

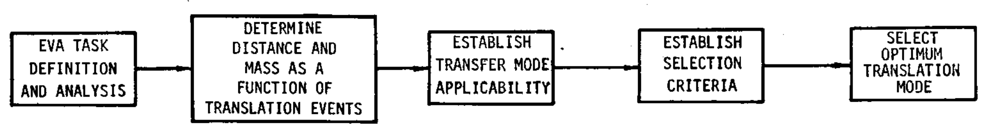

FIGURE 4–19. TRANSLATION MODES SELECTION LOGIC DIAGRAM

Based upon the results of the EVA/IVA tasks identification effort, the mass of equipment (cargo, tools, lights, etc.) to be carried by the EV/IV crewman was estimated. The results of this effort for each of the 645 planned EVA tasks is depicted in Figure 4-20. As an example, for 20% of the planned EVA/IVA tasks, the crewman will transport mass in the range of 20-40 pounds. Maximum estimated mass to be transferred is 195 pounds.

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4.2.8 Translation Modes - Continued

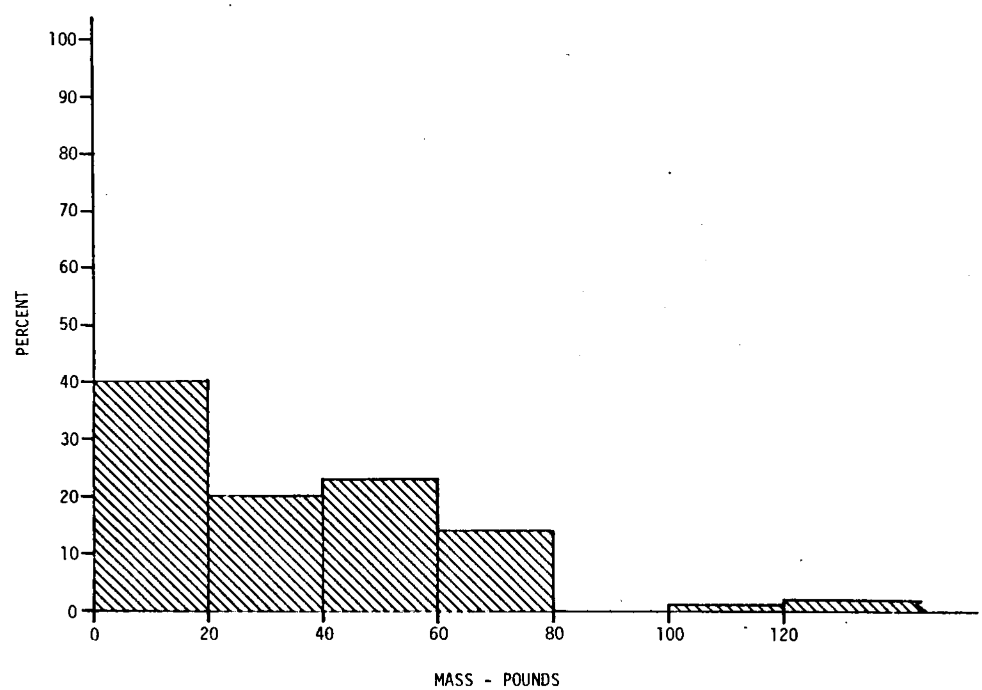

FIGURE 4-20. PLANNED TASK AS A FUNCTION OF MASS

The results of the planned task as a function of mass analysis was expanded to include planned tasks as a function of both mass and distance traveled. The results of this effort are shown in Figure 4-21.

4.2.8 <u>Translation Modes</u> - Continued

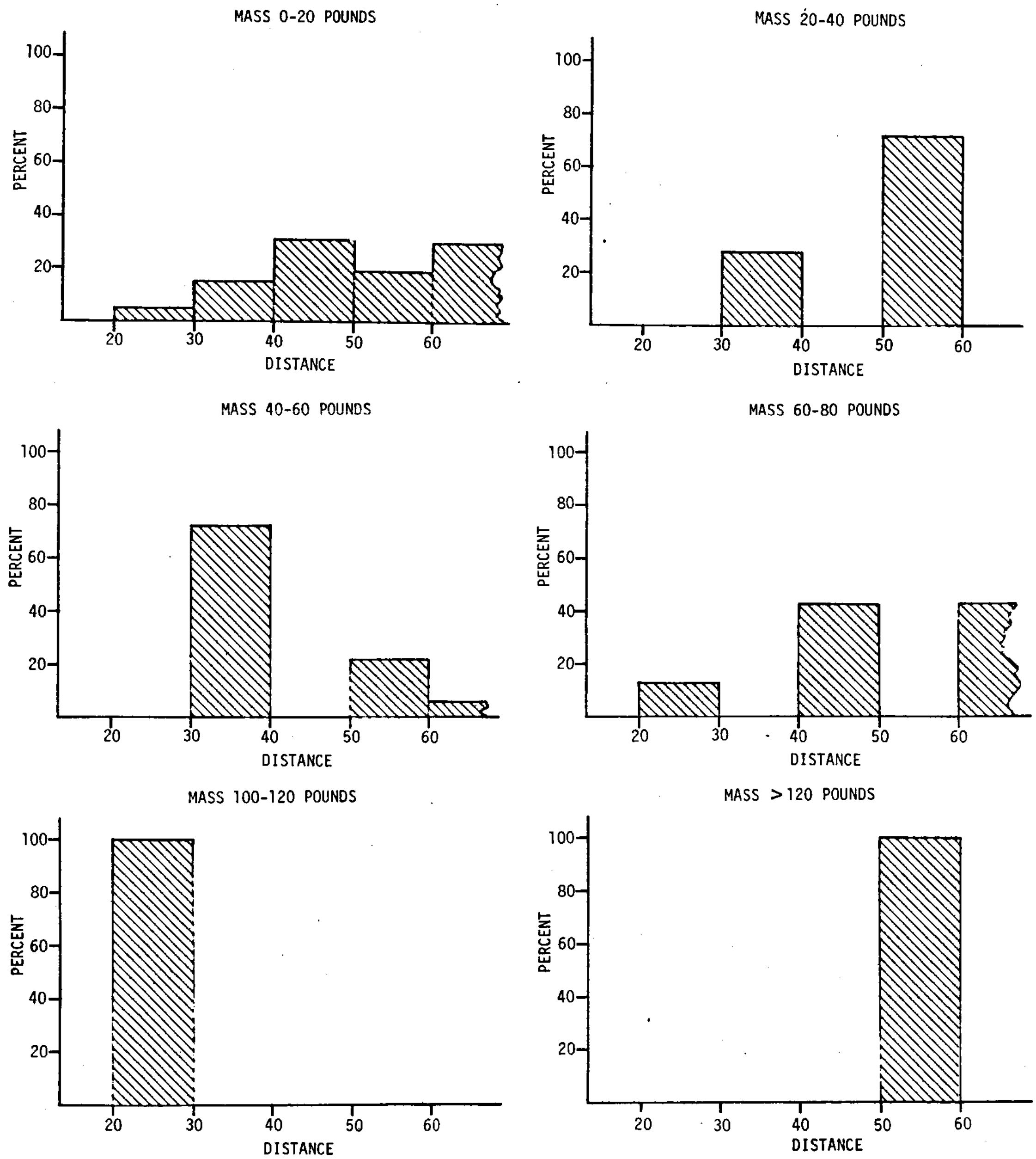

FIGURE 4—21 PLANNED TASKS AS A FUNCTION OF MASS/DISTANCE

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4.2.8 Translation Modes - Continued

There are 1096 translation events occurring during the 645 potential planned EVA tasks. Figure 4-22 presents the applicability (% of total) of each of the major categories of transfer modes to these translation events. As an example, 82.5% of these translation events can be accomplished manually through the use of handholds or handrails.

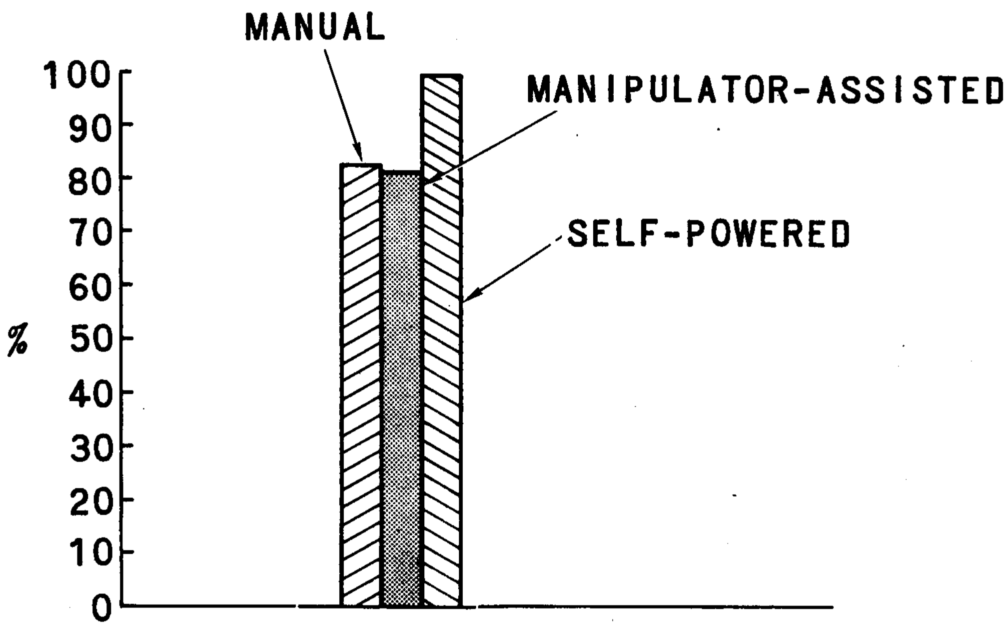

FIGURE 4-22. TRANSFER MODES—PLANNED TASKS

4.2.8 Translation Modes - Continued

There are 10,350 translation events occurring during the 1,148 potential unscheduled EVA tasks. Figure 4-23 presents the applicability (% of total) of each of the major categories of transfer modes to these translation events.

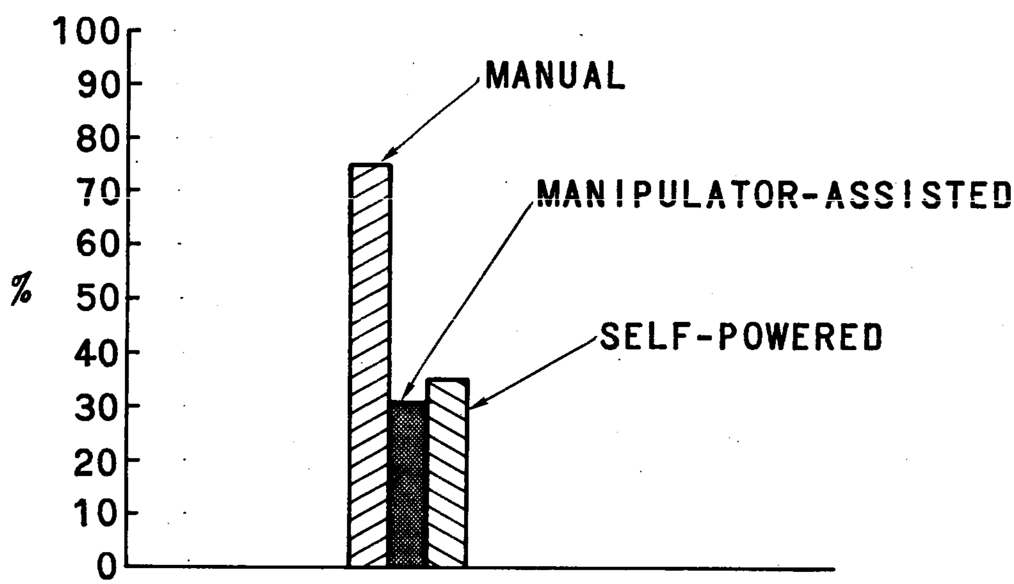

FIGURE 4—23 TRANSFER MODES — UNSCHEDULED TASKS

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4.2.8 Translation Modes - Continued

Final selection of the optimum transfer modes was made based on mass to be carried, distance to be traveled, general applicability of the transfer mode, and in accordance with the following selection criteria:

a) Manual Mode - EVA tasks within closed payload bay; EVA tasks within open payload bay in which crewman transports less than 100 pounds of mass.

b) Manipulator - Assisted Mode - EVA tasks within open payload bay in which crewman transports more than 100 pounds of mass; EVA tasks outside payload bay but within the manipulator reach envelope.

c) Manual Plus Manipulator - Assisted Mode - EVA tasks on the exterior of the Orbiter or payload and beyond reach of the manipulator.

d) Self-Powered Mode - To be used if there are no other alternatives.

Figure 4-24 presents the results of the optimum transfer modes selection effort.

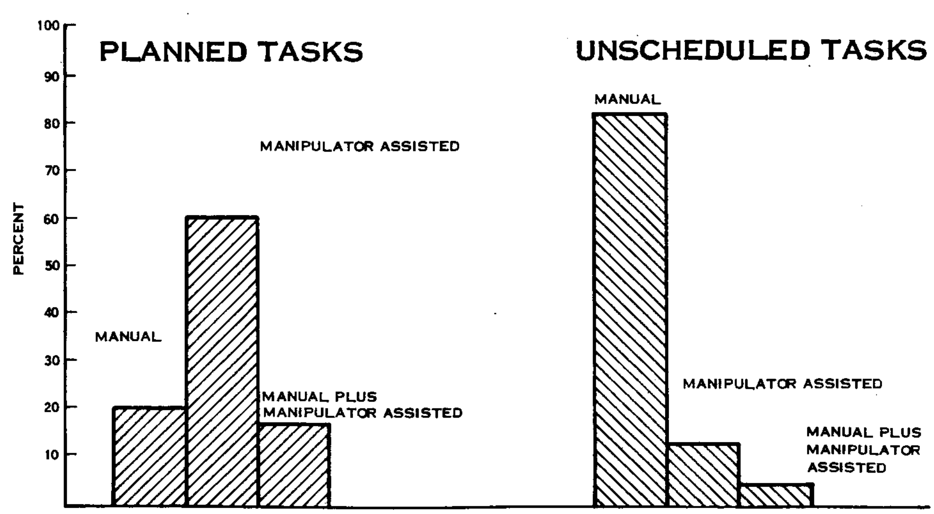

FIGURE 4—24. SELECTED TRANSFER MODES

4.2.9 Suit Requirements

Based upon the EVA/IVA task identification effort, specific mobility/dexterity/visibility requirements were generated. The mobility requirements generated are listed in Table 4-6. These requirements were then applied to the existing ILC A-7L-B suit.

TASK	ACTIVITY OR MOTION (DEGREES)									
	SHOULDER			ELBOW		WRIST			HIP	KNEE
	X AXIS	Y AXIS	Z AXIS	FE	R	SP	FE	AA	FE	F
Open/Close Airlock Hatch or Shroud										
Reach	90-110	15-20	45-60	20-90	± 30	70	-	-	60-90	60-90
Grasp	90-110	15-20	45-60	20-40	± 30	± 15	± 20	± 25	60-90	60-90
Hold	90-110	15	45-90	20-40	± 30	± 15	± 20	± 15	60-90	60-90
Transfer	30-80	15-45	45-60	0-90	± 20	70	-	± 25	60-90	60-90
Stow	90-110	15-45	45-60	0-90	± 20	70	-	± 25	60-90	60-90
Attach/Detach Tether										
Reach	-	15-20	45-80	20-90	± 30	70	± 20	± 15	-	-
Grasp	-	15-20	45-80	20-90	± 30	± 5	± 20	± 25	-	-
Hold	45-90	15	45-80	0-90	± 20	70	± 20	± 25	-	-
Squeeze	45-90	-	30	0-90	-	70	± 20	± 25	-	-
Traverse - Handhold/ Handrail	0-60	-	45-90	30-90	± 30	± 15	± 20	± 15	0-30	0-30
Conn/Disconn. Umbilical										
Reach	30-90	15-20	45-90	20-90	± 30	70	-	-	90	90
Grasp	30-90	15-20	45-90	20-90	± 30	± 15	± 20	± 25	90	90
Hold	45-80	15	45-80	0-90	± 20	± 15	± 20	± 25	90	90
Transfer	45-80	15-45	-	0-90	± 20	70	-	± 25	90	90
Connect	15-45	15-20	45-60	20-110	90	90	± 20	± 15	90	90
Stow	30-80	15-45	45-60	0-90	± 20	70	-	± 25	90	90
Inspection	90	15	30	20	-	70	-	15	-	-
Release Restraint	45	0-15	10	110	90	90	30	10	90	90
Restrain Equipment										
Grasp	-	15	45-80	20-90	± 30	± 5	± 20	± 15	-	-
Hold	45-80	15-20	45-80	0-90	± 20	± 5	± 20	± 15	-	-
Reach	-	10	45-80	20-90	± 30	70	-	-	-	-
Remove Equipment										
Reach	-	15-20	45-80	20-90	± 30	± 5	± 20	± 15	-	-
Grasp	-	15-20	45-80	0-90	± 20	± 5	± 20	± 15	-	-
Hold	45-80	15	45-80	20-90	± 30	70	-	-	-	-
Push-Pull	45-110	10	-	10	-	70	-	-	-	-

TABLE 4-6. REPRESENTATIVE MOBILITY REQUIREMENTS

4.2.9 Suit Requirements - Continued

TASK	ACTIVITY OR MOTION (DEGREES)									
	SHOULDER			ELBOW		WRIST			HIP	KNEE
	X AXIS	Y AXIS	Z AXIS	FE	R	SP	FE	AA	FE	F
Mount/Disassemble										
Reach	-	15-20	45-80	20-90	± 30	70	-	-	-	-
Grasp	-	15-20	45-80	20-90	± 30	70	± 20	± 15	-	-
Hold	45-80	15	45-80	0-90	± 20	± 5	± 20	± 15	-	-
Push-Pull	45-110	10	-	10	-	70	-	-	-	-
Turn	90-120	15-90	0-90	0-30	± 30	± 30	± 20	± 15	90	90
Remove Access Panel										
Hold	45-80	15	45-80	0-90	± 20	± 5	± 20	± 15	-	-
Grasp	-	15-20	45-80	20-90	± 30	± 5	± 20	± 15	-	-
Push-Pull	45-110	10	-	10	-	70	-	-	-	-
Place Item In Protective Container										
Grasp	-	15-20	45-80	20-90	± 30	70	-	-	-	-
Hold	45-80	15	45-80	0-90	± 20	± 5	± 20	± 15	-	-
Reach	-	15-20	45-80	20-90	± 30	70	-	-	-	-
Adhesive (Type) Applic.										
Reach	-	15-20	45-80	20-90	± 30	70	± 20	± 15	-	-
Grasp	-	15-20	45-80	20-90	± 30	± 5	± 20	± 25	-	-
Hold	45-80	15	45-80	0-90	± 20	± 5	± 20	± 15	-	-
Push-Pull	45-110	10	-	10	-	70	± 20	± 25	-	-
Squeeze	45-90	-	30	0-90	-	70	± 20	± 15	-	-
Release/Secure Latch										
Grasp	-	15-20	45-80	20-90	± 30	± 5	± 20	± 25		
Hold	45-80	15	45-80	0-90	± 20	± 5	± 20	± 15		
Reach	-	15-20	45-80	20-90	± 30	70	± 20	± 15		
Push-Pull	45-110	10	-	10	-	70	± 10	± 25	-	-
Manual Deploy.										
Grasp	-	15-20	45-80	20-90	± 30	± 5	± 20	± 15	-	-
Hold	45-80	15	45-80	0-90	± 20	± 5	± 20	± 15	-	-
Reach	-	15-20	45-80	20-90	± 30	70	± 20	± 15	-	-
Push-Pull	45-110	10	-	10	-	70	-	-	-	-

KEY: Shoulder Motion
X - Sagittal Plane
Y - Frontal Plane
Z - Transverse Plane
SP - Supernation - Pronation
FE - Flexion - Extension
AA - Adduction - Abduction
R - Rotation
F - Flexion

TABLE 4–6. REPRESENTATIVE MOBILITY REQUIREMENTS — CONTINUED

Results of this evaluation indicated that the ILC-A-7L-B suit mobility and dexterity is not adequate to meet the Shuttle EVA/IVA mission requirements. The specific areas of the ILC A-7L-B suit which require improvement are shoulder range and torque, wrist torque and stability and finger dexterity. The visibility afforded by the ILC A-7L-B suit was found to be adequate.

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4.2.9 Suit Requirements - Continued

The Shuttle EVA/IVA mobility requirements, as defined by this study, were then compared against the requirements specified in the 8.0 psi Orbital EVA Space Suit Assembly request for proposal dated June 20, 1972. The results of this comparative evaluation are presented in Table 4-7.

MOVEMENTS	RANGE		MAXIMUM TORQUE	
	SHUTTLE DESIGN GOALS (DEGREES)	STUDY REQMT'S AS A % OF DESIGN GOALS (AVG - MAX)	SHUTTLE DESIGN GOALS (IN-LBS)	STUDY REQMT'S AS A % OF DESIGN GOALS (AVG - MAX)
SHOULDER MOBILITY				
X AXIS (LATERAL-MEDIAL)	155	60 - 80	12	100
Y AXIS (ADDUCT-ABDUCT)	60 - 95	30 - 95	12	100
Z AXIS (ROTATION X-Z AND Y-Z PLANES)	140	45 - 65	12	100
ELBOW MOBILITY				
FLEXION-EXTENSION	115	40 - 95	12	100
FOREARM MOBILITY				
SUPINATION	145	20 - 60	2.5	100
PRONATION	25	80 - 100	2.5	100
WRIST MOBILITY				
FLEXION-EXTENSION	30 - 42	50 - 100	2.5	100
ADDUCT-ABDUCT	56 - 57	35 - 45	2.5	100
SUPINATION	145	35 - 60	2.5	100
PRONATION	25	40 - 100	2.5	100
HIP MOBILITY				
FLEXION-EXTENSION	90 - 20	90 - 100	24	100
KNEE MOBILITY				
FLEXION	110	70 - 80	12	100

TABLE 4—7 SHUTTLE EVA SUIT MOBILITY REQUIREMENTS COMPARISON

The need for Shuttle EVA suit waist mobility was evaluated and results indicated that although this feature would aid the crewman in the accomplishment of his tasks, it is not an absolute necessity.

The conclusion emanating from this comparative evaluation is that the 8.0 psi Orbital Space Suit Assembly design goals are adequate to meet the Shuttle mobility requirements as defined by this study.

4.2.10 Restraints

An extensive literature search of candidate restraint concepts was conducted with emphasis placed on the Apollo, Gemini, Skylab and NASA Contractor research and development programs. The restraint concepts considered were for crew worksite applications and not for translation. Restraints were for personnel and equipment, and considered planned, unscheduled and contingency tasks. Location of the worksites considered include:

a. Shuttle crew compartment

b. Airlock

c. Payload Bay

d. Payloads (Interior and exterior)

Results indicate that foot, waist and hand restraints, in various combinations, are generally the most applicable and effective crewman restraints. In general, the personnel and equipment restraint requirements can be satisfied by utilizing existing devices which have either been flight qualified or are presently being tested. Figure 4-25 depicts planned EVA tasks as a function of restraint concepts. As an example, all planned EVA tasks require some sort of foot restraint but only 16% of the planned EVA tasks require only foot restraint.

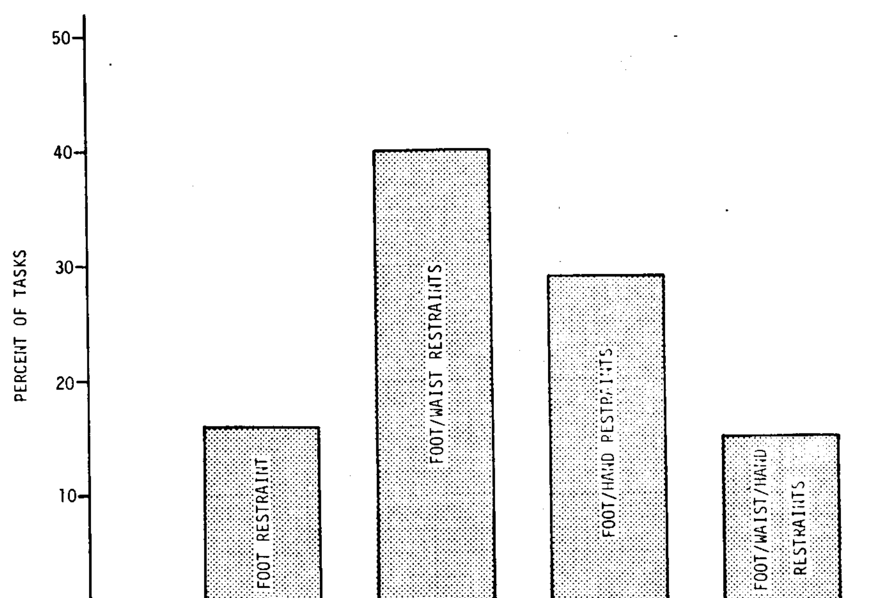

FIGURE 4–25. PLANNED TASKS AS A FUNCTION OF RESTRAINT CONCEPTS

4.2.11 Payload Contamination Sensitivity

The sensitivity of Shuttle payloads to contamination is a potential driving factor in establishing EVA equipment requirements. Utilizing sources of data such as the NASA Blue Book and the General Dynamics RAM Study, all the payloads listed in the March 21, 1972 NASA/DOD Shuttle Traffic Model were evaluated in detail to determine their contamination sensitivity. As a result of this investigation, eighty-five (85) of the total of 677 NASA and DOD Shuttle flights were estimated to be transporting contamination sensitive payloads.

On seventy-eight (78) of these flights, the payloads are sensitive to particulate deposition only. On seventy-three (73) of these seventy-eight (78) flights, the contamination sensitive payloads are astronomy free flyers. On these payloads, the experiment package utilizes contamination shields which normally remain closed whenever the Shuttle is in the immediate area and are not opened until forty-eight (48) hours after the Shuttle leaves the area. Since it takes from one (1) to thirty-five (35) hours for particulate to clear before an experiment can be activated, contamination will not normally pose a problem for these payloads. On the remaining five (5) flights which carry payloads that are sensitive to particulate contamination only, special precautions are required. The instrumentation shields must be closed during EVA on these flights and a waiting period of one (1) to thirty-five (35) hours are required before the experiment can be activated.

On the remaining seven flights, three (3) are sensitive to particulate contamination and all seven (7) are sensitive to water vapor contamination. The payload instrumentation shields must be closed during EVA on these flights to avoid payload contamination. Although a PLSS water umbilical could be used to eliminate the major source of water vapor, the water vapor contained in the EVA suit leakage is enough to contaminate these payloads.

A general conclusion of this effort is if the payload instrumentation shields are closed during EVA operations which are near contamination sensitive payloads, an Apollo-type EVA system using water as a thermal control subsystem evaporant and having a suit gaseous leakage rate of 100 scc/min. is a useable system for performing Shuttle EVA missions.

A detailed description of this effort is presented in Section 5.0, Appendix A of Volume II.

4.2.12 Conclusions

Based on the results of the EVA/IVA task analysis effort, the following major conclusions were drawn:

a. EVA mission duration required is four (4) hours.

b. The Shuttle Orbiter shall have the capability to support six (6) dual EVA missions and 32 manhours of EVA.

c. Most planned and unscheduled EVA/IVA tasks require two (2) crewmen.

d. Emergency duration required is fifteen (15) minutes.

e. The manipulator assisted mode of translation is the selected mode for sixty-two (62) percent of the planned tasks; the manual mode of translation is the selected mode for eighty-three (83) percent of the unscheduled tasks.

f. The 8.0 psi Orbital EVA Space Suit Assembly RFP design goals are adequate for the Shuttle EVA missions.

g. Required worksite restraints are foot, waist and hand restraints, in various different combinations.

h. Only thirteen (13) percent of all NASA and DOD Shuttle flights carry contamination sensitive payloads. If the instrumentation shields on these payloads are closed during EVA operations, they will not be contaminated by the EVA crewman or his equipment.

SECTION 5.0

GUIDELINES AND CONSTRAINTS

5.0 GUIDELINES AND CONSTRAINTS

Establishment of the study guidelines and constraints is based primarily on the results of the EVA/IVA task identification and analysis effort. The guidelines and constraints were periodically reviewed, updated and revised, as required. In addition to the Hamilton Standard study team, these guidelines and constraints were reviewed by personnel from NASA MSC, NASA MSFC, NASA HQ, NR, GAC and MDAC. In total, 51 guidelines and constraints were developed and are presented in this section.

5.1 GENERAL

a. EVA/IVA shall be utilized for planned Shuttle operations as required by the payload. An EVA/IVA capability is required on Shuttle for potential Shuttle, unscheduled and contingency operations.

b. Whenever feasible, EVA/IVA support equipment shall be designed for a service life of 10 years and 500 reuses with a minimum of maintenance and refurbishment.

c. EVA/IVA support equipment are not required to be flight maintainable, but shall be ground maintainable. Ground turn-around time from landing/return to the launch facility to launch readiness shall be less than 160 working hours covering a span of 14 calendar days for any class mission.

d. In the design of the EVA/IVA support equipment, the Shuttle design philosophy of "fail-operational, fail-safe" shall be taken into consideration; in no case shall it be less than "fail-safe".

e. EV/IV crewmen shall be within the 5th to 95th percentile range.

f. An EV crewman shall not be required to perform in, on, or near an uncontrolled tumbling spacecraft.

g. The EV crewman shall not contact the Shuttle Orbiter radiator and shall avoid contacting the Shuttle Orbiter reusable surface insulation (RSI) during planned operations.

h. For planned Shuttle EVA/IVA operations, crewman assistance shall be available for EVA/IVA equipment donning and checkout.

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5.1 GENERAL - Continued

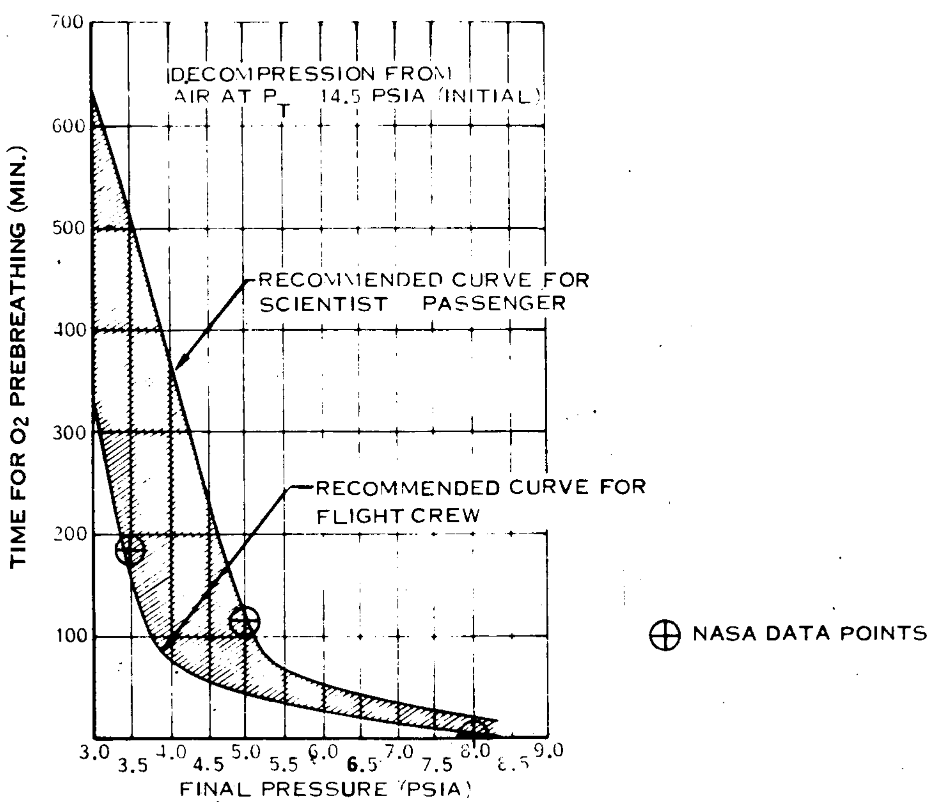
i. Recharging and/or regeneration of EVA/IVA equipment shall be accomplished without the use of tools.

j. EV and IV planned activities shall be performed by properly trained personnel.

5.2 PHYSIOLOGICAL

a. Prebreathing:

The prebreathing profile of Figure 5-1 shall be used as a guideline.



NOTES :

(1) THIS CURVE INDICATES THE TIME REQUIRED FOR OXYGEN PREBREATHING BEFORE DECOMPRESSION TO INDICATED PRESSURE AND THEN ENGAGE IN MILD EXERCISE

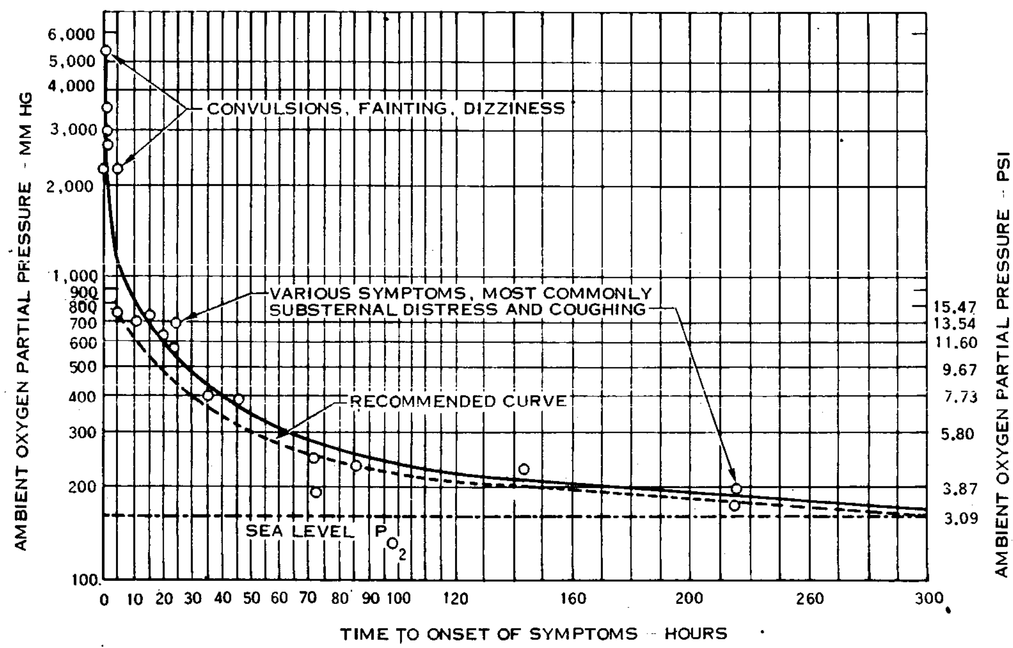
(2) REFERENCE :
DEGNER, E. A.; IKELS, K.G.; ALLEN, T. H.: DISSOLVED NITROGEN MIXTURE DURING EXERCISE AT DECREASED PRESSURES, AEROSPACE MED., 1965,: 418–425

FIGURE 5–1 OXYGEN PREBREATHING

5.2 PHYSIOLOGICAL - Continued

b. Oxygen Toxicity:

The EVA/IVA equipment and mission durations shall preclude crewman exposure beyond the limits of the recommended curve of Figure 5-2.



REFERENCE

WELCH, B.E.; MORGAN, T.E.; CLAMANN, H.G.; TIME CONCENTRATION EFFECTS IN RELATION TO OXYGEN TOXICITY IN MAN. FED. PROC., JUL AUG, 1963, 22; 1053 1056.

FIGURE 5–2 OXYGEN TOXICITY

5.2 PHYSIOLOGICAL - Continued

c. Oxygen Consumption:

For design purposes, the crewman's oxygen consumption shall be in accordance with Figure 5-3.

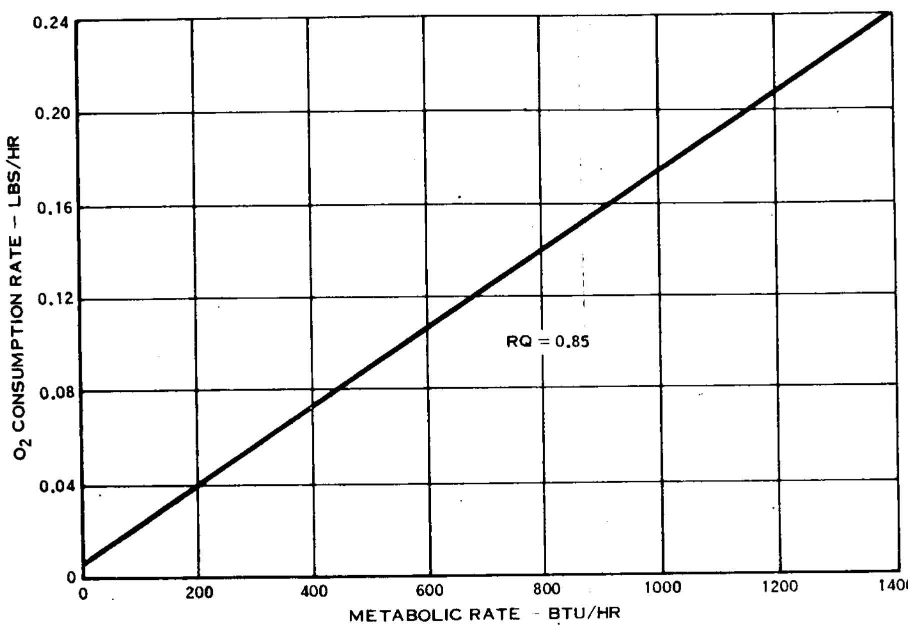
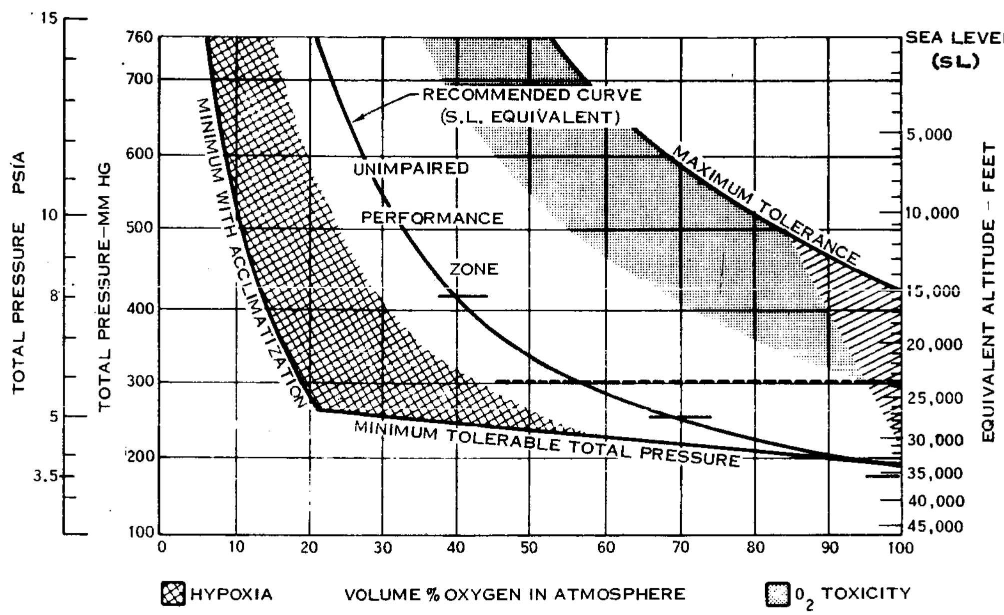


FIGURE 5–3 OXYGEN CONSUMPTION RATE VS METABOLIC RATE

5.2 PHYSIOLOGICAL - Continued

d. Oxygen Pressure:

The design of the EVA/IVA equipment shall preclude exposure of the crewman to oxygen concentration outside the unimpaired performance zone of Figure 5-4.



REFERENCE

AFSC DESIGN HANDBOOK, DH1 ... DN B!

SUB NOTE ...

FIGURE 5—4 OXYGEN PRESSURE EFFECTS

e. The maximum planned EVA/IVA duration shall be eight (8) hours per day.

f. Crewman heat storage shall be limited to 300 Btu per EVA/IVA.

5.3 LIFE SUPPORT

a. Primary life support system duration shall be of sufficient duration to accomplish all candidate EVA/IVA tasks.

b. The primary life support equipment shall be provided with a warning system to alert the EVA/IVA crewman of an impending critical failure condition.

c. The EVA/IVA crewman shall be equipped with a functionally independent emergency life support system. Duration of this system should be sufficient to permit a safe return to the Shuttle Orbiter.

d. The primary life support equipment shall not generate and/or emit contaminants which might adversely affect critical surfaces in or around the Shuttle Orbiter and the payload.

e. Primary life support equipment shall be capable of being recharged in flight, as required for multiple EVA/IVA's.

f. Emergency life support equipment is not required to be rechargeable in flight.

g. During all EVA/IVA operations, two-way voice communications shall be provided between EVA/IVA crewman and between an EVA/IVA crewman and the Orbiter.

5.4 PRESSURE SUIT

a. Suit operating pressure shall be that level which does not adversely affect the crewman or his performance, and has a minimum impact on the Shuttle mission and the Shuttle Orbiter.

b. The same pressure suit shall be utilized for both EVA and IVA missions. Light-weight IVA suits shall be worn for emergency IV operations and vertical development flights.

5.5 TRANSFER DEVICES

a. The transfer devices (crewman and/or cargo) shall not generate and/or emit any contaminants which might adversely affect critical surfaces on or around the Shuttle Orbiter and the payload.

b. Tethers, umbilicals, communication lines and mobility aids shall not be a constraint on the crewman's access to candidate work sites. (Candidate work sites include the 15' diameter by 60' long payload bay, the exterior surface of the Shuttle Orbiter, and the interior and/or exterior of a payload.)

5.6 RESTRAINTS

a. The EVA crewman shall always be tethered to the Shuttle Orbiter and/or the payload.

b. The crewman shall be provided with restraints at all work sites (permanent or portable).

c. Tools, cameras, instrumentation, etc. for EV usage, must always be restrained or tethered to either the vehicle, the worksite or the crewman.

5.7 WORKSITE PROVISIONS

a. All worksites shall have provisions for crewman restraints and equipment restraints.

b. The crewman shall be provided with adequate lighting at all worksites.

5.8 VEHICLE SUPPORT PROVISIONS

5.8.1 GENERAL

a. The Shuttle Orbiter shall provide a capability for EVA/IVA operation during docked operations.

b. The Shuttle Orbiter shall be capable of supporting either a dual or single crewman EVA/IVA, however, the planned mode of operation shall be a dual crewman EVA/IVA.

c. The Shuttle Orbiter shall be designed to allow pressure suit access to the unpressurized payload bay in flight.

5.8.2 AIRLOCK

a. Airlock pressurization controls and instrumentation shall be located such that an EV crewman can ingress to the cabin without relying on airlock or hatch operations by cabin personnel.

b. The airlock shall accommodate two 95th percentile crewmen wearing EVA equipment plus the equipment to be carried EV by the crewmen (such as, tools, experiments, etc.) and shall permit their operation of required airlock controls.

c. The airlock will be used for EVA/IVA only and will not be designed to accommodate crew or passengers in the event of a cabin decompression.

d. Hatches into and out of the airlock shall be designed such that latch/unlatch operations can be performed from either side of the hatch. Hatches shall be designed to accommodate the 95th percentile crewman with EVA equipment, tools, etc. The outer airlock hatch shall remain open during EVA/IVA.

e. Airlock to cabin communication shall be provided, both visual and oral.

f. Final EVA equipment checkout shall be accomplished in the airlock.

g. The airlock shall provide adequate lighting for airlock operations.

5.8.3 RECHARGE

a. EVA equipment recharge shall take place in a pressurized area.

5.8.4 STOWAGE

a. EVA/IVA equipment shall be stowed in a pressurized area.

5.8.5 EVA COMMUNICATION AND MONITORING

a. The Shuttle Orbiter shall provide provisions to enable two-way voice communications between (1) EVA/IVA crewman and the Orbiter and (2) EVA/IVA crewman and the space network via the Orbiter relay.

5.8.6 VEHICLE PENALTIES

a. Oxygen Storage:

Liquid O_2 - 0.25 lbs of tank per lb of O_2
Gaseous O_2 - 2.14 lbs of tank per lb of O_2

b. Power:

Fuel Cell - 0.286 lbs/watt + 0.00198 lb/watt-hr
Battery - 50 watt-hrs/lb

c. Water - None

d. Heating Penalty - Use electrical power

e. Cooling Penalty - 0.171 lbs/Btu/hr Sensible into cabin
0.134 lbs/Btu/hr Latent into cabin
0.054 lbs/Btu/hr Into vehicle coolant system

5.9 EMERGENCY IV

a. IV emergency equipment, if different from EVA/IVA equipment, shall not be required to be rechargeable.

SECTION 6.0

SUIT PRESSURE LEVEL DETERMINATION

6.0 SUIT PRESSURE LEVEL DETERMINATION

6.1 General

The objective of the suit pressure level determination effort is to establish the suit operating pressure which does not adversely affect the crewman or his performance, and has the most beneficial impact on the Shuttle mission and the Shuttle Orbiter. Since the Shuttle Orbiter will have an air atmosphere at 14.7 psia, use of Gemini, Apollo or Skylab type EVA systems (which operate at 3.5 to 4.0 psia) require that each EVA crewman prebreathes pure oxygen for a minimum of three (3) hours prior to airlock depressurization. This in turn increases EVA preparation time and requires additional vehicle support equipment and consumables to support prebreathing operations. Therefore suit operating pressure levels ranging from 3.5 to 14.7 psia must be evaluated to determine their applicability and impact upon the Shuttle program. As shown in Figure 6-1, there are a number of areas that are affected by variations in suit pressure level and must be evaluated to determine the optimum suit pressure level. This section discusses each of these areas in detail and summarizes our conclusions.

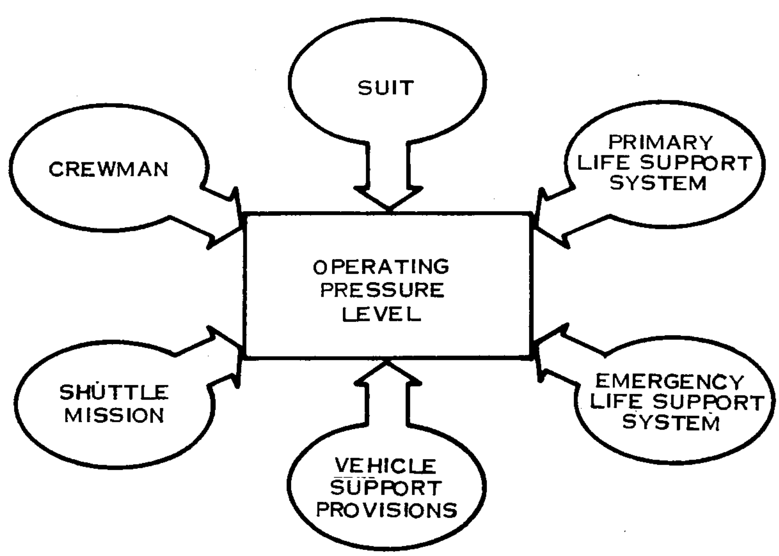


FIGURE 6—1 OPERATING PRESSURE LEVEL CONSIDERATIONS

6.2 Crewman Considerations

From a crewman's physiological standpoint, selection of a suit pressure level is dependent upon constraints imposed on the crewman by:

a. Denitrogenation requirements prior to decompression.

b. Oxygen toxicity.

Based upon the physiological guidelines and constraints presented in Section 5.0 of this volume, Figure 6-2 identifies the oxygen prebreathing requirements and oxygen toxicity constraints as a function of suit pressure level and exposure duration.

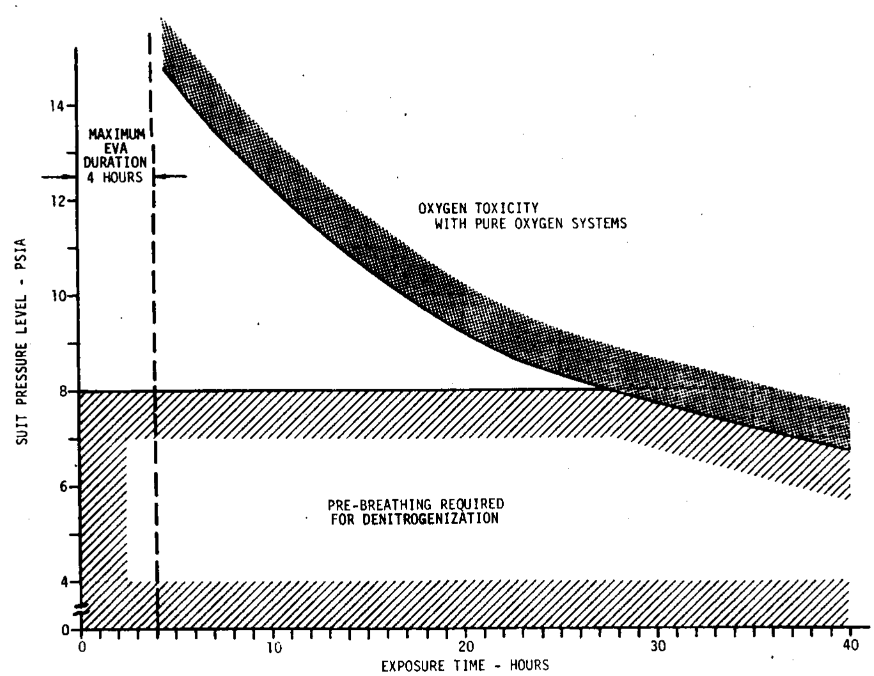


FIGURE 6–2 IMPACT OF DENITROGENATION AND OXYGEN TOXICITY

6.2.1 Decompression Sickness

A primary physiological consideration in the selection of a suit pressure level is decompression sickness, the most common form of which is termed the "bends". This problem is the result of the release of nitrogen from the body tissues after decompression. For aerospace usage, the customary means of preventing decompression sickness is prebreathing of pure oxygen to eliminate the dissolved nitrogen. The nitrogen contained in the lungs and dissolved in the blood is removed almost immediately upon starting prebreathing, while the nitrogen that is contained in the body tissue and bones requires considerably longer to remove. A plot of minimum prebreathing time versus final pressure level is presented as a physiological constraint in Section 5.0 of this report. The use of this guideline provides an extremely high degree of probability that decompression sickness will not occur. From examination of the curve in Section 5.0 and Figure 6-2, it can be seen that prebreathing is required at any pressure below 8.0 psia. Consequently, it is desirable to operate the suit at a minimum pressure of 8.0 psia to eliminate the possibility of decompression sickness.

6.2.2 Oxygen Toxicity

An overabundance of oxygen, known as oxygen toxicity, can be equally damaging as decompression sickness. The effect of excess oxygen can range from mild coughing to dizziness, fainting and even convulsions. Both the physiological limitation and the recommended limitation on how long a crewman can breathe pure oxygen at various pressure levels are defined in Section 5.0. In addition, the recommended level is presented in Figure 6-2. It can be seen on Figure 6-2 that, for the maximum projected EVA mission duration of four hours, oxygen toxicity is not predicted to occur at pressures below approximately 15 psia.

6.2.3 Summary

As an objective, the selected suit operating pressure level should eliminate or require a minimum of prebreathing, yet not adversely affect the crewman or his performance. Based on the physiological guidelines and constraints presented in Section 5.0 of this volume, it can be concluded that from a physiological standpoint, a suit pressure level of 8.0 to 14.7 psia is preferable. No prebreathing is required to decompress from sea level to pressures as low as 8.0 psia and there is no apparent danger of the occurrence of decompression sickness at this level. In addition, for the EVA durations and frequencies considered, oxygen toxicity is not considered to be a problem.

6.3 Suit Considerations

The space suit provides a mobile anthropomorphic enclosure with a controlled atmosphere to permit a crewman to perform useful functions in the hostile environment of space. The space suit considerations that must be evaluated to determine the effect of operating pressure level variations upon the suit are presented in Figure 6-3.

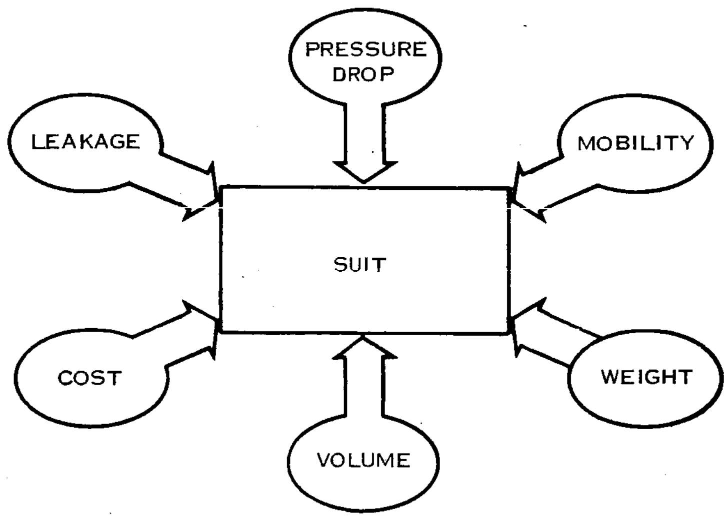


FIGURE 6–3 SUIT CONSIDERATIONS

6.3 Suit Considerations - Continued

As a basis for these evaluations, available data on the following suits/joints were utilized:

a. ILC A-7L-B Suit

b. Hamilton Standard MOL Suit

c. Litton Advanced EVA Suit

d. AiResearch Advanced EVA Suit

e. Space Age Control Advanced EVA Suit

f. Hamilton Standard Integrated Extravehicular Assembly (IEVA) Suit

g. Litton Experimental Suit Joints

h. ILC Experimental Suit Joints

i. Hamilton Standard Experimental Suit Joints

The results of these evaluations are presented in the remainder of this section.

6.3.1 Leakage

An estimate of suit leakage versus pressure level is shown in Figure 6-4. The curve shown is based on extrapolation of leakage data for Apollo flight-qualified suit wrist lip seals. This projection assumes that the Shuttle EVA suit will contain all bearing joints with lip seals at the wrists, shoulders, neck, torso closure and hip, and that leakage is proportional to pressure level.

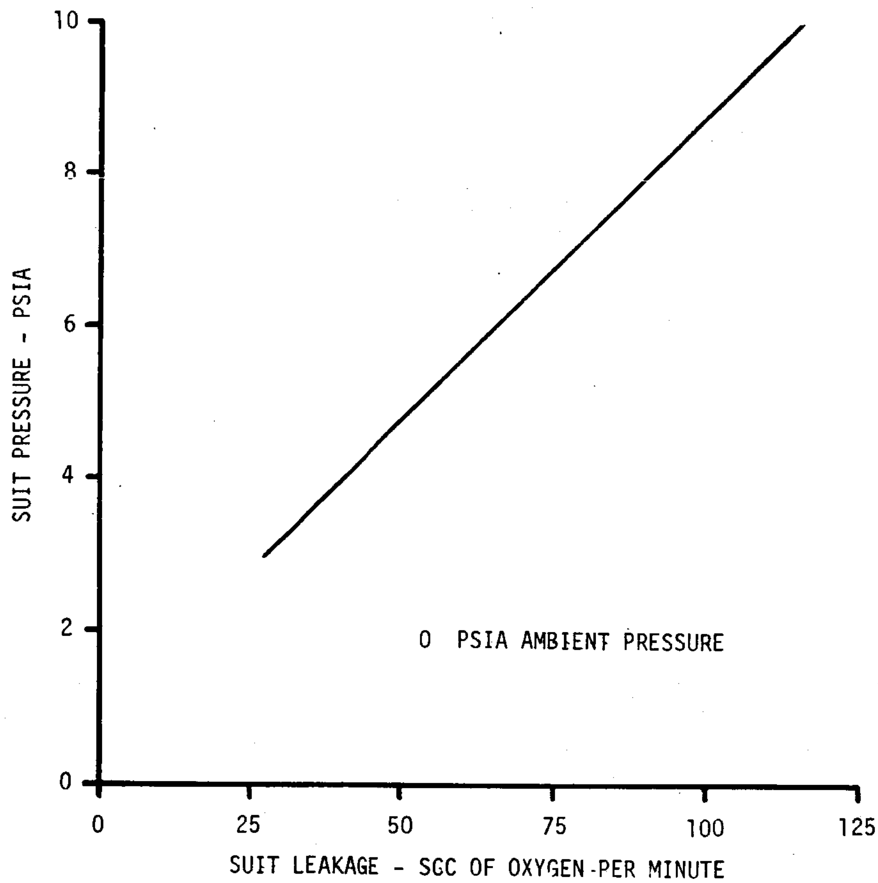


FIGURE 6—4 SUIT LEAKAGE VS PRESSURE LEVEL

6.3.1 Leakage - Continued

Based on the above projection, the total PLSS O_2 supply subsystem weight penalty associated with the higher leakage rates at 8.0 psia versus 4.0 psia is 0.24 pounds (O_2 + tankage). Therefore, it is concluded that although suit leakage does increase with pressure level, it is not a significant overall factor in establishing suit operating pressure level.

6.3.2 Pressure Drop

An estimate of suit pressure drop versus pressure level for various volume flows is shown in Figure 6-5.

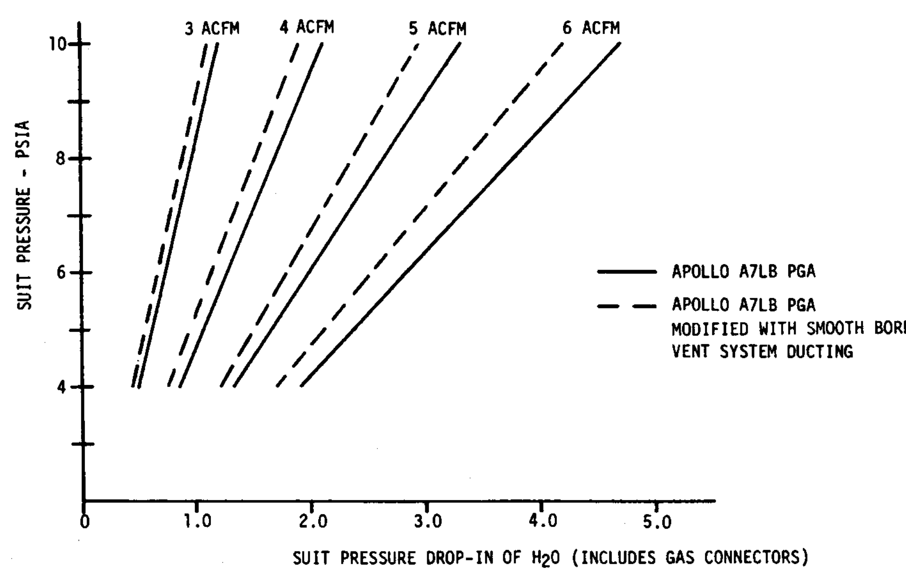


FIGURE 6–5 SUIT PRESSURE DROP VS PRESSURE LEVEL

6.3.2 Pressure Drop - Continued

Suit pressure level is proportional to pressure drop which is proportional to power which, in turn, is proportional to PLSS fan and battery weight. Based upon the Apollo EMU PLSS configuration, an increase in operating pressure from 3.8 psia to 8.0 psia results in a PLSS weight increase of 1.4 pounds. Although this weight increase is significant to the PLSS, overall it is not a significant factor in establishing suit operating pressure level.

6.3.3 Mobility

In general, and regardless of specific joint configuration, suit mobility tends to degrade as operating pressure increases. In order to achieve the mobility required to accomplish the Shuttle EVA/IVA tasks identified in Section 4.0 of this volume, the complex suit joints will most likely require the incorporation of bearings in the critical planes of motion. In order to assess the impact of various operating pressure levels upon suit mobility, it was necessary to review the available test data on current and past suits and suit joint concepts in terms of range and torque and to quantify, it possible, the effects of operating pressure upon these parameters. Unfortunately, a very limited amount of actual test data is available, and, where data are available, the information is usually made up of single points (i.e. - one specific joint concept at only one pressure level). Table 6-1 contains a list of the suit mobility data sources, including the manufacturers and their various suit concepts, as well as the pressure level at which test data were generated.

6.3.3 Mobility - Continued

1.	ILC INDUSTRIES, INC. a. APOLLO A7LB - 3.7, 8.0, 9.0 PSIA b. INTRAVEHICULAR SPACE SUIT ASSEMBLY (ISSA) - 8.0 PSIA c. EXPERIMENTAL JOINT - 8.0 PSIA
2.	HAMILTON STANDARD a. MOL PSA, FLT. CONFIG - 3.5 PSIA b. M-2A, IR&D CONFIG - 3.5 PSIA c. XM-3, MOL EVALUATION CONFIG - 3.5 PSIA
3.	SPACE AGE CONTROL (SAC) a. INTRAVEHICULAR SPACE SUIT (ISS) - 5.0 PSIA
4.	LITTON INDUSTRIES a. ADVANCED EXTRAVEHICULAR SPACE SUIT (LAES) - 8.0 PSIA b. EXPERIMENTAL JOINT - 8.0 PSIA
5.	AIRESEARCH a. ADVANCED EXTRAVEHICULAR SPACE SUIT (AAES) - 8.0 PSIA
6.	NASA-MSC: CSD-RFP a. 8.0 PSIA ORBITAL EV SUIT - 8.0 PSIA
7.	NASA-MSC: CSD-RFP a. EMERGENCY IV SUIT ASSEMBLY - 8.0 PSIA

TABLE 6—1 SUIT MOBILITY DATA SOURCES

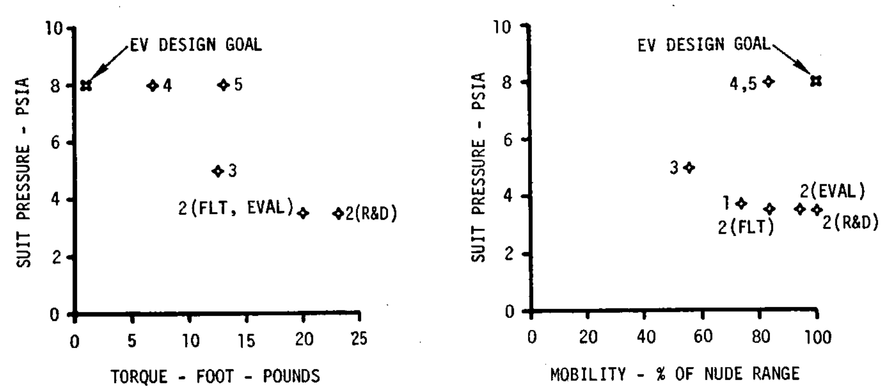
6.3.3 Mobility - Continued

Figures 6-6 through 6-10 present range and torque data of selected suit joints as scattergraphs because of the lack of comparative data points for any one configuration. Although curve fitting of the data is not possible, there are trends in the data that lead to the following conclusions:

a. Lowest torque and highest mobility as a percent of nude range can be achieved with constant volume joint configurations such as the stove pipe and rolling convolute joints, particularly for complex joints such as the shoulder and hip-waist.

b. Fabricated soft convolute or tucked fabric joints appear to provide satisfactory torque and range characteristic for single axis joints such as the elbow, knee and finger.

It is anticipated that with the incorporation of state-of-the-art constant volume joint technology in the complex suit joints, torque will be significantly reduced and effective range will be increased to satisfactory levels, and suit performance should not be affected to an appreciable degree by the operating suit pressure levels being considered. Therefore, it is concluded that suit mobility is not a significant factor in establishing suit operating pressure level.



KEY
1 A7L-B (MOLDED CONVOLUTE)
2 MOL PSA (FABRIC CONVOLUTE)
3 SAC-1SS (FABRIC CONVOLUTE)
4 LAES (ROLLING CONVOLUTE)
5 AAES (STOVEPIPE)

FIGURE 6–6 SHOULDER LATERAL/MEDIAL MOVEMENT (Y – Z PLANE) – RANGE/TORQUE

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6.3.3 Mobility - Continued

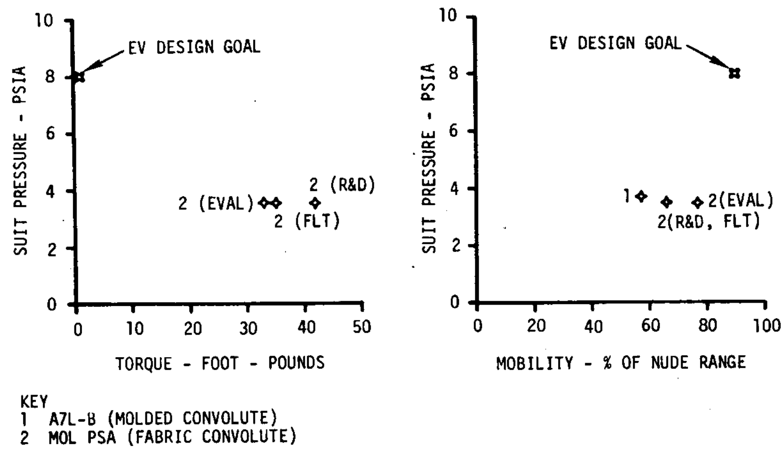


FIGURE 6-7 SHOULDER ADDUCTION/ABDUCTION (X - Y PLANE) - RANGE/TORQUE

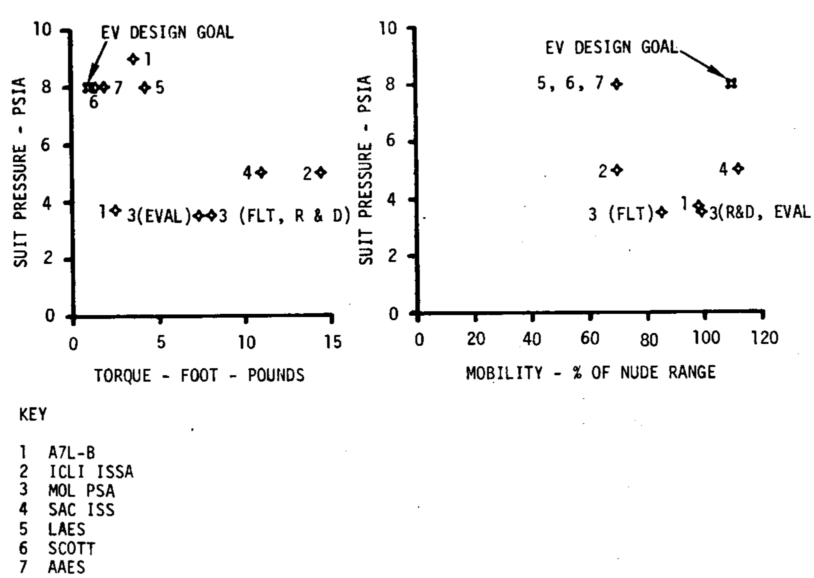
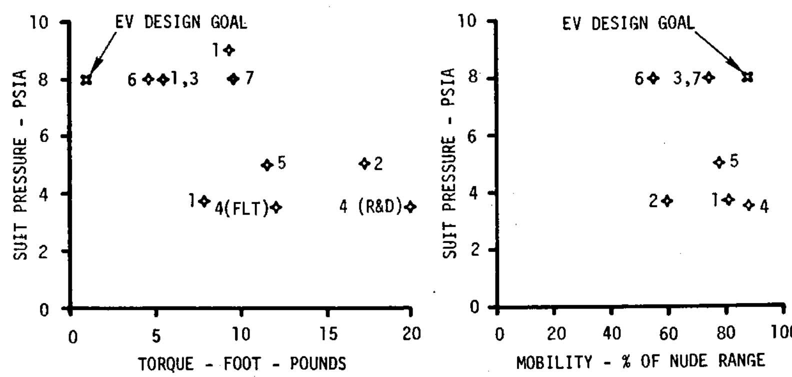


FIGURE 6-8 ELBOW FLEXION - RANGE/TORQUE

6.3.3 Mobility - Continued



KEY

1 A7L-B
2 ILCI ISSA
3 ILCI EXPERIMENTAL
4 MOL PSA
5 SAC ISS
6 LAES
7 AAES

FIGURE 6–9 KNEE FLEXION – RANGE /TORQUE

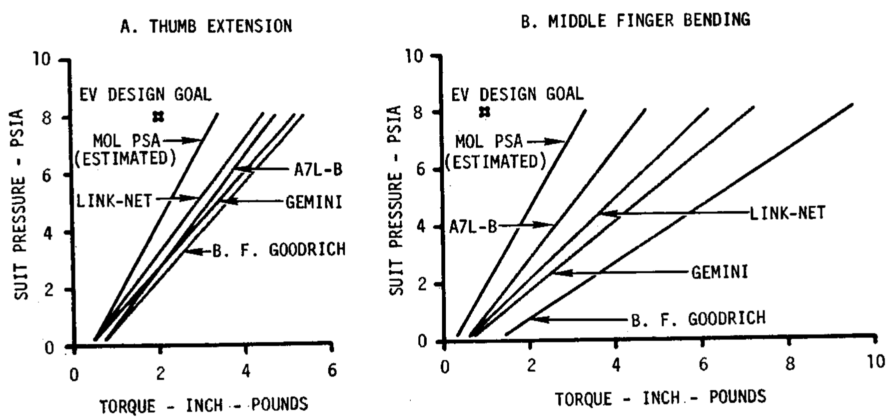


FIGURE 6–10 GLOVE MOBILITY

6.3.4 Weight and Stowage Volume

There are three (3) general suit types which were considered during this study:

a. Soft Suit: Upper and lower torso and limb transition sections (excluding joints) are constructed of soft fabric, such as restraint cloth and bladder material.

b. Hard Suit: Upper and lower torso and limb transition sections (excluding joints) are constructed of rigid material such as fiberglass and/or metal.

c. Combination Suit: Combination of soft and hard suit subassemblies.

Note that suit joints do not categorize the type of suit. The various types of joints mentioned in section 6.3.3, with or without bearings, can be utilized in any suit type.

6.3.4 Weight and Stowage Volume - Continued

Table 6-2 summarizes suit weight and stowage volume versus suit type based on available data for the Apollo, MOL and advanced suit configurations.

SUIT TYPE	WEIGHT (LB)	STOWAGE VOLUME (FT^3)
SOFT	59-71	5-6
HARD	65-75	11
COMBINATION	61-73	7-11

TABLE 6–2 WEIGHT AND STOWAGE VOLUME SUMMARY

Weight, which will have a relatively minor impact upon suit selection, is a negligible function of suit pressure level and, therefore, is not a significant factor in the selection of a suit pressure level. The stowage volume of a suit is purely a function of the type of suit selected. It should be noted that the volumes presented in Table 6-2 assume that the limbs are of soft construction and can be stored in the torso and also that the helmet is stowed within the suit. Since volume is uninfluenced by suit pressure level, it also is not a factor in the establishment of a suit pressure level requirement.

6.3.5 Cost

As discussed in this section, the general design and construction of the suit is not a significant function of the operating pressure level. Accordingly, the suit pressure level has little or no impact upon the cost of the suit. In fact, cost does not represent a significant factor in the selection of suit component design since suit detail costs do not represent a major part of the total suit program cost. The ultimate selection of suit components will be based primarily on performance and life requirements. Cost is primarily based on suit type. For a production program involving approximately 1000 suits, the soft suit configuration recurring cost is slightly higher than the hard suit configuration while the nonrecurring cost for the hard suit configuration is much higher than for the soft suit configuration. The suit cost picture is discussed in greater detail in Section 9.0 of this report, but, in summary, for selection of the suit operating pressure level, suit cost is not a significant factor.

6.3.6 Summary

Suit leakage, pressure drop, mobility, weight, volume and cost were evaluated to determine the effect of suit operating pressure level variations. Results of these evaluations indicate that none of these factors are significantly affected by variations in suit operating pressure level and are therefore not major determinants in our suit pressure level determination.

6.4 Primary Life Support System (PLSS) Considerations

The PLSS conditions and replenishes the atmosphere inside the space suit and cools the suited crewman during his EVA mission. The design of the ventilation subsystem of the PLSS is highly dependent upon the selected suit operating pressure level. Other subsystems such as the liquid cooling loop and the communications and telemetry are not affected by the suit pressure level. On that basis, this section concerns itself exclusively with the suit ventilation subsystem, and the summary parametric data presented refer to that subsystem only. Detail parametric data supporting the summary data are presented in Section 1.0, Appendix B in Volume II.

6.4.1 Ventilation Requirements

The basic requirements for the ventilation subsystem of the Primary Life Support System are as follows:

a. The mission duration is four hours.

b. The average metabolic rate of each extravehicular crewman is 1000 BTU per hour.

c. The maximum permissible partial pressure of carbon dioxide delivered to the crewman is 7.6 mm of mercury.

d. The maximum permissible moisture delivered to the suit inlet is a 50°F dewpoint.

To satisfy these requirements, four system concepts were evolved, with total oxygen consumption being reduced as system complexity increased. Each of these four concepts are described in Section 6.4.2 and evaluated in Section 6.4.3.

6.4.2 System Descriptions

6.4.2.1 Concept Commonality

Each of the candidate system concepts evolved were based on the same suit ventilation system and included both self-contained and vehicle-supplied oxygen sources. The suit ventilation system was assumed to be the same as used on the ILC A-7L-B suit, with the exception that smooth-bore, self-supporting ducting was used.

The oxygen supply for the ventilation circuit was evaluated for both self-contained systems (wherein oxygen bottles would be integrated into a back mounted PLSS and for vehicle supplied systems (wherein an umbilical would connect the crewman to the vehicle). In the case of the self-contained systems, it was assumed that the rechargeable bottle would be charged to 900 psia from the vehicle. With the umbilical system, it was assumed that the umbilical would have a 100 foot free length, would be of stainless steel braided construction, and would be stored in a spherical drum. The pressure and flow rate through the umbilical would be as required for each concept. In all cases, final regulation of the oxygen pressure would occur in the ventilation subsystem.

6.4.2.2 Open Loop Concept

The open loop concept represents the simplest ventilation subsystem considered and is shown schematically in Figure 6-11. It consists of a pressure regulator to obtain the required pressure level inside the suit and a purge valve to bleed the used oxygen from the suit. This concept has an extremely high oxygen usage rate since no attempt is made at recirculation of the oxygen.

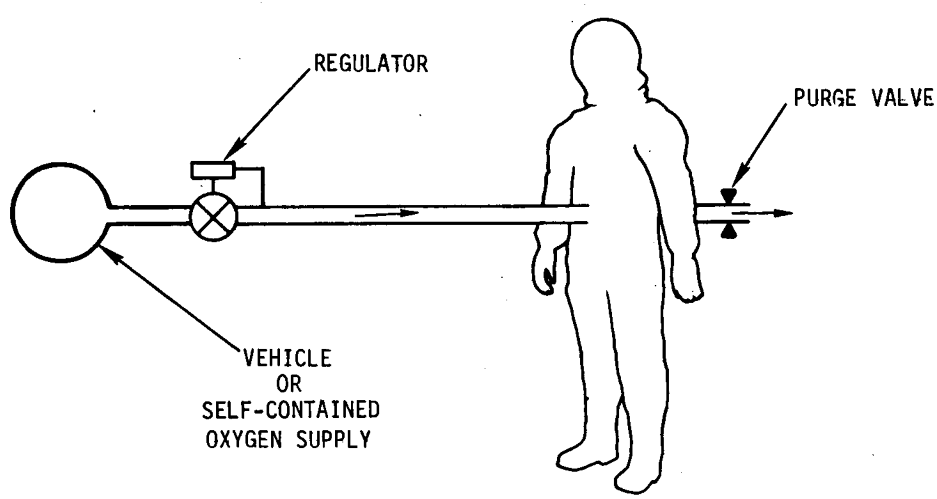


FIGURE 6–11 OPEN LOOP PRIMARY LIFE SUPPORT SYSTEM

6.4.2.3 Semi-Open Loop Concept

One technique for conserving oxygen is the semi-open loop concept shown in Figure 6-12. The oxygen saving is achieved by recirculating some of the exhaled oxygen. The incoming oxygen is reduced in pressure to approximately 100 psia by the regulator. From there, it enters the recirculation loop through the ejector and, in expanding upon entering, causes the oxygen to flow in the loop. The pressure control valve continuously bleeds sufficient oxygen out of the recirculation loop to prevent build-up of the carbon dioxide beyond acceptable limits. The recirculated oxygen is cooled as it passes through the ejector and the resultant condensed moisture is removed in the water separator thus providing humidity control. The oxygen consumption with this system is approximately 50% of that of the open loop.

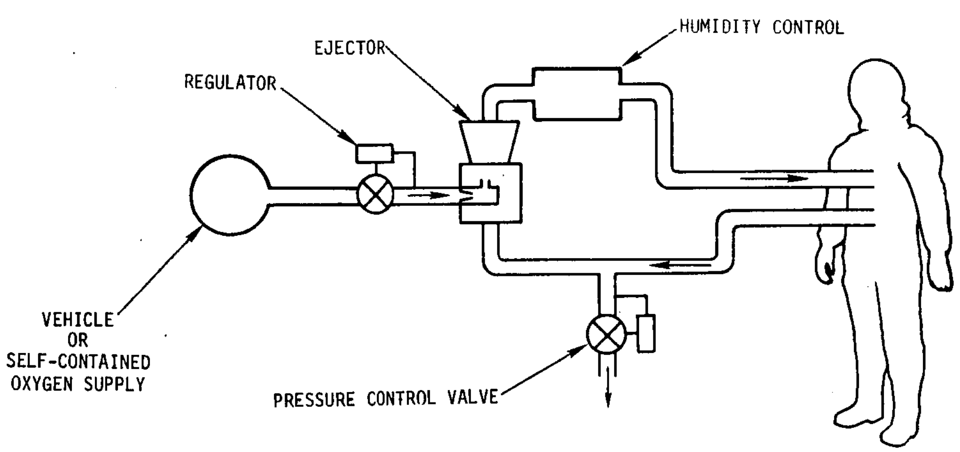


FIGURE 6-12 SEMI-OPEN LOOP PRIMARY LIFE SUPPORT SYSTEM

6.4.2.4 Semi-Closed Loop Concept

In order to achieve greater oxygen conservation than the semi-open loop offers, it is necessary to add carbon dioxide removal capability to the system. This is accomplished in the semi-closed loop shown in Figure 6-13. This system functions in the same manner as the semi-open loop except that a means for chemically removing the carbon dioxide is added. For this study, the use of lithium hydroxide was assumed. By use of this technique, it is possible to achieve an oxygen usage rate which is only 20% of its open loop consumption.

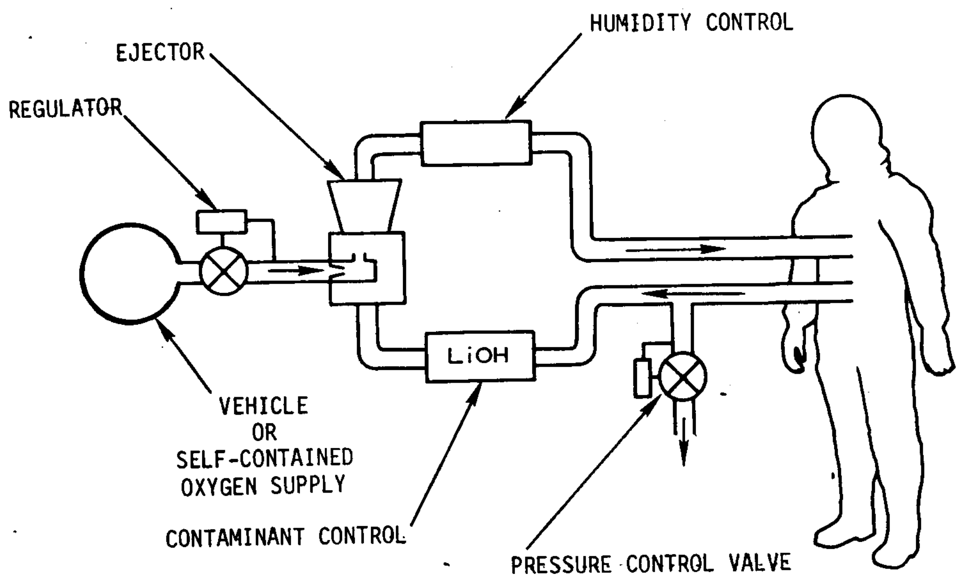


FIGURE 6-13 SEMI-CLOSED LOOP PRIMARY LIFE SUPPORT SYSTEM

6.4.2.5 Closed Loop Concept

From an oxygen usage standpoint, the most desirable ventilation subsystem is the closed loop shown in Figure 6-14. In this concept, the oxygen usage is reduced to that required for metabolic usage and to compensate for leakage from the PLSS and suit. The pressure level of this system is maintained by a demand regulator. Circulation within the loop is accomplished by a battery-powered, motor-driven fan. Humidity is controlled by first cooling the oxygen in an expendable water heat exchanger and then removing the condensed moisture in a water separator. Carbon dioxide removal is performed by lithium hydroxide as in the semi-closed loop.

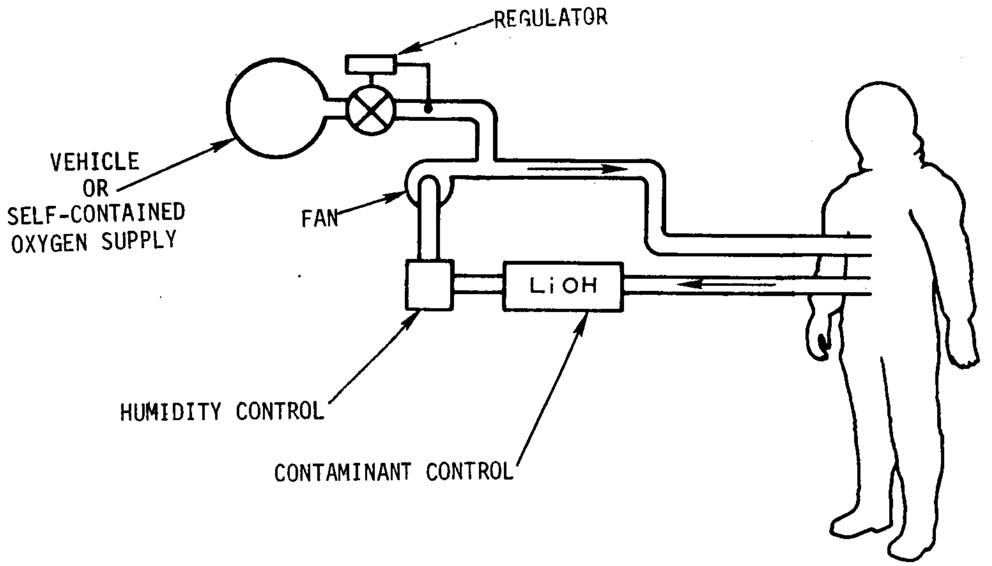


FIGURE 6-14 CLOSED LOOP PRIMARY LIFE SUPPORT SYSTEM

6.4.3 Concept

Weight and volume considerations provide an initial means for eliminating some of the eight ventilation subsystems concepts which are obviously uncompetitive.

For a vehicle oxygen supply system using a 100 foot long umbilical, the weight of the umbilical above is given in Figure 6-15 for each of the four basic concepts. The total weights of these umbilicals are a function of the required flow rate and pressure level.

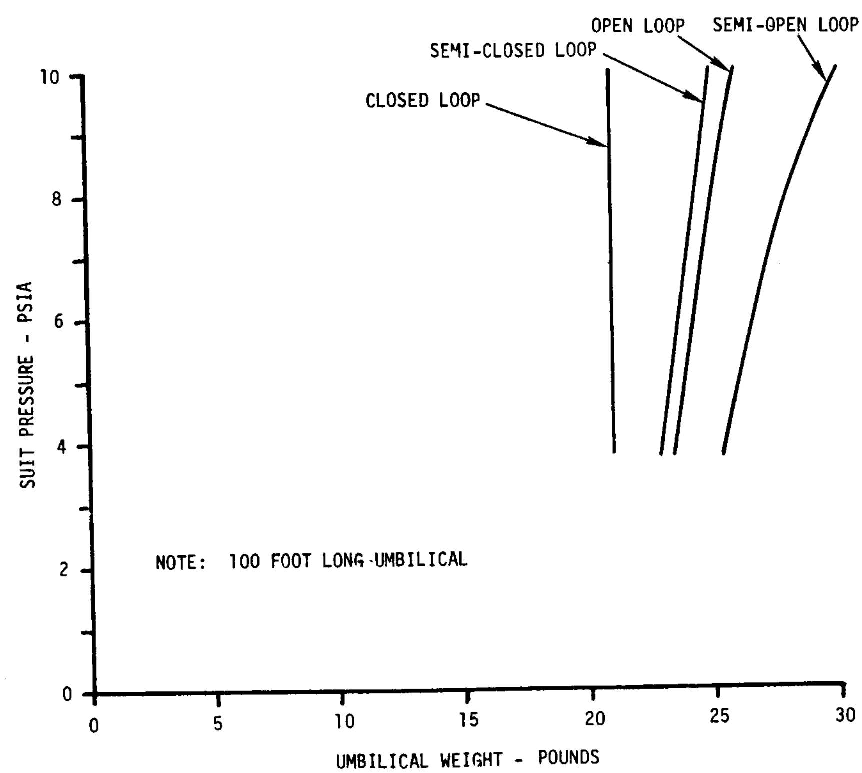


FIGURE 6-15 PRIMARY LIFE SUPPORT SYSTEM UMBILICAL WEIGHTS

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION UA®

6.4.3 Concept - Continued

Total weight and volume relationships for both self-contained and vehicle oxygen supply systems are shown in Figures 6-16 and 6-17 as a function of suit operating pressure. From the volume relationship curves, it can be seen that, regardless of pressure level, the self-contained open loop, semi-open loop and semi-closed loop systems are impractical. The required volume is too encumbering to be carried by an extravehicular astronaut. In addition, considering both weight and volume relationships, the closed loop, umbilical supplied system offers no clear cut advantages and is dropped from further consideration on that basis.

Based strictly on PLSS weight and volume, the remaining system concepts, namely the self-contained closed loop and the umbilical supplied open loop, semi-open loop and semi-closed loop systems, offer no clear cut choices of system schematic or suit operating pressure level. Accordingly, these four (4) systems are evaluated further in Section 6.6 of this volume to determine their impact upon the Shuttle Orbiter.

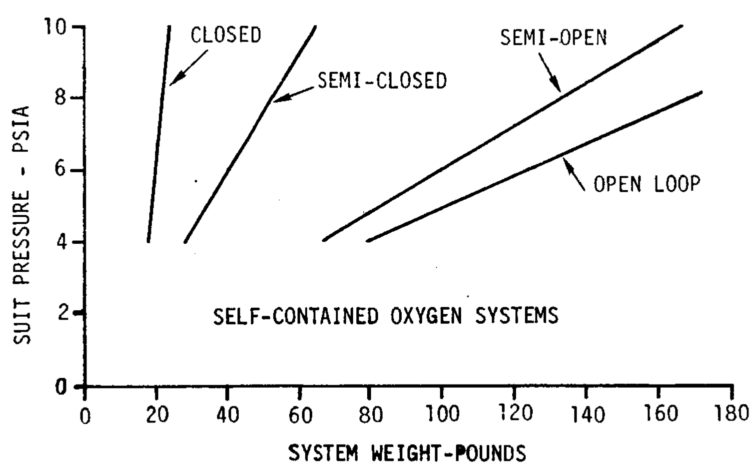


FIGURE 6—16 PRIMARY LIFE SUPPORT SYSTEM WEIGHTS

6.4.3 Concept - Continued

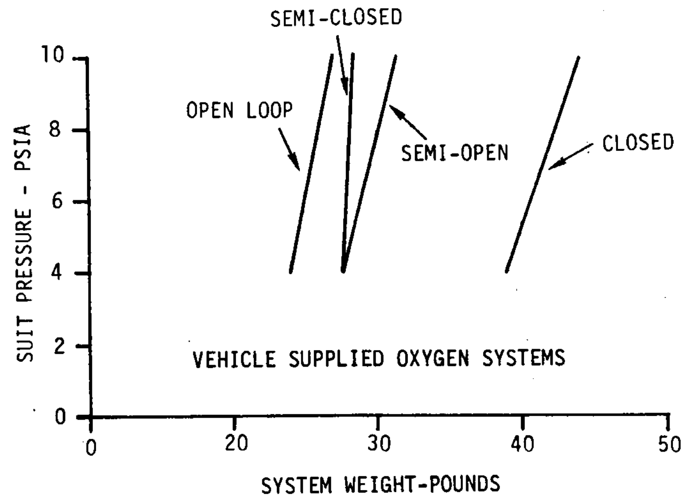


FIGURE 6-16. PRIMARY LIFE SUPPORT SYSTEM WEIGHTS - CONTINUED

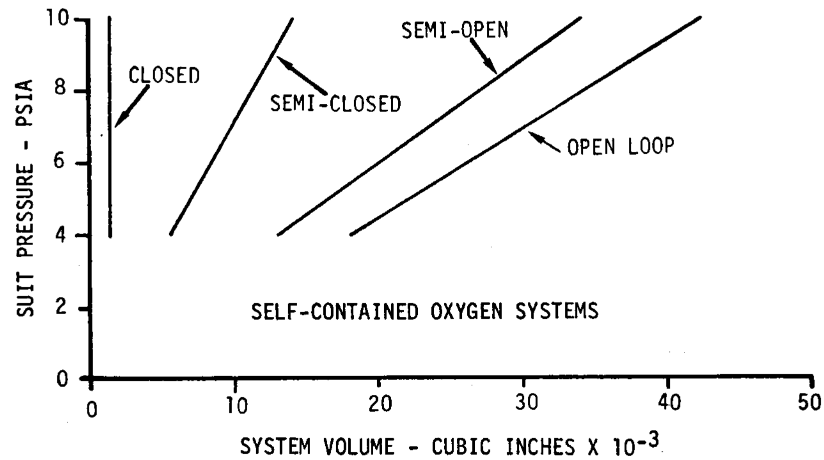


FIGURE 6-17 PRIMARY LIFE SUPPORT SYSTEM VOLUMES

6.4.3 Concept - Continued

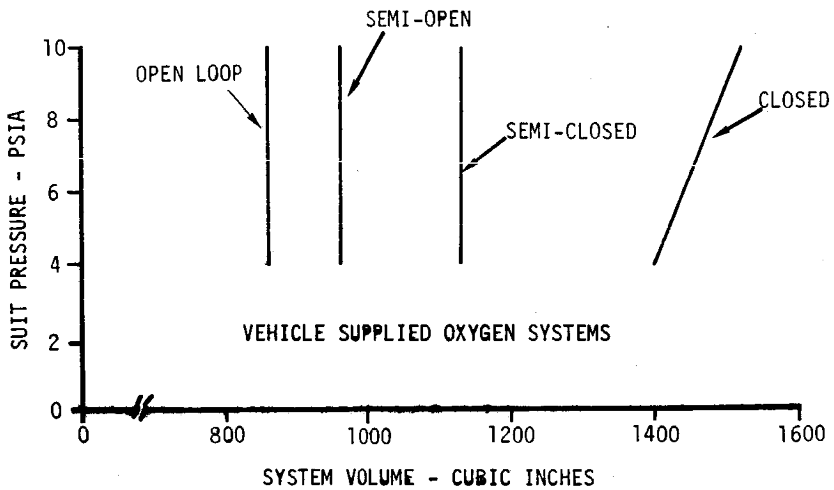


FIGURE 6—17 PRIMARY LIFE SUPPORT SYSTEM VOLUMES — CONTINUED

6.5 Emergency Life Support System (ELSS) Considerations

The ELSS provides emergency life support to a suited crewman in the event of a malfunction of his primary life support system or his suit. The ELSS is a self-contained unit that provides, as a minimum, an oxygen ventilation flow for pressurization, metabolic oxygen consumption and thermal control.

6.5.1 ELSS Requirements

The basic requirements for the ELSS are as follows:

a. The ELSS shall provide pressure-regulated oxygen for a period of fifteen minutes minimum.

b. The average metabolic rate of the crewman during the period of usage is 1600 BTU per hour.

c. The maximum permissible partial pressure of carbon dioxide delivered to the crewman is 7,6 mm of mercury.

Four candidate system concepts were evolved which satisfy the above requirements. These systems are described in 6.5.2 and evaluated in 6.5.3.

6.5.2 System Descriptions

Unlike the PLSS, all of the ELSS concepts considered were self-contained. This is necessary to ensure that the ELSS is completely independent of the vehicle. In all systems evaluated, the oxygen is delivered from a gaseous storage tank at 6000 psia. A trade-off study was conducted to determine the optimum ELSS gaseous storage pressure level and is presented in Section 2.0, Appendix B of Volume II. In the event of an emergency condition, the system would be manually actuated by opening a shut-off valve, thus permitting the oxygen to flow into the remainder of the system through a regulator which establishes the required pressure level.

6.5.2.1 Open Loop Concept

The simplest concept for an ELSS is the open loop concept shown in Figure 6-18. In addition to an oxygen supply bottle, valve and regulator, the system requires a purge valve to bleed the oxygen from the suit.

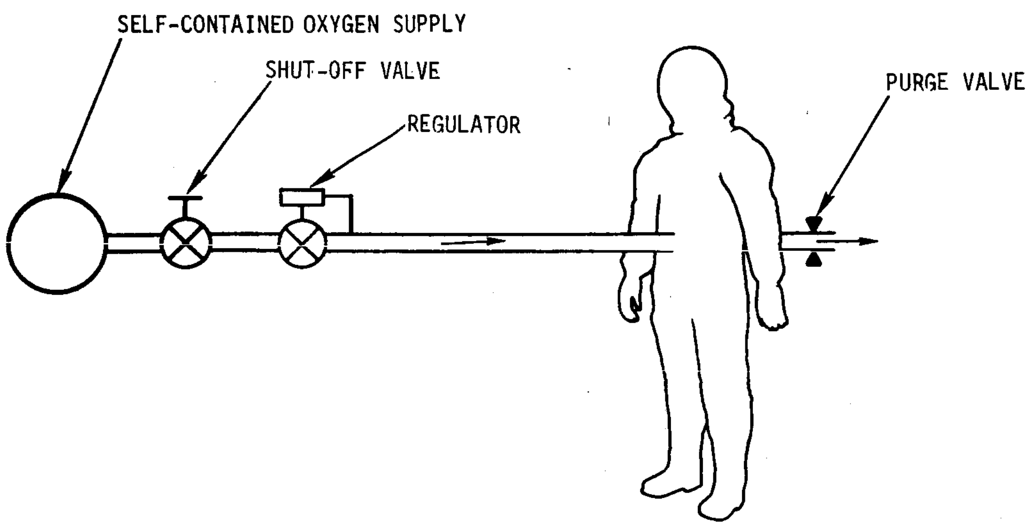


FIGURE 6—18 OPEN LOOP EMERGENCY LIFE SUPPORT SYSTEM

6.5.2.2 Semi-Open Loop Concept

The semi-open loop concept, shown in Figure 6-19, is essentially the same operationally as the semi-open PLSS described in Section 6.4.2.3. It conserves approximately 50% of the oxygen used by the open loop ELSS concept by recirculation of the oxygen with an ejector.

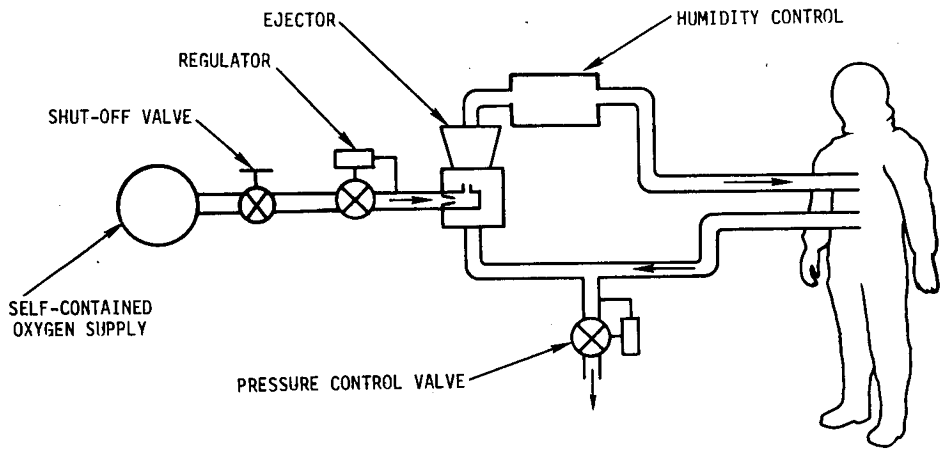


FIGURE 6-19 SEMI-OPEN LOOP EMERGENCY LIFE SUPPORT SYSTEM

6.5.2.3 Semi-Closed Loop Concept

In the semi-closed loop concept, shown in Figure 6-20, a contaminant control cartridge is added to the loop for carbon dioxide removal. Oxygen recirculation continues to be performed by the ejector, as in the PLSS semi-closed loop discussed in Section 6.4.2.4. This concept conserves approximately 80% of the oxygen used by the open loop ELSS concept.

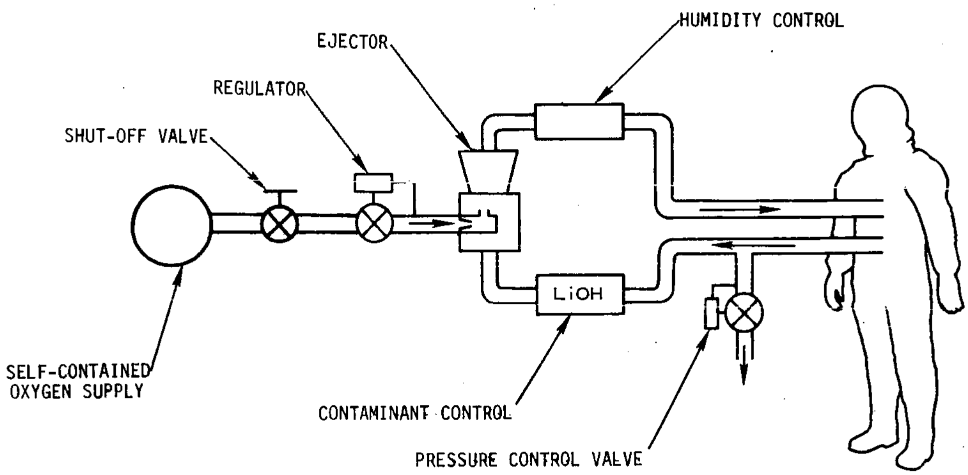


FIGURE 6-20 SEMI-CLOSED LOOP EMERGENCY LIFE SUPPORT SYSTEM

6.5.2.4 Closed Loop Concept

The ELSS concept shown in Figure 6.21 is a closed loop system utilizing a heat exchanger for humidity and temperature control and a fan for oxygen recirculation. Its mode of operation is the same as the PLSS closed loop described in 6.4.2.5. Oxygen consumption is reduced to the metabolic requirement and system leakage, the lowest level of any of the potential systems.

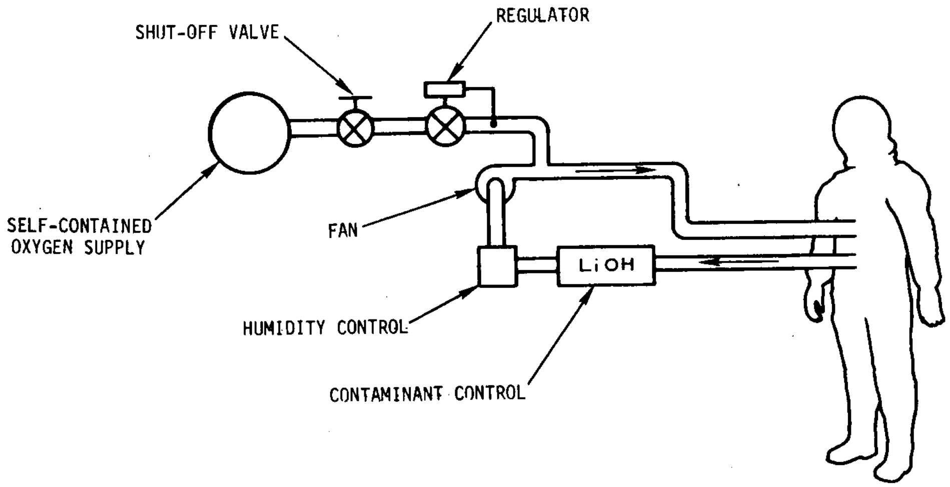


FIGURE 6—21 CLOSED LOOP EMERGENCY LIFE SUPPORT SYSTEM

6.5.3 Concept Evaluation

Unlike the PLSS concept evaluation, weight and volume considerations do not present a clear cut choice of an Emergency Life Support System. As the curves of Figures 6-22 and 6-23 indicate, there are only minor variations between the various system weights and volumes, although the semi-open loop does tend to be slightly smaller and lighter than the other concepts. The open loop system is carried forward for total vehicle impact considerations on the basis that it is the simplest system and its weight and volume are generally representative of any Emergency Life Support System.

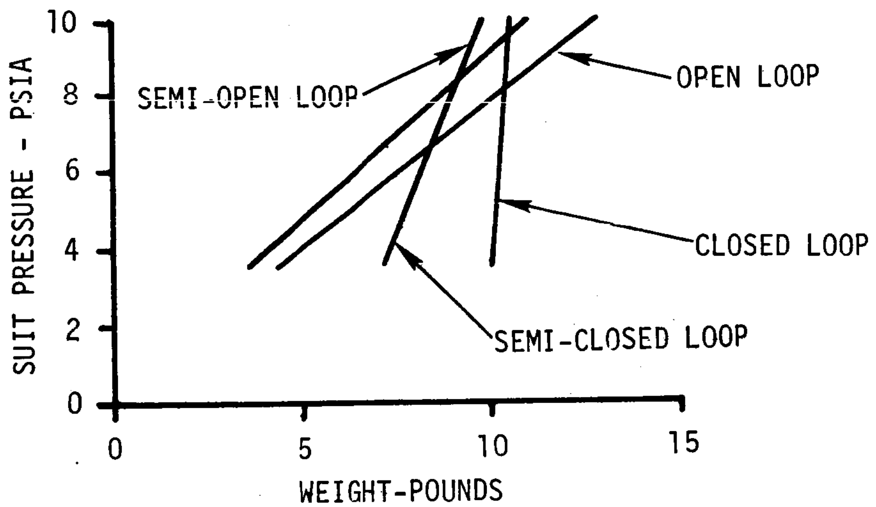


FIGURE 6–22 EMERGENCY LIFE SUPPORT SYSTEM WEIGHTS

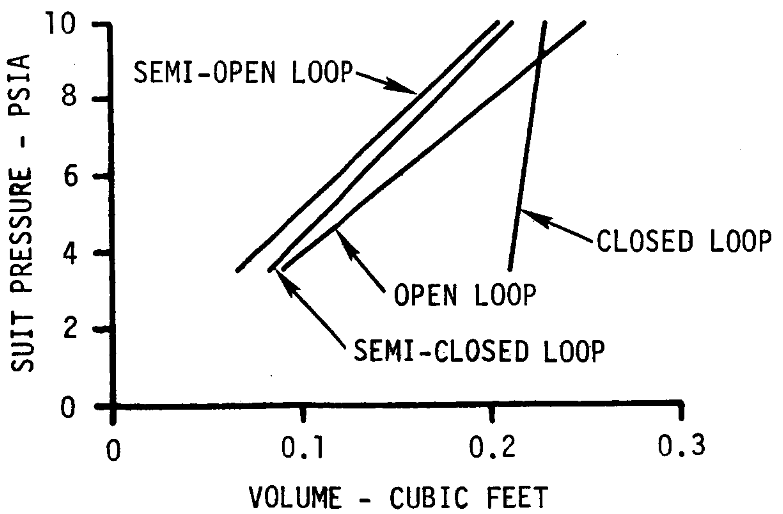


FIGURE 6–23 EMERGENCY LIFE SUPPORT SYSTEM VOLUMES

6.6 Vehicle Support Provisions

Vehicle support provisions are those provisions which are carried by the Shuttle Orbiter and are required to support the Shuttle EVA operations. There are two areas of vehicle support provisions that are affected by the selection of suit operating pressure level: (a) Prebreathing Equipment and (b) Orbiter PLSS expendables supply system. Expendables usage from the vehicle supply carries the following penalties:

a. Each pound of oxygen withdrawn from the vehicle represents 1.25 pounds of vehicle weight (1.0 pound of oxygen and 0.25 pound of tankage).

b. One cubic foot of vehicle volume is required for every 71 pounds of oxygen withdrawn.

c. Since vehicle oxygen stowage is liquid, it is necessary to heat the oxygen prior to use. To provide the electrical energy for this heating requires 286 pounds of fuel cell weight for each kilowatt plus 1.98 pounds of expendables (oxygen and hydrogen) for each kilowatt-hour. However, the fuel cells are sized by electrical requirements at times other than when the EVA life support equipment are being used or recharged and, consequently, more than sufficient capacity exists to handle this load. Accordingly, the only penalty associated with power consumption is the oxygen and hydrogen expendables requirement.

d. In the closed loop systems it is necessary to supply water to the condensing heat exchanger used for humidity control and power to operate the fan. Analysis indicates that the weight of the water involved is negligible and, therefore, it is not considered in this trade-off. The penalty for power used to recharge the batteries is 1.98 pounds of expendables (oxygen and hydrogen) per kilowatt-hour. As discussed earlier relative to oxygen supplies, no penalty is charged for actual fuel cell weight or volume.

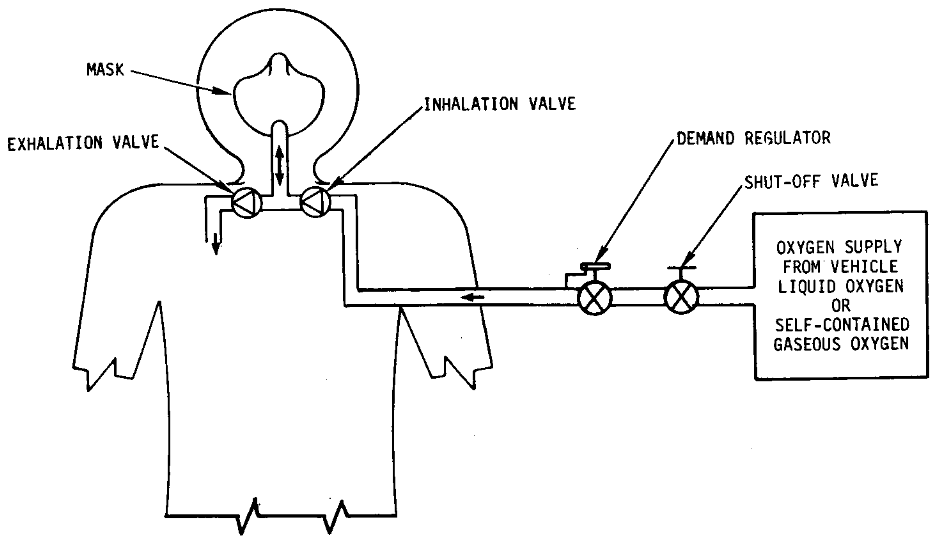
6.6.1 Prebreathing Equipment

If a pressure level below 8.0 psia is used for the suit, it is necessary for the crewman to denitrogenize his body and suit prior to depressurizing from the airlock atmosphere to his final suit pressure. To accomplish this, it is necessary to prebreathe pure oxygen for a period of time which is dependent upon the final pressure level selected. Therefore, part of the suit pressure level study involves the evaluation of prebreathing equipment.

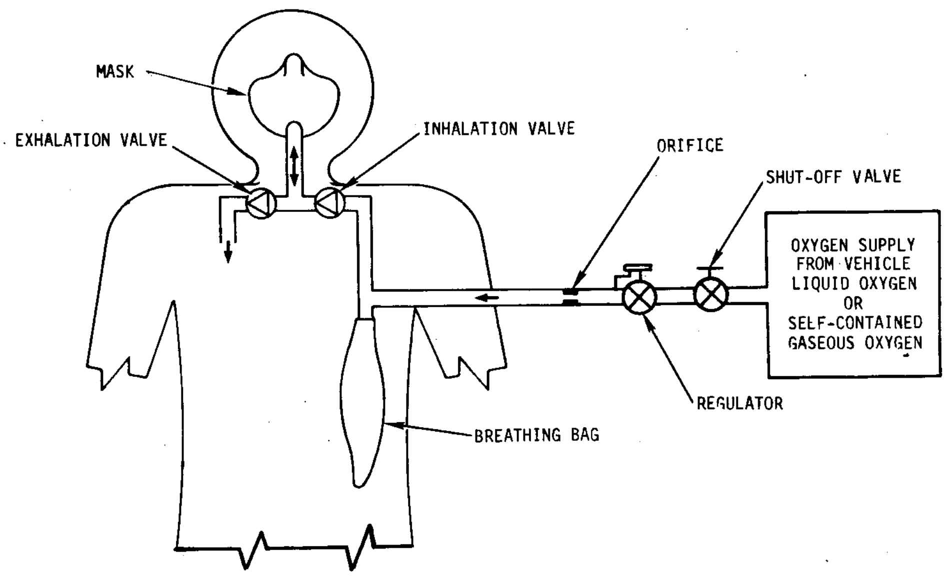
It was assumed that during the prebreathing period, the crewman would be relatively inactive and, on that basis, a metabolic load of 500 BTU per hour for the suited but unpressurized crewman was established. In addition, breathing oxygen purity levels were established as a maximum of 3% of nitrogen by volume and a maximum carbon dioxide partial pressure of 7.6 mm of mercury. From that information, the prebreathing equipment can be sized for any suit pressure level. If an open loop, continuous purge system is used, it is necessary to flow 1.5 standard cubic feet of oxygen per minute. In a semi-closed loop system utilizing CO_2 scrubbing, the flow rate can be reduced to 0.3 pounds of oxygen per hour.

Two potential open loop systems are shown in Figure 6-24. In both of these systems, the gaseous oxygen supply can be from either a vehicle liquid storage system or from self-contained gaseous oxygen tankage. Both systems utilize shutoff valves and face masks with check valves to prevent reverse gas flow upon inhalation and exhalation. In the first system, a demand regulator is used to supply oxygen only upon inhalation. In the second system, flow is continuous through both the regulator and the flow limiting orifice and into the breathing bag. Upon inhalation, the oxygen is drawn from the breathing bag into the mask. The advantage of these systems is the relative simplicity of the equipment, while the disadvantage is the quantity of oxygen consumed.

6.6.1 Prebreathing Equipment - Continued



A — DEMAND REGULATOR SYSTEM



B — BREATHING BAG SYSTEM

FIGURE 6—24 OPEN LOOP PRE BREATHING SYSTEMS

6.6.1 Prebreathing Equipment - Continued

The semi-closed loop system, which is shown in Figure 6-25, can also obtain its oxygen from either the vehicle or self-contained tankage. Incoming oxygen flow is continuous through the regulator and the flow limiting orifice. Upon exhalation, the gas flows through the mask outlet check valve and into the breathing bag. On inhalation, the gas is drawn from the breathing bag, through the lithium hydroxide cartridge for removal of carbon dioxide, and then through the face mask inlet check valve. System pressure is maintained at approximately two inches of water above ambient pressure by periodic opening of the purge valve.

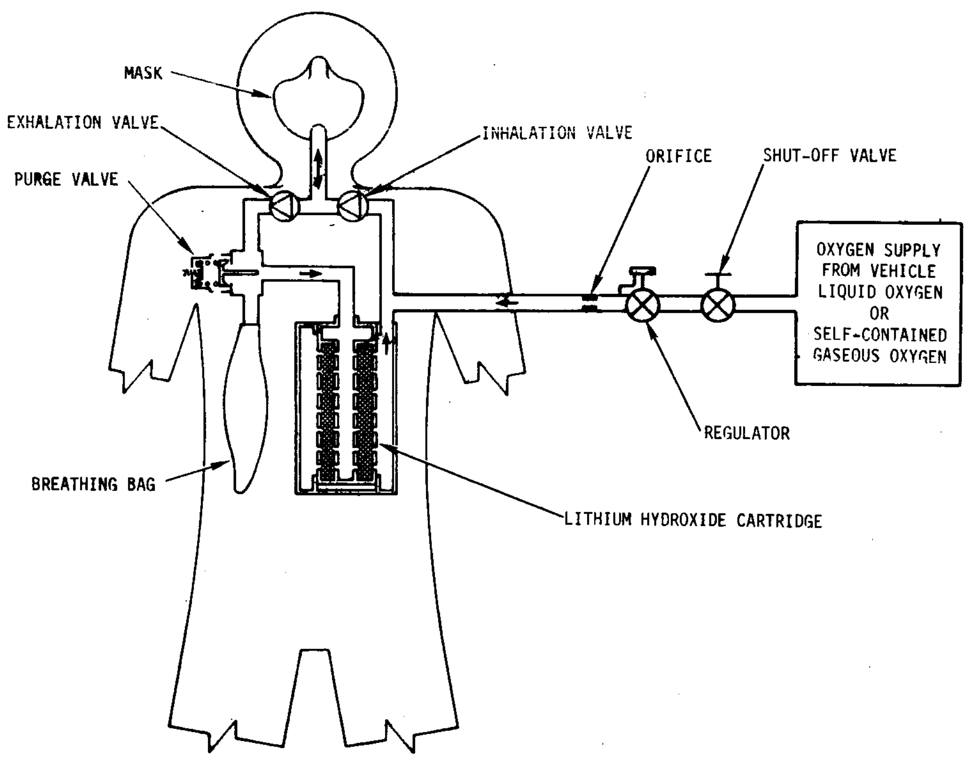


FIGURE 6-25 SEMI-CLOSED LOOP PREBREATHING SYSTEM

6.6.1 Prebreathing Equipment - Continued

The impact upon weight and volume for providing the prebreathing capability on Shuttle is summarized in Figure 6-26. These curves represent total weight and volume required, including both the actual prebreathing equipment and the oxygen and its tankage, whether the supply is from the vehicle or is self-contained. Clearly, the self-contained systems are unacceptable on this basis when compared with vehicle supplied oxygen systems. Due to its considerably lower oxygen consumption, the semi-closed loop offers substantial weight and volume advantages over the open loop and would, logically, be selected if prebreathing were required.

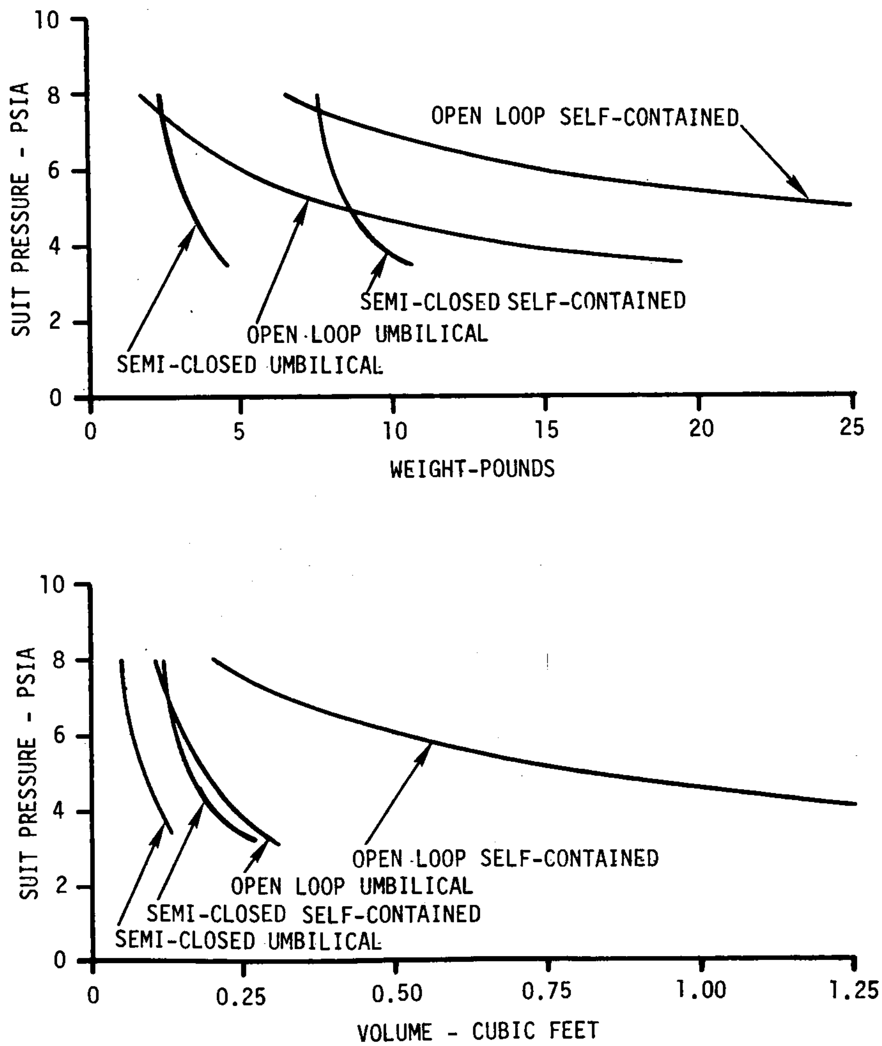


FIGURE 6—26 WEIGHT & VOLUME IMPACT OF PREBREATHING

6.6.1 Prebreathing Equipment - Continued

In addition to purging nitrogen from the crewman's body, it is necessary to purge it from his suit prior to closure of the suit before depressurizing. Since this purging must occur at a 14.7 psia ambient pressure and it is necessary to obtain a maximum of 3% nitrogen by volume, a total of 3.15 pounds of oxygen are required per crewman for each EVA. This oxygen comes from the vehicle oxygen supply. The impact upon the vehicle weight and volume of supplying this oxygen and its accompanying tankage is summarized in Figure 6-27.

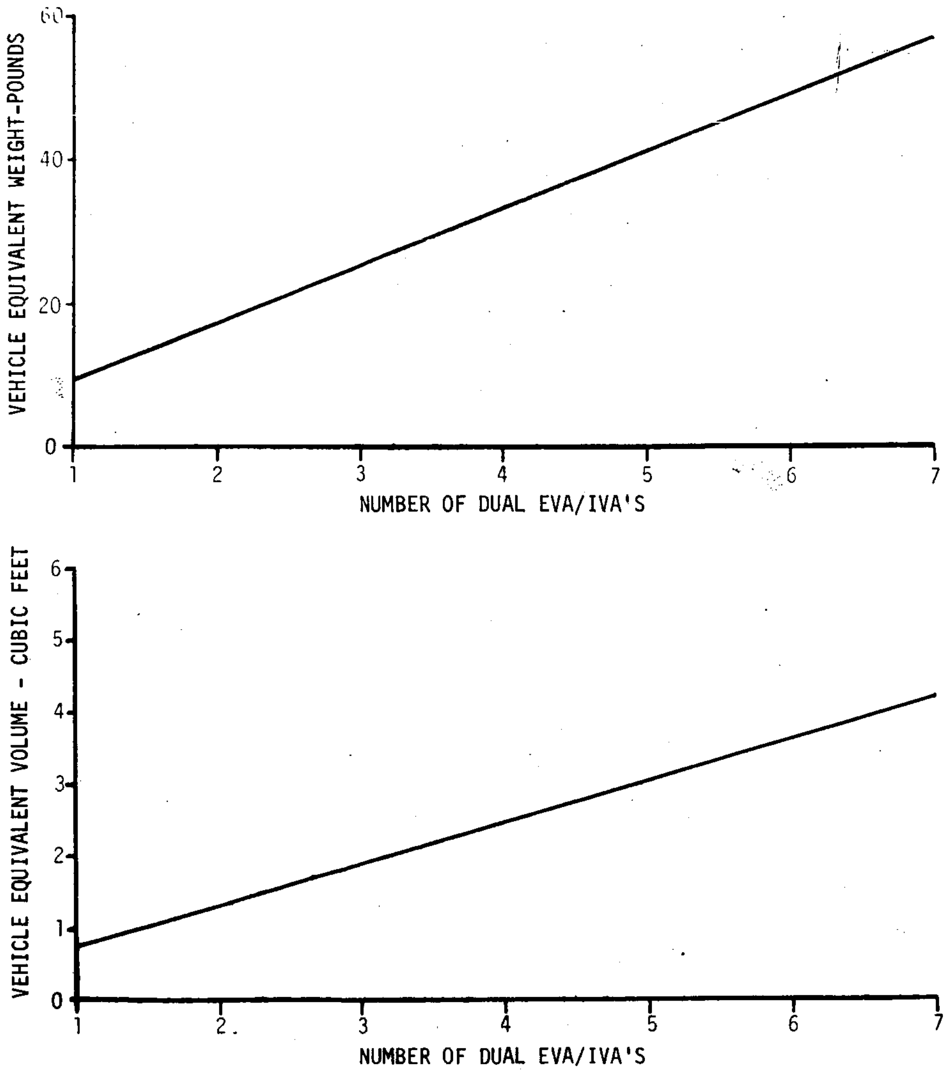


FIGURE 6–27 WEIGHT & VOLUME IMPACT OF SUIT PURGING

6.6.2 Orbiter PLSS Expendable Supply System

Based upon the vehicle penalties described in this section, a weight and volume evaluation of the Orbiter PLSS expendable supply system required for each of the four (4) PLSS ventilation subsystems identified in Section 6.4 was conducted. The total weight impact for operating each of the four subsystem concepts is presented in Figure 6-28 and the volume impact is presented in Figure 6-29. The data presented are for pressure levels of four, six, eight and ten psia and for one to seven dual extravehicular excursions. From these curves, it can be seen that the umbilical supplied open loop and semi-open loop concepts have excessive weight and volume impact upon the vehicle at any suit operating pressure level. Of the other two concepts, the self-contained closed loop offers lower volumetric requirements regardless of suit pressure level. The vehicle weight trade-off indicates that an 8.0 psia self-contained closed loop ventilation subsystem is acceptable for any number of EVA's and is actually the lightest weight approach for four or more dual EVA's.

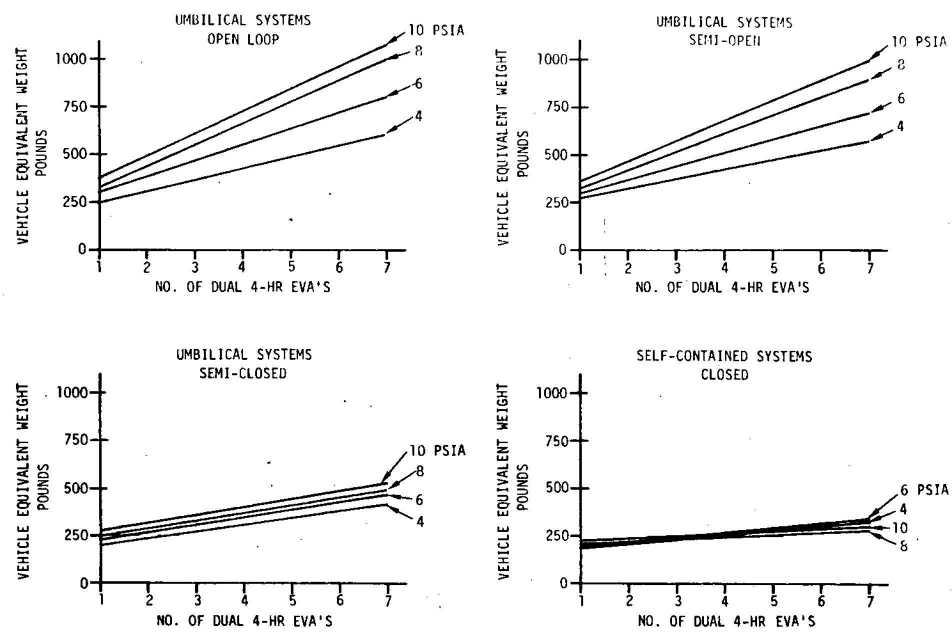


FIGURE 6—28 TOTAL IMPACT UPON VEHICLE WEIGHT

6.6.2 Orbiter PLSS Expendable Supply System - Continued

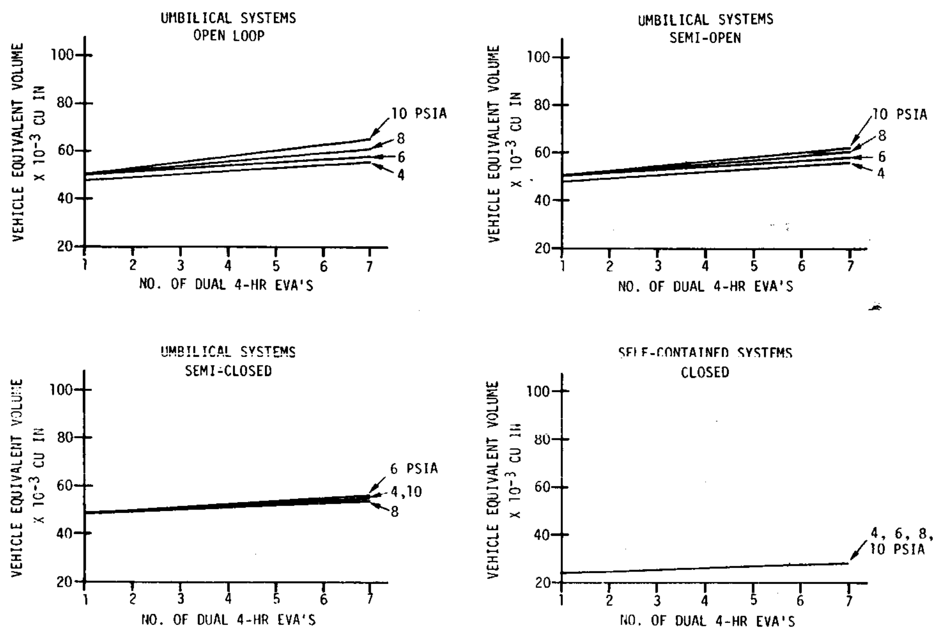


FIGURE 6—29 TOTAL IMPACT UPON VEHICLE VOLUME

6.7 Shuttle Mission

Selection of suit operating pressure level affects the Shuttle mission in two general areas: (a) Crewman utilization and (b) EVA equipment materials oxygen compatibility.

6.7.1 Crewman Utilization

An additional impact resulting from the requirement for prebreathing is the reduction in crewman utilization. As stated earlier, the prebreathe period is one of relatively light activity and, as a consequence, the crewman is essentially unproductive. The effect upon mission manpower utilization as a function of suit pressure is shown in Figure 6-30. Based on the above curves, it becomes clear that a suit pressure level below 8.0 psia is undesirable from a crewman utilization standpoint.

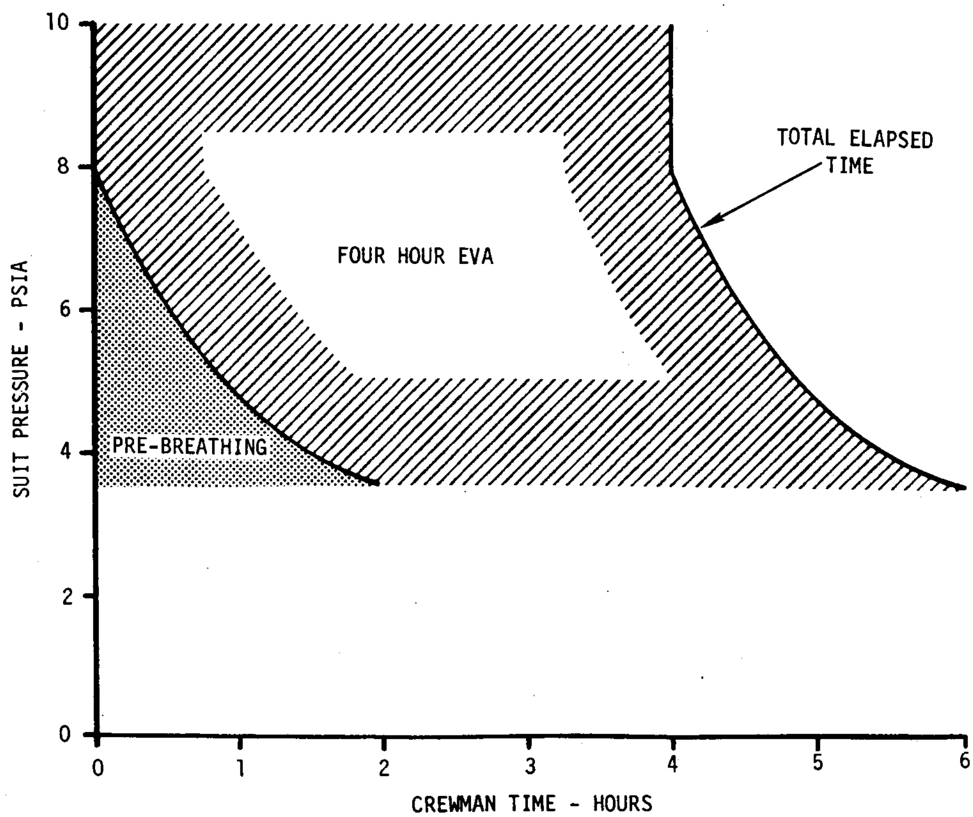


FIGURE 6—30 IMPACT OF PREBREATHING UPON CREWMAN UTILIZATION

6.7.2 Oxygen Compatibility

During the Apollo program a major effort was expended to qualify non-metallic materials for pure oxygen exposure (Reference: NASA Document MSC-PA-D-67-3 Titled "Non Metallics Requirements for the Apollo Spacecraft"). Consequently, in establishing the suit pressure level for the Shuttle EVA system, materials qualification to higher O_2 pressure levels was assessed. It was concluded that the Shuttle application does not require any significant materials qualification effort for pure O_2 exposure due to suit pressure level changes and therefore is not a factor in establishing the suit pressure level. This conclusion was based on the following:

a. The EVA equipment high pressure oxygen supply subsystem materials and design configurations have been fully qualified for O_2 use and will satisfy the Shuttle needs. Materials which would normally be exposed to the Shuttle cabin atmosphere, are currently qualified for 16.0 psia pure O_2 with the Shuttle cabin O_2 pressure significantly lower than 16 psia.

b. A few materials, normally utilized in the ventilation circuits of the EVA equipment, such as water separator wicking (nylon or dacron), silicone rubber, suit fabric and fan bearing grease will not fully meet the non-metallic requirements. However, they can be made completely safe by utilizing the procedures used in the Apollo program. This was accomplished by encapsulating the marginal materials in fire shielding material and/or designing the equipment to eliminate all credible ignition sources.

6.8 Conclusions

A suit operating pressure level of 8.0 psia is selected based on the following major conclusions drawn during this study:

a. The potential for decompression sickness is eliminated.

b. No potential for oxygen toxicity exists.

c. By elimination of the prebreathing and suit purging requirements, there are savings in equipment, cost, and crewman utilization.

d. No major technological advances are required in suits or life support systems to provide the necessary performance.

e. The 8.0 psia self-contained closed loop primary life support system represents the minimum total impact upon vehicle weight and volume for four or more dual EVA's per mission.

SECTION 7.0

PRIMARY LIFE SUPPORT SYSTEM

7.0 PRIMARY LIFE SUPPORT SYSTEM

7.1 General

The primary functions of a Primary Life Support System (PLSS) are to condition and replenish the atmosphere inside the space suit and to cool the suited crewman during his EVA mission. In order to accomplish this, the PLSS must provide the specific life support functions depicted in Figure 7-1.

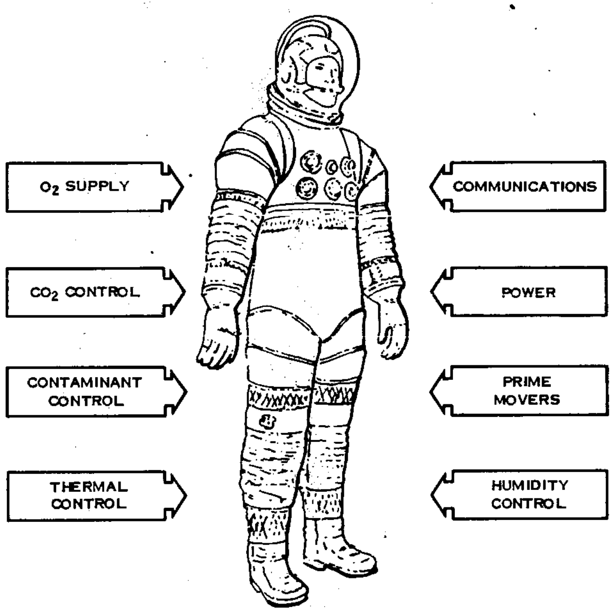


FIGURE 7–1. PLSS FUNCTIONS

This section presents the results of the PLSS requirements definition effort. Various candidate life support subsystem concepts were identified and evaluated to determine the most desirable approaches. The selected concepts were then carried into the system studies where the subsystem concepts were combined into various candidate system concepts. The system concepts considered included both independent self-contained and umbilical configurations. Because certain potential planned and unscheduled EVA missions could involve contamination-sensitive payloads, the impact of integrating noncontaminating equipment into the most desirable PLSS system concepts was also evaluated. These efforts resulted in the definition of PLSS requirements presented herein.

7.1.1 Evaluation Criteria

The determination of the evaluation criteria was based on the recognition that some requirements are absolute while others are comparative. The absolute criteria define the minimum

7.1.1 Evaluation Criteria - Continued

acceptable requirements for a concept. If a concept does not meet all of the absolute criteria, it is eliminated. The absolute criteria are listed as follows:

a. Performance - All concepts must be capable of meeting the entire performance spectrum.

b. Safety - Safety of each concept was evaluated to determine if there are any hazards present which cannot be eliminated. If any serious problems were discovered which could not be reasonably avoided, the concept was eliminated.

c. Availability - Availability is a measure of the probability of a concept being fully operational within the required time period (following reasonable development effort).

The comparative criteria are the principal evaluation criteria for all concepts that pass the absolute criteria requirements and are listed as follows:

a. Shuttle Weight - The physical aspects of any given concept can be converted to a vehicle launch weight penalty for purposes of comparison. Shuttle weight consists of subsystem or system fixed weight, expendables, power requirements, heat rejection requirements, recharge equipment, spares and interface equipment.

b. Shuttle Volume - Shuttle volume is a volumetric measure of the items referenced in a. above.

c. PLSS Weight - PLSS weight consists of all PLSS equipment with which the crewman must egress from the vehicle.

d. PLSS Volume - PLSS volume is a volumetric measure of all PLSS equipment with which the crewman must egress from the vehicle.

e. Operability - Operability is a measure of the concept's ability to be simply used for the mission's various operating modes.

f. Cost - Cost consists of both Shuttle program and PLSS program recurring and nonrecurring costs.

7.1.2 Subsystem and System Studies Requirements

Table 7-1 presents the initial requirements developed as a result of the EVA/IVA task identification and analysis effort and utilized in the conduct of the subsystem and system studies.

Mission Duration	4 Hours
Metabolic Loads Average Minimum Peak	 1000 Btu/Hr. 400 But/Hr. 1600 Btu/Hr.
Suit Pressure Control	8.2 ± 0.2 psia
CO_2 Control	7.6 mm Hg Max. Inspired
Humidity Control	Suit inlet dewpoint less than 50°F
Ventilation Flow	As required to obtain humidity and CO_2 control
Thermal Control	Maintain crewman thermal comfort with an inward heat leak of 200 Btu/Hr.

TABLE 7—1. PLSS REQUIREMENTS

7.1.3 Vehicle Penalties

Table 7-2 presents the vehicle penalties utilized in the conduct of the subsystem and system studies.

Oxygen: LOX Storage - .25 lbs. of tank per lb. of O_2 Gaseous Storage - 2.14 lbs. of tank per lb. of O_2
Power: Expendables - .289 lb./watt + .00198 lb./watt-hr. Fuel Cell - 50 watt-hours/lb.
Water - None
Cooling Penalty: .171 lbs./Btu/Hr. sensible heat load into cabin .134 lbs./Btu/Hr. latent heat load into cabin .054 lbs./Btu/Hr. heat load into vehicle cooling system
Heating Penalty - Use Electrical Power
Radiator - None (has excess capacity during EVA phases of Shuttle mission)

TABLE 7—2. VEHICLE PENALTIES

7.1.3 Vehicle Penalties - Continued

These vehicle penalties were applicable at the time they were utilized. In the event that these change, it is felt that the overall study results will remain applicable as the bulk of the trade-off analysis is relative and the trends indicated would not vary significantly.

7.2 Subsystem Studies - Self-Contained System

The objective of the subsystem studies was to evaluate and select the most competitive subsystem concepts for the closed loop, self-contained PLSS. This section summarizes the results of this effort. The detailed results of this effort, including schematics and parametric data for all subsystem concepts considered, are contained in Appendix C of Volume II.

7.2.1 Oxygen Supply

The oxygen supply subsystem maintains suit pressure and provides oxygen make-up flow for crewman metabolic O_2 consumption and suit and PLSS external leakage in accordance with the requirements listed below:

a. Suit Pressure	8.2 ± 0.2 psi
b. Oxygen Storage	0.77 lbs useable O_2
c. Oxygen Delivery	
Metabolic Consumption	0.175 lbs/hr
Leakage	0.017 lbs/hr

7.2.1 Oxygen Supply - Continued

A listing of the O_2 supply subsystem concepts identified and evaluated is presented in Table 7-3.

I.	Oxygen Storage
	1. Gaseous (900-6000 psi)
	2. Supercritical Utilizing Thermal Pressurization
	3. Subcritical Utilizing Thermal Pressurization
	4. Subcritical Utilizing Positive Expulsion
	5. Solid
II.	Solid Decomposition
	6. Superoxides (KO_2)
	7. Peroxides (Li_2O_2)
	8. Ozonides
	9. Sodium Chlorate Candles ($NaClO_3$)
	10. Lithium Perchlorate Candles ($LiClO_4$)
III.	Liquid Decomposition
	11. Hydrogen Peroxide
	12. Reactant Storage (N_2H_4/N_2O_4)
	13. Reactant Storage (N_2H_4/N_2O_4)
IV.	Electrolysis
	14. Water Electrolysis

TABLE 7-3. OXYGEN SUPPLY SUBSYSTEM CONCEPTS

The results of the O_2 supply subsystem evaluation are presented in detail in Section 1.0 of Appendix C and indicate that the most competitive concepts are gaseous O_2 storage (900-6000 psi). The present Shuttle Orbiter baseline configuration has the capability to provide a maximum PLSS O_2

7.2.1 Oxygen Supply - Continued

supply subsystem recharge presssure of 900 psi. A schematic depicting this candidate configuration is pictured in Figure 7-2.

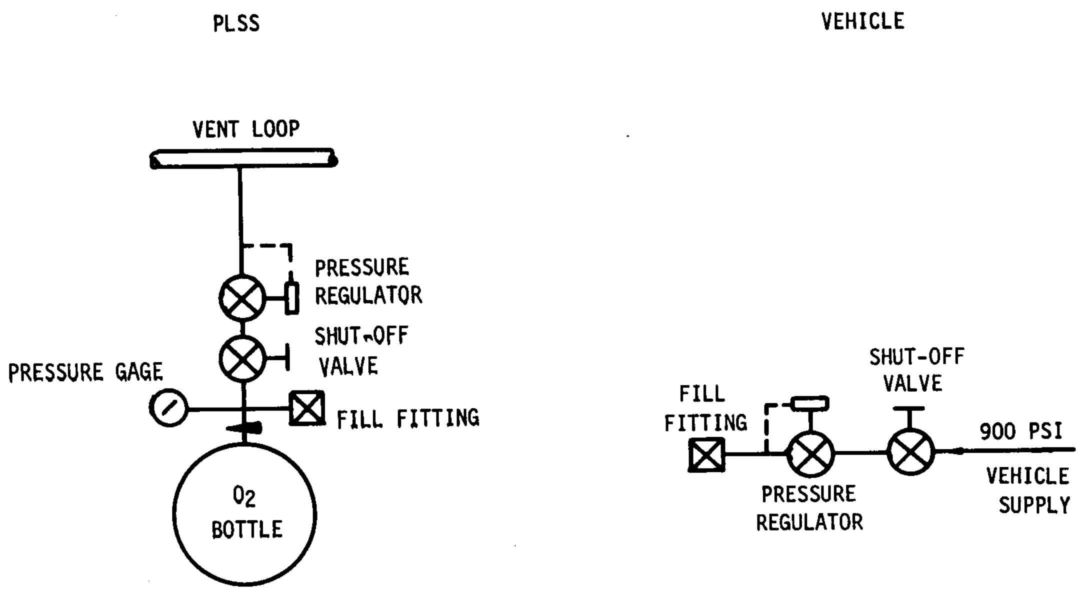


FIGURE 7—2. 900 PSI OXYGEN SUPPLY SUBSYSTEM SCHEMATIC

7.2.1 Oxygen Supply - Continued

If a higher pressure O_2 supply subsystem is desired to decrease PLSS volume, a replaceable (vs rechargeable) subsystem presented schematically in Figure 7-3 would be a viable candidate.

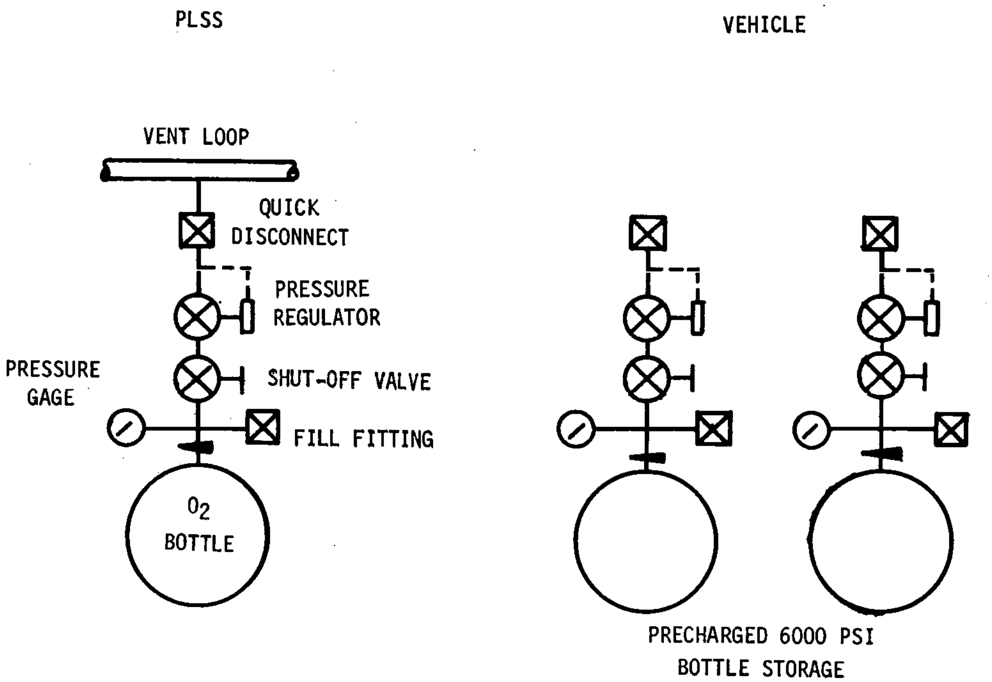


FIGURE 7–3. 6000 PSI OXYGEN SUPPLY SUBSYSTEM SCHEMATIC

7.2.1 Oxygen Supply - Continued

Figure 7-4 depicts the effect of both of these concepts on PLSS and Shuttle weight and volume. Note that while there is a PLSS volume benefit in going to the replaceable 6000 psi subsystem, PLSS weights are about the same for both concepts and there is a much greater Shuttle weight and volume penalty associated with the replaceable 6000 psi subsystem. In addition, use of a replaceable 6000 psi bottle might also require replacement of the regulator to avoid connection/disconnection of high pressure lines. This approach could prove to be costly and would introduce undesirable interface constraints. Therefore, if the Shuttle Orbiter baseline configuration remains the same, the most desirable O_2 supply subsystem is a rechargeable 900 psi gaseous O_2 storage subsystem.

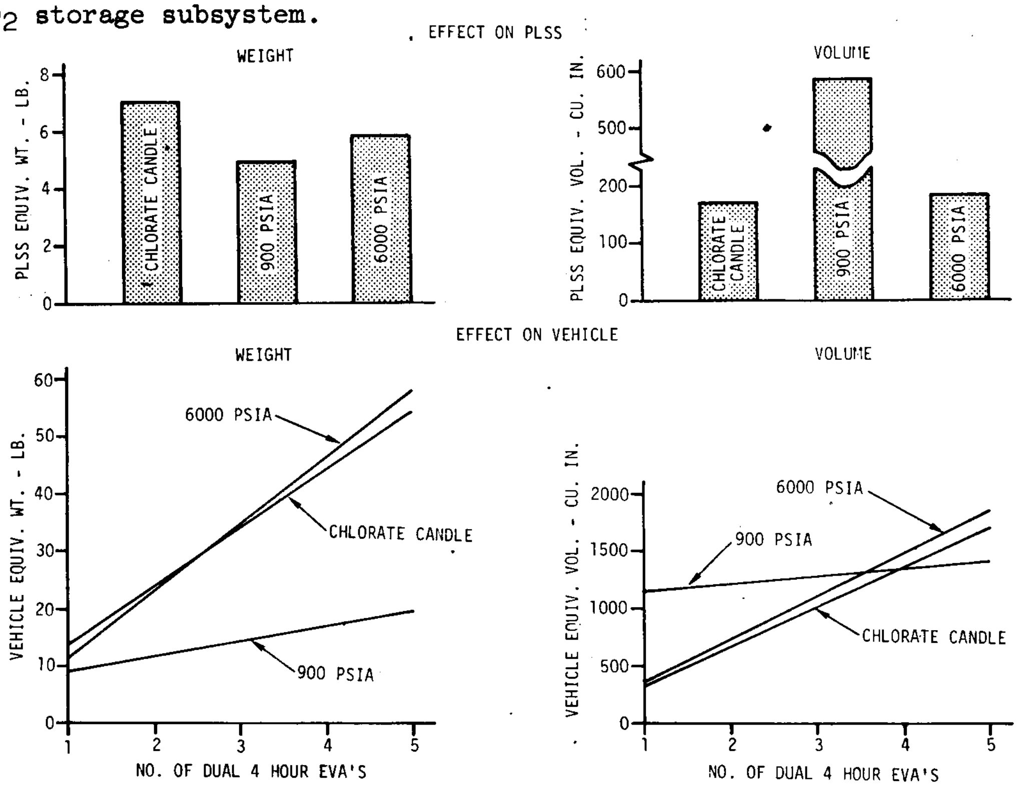


FIGURE 7–4. OXYGEN SUPPLY SUBSYSTEM WEIGHT & VOLUME COMPARISON

In the event that the Shuttle Orbiter baseline configuration is modified to permit a higher PLSS O_2 supply subsystem recharge pressure, there are other pressure level options available that must be evaluated. Figure 7-5 presents O_2 supply subsystem weight and volume versus bottle pressure for rechargeable and replaceable configurations.

7.2.1 Oxygen Supply - Continued

Shuttle weight and volume versus bottle pressure for replaceable bottle/regulator, replaceable bottle, and rechargeable configurations are presented in Figure 7-6. Review of the data in Figures 7-5 and 7-6 indicate that an O_2 supply subsystem pressure of 2500 - 3000 psi is the most desirable pressure level when considering the impact upon PLSS volume and weight.

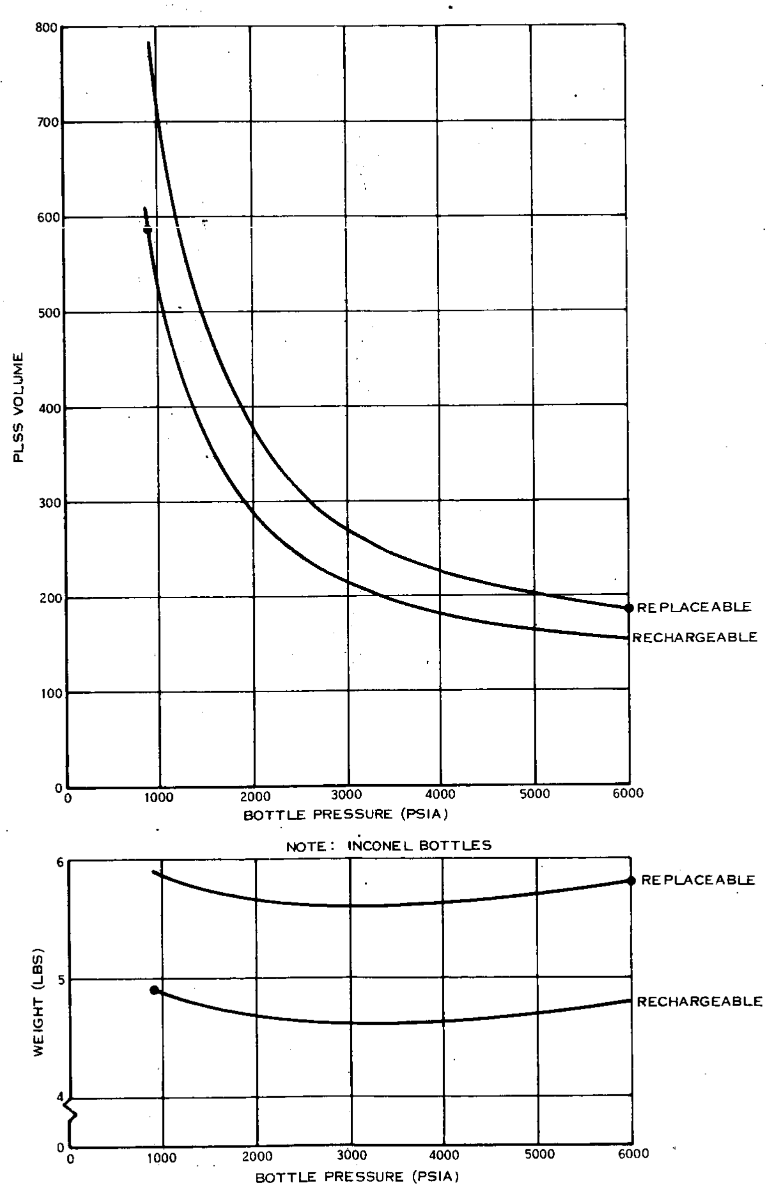


FIGURE 7-5. OXYGEN SUPPLY SUBSYSTEM VOLUME & WEIGHT VS BOTTLE PRESSURE

7.2.1 Oxygen Supply - Continued

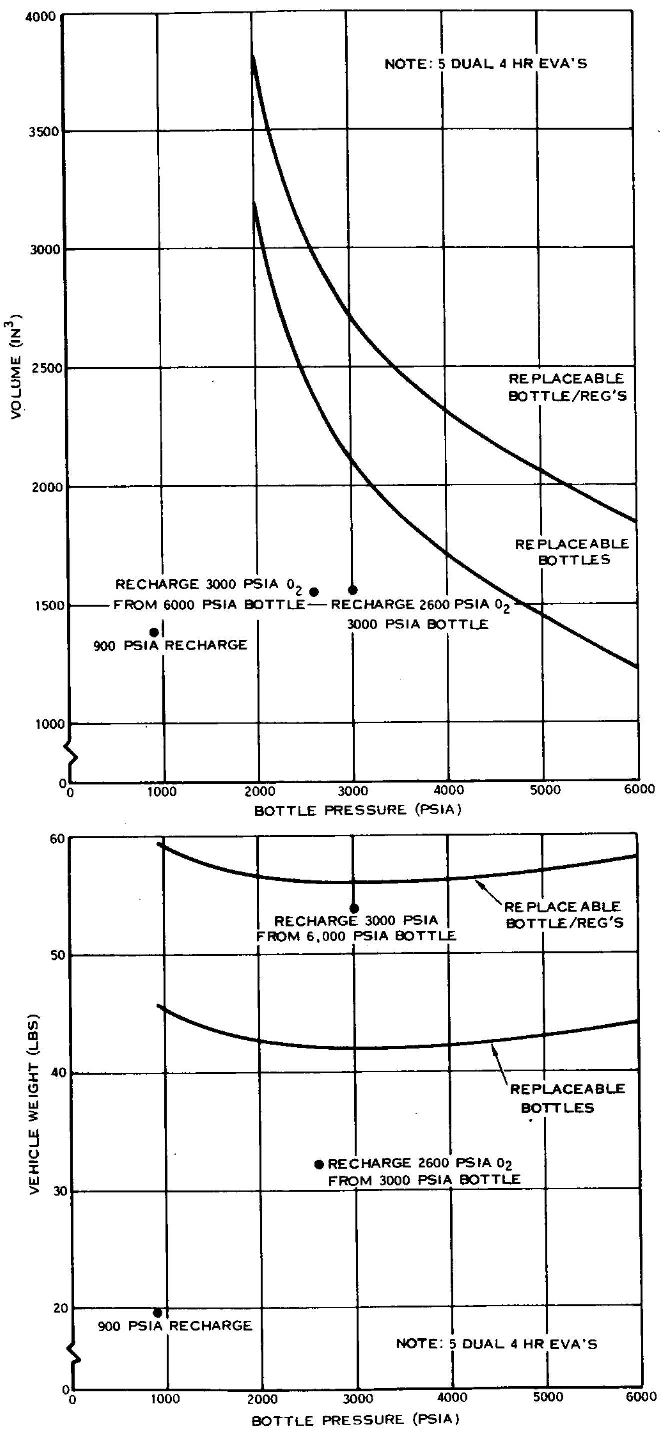


FIGURE 7-6. SHUTTLE WEIGHT AND VOLUME VS BOTTLE PRESSURE

7.2.2 CO_2 Control Subsystem

The CO_2 control subsystem performs the function of maintaining CO_2 partial pressure of the gas entering the unit within an acceptable level.

The requirements specified for the CO_2 control subsystem are listed below:

a. Maintain inspired CO_2 partial pressure below 7.6 mm Hg.

b. Remove 0.82 lbs. of CO_2.

Table 7-4 lists the CO_2 control subsystem concepts which were evaluated. The results of the CO_2 control subsystem evaluation are presented in detail in Section 2.0 of Appendix C and indicates that lithium hydroxide (LiOH), shown schematically in Figure 7-7, is the most competitive subsystem for the Shuttle EVA requirements. LiOH was found to provide the lowest PLSS and vehicle weight penalty and the lowest vehicle volume penalty for the EVA requirements of less than 32 man-hours per flight. The selection of LiOH also considered the development status and its use in all previous manned spacecraft programs.

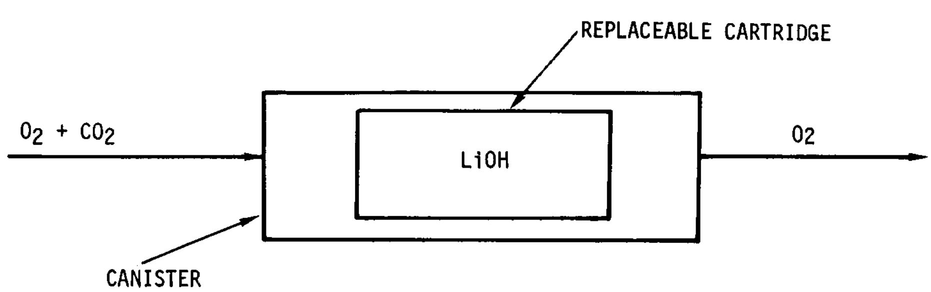


FIGURE 7—7. LiOH CO_2 CONTROL SUBSYSTEM SCHEMATIC

7.2.2 CO_2 Control Subsystem - Continued

I. EXPENDABLES

SOLID SORBENTS

1. HYDROXIDES (LiOH)
2. SUPEROXIDES (KO_2)
3. PEROXIDES (Li_2O_2)
4. OZONIDES

LIQUID SORBENT

5. HYDROXIDE SOLUTIONS

OPEN LOOP

6. PURGE FLOW

II. REGENERABLES

SOLID SORBENTS

7. ACTIVATED CHARCOAL
8. MOLECULAR SIEVE
9. METALLIC OXIDES
   ZnO, MgO, $Mg(OH)_2$
10. SOLID AMINES

LIQUID SORBENTS

11. CARBONATE SOLUTIONS
12. LIQUID AMINES

III. ELECTROCHEMICAL

13. HYDROGEN DEPOLARIZED CELL
14. TWO-STAGE CARBONATION CELL
15. ONE-STAGE CARBONATION CELL
16. ELECTRODIALYSIS
17. FUSED SALT

IV. MECHANICAL

18. SIMPLE MEMBRANE DIFFUSION
19. IMMOBILIZED LIQUID MEMBRANE DIFFUSION
20. MECHANICAL FREEZEOUT
21. CRYOGENIC FREEZEOUT

TABLE 7-4. CO_2 CONTROL SUBSYSTEM CONCEPTS

7.2.3 Contaminant Control Subsystem

The function of the contaminant control subsystem is to remove trace and particulate contaminants which could adversely affect the crewman or the system operation.

7.2.3.1 Trace Contaminant Control

The contaminant control subsystem maintains the concentration of particulate matter, biological microorganisms, and trace gases at acceptable levels so that the health and comfort of the crewman is safeguarded.

The requirement for the trace contaminant control subsystem is to limit the trace contaminant concentration to the levels of Table 7-5. The trace contaminants in Table 7-5 are those which are biologically generated and do not include trace contaminants resulting from outgassing of system materials such as coatings, lubricants, epoxies, etc. These trace contaminants must be controlled at the design stage through proper materials selection.

CONTAMINANT	BIOLOGICAL PRODUCTION RATE, LB/HR	ALLOWABLE CONCENTRATION, MG/M^3
ACETALDEHYDE	9.6×10^{-9}	360
ACETONE	2.02×10^{-8}	2400
AMMONIA	2.62×10^{-5}	70
n-BUTANOL	1.2×10^{-7}	303
BUTYRIC ACID	6.92×10^{-5}	144
CARBON MONOXIDE	1.43×10^{-6}	115
ETHANOL	3.68×10^{-7}	1880
HYDROGEN	8.08×10^{-7}	(4.1%)
HYDROGEN SUFFIDE	4.61×10^{-10}	28
INDOLE	9.18×10^{-6}	126
METHANE	1.3×10^{-5}	(5.3%)
METHANOL	1.39×10^{-7}	262
PHENOL	3.46×10^{-5}	19
PYRUVIC ACID	1.92×10^{-5}	9.2

TABLE 7–5. TRACE CONTAMINANT MODEL

7.2.3.1 Trace Contaminant Control - Continued

The exposure limits presented in Table 7-5 are based on Threshold Limit Values. These limits generally apply to eight (8) hour exposures for an industrial worker subject to a five (5) day work week with the recovery of non-work time taking place in a relatively contaminant-free atmosphere. Space Maximum Allowable Concentrations are normally utilized for space vehicle applications. However, these are defined for continuous exposure and are considered too restrictive for the PLSS application.

Based upon the defined model, the following trace gases build up in the PLSS beyond the allowable concentration during the four (4) hour EVA mission:

a. Butyric Acid
b. Indole
c. Phenol
d. Pyruvic Acid

All other trace gases generated remain within acceptable limits.

The concepts evaluated for trace contaminant control are listed below:

a. Sorbead
b. Purafil
c. Activated Charcoal
d. Phosphoric Acid/Impregnated Charcoal
e. Catalytic Oxidizer

The results of the evaluation concluded that activated charcoal is the most desirable concept since it is effective for removal of butyric acid, indole, phenol and pyruvic acid, and it is lightweight, inexpensive and can be integrated within the LiOH cartridge to permit simple replacement prior to each EVA.

7.2.3.2 Particulate Contamination Control

Control of particulate contaminants is required to prevent particles of materials within the system from adversely affecting the crewman or system operation. The requirements of the particulate contamination control subsystem are listed below:

a. Filter particulate contaminants as required to assure system operation.

b. Limit LiOH dust to 0.1 mg/m^3 of suit ventilating gas.

The PLSS design must consider the potential entry of particulate contaminants such as hair, lint, skin flakes, fabric particles, vomitus and fecal matter and a means must be incorporated to prevent these particles from entering the system. The use of a debris trap at the inlet to the PLSS is an effective means for control of these relatively large particles.

The requirement for LiOH dust control is the same as the requirement specified for the Apollo EMU Program which can be satisfied through the use of filters to limit the number of LiOH dust particles. Selection of the filter type, size and location is part of a future preliminary design study.

7.2.4 Thermal Control

The thermal control subsystem maintains thermal equilibrium of the suited crewman and provides PLSS equipment cooling, as required. The specific thermal loads imposed on this subsystem consist of the crewman's metabolic load, PLSS equipment loads, and the inward environmental heat leak. The thermal control subsystem requirements are listed below:

a. Integrated Thermal Load - 7120 Btu
b. Peak Thermal Load - 2900 Btu/Hr
c. Average Thermal Load - 1480 Btu/Hr
d. Minimum Thermal Load - 760 Btu/Hr
e. Suit Inlet Dewpoint - 50°F Max
f. Provide Variable Log Inlet Temperatures

7.2.4 Thermal Control - Continued

A listing of the thermal control, subsystem concepts identified and evaluated are presented in Table 7-6. The results of the thermal control subsystem evaluation are presented in detail in Section 3.0 of Appendix C and indicate that the most competitive concepts are expendable water concepts. The three (3) expendable water concepts selected are the water boiler, water sublimator and flash evaporator concepts. Three representative PLSS schematics utilizing each of these concepts are presented in Figures 7-8, 7-9 and 7-10, respectively.

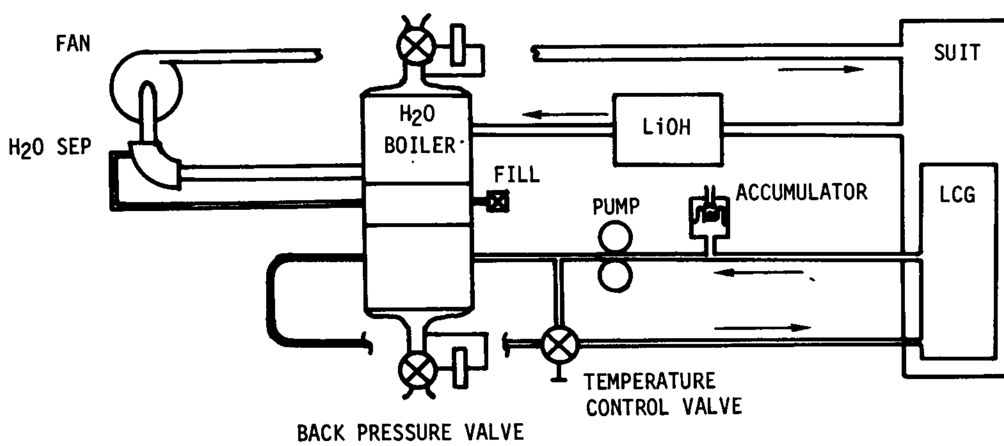


FIGURE 7–8. WATER BOILER SYSTEM SCHEMATIC

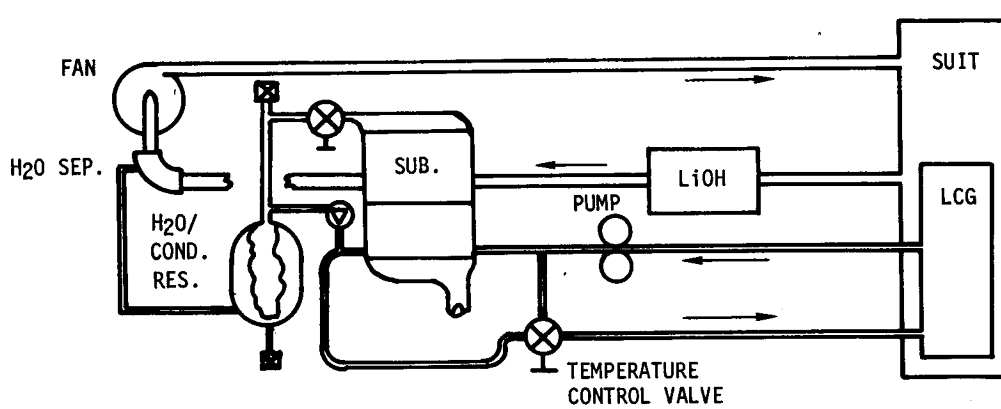


FIGURE 7–9. SUBLIMATOR SYSTEM SCHEMATIC

7.2.4 Thermal Control - Continued

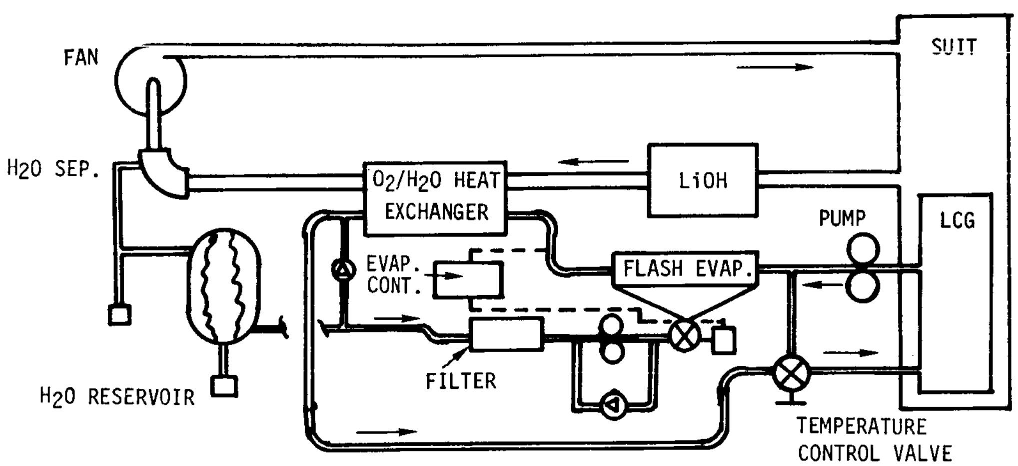


FIGURE 7-10. FLASH EVAPORATOR SYSTEM SCHEMATIC

7.2.4 Thermal Control - Continued

I. Expendables

Water

1. Water Boiler
2. Super-Cooled Water Boiler
3. Super-Cooled Water Boiler with Vapor Regnerative Cooling
4. Water Sublimator
5. Super-Cooled Water Sublimator
6. Super-Cooled Water Sublimator with Vapor Regenerative Cooling
7. Plate Fin Flash Evaporator
8. Nonsteady State Pulse Feed Flash Evaporator
9. Static Vortex Flash Evaporator
10. Turbine-Rotary Vortex Flash Evaporator
11. Motor-Rotary Vortex Flash Evaporator
12. Multi-Stage Flash Evaporator
13. Vapor Diffusion Through Suit Pressure Valves
14. Vapor Diffusion Through Water Permeable Membrance

Hydrogen Peroxide (H_2O_2)

15. H_2O_2 Dissociation into H_2O and O_2

Ammonia (NH_3)

16. NH_3 Boiler
17. NH_3 Sublimator

Carbon Dioxide (CO_2)

18. CO_2 Boiler
19. CO_2 Sublimator

Methane (CH_4)

20. CH_4 Sublimator

Cryogenics

21. Cryogenic O_2
22. Cryogenic H_2

II. Radiation

Direct Cooling

23. LCG
24. Heat Pipe
25. Water Adsorption Utilizing
    26. $LiCl \cdot 3H_2O$
    27. $CaCl \cdot 6H_2O$
    28. Molecular Sieve
    29. Silica Gel
    30. $LiBr \cdot 3H_2O$
    31. $Na_2Se \cdot 1\ H_2O$

Indirect Cooling

32. Vapor Compression Refrigeration Cycle Using Freon
33. Water Adsorption Cycle Using NH_3
34. Water Adsorption Cycle Using LiBr
35. Brayton Cycle Using Air

III. Thermal Storage

36. Ice
37. Subcooled Ice
38. Thermal Wax - Transit 86
39. Eutectic Salt - Sodium Sulphate ($NA_2SO_4 \cdot 10H_2O$)
40. Phosphonium Chloride (PH_4Cl)
41. Hydrogen (H_2)

IV. Hybrids

42. Expendable/Radiation - Direct Cooling
43. Expendable/Radiation - Indirect Cooling
44. Expendable/Thermal Storage
45. Radiation/Thermal Storage
46. Thermal Storage/Water Adsorption

TABLE 7-6. THERMAL CONTROL SUBSYSTEM CONCEPTS

7.2.4 Thermal Control - Continued

Figure 7-11 presents the weights and volumes of the three (3) candidate thermal control subsystems concepts. The advantages and disadvantages of each concept are listed in Tables 7-7, 7-8 and 7-9. An evaluation of the operational and cost aspects of these candidate concepts in conjunction with the weights and volumes depicted in Figure 7-11 does not indicate a clear-cut advantage for either of the three (3) candidates. Therefore, each of these concepts are still considered as viable candidates to provide the PLSS thermal control subsystem function.

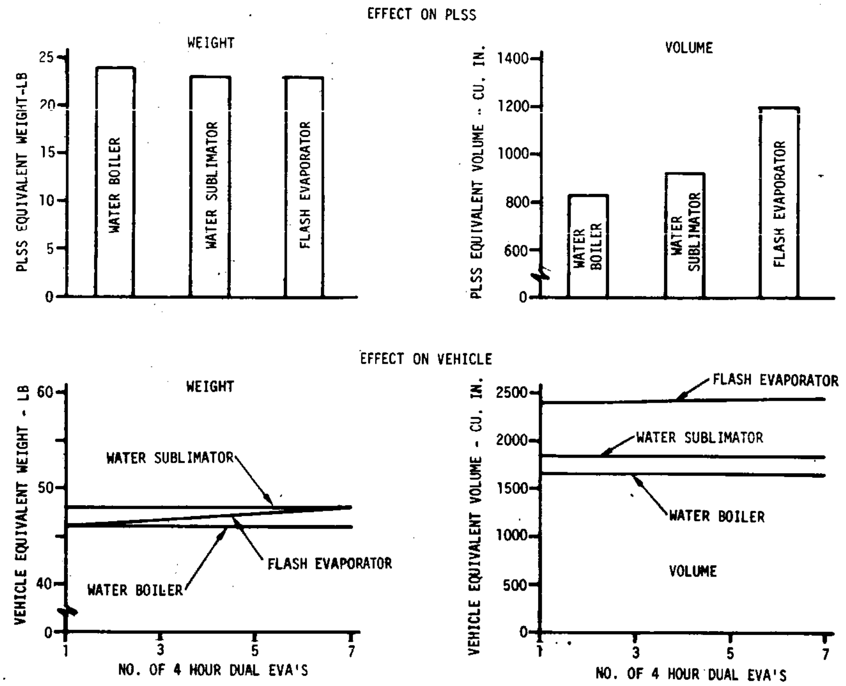


FIGURE 7—11. THERMAL CONTROL SUBSYSTEM WEIGHT & VOLUME COMPARISON

7.2.4 Thermal Control - Continued

ADVANTAGES
1. HAS BEEN DEVELOPED AND USED IN MANNED SPACECRAFT PROGRAMS
2. CAN BE SHUT DOWN INSTANTLY
3. MINIMUM SUSCEPTIBILITY TO CORROSION
4. RELATIVELY SIMPLE CONTROL SYSTEM
DISADVANTAGES
1. POSSIBLE WATER CARRY OVER DURING START
2. RECHARGING WITHOUT WATER SPILLAGE REQUIRE WATER LEVEL SENSORS AND ASSOCIATE COMPLEXITY
3. SENSITIVE TO GAS BUBBLES IN EXPENDABLE WATER SUPPLY
4. POTENTIAL WICK CONTAMINATION

TABLE 7-7. WATER BOILER ADVANTAGES AND DISADVANTAGES

ADVANTAGES
1. HAS BEEN DEVELOPED AND USED IN PORTABLE SYSTEMS AND SPACECRAFT SYSTEMS
2. DOES NOT REQUIRE AN ACTIVE CONTROL SYSTEM FOR VARYING HEAT LOADS. IT IS SELF REGULATING
DISADVANTAGES
1. SUSCEPTABLE TO PERFORMANCE DEGRADATION DUE TO CONTAMINATION AND CORROSION
2. CANNOT BE STARTED AND SHUT DOWN INSTANTLY
3. GAS BUBBLES IN EXPENDABLE WATER SUPPLY MAY BE DETRIMENTAL TO SYSTEM DEPENDING ON SYSTEM DESIGN

TABLE 7-8. WATER SUBLIMATOR ADVANTAGES AND DISADVANTAGES

7.2.4 Thermal Control - Continued

ADVANTAGES
1. IMMEDIATE START-UP AND SHUT-DOWN CAPABILITY
2. LEAST SUSCEPTIBLE TO CORROSION AND CONTAMINATION
3. NOT SENSITIVE TO GAS BUBBLES IN EXPENDABLE WATER SUPPLY SINCE WATER PRESSURE IS EXPECTED TO BE HIGHER THAN THE SATURATION PRESSURE
4. SOLENOID VALVE AND NOZZLE ARE EASILY REPLACED FOR SERVICING
5. RELATIVELY LOW RECURRING COST
DISADVANTAGES
1. REQUIRES DEVELOPMENT FOR SPACECRAFT AND PORTABLE SYSTEMS OPERATION
2. SIGNIFICANT CONTROL PROBLEMS ARE EXPECTED WHEN USED WITH AN EVA SYSTEM DUE TO THE RELATIVELY LOW HEAT LOADS
3. MOST COMPLEX CONTROL SYSTEM

TABLE 7-9. FLASH EVAPORATOR ADVANTAGES AND DISADVANTAGES

7.2.5 Cooling Control Subsystem

The study baselined a liquid cooling system for removal of metabolic heat from the crewman. Temperature control is to provide crewman comfort over the entire range of metabolic work rates and environmental conditions. The concepts evaluated are listed in Table 7-10.

CONSTANT LCG FLOW A) MANUAL TEMPERATURE CONTROL VALVE B) AUTOMATIC TEMPERATURE CONTROL VALVE
VARIABLE LCG FLOW A) MANUAL FLOW CONTROL VALVE B) AUTOMATIC FLOW CONTROL VALVE

TABLE 7–10. COOLING CONTROL SUBSYSTEM CONCEPTS

The evaluation concluded that either the constant or variable LCG flow concept can be used although the variable LCG flow concept results in larger temperature gradients across the LCG.

The selection of manual control over automatic control was made after review of Apollo EVA performance data which showed that LCG inlet temperatures did not change frequently and were usually maintained within a range of 65 to 80°F. Secondly, manual control avoids the complexity and expense inherent in the design and development of an automatic temperature control subsystem. And lastly, manual control is completely adequate for the intended task.

7.2.6 Humidity Control

The humidity control subsystem controls the relative humidity within the space suit to prevent visor fogging and to maintain a comfortable level for the suited crewman. It continually removes water vapor which enters the gas stream as a product of crewman respiration and sweating.

The candidate humidity control subsystem concepts identified and evaluated are presented in Table 7-11.

A. CONDENSING HEAT EXCHANGER COMBINED WITH ANY OF THE FOLLOWING "CHANGE-OF-MOMENTUM" TYPE DEVICES: 1) ELBOW WICK SEPARATOR 2) ELBOW SCUPPER SEPARATOR 3) U-SHAPED GRAVITY SEPARATOR 4) VORTEX GRAVITY SEPARATOR 5) MOTOR-DRIVEN ROTARY SEPARATOR 6) TURBINE-DRIVEN ROTARY SEPARATOR
B. WATER VAPOR ADSORPTION UTILIZAING A DESSICANT SUCH AS SILICA GEL
C. WATER EMULSION FORMATION AND STORAGE
D. FREEZEOUT 1) MECHANICAL 2) CRYOGENIC
E. CONDENSING HEAT EXCHANGER IN SERIES WITH A HYDROPHOBIC HYDROPHYLLIC SCREEN SEPARATOR
F. WATER VAPOR DIFFUSION THROUGH PERMEABLE MEMBRANE
G. CONDENSATION AND SEPARATION UTILIZING A HILSCH TUBE
H. UTILIZATION OF ELECTRICAL ENERGY TO PROVIDE SEPARATION BY - 1) ELECTROLYSIS 2) ELECTROPHORESIS 3) ELECTRO-OSMOSIS

TABLE 7-11. HUMIDITY CONTROL SUBSYSTEM CONCEPTS

A condensing heat exchanger in series with an elbow wick separator was selected as the most desirable concept for the Shuttle PLSS application. This concept is relatively simple, small, light, not gravity sensitive, and does not require electrical power for operation. In addition, a condensing heat exchanger is an integral part of the thermal control subsystem. Provisions for storing the condensed water must be provided.

7.2.7 Power Supply

Electrical power is required by the PLSS for the operation of the prime movers and communications. The requirements for the PLSS power supply are specified and listed below:

a. Power - 55 watts
b. Voltage - 10 to 30 VDC
c. Mission Duration - 4 hours
d. Activation Life - 30 days
e. Recharge Time - 12 hours
f. Shelf Life - 10 years

Many different power supply concepts were investigated, however, as can be seen from Figure 7-12, only batteries trade-off in the particular range required for the PLSS. Of all the battery

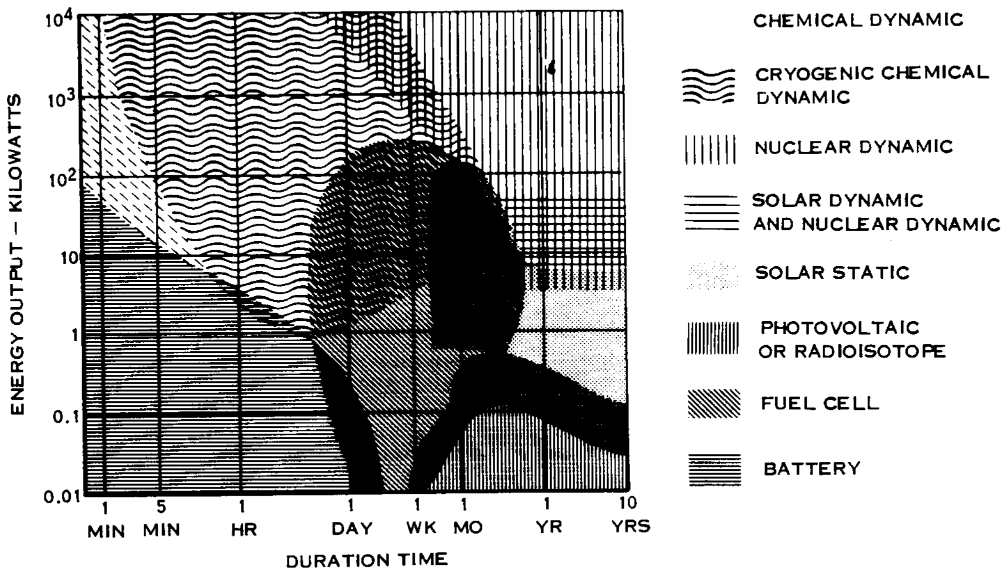


FIGURE 7–12. POWER SUPPLY APPLICABILITY

systems currently in use, many can be eliminated because of their very low energy densities, hazardous characteristics, or very low state of development relative to the time period of interest. The battery concepts identified as meriting further evaluation are listed below:

7.2.7 Power Supply - Continued

a. Nickel-Cadmium
b. Nickel-Iron
c. Nickel-Zinc
d. Silver-Cadmium
e. Silver-Zinc
f. Zinc-Air
g. Lithium-Organic

Figures 7-13 and 7-14 present the energy currently attainable per unit weight and volume respectively for these different systems.

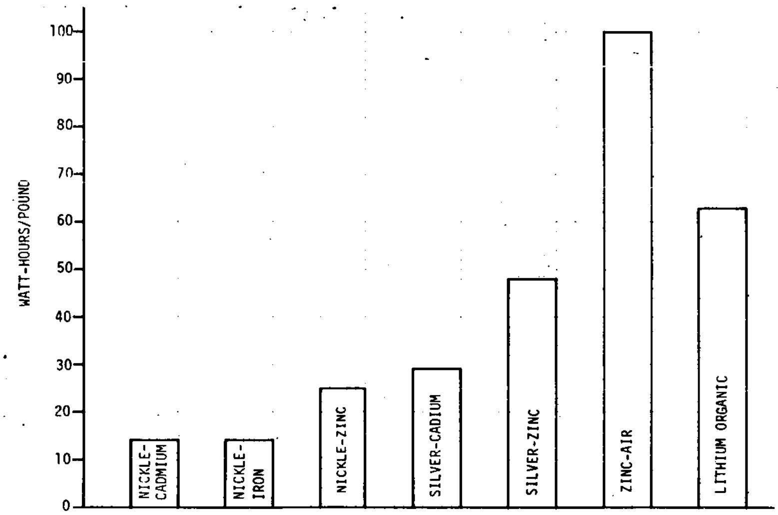


FIGURE 7–13. POWER SUPPLY WEIGHT COMPARISON

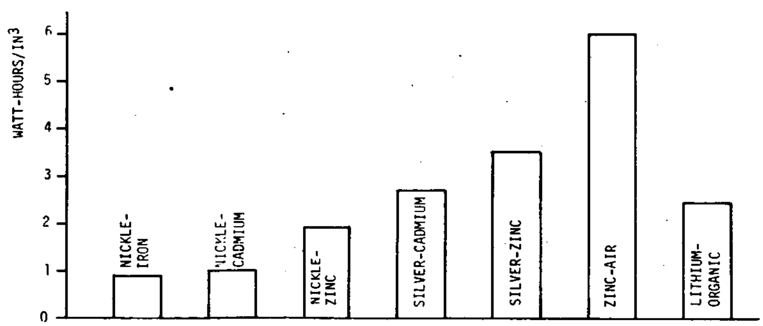


FIGURE 7–14. POWER SUPPLY VOLUME COMPARISON

7.2.7 Power Supply - Continued

From these it is evident that the Zinc-Air System has the highest watt-hr per unit weight and volume. However, it only has a 7 day activation life making it unsatisfactory. Further it requires an oxygen flow of at least 48 cc/min to meet the requirements and thus poses an interface within the PLSS not otherwise present.

The silver-zinc system is the next best on a watt-hour per unit volume basis and is very competitive on a weight basis. Although it is basically a disposable system, it is also capable of 10-25 deep discharges as a rechargeable system. The Ag-Zn system can obtain energy densities of 80 watt-hrs/lb and 3.7 watt-hrs/in^3, has good regulation characteristics, and meets the other basic requirements.

The Lithium Organic System is also an attractive concept on a watt-hour per unit weight and volume basis. Since it is a relatively new approach, this system requires more development work, especially involving failure modes, before further consideration can be given to it. With normal development, however, it could become a strong contender and should not be eliminated at this time.

The other systems considered were not selected because their power per unit weight and volume were significantly less than the silver-zinc and lithium organic systems.

Figure 7-15 presents a comparison between silver-zinc disposable and rechargeable systems and a lithium organic disposable system.

From these curves, it is evident that the rechargeable silver-zinc system is the most efficient system, even with the additional weight penalty of 2.6 lbs for a single battery charger. In addition, battery recharging during Shuttle station keeping operations impact fuel cell capacity, and the fuel cell consumables (O_2 and H_2) required for battery recharge are minimal. For these reasons, the silver-zinc rechargeable system was selected for use in the System Studies (Section 7.4).

7.2.7 Power Supply - Continued

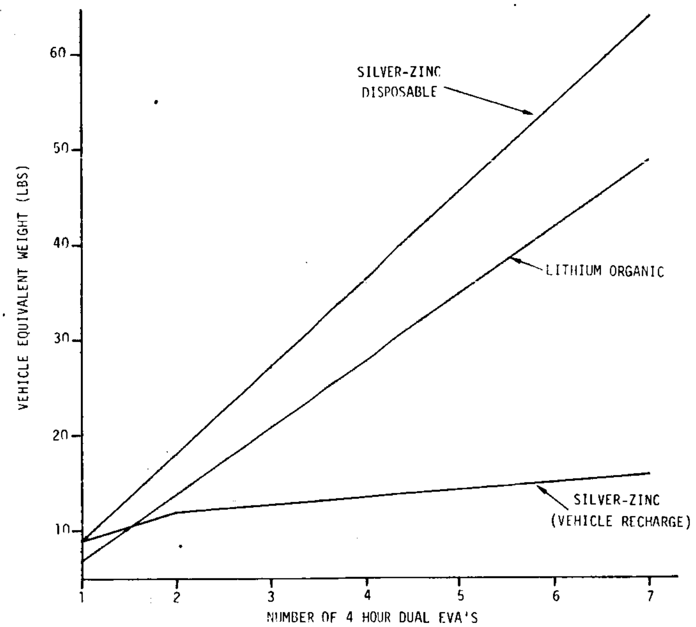


FIGURE 7-15. SILVER-ZINC/LITHIUM ORGANIC WEIGHT COMPARISON

7.2.8 Closed Loop System Selection

The subsystem studies for the closed loop system have identified the most desirable subsystems for this system. Figure 7-16 identifies the selected subsystems which will be evaluated against the umbilical systems. Figure 7-17 presents PLSS weight and volume and Shuttle weights and volumes to support various quantities of 4 hour dual EVA's. The weights and volumes of Figure 7-17 does not include the weights and volumes of a communications system or packaging hardware such as hard covers, thermal covers, miscellaneous brackets and etc. These items will be added after the number of system candidates have been reduced further.

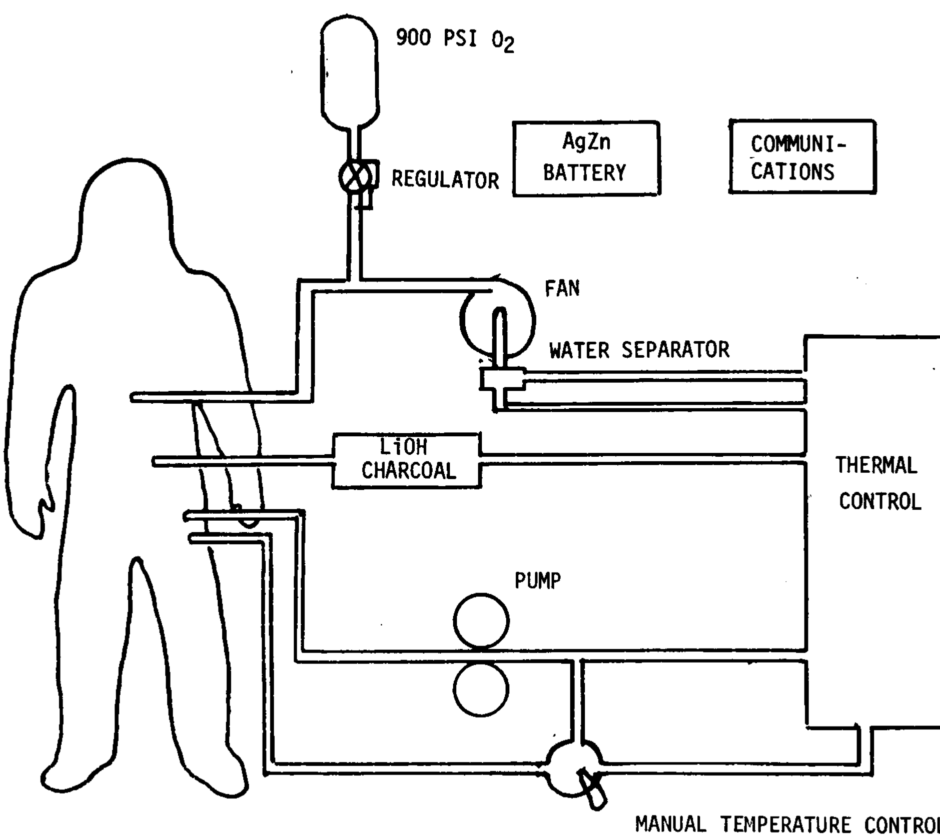


FIGURE 7–16. SELECTED CLOSED LOOP PLSS

7.2.8 Closed Loop System Selection - Continued

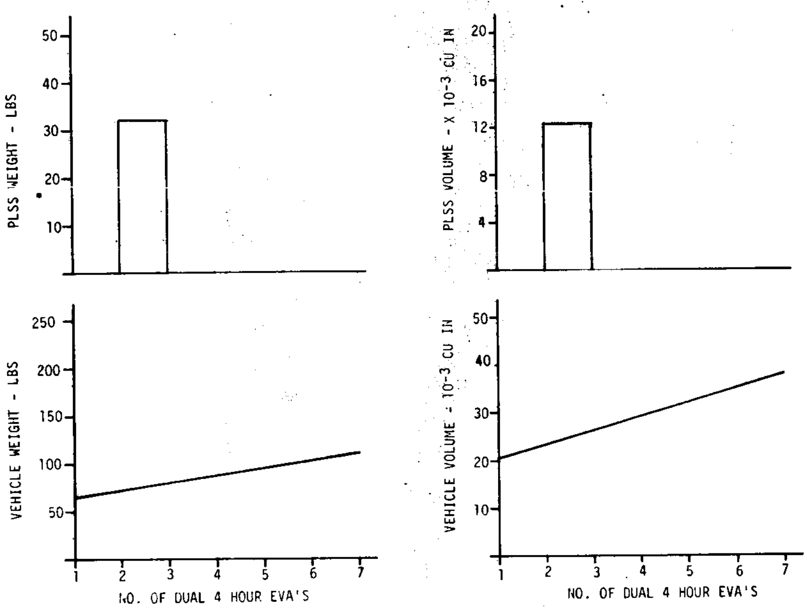


FIGURE 7—17. WEIGHT & VOLUME ANALYSIS OF CLOSED—LOOP PLSS

7.3 Subsystem Studies - Umbilical System

7.3.1 Oxygen Supply Subsystem

The results of Suit Pressure Level Determination portion of the study (Section 6.0) showed that the optimum source of the oxygen is from the vehicle liquid oxygen (LOX) supply. This is primarily due to the low penalties associated with liquid oxygen storage. System sizing studies were performed to satisfy the requirements of Table 7-1 which resulted in the oxygen usages listed in Table 7-12 for each candidate umbilical system.

SYSTEM CONCEPT	O_2 FLOW LBS/HR
OPEN LOOP	11.0
SEMI-OPEN LOOP	8.75
SEMI-CLOSED LOOP	3.15

TABLE 7-12. UMBILICAL SYSTEM O_2 FLOW REQUIREMENT

7.3.2 CO_2 and Contaminant Control Subsystem

Control of CO_2 and trace contaminants with the open loop and semi-open loop system is achieved by means of an overboard dump. For the semi-closed loop system, the CO_2 and trace contaminant removal requirements are not significantly different than those of the self contained closed loop system. Therefore, the selected subsystems of the closed loop system are also applicable to the semi-closed umbilical system. These subsystems are Lithium Hydroxide (LiOH) for CO_2 control and activated charcoal for control of trace contaminants.

7.3.3 Thermal Control

For the umbilical system, it was assumed that a liquid cooling loop umbilical would be used for thermal control (similar to the Skylab ALSA). This assumption is compliant with the primary advantage of umbilical systems which is to minimize the on-the-back volume of the PLSS. Secondly, the addition of cooling umbilicals does not add significantly to any umbilical management problems.

7.3.4 Temperature Control

The temperature control requirements for an umbilical system are the same as those for the closed loop system discussed in paragraph 7.2.5. Therefore, the same selection is made for the umbilical systems.

7.3.5 Humidity Control

Control of system humidity levels is achieved by overboard dump in the open loop umbilical system. The semi-open and semi-closed loop systems require an active humidity control system. An evaluation of the concepts listed in Table 7-16 of paragraph 7.2.6 resulted in selection of a condensing heat exchanger with a downstream elbow water separator as selected for the closed loop system. However, the heat exchanger loads and the storage capacity are reduced for the umbilical systems due to the inherent cooling capabilities of the ejector and the quantity of water vapor which is dumped overboard.

7.3.6 Prime Movers

Prime movers for the umbilical systems are not required since ventilation is provided by means of ejectors or flushing oxygen directly through the suit. Circulation of liquid cooling through the liquid cooling garment is assumed to be provided by the Orbiter thermal control subsystem. For assessment of vehicle weights and volumes, an electrically driven pump is used because of the low penalties for electrical power during EVA operations.

7.3.7 Power

The power required for umbilical systems is that necessary to drive the communications and warning systems. The concept selected for the umbilical PLSS configurations is a hardline from the Shuttle and is similar to the existing Skylab system.

7.3.8 Umbilical Systems Selection

Each of the umbilical systems selected for systems evaluation is shown schematically in Figures 7-18, 7-19, and 7-20. The weights and volumes for each system are shown in Figure 7-21. This figure does not include the weights and volumes of the communications systems, and packaging hardware such as hard-covers, thermal covers and miscellaneous brackets. Figure 7-21

7.3.8 Umbilical Systems Selection - Continued

shows that the semi-closed system has the least weight and volume impact on the Orbiter and, on the basis of weight and volume, is the most attractive system. However, the other two systems are less complex, lower in cost, and more desirable from an operational standpoint. Therefore, all three umbilical systems were selected for further comparative system level evaluation with the self-contained closed loop system.

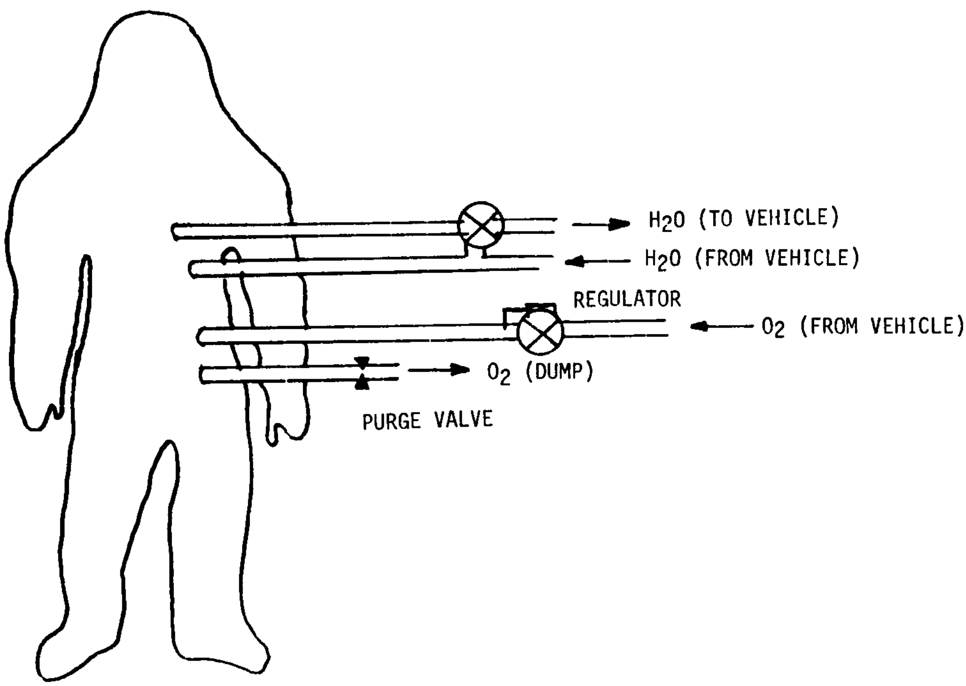


FIGURE 7-18. OPEN LOOP UMBILICAL SYSTEM SCHEMATIC

7.3.8 Umbilical Systems Selection - Continued

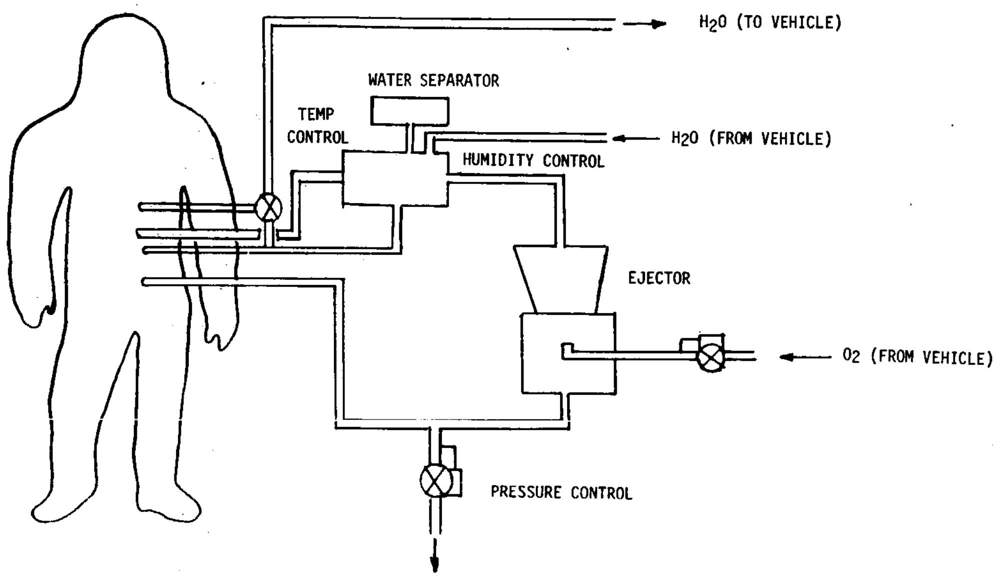


FIGURE 7–19. SEMI–OPEN LOOP UMBILICAL SYSTEM SCHEMATIC

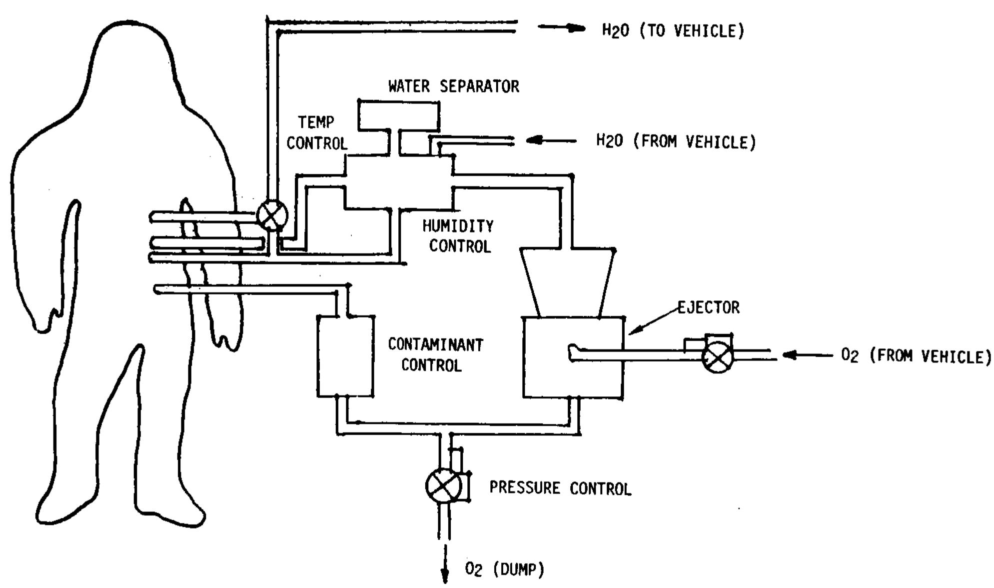


FIGURE 7–20. SEMI–CLOSED LOOP UMBILICAL SYSTEM SCHEMATIC

7.3.8 Umbilical System Selection - Continued

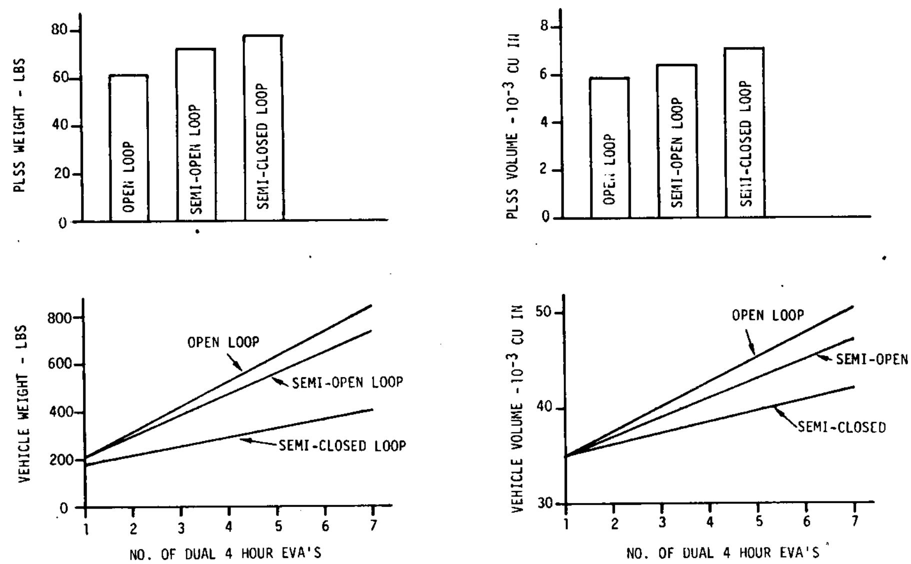


FIGURE 7-21 UMBILICAL SYSTEMS WEIGHT & VOLUME COMPARISON

7.4 Systems Studies

The objective of the system studies is to select the best overall system for Shuttle EVA's. The effort performed as part of the suit pressure level determination (Section 6.0) reviewed life support systems and found that four basic systems are competitive. These four systems are listed in Table 7-13.

SELF-CONTAINED CLOSED LOOP SYSTEM	FIGURE 7-16
UMBILICAL OPEN LOOP SYSTEM	FIGURE 7-18
UMBILICAL SEMI-OPEN LOOP SYSTEM	FIGURE 7-19
UMBILICAL SEMI-CLOSED LOOP SYSTEM	FIGURE 7-20

TABLE 7–13. COMPETITIVE PRIMARY LIFE SUPPORT SYSTEMS

The approach utilized to select the most desirable PLSS system concept consisted of first conducting subsystem studies to select the most desirable subsystem concepts for each of the four competitive system concepts. Then each of these system concepts were comparatively evaluated and a selection made. This section describes the systems evaluation.

Figure 7-22 summarizes the weight and volume of each competitive system in addition to the weight and volumes imposed on the Orbiter to support each system for multiple quantities of four hour EVA's.

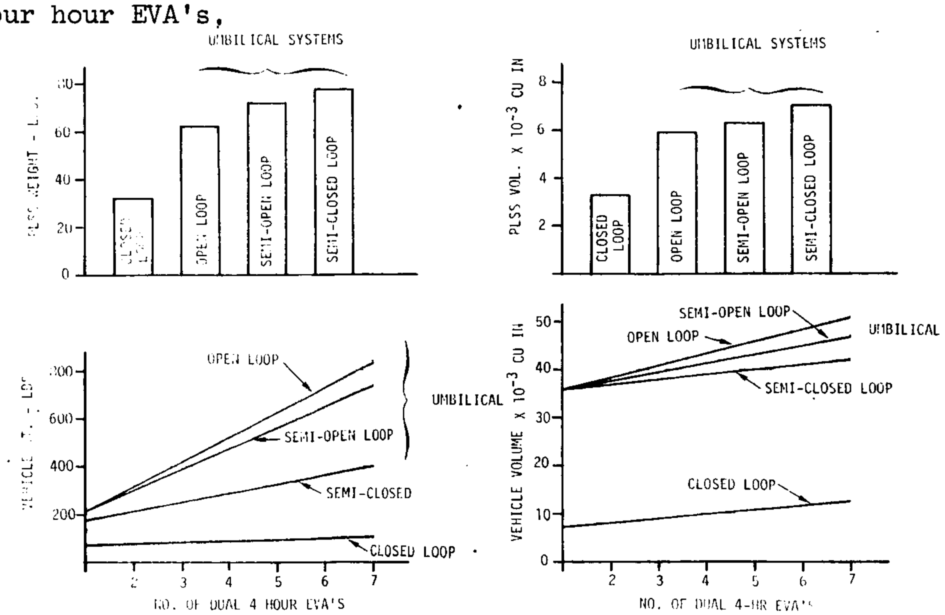


FIGURE 7–22 OVERALL PLSS WEIGHT & VOLUME COMPARISON

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

7.4.1 Weight and Volume Comparisons - Continued

Although communications and packaging hardware are not included, the closed loop system is the superior system from a weight and volume standpoint. However, since the closed loop system has considerably more components than the other system candidates it is reasonable to expect the system weight and volume to increase more than the other systems with the inclusion of packaging hardware and communications system.

An assessment of complete systems was made by adding the weight and volumes of packaging hardware and communications systems into the two most competitive systems from the weight and volume standpoint. The semi-closed loop umbilical system was selected for evaluation with the self-contained closed loop system. For communications, an Apollo EVCS was added to the self-contained closed loop system and a Skylab communication umbilical was added to the semi-closed loop umbilical system. Packaging hardware weight additions consisted of ten (10) pounds for the umbilical system and thirty (30) pounds for the self contained system. Figure 7-23 compares the two systems and reconfirms that the closed loop system results in the minimum weight and volume system.

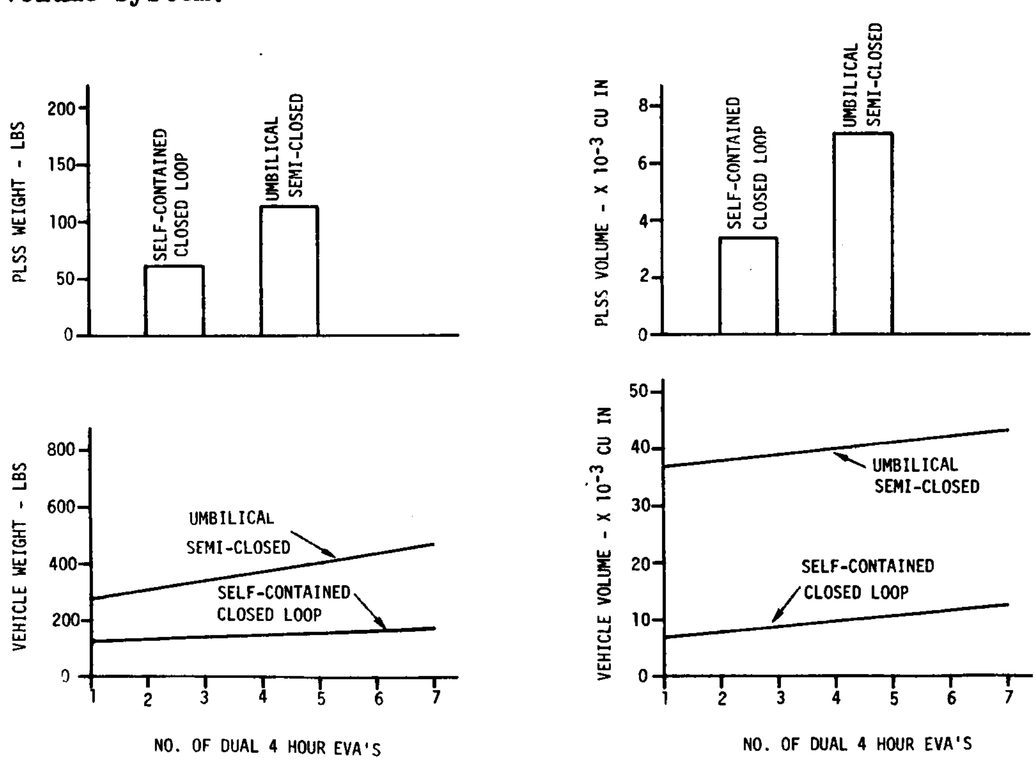


FIGURE 7—23. PLSS WEIGHT & VOLUME COMPARISON

7.4.2 Cost Comparisons

From the cost standpoint, the open loop system is anticipated to be superior to the other systems since it has the fewest components and is the system with least complexity. The cost comparisons of the open loop, semi-closed and the closed loop systems shown in Figure 7-24 are based on the following:

a. Program cost estimates include design, development, qualification, production and flight operation for each system. Program period is from 1974 to 1990.

b. Vehicle non-recurring costs are equivalent to $15,230 per pound of EVA related equipment carried by the Orbiter.

c. An operational penalty of $154 per pound per flight was assumed for EVA related equipment. This is based on $10,000,000 recurring cost per flight and 65,000 pound payload capacity.

d. There are 677 Shuttle flights from 1979 to 1990.

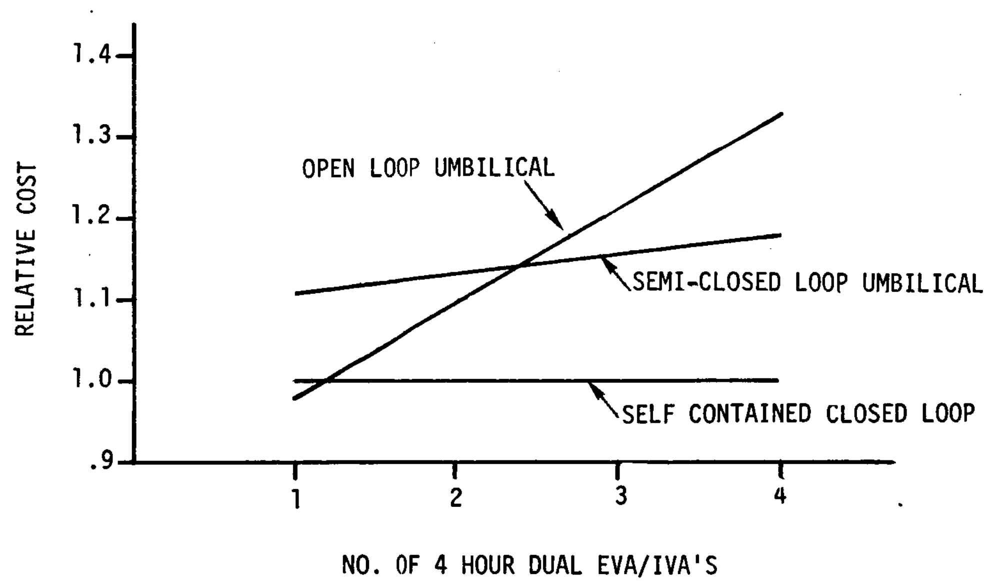


FIGURE 7–24. PLSS COST COMPARISONS

7.4.2 Cost Comparisons - Continued

Figure 7-24 shows that the cost variations between the open loop umbilical system and the closed loop, self-contained system are not sufficient to dicate selection of the type of primary life support system to be used for Shuttle. Therefore, PLSS selection must be based on weight, volume and operational considerations which are presented in Table 7-14.

FACTOR	SYSTEM	
	SEMI-CLOSED LOOP UMBILICAL	SELF CONTAINED
WEIGHT - PLSS (ONE CREWMAN) - VEHICLE (ONE DUAL EVA)	113 LB. 270 LB.	61 LB. 122 LB.
VOLUME - PLSS (ONE CREWMAN) VEHICLE (ONE DUAL EVA)	5920 IN^3 36000 IN^3	3350 IN^3 6700 IN^3
OPERATIONAL CONSIDERATIONS		
● STORAGE EASE	EQUIVALENT	EQUIVALENT
● DONNING/DOFFING EASE	ENGAGE UMBILICAL	DON PACK & ENGAGE UMBILICAL
● CHECKOUT	SIMPLER	MORE COMPONENTS INVOLVED
● TRANSLATION-UMBILICAL/TETHER MANAGEMENT	COMPLEX	SIMPLER
● TASK EXECUTION	LEAST EFFICIENT - RIGID ADHERENCE TO PREPLANNED SEQUENCE - SLIGHT FORCE & MOMENT CONSTRAINT	MORE EFFICIENT - GREATEST LATITUDE FOR CHANGE IN TASK PLAN - COMPLETE FREEDOM
● RECHARGE	NOT REQUIRED	MUST REPLENISH 4 EXPENDABLES
● OPERATING LIFE AND MAINTAINABILITY	SLIGHTLY BETTER DUE TO FEWER COMPONENTS	GOOD
● POTENTIAL FOR CONVERSION TO NON-CONTAMINATING SYSTEM	POOR - ALL SUBSYSTEMS AFFECTED	GOOD - ONLY HEAT REJECTION SUBSYSTEM AFFECTED
● VEHICLE SCAR	GREATEST IMPACT	MINIMUM IMPACT
● COMPATIBILITY W/MANIPULATOR ASSISTED TASKS	FAIR	EXCELLENT

TABLE 7-14. OVERALL PLSS COMPARISON

7.4.3 Operability Considerations

The closed loop system possesses more operational complexity during EVA mission phases of check-out, start-up and recharge than the umbilical systems. However, during operational phases of EVA, such as task execution, the crewman must ensure that the umbilical does not become tangled or dynamically excited. Secondly, with the umbilical system, the crewman must translate between worksites via a route that is most convenient for the umbilical rather than the most direct route available to him. This becomes a more significant constraint for emergency return to the airlock subsequent to a failure condition. Therefore, it is concluded that the self-contained system is superior from the operability aspect.

7.4.4 Summary

As a result of the system studies, it is concluded that the self contained closed loop system is the superior system and is recommended for the Shuttle EVA primary life support system for the following reasons:

a. Minimum weight.

b. Minimum volume.

c. Superior operability during EVA by elimination of umbilical management problems.

d. Basic system requires minimum modification for use on contamination sensitive missions.

e. Cost is competitive with other system candidates.

7.5 System Integration Studies

This section summarizes system level integration studies which consider the total EVA system. Detail results of this effort are reported in Appendix D. These studies established requirements for the topics listed in Table 7-15.

TOPIC	PARAGRAPH
SUIT, PLSS, ELSS DESIGN INTEGRATION	7.5.1
COMMUNICATIONS	7.5.2
WARNINGS	7.5.3
INSTRUMENTATION	7.5.4
THERMAL MODEL	7.5.5
SYSTEM TEST REQUIREMENTS	7.5.6
SYSTEM LIFE REQUIREMENTS	7.5.7

TABLE 7–15. SYSTEM LEVEL REQUIREMENTS SUMMARY

7.5.1 Suit, PLSS, ELSS Design Integration

The configuration of the operational EVA system is dictated to a large extent by the design approach taken for the physical integration of the system. A totally integrated system such as the Integrated Maneuvering/Life Support System (IMLSS) has certain advantages which must be considered. These advantages include minimum weight and volume through the elimination of interfacing umbilicals and more efficient utilization of available volume by packaging PLSS and ELSS components within the suit enclosure. A separate and independent system such as the Apollo EMU also has discrete advantages which must be traded off with those of the integrated system.

The study considered design integration of the PLSS and ELSS into the pressure suit and design integration of the ELSS into the PLSS and concluded that the ELSS and PLSS systems should be integrated and that the pressure suit should not be integrated with the life support systems. The primary factors for this recommendation include design complexity, ground handling and servicing, program cost and crew training.

7.5.2 Communications

The task analysis effort described in Section 4.0 indicated that most of the EVA's are dual EVA's where two crewman are simultaneously performing tasks associated with a payload. For normal EVA operations, it is essential that the EVA crewmen have two-way voice communications with each other to coordinate their activities. It is also necessary to have communications with the crew within the Orbiter, manned payloads or space stations to coordinate activities such as refueling, manipulator operations, retrieval of film cassettes, etc. Two-way voice communications is also required for coordination with ground crews, including NASA personnel and principle investigators, for resolution of any anomalies which may occur during a flight.

Since voice communication plays a vital role in the coordination of EVA tasks between EVA crewmen, Orbiter crews, and ground personnel, it is considered essential that a back-up two-way voice communications system be provided to allow completion of mission objectives subsequent to an EVA or Orbiter primary communications system failure.

Consideration was also given to payload or Orbiter conditions which could affect the safety of the EVA crewman. Such conditions include leakage of payload or Orbiter fuels or oxidizers, malfunction of RCS thrusters, and any other failures of payload or Orbiter subsystems that require the immediate alert of the crew. An alert of such conditions would be initiated by either the Orbiter crew or ground crews to notify the entire crew to return to the Orbiter cabin. Since the EVA crewmen are part of the Orbiter crew, any alert initiated by either the ground or Orbiter personnel should be automatically transmitted to EVA crewmen.

Voice communications via an umbilical or RF link was also considered and it was concluded that an RF system is desired for the independent self-contained system to eliminate umbilical management and stowage problems. Based on the above rationale, the voice communications system requirements are listed below:

7.5.2 Communications - Continued

a. The Orbiter and EVA system shall provide for two-way simultaneous voice communications between each crewman and the Orbiter crew.

b. The Orbiter shall be capable of relaying the voice communication from an EVA crewman to other EVA crewman, ground, Space Station or other manned spacecraft associated with the mission.

c. The Orbiter shall be capable of relaying voice communications from ground, Space Station or other manned spacecraft to the EVA/IVA crewmen.

d. Any paging or alerts from ground, Space Station or other manned spacecrafts shall automatically be transmitted to the EVA/IVA crewmen.

e. A back-up communications system shall be incorporated to provide two-way voice communications between the EVA/IVA crewmen and the Orbiter crew.

f. The communication range getween the EVA crewmen and the Orbiter should be limited to a maximum of 100 meters, with omni-directional coverage, to minimize EVA communication systems complexity.

An evaluation of communication system concepts resulted in the following recommendations:

a. All PLSS communications systems should be identical.

b. Establishing the operational frequencies of the EVA system must be accomplished by NASA to ensure noninterference with the Orbiter, payloads, Space Station and operational satellites.

7.5.3 Instrumentation

7.5.3.1 Required Instrumentation

EVA equipment instrumentation is required to provide EVA equipment performance monitoring to permit checkout prior to EVA and to permit status monitoring during conduct of an EVA. Instrumentation to provide these functions fall into two (2) categories:

7.5.3.1 Required Instrumentation - Continued

a. Warnings - The purpose of a warning system is to alert the crewman of PLSS failures which could jeopardize his life or safety. Identification of candidate parameters for warnings was accomplished by considering the man's need for life support rather than performing a failure analysis on the proposed EVA system. The candidate parameters were then screened by giving consideration to the ability of man as a sensor and to the type system he uses.

It was concluded that a minimum of three warnings are required to alert the crewman both visually and audibly of low suit pressure, battery voltage and of high CO_2 partial pressure levels. If the CO_2 levels are sampled in a location other than the helmet, such as in the Apollo EMU PLSS, then an additional warning is required to alert the crewman that the CO_2 level may be building up within the helmet due to loss of ventilation flow (i.e.-a ventilation flow sensor). The feasibility of placing a CO_2 sensor within the helmet was also investigated based upon a CO_2 sensor similar in concept to that of the Apollo PLSS. It was found that the sensor element with a pre-amplifier is small enough (1 in. dia. x 3 in. long) to fit within the helmet. Its power requirements are estimated to be less than 20 milliamps at 16 VDC. Placement of a CO_2 sensor within the helmet is recommended for further design study since it can decrease the complexity, power, weight, volume and cost associated with the ventilation flow sensor.

b. Visual Displays - Visual displays are required for checkout of the PLSS and ELSS prior to EVA, to monitor critical subsystem performance parameters during EVA, to monitor PLSS consumables status during EVA, and as part of the warnings system.

Pressure level displays are required for checkout of the PLSS and ELSS high pressure O_2 supply subsystems to establish proper subsystem operations and consumables status prior to EVA. A power supply check-out is also recommended since the power supply is essential to certain PLSS functions including CO_2 and contaminant control, humidity control, thermal control, warnings and communications.

Monitoring of critical subsystem performance parameters during an EVA is required by the crewman to verify proper system operation and expendables status. However, it is desirable to minimize the amount of instrumentation to be

7.5.3.1 Required Instrumentation - Continued

b. Visual Displays - Continued

placed within the visual field of the EVA crewman since it occupies the visual field which could be utilized for accomplishing productive tasks, and also to minimize system complexity. After a review of system operations, it is recommended that visual displays for the crewman to monitor during EVA should consist of suit pressure, battery voltage and PLSS O_2 supply pressure. The suit pressure display provides verification of proper suit pressure control which is a common function of both the primary and emergency life support systems. The power supply voltage display provides verification that the power supply is functioning properly. This display could indicate degraded battery or battery cell performance and should be appropriately color coded to indicate unacceptable voltage levels. Since the power supply performance (power output) is dependent upon the type of power consuming devices, it may be found that other displays such as an ammeter or wattmeter would serve as a better indication of power supply performance.

The crewman desires the capability to periodically check status of system consumables to verify that the EVA tasks can be completed during the scheduled time period. A visual display of oxygen quantity has little design complexity when compared to that of LiOH, power supply and water quantity status. To minimize the design complexity, cost and number of visual displays, it is recommended that a visual display of oxygen quantity be required and that the consumables be sized such that oxygen is the constraining consumable for all normal operating modes.

The suit pressure and O_2 quantity displays are also utilized in conjunction with warning system activation for low suit pressure. Firstly, a display of suit pressure is required for the crewman to verify suit pressure level following a low suit pressure warning. Secondly, a visual display of O_2 supply pressure or quantity is necessary to determine if the cause of the low suit pressure warning is a regulator failure or depletion of the oxygen supply.

7.5.3.2 Desirable Instrumentation

EVA instrumentation is desirable, but not absolutely mandatory, for on board automatic monitoring of EVA performance and data storage and transmittal to ground. On board automatic monitoring provides the following benefits:

a. Redundancy for the crewman's warning system.

b. Guidance and consultation in the event of a PLSS malfunction.

EVA performance data storage and transmittal to ground provides the following benefits:

a. A basis for assessing ground maintenance requirements, especially since ground checkout may not always reveal problems associated with zero gravity.

b. Operational data which could significantly reduce EVA equipment checkout requirements between Shuttle missions. A more detailed study effort is required to determine the true impact on Shuttle equipment servicing.

c. A means for real-time anomaly assessment either during an EVA or between EVA's. This capability contributed significantly to the Apollo program.

Based upon the experience gained on past manned space programs, plus that to be gained on Skylab, it is felt that telemetry of biomedical data is not necessary for the Shuttle missions.

The Orbiter baseline includes the requirement to receive, display and relay telemetry data. In accordance with our discussions with North American Rockwell personnel, the addition of EVA telemetry data does not adversely impact the Orbiter since the quantity of EVA telemetry data is insignificant when compared to Orbiter and payload requirements. The Orbiter capability to display EVA data can be utilized to provide an additional warning capability to the Orbiter crew. For example, the system could be used to alert the Orbiter crew when the PLSS oxygen quantity reaches the level that EVA close-out operations should begin. Similar use of the system can provide warnings of abnormal operations during EVA. These parameters could include high current drain, low voltage, and abnormal thermal control system performance.

This study identifies the recommended telemetry parameters to be included in the EVA system. However, since there are three viable candidates for the thermal control subsystem, a complete listing cannot be made at this time.

7.5.3.3 Summary

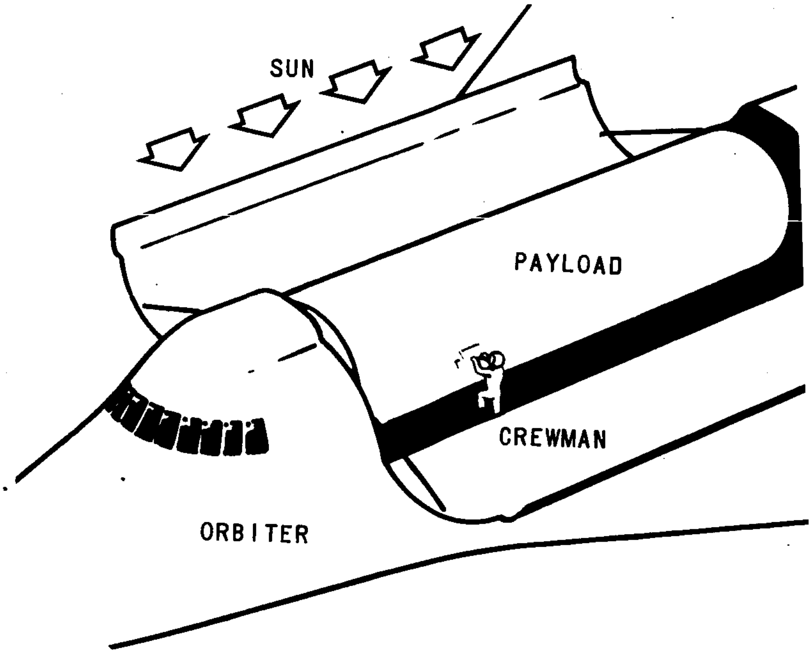
A summary of the recommended instrumentation for warnings, visual displays and telemetry is presented in Table 7-16.

PARAMETER	WARNING	VISUAL DISPLAY	TM	REMARKS
SUIT PRESSURE	X	X	X	LOCATED IN VISUAL FIELD DURING EVA
PLSS O_2 SUPPLY PRESSURE		X	X	LOCATED IN VISUAL FIELD DURING EVA
CO_2 PARTIAL PRESSURE	X		X	IF SENSOR IS NOT PLACED IN HELMET, A VENT FLOW SENSOR IS ALSO REQUIRED
POWER SUPPLY VOLTAGE	X	X	X	LOCATED IN VISUAL FIELD DURING EVA
POWER SUPPLY CURRENT			X	
THERMAL CONTROL PERFORMANCE			X	4 PARAMETERS ESTIMATED
ELSS O_2 SUPPLY PRESSURE		X		NOT NECESSARY TO LOCATE IN VISUAL FIELD DURING EVA
ELSS O_2 OUTLET PRESSURE		X		

TABLE 7–16 INSTRUMENTATION SUMMARY

7.5.4 Thermal Models

Evaluation of orbit altitudes and inclination angles indicates that it is possible to conduct EVA's with the majority of the time exposed to direct sun. Re-orientation of the Orbiter can place the EVA crewman such that he will be continually in the shadow of the spacecraft and exposed to cold conditions of deep space. Thermal models for both the hot and cold environments are included in Figures 7-25 and 7-26. The surface temperatures indicated are North American Rockwell estimates.



VIEW FACTORS

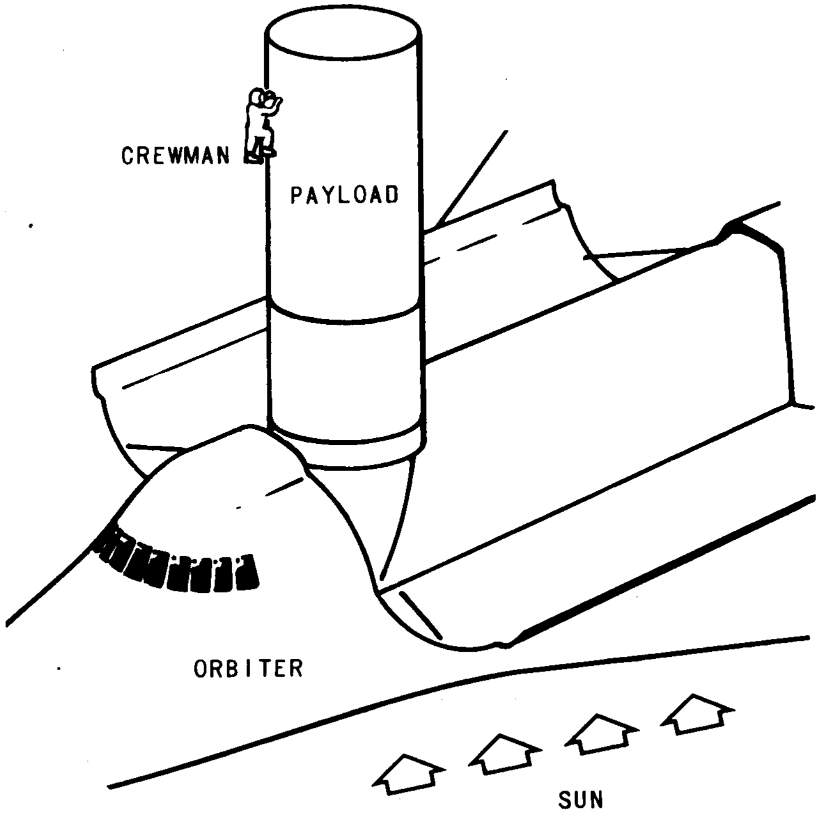
TO VEHICLE SURFACES	80%
TO SPACE	20%

VEHICLE AND PAYLOAD SURFACE PROPERTIES

SOLAR ABSORBTIVITY	0.2
INFRARED EMISSIVITY	0.8
SURFACE TEMPERATURE	+ 200F
DURATION OF EXPOSURE	4 HOURS

FIGURE 7–25. THERMAL MODEL—HOT CASE

7.5.4 Thermal Models - Continued



CREWMAN LOCATIONS
IN SHADOW OF ORBITER WITH NO VIEW FACTOR TO EARTH OR ORBITER RADIATORS

VIEW FACTORS	
TO DEEP SPACE	80%
TO VEHICLE AND PAYLOAD SURFACES	20%
VEHICLE AND PAYLOAD SURFACE PROPERTIES	
SOLAR ABSORBTIVITY	0.2
INFRARED EMISSIVITY	0.8
SURFACE TEMPERATURE	-250F
DURATION OF EXPOSURE	4 HOURS

FIGURE 7-26. THERMAL MODEL—COLD CASE

7.5.5 Test Philosophy

This section presents an evaluation of PLSS ground acceptance test requirements in order to evolve a test philosophy that provides effective system verification. The objective of a ground acceptance test program is to demonstrate that the hardware is capable of meeting all requirements that can be imposed upon it in the subsequent flights. This acceptance testing of hardware must be such that it not only indicates performance against "go/no-go" criteria, but also highlights any incipient performance degradation which could cause flight anomalies. Because of the Shuttle program's flight frequency, between-flight testing must be held to a minimum of cost, time and manpower.

PLSS ground acceptance testing consists of three basic categories:

- Pre-Delivery Test Programs
- Pre-Flight Acceptance Testing
- Periodic Maintenance

The following paragraphs expand on these three categories.

7.5.5.1 Pre-Delivery Test Programs

The key to an effective pre-flight acceptance test lies in a thorough knowledge of the equipment's life and performance characteristics. This knowledge is gained in the overall sense by the development and qualification phases, and in particular, by the pre-delivery acceptance test of the individual unit. Actual experience acquired during usage further supplements the formal test program information.

The basic knowledge of the performance and life expectancy of the total system and the individual components within it is obtained during the development and qualification test programs. Development testing is performed on equipment to provide assurance that the item will meet its end use performance and environmental requirements and will successfully pass the qualification program. The development test program consists of structural, functional and endurance testing oriented primarily to support and extend the design program.

The more formal qualification test program demonstrates that the hardware meets or exceeds all requirements of the system specification and is thus suitable for its intended purpose. The hardware to be tested are manufactured with production tooling and from production drawings made subsequent to

7.5.5.1 Pre-Delivery Test Program - Continued

completion of development testing. Two units are tested during the qualification test program with one unit being subjected to a program probing its performance endurance limits, and the other to a structural limit program. Full performance maps of all functional components are obtained over a spectrum both within and outside nominal specification ranges. Performance characteristics of all components are obtained as a function of operational hours or cycles, as appropriate.

Acceptance testing of production hardware prior to delivery is an extensive program designed to:

a. Verify that the system, as assembled, functions to specification requirements at both the component and assembly levels.

b. Screen all components to eliminate any infant mortality.

c. Establish a reliable baseline for monitoring of changes in system performance during pre-flight checks and flight usage.

The recommended test program would consist of the following tests:

a. Drawing compliance and examination of product
b. Vibration (electronic and electrical assemblies)
c. Thermal cycling (electronic and electrical assemblies)
d. Proof pressure
e. Leakage
f. Performance
g. Weight
h. Examination of product

7.5.5.2 Pre-Flight Acceptance Testing

During the pre-delivery production acceptance test program, extensive testing is performed to demonstrate the total capability of the hardware. In large measure, these tests are made extensive in order to reduce field pre-flight acceptance testing to a minimum. With a minimum time span of approximately two weeks between flights, it is essential that time utilization efficiency be maximized. On that basis, all tests not essential to assurance that the system is

7.5.5.2 Pre-Flight Acceptance Testing - Continued

capable of flight are eliminated and those tests that are required are reduced to the minimum practical limit. The proposed test sequence consists of:

a. Examination of product
b. Deactivation
c. Leakage
d. Functional

Following this test sequence, the system is ready for recharging and vehicle stowage.

7.5.5.3 Periodic Maintenance

It is anticipated that periodic maintenance will be required for any system that must have the overall life span of the Shuttle Primary Life Support System. The frequency of this maintenance will be defined by the results of the development and qualification test programs and the monitoring of the results of the pre-flight acceptance tests. Close monitoring of performance is more than adequate to define the amount of time remaining before a particular item needs maintenance. The periodic maintenance is performed on the total system at one time. Once maintenance is performed, the complete production acceptance test defined above is performed to verify that the system has been returned to a totally acceptable condition.

7.5.6 System Life Requirements

Table 7-17 summarizes the life requirements of major items of the EVA system and the rationale use to establish the requirements.

7.5.6 System Life Requirements - Continued

ASSUMPTIONS AND REQUIREMENTS		RATIONALE
FREQUENCY OF FLIGHT	1 FLIGHT/WEEK	BASED ON MARCH 21, 1972 TRAFFIC MODEL
NO. OF ORBITERS	5	CURRENT NASA PLANS
NO. OF CREWS	2 PER ORBITER	SIMILAR TO MILITARY USAGE OF BLUE AND GOLD CREWS
EVA EQUIPMENT ASSIGNMENTS		
PLSS & ELSS	2 PER ORBITER	TWO PLSS'S AND ELSS'S ARE ASSIGNED TO EACH ORBITER
PERSONAL EQUIP. (PRESSURE SUIT, LCG & ETC.)	1 PER CREWMAN	
AVERAGE EVA TIME	4 1/2 HOURS/ FLIGHT	BASED ON 645 PLANNED EVA'S OF 4 HOURS DURATION EACH PLUS PRE-EGRESS CHECK OUT AND POST EVA OPERATIONS
EVA EQUIPMENT USEFUL LIFE		
HARDWARE (PLSS & ELSS)	15 YEARS MIN	SIMILAR TO ORBITER EC/LSS
SOFT GOODS (PRESSURE SUIT, LCG & ETC.)	YEARS MIN	CONSIDERED REASONABLE GOAL FOR SUIT MATERIALS
OPERATIONAL EVA TIMES		
PLSS	600 HOURS	BASED ON 4 1/2 HRS OPERATION EVERY 5 WEEKS FOR 12 YEAR PERIOD
ELSS	30 HOURS	CONSERVATIVE ESTIMATE OF 15 MINUTE USAGE ON EACH FLIGHT
SOFT GOODS	95 HOURS	BASED ON 4 1/2 HRS OF OPERATION EVERY 10 WEEKS OVER A 4 YEAR PERIOD
TEST TIMES		
PLSS	600 HOURS	ASSUMED TO BE SAME AS EVA TIMES
ELSS	30 HOURS	ASSUMED TO BE SAME AS EVA TIMES
SOFT GOODS	30 HOURS	BASED ON 1 1/2 HRS OF TEST PRIOR TO EACH FLIGHT
TOTAL OPERATIONAL TIMES		
PLSS	1200 HOURS	SUMMATION OF EVA TIMES AND TEST TIMES
ELSS	60 HOURS	SUMMATION OF EVA TIMES AND TEST TIMES
SOFT GOODS	125 HOURS	SUMMATION OF EVA TIMES AND TEST TIMES
RECOMMENDED OPERATIONAL LIFE REQUIREMENTS		
PLSS	6000 HOURS	A FACTOR OF 5 IS APPLIED TO TOTAL OPERATIONAL TIME TO ACCOUNT FOR VARIATION IN NUMBER OF EVA'S, POTENTIAL REDUCTION IN NUMBER OF CREWS OR ORBITERS AND TO ADD DESIGN MARGIN.
ELSS	300 HOURS	
SOFT GOODS	700 HOURS	

TABLE 7-17. EVA SYSTEM LIFE REQUIREMENTS AND RATIONALE

7.6 Noncontaminating System Studies

7.6.1 General

As a result of the EVA/IVA task Identification and Analysis effort described in Section 4.0 of this volume, it was determined that eighty-eight (88) of the total of 677 NASA and DOD Shuttle flights will transport contamination sensitive payloads. An analysis of these payloads indicated that an Apollo-type EVA system using water as a thermal control subsystem evaporant and having a suit gaseous leakage rate of 100 scc/min is a usable system for performing Shuttle EVA missions if the instrumentation shields on the contamination sensitive payloads are closed during EVA operations.

However, since the results of a strictly analytical study of a complex subject such as contamination sensitivity is subject to controversy, and since instrumentation shields can malfunction, Hamilton Standard evaluated the options available in the area of noncontaminating EVA systems. There are three (3) main categories of potential EVA system contaminants:

a. Water vapor exhausted from a PLSS expendable water thermal control subsystem

b. Suit and PLSS gaseous leakage (O_2 + N_2 + CO_2 + H_2O)

c. Particles

The most critical of the above three (3) categories, and the one which is most easily eliminated is water vapor exhausted from a PLSS expendable water thermal control subsystem. The remainder of this section identifies and evaluates noncontaminating thermal control subsystems that can be incorporated in or added onto the basic PLSS configuration. For purposes of this evaluation, the contamination sensitive mission requirements are specified in Table 7-18.

CONTAMINATION SENSITIVE MISSION REQUIREMENTS	
EVA DURATION	3 HOURS
METABOLIC RATE	1000 BTU/HR (AVERAGE)
DISTANCE FROM AIRLOCK	100 FEET

TABLE 7-18 CONTAMINATION SENSITIVE MISSION REQUIREMENTS

7.6.2 Systems Evaluated

Table 7-19 presents a listing of the concepts identified and evaluated as noncontaminating thermal control systems.

CONCEPTS	REFERENCE PARAGRAPH
THERMAL STORAGE/ICE	7.6.2.1
UMBILICAL TO ORBITER	7.6.2.2
ADSORPTION/RADIATOR	7.6.2.3
RADIATOR/HEAT PUMP	7.6.2.4
RADIATOR/HEAT PUMP/THERMAL STORAGE	7.6.2.5

TABLE 7-19. NONCONTAMINATING SYSTEMS EVALUATED

7.6.2.1 Thermal Storage/Ice

Figure 7-27 presents the thermal storage/ice system schematic.

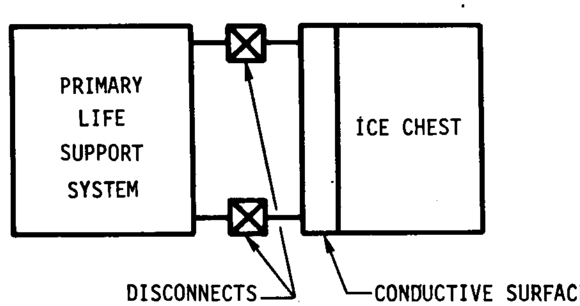


FIGURE 7-27 THERMAL STORAGE/ICE SYSTEM SCHEMATIC

7.6.2.1 Thermal Storage/Ice - Continued

As can be seen from this schematic, ice, in contact with a conductive surface, is utilized to provide cooling of the LCG water and the ventilation loop. This heat exchanger device is attached to the PLSS when no venting is allowed and thus precludes the necessity of using the PLSS thermal control system and its resulting water vapor exhaust.

A prime consideration in utilizing the ice chest is the selection between a replaceable or regenerable chest. Figure 7-28 presents a comparison between regenerative and non-regenerative ice chests on a vehicle equivalent weight basis.

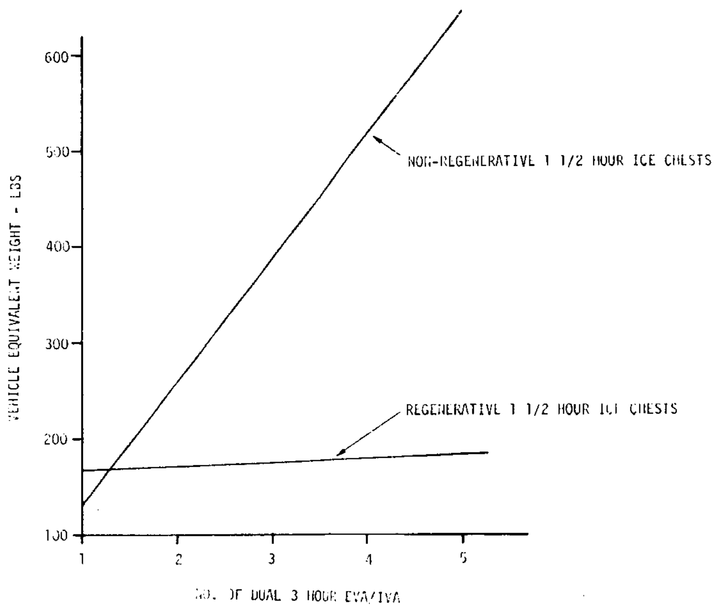


FIGURE 7—28. COMPARISON OF REGENERATIVE & NON—REGENERATIVE ICE CHEST

From this figure it can be seen that a regenerative ice chest has a significant vehicle weight advantage when more than one (1) EVA is required.

7.6.2.1 Thermal Storage/Ice - Continued

Figure 7-29 presents a freezer system schematic that could be utilized for regenerating the ice chest.

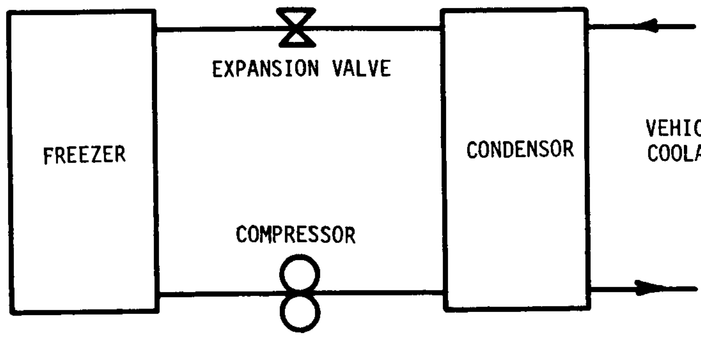


FIGURE 7–29. FREEZER SYSTEM SCHEMATIC

7.6.2.2 Umbilical to Orbiter

This concept, shown schematically in Figure 7-30, is an umbilical PLSS and returns the liquid cooling loop flow to the Shuttle for temperature conditioning.

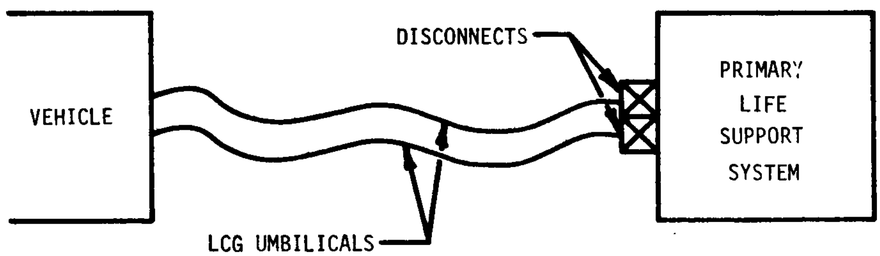


FIGURE 7–30. UMBILICAL SYSTEM SCHEMATIC

An unattractive feature of this concept is the long umbilical required which encumbers the crewman and limits his flexibility for task performance.

7.6.2.3 Adsorption/Radiator

This concept, shown schematically in Figure 7-31, removes the water exhaust from the PLSS expendable thermal control subsystem and adsorbs it.

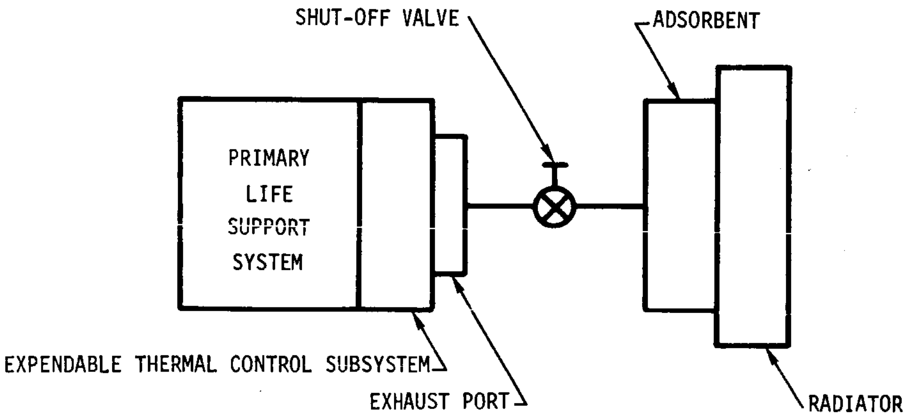


FIGURE 7-31. ADSORPTION/RADIATOR SYSTEM SCHEMATIC

The heat resulting from this adsorption is then radiated to space. This concept is an add-on to the PLSS and allows use of the PLSS thermal control subsystem.

7.6.2.4 Radiator/Heat Pump

This concept is schematically presented in Figure 7-32.

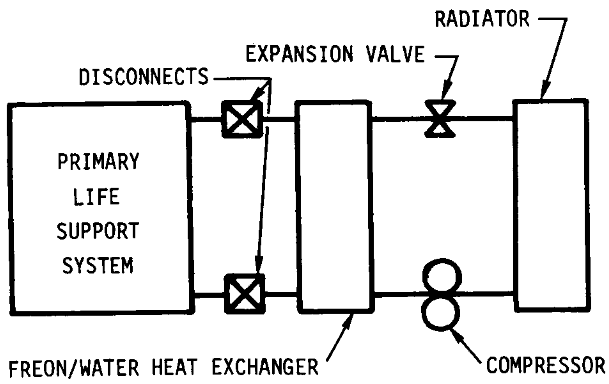


FIGURE 7-32. RADIATOR/HEAT PUMP SYSTEM SCHEMATIC

As can be seen from this schematic, a freon/water heat exchanger is utilized to provide LCG and ventilating loop cooling in place of the PLSS thermal control subsystem. A radiator is employed for heat transfer to the ambient.

7.6.2.5 Radiator/Heat Pump/Thermal Storage

This concept, shown in Figure 7-33, is similar to the preceding radiator/heat pump concept except a thermal storage unit is employed to minimize the heat load transmitted to the radiator. Thus the radiator size can be reduced by designing for average rather than peak loads.

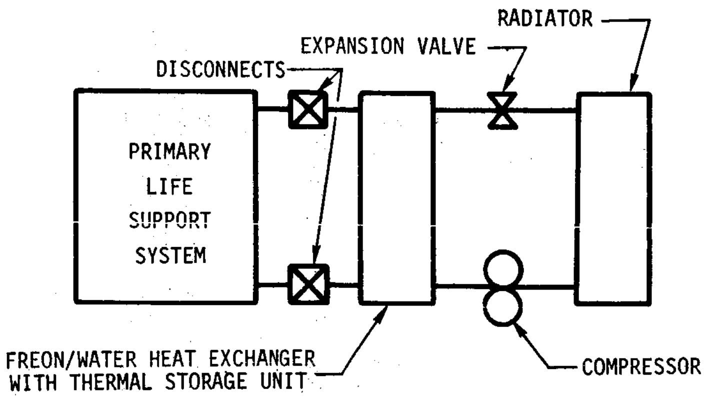


FIGURE 7–33. RADIATOR/HEAT PUMP/THERMAL STORAGE SYSTEM SCHEMATIC

7.6.3 Concept Evaluation

Based on a preliminary evaluation, all the radiator concepts were eliminated as they require surface areas of 12 to 17 sq. ft. which is considered impractical for an EVA system. Thus, the viable noncontaminating system concept are reduced to:

- Thermal Storage/Ice
- Umbilical to Orbiter

7.6.3 Concept Evaluation - Continued

Figure 7-34 presents a comparison between these concepts on a PLSS and vehicle weight and volume basis.

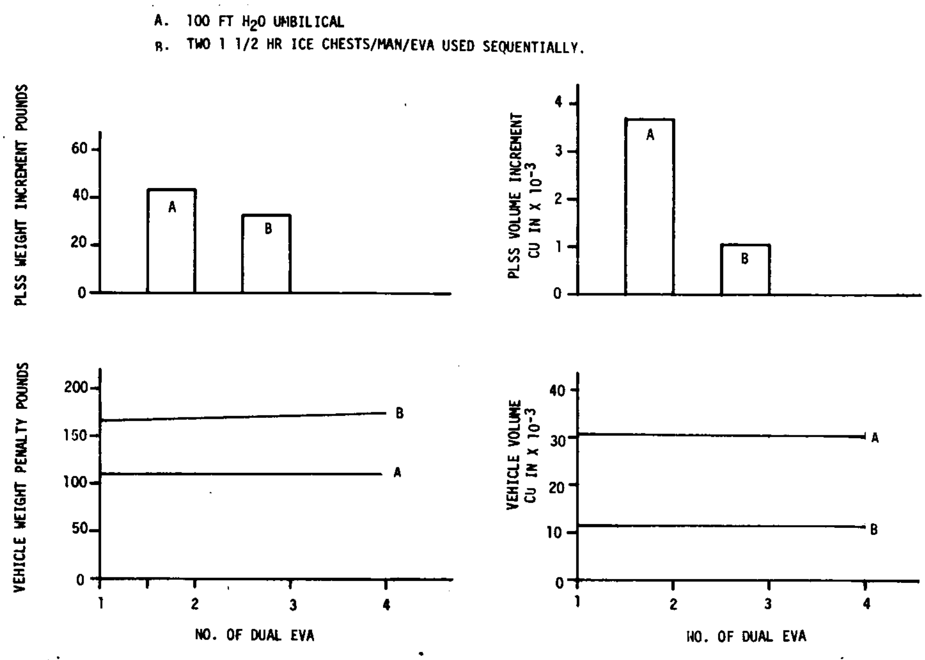


FIGURE 7—34. WEIGHT & VOLUME COMPARISON

These curves are somewhat inconclusive since the concept with the minimum PLSS weight penalty results in the maximum weight penalty for the Orbiter.

Table 7-20 presents a more comprehensive comparison of a self-contained ice chest and a water umbilical as an alternative to using expendable water for heat rejection.

7.6.3 Concept Evaluation - Continued

The same factors that were used to select the basic PLSS for noncontamination sensitive flights are applied in this table.

FACTOR	PLSS WITH: WATER UMBILICAL	PLSS WITH: TWO 1 1/2 HOUR ICE CHESTS/EVA
WEIGHT - SUBSYSTEM (ONE CREWMAN) - VEHICLE (ONE DUAL EVA)	104 LBS 211 LBS	93 LBS 288 LBS
VOLUME - SUBSYSTEM (ONE CREWMAN) - VEHICLE (ONE DUAL EVA)	2790 CU. IN. 38,200 CU. IN.	4440 MIN 16,900 MIN
RELATIVE COST	1.0	1.04
OPERATING LIFE & MAINTAINABILITY	SLIGHTLY BETTER DUE TO SIMPLICITY	GOOD
VEHICLE SCAR	REQUIRES COOLANT	REQUIRES COOLANT AND POWER
DEVELOPMENT RISK	LOW	GREATER (REFLECTED IN COST)
OPERATIONAL CONSIDERATIONS		
STORAGE		
- EASE - INTERFACE	EQUIVALENT AIRLOCK	EQUIVALENT PAYLOAD BAY (FREEZER CONTAINS FREON)
DONNING/DOFFING EASE	SIMPLE	MORE COMPLEX
CHECKOUT	EQUIVALENT	MORE COMPLEX
TRANSLATION - UMBILICAL/TETHER MANAGEMENT	COMPLEX	SIMPLER
TASK EXECUTION	LEAST EFFICIENT - RIGID ADHERENCE TO PREPLANNED SEQUENCE - SLIGHT FORCE AND MOMENT CONSTRAINT	MORE EFFICIENT - GREATEST LATITUDE FOR CHANGE IN TASK PLAN - COMPLETE FREEDOM - MORE ON BACK MASS AND VOLUME
RECHARGE	NOT REQUIRED	SIMPLE
COMPATIBILITY WITH MANIPULATOR ASSISTED TASKS	FAIR	EXCELLENT

TABLE 7—20 NONCONTAMINATING SYSTEMS COMPARISON

As can be seen in this table, the ice chest approach imposes the greatest weight impact on the vehicle, costs more, has greater development risk, does not lend itself to check-out and requires refreezing between EVA's. It does, however, provide the greatest flexibility for task execution as it does not require a cumbersome umbilical and does not limit the crewman to specific transfer routes.

7.6.4 Noncontaminating System Selection

Based on the preceding evaluation, it appears that a liquid cooling loop umbilical is the most desirable concept for incorporation into the PLSS for contamination sensitive EVA missions. The umbilical system has minimum overall impact on the Shuttle as it offers the lightest weight and smallest on-the-back volume, is simpler, and presents minimal development risk. The ice chest, however, is not eliminated at this juncture because of the potential management problems with the umbilical system. Pending resolution of development risks, the ice chest approach could still be very competitive.

7.7 Conclusions

Based on the results of the PLSS system and subsystem studies, it is concluded that the Primary Life Support System, as described in Table 7-21, be used for the Space Shuttle Program.

SYSTEM TYPE	CLOSED LOOP SELF CONTAINED
O_2 SUPPLY	900 PSIA GASEOUS OXYGEN
CO_2 CONTROL	LiOH REPLACEABLE CARTRIDGE
CONTAMINANT CONTROL	ACTIVATED CHARCOAL
THERMAL CONTROL	
BASIC SYSTEM	EXPENDABLE WATER
NONVENTING MODES	WATER UMBILICAL
HUMIDITY CONTROL	CONDENSING HEAT EXCHANGER WITH ELBOW TYPE WATER SEPARATOR
PRIME MOVERS	ELECTRICALLY DRIVEN
POWER	RECHARGEABLE SILVER-ZINC BATTERY
COMMUNICATIONS	RF DUPLEX SYSTEM WITH TELEMETRY OF PERFORMANCE DATA

TABLE 7-21. SHUTTLE PLSS DESCRIPTION

7.7 Conclusions - Continued

System integration studies performed as part of the PLSS effort provided additional system requirements as summarized in Table 7-22.

CONFIGURATION	PHYSICAL INTEGRATION OF ELSS AND PLSS
COMMUNICATION	RF DUPLEX SYSTEM WITH ORBITER RELAY
WARNINGS	LOW SUIT PRESSURE HIGH CO_2 PARTIAL PRESSURE
INSTRUMENTATION	
VISUAL DISPLAYS	SUIT PRESSURE PLSS O_2 SUPPLY PRESSURE POWER SUPPLY VOLTAGE ELSS O_2 SUPPLY PRESSURE ELSS REGULATED O_2 PRESSURE
TELEMETRY DATA	SUIT PRESSURE PLSS O_2 SUPPLY PRESSURE CO_2 PARTIAL PRESSURE POWER SUPPLY VOLTAGE POWER SUPPLY CURRENT THERMAL CONTROL PERFORMANCE

TABLE 7-22. ADDITIONAL SYSTEMS REQUIREMENTS

SECTION 8.0

EMERGENCY LIFE SUPPORT SYSTEM

8.0 EMERGENCY LIFE SUPPORT SYSTEM

8.1 General

The primary function of the Emergency Life Support System (ELSS) is to provide emergency life support to a suited crewman in the event of a malfunction of his PLSS or suit. Such a provision is required to ensure the safe return of an EVA astronaut to the Shuttle Orbiter.

This section presents the results of the ELSS requirements definition effort. Various candidate emergency system concepts are evaluated to determine the most desirable approach. The concepts considered include open loop, semi-open loop, semi-closed loop and closed loop systems. The following sections present the results of this definition and evaluation effort.

8.1.1 Evaluation Criteria

The determination of the evaluation criteria is based on the recognition that some requirements are absolute while others are comparative. The absolute criteria define the minimum acceptable requirements for a concept. If a concept does not meet all of the absolute criteria, it is eliminated. The absolute criteria are listed as follows:

a. Performance

All concepts must be capable of meeting the entire performance spectrum.

b. Safety

Safety of each concept is evaluated to determine if there are any hazards present which cannot be eliminated. If any serious problems are discovered which cannot be reasonably avoided, the concept is eliminated.

c. Availability

Availability is a measure of the probability of a concept being fully operational within the required time period (following reasonable development effort).

8.1.1 Evaluation Criteria - Continued

The comparative criteria are the principal evaluation areas for all concepts that pass the absolute criteria requirements. Comparative criteria are listed as follows:

a. ELSS Weight

ELSS weight consists of all ELSS equipment with which the crewman must egress from the vehicle.

b. ELSS Volume

ELSS volume is a volumetric measure of 8.1.1a.

c. Operability

Operability is a measure of the concept's ability to be simply used as emergency requirements demand rapid activation.

d. Cost

Cost consists of both Shuttle program and ELSS program recurring and nonrecurring costs.

8.1.2 Emergency Life Support System Study Groundrules

The following groundrules were utilized in identifying and evaluating ELSS candidates:

a. The ELSS shall be functionally independent of the PLSS and its operational duration shall be sufficient to permit a safe return to the Shuttle Orbiter.

b. Emergency life support equipment is not required to be rechargeable in flight.

8.1.3 Emergency Life Support System Requirements

Studies presented previously (Section 4.2.7) have indicated that a fifteen (15) minute emergency system is required to provide sufficient time for return to the Shuttle following a failure involving the EVA system. General performance requirements are listed in Table 8-1.

8.1.3 Emergency Life Support System Requirements - Continued

MISSION DURATION	15 MINUTES
METABOLIC LOAD	1600 BTU/HR
HEAT LEAK	200 BTU/HR
SUIT PRESSURE CONTROL	8.2 ± .2 PSIA
HUMIDITY CONTROL	SUIT INLET DEWPOINT LESS THAN 50°F
CO_2 CONTROL	7.6 MM HG MAXIMUM INSPIRED
THERMAL CONTROL	LIMIT CREWMAN HEAT STORAGE TO 300 BTU

TABLE 8–1. ELSS PERFORMANCE REQUIREMENTS

8.2 System Studies

8.2.1 ELSS Candidates

The specific life support functions required for an ELSS are depicted in Figure 8-1.

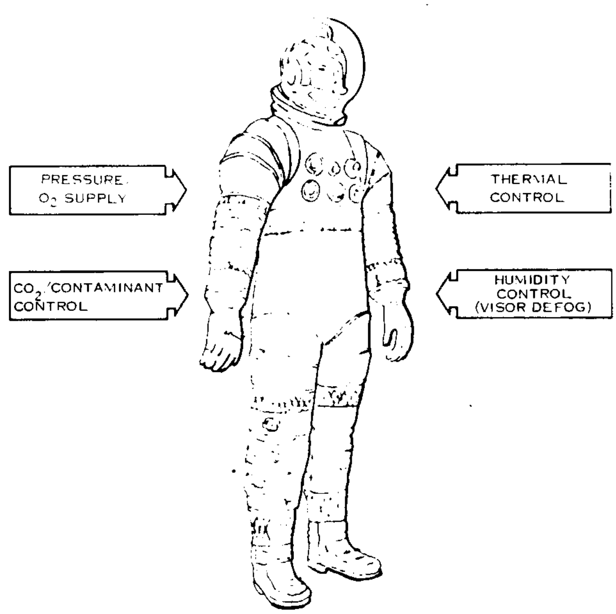


FIGURE 8–1. ELSS FUNCTIONS

8.2.1 ELSS Candidates - Continued

Based on the functional requirements presented above, the following systems were selected for evaluation to determine the most desirable ELSS approach.

a. OPEN LOOP - 6000 PSIA O_2 SUPPLY

b. SEMI-OPEN LOOP - 6000 PSIA O_2 SUPPLY

c. SEMI-CLOSED LOOP SYSTEM - 6000 PSIA O_2 + LiOH

d. CLOSED LOOP

1) 6000 PSIA O_2 + LiOH
2) 6000 PSIA O_2 + Li_2O_2
3) KO_2

Note that the concepts utilizing high pressure gaseous storage all have a storage pressure of 6000 psia. An ELSS bottle pressure trade-off study was conducted and the detail results are presented in Appendix D, Volume II.

The following sections present the methodolgy involved in each candidate's selection as well as a system description and schematic for each concept.

8.2.1.1 Open Loop - 6000 psia O_2 Supply

This system was selected as it is the simplest approach to an ELSS and has successfully been employed on past programs (Apollo and Skylab). Simplicity is achieved by utilizing a constant purge flow of oxygen to provide the required O_2 supply, and CO_2 and contaminant control. Figure 8-2 schematically illustrates the operational concept for this system.

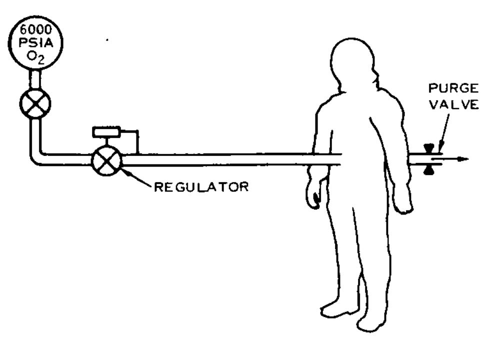


FIGURE 8–2. OPEN LOOP–6000 PSIA O_2 SUPPLY SCHEMATIC

8.2.1.1 Open Loop - 6000 psia O_2 Supply - Continued

From this schematic, it can be seen that oxygen is drawn from a 6000 psia storage tank through a downstream pressure regulator which maintains the suit at 8 psi. A purge valve in the suit wall establishes the flow required to properly exhaust CO_2 from the helmet. A thermal control subsystem is not required with this concept. The total heat load is 475 Btu's for 15 minutes at an average metabolic load of 1600 Btu/hr and an inward thermal heat leak of 300 Btu/hr. For a 4 cfm, 8 psia purge system with an inlet gas temperature of 50°F, 12 Btu of sensible heat load is dissipated. Assuming 100% drying efficiency, 180 Btu's of latent heat are also dissipated. This leaves a net of 283 Btu's (475 - 180 - 12) which is within the thermal storage capability of the crewman.

An unattractive feature of this concept is the relatively large amount of oxygen dumped overboard. The large flow capacity of this device, however, is a significant advantage if suit leakage demands large flows to maintain pressure.

8.2.1.2 Semi-Open Loop - 6000 psia O_2 Supply

In an effort to reduce the amount of oxygen utilized in the open loop concept, a semi-open loop concept was selected for evaluation. The amount of oxygen dumped overboard is reduced by adding an ejector to provide recirculation in accordance with the high helmet flow requirements. Only the oxygen required for CO_2 and contaminant control and ejector operation is dumped. This system is schematically depicted in Figure 8-3.

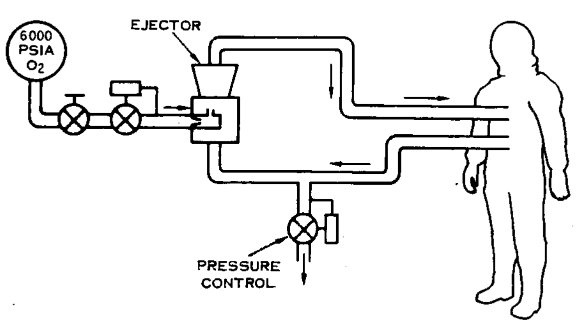


FIGURE 8–3. SEMI–OPEN LOOP–6000 PSIA O_2 SUPPLY SCHEMATIC

8.2.1.2 Semi-Open Loop - 6000 psia O_2 Supply - Continued

Oxygen is supplied from a high pressure gas bottle through a downstream pressure regulator and finally into the primary nozzle of an ejector which determines the rate of fresh O_2 flow. This primary flow induces suit ventilation flow through the venturi of the ejector. A pressure control valve is utilized to maintain suit pressure by relieving overboard. A thermal control subsystem is not required for similar reasons as those presented for the open loop concept, Section 8.2.1.1.

8.2.1.3 Semi-Closed Loop - 6000 psia O_2 Supply and LiOH

In order to reduce the oxygen required still further, a semi-closed loop with active thermal/humidity, CO_2 and contaminant control was investigated. This approach requires increased ejector performance in order to conserve the oxygen dumped.

This semi-closed system is shown schematically in Figure 8-4.

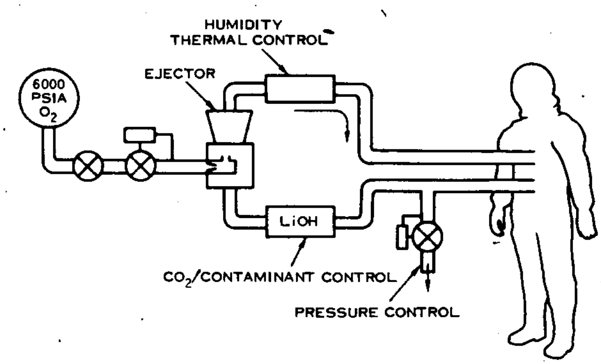


FIGURE 8-4. SEMI-CLOSED LOOP-6000 PSIA O_2 SUPPLY AND LiOH SCHEMATIC

Oxygen is supplied from a high pressure storage bottle through a downstream pressure regulator to the ejector loop for metabolic O_2 consumption and ejector requirements. The ejector circulates oxygen through the suit and ELSS where humidity, thermal, CO_2 and contaminant control is provided by active subsystems. A pressure relief valve maintains the suit loop pressure by exhausting to ambient. This concept requires isolation during normal operation of the PLSS to preclude unnecessary consumption of LiOH.

8.2.1.4 Closed Loop - 6000 psia O_2 and LiOH

To further reduce oxygen storage requirements, a closed loop system utilizing a fan for circulation was studied. This system, schematically presented in Figure 8-5,requires electrical power to drive the fan instead of oxygen to drive the ejector as in preceeding concepts. Thus, no overboard dump is required.

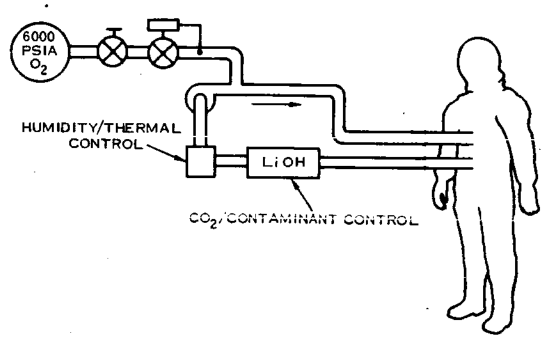


FIGURE 8–5. CLOSED LOOP–6000 PSIA O_2 SUPPLY & LiOH SCHEMATIC

The fan circulates oxygen through the suit and ELSS which contains provisions for thermal, humidity, and contaminant control. LiOH is incorporated for control of CO_2. Isolation provisions are again required for this concept during operation of the PLSS to conserve the ELSS CO_2 removal capability.

8.2.1.5 Closed Loop - 6000 psia O_2 Supply and Li_2O_2

This system, shown schematically in Figure 8-6, is the same as the closed loop system previously presented except lithium peroxide (Li_2O_2) replaces lithium hydroxide (LiOH) for CO_2 removal.

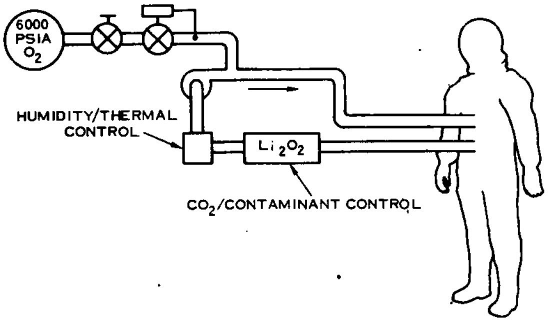


FIGURE 8-6. CLOSED LOOP-6000 PSIA O_2 SUPPLY AND LiOH SCHEMATIC

In addition to removing CO_2, Li_2O_2 also generates O_2, thus reducing the amount of O_2 that must be stored in the high pressure bottle.

8.2.1.6 Closed Loop - KO_2 Solid Chemical O_2 Supply and CO_2 Removal

This concept, shown schematically in Figure 8-7, utilizes KO_2 which has the dual capacity to remove CO_2 and release all required oxygen. Thus no oxygen supply tankage is necessary.

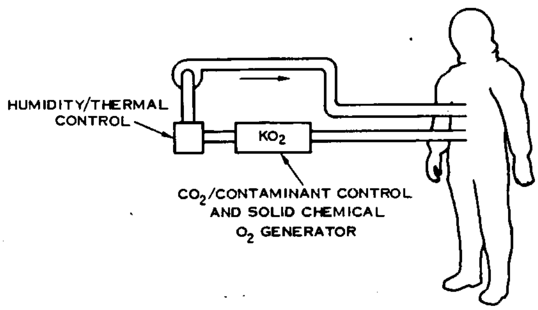


FIGURE 8-7. CLOSED LOOP-KO_2 SUPPLY & CO_2 REMOVAL SCHEMATIC

8.2.1.6 Closed Loop - KO_2 Solid Chemical O_2 Supply and CO_2 Removal - Continued

As can be seen from this schematic, a fan is utilized for circulation through the suit, the KO2 and the thermal/humidity control provision. A distinct disadvantage associated with this concept is its limited O_2 supply capability making it impossible to handle any excessive suit leakage condition which might occur.

8.2.2 ELSS Evaluation

All of the ELSS concepts presented in Section 8.2.1 meet the absolute criteria of Section 8.1.1 for performance, safety and availability. The following sections present a comparison of these concepts in terms of the comparative criteria of weight, volume, operability and cost.

8.2.2.1 ELSS Weight

Figure 8-8 presents a weight comparison between the ELSS candidates as a function of mission duration.

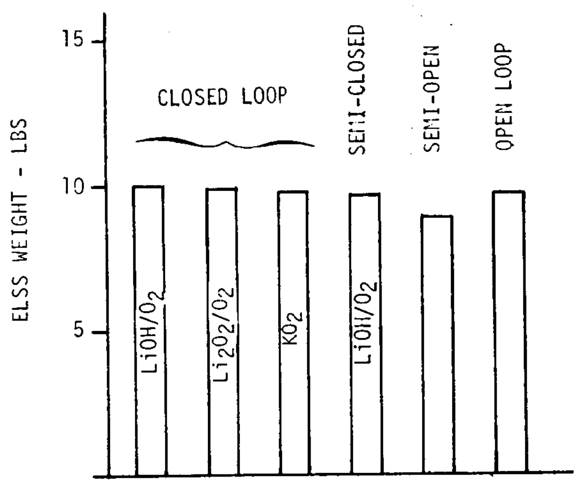


FIGURE 8-8. ELSS CONCEPTS WEIGHT COMPARISON

8.2.2.1 ELSS Weight - Continued

The weights indicated in this curve are for components only. Packaging hardware was not included since the ELSS may be integral with the Primary Life Support System. From this curve it can be seen that for a fifteen (15) minute capacity, all the systems evaluated weigh approximately the same, although the closed and semi-closed loop systems are slightly heavier.

8.2.2.2 ELSS Volume

Figure 8-9 presents the volumes for the ELSS concepts studied as a function of mission duration. Again, these volumes are for the components only.

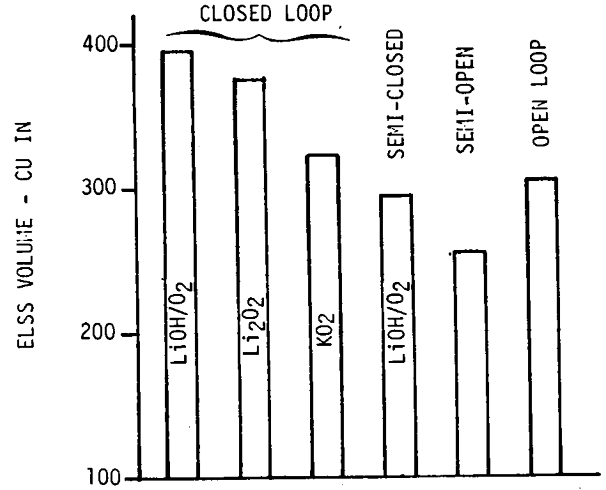


FIGURE 8-9. ELSS CONCEPTS VOLUME COMPARISON

From this graph it can be seen that the volume of the closed loop systems are significantly higher than for the other systems analyzed.

8.2.2.3 Operability

Comparing the operability of these systems, the open loop system is the least complex and easiest to activate. The closed, semi-closed, and semi-open loop systems require pre-egress check out of all functions by additional instrumentation and are more complex than the open loop system.

8.2.2.4 Cost

Since all the concepts studied are within the state-of-the-art, cost variances are primarily a function of the complexity differences with no significant development problems and risks. As such, the open loop system being the simplest is also the cheapest. The closed and semi-closed loop systems are the most complex and consequently the most expensive.

8.2.2.5 Concept Selection

Based on the preceeding evaluation, the open loop system is recommended for Shuttle ELSS applications. A summary of the reasons for this selection follows:

- Competitive on a weight and volume basis
- Least complex
- Simple pre-egress check out of all functions
- Lowest cost
- Not flow limited and can thus handle a greater variety of suit leakage conditions.
- Does not require isolation during PLSS operation

8.3 Conclusions

An open loop ELSS was selected for Shuttle EVA applications. This was the simplest and cheapest system evaluated and consisted of a regulated oxygen purge through the suit from a high pressure bottle. The adequacy of this concept has previously been demonstrated on the Apollo and Skylab Programs.

SECTION 9.0

PRESSURE SUIT ASSEMBLY

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORPORATION

9.0 PRESSURE SUIT ASSEMBLY

9.1 General

This section summarizes a study to define requirements for the EVA Pressure Suit Assembly. To obtain this information, it was necessary to survey space suit technology, to identify state-of-the-art concepts and problems, and to obtain data and other test and usage experience relevant to the Space Shuttle EVA/IVA Requirements Study. Within this section, system level requirements and their impact upon existing suit technology are discussed first. The second part reviews suit components currently available or under development for applicability to the EV suit. In addition, a final section reviews emergency IV suit requirements.

The potential use of female crewmembers was not considered in this study. However, the only area of the study that would be impacted by their use would be the suit sizing schedule and the waste management system.

9.2 Suit System Study

9.2.1 General

Presented within this section are the basic system level requirements for the pressure suit. Existing suit technology is evaluated against each requirement and, where developments beyond the state-of-the-art are required, the magnitude of such improvement is discussed.

9.2.2 Pressure Level

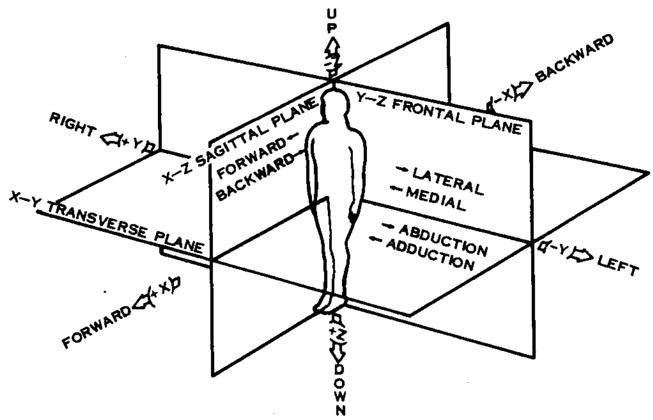
The impact of operating pressure level upon the suit is discussed in detail in Section 6. Accordingly, no further discussion will be presented here. All other parameters evaluated and discussed in this Section 9 assumed a suit pressure level of 8.0 psi.

9.2.3 Mobility

The primary impact upon extravehicular astronaut performance comes from suit mobility. Mobility is a measure of the

9.2.3 Mobility - Continued

suited crewman's ability to perform useful tasks. It is quantitatively measured in terms of range and torque.



DEFINITIONS

ABDUCTION	AWAY FROM X-Z PLANE IN X-Y PLANE
ADDUCTION	TOWARD X-Z PLANE IN X-Y PLANE
EXTENSION	STRAIGHTENING OR INCREASING ANGLE BETWEEN BODY PARTS
FLEXION	BENDING OR DECREASING ANGLE BETWEEN BODY PARTS
LATERAL	AWAY FROM X-Z PLANE IN Y-Z PLANE
MEDIAL	TOWARD X-Z PLANE IN Y-Z PLANE
PRONATION	FACE DOWN
SUPINATION	FACE UP OR ON BACK
ROTATION	REVOLVING ABOUT THE AXIS OF A BODY PART

FIGURE 9—1 PLANES & DIRECTIONS OF MOTION

9.2.3 Mobility - Continued

In Section 4.2.9, a detailed analysis was performed of the actual movement ranges involved in various activities to be performed by an extravehicular crewman. From this analysis, the suit mobility requirements were developed and compared with those contained in the Statement of Work of the June 20, 1972 Request for Proposal on an 8.0 psi Orbital EVA Space Suit Assembly. It was concluded that all mobility design goals specified in the Statement of Work are adequate for the anticipated movements. It must be noted, however, that it is customary to measure mobility performance on an unoccupied suit and, therefore, the actual mobility achieved by the suited astronaut is not necessarily the same. The complete range of suit mobility design goals for the Shuttle EVA missions are presented in Figures 9-2, 9-3, 9-4 and 9-5 for the shoulder, arm, hip and leg joints respectively.

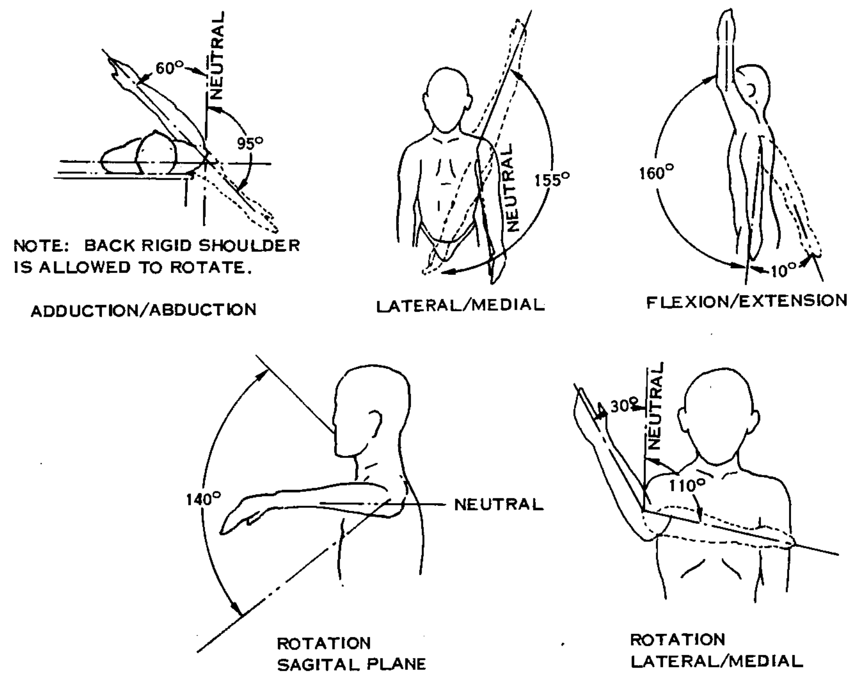


FIGURE 9—2 SHOULDER MOBILITY

9.2.3 Mobility - Continued

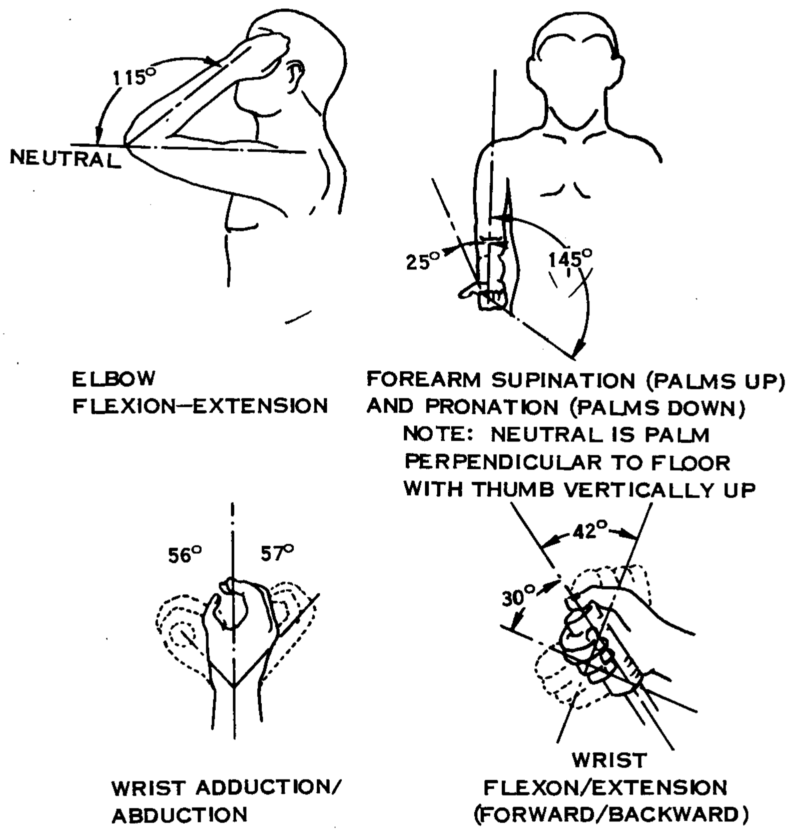


FIGURE 9—3 ARM JOINT MOBILITY

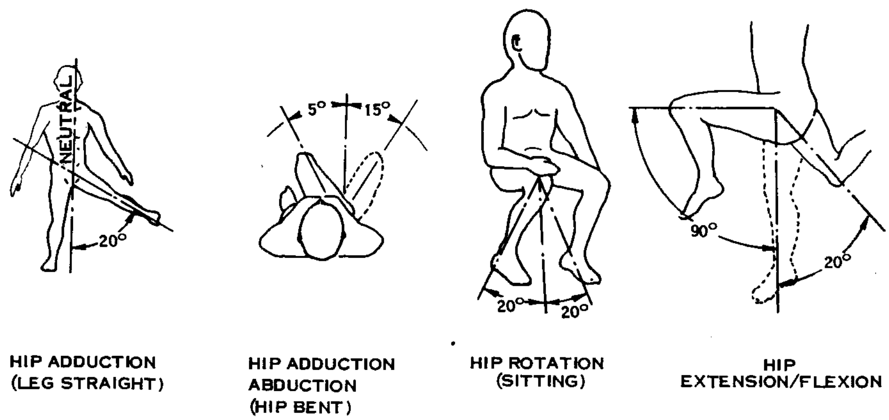


FIGURE 9—4 HIP MOBILITY

9.2.3 Mobility - Continued

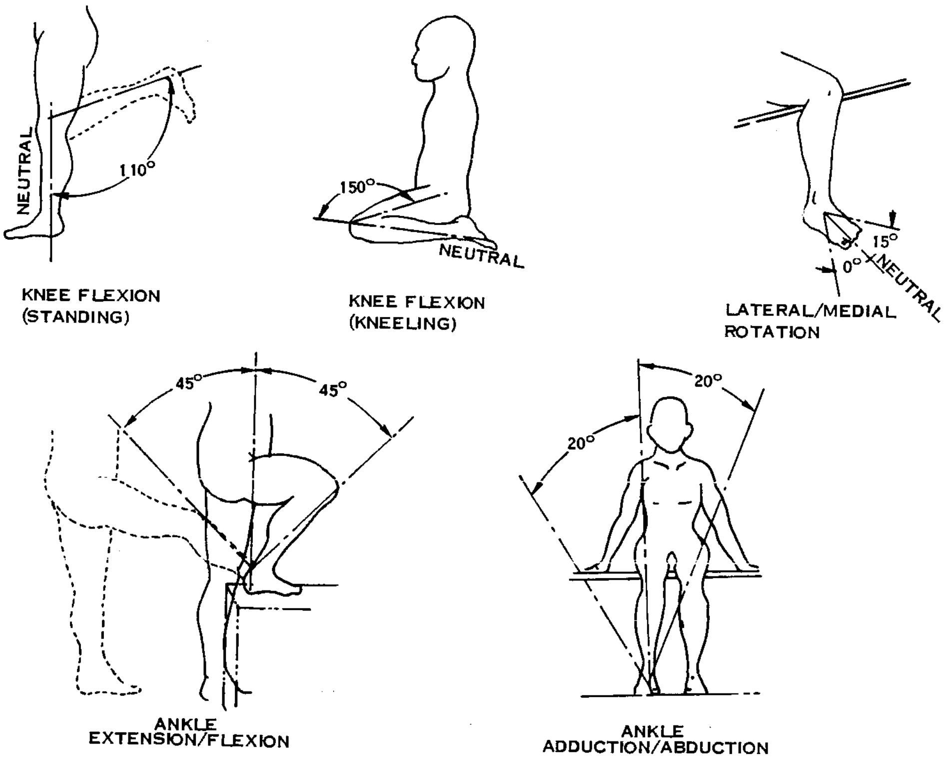


FIGURE 9—5 LEG JOINT MOBILITY

9.2.3 Mobility - Continued

No mobility requirements are given for the neck joint since the results of this study indicate that the nodding motion which is required on the A7l-B suit is not necessary when a hemispherical bubble helmet is used. Similarly, no requirements are given for waist mobility since this form of motion is desirable but not considered essential for Shuttle EVA.

As stated earlier in this section, a complete mobility requirement consists of both a range of movement and a force required to achieve that movement. For the Shuttle EV Suit, the actuating torque requirements for the various joints are as defined in Table 9-1. These requirements were derived from analysis of the tasks required and basic anthropometric data.

JOINT	MOVEMENT	TORQUE
Shoulder	Adduction/Abduction	1.0 Foot-pound
	Lateral/Medial	1.0 Foot-pound
	Flexion/Extension	1.0 Foot-pound
	Rotation	0.1 Foot-pound
Elbow	All	1.0 Foot-pound
Wrist	All	0.1 Foot-pound
Glove	Finger	1.0 Inch-pound
	Thumb	2.0 Inch-pound
Hip	All	1.0 Foot-pound
Knee	Standing Flexion	1.0 Foot-pound
	Kneeling Flexion	2.0 Foot-pound
Ankle	All	1.0 Foot-pound

TABLE 9-1 SUIT JOINT ACTUATION TORQUES

9.2.3 Mobility - Continued

In terms of mobility alone, the A7L-B suit is unacceptable for the Shuttle EV application. At the required pressure level the energy necessary to move the suit itself is prohibitive (in fact, some joints cannot be moved at all at 8.0 psi). To achieve the required torque values, it is necessary to use the constant volume concepts (such as the stovepipe) for certain joints. These joints utilize bearings in the critical planes of motion. Joints of this type are currently under development and are discussed in Section 9.3.2.

9.2.4 Weight and Stowage Volume

9.2.4.1 Weight

The previously mentioned Statement of Work for the 8.0 psi Orbital EVA Space Suit Assembly specifies a design goal maximum dry weight of 40 pounds for the complete suit excluding the Integrated Thermal Meteoroid Garment. In assessing this requirement, actual weights of current suit assemblies were obtained. These are presented in Table 9-2.

SUIT COMPONENT	APOLLO A7L-B	TARGET	AAES	LAES
Torso Limb Assembly	47.18*	35.70	42.00	33.60
Thermal Meteoroid Garment	-	18.00	16.50	15.00
Helmet	2.71	2.12	2.15	2.50
Visor Assembly	5.68	3.57	4.00	4.40
Liquid Cooling Garment	4.60	4.40	4.60	4.60
Fecal Collection System	0.50	0.34	0.50	0.50
Urine Collection System	0.52	0.52	0.52	0.52
Gloves	2.99	2.40	2.40	2.40
Electrical Harness	0.42	0.45	0.42	0.42
Bio-medical Harness	0.21	0.21	0.21	0.21
Relief Valve	0.14	0.14	0.14	0.14
Purge Valve	0.55	0.55	0.55	0.55
TOTAL	65.50	68.40	73.99	64.84

*This weight includes the Integrated Thermal Meteoroid Garment.

TABLE 9-2 CURRENT SUIT WEIGHTS

9.2.4.1 The A7L-B suit has been shown to be unacceptable for the Shuttle EV application from a mobility standpoint. To a large extent the Shuttle suit will have to utilize the joints uned on the AES's to achieve the mobility requirements. Allowing approximately 15 pounds for the ITMG, the total EV suit weight is expected to be approximately 15 pounds over the design goal based on the use of a soft body suit. The suit weight would increase approximately two pounds beyond that level if a combination suit construction were used instead of a soft suit and approximately five pounds if a hard suit were used.

9.2.4.2 Stowage Volume

The 8.0 psi Orbital EVA Space Suit Assembly Statement of Work establishes a stowage volume design goal of 6.0 cubic feet. The Apollo A7L-B suit can be stowed in a 5.0 cubic foot volume and the LAES could be stowed in a 10.15 cubic foot volume. Since the basic configuration of the Shuttle suit is expected to be closer to the A7L-B than to the LAES, it should be possible to meet the stowage design goal. The maximum stowage volume would be required by a hard suit and would be approximately 11.0 cubic feet.

9.2.5 Life

9.2.5.1 Useful Life

Based upon an analysis of flight frequency, crew utilization, interchangeability of suits between crewmembers and suit materials capability, a useful life requirement of four (4) years after delivery and testing has been established. During this four year period, the suit would be used approximately 125 hours. In the Orbital EVA Suit Statement of Work, the service life design goal is specified as 50 EVA missions of 6 hours each over a one year period. The one year period can be increased as any suit designed and fabricated for the Shuttle EVA should be able to meet the four year useful life. Neoprene rubber which is used in molded joints and dipped fabrics has a life span of five years by military standards and typifies the limitations imposed on soft goods. The other requirement, for 300 EVA hours within the useful life period, is conservative. Based upon the analysis made in this study, it is more likely that total suit or suit component would be exposed to 95 EVA hours during its useful life.

9.2.5.2 Cyclic Life

The establishment of a cyclic life requirement presents a more complex problem than does the service life requirement. First, it is difficult to forecast the precise number of flexures that will occur in a particular joint during any given EVA. Secondly, as shown in Section 4.2.9, the bulk of the anticipated motions occur over a smaller range than the entire cyclic range specified for the joint. However, based on the work to be performed on a typical EVA mission and considering the previously established service life, a cyclic life requirement of 100,000 flexures per joint was established. This requirement is the same as the design goal given in the Orbital EVA Suit Statement of Work. Existing suit component data were reviewed to evaluate the potential for meeting this 100,000 cycle requirement. The available data are presented in Table 9-3.

JOINT TYPE	APPLICATION	CYCLIC TEST EXPERIENCE
• Stovepipe	AAES Shoulder	450,000 rotary; some spalling, torque and leakage increased.
• Rolling Convolute	LAES Shoulder	120,000 axial, 100,000 rotary; minor pivot wear.
• Molded Convolute	A7L-B Shoulder	56,000; slight abrasion
• Convolute	LAES Elbow	100,000; delamination, pivot wear
• Convolute	Scott Joint	100,000; no failure
• Convolute	LAES Knee	109,859; pivot wore through
• Convolute	A7L-B Knee	700; root tapes slipped
• Convolute	LAES Ankle	100,000; some pivot wear
• Tucked Fabric	SAC Knee	255,000; developed leakage.

TABLE 9—3 JOINT CYCLIC LIFE

9.2.5.2 Cyclic Life - Continued

From this limited test data it can be projected that the cyclic life requirement is practical, depending upon the selection of particular joint types. However, since the majority of these tests were not conducted to failure, the results are insufficient to allow projection of the margin by which actual performance will exceed the requirement.

9.2.6 Leakage

The design goal maximum EV suit leakage established by the suit Statement of Work is 400 scc per minute at 8.0 psig (relative to atmospheric pressure) upon delivery to NASA. Over the design service life, this leakage rate is allowed to increase to an absolute maximum of 1000 scc per minute. Both of these goals are considered low considering total mission requirements.

No empirical data for total suits at 8.0 psia exists, so assessment of the requirement must be extrapolation. Assuming that the final suit will use closure rings rather than zippers (which are the primary source of leakage on the A7L-B suit) a reasonable approximation of the leakage rate can be obtained by extrapolation of leakage data for the flight qualified A7L-B suit wrist lip seals. This calculation indicates a total suit leakage rate of 85 scc per minute or less at 8.0 psia. This extrapolation then tends to indicate that the established leakage requirement is one that the production suits can meet. It should be noted that severe leakage problems have been experienced during suit development phases; for example, the stovepipe shoulder joint on the AAES had a leakage rate in excess of 1000 scc per minute at 3.7 psig due to distortion of a bearing. However, as discussed later (see 9.3.2.1.1) solutions do exist for these leakage problems.

9.2.7 Suit Sizing Schedule

9.2.7.1 Purpose

One of the most critical factors in achieving maximum mobility and comfort in a suit is the extent of custom sizing. Independent of all other considerations, the greater the degree of personalized fit provided, the greater is the mobility and overall performance efficiency of the man-suit system. However, on the Shuttle Program it is desirable to reduce the amount of customized hardware to the absolute minimum. Experience indicates that it should be possible to develop a suit sizing schedule such that selected "off-the-shelf" components could be assemblied into one unit for a particular crewman and thus provide the maximum possible mobility and comfort. These suit components (such as shoulder, upper torso, gloves, etc.) would each incorporate a degree of personal adjustment in certain critical anatomical dimensions. This personal adjustment capability could be as simple as a lacing cord-restraint section located at strategic points within the component. A detailed sizing schedule would be evolved from detailed analysis of anthropometric data. Data typical of that evaluated during this study is presented for the glove, shoulder and boot in Table 9-4 on the next page. Of all body areas studied, these three represent the most critical from a sizing standpoint.

9.2.7.2 Sizing Schedule

As Figure 9 - 6 shows, it is expected that the number of sizes of each component can be reduced to a maximum of three with the exception of the gloves. This is felt to be the optimum attainable. There are three specific areas where considerable effort will be required to provide component type suits that will satisfy all Shuttle mission requirements. These are, in order of criticality, the glove, the boot and the shoulder. The glove is undoubtedly the most critical area requiring optimum fit or adjustment capability. Elongation and ballooning of the fingers and ballooning of the palm are major causes of mobility-tactibility-dexterity loss. These parameters can be controlled only through proper sizing of the associated patterns and a significant degree of final fit adjustment. At present there is no program which provides pressure gloves of the required type using a standard DOD procurement schedule (6-8-12 sizes). Table 9 - 4 clearly demonstrates this need for vernier adjustment capability in the gloves. The boot is critical from the standpoint of using lower leg/foot restraints in both EV and IV modes.

9.2.7.2 Sizing Schedule - Continued

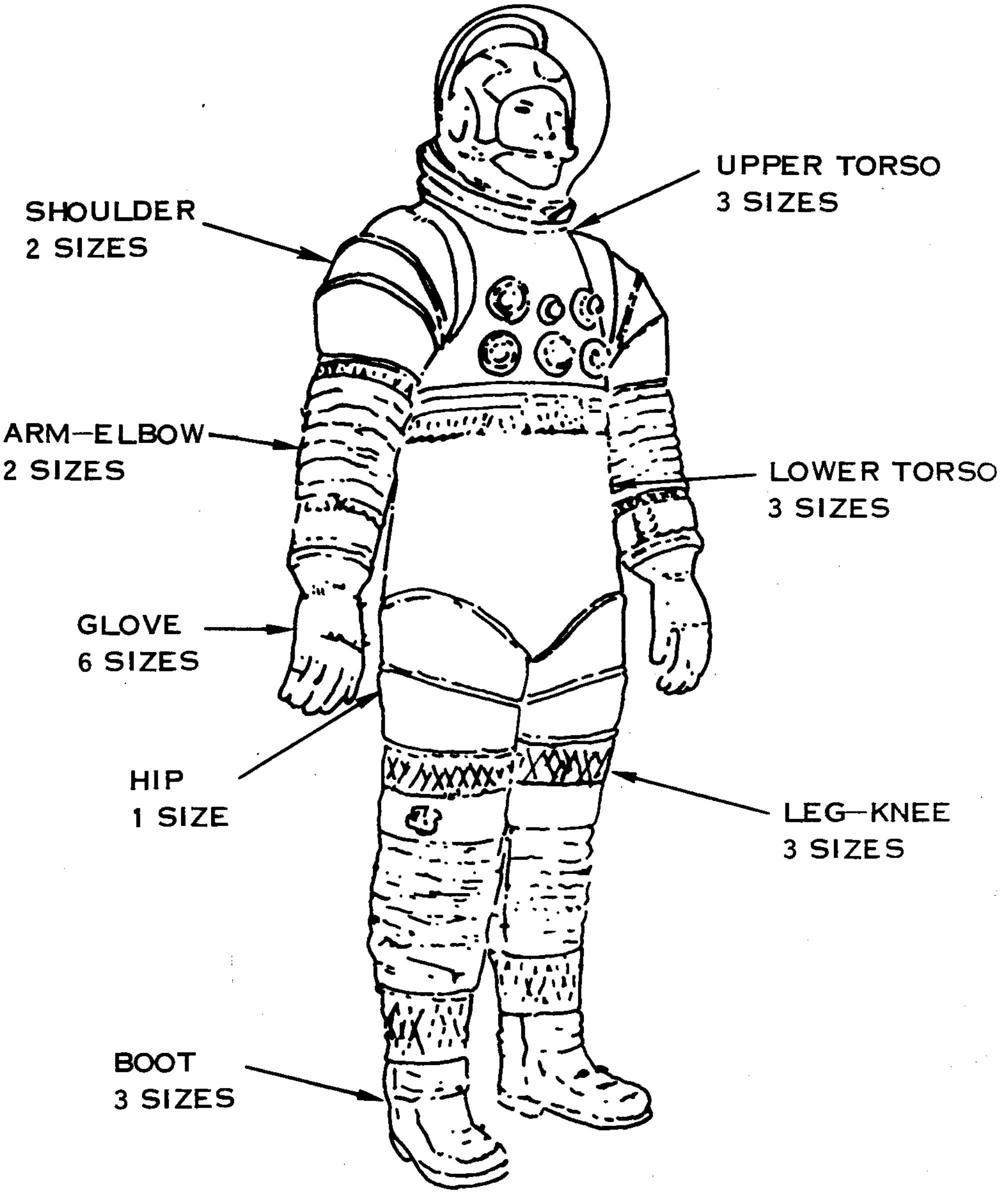


FIGURE 9—6 SUIT SIZING SCHEDULE

9.2.7.2 Sizing Schedule - Continued

The number of standard sized boots required could be held to a minimum by the use of as few as three pressure/restraint shells and a limited number of liner inserts. The shoulder is also a critical area primarily because of its ultimate effect upon arm/glove efficiency. This section must provide clearance for donning and doffing while minimizing the pressurized free-volume in order to maintain a stable crewman position in the suit. Excessive free-volume within the shoulder allows the glove to move away from the hand, particularly at the finger tips, severely degrading the effectiveness of the glove.

In summary, using standard components with vernier adjustment capability where necessary, the most probable combination of suit component configurations is as follows:

Component	Configuration
Glove	6
Arm-elbow	2
Shoulder	2
Upper torso	3
Lower torso	3
Hip	1
Leg-knee	3
Boot	3 (plus liner & inserts)

TABLE 9—4 SUIT COMPONENT CONFIGURATION

9.2.8 Relative Cost

Actual comparative cost data for each of the various suit construction concepts presented herein was not available. The relative cost of these various concepts will not differ greatly since suit detail costs do not constitute a major percentage of the total cost of a suit program. The ultimate selection of suit components will be based on performance and life requirements and cost will not be a significant factor, although the more promising joints from a performance standpoint are also cheaper to produce. It should be possible, however, to accomplish significant cost savings over the unit cost of the A7L-B program. There are several reasons for this; the use of a standard sizing schedule rather than custom-fit suits, joints which are less expensive to produce, reduced field maintenance and design improvements.

9.3 Suit Component Study

9.3.1 General

This section summarizes the state-of-the-art in advanced space suit concepts and hardware. Each major suit component is treated separately with the available concepts being described and assessed for applicability to the Shuttle suit. The primary sources for the data presented here were, chronologically, the ILC Industries' Apollo A7L-B Suit, the Hamilton Standard MOL Suit, the AiResearch and Litton Advanced Extravehicular Spacesuits (AAES and LAES respectively) and various NASA development programs.

9.3.2 Suit Joints

9.3.2.1 Shoulder Joint

There are four basic shoulder joints which have been considered for use on advanced space suits; the stovepipe joint, the rolling convolute, the modified A7L-B joint, and the two bearing fabric joint. Of these, the stovepipe joint and the rolling convolute appear to be the best prospects for the 8 psi suit while the modified A7L-B joint is not acceptable.

9.3.2.1.1 Stovepipe Joint

This concept was generated at NASA/Ames and was used in the AiResearch AES. It consists of five (5) rotary bearings interconnected by four (4) sections of suit restraint material. The interconnecting sections of suit restraint material are shaped roughly like the bases of oblique truncated cones. Figure 9-7 shows a stovepipe joint. All motions (abduction/adduction, flexion/extension, and lateral/medial) are accommodated by the rotation of the five (5) bearings.

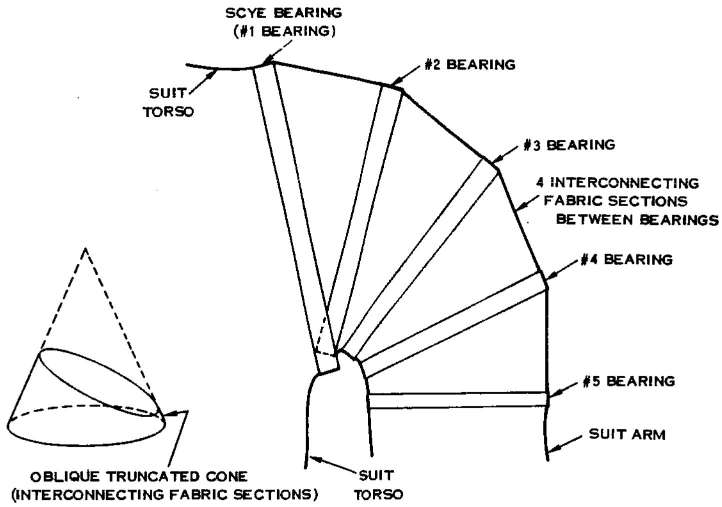


FIGURE 9-7 STOVEPIPE SHOULDER JOINT

The measured average work for this joint on the AAES was 13.0 foot-pounds for a 150° range of lateral/medial movement. Although this torque is somewhat high, it is believed to have been caused by distortion of the innermost, or scye, bearing. This distortion resulted in high torques for certain motions and high leakage.

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9.3.2.1.1 Stovepipe Joint - Continued

Both of these leakage and torque problems could be resolved by modification of the bearing mounting technique. Potential sealing technique are shown in Figure 9-8.

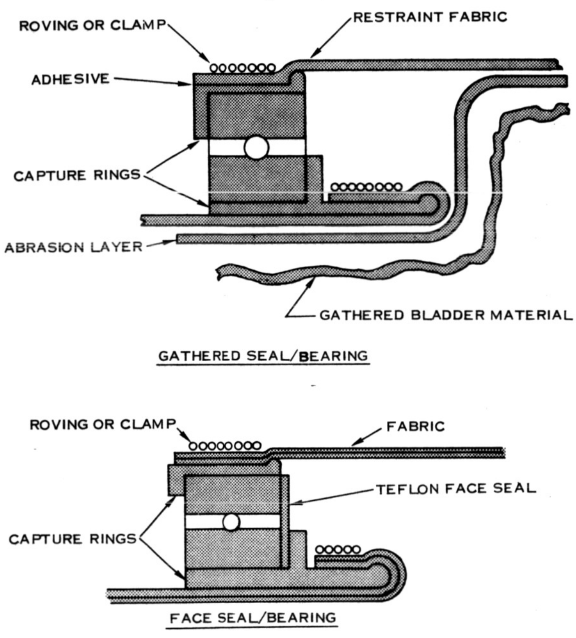

FIGURE 9-8 POTENTIAL SEALING TECHNIQUES

Accordingly, the stovepipe joint is believed to offer the most potential for the Shuttle EV Suit shoulder joint.

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9.3.2.1.2 Rolling Convolute Joint

This concept was developed by Litton and used in the Litton AES. The convolute, rather than being molded in a bellows shape, is constrained by metal bands in such a manner that it is forced to roll when the joint is flexed rather than extend or compress as is the case with the A7L-B molded convolute joints. A concept sketch of this type of joint is shown in Figure 9-9. Plug loading is carried by linkages attached to the restraining bands of the rolling convolute joint along the constant length lines. Rotation is permitted by a bearing at each end of the joint.

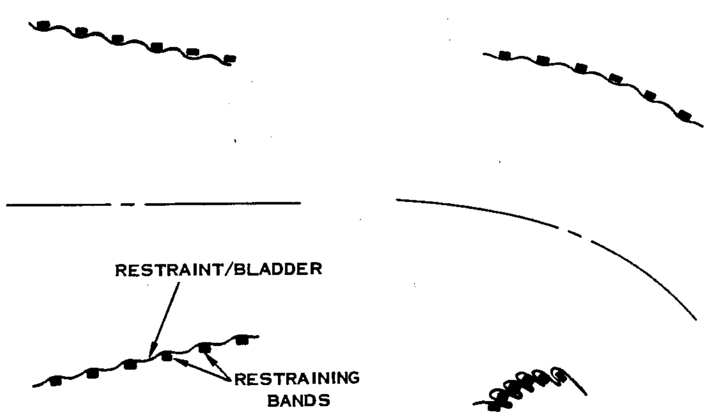

FIGURE 9—9 ROLLING CONVOLUTE JOINT

The measured average work for this joint on the LAES was 6.9 foot-pounds for a 150° range of lateral/medial movement. No significant potential for improvement of these work levels exists and, on that basis, it is not considered to have the potential for use on the Shuttle suit that the stovepipe joint has.

9.3.2.1.3 Modified A7L-B Joint

The A7L-B joint consists of a molded bellows-shaped convolute which flexes as shown in Figure 9-10. Plug loading is taken by cable restraints. Rotation is permitted by bearings. The modified A7L-B joint would be essentially the same as the A7L-B joint except that the cable restraints would be external to the molded convolute rather than molded integrally. The reason for this is that the integrally molded cable has cycle life problems. Molding cables integrally with the bellows results in cable strands rubbing together and abrading. External cabales would not have this problem.

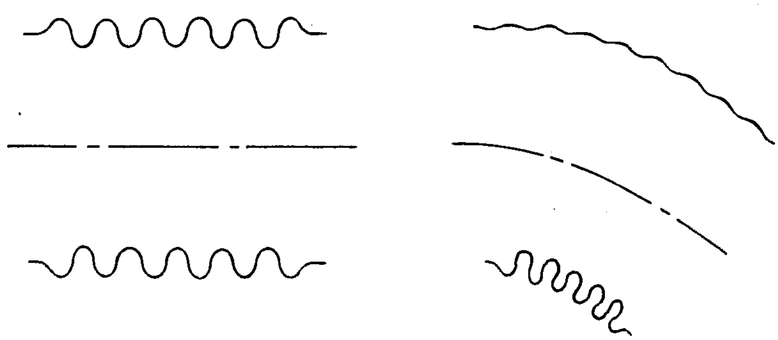

FIGURE 9–10 MOLDED CONVOLUTE JOINT

This type of joint appears unacceptable for use at pressures over approximately 6.0 psi at which point it becomes essentially too stiff to move due to the tendency of the convolutes to balloon.

9.3.2.1.4 Two Bearing Fabric Joint

The two bearing fabric joint consists of an all fabric joint with a rotary bearing at each end. An all fabric joint (such as used in the elbow or knee joints) is shown in Figure 9-11 and described in 9.3.2.4.2. It would be attached to the bearings by one of the techniques shown in Figure 9-8. With this type joint, the fabric provides axial bending and the bearings provide rotary motion.

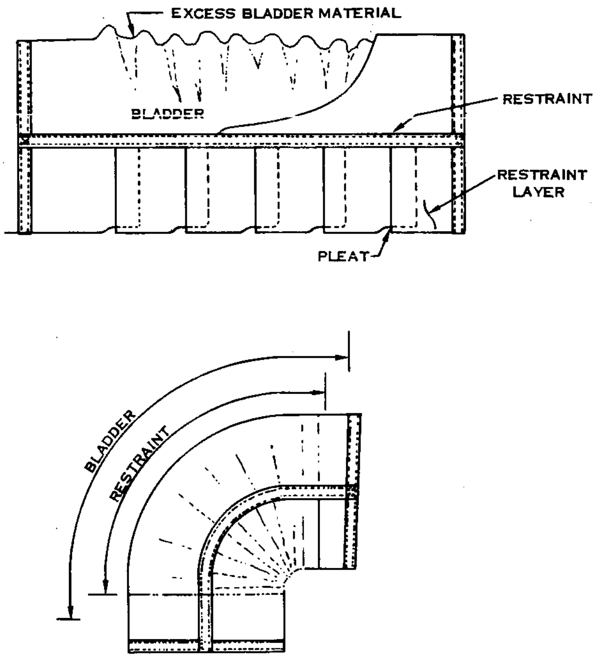

FIGURE 9—11 ALL FABRIC JOINT

9.3.2.1.4 Two Bearing Fabric Joint - Continued

This type of joint permits good mobility in abduction/adduction and flexion/extension but minimal mobility in the lateral/medial range. This reduces its acceptability for the EV Suit shoulder, however, its relatively low bulk and weight make it attractive for an IV Suit.

9.3.2.2 Neck Joint

As described in 9.3.6, a spherical helmet should be used on the suit. Since a helmet of this type permits adequate head movement and visibility without the need for a neck joint, no neck joint should be included in the Shuttle suit. By eliminating the neck joint, the suit design can be simplified, the quantity of hardware required can be reduced and the potential for leakage can be reduced.

9.3.2.3 Hip Joint

The three types of hip joints available for the suit are the stovepipe, the AAES hip joint and the A7L-B hip joint. Of these, the stovepipe joint presents the best potential for the Shuttle Program.

9.3.2.3.1 Stovepipe Joint

The stovepipe hip joint would be the same as the shoulder joint described in 9.3.2.1.1 above and shown in Figure 9-7 except that three bearings and two fabric interconnections would be used instead of five bearings and four interconnections. This joint was used on the LAES and in testing exhibited an average work load of 6.6 foot-pounds for a 70° flexion range.

9.3.2.3.2 AAES Joint

This joint consists of a fabric convolute section which provides flexure motion with rotary bearings at each end of the joint. A fabric "wedge" section (or oblique truncated cone section) connects the upper end of the convolute to the upper thigh bearing. The average measured work for this joint was 5.3 foot-pounds over a 60° flexion range.

9.3.2.3.3 A7L-B Joint

The A7L-B hip joint is a molded convolute type as described above in 9.3.2.1.3. As with the shoulder joint, it is unacceptable for the Shuttle Suit application since it is too stiff to move at the required operating pressure.

9.3.2.4 Elbow and Knee Joints

These are grouped together as the same concepts are applicable to both areas. There are basically two types of joints considered for these areas: convoluted joints and all fabric joints. The all fabric joint offers the greater potential of the two types.

9.3.2.4.1 Convoluted Joints

The LAES, AAES, and A7L-B suits all utilize convoluted joints. These are all roughly similar in concept, incorporating bellows-shaped convolutes which flex as shown in Figure 9-10 and which are restrained axially by cables. In addition to the LAES convolute, Litton has developed a soft convolute (called the Scott convolute) which utilizes a tape rather than cable restraint.

The average measured work on this type of elbow joint has varied from a low of 1.1 foot-pounds for the Scott convolute to a high of 4.5 foot-pounds for the LAES, all over a range of 100° of flexion/extension. On the knee joint in standing flexion, the required work varied between 4.7 (LAES) and 7.5 (AAES) foot-pounds over a 100° range.

9.3.2.4.2 All Fabric Joints

This type of joint (also called tucked fabric joint) is depicted in Figure 9-11. Plug loading is taken by restraint tape. Flexure of the joint occurs by virtue of the fact that the joint contains a greater free length of bladder material than of restraint material. One of the prime advantages of this type of joint is high cycle life; one knee joint was subjected to over 255,000 109° bend cycles before excessive leakage occurred. Additionally, this type of joint has a somewhat lower torque/range characteristic than the convoluted joint.

9.3.2.5 Ankle Joints

Concepts similar to those used for elbow and knee joints (i.e., convoluted and all fabric joints) are applicable to ankle joints, with the most appropriate being a single axis, all fabric ankle joint. The AAES utilized a two axis joint for this application.

9.3.2.5 Ankle Joints - Continued

This consisted of two convoluted joints with their planes of flexure 90° apart to provide bending in the sagittal and frontal planes. This joint is considered too sophisticated for the needs of a Shuttle suit.

9.3.2.6 Waist Joints

All of the applicable waist joints employ convolutes for bending. Again, the AAES was unique in that it had two convolute joints with their planes of flexure 90° apart to allow bending in the sagittal and frontal planes. The other suits allowed bending only in the sagittal plane.

The A7L-B waist joint was totally unacceptable at 8 psi. It would not bend full range as at 4 psi. Adjacent areas of the suit would collapse before the joint would bend full range at 8 psi. The LAES waist joint had the best torque/range characteristics. However, it had a serious problem in that it pinches the subject's skin in the belly area during flexion. The AAES waist joint required about three times as much work to move it through a given range as the LAES waist joint. It did not pinch the subject, however. Both the LAES and the AAES joints require structural strengthening before they can be considered acceptable for 8 psi use.

However, based on the analysis of mobility requirements, it is questionable if a waist joint is really necessary for the Shuttle Suit. The minor convenience that results from a waist joint does not justify the increased suit complexity that would result from its incorporation.

9.3.3 Gloves

There are four basic types of glove design which are of interest for advanced suits: A7L-B type, MOL suit type, Slip Net type, and Mini-convolute type. Of these, the Mini-convolute glove appears to hold the most promise for improvement in mobility and comfort for the EV application.

9.3.3.1 A7L-B Glove

This type of glove utilizes a dipped bladder which serves as both the pressure retaining and load carrying material. The bladder is thick and thus presents mobility/tactility problems, especially at higher pressures. Wrist mobility is provided by a convoluted joint and is considered poor. Fatigue in the fingers and wrist and ballooning in the palm area are unresolved problems with this type glove.

9.3.3.2 MOL Suit Glove

This glove is similar in construction to the tucked fabric joint described in 9.3.2.4.2 in that a thin dipped bladder is used to retain pressure while a separate fabric layer carries the pressure load. The thinner bladder allowed improved mobility.

9.3.3.3 Slip Net Glove

The Slip Net Glove, used in the Lunar Receiving Laboratory at MSC, is essentially a variation of the link net joint concept used in the Gemini suits. Its mobility characteristics are not as good as the Mini-convolute Glove. Its mobility relative to the Apollo A7L-B and MOL Suit Gloves is not known.

9.3.3.4 Mini-Convolute Glove

This glove, the construction of which is shown in Figure 9-12, was developed for NASA/Ames. The concept appears to provide excellent mobility with little, if any, spring back tendency. The NASA/Ames glove has relatively low-wrist mobility; however, this could be provided by adding mini-convolutes in the wrist area.

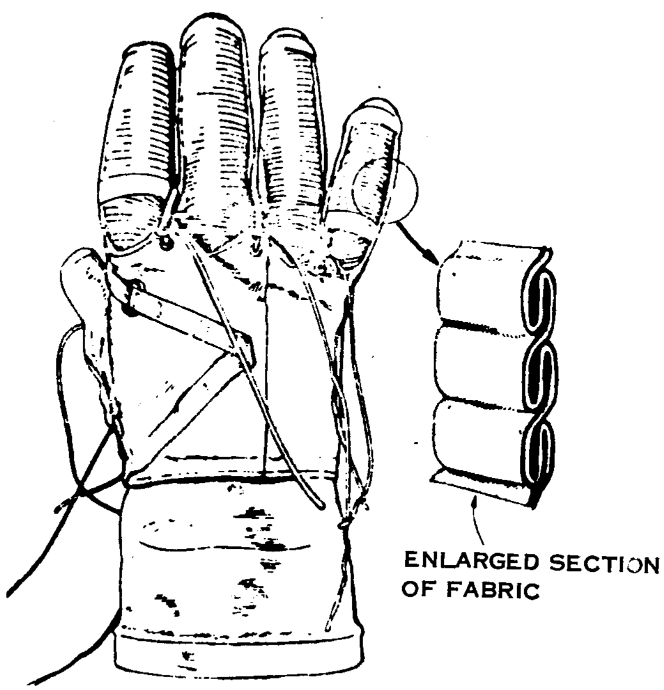

FIGURE 9—12 MINICONVOLUTE GLOVE

9.3.3.4 Mini-Convolute Glove - Continued

The wrist joint would then be a true two axis joint (i.e., two single axis joints with planes of flexure 90° apart). Two separate single axis joints could also be used for thumb mobility.

9.3.4 Closures

The basic type of closures considered for the Shuttle suit were pressure sealing zippers, roll seals and closure rings. Closure rings are felt to hold the highest potential for the EV suit.

9.3.4.1 Pressure Sealing Zippers

The Apollo A7L-B suit makes use of an inner pressure sealing zipper and an outer restraint zipper which takes plug loading plus the man-induced loading. However, the loads imposed upon a zipper by the 8.0 psia pressure level represent considerably higher stresses than the present zippers are capable of absorbing. To provide the necessary factors of safety it would be necessary to develop a new zipper with approximately twice the strength of the strongest zipper currently available.

9.3.4.2 Roll Seals

A roll cuff seal, shown in Figure 9-13, consists of the bladder material of each portion of the suit to be joined together and a restraint zipper. The crewman completes the closure by rolling the two halves of bladder material together around the circumference of the portion of the suit to be connected and then zips up the outer restraint zipper. The rolled up bladder material restrains pressure (much like a tin can seam) and the restraint zipper carries the plug load. This system gave satisfactory results on the Intravehicular Space Suit Assembly (ISSA) and is considered more reliable than a pressure sealing zipper.

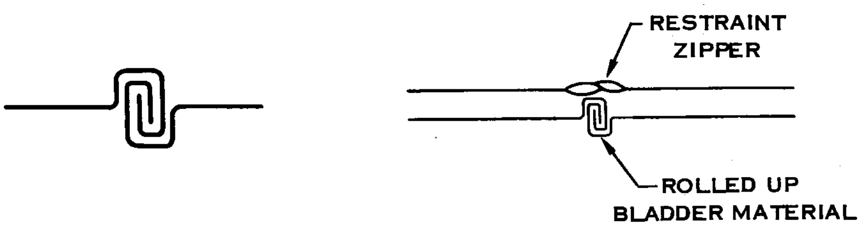

FIGURE 9-13 ROLL CUFF SEAL

9.3.4.3 Closure Rings

Closure rings, or hard disconnects, are used at the wrist and neck of the A7L-B suit. In service, these have proven reliable and easy to actuate. On the EV suit, the waist disconnects would be essentially identical to the A7L-B rings except, possibly, for some structural strengthening for the higher pressure loads. Similarly, the neck ring would be of the same type although additional helmet retaining pins would be required for 8.0 psi operation.

Analysis of waist closure techniques indicates that a closure ring should be used for that application in the Shuttle EV Suit. Closure rings were used at the waist of the AAES and LAES and proved satisfactory. The only disadvantage to a closure ring system is its weight but this is more than offset by its reliability advantage. Additionally, with a closure ring it is easier to don and doff a suit than it is with either a zipper or roll seal system.

9.3.5 Basic Suit Construction

Three general types of suits were considered for this study; namely, soft, hard and combination suits. A soft suit is an assembly wherein the upper and lower torso and the limb transition sections (excluding joints) are constructed of soft fabrics (usually a restraint cloth and a bladder material). In a hard suit, these same components are constructed of rigid materials (such as fiberglass or metal). A combination suit is one that utilizes components of both types. The type of suit does not categorize the joints used; for example, a stovepipe shoulder joint is appropriate for use in a soft, hard or combination suit. The applicability of various components to suit types is shown on Table 9-5 on the next page.

Suit stowage volume is primarily a function of suit construction. Stowage volumes were determined for each of the types of suits under consideration. It was assumed in deriving these numbers that the limbs and helmet could be stowed inside the torso assemblies. Weight ranges were also estimated for the three types of suits.

9.3.5 Basic Suit Construction - Continued

The results are presented in Table 9-5. As can be seen, the soft suit configuration offers both weight and stowage volume advantages and should be selected on that basis. The other concepts should be considered only if materials availability or other problems preclude a soft suit.

SUIT TYPE	WEIGHT RANGE - POUNDS	STOWAGE VOLUME - CUBIC FOOT
Soft	59 - 71	5.0 - 6.0
Hard	65 - 75	11.0
Combination	61 - 73	7.0 - 10.0

TABLE 9—5 SUIT WEIGHT AND STOWAGE VOLUME REQUIREMENTS

If a soft type suit is used, three various types of restraint and bladder constructions may be used in the suit. These are:

(a) A uni-layer material including a single substrate coated on one or both sides.

(b) A uni-layer material including multiple fabric substrates that are coated on one or both sides and then laminated together.

(c) A bi-layer material consisting of two distinct fabrics; one being a bladder layer and the other a restraint layer.

Evaluation of the characteristics of these methods of construction results in the selection of the bi-layer for the EVA suit. All three materials are essentially equal with regard to sealing, gas retention and abrasion resistance. The uni-layer, multi-substrate construction is considerably heavier and bulkier and less comfortable than the other two materials, and, since it offers no distinct advantages, is not considered a viable

9.3.5 Basic Suit Construction - Continued

candidate material. The remaining two materials are approximately equal in weight. Of the two, the single-substrate, uni-layer construction is easier to fabricate and should prove easier for the crewman to don and doff. However, the bi-layer system offers advantages of greater user comfort, lower stiffness and higher reliability and is selected on that basis.

9.3.6 Helmet

Evaluation of the A7L-B helmet for the Shuttle application shows it to be unacceptable based on two stress areas. The A7L-B helmet-suit ring has two hold-down points. Since it is desirable to provide uniform loading distribution at an 8.0 psi differential, this attachment technique is not acceptable. The second point is that the A7L-B helmet basically follows head contours and has flattened areas on the sides. At the higher pressure levels this results in an undesirable stress pattern. Accordingly, a hemispherical blown bubble, such as used in the LAES, is the type of helmet that should be used, designed, of course, to the higher pressure level.

9.3.7 Boots

Evaluation of existing boot designs indicates that the boots for the EV suit should be of a soft fabric design with a semi-rigid sole. A restraint layer/pressure layer construction is preferred over a laminated structure because of weight, volume and comfort considerations. As stated in 9.3.2.5, the ankle joint on the boot should be a single-axis all-fabric joint.

9.3.8 Vent System Ducting

The A7L-B suit utilizes a soft walled ducting with "triloc" used to prevent crushing of the ducts. This triloc is a nylon covered helix and three of them are used inside each duct. The AES's utilizes a smooth-bore duct of approximately the same cross-sectional shape and size of the A7L-B ducting.

9.3.8 Vent System Ducting - Continued

However, as shown in Figure 9-14, the ducts in the AES's achieved wall rigidity by the use of a spirally wound wire integral with the duct wall. Based on this type of ducting, significant improvements in pressure door are expected. Figure 9-15 shows the pressure drop in the total suit that could be expected from the use of this self-supporting ductwork.

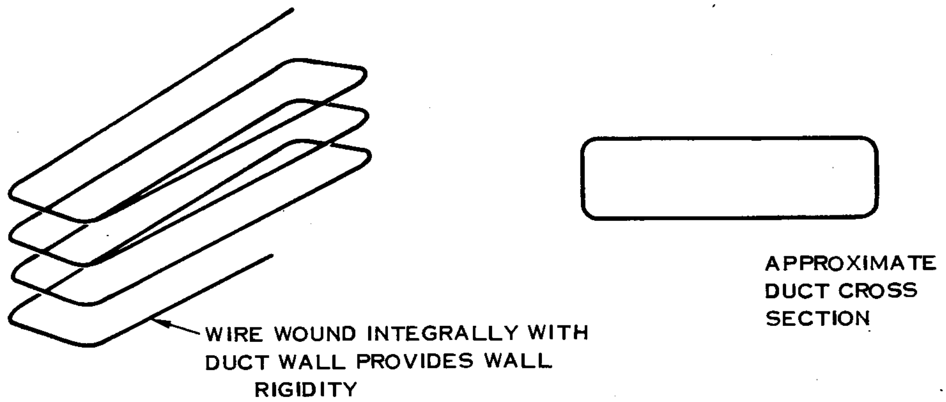

FIGURE 9-14 SMOOTH BORE VENT DUCTS

9.3.8 Vent System Ducting - Continued

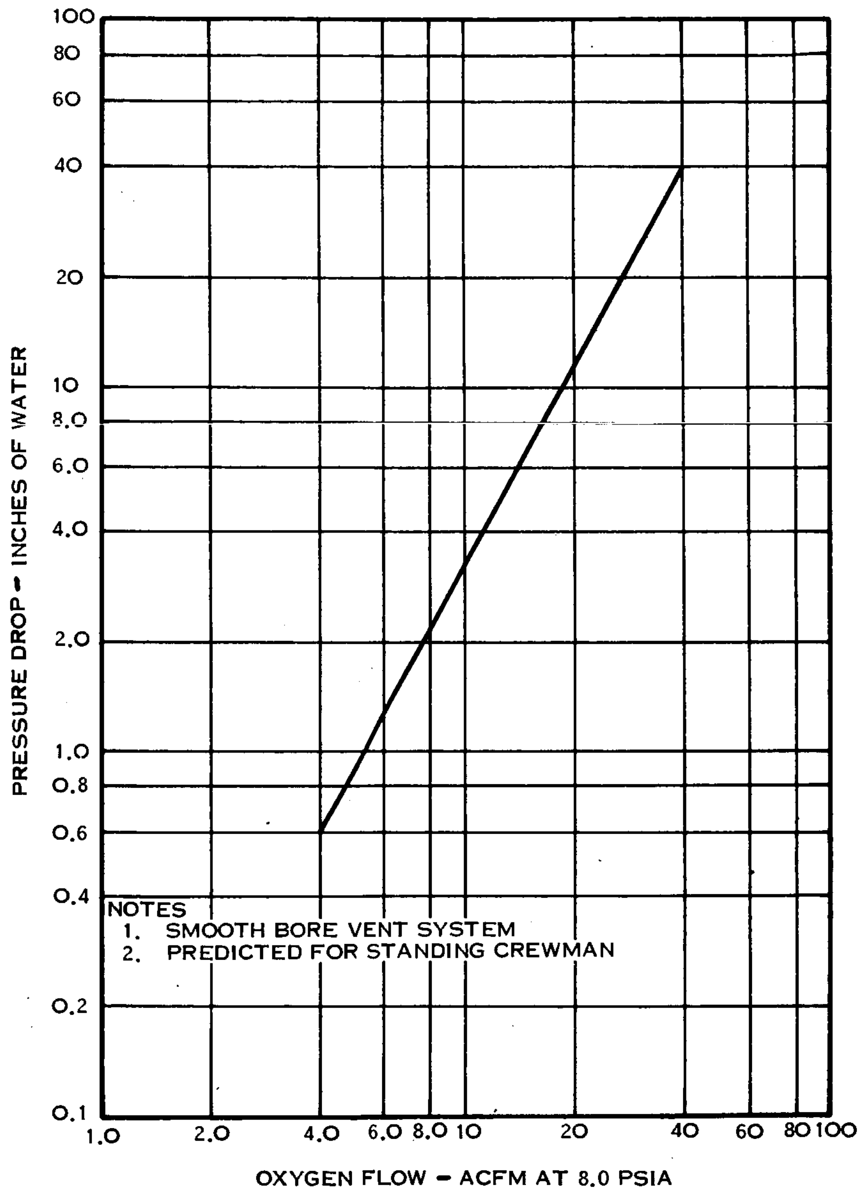

FIGURE 9-15 VENT SYSTEM PRESSURE DROP

9.3.9 Liquid Cooling Garments

Work has been initiated to evaluate various advanced liquid cooling garment (LCG) concepts to improve the cooling effectiveness of LCG's. However, to date no advanced LCG's have been built. All tests have been performed on sample "patches" of various LCG concepts. These include capillary tube constructions and a laminated type of construction where coolant flows through channels in laminated layers of LCG material. Test data is not yet available, hence it is not possible to estimate flow vs. pressure drop characteristics of each concept. As higher thermal effectiveness is achieved, crewman comfort will depend on increasingly accurate control of coolant inlet temperature. Hence, advanced temperature control systems may be required for advanced LCG's.

Three types of advanced temperature controllers are currently under development, but no test data are available. The types are:

(a) Sweat Rate Thermal Controller

(b) Honeywell Fluidic Temperature Controller

(c) Webb Skin Temperature Sensitive Thermal Controller

It must be noted, however, that it is doubtful that these advanced LCG systems will be required. The Shuttle EVA metabolic loads are comparable to, or lower than, the metabolic loads of the Apollo EMU. In addition, the Apollo mission durations are longer. The Apollo LCG and its three-position manual flow control valve on the PLSS proved satisfactory for that application and, therefore, should prove acceptable for the Shuttle application. The advanced systems do not offer any advantages to off-set their increased complexity, expense and inherent unreliability of automatic control systems.

9.3.10 Waste Management Systems

The waste management system developed for the Apollo EMU has proven itself fully acceptable for the over-seven-hour duration missions of that program. With the shorter duration missions of the Shuttle program, both the Apollo urine and fecal collection systems should adequately satisfy the waste management requirements for Shuttle EVA and no further design or development effort is required.

9.4 EVA Suit Conclusions

Based on the results of the EVA suit evaluation study, the following major conclusions were drawn:

(a) The design goals established in the 8.0 psia EVA Suit Statement of Work for mobility, leakage, weight, life and other parameters are adequate based upon current program scope.

(b) Suit mobility requirements necessitate the use of advanced constant volume joints in most areas and also preclude the use of the A7L-B suit.

(c) Suit-generated contamination should be minimized by system design.

(d) A suit sizing schedule should be used to minimize the necessity for custom-fitting and to permit interchanging of suit components.

(e) The recommended suit configuration consists of the following components:

1. Helmet - blower hemisphere
2. Neck Joint - not required
3. Torso-Limb Assembly - bi-layer soft suit
4. Shoulder Joint - stovepipe
5. Elbow Joint - all fabric
6. Glove - mini-convolute
7. Waist Joint - not required
8. Hip Joint - stovepipe
9. Knee Joint - all fabric
10. Ankle Joint - all fabric
11. Boots - bi-layer fabric
12. Closures - hard ring disconnects
13. Liquid Cooling Garment - existing Apollo EMU
14. Waste Management - existing Apollo EMU

(f) There is no significant cost differential between applicable suit concepts. The unit cost for the Shuttle suit should be relatively lower than the Apollo A7L-B suit. The final selection of a suit concept will be based on mobility and other requirements, not on a cost basis.

9.5 Emergency IV Suit

Based upon the results of the emergency IV evaluation described in Section 13.0, the need for an emergency IV suit was identified. The emergency IV suit must provide a lightweight, quick-donning mobile anthropomorphic enclosure with a controlled atmosphere to permit a crewman to perform useful functions within a vehicle enclosure under emergency conditions such as a depressurized cabin or a contaminated cabin. In order to define requirements for this configuration, it was necessary to survey present technology, identify state-of-the-art concepts and problems, and obtain data and other test and usage experience analogous to Shuttle emergency IV situations. Based on these efforts, and as a result of the emergency IV modes and requirements effort, the following emergency IV suit requirements were generated:

(a) Operating Pressure - 8.2 $\pm$ 0.2 psia

(b) Pressure Relief - 8.5 to 8.9 psid

(c) Leakage - 400 scc/min maximum

(d) Pressure Drop - 3.4" H_2O at 6 ACFM and 8.2 psia

(e) Donning Time - One (1) minute maximum

(f) Waste Management - Urine collection and transfer of up to 1000 cc is required. In addition, feces containment is also required.

(g) Comfort - The suit should provide reasonable comfort for periods of up to 96 hours which is the maximum duration required for a Shuttle rescue operation.

(h) Shelf Life - Four (4) years minimum

(i) Cyclic Life - 50,000 cycles per joint

(j) Weight - 19.0 pounds

(k) Stowage Volume - 2.0 cubic feet

The above listed performance requirements may be satisfied through use of the same technology or designs as used for the EVA suit. The weight and volume requirements may be satisfied through elimination of the thermal/meteoroid cover, use of soft

9.5 Emergency IV Suit - Continued

helmet, and by reducing the number of mobility joints. The arm and hand mobility should be equivalent to that of the EVA suit to allow the crewmen to perform flight related tasks for a mission abort. Therefore, some weight savings may be realized by reducing the range capability of the leg, knee and ankle joints.

Consideration should be given to design integration of the microphones and ear phones into the helmet. This approach may reduce weight and stowage volume, but more importantly can enhance suit donning time by elimination of procedures for communications carrier donning and an electrical connection to the suit wiring harness.

The sizing schedule for the emergency IV suit should not exceed that of the EVA suit.

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SECTION 10.0

RESTRAINTS

10.0 RESTRAINTS

Provision for adequate body and equipment restraint is one of several factors which can assure the success of an Extravehicular Activity (EVA) or Intravehicular Activity (IVA) mission. Pursuant with this importance this section presents specific body restraints (hand, torso and foot) and equipment restraints which may be utilized for the Shuttle orbiter/payload based upon present definition of EV/IV mission task requirements. Candidate restraint devices, taken from Gemini, Apollo, MOL, Skylab and various NASA-Contractor R&D programs, are considered in terms of the associated crew stations/tasks (planned, unscheduled and contingency) as a sole restraint and in various combinations with other devices.

The remainder of this section is presented in accordance with the outline in Table 10-1.

TOPIC	REFERENCE PARAGRAPH
BODY RESTRAINTS	10.1
EQUIPMENT RESTRAINTS	10.2

TABLE 10—1. RESTRAINT PROVISIONS OUTLINE

10.1 Body Restraints

Body restraint devices can be classified according to location, i.e., hand, torso or foot. Table 10-2 presents a listing of the various restraint devices considered under each classification. In addition, special restraint devices that are not classified by hand, torso or foot locations are also presented

10.1 Body Restraints - Continued

Handheld Restraint Devices (Reference Appendix E.1)
Handrails, permanent* Handrails, portable Handrails, permanent deployable Handholds, permanent* Handholds, portable (Velcro, pip-pins)* Handholds, permanent deployable Ladder and Handrail Combination+ Portable Handrail+ Linear Induction Mobile Handhold+ Rigid Rope+ Hand Model (Single-Pole) Electroadhesor+ Flexible (Single-pole) Electroadhesor+ Hand Model (Two-pole) Electrcadhesor+
Torso Restraint Devices (Reference Appendix E.2)
Pelvic Restraint+ Inflatable Mid-Torso Restraint+ Tigid Waist Tether+ Slide Assembly-Rigid Tether+ Belt-Waist Tether+ Flexible Waist Tether+ Leg-Rail Restraint+ Astronaut Boom Attachment System (Multi STEM)+ Positioning Tool (Maintenance Tether System)+ Serpentuator (Serpentine Actuator)+ NASA Shuttle Crew Seat (RFP definition, only)✦ USAF Dutch Chair (Flt. Test Support Equipment)+
Foot/Lower Leg Restraint Devices (Reference Appendix E.3)
Fixed Foot Restraint (Dutch Shoes).* Astrogrid Shoes Restraint+ Lower Leg Restraint+ Foot Restraint Platform+ Magnetic "Shuffler" Shoes+ Suction Shoes+ Zero Gravity Surface and Interlocking Structure+ Variable Foot Restraint (Skylab, Dutch Shoes)+
Special Restraint Devices (Reference Appendix E.4)
KUPU Latch+ Extendable Boom+ Restraint Buttons and Applicator+ Stud Bonding Tool+ Restraint/Translation Track+ Continuous "Clothesline" Restraint/Translation Device* Electromagnetic Restraint+

* Flight Qualified
\+ R&D concept and/or feasibility/development tested
✦ Concept only

TABLE 10-2. BODY RESTRAINT TYPES

Detailed descriptions and uses for each of the hand, torso, foot and special restraints listed in this table are presented in Appendix E.

10.1 Body Restraints - Continued

The purpose of this section is to investigate the applicability of these devices for Shuttle EVA restraint requirements. To achieve this objective, the candidate restraint devices are evaluated in terms of mission constraints, crew station applicability, and orbiter/payload task requirements in order to select the best restraints for the Shuttle. Table 10-3 presents a sample of the evaluation matrix which was applied to each of the candidate concepts.

As a result of this evaluation, handholds or handrails, the rigid waist tether, and a variable foot restraint are found to be the most generally applicable restraint devices. Other devices which may be used for specific "limited" locations are as follows; (1) the ladder handrail combination in the payload bay, so arranged that it could be used by ground crew members during payload installation and/or checkout; (2) the Pelvic Restraint and the "Dutch chair" for crew/work stations where long timelines involving continuing activities are programed; (3) Lower Leg Restraints for short duration tasks in place of the foot restraints, and; (4) the Special Restraints, to construct a temporary restraint mounting point for contingency and/or emergency modes.

During this evaluation special use (i.e., rigid rope, etc.) and/or limited application (i.e., serpentuator, etc.) devices were eliminated, as were those devices which required elaborate and/or unique support equipment (i.e., hand model electroadhesor and the magnetic restraints).

The selection between handholds, waist tethers and foot restraints is primarily dependent upon the nature of the work tasks. Analysis of Shuttle planned tasks, shows that combinations of the above restraints are required for most of the tasks and that several tasks can be accomplished by foot restraints alone. Figure 10-1 depicts the percentage of Shuttle planned tasks requiring a particular restraint or combination of restraints.

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10.1 Body Restraints - Continued

Restraint Device Evaluation Summary	Primary Mission Constraints									Primary Crewstation Applicability								Primary Task Applicability												Notes/Remarks:
Evaluation Criteria Crew Interface - Selected Restraint Concepts	Personnel Restraint	Planned Tasks	Unscheduled Tasks	Contingency Tasks	RAM, Sortie Can Interior	RAM, Sortie Can Exterior	Payload Bay Interior	Orbiter Exterior	Airlock	Instrument/Control Console	Hatch, Door, Access Panel	Work Bench	Don/Doff Station	Expendable Recharge	System/Subsystem Package	Equip/Payload Storage	Observation/Monitor Station	Deploy/Retrieve	Cargo/Equip/Payload Transfer	Align/Assemble/Mate	Maintain/Service	Operate/Monitor	Inspect/Diagnose	Remove/Replace	Repair/Recharge/Refurbish	Housekeeping	Satellite Deploy/Retrieve	Translation, Intra-Crewstation	Crewman Rescue	
Handheld Restraints (Ref. Appd. E.1)																														
- Handrail	X	X	X	X	X	X	X	-	X	X	X	X	X	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	1. Most effective device at crew/work station when used with waist and/or foot restraint.
- Handhold*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	2. Same as above.
- Ladder-Handrail Combination	X	X	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	3. Limited application because of structural mass and route limitations.
Torso Restraints (Ref. Appd. E.2)																														
- Pelvic Restraint	X	X	-	-	X	-	-	-	-	X	-	X	-	X	-	-	-	-	-	X	X	X	X	-	-	-	-	X	-	4. Limited to "permanent" continuous use crew/work stations.
- Rigid Waist Tether	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	5. Most effective device at crew/work station when used with hand and/or foot restraints.
- USAF "Dutch Chair" Variable	X	X	-	-	X	-	-	-	-	X	-	X	-	-	-	-	-	-	-	X	X	X	X	-	-	-	-	-	-	- Same as 4 above.
Foot Restraints (Ref. Appd. E.3)																														
- Variable Foot Restraint *	X	X	X	-	X	X	X	-	X	X	X	X	X	X	X	X	X	X	-	X	X	X	X	X	X	X	X	X	X	6. Most effective device at crew/work station when used with waist and/or hand restraints.
- Lower Leg Restraint	X	X	X	-	X	X	X	-	-	X	X	X	-	-	X	X	X	-	-	X	X	X	X	X	X	X	-	-	-	7. Effective device at crew/work station when used with waist and/or hand restraints.
Special Restraints (REf. Appd. E.4)																														
- KUPU Latches	X	X	X	X	X	X	X	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X	8. This device could be used effectively at crew/work station - where a pegboard panel is provided. In an emergency, holes could be made in structures not critical for re-entry.
- Restraint Buttons and Applicator	X	X	X	X	X	X	X	X	-	-	-	X	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	X	9. This device would be an excellent temporary personnel/equipment restraint for unscheduled and contingency modes. In an emergency, it could be applied to the exterior of the Orbiter, without affecting re-entry re-entry. *Best restraint combination for general EV task requirements.

TABLE 10—3. RESTRAINT CONCEPTS EVALUATION MATRIX

10.1 Body Restraints - Continued

From this graphical presentation it can be seen that all planned tasks require some sort of foot restraint with 16% requiring only foot restraints.

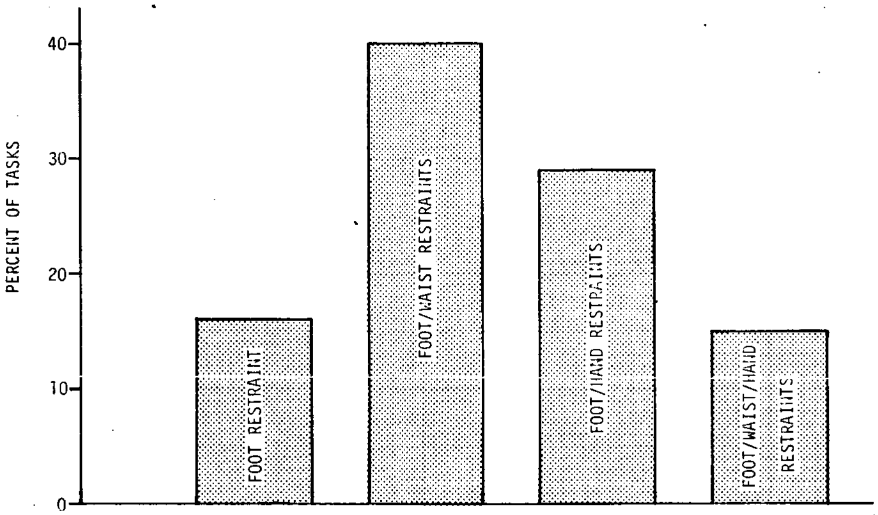

FIGURE 10—1. PLANNED TASKS AS A FUNCTION OF RESTRAINT CONCEPTS

Having established that handholds or handrails, the rigid waist tether and the variable foot restraint are the perfered restraint mechanisms offering a wide range of applications, the following sections are devoted to a description of these devices, and a presentation of their merits, deficiencies, and design requirements.

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10.1.1 Handholds/Handrails

Handholds and handrails can be either permanent or portable; and as shown in Figure 10-2, they can be either recessed or protruding.

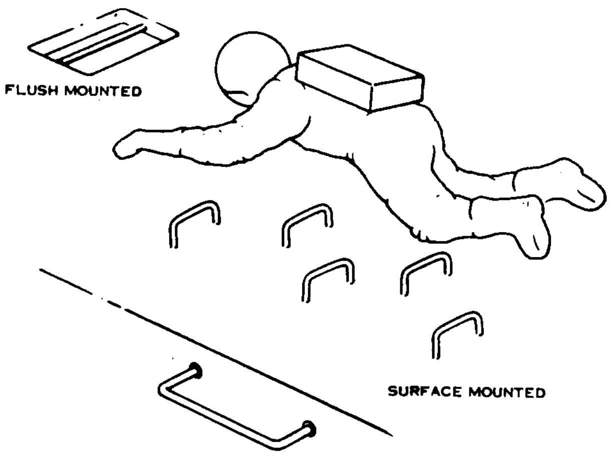


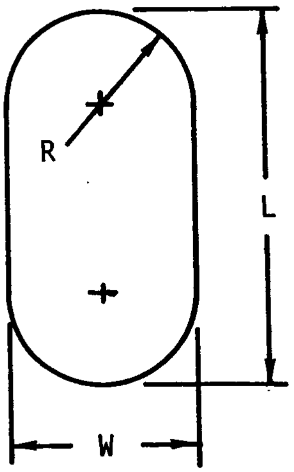
FIGURE 10—2. HANDRAILS AND HANDHOLDS

Both handholds and handrails have been qualified on the Gemini and Apollo Programs.

Specifications (from SC-E-0006 - Preliminary)

Size - Cross section shall be as shown in Figure 10-3.

Clearance - At least 2.25 inches above mounting surface for EVA.
At least 1.50 inches above mounting surface for IVA.



L/W RATIO = 1.66 TO 3.00
PREFERRED L/W = 2.00
R = 1/2 W
L(EVA's) = 1.22 TO 1.50 IN.
L(IVA'S) = .75 TO 1.50 IN.
LONGITUDINAL GRIP LENGTH 5.81"

FIGURE 10—3. SECTIONAL VIEW OF HANDHOLD

10.1.1 Handholds/Handrails (Continued)

Load Capability - 600 pounds in any direction for EVA
250 pounds in any direction for IVA

Advantages

- Requires no electrical power
- Light weight
- Durable
- Reliable
- Simple
- Maintenance Free
- Applicable at all levels of gravity
- Positive control
- Previously qualified

Disadvantages

- Requires use of one or both hands
- Difficult to manage large packages
- Structural interface with vehicle - should be incorporated in vehicle design

10.1.2 Rigid Waist Tether

The rigid waist tether, shown in Figure 10-4 consists of a telescoping, rigid tube affixed to the crewman's waist tether belt.

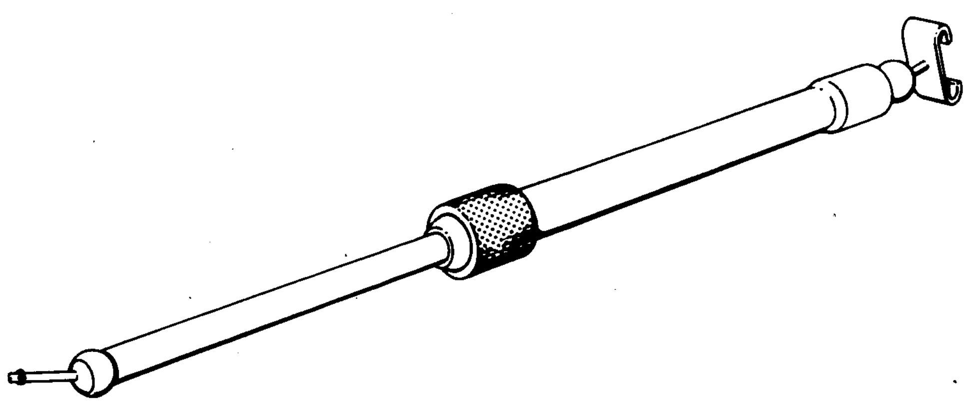


FIGURE 10—4. RIGID WAIST TETHER

As can be seen from this sketch, the rigid tube has a ball joint on a slide permitting the tether to swivel at the waist. Once extended to the desired length, a collet clamp is used to lock the position. This restraint can be used with swiveling pip-pins which can be locked into receptacles on the vehicle/payload surface.

10.1.2 Rigid Waist Tether (Continued)

Specifications

Although no explicit specification requirements have been published, the restraint(s) must be of sufficient length and have adequate adjustment capability to maintain the crewmen in the proper position relative to the worksite. Its load capability must be compatible with the crewman induced loads, which depend on the restraint length, crewman forces and torques, and on the amount of load taken by other restraints.

Advantages

Uses no electrical power
Broad applicability
Usable in all gravity levels
Simple
Light weight
Can be made portable

10.1.3 Variable Foot Restraints

The variable foot restraint consists of a toe section and a caming heel section as illustrated in Figure 10-5.

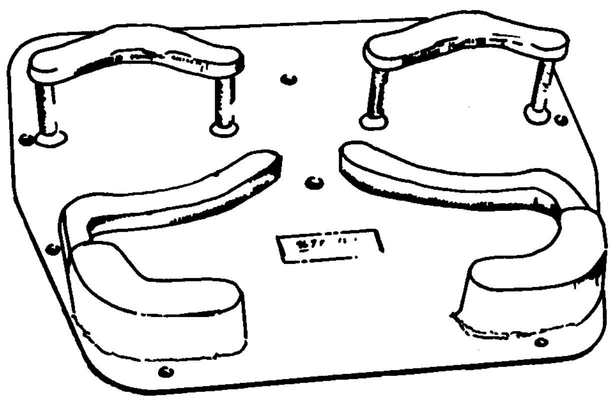


FIGURE 10–5. VARIABLE FOOT RESTRAINT

This device is utilized by inserting the toe in the forward section with the heel facing the open contour section of the heel restraint (foot at an angle). The foot is then rotated into the heel restraint which forces and retains the heel of the boot into a fixed position. Work forces are through the reaction points at the heel and toes.

10.1.3 Variable Foot Restraints - Continued

Specifications (from SC-E-0006 - Preliminary)

Spacing

Nominal center-to-center distance for EVA foot restraints shall be 10 to 17 inches. The actual dimension shall be determined from analysis of the tasks to be performed.

Load Capability

All foot restraints shall be designed to withstand the ultimate design loads of 140 pounds in tension and shear and 1,800 in-lbs torsion.

10.2 Equipment Restraints

Restraints must be provided to handle packages and equipment at the worksite when they are not in the EV astronaut's hands. Brown and Hayes (Reference) have identified the following requirements for equipment restraints/tethers:

- Tethering of equipment is not required when hard locks are provided or when transferring equipment from one locked location to another, if both hands are available. Tethering of equipment is required in all other conditions.
- Equipment tethering techniques to be considered include:
  - Wrist Tethers
  - Waist Tethers
  - Locks to fix equipment to structures
  - Telescoping tethers either attached to the crewman or to structures.

Table 10.4 lists body restraint concepts previously discussed which can also be used as temporary cargo-equipment restraint interfaces for the Shuttle. The handholds, handrails and ladder-handrail combination provide excellent restraint points for using short, flexible tethers (i.e., D-rings, clips and fabric) for all sizes and shapes of payloads. In addition, the latter two devices could incorporate the capability for a continuously engaged tether using a slot in the rail and an

10.2 Equipment Restraints - Continued

HANDHELD RESTRAINTS	HANDRAIL HANDHOLD
TORSO RESTRAINTS	LADDER - HANDRAIL COMBINATION ADJUSTABLE - RIGID WAIST RESTRAINT
SPECIAL RESTRAINTS	KUPU LATCHES RESTRAINT BUTTONS AND APPLICATOR EXTENDABLE BOOM

TABLE 10–4. BODY/EQUIPMENT RESTRAINTS

interface connector on tether. The adjustable rigid waist restraint may be used as a temporary restraint point to the crewman for small payloads (i.e., less than 100 pounds) during translation to and brief stops at crew/work stations. The special restraints may serve as cargo-equipment restraints in much the same manner and mission modes as they are used as personnel restraints.

SECTION 11.0

TRANSLATION AIDS

11.0 TRANSLATION AIDS

The successful accomplishment of Shuttle EV tasks is dependent on the ability of the astronaut to maneuver outside the spacecraft to various worksite locations. The requirement for an astronaut to move from place to place and to control his body orientation during the activity requires specific techniques primarily due to the absence of gravity. There are a variety of such techniques which an astronaut can utilize to accomplish this locomotion and they can basically be divided into the four categories of Table 11-1.

MANUAL
MANIPULATOR ASSISTED
MANIPULATOR ASSISTED/MANUAL
SELF-POWERED

TABLE 11—1. TRANSLATION CATEGORIES

Manual locomotion is accomplished by using only the astronaut's arms and legs to propel and orient himself. The Shuttle mainpulator can be utilized for translation by incorporating an astronaut carrying platform at the end. The manipulator assisted/manual mode involves utilization of the manipulator to the end of its range followed by manual devices for increased range. Powered systems span the gamut from simple unstabilized thrusting units to thrust platforms which provide facilities for tools, spare parts, telemetry and life support provisions for missions of extended range and duration.

Specific translation concepts evaluated for Shuttle EVA utilization are listed in Table 11-2.

MANUAL TRANSLATION HANDHOLDS HANDRAILS ASTROGRID SHOE MAGNETIC SHOE VELCRO SHOE SOARING
MANIPULATOR ASSISTED
MANIPULATOR ASSISTED/MANUAL
SELF-POWERED HAND HELD BACK MOUNTED PLATFORM

TABLE 11—2. TRANSLATION CONCEPTS

11.0 (Continued)

Selection of particular translation aids is dependent on vehicle interfaces, translational distances, and mass transport requirements. Section 4.0 presents a transfer mode analysis as to the applicability of each major transfer category. The results of this analysis are summarized in Figure 11-1, showing the utilization percentage of each transfer mode for both planned and unscheduled tasks.

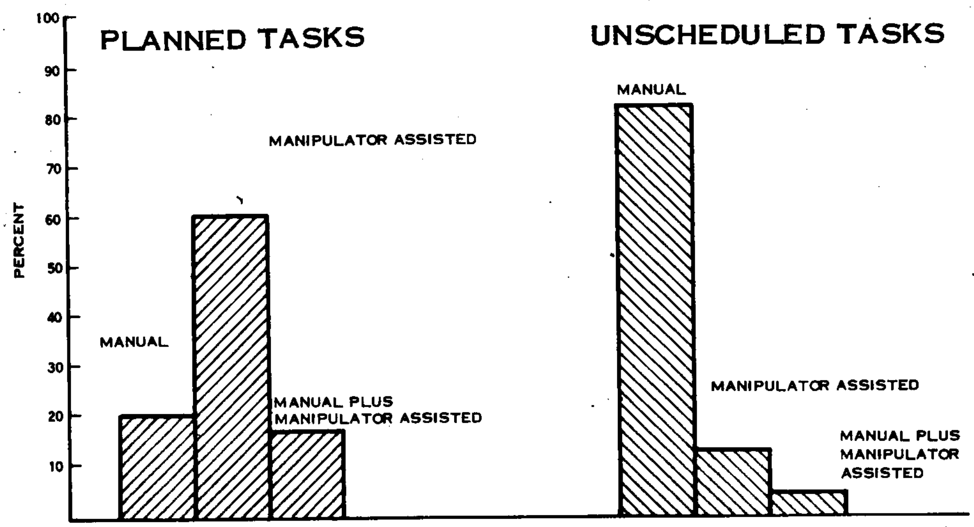


FIGURE 11-1. SELECTED TRANSFER MODES

The selection criteria listed in Table 11-3 was utilized in arriving at the above transfer mode utilization.

MANUAL MODE
EVA TASKS WITHIN CLOSED PAYLOAD BAY: EVA TASKS WITHIN OPEN PAYLOAD BAY IN WHICH CREWMAN TRANSPORTS LESS THAN 100 POUNDS OF MASS.
MANIPULATOR - ASSISTED MODE
EVA TASKS WITHIN OPEN PAYLOAD BAY IN WHICH CREWMAN TRANSPORTS MORE THAN 100 POUNDS OF MASS; EVA TASKS OUTSIDE PAYLOAD BAY BUT WITHIN THE MANIPULATOR REACH ENVELOPE.
MANUAL PLUS MANIPULATOR - ASSISTED MODE
EVA TASKS ON THE EXTERIOR OF THE ORBITER OR PAYLOAD AND BEYOND REACH OF THE MANIPULATOR.
SELF-POWERED MODE
TO BE USED IF THERE ARE NO OTHER ALTERNATIVES.

TABLE 11-3. TRANSFER MODE SELECTION

11.0 (Continued)

As can be seen from this analysis, all planned and unscheduled translational tasks are scoped for either manual or manipulator transfer modes; self-powered devices are not required. However, certain contingency tasks, namely astronaut rescue from a disabled Shuttle, might require powered translation and thus such a mode must be considered for this requirement.

The following sections present details of the various manual, manipulator and powered translation aids as well as pertinent considerations regarding each concept.

11.1 Manual Translation

Results from both the Gemini and Apollo programs as well as from zero-g aircraft testing have indicated that manual translation techniques are effective for astronaut maneuvering around spacecraft surfaces. Concepts studies in the manual locomotion category are presented in Table 11-4.

HANDHOLDS
HANDRAILS
ASTROGRID SHOES
MAGNETIC SHOES
VELCRO SHOES
SOARING

TABLE 11-4. MANUAL TRANSLATION CONCEPTS

Based on an initial evaluation (reference Appendix F), handholds and handrails were selected for the Shuttle EVA manual translation requirements. This selection was made primarily because of the advantages associated with these concepts as listed in Table 11-5.

These advantages are offset somewhat by the disadvantages associated with handholds and handrails and listed in Table 11-6.

11.1 Manual Translation - Continued

REQUIRES NO ELECTRICAL POWER
LIGHT WEIGHT
SIMPLE
FLIGHT QUALIFIED
DURABLE
RELIABLE
READILY MADE TETHER ATTACH POINTS
MAINTENANCE FREE
APPLICABLE AT ALL LEVELS OF GRAVITY
POSITIVE CONTROL

TABLE 11–5. MANUAL TRANSLATION ADVANTAGES

REQUIRES USE OF ONE OR BOTH HANDS
DIFFICULT TO MANAGE LARGE PACKAGES
TIRING - ESPECIALLY TO WRISTS
STRUCTURAL INTERFACE WITH VEHICLE - SHOULD BE INCORPORATED IN VEHICLE DESIGN
LIMITED TO VEHICLE SURFACE TRANSLATION

TABLE 11–6. MANUAL TRANSLATION DISADVANTAGES

11.1 (Continued)

As shown in Figure 11-2, handholds and handrails can be either recessed or protruding from the surface.

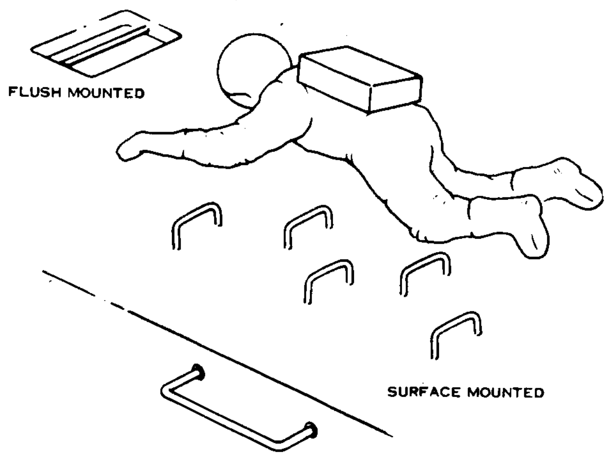


FIGURE 11–2. HANDRAILS AND HANDHOLDS

For mobility, the recessed type have an advantage in that they do not present "elbow knockers". However, the protruding type offer better restraint.

Handholds can be portable or permanent depending on application and vehicle interface requirements. Portable devices offer an advantage over permanent installations in that they are only attached during translations and, therefore, do not cause potential aerodynamic and heating problems during the entire mission. They also avoid "cluttering-up" the vehicle surface with permanent protrusions. Inherently, however, portable devices have a disadvantage in that they must be carried by the astronaut over the course of his translation and result in slower transfers. Selection between permanent or protruding devices is, therefore, a trade-off between the vehicle interface and ease of translation. Frequently traveled routes are probably most amenable to permanent type devices, whereas seldom used paths can sacrifice translation ease for the vehicle interface gains offered by the portable devices.

In addition to handholds and handrails, soaring must also be considered as a possible manual translation technique for Shuttle EVA's. The applicability of such a technique for contingency astronaut rescue operations is the main advantage of this translation mode.

11.2 Manipulator-Assisted

Inclusion of an astronaut carrying platform on the end of the Shuttle attached manipulator as shown in Figure 11-3, is a viable

11.2 (Continued)

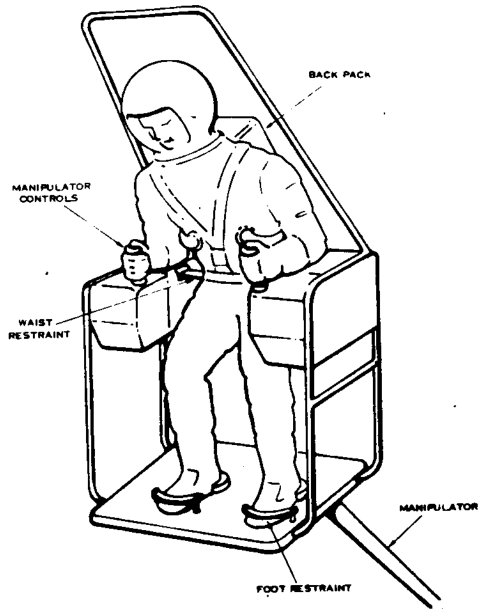


FIGURE 11–3. MANIPULATOR ASSISTED TRANSLATION

astronaut translation device. The platform could be considered another end effector for the manipulator just like any other special end effector for specific applications. It could be removed or added as necessary.

This manipulator approach affords the capability of translations over a radius of 30-60 feet (length of manipulator) either along the vehicle surface or away from the vehicle. This ability to maneuver the astronaut away from the vehicle surface presents a significant advantage over manual aids which are limited to vehicle surface locomotion only. Another advantage that manipulator translation has over manual translation lies in the fact that it does not interface with the vehicle surface. Such a concept precludes the need for cluttering the vehicle surface with handholds and handrails within the range of the manipulator.

Incorporation of worksite provisions (lights, tools, work restraints, etc.) on the carrying platform as well as grapplers to secure this platform to the worksite converts it into a portable work base as shown in Figure 11-4. This approach precludes the necessity of providing separate work provisions at each expected worksite. Rather, a single work base can serve all expected worksites within its range.

Dual controls (one at the platform, one at the Shuttle control station) would be required for manipulator assisted translation with the preferred mode being at the platform. This gives the EVA astronaut control over his own translation and provides for a better view of the translation path and ultimate target. Control from the Shuttle would serve as a back-up and emergency provision for return of an incapacitated crewman.

Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORPORATION

11.2 (Continued)

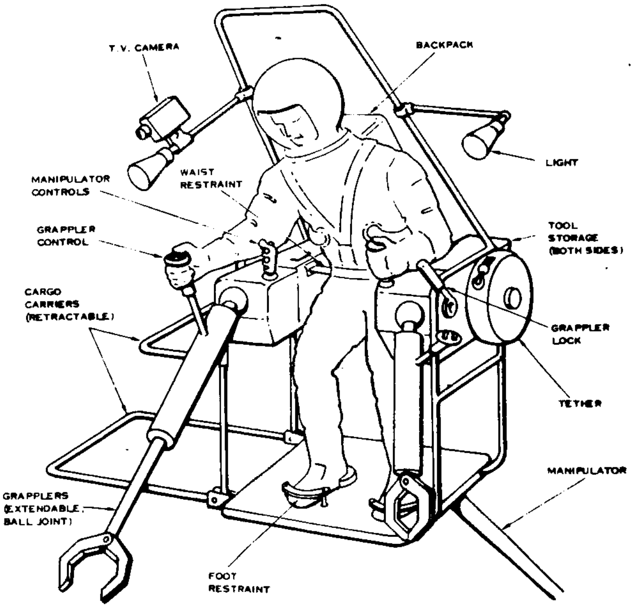


FIGURE 11—4. MANIPULATOR ASSISTED TRANSLATION/WORKSITE

The most significant problem to date concerning the manipulator is the arm dynamics associated with handling large masses. The manipulator boom undergoes large amplitude, low frequency vibrations when trying to stop translations. This results from the payload momentum coupled with the relatively flimsy manipulator boom and presents a potential hazard to an astronaut utilizing the manipulator as a translation aid. Manipulator boom dynamics with an attached platform, crewman and equipment should be analyzed for assessment of this potential hazard.

Pertinent advantages and disadvantages associated with manipulator assisted translation are listed in Table 11-7.

ADVANTAGES	DISADVANTAGES
PROVIDE FOR TRANSLATIONS AWAY FROM VEHICLE SURFACE	ARM DYNAMICS PROBLEMS
DOES NOT REQUIRE SIGNIFICANT VEHICLE INTERFACE	COMPLICATES MANIPULATOR CONTROL DESIGN
RELATIVELY LITTLE ENERGY EXPENDITURE DURING TRANSLATION	LIMITED RANGE (30 - 60 FEET)
COULD PROVIDE WORK BASE	
REDUCES NUMBER OF PREPARED WORKSITES	
COULD HANDLE SOME MANIPULATOR TASKS WITH ON-SITE VIEWING	
PROVIDES PLATFORM FOR CARRYING CARGO	
EXCELLENT FOR GENERAL VEHICLE INSPECTION TASKS	
DOES NOT REQUIRE TETHER	

TABLE 11—7. MANIPULATOR ASSISTED TRANSLATION

11.3 Manipulator Assisted/Manual

Manipulator assisted/manual translation consists of utilizing the manipulator for translation to the end of its range followed by manual translation beyond the range of the manipulator. Such a concept possesses the manipulator's translation advantages over the manual technique (reference Section 11-2) and at the same time is not limited by manipulator's range.

The manual translation technique selected following the manipulator translation is again handholds and handrails. The reason for their selection has previously been presented in Section 11.1.

11.4 Self-Powered Devices

Self-powered maneuvering devices offer a more extensive translation range than the manual and manipulator mechanisms discussed previously. They are not limited to the vehicle surface such as manual aids nor are they dependent on the reach envelope of the manipulator. As such, their applicability lies mainly in the maneuvers away from the vehicle and to vehicle surface areas where it is impractical to locate manual devices due either to the length of travel or limited translation occurrences along a path. Three basic powered maneuvering systems, listed in Table 11-8, have been investigated as translation aids for the Shuttle EV missions in the event a specific need was defined.

HAND HELD
BACK MOUNTED
PLATFORM

TABLE 11—8. POWERED MANEUVERING SYSTEMS

Based on an initial evaluation, Appendix F , a back-mounted device was selected as the best approach for Shuttle EVA's as determined by performance requirements and a task analysis. This selection is essentially predicated on the fact that a back-mounted unit affords better stability and control than a handheld device and is more compatible with the task requirements than a self powered platform.

Stability and control problems associated with the (HHMU) Hand Held Maneuvering Unit stem primarily from the fact that the forces from the thrusters are directed by hand motions and are thus not always through the c.g. of the astronaut.

11.4 (Continued)

Thus, unwanted rotations, pitches and yaws are continually experienced and they require a considerable effort and expenditure of fuel to stabilize. The fixed thruster location on a back-mounted unit assures thrusts through the c.g. by designing for such.

The powered platform provides an excellent means of astronaut translation and a Manned Work Platform (MWP) is scheduled for a flight experiment in 1981. An artists concept of the MWP is shown in Figure 11-5.

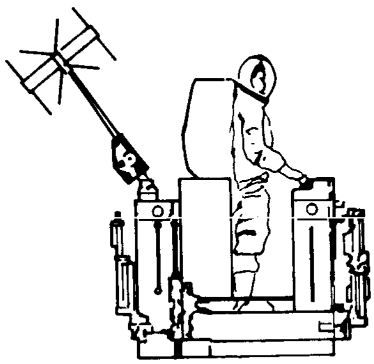


FIGURE 11–5. MANNED WORK PLATFORM

Selection of such a concept for the contingency rescue task is impractical as it is too heavy and expensive and more amenable to long-range translation. The relative simplicity and low cost of a back-mounted unit coupled with the limited contingency task range requirement (about 500 lb-sec total impulse) makes the back-mounted unit more attractive than the powered platform.

Appendix F presents preliminary design considerations for a back-mounted propulsion unit. In general, the Shuttle requirements can be satisfied by a 6 Degree of Freedom (DOF) system with automatic attitude hold and proportional rate command capable of about 500 lb-sec total impulse. In this range, a cold gas propulsion system affords the simplest approach although it is somewhat heavier (lower specific impulse) than a hydrazine system. The cold gas advantages in donning, doffing, checking, servicing and storing the unit inside the Shuttle cabin or airlock make up for the low specific impulse of the cold gas.

Advantages and disadvantages associated with the utilization of a back-mounted propulsion system are presented in Table 11-9.

11.4 (Continued)

ADVANTAGES	DISADVANTAGES
STABLE	MOUNTED ON BODY
RELATIVELY EASY TO OPERATE	RANGE LIMITED TO ABOUT 500 FEET
RELATIVELY LIGHT	TIES UP HANDS IF THEY ARE USED FOR CONTROL OPERATION
MINIMAL VEHICLE INTERFACE	SOMEWHAT DIFFICULT TO DON

TABLE 11-9. BACK MOUNTED PROPULSION SYSTEM

11.5 Conclusions

Four basic translation aids have been presented: manual, manipulator-assisted, manipulator-assisted/manual, and self-powered. As can be seen from this presentation, each concept has applicability for the Shuttle EVA task performance.

Manual devices, the best candidates being handholds and handrails, are best suited for short, often-used translations with limited cargo carrying requirements. These devices are attractive because they are simple, reliable and do not require maintenance. However, their employment must be selective to aboid "cluttering up" the vehicle surface. The fact that the vehicle structure must support these devices also limits their use to locations where such support is available.

The manipulator-assisted concept utilizing an astronaut carrying platform at the end of the manipulator provides an excellent locomotion device capable of covering all points within the range of the manipulator boom. The addition of worksite provisions to this platform converts it into a portable work station and eliminates the need for manual vehicle mounted devices over its coverage area and allows for translations away from the vehicle surface--not available with manual devices.

The manipulator-assisted/manual concept provides all the advantages of the manipulator-assisted system and adds handrails to extend the range beyond the point of maximum travel of the manipulator.

Self-powered maneuvering devices offer the widest range of locomotion of all those studied. Their inherent maintenance requirements and the

11.5 (Continued)

fact that they are less reliable than the other concepts limits their usage application to areas where the other devices cannot reach or where the length of reach is impractical for manual aids. The significant advantage over and above range capabilities lies in the fact that vehicle interfacing requirements are minimal.

SECTION 12.0

WORKSITE PROVISIONS

12.0 WORKSITE PROVISIONS

A worksite is defined as any location where special EVA work tasks must be performed. Two general classes of worksites are applicable to the Shuttle: unprepared and prepared. Unprepared sites refer to the location where a crewman terminates transfer activities to perform an EVA task. The location of the unprepared worksite may or may not be predetermined; if not, it is selected by the crewman during the EVA. A prepared worksite constitutes one in which location and operations are established during the Shuttle/payload design phase.

The types of provisions required to perform worksite operations are listed in Table 12-1. Detailed selection of particular provisions is dependent upon the task definition and analysis. Once the task has been defined and the limiting constraints and guidelines have been identified, a selection of specific hardware systems and procedural options can be integrated to provide adequate worksite provisions. The following sections present criteria involved in the selection of controls and displays, lighting, tools and restraints for Shuttle worksites, and presents a work platform concept.

CONTROLS AND DISPLAYS
LIGHTING
TOOLS
RESTRAINTS

TABLE 12-1. WORKSITE PROVISIONS

12.1 Controls and Displays

Controls and displays are required at EV worksites to monitor and operate various systems and equipment as required for particular tasks. The selection of controls and displays is dependent on the specific tasks to be accomplished at each worksite and the designation of particular controls and displays is not possible at this juncture. Instead, general underlying considerations regarding controls and displays are presented.

12.1 Controls and Displays - Continued

The ability of the astronaut to see a display and operate a control is the most critical requirement irrespective of the different controls and displays required at each site. Once the specific control and display requirements have been specified, a detailed equipment layout is required to determine location and orientation, size, type, illumination and labeling. Considerations involved in these determinations are: type of site, astronaut orientation, operating characteristics, relation of controls to displays and astronaut mobility. Table 12-2 lists these considerations and presents detailed options regarding each.

CONSIDERATIONS	OPTIONS
TYPE OF SITE	UNCONFINED SEMI-CONFINED CONFINED LIMBS WHOLE BODY (CLEARANCES, PROTRUSIONS)
ASTRONAUT ORIENTATION	BODY AXIS PARALLEL TO MAIN AXIS OF SITE BODY AXIS PERPENDICULAR TO MAIN AXIS OF SITE BODY AXIS OFFSET FROM MAIN AXIS OF SITE
OPERATING CHARACTERISTICS	TYPE OF OPERATION BUTTON ROTATING HANDLE FLIP HANDLE ASTRONAUT ACTIVATOR FOOT HAND LENGTH OF TIME CONTINUOUS/ON-OFF
RELATION OF CONTROLS TO DISPLAYS	CONTROL TO A DISPLAY READING NO RELATION
ASTRONAUT MOBILITY	MOTIONS REQUIRED IN WORKSITE WHOLE BODY ROTATION TRANSLATION LATERAL FRONT-BACK UP-DOWN TWISTING LIMBS DIRECTION OF MOTION RANGE OF MOTION EXTENT OF MOTION FREQUENCY OF MOTIONS

TABLE 12–2. WORKSITE CONSIDERATIONS

12.2 Lighting

During the course of a single orbit, the Space Shuttle EV worksites will be subjected to natural illumination of varied brightness and intensity depending upon their location relative to the sun, earth and moon. Figure 12-1 presents various natural illumination environments that might be encountered at an EV worksite.

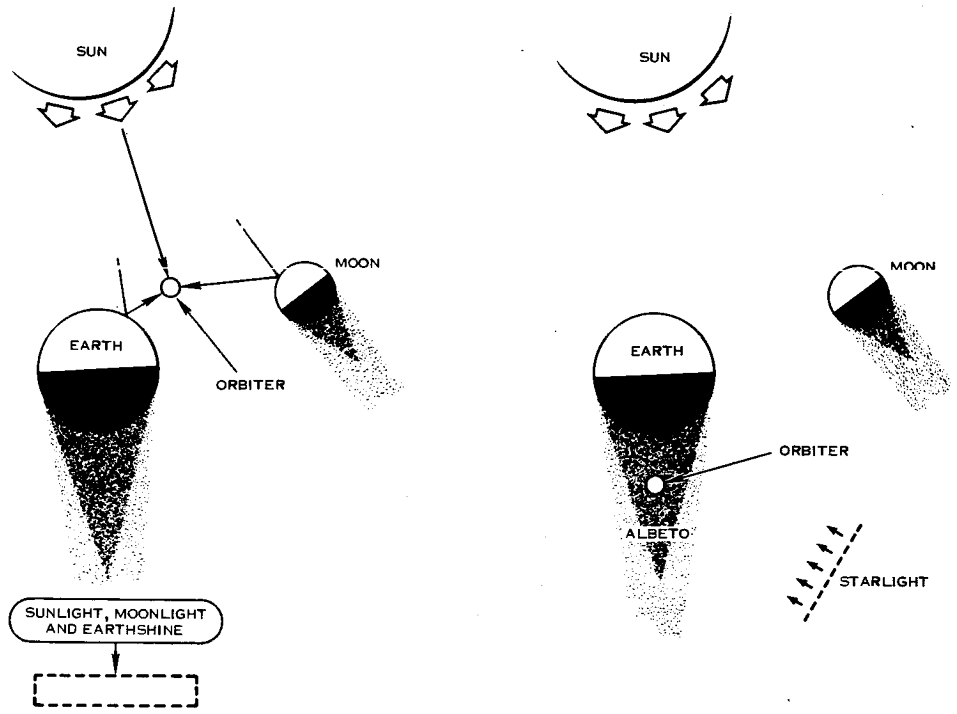


FIGURE 12-1. VARIED NATURAL ILLUMINATION

Approximately three-quarters of the Shuttle orbit is illuminated by the sun and light side of the earth and moon, either singularly or in various combinations. Albedo provides some illumination during the remaining one-quarter orbit. The illumination in orbit can thus vary from bright direct sunlight to almost total darkness (with just albedo).

12.2 Lighting (Continued)

In addition, the relative position of the worksite to the Orbiter is also significant as for as natural illumination is concerned. Figure 12-2 shows that the Orbiter can either block light from the sun, earth and moon causing shadows of extreme constrast, or reflect this light to the worksite.

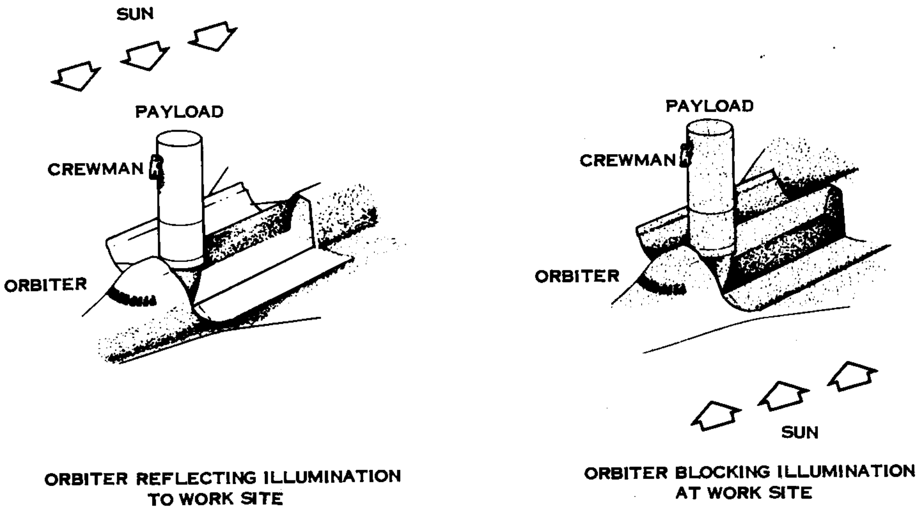


FIGURE 12–2. EFFECT OF SHUTTLE ON WORKSITE ILLUMINATION

The effect of this varied natural lighting presents a significant problem for the EV crewman. Visors must be worn to protect the eye when working in sunlight, and artificial lighting must be considered for both night operation illumination in shadowed areas. The following paragraphs are devoted to worksite artificial lighting requirements in regards to types, number, location, illumination, controls and adjustments.

12.2.1 Lighting Types

Types of lighting fall into two broad classes: permanent lighting at the worksite and portable lighting carried to the worksite by the EV astronaut. This portable lighting can be mounted to the astronaut (wrist, helmet, chest), mounted to the worksite upon astronaut arrival, or hand held. The advantages and disadvantages of permanent and portable lighting as well as the relative merits of different types of portable lighting are presented in Table 12-3.

PERMANENTLY MOUNTED LIGHTING	
ADVANTAGES	DISADVANTAGES
NOT CARRIED BY EV ASTRONAUT TO EACH WORKSITE ACTIVITY	ONLY USABLE AT ONE WORK STATION VEHICLE INTERFACING SINGLE BASE SYSTEM AVAILABLE SHOULD HAVE REMOTE TURN OFF IF INADVERTANTLY LEFT ON
PORTABLE LIGHTING (WORKSITE MOUNTED)	
ADVANTAGES	DISADVANTAGES
CAN BE FIXED IN PLACE MINIMAL VEHICLE INTERFACE ELIMINATES NEED FOR MANY PERMANENT LIGHTS	MUST BE TRANSPORTED FROM WORKSITE TO WORKSITE POSSIBILITY OF DAMAGE DURING TRANSLATION FIXED BASE LOCATION
PORTABLE LIGHTING (BODY MOUNTED)	
ADVANTAGES	DISADVANTAGES
NO VEHICLE INTERFACE MOVABLE BASE BY BODY MOVEMENT ELIMINATES NEED FOR MANY PERMANENT LIGHTS	MUST BE TRANSPORTED FROM WORKSITE TO WORKSITE POSSIBILITY OF DAMAGE DURING TRANSLATION INTERFERENCE DURING WORK IS POSSIBLE MOVEMENT OCCURS FROM NORMAL WORKING MOTION
PORTABLE LIGHTING (HAND HELD)	
ADVANTAGES	DISADVANTAGES
NO VEHICLE INTERFACE MOVABLE BASE BY HAND MOVEMENT ELIMINATES NEED FOR MANY PERMANENT LIGHTS	TIES UP ONE HAND - POSSIBLY UNACCEPTABLE AT SOME WORKSITES POSSIBILITY OF DAMAGE DURING TRANSLATION MUST BE HELD STEADY

TABLE 12–3. LIGHTING CONCEPTS—ADVANTAGES AND DISADVANTAGES

12.2.1 Lighting Types - Continued

The selection between portable and permanent lighting is primarily dependent on the tasks associated with each worksite. Those worksites which are frequently utilized should probably be equipped with permanent lighting to preclude the necessity of constantly carrying lighting provisions to them. Portable lighting is most advantageous for limited usage sites with the particular selection of a portable device primarily dependent on task requirements. Long duration occupancies as well as those worksites requiring fixed (motion free) illumination are probably best suited to site mounted lighting. Short duration sites and sites requiring mobile bases are best suited for body or hand held lighting provisions.

12.2.2 Number of Lights

The number of lights required is dependent on the worksite and must take into account the physical design, tasks and natural lighting available.

12.2.3 Location of Lights and Field of View

This parameter is again primarily dependent on the physical characteristics of the worksite, the tasks to be performed and the natural lighting available. In addition, however, the placement of lights must be selected so as to preclude shining in the astronaut's eyes (both direct and reflected), and the astronaut's location and orientation is critical in achieving this requirement.

12.2.4 Illumination

From the NASA Manned Spacecraft Center general specification (SC-L-0002) regarding spacecraft lighting requirements, the EV worksite lighting luminescense requirements are as listed in Table 12-4.

12.2.4 Illumination - Continued

LIGHT SHALL BE INCANDESCENT OR ANY OTHER TYPE LAMP MEETING ILLUMINATION REQUIREMENTS
LUMINOUS INTENSITY (CANDLE POWER) SHALL BE SUFFICIENT TO ILLUMINATE THE SURFACE OF THE VEHICLE FOR THE CREW TO PERFORM THEIR TASK
BRIGHTNESS OF THE TRANSFER ROUTES SHALL BE GREATER THAN 1 FOOT LAMBERT
BRIGHTNESS OF WORK STATIONS SHALL BE 5 FEET LAMBERT OR GREATER

TABLE 12–4. ILLUMINATION REQUIREMENTS

12.2.5 Controls

Lighting controls for on-off operation, intensity selection and positioning should be readily accessible, operable by a suited astronaut and adequately labeled. In addition, positioning control should bear a resemblance to the positioning motion of the light.

12.2.6 Adjustments

Significant utilization of a minimal number of lights can be achieved by providing adjustment capabilities to vary direction, brightness, field of view and location. Final worksite design is required to determine the range and types of adjustment necessary for lighting provisions. Worksites which are large and in which only one particular area is utilized at a time, are amenable to adjustable lights to limit the number required. Also, certain tasks and natural lighting effects which require variance in brightness lend themselves to the utilization of adjustable intensity lighting.

12.3 Tools

Tools are required to perform certain tasks at Shuttle worksites. This section is concerned with the general requirements associated with both the tooling itself and the equipment interfacing this tooling. The primary goal regarding tooling interfaces is to design replaceable or maintainable spacecraft equipment which is easily accessible and only requires simple, standardized, commercially available tooling. This philosophy minimizes both the cost and the number of different tools required and maximizes working effectiveness.

The following sections summarize the constraints involved in tooling provisions (worksite, environmental and astronaut) followed by a presentation of tools previously developed for space applications.

12.3.1 Worksite Constraints

The most significant worksite constraints concern the room available and the restraints necessary to use the required tools. Care must be taken to layout the worksite so as to provide access to equipment requiring replacement or maintenance. Tooling required must then be both commensurate with this access provided and compatible with the worksite restraint provisions. Table 12-5 presents a summary of the restraint categories and the type of working motions most suitable to each for the selection of the tools and forces required for operation. A pertinent consideration in tool/restraint selection lies in the fact that the use of hand restraints ties up at least one hand and thus tools requiring the use of two hands are unacceptable when only hand restraints are provided.

CATEGORY	BEST WORKING MOTIONS
HAND RESTRAINT	LEFT - RIGHT
TORSO RESTRAINT	PUSH - PULL
FOOT RESTRAINT	UP - DOWN

TABLE 12–5. WORKSITE RESTRAINTS

12.3.2 Environmental Constraints

The vacuum, temperature and gravity of EV working operations must be considered in the design of tools for space maintenance. The vacuum environment creates problems with lubrication of moving parts and cold welding of cutting edges to the material being worked. In addition, it contributes to the temperature problem because of the absence of a conductive fluid for cooling. The temperatures of the equipment being worked on also pose problems of heat flow which affects the design of tools and accessories. In addition, the zero gravity environment radically changes the force and positional relationships of the maintenance worker, the worksite and the tools.

12.3.3 Astronaut Mobility Constraints

The effect of a pressurized suit on the astronaut's reach, visibility, force and dexterity must be considered in designing worksite tools. Studies involving dexterity, especially pertaining to gloved work with small parts, indicates potential handling problems. The visibility problems resulting from both shadows and bright sunlight were considered in the preceding section and should be kept in mind when designing tools. Finally, limited force applications available due to suit constraints as well as astronaut restraint limitations must be considered in tooling designs requiring significant forces to operate.

12.3.4 Tools Developed for EVA/IVA Applications

Various tools have been developed for space applications and it is anticipated that most of the Shuttle space tools requirements will be similar. An overview of the current tool development technology reveals that the classifications listed in Table 12-6 encompass all tools that might be utilized on Shuttle EVA/IVA missions.

12.3.4 Tools Developed for EVA/IVA Applications (Continued)

BONDING AND ELECTROADHESOR TOOLS
CUTTING TOOLS
HAMMERS
GAS LEAK, PRESSURE DETECTION AND MEASUREMENT TOOLS
ELECTRICAL AND ELECTRONIC MAINTENANCE TOOLS
TOOL KITS AND SETS
SCREWDRIVING AND TORQUING TOOLS
TUBE CONNECTION TOOLS
WELDERS

TABLE 12-6. EVA/IVA TOOLS

12.4 Restraints

Restraint provisions for both the EV astronaut and his equipment are necessary for task performance at EV work-sites. Body restraints are generally classified according to personal attachment points (hand, foot, torso) with the selection of a particular restraint dependent upon work-site interfaces and task requirements. Section 10.0 (Restraints) presents a summary of body restraints that have previously been either qualified or investigated for space usage. Also included in this summary are advantages and disadvantages associated with each concept.

Section 10.0 (Restraints) also presents equipment tethering restraint devices; most of which are the same as body restraint concepts.

12.5 Work Platform Concept

12.5.1 General

For the astronaut engaged in extravehicular activity (EVA) from an orbiting spacecraft, there are many advantages to working from a stable, maneuverable platform rather than being free floating and relying upon vehicle protuberances for restraints and handholds. Results of the EVA/IVA task identification and analysis effort indicated that a work platform located at the end of the manipulator boom is a viable candidate to provide crewman translation and to permit the EVA crewman to service, maintain or repair payloads and to assist in the conduct of experiments.

Trade-off studies were performed on various concepts for the following major areas of work platform design:

a. The interfaces between the work platform and the manipulator boom.

b. The interfaces between the work platform and the worksite.

c. The interfaces between the work platform of the crewman.

The following guidelines were used as the basis for the study of platform concepts:

a. Platform shall interface with the boom defined by MSC Internal note 72-EW-3.

b. The platform shall not be required to dock with a free flying payload.

c. The work platform shall provide for camera, TV, lighting, mechanical and electrical tool stowage and use, payload servicing equipment stowage and use; crewman restraint to the platform, platform docking and restraint to the payload work site and controls which will enable the crewman on the platform to control the movement of the platform.

d. The work platform shall not restrict manipulator movement.

12.5 Work Platform Concept (Continued)

e. Platform design shall permit the EVA crewman to board or leave the platform at any time it is in any stationary operational mode.

f. Communications are provided by the EVA life support system.

g. All mechanical and electrical interfaces between the platform and the boom are assumed to be accomplished with one multiple function connector.

h. Docking and platform restraint system shall not require electrical power.

i. Platform crewman restraints shall not interfere with the crewman life support system.

j. The platform shall be of both minimum weight and volume in both usage and stowage modes.

k. The maximum torque to be exerted by the crewman on any connection or disconnection at the work site is 20 foot-pounds.

l. Two manipulator control levers are necessary to achieve control of the number of degrees of freedom.

12.5 Work Platform Concept (Continued)

An artist sketch of the complete work platform installed on the Shuttle attached manipulator system is shown in Figure 12-3. The work platform consists of three major areas; the basic structure, the control console and the docking system.

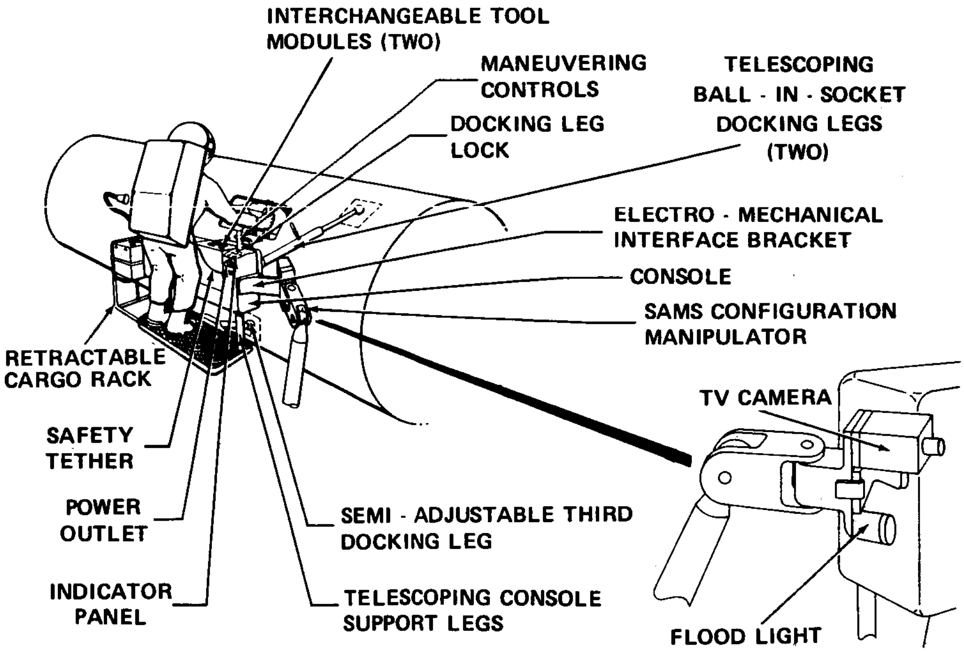


FIGURE 12—3. WORK PLATFORM CONCEPT

12.5.2 Work Platform Structure

The basic work platform structure consists of the following:

a. Floor - The floor is fabricated from perforated plate to minimize weight. The floor would be designed to support the extravehicular crewman and the cargo stowage system. The total size of the floor is approximately 48 inches by 18 inches. This size provides for two distinct work stations

12.5.2 Work Platform Structure (Continued)

a. and thus permits the crewman a greater work range without moving the platform than would be possible if the floor were sized for a single standing position.

b. Foot Restraints - The foot restraints are permanently attached to the floor. Two pairs of restraints are provided, one for each platform work position.

c. Support Legs - Since the interconnection between the work platform and the manipulator is at the console, the two tubular support legs attach the floor and cargo stowage system to the console. The supports are telescoping to yield a reduction in stowed volume of the assembled work platform. In addition, the interconnection between the floor and the supports is a locking swivel joint, which permits folding to give an even greater reduction in stowed volume.

d. Cargo Stowage System - The cargo rack is located on the opposite end of the work platform from the manipulator interface. Being located at the crewman's left will present no handling problems and should help to prevent any accidental bumping of the various controls during cargo transfer. In the retracted position, the base of the cargo rack fits under the platform floor and the outboard upright fits flush against the left side of the platform.

e. Manipulator/Platform Interface - The interface between the work platform and the manipulator consists of both a mechanical and an electrical connection. The mechanical locking system must secure the platform to the manipulator, must be easily actuated by the crewman for assembling and disassembling the platform to the manipulator and must withstand an imposed force of at least 30 pounds applied in any direction. The electrical interconnection will require approximately 150 pins to handle all of the necessary maneuvering controls and the power supply for the lighting system and power tolls. A side mount concept was selected for the work platform to manipulator interface, primarily because it represents the more readily accessible system and can more readily use the manipulator's flood-lighting and television camera.

12.5.3 Control Console

The work platform control console, shown in more detail in Figure 12-4, consists of a structural metallic box which acts as the primary load carrying structure of the work platform. Mounted on the console are the following:

a. Maneuvering Control - The controls for maneuvering the manipulator are of the "joystick" type and are within comfortable reach and peripheral vision and are also completely clear of the work area.

b. Indicator Panel - The indicator panel is located at the top right end of the console and consists of switches for power to the flood and spot lights and the manipulator and indicator lights to show if power to these systems is on or off. In addition, there would be an indicator to verify that the interconnection between the manipulator and the work platform had been made securely.

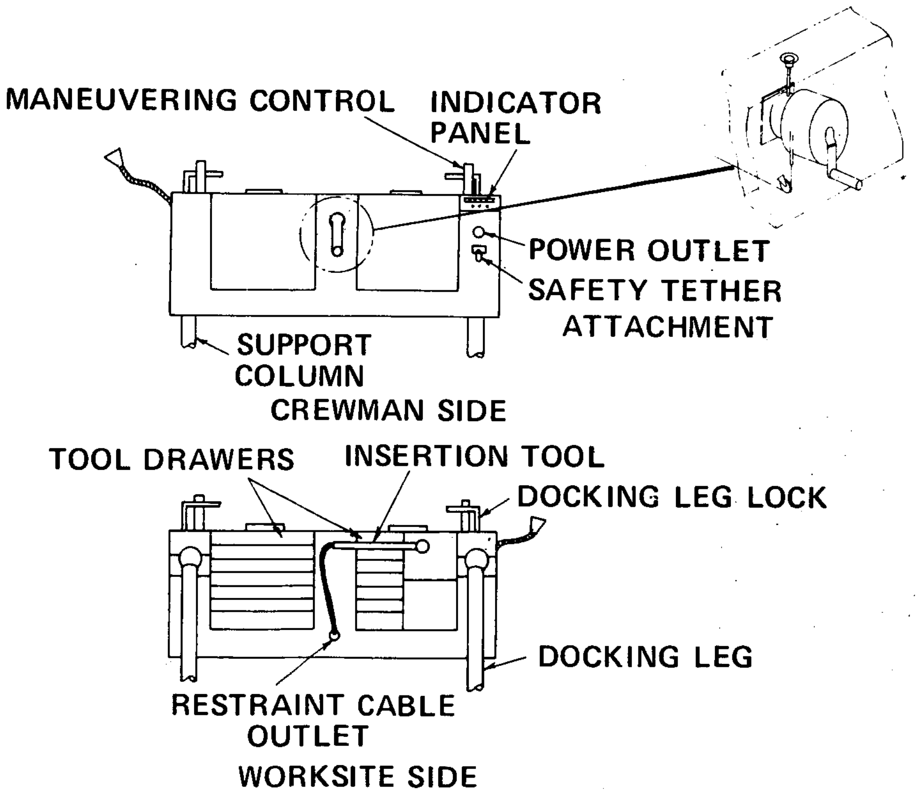


FIGURE 12-4. CONTROL CONSOLE

12.5.3 Control Console (Continued)

c. Power Outlet - The outlet for supplying electricity to power operated tools is located on the right side immediately below the indicator panel. This location is in accordance with the clustering of controls on the right for crewman convenience and for simplicity of wire routing. The outlet and the mating tool connector would be of the quick disconnect type and designed for one-handed operation. A switch to control the power supply to the outlet could be provided on the indicator panel to preclude connecting or disconnecting a hot line.

d. Tool Modules - There are two modules which are simply drawered, interchangeable tool chests.

e. Lighting - Flexible arm floodlights are mounted on the ends of the console. Stowage of the lighting arms during platform translation and vehicle stowage would be along the support legs.

f. Winch - The winch is manually operated with ratchet locking, an overriding clutch mechanism and a quick release. The handle folds flush with the control console for stowage while not in use. The winch is mounted so that rotation in the vertical plane is required rather than in a horizontal plane since vertical motion is more readily counteracted by the foot restraints. The cable feed hole is on the work-site side of the console and is a non-fraying, omni-directional cable guide. This guide is located as close as possible to the theoretical apex of the tripod formed by the three docking legs.

g. Safety Tether - Just below the power outlet on the right hand-side of the control console is a crewman safety tether. This tether is attached to the crewman at all times he is on the work platform. In normal operation, no forces are counteracted by the tether nor does it exhibit any constant tug upon the crewman. It is intended as a purely emergency measure, although this tether may be used as a third restraint point if it is decided to supplement the foot restraint system.

12.5.4 Docking System

The docking system secures the work platform to the worksite and consists of the docking legs, ball/socket locks, and an insertion tool. An artist's sketch of the docking system is shown in Figure 12-5.

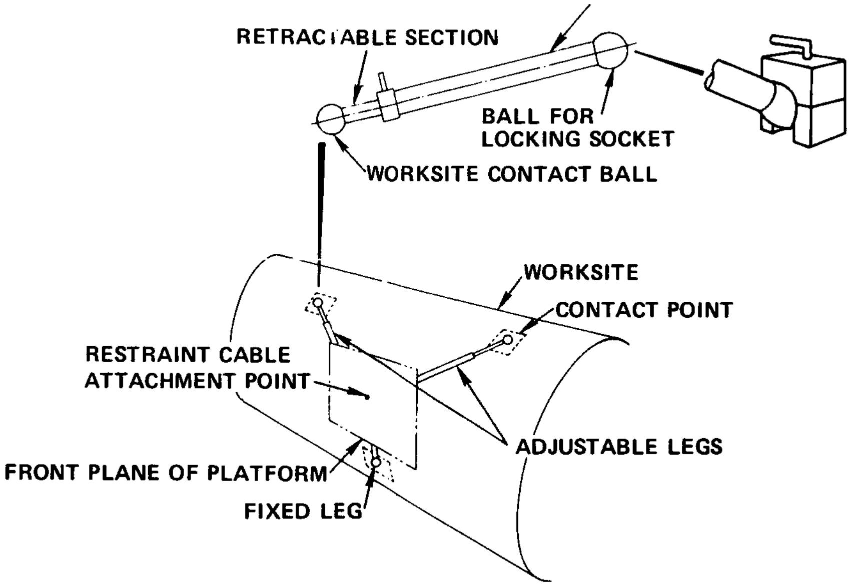


FIGURE 12–5. DOCKING SYSTEM

Of the three legs which form a tripod for docking restraint, two are adjustable and one has a fixed length and position. The two adjustable tripod legs are made up of two concentric tubes to give a maximum extended length of 4.0 feet. Contact between the leg and the vehicle is made by a spherical metal ball with a textured surface. This provides a non-slip contact at estimated interface pressure forces of five pounds. Locking of the movable leg is achieved by a handle actuated collet sleeve on the fixed leg. At the other end of the fixed leg is another textured ball which is installed in a socket on the platform. Upon reaching the worksite, the crewman moves each leg from its stowed position and sets the length by moving the inner tube to the approximate point of contact with

12.5.4 Docking System (Continued)

the worksite surface. The leg length is then locked in position with the collet lock. The legs are then rotated to contact with the vehicle and, when all legs are in position, the socket locking mechanism is set, thereby firmly holding the legs in place.

The restraint cable insertion tool is a simple, ball-lock device. The tool consists of a rod attached to the end of the restraint cable. At the end of the rod is a spherical ball. To dock the work platform to the worksite, the ball is inserted into the top of a keyhole shaped opening in the worksite and is then pushed into the leg of the opening. The use of a ball ensures balanced force components once the cable is made taut.

SECTION 13.0

EMERGENCY IV

13.0 EMERGENCY IV

13.1 General

In the Space Shuttle Program as in all manned spaceflight programs, the safety of the crew is of prime importance. Crew safety is ensured by providing emergency crew support capability. Experience gained during previous manned spaceflights such as Gemini VIII and Apollo 13 provides ample evidence of the need to provide protection for contingencies. The baseline orbiter systems are designed to be "fail operational - fail safe" which allows the crew to safely abort following two malfunctions of any given system. There are, however, other failure conditions where the baseline orbiter cannot provide crew support to insure a safe return of the crew to earth.

In this section, other failure modes which could affect the safety of the crew are identified along with the procedures which can be followed by the crew for a safe return. Based on the failure modes, the procedural and mission options available, Emergency IV requirements are formulated and equipment concepts are identified.

The Orbiter spacecraft is currently required to carry equipment and consumables for use during such emergencies. Each flight carries contingency consumables as required to support a crew of four (4) men for a period of 96 hours. These consumables are used in conjunction with the EC/LSS to satisfy contingency requirements. A portable breathing system for each crewman is also on each flight to be used in the event that the cabin atmosphere becomes contaminated with smoke or other toxic gases. The breathing system contains a ten (10) minute supply of oxygen which can be recharged from the spacecraft 900 psia O2 supply system. However, the spacecraft baseline requirements do not allow for crew support in a depressurized cabin.

The Orbiter has the capability of rescuing the crew of another Orbiter following failure conditions which prohibit a safe de-orbit and landing. A docking module is carried when docking is a planned operation of that particular flight. Rescue of an Orbiter which has an attached docking module can be accomplished by means of direct docking of the two Orbiters followed by intravehicular crew transfer to the rescuing Orbiter. The rescue of an Orbiter which does not have an attached docking module require other methods of rescuing the crew which will be identified and assessed.

13.2 Emergency IV Modes Identification and Effect

A North American Rockwell Study, (Safety in Earth Orbit Study) identified the credible emergencies listed below chich were used in this study to assist in the identification of emergency IV modes.

- Loss of Cabin Pressure
- Fire
- Toxic Gases in Cabin
- Explosion

Loss of cabin pressure can result from a collision between the Orbiter and another space vehicle or space debris, meteoroid penetration, hatch or window failure or puncture of Orbiter pressure shell due to improper handling of equipment within the Orbiter. Loss of cabin pressure requires that the crew obtain pressure protection through pressure suit operation or seek refuge in the airlock, Sortie Lab, or a pressurizable module specifically carried for this purpose.

A fire in the Orbiter cabin or an attached payload such as a Sortie Lab has the affect of contaminating the atmosphere with products of combustion including carbon dioxide and carbon monoxide. The occurrence of a fire requires that the crew be provided with an acceptable breathing oxygen supply or enter an enclosed compartment which isolates the crew from the contaminated atmosphere.

Toxic gases within the cabin or Sortie Lab can result from spillage of experiment related materials which can contaminate the cabin environment. For this case, the crew requires protection similar to that required subsequent to a fire.

An explosion occurring in the payload bay or cabin can result in loss of cabin pressure, fire and toxic gases in the cabin and/or structural damage to the Orbiter which may be too extensive for the Orbiter to de-orbit and land. Crew protection subsequent to an explosion is similar to that of a depressurized cabin and/or a fire.

Failure of an airlock hatch to open could trap a crewman within a Sortie Lab or servicing module unless a redundant escape route is available. It appears to be more desireable to leave both airlock hatches open while pressurized payloads are manned to avoid the possibility of trapping a crewman and to eliminate

13.2 Emergency IV Modes Identification and Effect - Continued

the cost and weight impacts of redundant escape routes or long term EC/LSS equipments.

Failure of the airlock external hatch to close or the internal hatch to open requires that the cabin be depressurized to permit EVA crew ingress. This failure mode requires that all personnel on board have pressure suits since the airlock is not available to the cabin personnel and access to a Sortie Lab is blocked by the failed airlock.

Figure 13-1 summarizes the effect of each failure mode. The failure modes of loss of cabin pressure, and explosion can result in a depressurized cabin condition. Similarly, the failure modes of fire, toxic gases, and explosion can contaminate the cabin atmosphere.

FAILURE MODE	FAILURE EFFECT
LOSS OF CABIN PRESSURE	DEPRESSURIZED CABIN
EXPLOSION	
FIRE	CONTAMINATED CABIN ATMOSPHERE
TOXIC GASES	

FIGURE 13—1. FAILURE MODES EFFECT

13.3 Emergency IV Procedures and Mission Options

In this section, the crew procedures and mission options available following an emergency mode are identified and discussed.

Figure 13-2 summarizes the procedures which the crew must implement following the occurrence of a failure.

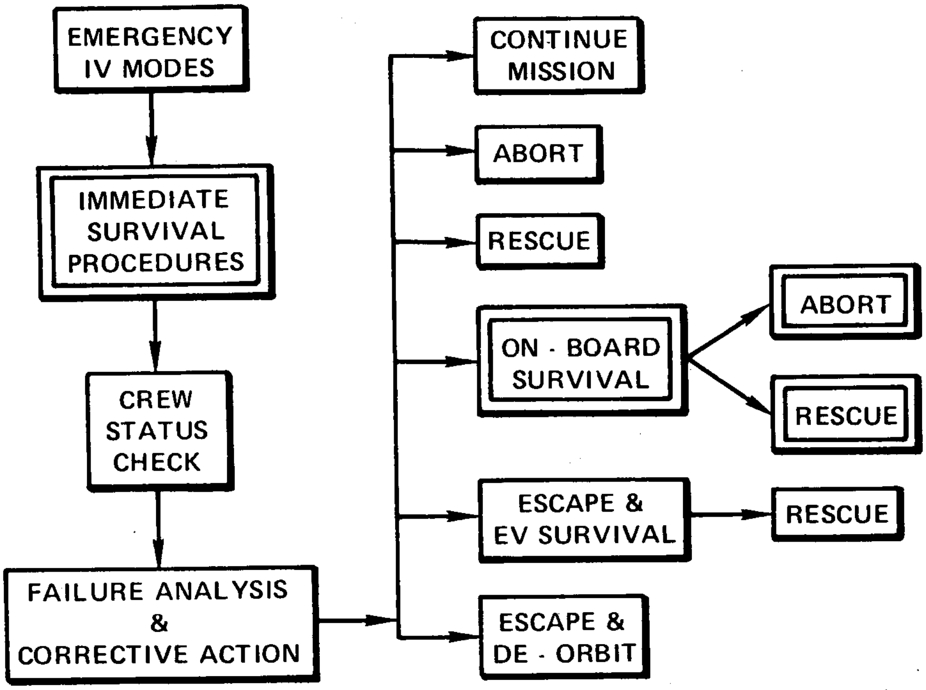


FIGURE 13–2. CREW PROCEDURES AND MISSION OPTIONS

a) Immediate Survival Procedures - The objective of these procedures is to obtain crewmen protection for sufficient duration to allow the crew to take corrective action, establish emergency operating modes and to eliminate the failure mode where possible. The procedures include donning of pressure suits or breathing systems, and isolation of crewmen in compartments such as the airlock or Sortie Lab.

After equipment donning at least two crewmen must have the freedom to move about the cabin to perform various tasks associated with crew status check, failure analysis and corrective action.

13.3 Emergency IV Procedures and Mission Options - Continued

b) Crew Status Check - A crew status check is performed to verify that all crewmen have obtained the required protection. As part of these procedures any crewmen injured as a result of the failure would be located, attended to and/or rescued from dangerous areas such as a contaminated Sortie Lab environment.

c) Failure Analysis - The objective of these procedures is to identify the source, cause, or location of the failure such that corrective action can be taken. For example, as part of these procedures, a fire in an avionics bay would be identified and located.

d) Corrective Action - The purpose of these procedures is to eliminate the failure condition or its progression and to establish proper spacecraft systems configuration for continued operation or survivability.

The mission options following occurrence of a failure mode are also shown in Figure 13-2. The following paragraphs discuss these options and give examples.

a) Continue Mission - This option is available when the failure condition does not significantly affect the Orbiter or its payload and allows completion of the flight. A fire which has been isolated to a Sortie Lab but did not affect equipment operation allows continuation of the mission after an atmosphere change out through an airlock/Sortie Lab depressurization and repressurization.

b) Abort - A mission abort is required if the failure condition affects spacecraft systems or its payload such that the mission objectives cannot be achieved. For this case, the cabin environment is not affected, thereby eliminating the need for additional survival equipment. For example, the Sortie Lab fire previously discussed has destroyed the experiment equipment such that the mission objective cannot be met.

c) Rescue - Rescue is required when the failure condition does not allow the Orbiter to safely de-orbit and land, although the Orbiter cabin is habitible. Examples of this option are failure to undock from an LST or Space Station following a revisit or an explosion in the payload bay that affects the structural integrity of the spacecraft.

13.3 Emergency IV Procedures and Mission Options - Continued

d) On-Board Survival - On-board survival is required if the failure affects the Orbiter such that its life support functions are not available thereby requiring other means of providing life support for the crew. For example, a collision during a docking maneuver results in cabin depressurization, the crew then must obtain pressure protection in the airlock, Sortie Lab or pressure suits. Depending on the extent of damage, the crew may either de-orbit and land or await rescue by another Orbiter. As part of the rescue, the stranded crew must transfer to the rescue vehicle.

e) Escape and EV Survival - Escape and EV survival is required if the damage due to a failure is too extensive for on-board survival. The crew evacuates the Orbiter and remains in a "lifeboat" until a rescue can be affected. For example, an explosion damages all Orbiter systems such that on-board survival is not possible. The crew enters a separable crew compartment(s) with life support capabilities to await a rescue.

f) Escape and De-orbit - This option is similar to escape and EV survival except the life boat has de-orbit re-entry capability.

Each of the above options are reviewed to determine their applicability to the Shuttle Program. The options requiring escape with EV survival or de-orbit are not considered applicable because these options are preceded by a massive failure of the Orbiter such as an explosion. It is highly probable that such a failure would also result in failure of the life boat or re-entry vehicle. In addition, the "life boat" concepts impose excessive cost, weight and volume impacts on all flights; an application which has an extremely low probability of usage.

Review of the crew procedures and options shows that the following phases require special support considerations for the crew:

a) Immediate survival

b) On-board survival during mission aborts and while awaiting a rescue.

c) Crew transfer to complete a rescue.

13.3 Emergency IV Procedures and Mission Options - Continued

Each of these phases are reviewed in detail to establish requirements, to identify potential support options and to assess potential equipment concepts.

Groundrules established for conduct of the study are listed in Table 13-1. The availability of vehicle subsystems are highly probable because of the fail operational-fail safe criteria of the Orbiter subsystem design. A four man crew is specified since most flights are for payload deployment which does not require additional crewmen. A tumbling spacecraft is also highly unlikely because of the fail operational - fail safe criteria. Secondly a study performed by North American Rockwell (Safety in Earth Orbit) identifies two viable concepts for vehicle stabilization as part of a Shuttle-to-Shuttle rescue.

VEHICLE SUPPORT SYSTEM OF O_2, POWER AND COOLING ARE AVAILABLE
FOUR (4) CREWMEN ARE ON BOARD
A FAILED ORBITER WILL NOT BE TUMBLING DURING A CREW TRANSFER PHASE

TABLE 13–1. EMERGENCY IV GROUNDRULES

13.4 Short-Term Survival Phase

As discussed earlier, the short-term survival phase provides crew support during crew status checks, failure analysis, performance of corrective action and initiating the on-board survival operating modes. Upon receipt of a warning or indication of cabin contamination or pressure loss, all crew members must obtain breathing and pressure protection as rapidly as

13.4 Short-Term Survival Phase - Continued

possible. In compliance with this need, a requirement of one (1) minute is established as a reasonable design objective for a trained crewman to accomplish one of the following:

a) Don a breathing system and initiate operation.

b) Don a pressure suit and activate pressure control of a supporting system.

c) Enter an isolatable compartment and secure a hatch. This option is not available to all of the crew since cabin occupancy is required by at least two crewmen to perform the tasks discussed below.

At least two of the crewmen must have the freedom to move about the cabinvehicle wearing breathing systems or pressure suits to perform all or some of the tasks listed below:

Extinguish Fire
Provide Protective Equipment for Injured Personnel
Stow Equipment Prior to Initiating an Abort
Inspect Damage
Coordinate Corrective Action with Ground Personnel
Initiate On-Board Survival

The time required to perform the tasks involving complete freedom of movement is established at one (1) hour during which two of the crewmen may extinguish fire, stow equipment or care for any injured personnel. Following this one hour period, protection for an additional three hours is required for the crew to coordinate all activities with ground and initiate on-board survival operating modes. This time period allows for two orbits during which ground coordination takes place.

Table 13-2 summarizes the short-term survival requirements which are to be satisfied under contaminated or depressurized cabin conditions.

13.4 Short-Term Survival Phase - Continued

DONNING TIME	1 MINUTE MAXIMUM
DURATION	4 HOURS MAXIMUM (WITH 3 HOURS OF VEHICLE SUPPORT)
INDEPENDENT OPERATIONAL TIME	1 HOUR MAXIMUM
METABOLIC RATE	800 BTU/HR AVERAGE
CO_2 CONTROL	7.6 MM HG MAXIMUM
PRESSURE CONTROL	8.0 TO 14.7 PSIA
CO_2 PARTIAL PRESSURE	3.1 TO 14.7 PSIA
THERMAL CONTROL	THERMAL STORAGE LESS THAN 300 BTU

TABLE 13-2. SHORT TERM SURVIVAL REQUIREMENTS

13.4.1 Contaminated Cabin Conditions

A breathing system is the preferred system for short-term survival since it provides for breathing protection, can be donned and activated quickly and can be portable. Figure 13-3 schematically defines the baseline Orbiter breathing system which is on-board for each crewman. This system provides ten (10) minutes of independent operation and can be operated or recharged from the vehicle 900 psia O_2 supply for extended operation. The primary disadvantage of this sytem is its high oxygen usage rate which results in depletion of the Orbiter contingency O_2 supply (50 pounds) in approximately six (6) hours as indicated by Figure 13-4. Although this approach satisfies the short-term survival requirements, the high oxygen usage rate is not desireable because:

13.4.1 Contaminated Cabin Conditions - Continued

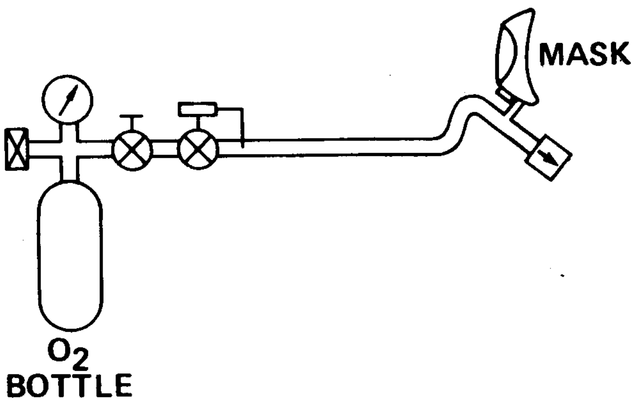


FIGURE 13–3. SHUTTLE BASELINE BREATHING SYSTEM

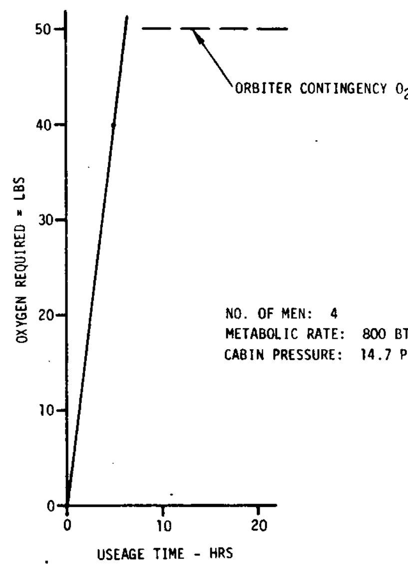


FIGURE 13–4. BASELINE BREATHING SYSTEM OXYGEN USAGE

13.4.1 Contaminated Cabin Conditions - Continued

a) Additional oxygen would be required to satisfy on-board survival requirements.

b) Oxygen exhausted from the system increases the cabin oxygen concentration which should be avoided while trying to extinguish a fire.

c) The in flow of oxygen results in continuous operation of cabin relief valves.

A modification of the baseline breathing system is shown in Figure 13-5 which converts the sytem to a re-breather type to significantly reduce the O_2 usage rate. Table 13-3 compares the performance capabilities of the baseline system with and without the modification.

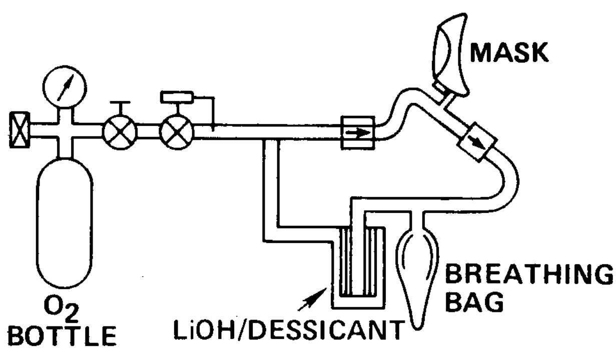


FIGURE 13–5. MODIFIED BASELINE BREATHING SYSTEM

13.4.1 Contaminated Cabin Conditions - Continued

	BASELINE SYSTEM	MODIFIED BASE-LINE SYSTEM
TYPE	OPEN LOOP	RE-BREATHER
DURATION	10 MINUTES	ONE HOUR
O_2 USAGE RATE	2.0 LBS/HR	0.14 LBS/HR
WEIGHT	*	1.0 LBS INCREASE

* WEIGHT IS INCLUDED IN SHUTTLE BASELINE

TABLE 13-3. BREATHING SYSTEM CONCEPT COMPARISONS

Note that breathing protection can be increased from ten (10) minutes to one hour with less than a one pound increase in system weight which is mostly due to LiOH and canister. The O_2 bottle and regulator are unchanged. Figure 13-6 compares oxygen usage of the baseline system with and without the modification.

Extended operation for the additional three (3) hours can be achieved by umbilical operation from the spacecraft O_2 supply. For CO_2 control, several options are available including:

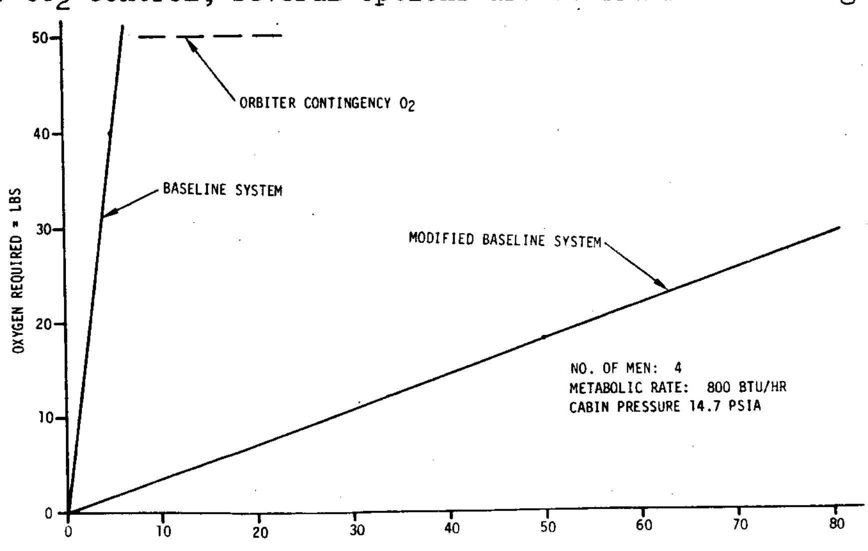


FIGURE 13-6. BREATHING SYSTEM OXYGEN USAGE COMPARISON

13.4.1 Contaminated Cabin Conditions - Continued

a) Replace breathing system cartridges at one hour intervals.

b) Design breathing system cartridge for four (4) hours of operation.

c) Add an adapter which permits use of PLSS or Shuttle EC/LSS LiOH cartridges.

It must be pointed out that the re-breather type system introduces a humidity problem when used in conjunction with a face mask. Visor fogging is an unacceptable condition while performing the various tasks associated with the short term survival phase. The potential solutions to the visor fogging problem include:

a) Anti-fog Sprays
b) Inlet O_2 Cooling with Phase Change Materials Including Ice
c) Inlet O_2 Cooling with Vehicle Coolant
d) Use of Dessicants

Further analysis and test is required to determine the extent of visor fogging and to select the proper concept.

From review of the short term survival phase under contaminated cabin conditions, the following conclusions are reached:

a) A breathing system is required
b) O_2 usage of the breathing system should be minimized.
c) Additional study and test is required for breathing system optimization.

13.4.2 Depressurized Cabin Conditions

Short term survival in the event that cabin pressure is lost requires that the crew obtain pressure protection as soon as possible. Since pressure suits are required for all personnel on board the perferred approach is for the crew to don their pressure suits and activate the supporting equipment. The type of equipment required for this phase is similar to the on-board survival phase which is discussed paragraph 13.5.2.

13.5 On-Board Survival Phase

During the on-board survival phase, crew support is required until a mission abort or a rescue is successfully completed.

The time required to de-orbit and land under abort condition depends upon the spacecraft orbit, available landing sites and the activities in progress at the time of the failure. For this study, it was assumed that KSC and the Western Test Range are the only landing sites available and that the failure occurs with the Orbiter in a polar orbit and located over the Western Test Range. Based on these conditions, a requirement of ten (10) hours was established for crew support during mission abort conditions.

The capability for the crew to consume food and water is considered desireable but not mandatory for the safety of the crew.

The most important aspect of the mission abort crew procedures are those required for Orbiter de-orbit, re-entry and landing. Therefore, all critical spacecraft controls and displays should be operable and visible with the flight crew wearing either pressure suits or breathing masks.

The time required to accomplish a rescue depends primarily upon the status of rescueing spacecraft. Since it could take several days to prepare another Orbiter for launch, the study assumed that the rescue could be accomplished within a four (4) day period since each Orbiter carries four days of contingency consumables to support a crew of four (4) men.

The capability to administer food and water to the crew is essential during the four day period. Similarly a capability is required for the management of waste products during operation in a depressurized and a contaminated cabin atmosphere.

Table 13-4 summarizes the on-board survival requirements which commence at the time of failure and end at completion of mission abort or transfer of the crew to a rescue vehicle.

13.5 On-Board Survival Phase - Continued

DURATION	
MISSION ABORT	10 HOURS MAXIMUM
RESCUE MISSION	96 HOURS MAXIMUM
LIFE SUPPORT	
METABOLIC RATE	500 BTU/HR AVERAGE
PRESSURE CONTROL	
BREATHING SYSTEM	3.5 TO 14.7 PSIA
PRESSURE SUIT	3.5 TO 8.4 PSIA
O_2 PARTIAL PRESSURE	3.2 PSIA MINIMUM
CO_2 CONTROL	7.6 MM HG MAXIMUM
THERMAL CONTROL	300 BTU/MAXIMUM HEAT STORAGE
OTHER	
FOOD AND WATER ADMINISTRATION	
WASTE MANAGEMENT PROVISION	
BREATHING SYSTEM OR PRESSURE SUIT OPERATION OR CONTROLS	

TABLE 13—4. ON BOARD SURVIVAL REQUIREMENTS

Figure 13-7 identifies the potential locations for on-board survival as being the cabin or an isolateable compartment such as the airlock or a Sortie Lab. As mentioned previously, at least two crewmen (i.e. Pilot and Co-Pilot) must remain in the cabin for spacecraft control during de-orbit and landing. Crew support in the Sortie Lab is not recommended because it is not available on all flights. Air Lock support which may not be available due to the failure condition, also requires duplication of cabin facilities including crew restraints for de-orbit and landing, food, water, waste management and life support equipment. Therefore, the cabin area is the recommended location for on-board survival of the crew.

13.5 On-Board Survival Phase - Continued

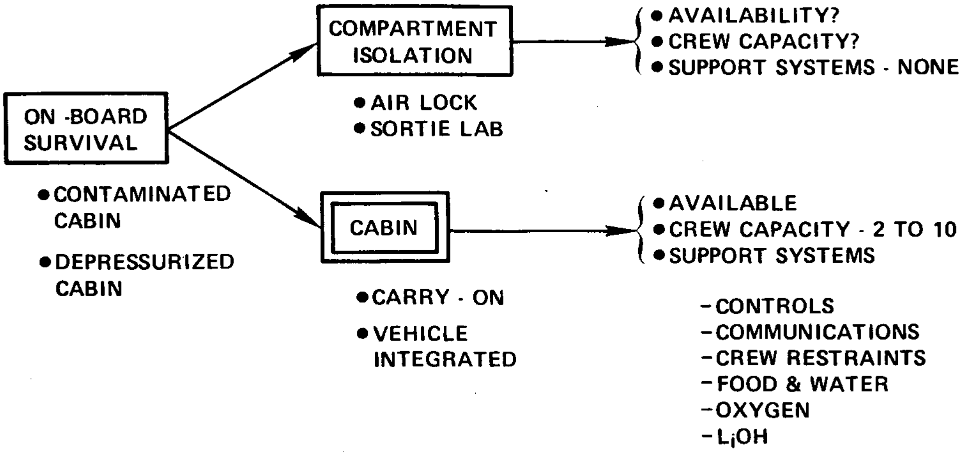


FIGURE 13—7. ON BOARD SURVIVAL LOCATIONS

13.5.1 Contaminated Cabin On-Board Survival

Figure 13-8 identifies the options available for long term crew support in a contaminated cabin. The options are as follows:

a) Breathing system operation: The crew remains on the breathing system for up to 96 hours.

b) Suited operation: After completion of short term survival operations, the crew dons pressure suits which serve as a barrier between the crewman and the contaminated environment.

c) Cabin Depressurization: The cabin is depressurized and the crew utilize the equipment for depressurized cabin support.

d) Shirt-Sleeve: After the crew is suited, the cabin is depressurized and then repressurized to clear the contaminated environment which then permits return to shirt sleeve operation

13.5.1 Contaminated Cabin On-Board Survival - Continued

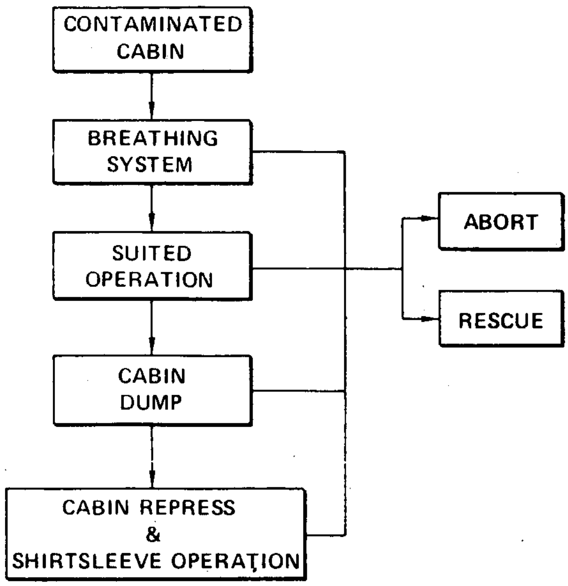


FIGURE 13–8. CONTAMINATED CABIN LIFE SUPPORT OPTIONS

Figure 13-9 identifies the potential problems which may be encountered with each of the available options.

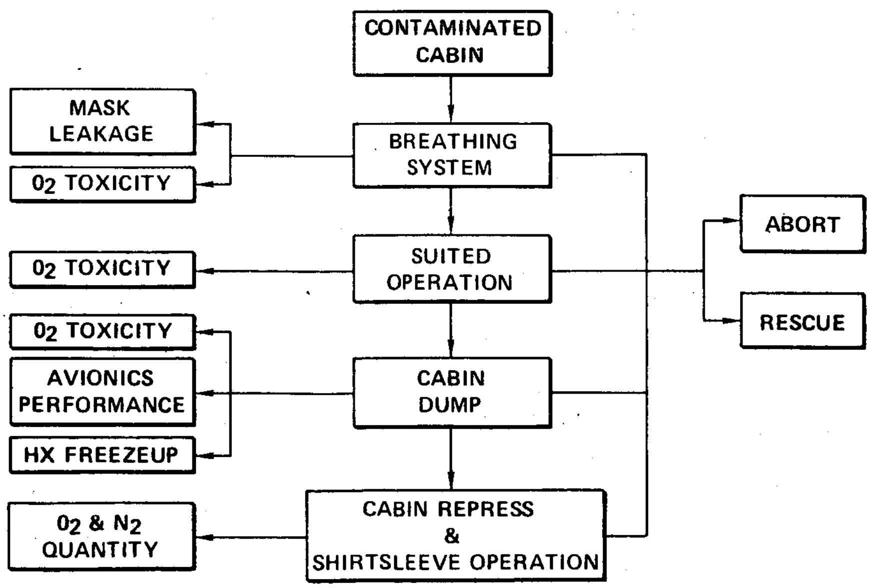


FIGURE 13–9. CONTAMINATED CABIN LIFE SUPPORT OPTIONS ASSESSMENT

13.5.1 Contaminated Cabin On-Board Survival - Continued

With long term mask operation, problems of oxygen toxicity and mask leakage could be encountered. Pure oxygen breathing system operation at 14.7 psia is limited to approximately four (4) hours (per Guidelines established for this study). Potential solutions include the use of a two-gas breathing system or reduction of cabin pressure to approximately 5 psia to allow continued operation. Leakage of contaminants into the breathing system is possible due to beard growth and intake of food and drink. Potential solutions of mask leakage include the use of a neck seal and/or a positive pressure breathing system.

The suited operation mode eliminates the mask leakage problem but requires a two-gas pressure control system or reduced cabin pressure to avoid oxygen toxicity problems.

The depressurized cabin option alleviates the oxygen toxicity problem since an 8 psia suit operating pressure allows 30 hours of operation before onset of oxygen toxicity. This capability can satisfy the mission abort requirements but two-gas systems or reduced operating pressures are required for rescue missions. In addition, complete cabin depressurization could result in freeze-up of the EC/LSS heat exchanger and in loss of avionics cooling. A potential solution to these problem areas is to limit the cabin depressurization to 0.5 to 1.0 psia with the avionics equipment powered down during the depressurization. Further analysis and possibly tests are required to establish the minimum acceptable pressure level.

The final option provides for crew operation in a shirt sleeve mode following cabin depressurization to the minimum acceptable level, nitrogen purge and repressurization to an acceptable level for life support. This option allows for maximum utilization of Orbiter facilities with the crew in the shirt sleeve operating mode. Implementation of this option requires the capability to depressurize the cabin and possibly the addition of some nitrogen and oxygen depending on the level of cabin depressurization, amount of nitrogen purge and the final cabin pressure level.

13.5.2 Depressurized Cabin On-Board Survival

As concluded earlier, pressure suits should be provided for all on board personnel for support of depressurized cabin conditions. This section identifies potential suit support equipment and reviews the advantages and disadvantages of candidate concepts.

13.5.2 Depressurized Cabin On-Board Survival - Continued

An assessment of the Orbiter capability to perform under depressurized cabin conditions shows the following potential problem areas:

- Avionic equipment cooling
- Collapsing cabin pressure during re-entry
- Condensing heat exchanger freeze-up

The avionics equipment is normally cooled by either cold plate or by a continuous flow of air. Depressurized cabin conditions may result in loss of all avionics equipment which relies on gas cooling. To allow for Orbiter operations for mission aborts and rescues. It is recommended that all avionics equipment required for de-orbit, re-entry, landing, rendezvous and Shuttle-to-Shuttle docking be cold plated.

During re-entry, under depressurized cabin conditions, the ambient pressure rises at a higher rate than the cabin pressure due to the EC/LSS in-flow restriction of 150 lbs/hour. This condition may result in a significant collapsing load imposed on the Orbiter cabin, which should be fully assessed to determine if the collapsing load is excessive for the cabin and, if so, to select a concept to alleviate the condition. Concepts should include:

- Addition of cabin in-flow values to allow equalization of cabin pressure with atmosphere pressure.
- Modification of cabin in-flow restrictions to assure safe structural loadings
- Addition of cabin structure

The coolant within the condensing heat exchanger of the EC/LSS may freeze due to the rapid boiling of the condensate upon exposure to vacuum. Potential solutions are discussed later in this section.

13.5.2 Depressurized Cabin On-Board Survival - Continued

Table 13-5 identifies the suit support equipment types which could be used.

VEHICLE INTEGRATED EQUIPMENT -SUIT LOOP
CARRY - ON EQUIPMENT -MINI - EC/LSS -PLSS -ELSS

TABLE 13-5. SUIT SUPPORT EQUIPMENT TYPES

The vehicle integrated equipment concepts are similar to the Apollo Command Module and Lunar Module concepts where common EC/LSS equipment is used for environmental control of both the cabin and suit loops.

The carry-on equipment concepts include use of suit support isolated from the cabin environmental control equipment. Use of the PLSS for suit support in a depressurized cabin is an example of this approach.

13.5.2 Depressurized Cabin On-Board Survival - Continued

Figure 13-10 is a schematic of the Shuttle EC/LSS which has been simplified through the elimination of redundant water loop fluid lines and heat exchanger passages.

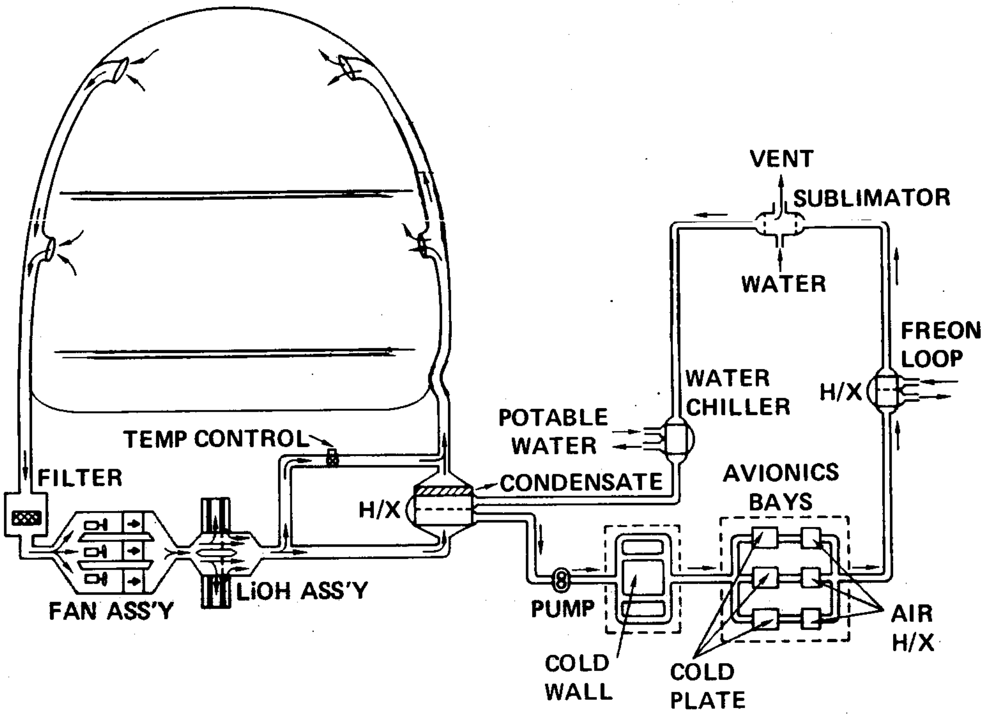


FIGURE 13—10. SHUTTLE EC/LSS SCHEMATIC

13.5.2 Depressurized Cabin On-Board Survival - Continued

In Figure 13-11 a suit loop is added to the EC/LSS to utilize the system fans, LiOH and heat exchanger.

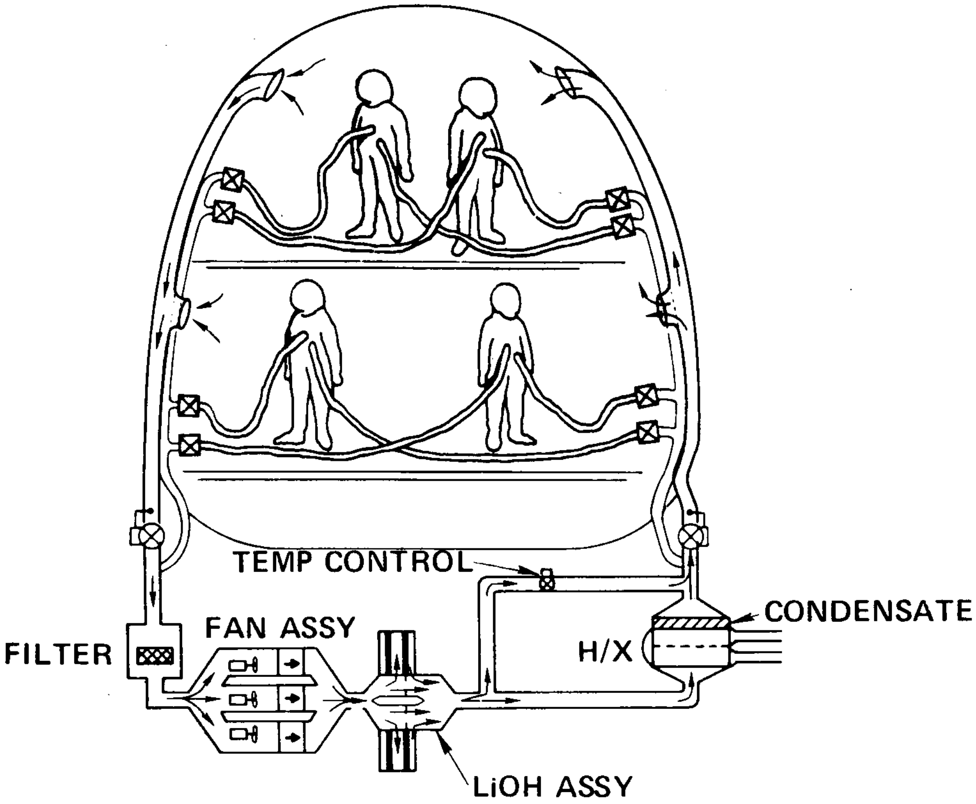


FIGURE 13-11. SUIT LOOP SCHEMATIC—BASIC

Two pressure actuated isolation valves are added to isolate the suit loop from the cabin environment. The umbilicals must be of sufficient length to allow freedom of crewman movement to perform the tasks identified for short-term survival.

Further review of the system reveals that the EC/LSS fans are not compatible for suit loop support since the axial fans are designed for high flow (approximately 200 cfm) and low pressure rise operation. They do not have sufficient pressure rise to support the suit loop conditions.

13.5.2 Depressurized Cabin On-Board Survival - Continued

Fan design for support of the suit loop mode results in low efficiency operation during the normal operating mode. To minimize vehicle penalties during normal operation, a suit loop centrifugal fan is added as shown in Figure 13-12.

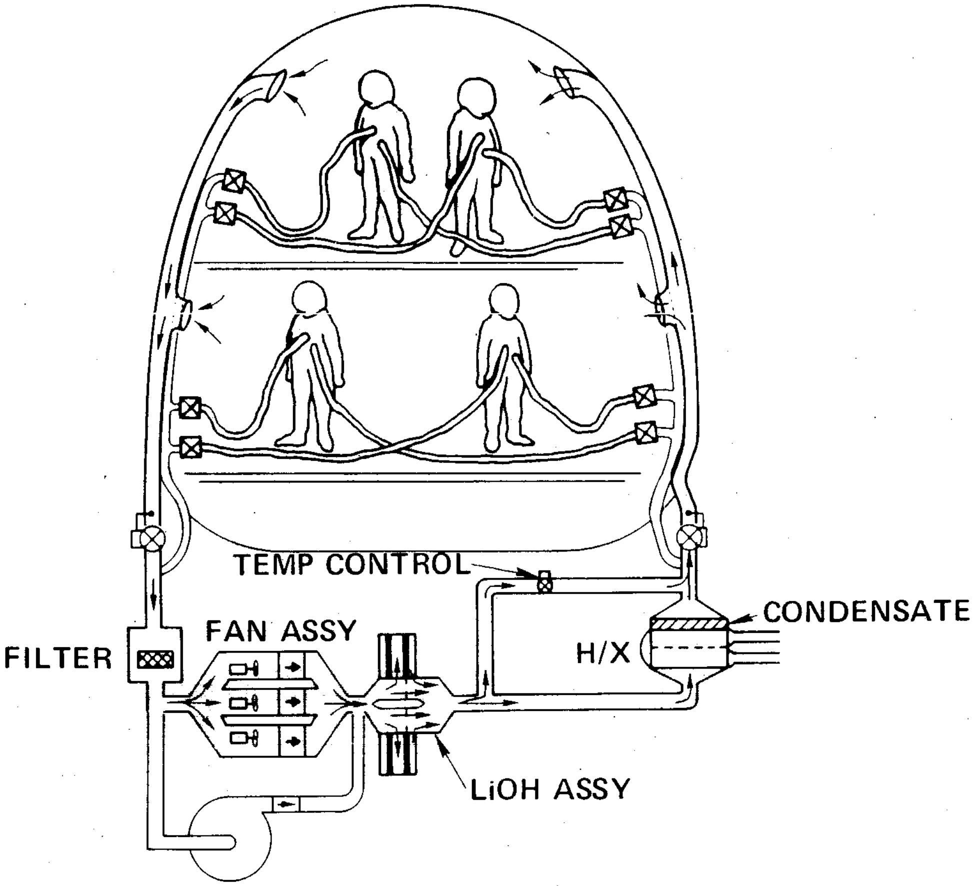


FIGURE 13-12. SUIT LOOP SCHEMATIC—FAN ADDITION

The check valve at the outlet of the suit loop fan prevent back flow of cabin air during normal modes. During the 96 hour rescue missions, it will be necessary to replace LiOH cartridges. Figure 13-13 adds LiOH cartridge isolation valves which permit cartridge change out without loss of suit loop pressure.

13.5.2 Depressurized Cabin On-Board Survival - Continued

The suit loop system of Figure 13-13, with the addition of a pressure control subsystem (not shown for clarity), has the capability of long-term support of suited operation.

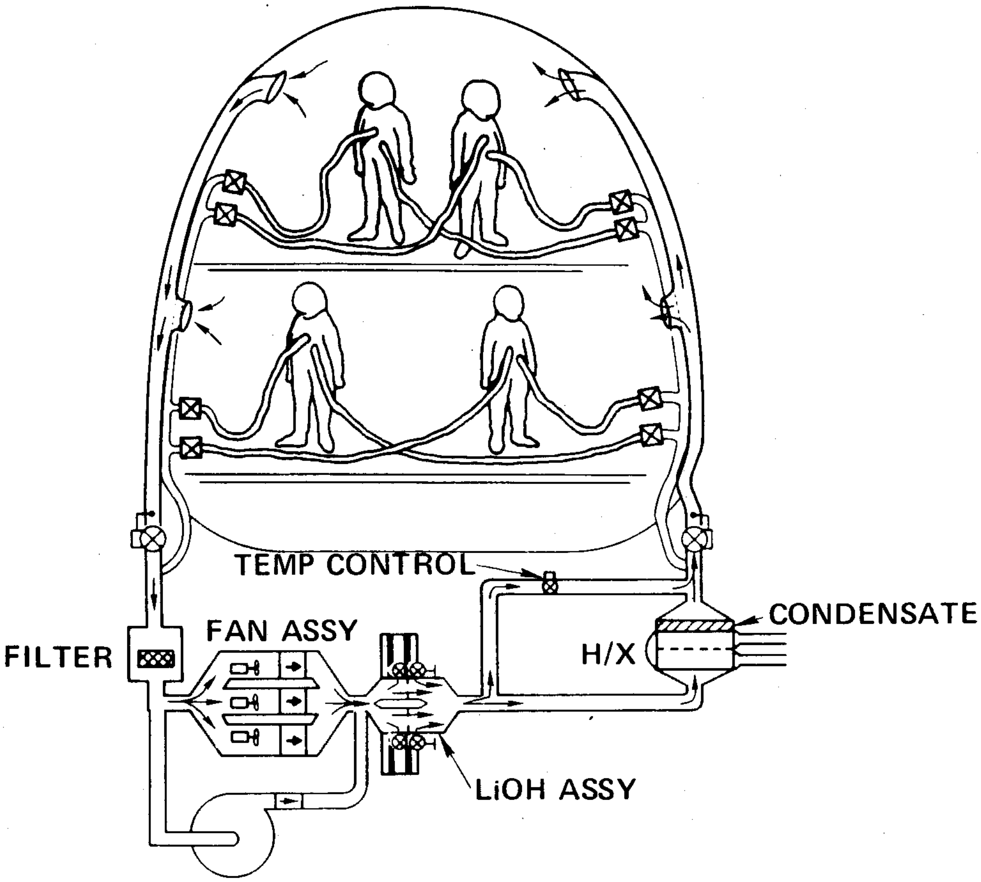


FIGURE 13–13. SUIT LOOP SCHEMATIC–LiOH ISOLATION

The pressure control subsystem requires regulators capable of maintaining suit pressure at 8.0 psia.

The entire EC/LSS system with the integrated suit loop must now be reviewed to ensure compliance with the fail operational - fail safe criteria.

13.5.2 Depressurized Cabin On-Board Survival - Continued

Figure 13-14 shows the addition of parallel suit loop isolation valves required in the event that one of the suit loop isolation valves should fail in the closed position.

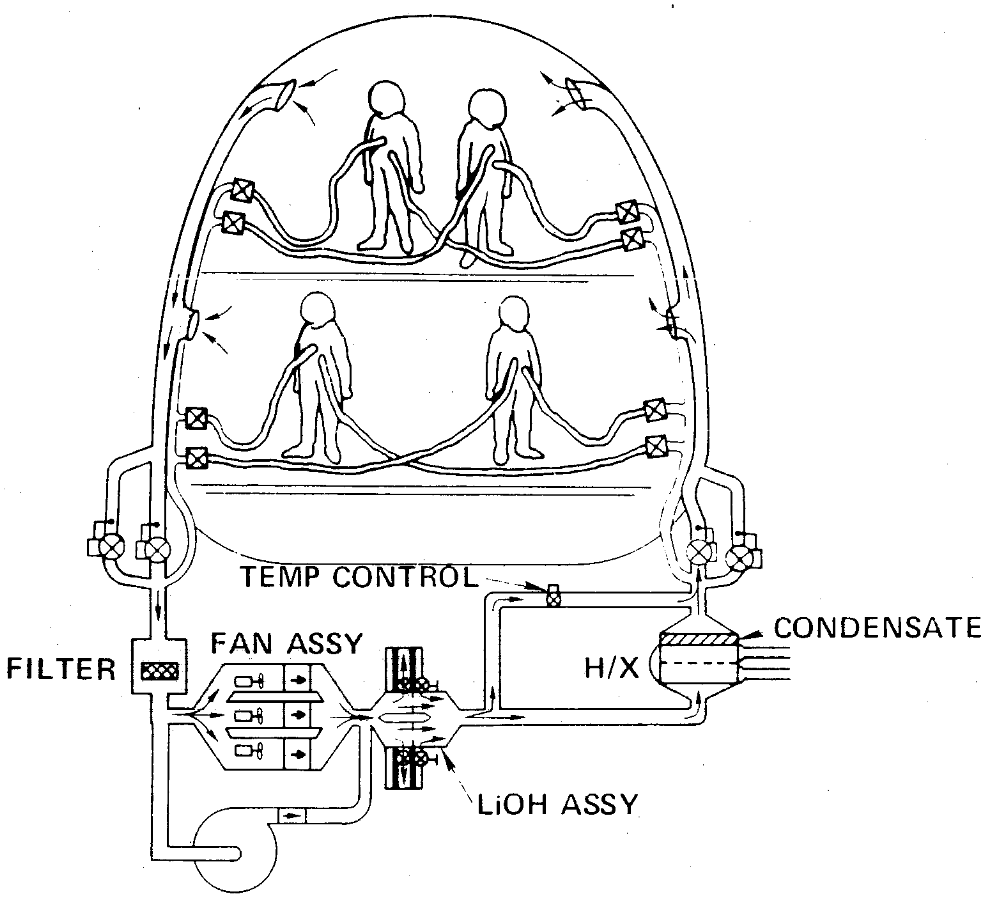


FIGURE 13–14. SUIT LOOP SCHEMATIC–PARALLEL ISOLATION VALVES

Without this redundancy such a failure would result in loss of cabin ventilation cooling, CO_2 control and humidity control.

13.5.2 Depressurized Cabin On-Board Survival - Continued

If any of the four (4) suit loop isolation valves fail to close, the system does not satisfy the fail safe criteria. Therefore, four (4) more suit loop isolation valves are added as shown in Figure 13-15.

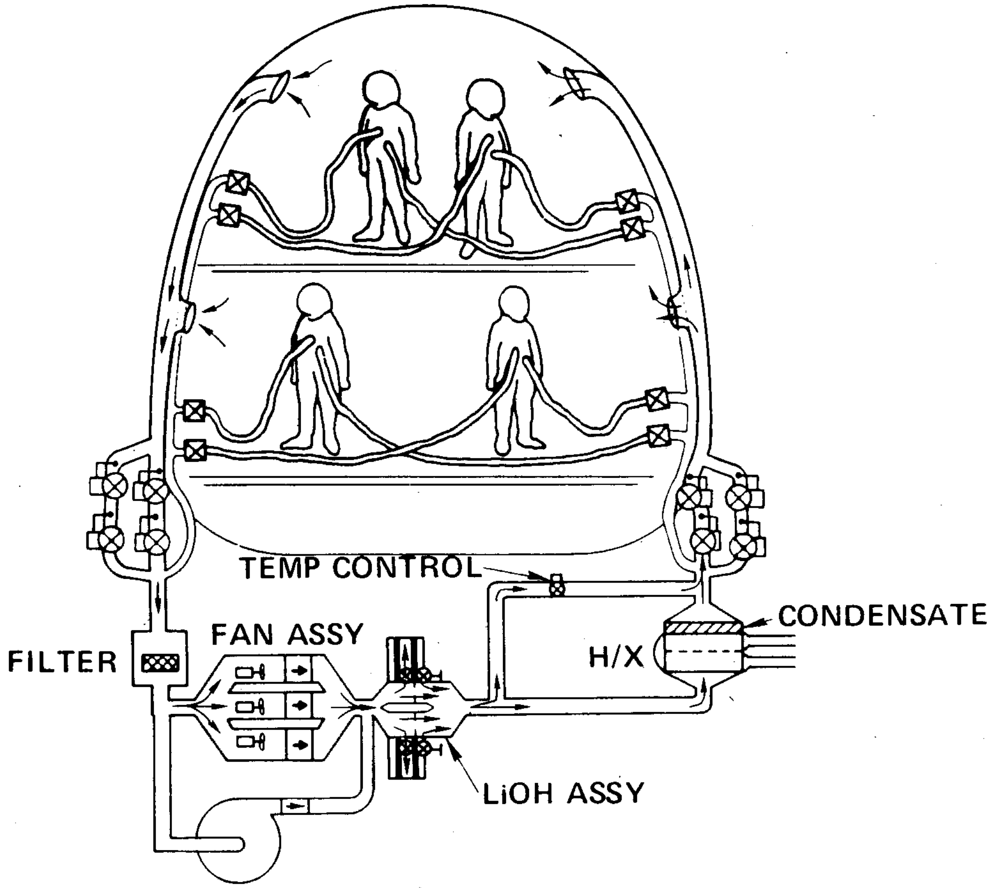


FIGURE 13-15. SUIT LOOP SCHEMATIC-REDUNDANT ISOLATION VALVES

In order to fully comply with the fail operational - fail safe criteria, it may also be necessary to add similar valving arrangements for the LiOH cartridge isolation valves and to the pressure control subsystem.

Although the suit loop concept can be designed to support suited operation, it yields a complex system which could significantly impact the reliability of the EC/LSS during normal operating modes.

13.5.2 Depressurized Cabin On-Board Survival - Continued

The carry-on equipment concepts utilize a "mini-EC/LSS" or the PLSS to provide support of suited operation as shown in Figure 13-16.

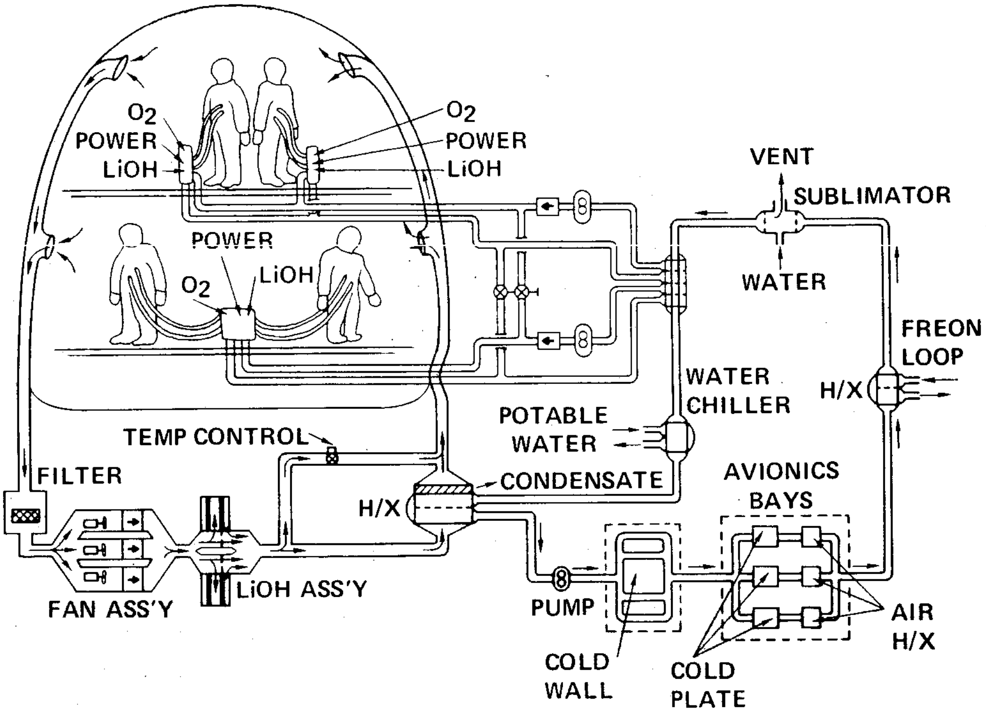


FIGURE 13-16. CARRY ON CONCEPT SCHEMATIC

The schematic shown in Figure 13-16 is intended to show concept rather than a selected approach or equipment assignments.

The concepts utilize consumables available in the cabin consisting of 900 psia O_2, power supplies and contingency LiOH cartridges. Cooling is achieved by adding a heat exchanger down-stream of the freon-water interchanger which provides an independent coolant loop to the carry-on units.

13.5.2 Depressurized Cabin On-Board Survival - Continued

Fail operational - fail safe criteria is satisfied by utilizing redundant heat exchanger passages and pumps designed so that each one is capable of handling the total load. Pressure control is achieved by an oxygen regulator capable of controlling pressure at 8.0 psia for short-term survival and 5.0 psia for periods in excess of 30 hours to avoid oxygen toxicity problems.

If the cabin depressurization freezes the condensing heat exchanger such that the coolant within the unit also freezes, all cooling to the carry-on units and the avionics bay is lost. Figure 13-17 shows two potential options for system operation following freeze up of the heat exchanger.

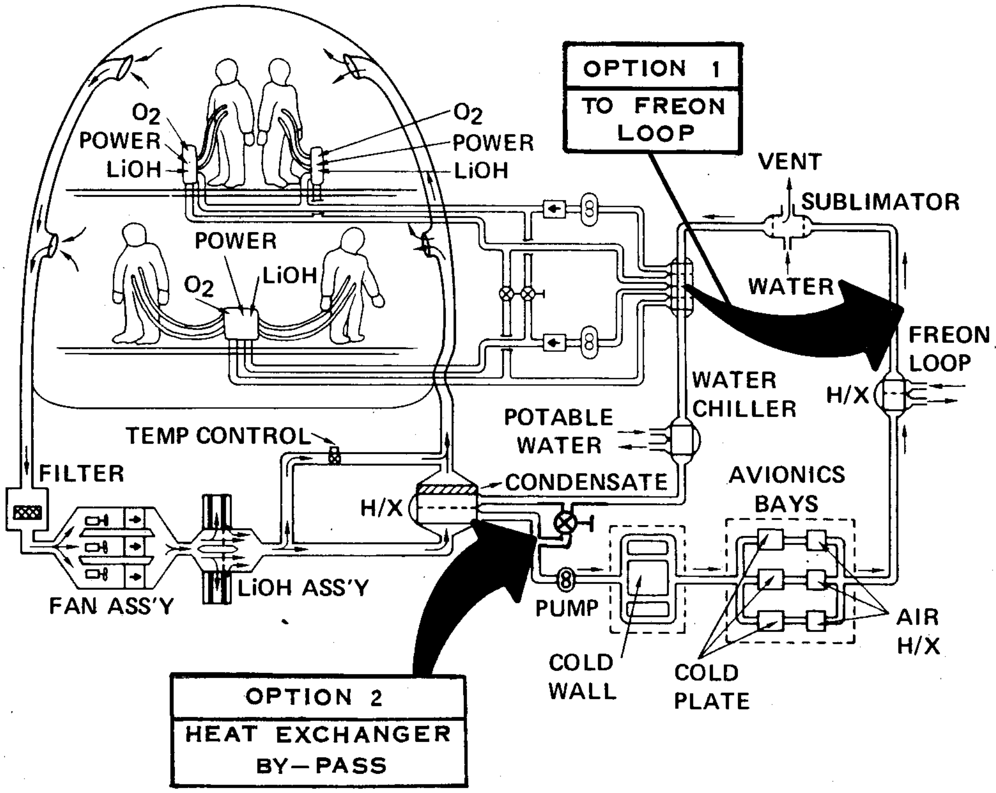


FIGURE 13-17. HEAT EXCHANGER FREEZE UP OPTIONS

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13.5.2 Depressurized Cabin On-Board Survival - Continued

One option is to locate the heat exchanger carry-on equipment in the freon loop which ensure crewman cooling but no avionics cooling. The second option is to add a bypass around the blocked condensing heat exchanger to provide cooling of the crewman and avionics equipment. However, the fail operational - fail safe criteria may require a significant quantity of bypass valves (a minimum of two (2) valves are required). It appears that the heat exchanger bypass is the better of the two options which should be confirmed by additional study.

Figure 13-18 schematically defines a carry-on "mini-EC/LSS" capable of supporting two (2) suited crewmen. The LiOH canisters contain sufficient cartridges to support the two (2) crewmen for 96 hours.

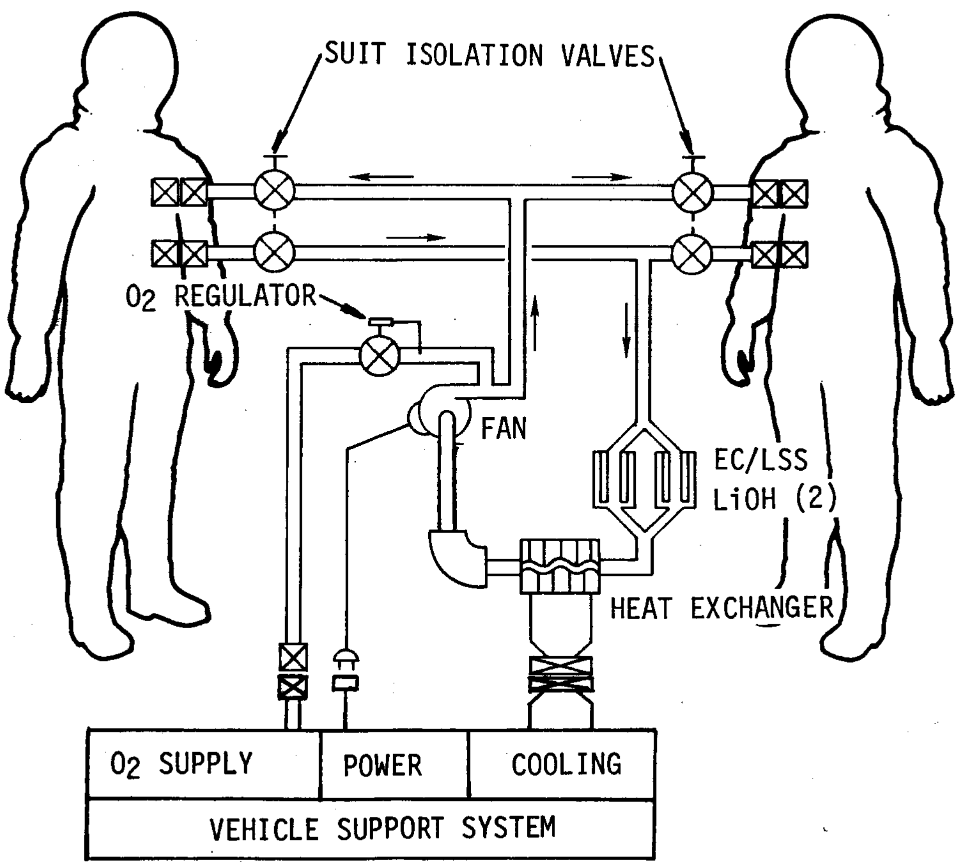


FIGURE 13–18. MINI EC/LSS SCHEMATIC

13.5.2 Depressurized Cabin On-Board Survival - Continued

A concept for PLSS usage is shown in Figure 13-19 which employs a control module located between the PLSS/ELSS.

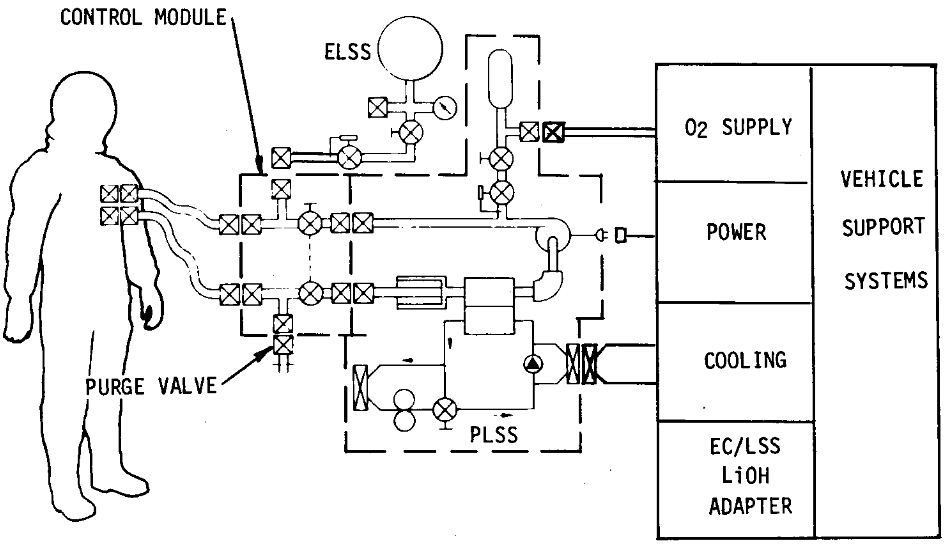


FIGURE 13–19. PLSS EMERGENCY IV SUPPORT

In this concept, an adapter is used to allow usage of the EC/LSS contingency cartridges in the PLSS. Cartridge change-out, if required is accomplished by closing the control module valve to isolate the PLSS from the suit. The ELSS and a low purge is then activated to provide pressure and CO_2 control while the LiOH cartridge is changed. PLSS usage has the following advantages for support of emergency suited operations:

a. Two (2) are available on all flights.

b. It is a portable unit for use while performing short-term survival tasks.

13.5.2 Depressurized Cabin On-Board Survival - Continued

Full advantage of PLSS utilization could be realized by supporting two (2) crewmen on one PLSS in a buddy system approach as was employed for emergency lunar surface operation during the Apollo program. However, the Orbiter crew would be required to wear liquid cooling garments at all times in order to provide adequate crewman cooling unless a significant penalty is imposed on the PLSS to provide for gas cooling of two crewmen.

The addition of the vehicle water cooling subsystem allows for other uses, including crewman cooling during EVA preparation or while performing short-term experiment related tasks within a sortie lab which does not have an active temperature control system.

Based on a subjective evaluation of the parameters identified in Figure 13-20, the carry-on equipment concept appears to be the superior approach. However, additional study is required to quantify these parameters.

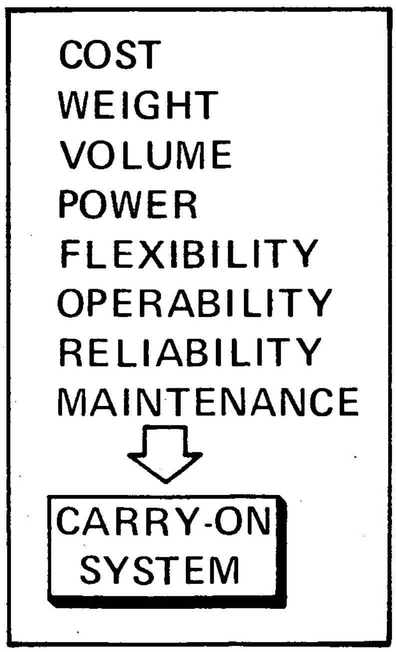


FIGURE 13—20. SUIT SUPPORT SYSTEM SELECTION

13.5.2 Depressurized Cabin On-Board Survival - Continued

The carry-on approach is believed to have lower cost, weight and volume than the integrated suit loop in addition to the following advantages:

a. Improved overall flexibility and capability since the equipment can be used for various other applications.

b. The amount of equipment carried on each flight can be tailored to specific flight needs (two men versus four men, for example).

c. Minimum changes are imposed on the basic EC/LSS to maintain its high reliability.

d. Equipment servicing can be performed off the vehicle thereby minimizing interference with vehicle servicing and maintenance operations.

13.6 Crew Transfer Phase

Completion of a rescue mission is achieved upon successful transfer of the crew from the failed Orbiter to the rescueing vehicle. The potential options for accomplishing the transfer is illustrated in Figure 13-21.

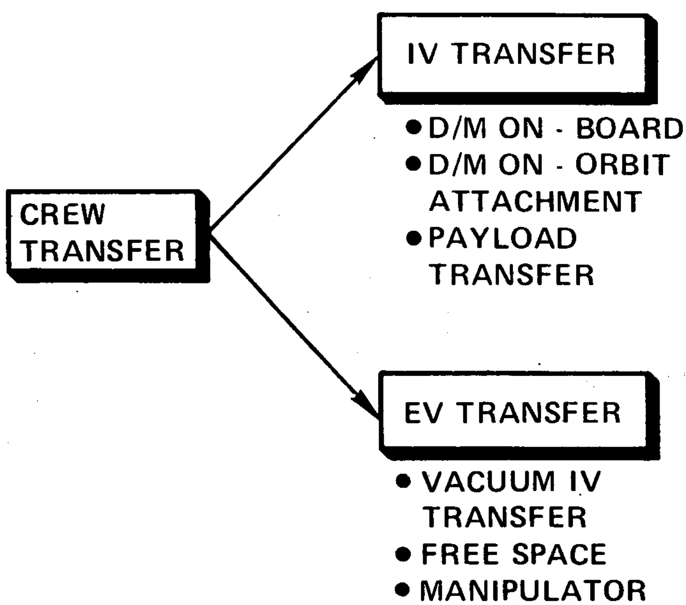


FIGURE 13-21. CREW TRANSFER OPTIONS

13.6 Crew Transfer Phase - Continued

Based on the selected options, the crew transfer requirements of Table 13-6 are established.

TIME FOR TRANSFER	1 HOUR
METABOLIC RATE	800 BTU/HR/MAN
CO_2 CONTROL	15 MM Hg MAX
PRESSURE CONTROL	8.5 PSIA MAX
O_2 PARTIAL PRESSURE	3.1 PSIA MIN
THERMAL CONTROL	300 BTU MAX HEAT STORAGE

TABLE 13–6. CREW TRANSFER REQUIREMENTS

The duration of transfer is based on a review of crew procedures including pressurization and repressurization of both airlocks and manual translation along the manipulator while carrying an injured crewman. A contingency factor of two (2) is applied to account for operations which cannot be identified at this time.

13.6 Crew Transfer Phase - Continued

Table 13-7 identifies potential equipment concepts for crew support during the crew transfer.

• PLSS - ONE CREWMAN PER UNIT - TWO CREWMEN PER UNIT
• MINI - EC/LSS - ONE CREWMAN PER UNIT - TWO CREWMEN PER UNIT
• ELSS

TABLE 13–7. CREW TRANSFER EQUIPMENT CONCEPTS

Use of the ELSS or the "mini-EC/LSS" will not satisfy the duration requirement without significant weight and volume penalties which are too great for this application which has such a low probability of occurrence. Use of the basic PLSS is recommended because it has ample capacity, a communications capability, a backup system, and at least two (2) units are available on each flight. The rescue vehicle could bring the additional PLSS's as required for transfer of the entire crew.

13.6 Crew Transfer Phase - Continued

Intravehicular (IV) transfer is possible if both vehicles have operable docking modules (D/M) which permit normal docking and crew transfer. If the failed vehicle does not have a docking module on board, it is conceivable that the rescue vehicle carry an extra docking module for on-orbit attachment to the failed vehicle through use of manipulators and EV crewmen. Another potential option is for the crew to enter an attached sortie lab having an integral life support system and transfer with the payload to the rescue vehicle by means of the manipulator. EV crewmen could be employed for payload detachment and attachment of the payload to the vehicles.

Extravehicular transfer concepts include free space transfer utilizing a propulsion system or by means of the manipulator end effector or by manual translation along the manipulator boom.

Of the options available, EV transfer is the recommended approach for establishing crew transfer requirements. The basis of this selection is as follows:

a. Sortie labs and docking modules are available on a few percentage of the flight.

b. IV transfer from a depressurized cabin or a contaminated cabin requires similar equipment as EV transfer since the docking module must be depressurized.

13.7 Emergency IV Summary Conclusions

Based on the results of the emergency IV study effort, the following conclusions are reached.

a. The Orbiter crew should be provided with equipment for protection from a depressurized and contaminated cabin condition.

   This requires that all personnel on board have breathing systems and pressure suits with appropriate support equipment.

b. The support equipment should provide for up to 96 hours of on-board survival.

c. The Orbiter should have the capability for cabin depressurization and nitrogen purge adequate to remove cabin contaminates.

d. The capability should be provided for administering food and water to a crewman in a pressurized suit and for the transfer of urine from a pressurized suit.

e. The Orbiter crew restraints and flight controls used for de-orbit and landing should be compatible with pressure suit operations.

f. The PLSS should be used for crew transfer during a Shuttle-to-Shuttle rescue.

g. Airlock hatches should remain open when an attached payload is manned unless a redundant escape route is available or long-term life support equipment is available within the payload.

h. The Orbiter avionics required for mission abort and Shuttle-to-Shuttle rescue should be operational during depressurized cabin conditions.

SECTION 14.0

DEVELOPMENT FLIGHTS

14.0 DEVELOPMENT FLIGHTS

14.1 General

The initial Shuttle flights involve greater risks than later flights as they are used to verify the structural and functional integrity of the orbiter for the first time following qualification under simulated use conditions. The Emergency IV findings and recommendations of section 13.0 apply to the development flights also. In addition, it is recommended that the crew fly with the pressure suits donned during the powered portions of the flights and with the suits donned less helmet and gloves during manipulator operations. Implementation of this recommendation will provide maximum crew protection as it provides redundant and independent life support protection, for the crewman, under all credible failure modes. This approach also results in a system having a known capability as opposed to a cabin system which is sized to accomodate an arbitrary maximum leakage following a malfunction.

In this section, the options available for crew support during suited flights are identified, the requirements are established and equipment concepts are recommended.

14.2 Crew Rescue Options

The first manned vertical flight is currently scheduled for March 1, 1978. During this flight, there may be no Shuttle vehicles capable of affecting a Shuttle-to-Shuttle rescue if the need should arise. For these early flights, the following options exist:

a. Carry an Apollo CSM as an escape and de-orbit vehicle.

b. Carry personal re-entry systems (cocoons).

c. Ready an Apollo CSM and launch vehicle and maintain in standby status during the Shuttle development flights.

d. Reschedule the early flights such that a rescue Shuttle and launch facilities can be available.

e. Take the risk.

14.2 Crew Rescue Options (Continued)

Selection of the most desirable option requires more data than is currently available including systems development and qualification data, horizontal and unmanned vertical test performance and the cost impacts associated with each option. It is apparent that the requirements for crew support should include sufficiently flexibility such that it does not constrain selection of any of the rescue options at a later date.

14.3 Crew Support Requirements

The requirements for crew support during suited development flights are:

a. Provide crew protection in a depressurized cabin or contaminated cabin for up to 96 hours.

b. Provide crewmen cooling while wearing a pressure suit (helmet and gloves off) in an environmentally controlled cabin.

The requirement for depressurized or contaminated cabin protection reflects the results of the Emergency IV effort discussed in Section 13.0 of this report. Support of suited crewmen in an environmentally controlled cabin is not a capability of the baseline Orbiter nor is it a requirement imposed on the equipment concepts discussed in Section 13.0. Since the crew may be required to wear pressure suits during critical mission phases, crewman cooling under these conditions is to be required.

14.4 Crew Support Concepts

The Emergency IV (Section 13.0) portion of this study identified two potential concepts for providing up to 96 hours of crew protection in a depressurized or contaminated cabin environment. These concepts were:

a. Integrated suit loop or carry-on equipment.

b. Breathing systems.

14.4 Crew Support Concepts (Continued)

The integrated suit loop shown schematically in Figure 14-1 has the capability of providing crew support for up to 96 hours.

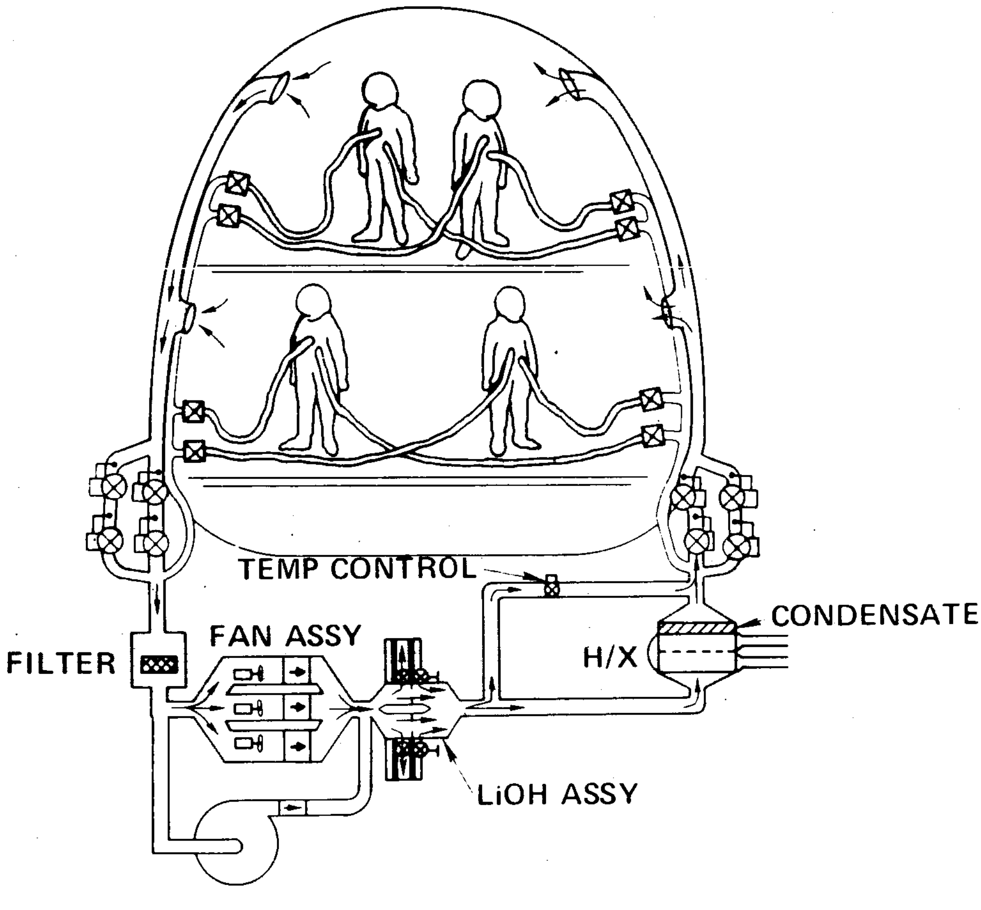


FIGURE 14—1. VEHICLE INTEGRATED SUIT LOOP

However, to satisfy the requirements for crewman cooling in a pressure suit under normal cabin conditions, additional impacts are imposed on the EC/LSS system. These impacts include:

14.4 Crew Support Concepts (Continued)

a. The addition of a flow restrictor in the vehicle cabin duct to force flow to the pressure suit. This restriction may significantly reduce the amount of cabin ventilation and avionics cooling. It also increases EC/LSS fan power consumption and may affect the response of the system such that high humidity and CO_2 levels exist in the cabin.

b. Degraded cabin ventilation, in addition to that caused by the restrictor, due to simultaneous operation of the cabin and suit loop fans. The suit loop fan, having a greater pressure rise capability than the cabin fans, could back pressure the cabin fans such that a low flow condition exists with a simultaneous high power consumption.

The above impacts can be avoided by using the suit ventilator (modified to add a pressure actuate isolation valve as shown in Figure 14-3) to provide to crewman cooling while suited with helmet and gloves off. The suit loop would then be used solely for support of depressurized cabin conditions.

14.4 Crew Support Concepts (Continued)

The Emergency IV concept shown in Figure 14-2 represents a carry-on equipment approach for crew support during the suited flight modes. The concept, discussed in detail in Section 13.0, utilizes a vehicle cooling system to support carry-on equipment such as the PLSS or a "Mini-ECS".

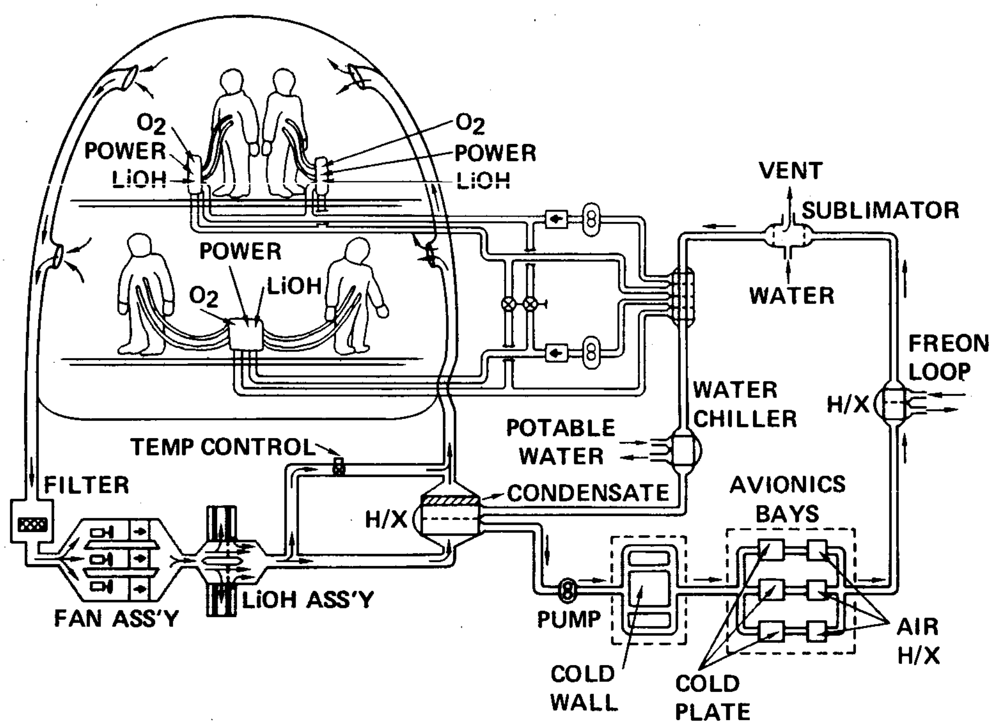


FIGURE 14–2. CARRY ON EQUIPMENT

14.4 Crew Support Concepts (Continued)

Figure 14-3 shows the PLSS concept with the addition of the suit ventilator to provide crewman cooling by forcing cabin air through the suit during the suited operational modes. An isolation valve is added to the inlet to the suit ventilator which closes immediately in the event of a rapid cabin decompression. This valve is the only modification required over that recommended for support of Emergency IV modes. Secondly, this concept utilizes the suit ventilator which is required for operational Shuttle flights.

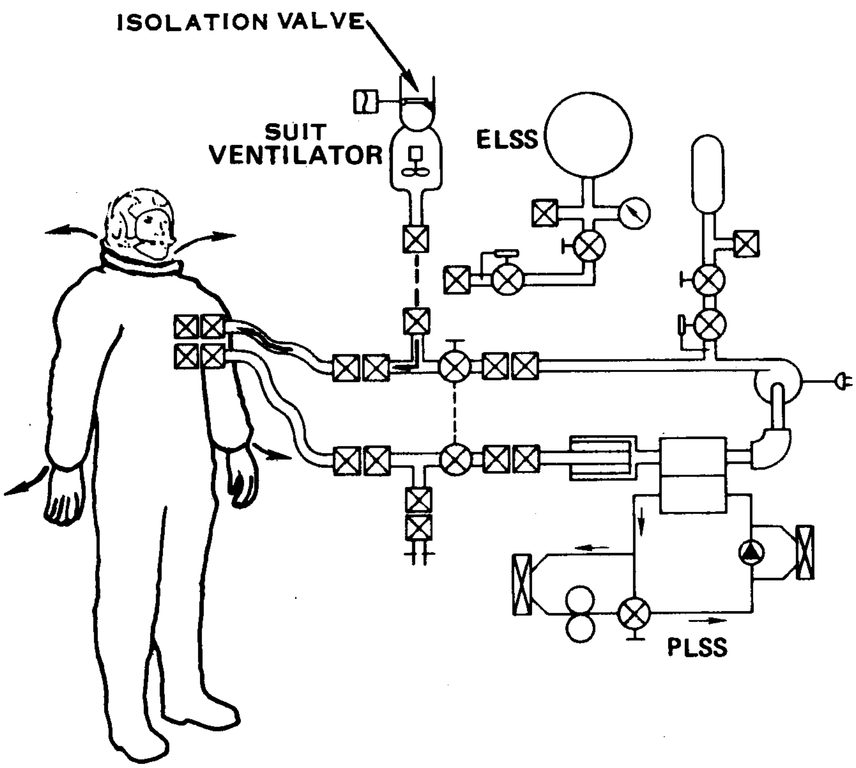


FIGURE 14–3. SUITED OPERATION—PLSS SUPPORT

14.4 Crew Support Concepts (Continued)

Figure 14-4 shows the use of the "Mini'ECS" to support suited development flights as well as depressurized cabin operation. For suited development flights, an isolation valve is added at the fan inlet to provide for an inflow of cabin air which is forced through the suit for crewman cooling. As in the PLSS concept, this pressure actuated valve clcses to protect the crewman in the event of a rapid cabin decompression.

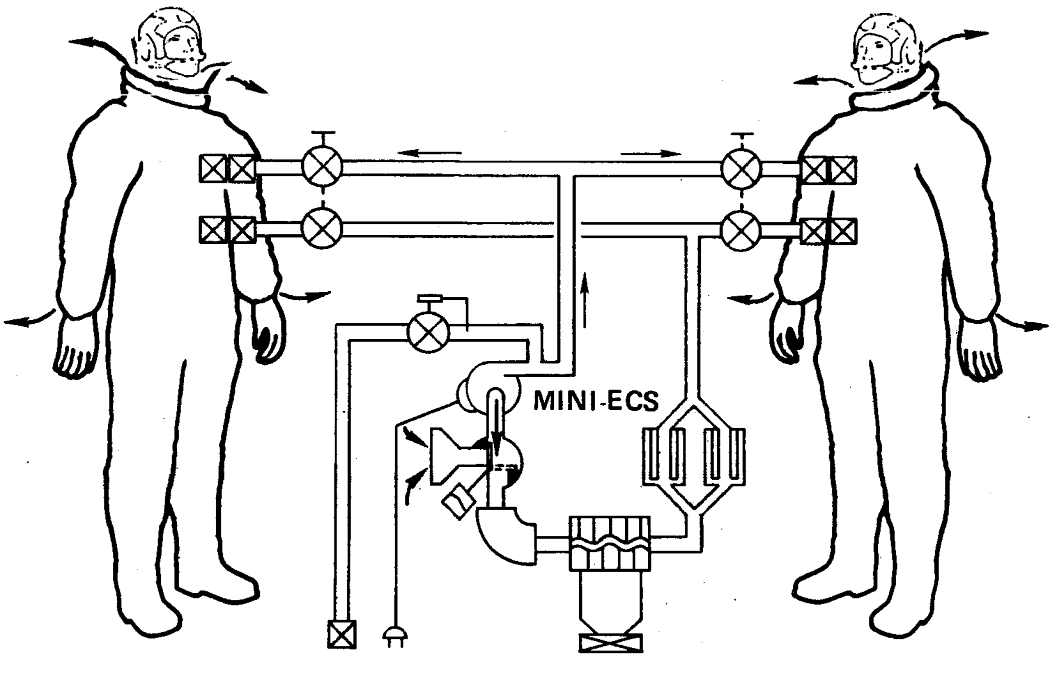


FIGURE 14-4. SUITED OPERATION—MINI ECS SUPPORT

14.4 Crew Support Concepts (Continued)

A review of the concepts for support of development flights can be summarized as follows:

a. The integrated suit loop can satisfy the 96 hours of emergency operation but should not be used to provide cooling of a suited crewman in an environmentally controlled cabin.

b. The carry-on "Mini-ECS" can be used to support the 96 hours of emergency operation and the suited modes with the addition of a pressure actuated isolation valve.

c. The PLSS concept can be used to support the 96 hours of crew support but requires the use of the suit ventilator for cooling of a suited crewman, in an environmentally controlled cabin.

14.5 Summary

This study has identified several equipment concepts which could be used to support the crewmen during suited development flights. Final selection of the equipment require more detailed trade studies and should be conducted in conjunction with the additional Emergency IV studies recommended in section 13.0 of this report.

SECTION 15.0

VEHICLE INTERFACES

15.0 VEHICLE INTERFACES

15.1 General

The interfaces between the EVA system and the spacecraft are key considerations in establishing an operational space system such as the Space Shuttle. Well defined interface requirements serve to simplify EVA crewman and Orbiter crewmen operations, minimizes EVA system and Orbiter system complexity, weight, and volume and increase the flexibility of the Space Shuttle Program. Throughout the study, interface coordination was maintained with the Orbiter contractor, North American Rockwell. This coordination provided continuous updating of crew compartment configuration and supporting vehicle system requirements and capabilities.

This section summarizes the effort performed to establish the interface requirements for EVA/IVA equipment preparation, stowage, and servicing during the Space Shuttle flights.

The task analysis portion of this study (Section 4.0) shows that the Orbiter should provide for a maximum of 32 manhours of EVA expendables and six (6) airlock depressurizations/ repressurizations. These requirements serve as a baseline for establishing the vehicle interface requirements.

As indicated by Figure 15-1, the vehicle interfaces are identified by review of:

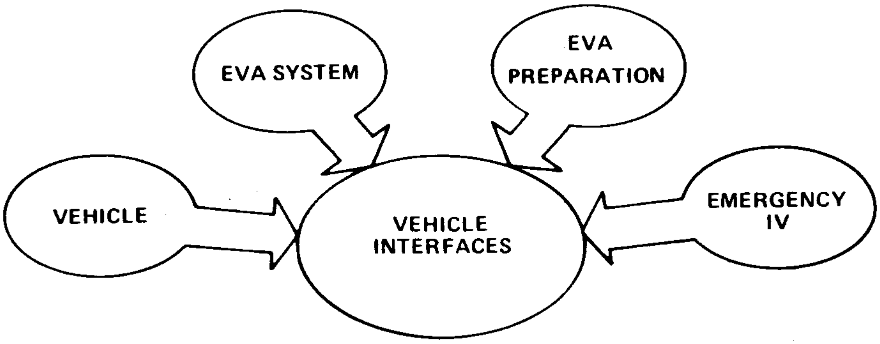
a) The vehicle configuration and capabilities

b) The EVA system configuration and needs

c) The tasks, support system and sequences for EVA preparation

d) The equipment considerations for support of Emergency IV modes.

15.1 General - Continued



- EVA PREP SUPPORT SYSTEMS
- STOWAGE REQ'TS
- COMMUNICATIONS & MONITORING
- AIRLOCK
- MOBILITY AIDS

FIGURE 15–1. VEHICLE INTERFACES

15.1.1 Vehicle Considerations

The Orbiter configuration as of December, 1972, is shown in Figure 15-2 which consists of the cabin, airlock and payload bay. These areas are potential locations where interfaces with the EVA system could exist. The cabin, consisting of an upper and lower level, is pressurized to 14.7 psia air with active temperature, humidity and CO_2 control. From the upper level, flight operations are performed including both vertical and horizontal flight operations. The Orbit Station is located at the aft portion of the upper level where the crewman controls manipulator operations. The lower level contains provisions for passengers, food preparation, waste management, avionics equipment and the airlock. The airlock allows crew members to transfer from the cabin to the attached payload or to perform EVA tasks without affecting the cabin environment. The payload bay is baselined to be 15 feet in diameter by 60 feet ling. Two doors cover half of the payload bay circumference during all mission phases except orbital operations which require that the doors be open to expose the radiators which are also deployable.

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15.1.1 Vehicle Considerations - Continued

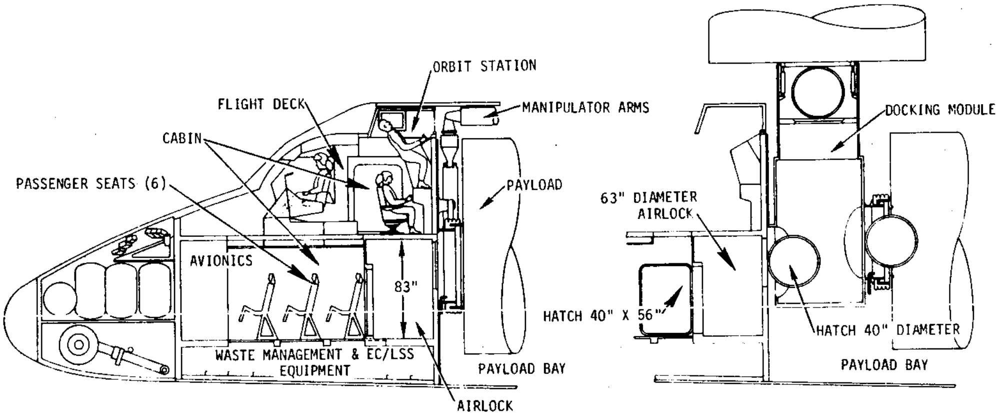

FIGURE 15-2. ORBITER CONFIGURATION

A docking module is carried on missions requiring docking to payloads for on orbit servicing such as LST revisit missions. The docking module is attached to the airlock to allow crew and equipment transfer between the payload and the cabin.

15.1.2 EVA System

The EVA system shown in Figure 15-3 identifies several items and functions with potential interfaces with the vehicle. Although most of the items identified are stowage interfaces, definition of functional interface requirements such as communications and recharging systems are essential for establishing the basic vehicle design requirements.

15.1.2 EVA System - Continued

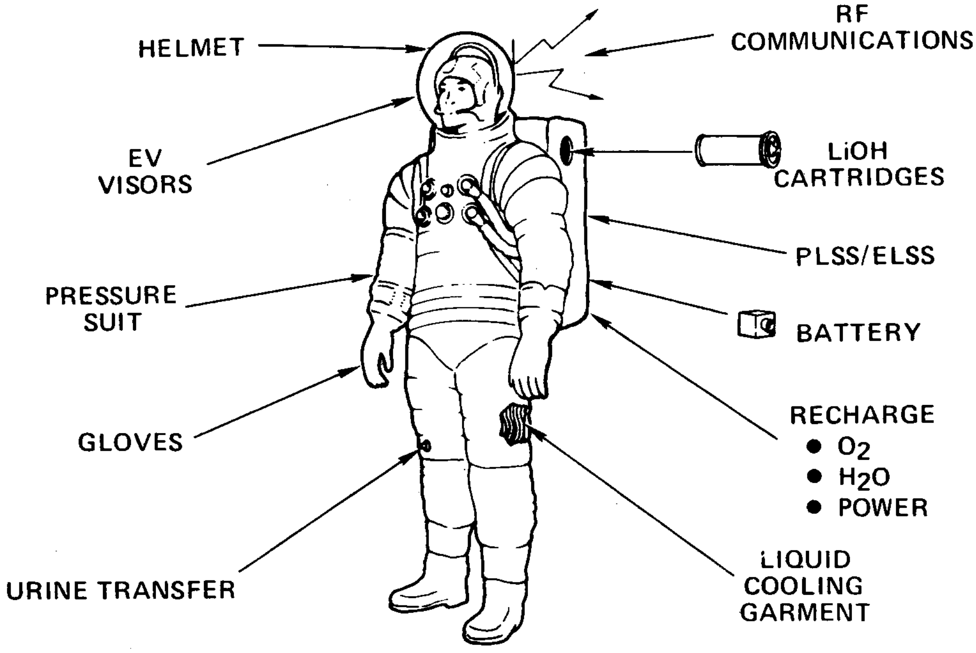

FIGURE 15–3. EVA SYSTEM

15.2 EVA Preparation Support Systems

EVA preparation includes all crew activities to prepare the equipment for an EVA and, upon completion, to prepare for a subsequent EVA. During these activities, the majority of EVA system-to-vehicle interfaces are apparent including stowage locations, donning/doffing locations, supporting vehicle system usage during EVA system check-out and recharge. To ensure complete identification of these interfaces, the crewman operations performed for EVA preparation were broken into sequences and then analyzed individually to identify the EVA equipment and vehicle equipment involved with each sequence and the perferred locations of conduct of the activity. Table 15-1 is a sample of the approach taken for analysis of the activities from equipment donning through egress for conduct of an EVA.

SEQUENCE	EVA EQUIPMENT INVOLVED	SUPPORT PROVISIONS REQUIRED	POTENTIAL CHANGES OF SEQUENCE	PERFERRED VEHICLE LOCATIONS FOR OPERATIONS	CREW TASKS	PERFORMANCE CHECKS ACCOMPLISHED	ESTIMATED TIME TO COMPLETE
UNDERGARMENT DONNING	URINE COLLECTION ASSEMBLY LIQUID COOLING GARMENT	SEE NOTE 1	NONE - EXCEPT USE OF URINE COLLECTION ASS'Y IS CREW OPTION	CABIN	REMOVE EVA EQUIP. FROM STOWAGE AND DON	NONE	4 MINUTES
PRESSURE SUIT DONNING	PRESSURE SUIT UPPER AND LOWER SECTIONS	SEE NOTE 1 SUIT VENTILATION AFTER DONNING DONNING STATION OR CREWMAN ASSISTANCE	NONE	CABIN	REMOVE EVA EQUIP. FROM STOWAGE AND DON INTERNAL CONNECTION OF UNDERGARMENTS TO PRESSURE SUIT CONNECTION AND OPERATION OF SUIT VENTILATOR	VENTILATOR OPERATION	5 MINUTES
ELSS CHECK-OUT	PLSS/ ELSS	SEE NOTE 1	MAY BE PERFORMED AFTER REMOVAL FROM STOWAGE AND BEFORE PRESSURE INTEGRITY CHECK	CABIN	REMOVE PLSS/ ELSS FROM STOWAGE OPEN AND CLOSE ELSS SHUT-OFF VALVE READ GAGE	ELSS O_2 SUPPLY QUANTITY ELSS O_2 REGULATOR PERFORMANCE	2 MINUTES
PLSS/ ELSS DONNING	PLSS/ ELSS	SEE NOTE 1 PLSS DONNING STATION OR CREWMAN ASSISTANCE	NONE	CABIN OR AIRLOCK	CONNECT PLSS AND ASSOCIATED UMBILICALS TO PRESSURE SUIT		3 MINUTES
CONNUNICATIONS CHECK	PLSS/ ELSS COMMUNICATIONS CARRIER PRESSURE SUIT	VEHICLE COMM. T/M SYSTEMS	NONE	CABIN OR AIRLOCK	DON COMM. CARRIER CONNECT TO SUIT WIRING PLSS/ELSS ANTENNA DEPLOYMENT OPERATE COMM. CONTROLS READ O_2 SUPPLY AND BATTERY VOLTAGE VERIFY SUIT PRESSURE WARNING	COMM. & T/M OPERATION VOLUME CONTROL T/M DISPLAY & RELAY SUIT PRESSURE WARNING BATTERY VOLTAGE O_2 SUPPLY PRESS. BATTERY CURRENT (THRU T/M)	6 MINUTES
PRESSURE INTEGRITY CHECK	ENTIRE EVA SYSTEM	SEE NOTE 1 VEHICLE LIQUID COOLING SYSTEM	NONE	AIRLOCK	REMOVE HELMET, EV VISORS AND GLOVES FROM STOWAGE & DON CONNECT PURGE VALVE CONNECT VEHICLE LIQUID COOLING AND ACTUATE DISCONNECT SUIT VENTILATOR OPERATE PLSS O_2 & TEMP. CONTROLS READ O_2 GAGES VERIFY CO_2 WARNING OPERATE PLSS PUMP AND FAN CONTROLS	PLSS TEMP. CONTROL PLSS PRESSURE CONTROL PLSS CO_2 CONTROL SYSTEM PRESSURE INTEGRATE PLSS FAN AND PUMP OPERATION FULL LOAD VOLTAGE FULL LOAD CURRENT (VIA T/M) CO_2 WARNING	5 MINUTES
AIRLOCK DEPRESSURIZATION	ENTIRE EVA SYSTEM	SEE NOTE 1 AIRLOCK HATCHES & CONTROLS	NONE	AIRLOCK	CLOSE AND LOCK AIRLOCK INTERNAL HATCH DEPRESSURIZE AIRLOCK ACTUATE PLSS THERMAL CONTROL SUBSYSTEM VISOR ADJUSTMENT PLSS CONTROLS OPERATIONS SYSTEM STATUS VERIFICATION EXTERNAL HATCH OPENING DISCONNECTION FROM VEHICLE LIQUID COOLING SYSTEM EGRESS VERIFY COMM. & T/M OPERATION	PLSS THERMAL CONTROL PERFORMANCE SYSTEM OPERATION THRU: VISUAL DISPLAYS WARNING SYSTEMS CREWMAN COMFORT PERFORMANCE OF EVA SYSTEM/VEHICLE COMM. AND T/M SYSTEMS	3 MINUTES

NOTE 1: VEHICLE SUPPORT PROVISIONS ALSO INCLUDE CREWMAN RESTRAINT DURING EVA PREPARATION. EQUIPMENT RESTRAINTS OR TEMPORARY STOWAGE PROVISIONS ARE NEEDED FOR ITEMS WHICH CANNOT BE REMOVED FROM STOWAGE AND PLACED DIRECTLY IN THE EVA SYSTEM. FOR EXAMPLE, THE HELMET AND GLOVES MUST BE STOWED IN THE CABIN BUT ARE DONNED IN THE AIRLOCK. THEREFORE, TEMPORARY STOWAGE OR RESTRAINT IS REQUIRED IN THE AIRLOCK.

TABLE 15-1. EVA PREPARATION ANALYSIS

15.2 EVA Preparation Support Systems - Continued

As a result of this review, the perferred locations for performing the various activities are identified as shown in Figure 15-4. Donning of equipment in the cabin rather than the airlock is recommended for the following reasons:

a) Emergency IV considerations recommended suit and PLSS stowage in the cabin.

b) minimizes the size and weight of the basic airlock.

c) Provides maximum donning and doffing volume for the crew.

d) Airlock stowage restricts the passageway during shirt sleeve crew and equipment transfer between the payloads and cabin.

e) Equipment donning in vicinity of equipment stowage locations minimizes the need for interim stowage facilities and equipment handling.

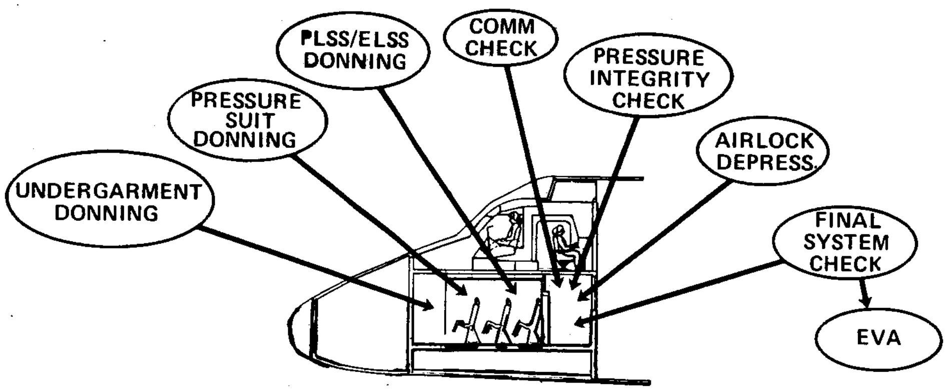

FIGURE 15—4. PRE EVA PREPARATION

15.2 EVA Preparation Support Systems - Continued

Figure 15-5 represents an estimate of the time required for two men to prepare for EVA.

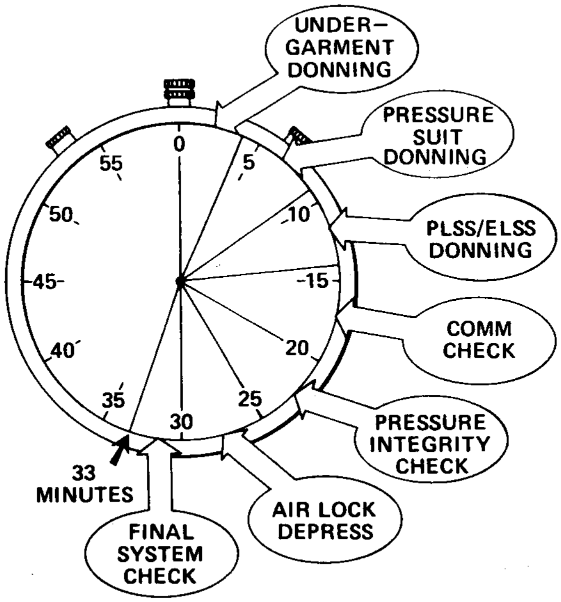

FIGURE 15—5. EVA PREPARATION TIMELINE

A similiar review of post EVA operations further identifies the perferred locations for equipment shut-down, doffing and recharge operations as indicated by Figure 15-6.

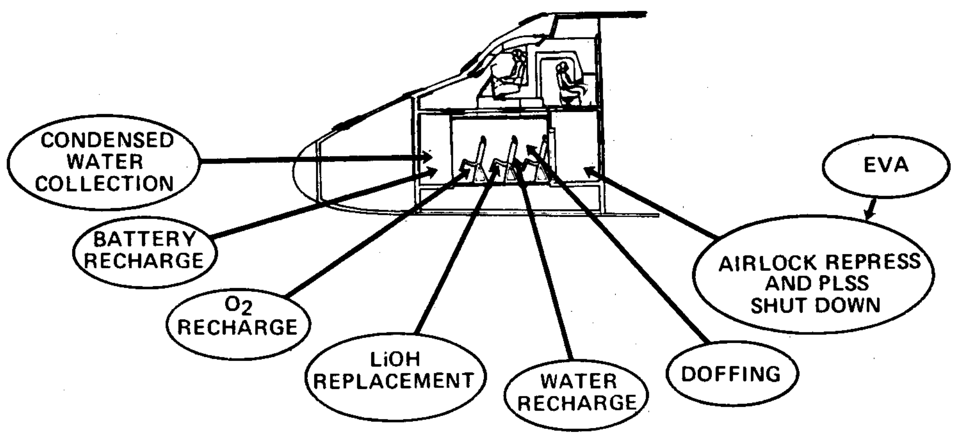

FIGURE 15—6. POST EVA PREPARATION

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15.2 EVA Preparation Support Systems - Continued

The EVA preparation analysis also serves to identify the supporting functions required as part of EVA preparation. Figure 15-7 identifies the type of support functions and when its use is required during the EVA preparation sequences.

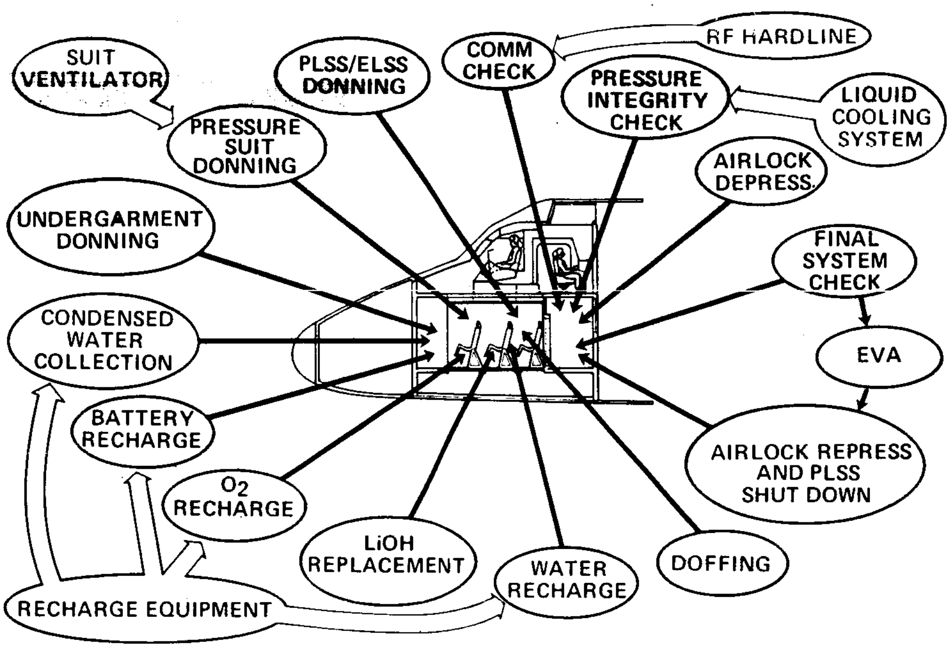


FIGURE 15–7. EVA PREPARATION SUPPORT FUNCTIONS

The following support functions are required:

a) Suit Ventilator - Provides suit ventilation for crewman cooling after pressure suit donning. The ventilator remains on until liquid cooling is initiated as part of the pressure integrity check sequence.

b) RF Hardline - Provides an RF link between the EVA crewman and the vehicle communications systems while the crewman is in the airlock. It may be found, as in Apollo, that an RF link exists without the hardline. However, equipment tests are required for verification.

15.2 EVA Preparation Support Systems - Continued

c) Liquid Cooling System - Provides crewman cooling during the pressure integrity check and remains in use until activation of the PLSS expendable water cooling system.

d) Recharge Equipment - Provides for replenishment of PLSS expendable water, oxygen and power following each EVA.

e) Condensed Water Collection - Provides for transfer of condensed water from the PLSS to vehicle systems.

The requirements of each of the above functions are specified in the following paragraphs.

15.2.1 Suit Ventilator

The suit ventilator recommended for use on Shuttle is shown in Figure 15-8 which basically consists of a fan with an interface umbilicals for the suit and the vehicle power source. The suit umbilical is short umbilical whose length allows mounting of the ventilator to the suit. The power cable is of sufficient length to allow the ventilator/vehicle electrical connection to be made in the airlock and provide suit ventilation after suit donning in the cabin area. This concept was selected after comparison of the following concepts.

a) A wall mounted ventilator assembly which is connected to two (2) suits by long gas umbilicals.

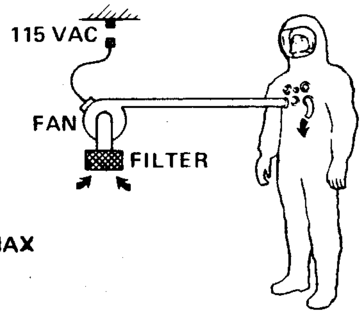
b) Two ventilators (one for each suit) with short gas umbilicals and long electrical cords.

c) One ventilator assembly with a long electrical cord and connected to two suits by moderate length gas umbilicals.

d) A wall mounted ventilator which is connected to a hard mounted distribution duct. The suits are connected to the duct by short flexible umbilicals.

e) Two wall mounted ventilators connected to each suit by long gas umbilicals.

15.2.1 Suit Ventilator - Continued



REQUIREMENTS

- FLOW RATE: 10 ACFM
- PRESSURE RISE: 20 IN OF H_2O
- POWER CONSUMPTION: 70 WATTS MAX

OTHER POTENTIAL USES

- SUIT DRYER
- SUITED DEVELOPMENT FLIGHTS
- EMERGENCY IV
- VACUUM CLEANER
- SUPPLEMENTAL COOLING FOR EXPERIMENTS

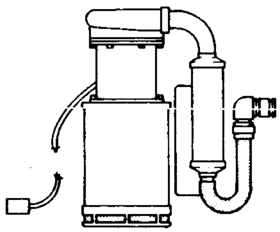


FIGURE 15–8. SUIT VENTILATOR

The power source of 400 vac is recommended over the 28 vdc supply to minimize fan weight, volume and cost.

The suit ventilator also has the capability to perform other functions as indicated by Figure 15-7. Following an EVA, the unit can be used to dry the pressure suit and LCG by forcing cabin conditioned air through the pressure suit. Under worst case conditions of suit dampness, and cabin humidity, a maximum of 6 1/2 hours is required for suit drying.

Other potential uses include suit ventilation during suited development flight and during Emergency IV modes in conjunction with other support equipment.

During the Apollo Program a need for a vacuum cleaner was identified to remove dust from each crewman upon ingress from the lunar surface. For Shuttle, the suit ventilator could be used for removing dust and lint particles from crewmen prior to entering payloads such as an LST servicing module which have cleanliness requirements more stringent than those of the cabin.

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15.2.1 Suit Ventilator - Continued

For Sortie missions, the unit could be used to provide air circulation within Sortie Labs which do not have EC/LSS capabilities. Secondly, the unit could be used to provide supplemental air cooling of experiment related electronic packages.

15.2.2 RF Hardline

As previously indicated by Figure 15-4, the communications check takes place in the airlock. The RF communciations from the EVA system may be shielded from Orbiter antenae by the metallic enclosure of the airlock as indicated by Figure 15-9.

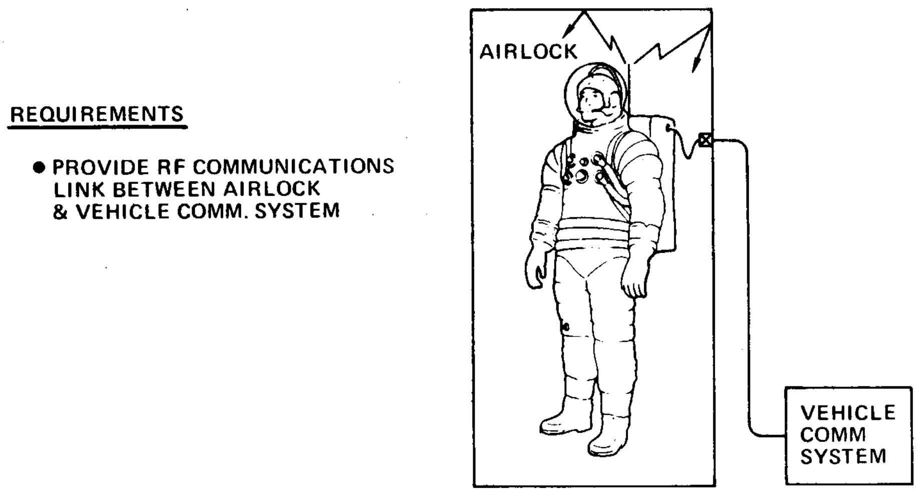


FIGURE 15—9. RF HARDLINE

Communications between EVA crewmen in the airlock and Orbiter or Ground Personnel is assured by means of an RF hardline which provides a direct link to the vehicle communciations system. This requirement does not impose significant penalties to the Orbiter since similiar provisions are required for support of payloads.

15.2.2 RF Hardline - Continued

It is pointed out that a similiar provision was baseline for the Lunar Module but equipment tests verified that an RF link was available through direct radiation rather than by the hardline. It is recommended that the hardline be baseline for the Orbiter.

15.2.3 Cooling System

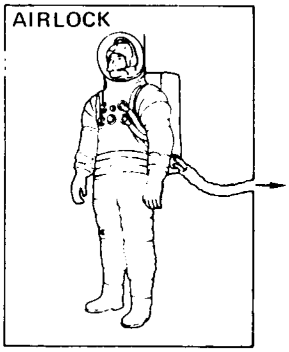
The Emergency IV effort, discussed in Section 13.0, concluded that the incorportion of a cooling system for use with carry-on support equipment is a viable candidate for crew support under depressurized cabin conditions. A similiar cooling system is highly desireable for crewman and equipment cooling during EVA preparation activities. As part of the pressure integrity check, the crewman is fully enclosed in the suit with the PLSS fan operating for CO_2 removal.

None of the heat generated by the man (600 btu/hr), LiOH (165 btu/hr), or fan (130 btu) is dissipated until the PLSS thermal control system is activated. The use of the liquid cooling system provides crewman and equipment cooling and minimizes total system heat load during the PLSS start-up.

Since the liquid cooling system is can be used for Emergency IV and for EVA preparation, it is recommended that it be included in the Orbiter baseline. Figure 15-10 summarizes the performance requirements for the cooling system under operating modes of EVA preparation and Emergency IV.

REQUIREMENTS

	EVA PREP	EMERG IV
HEAT LOAD	2100 BTU/HR	3600 BTU/HR
FLOW RATE (EACH PUMP)	240 LBS/HR	240 LBS/HR
PRESSURE RISE	5.0 PSI	5.0 PSI
TEMPERATURE	55 – 60° F	55 – 60° F



OTHER POTENTIAL USES

- EMERGENCY IV
- SUITED DEVELOPMENT FLIGHTS
- SUPPLEMENTAL COOLING
- IV SERVICING

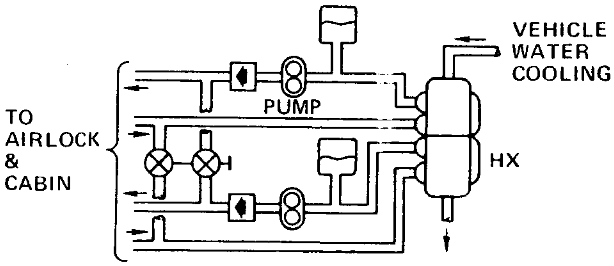


FIGURE 15–10. COOLING SYSTEM

15.2.3 Cooling System - Continued

Another potential use of the cooling system is for IV servicing of the unpressurized LST concept. Heat removal by the umbilical prevents the condensation of water vapor on the interior surfaces of the LST.

15.2.4 Recharge Equipment

The results of the task analysis portion of the study concluded that the Orbiter should provide a maximum of 32 man-hours of EVA support and six (6) airlock depressurizations/repressurizations. These findings coupled with the need to minimize vehicle weight and volume penalties are primary considerations for establishing the expendable quantities and condition and the recharge methods.

The study considered the use of a recharge station where the PLSS would be placed during refurbishment of all expendables. After consideration of EVA preparation, Emergency IV, and stowage requirements, it is recommended that recharge of the PLSS's be performed in the PLSS stowage location. This recommendation is based on the following:

a) Minimizes vehicle interfaces. A separate dedicated recharge station requires duplication of vehicle support structure with associated weight and volume penalties.

b) Minimizes equipment handling. An integrated stowage/recharge station requires less equipment handling than required for a separate recharge station.

Based on the above recommendation, the following requirements should be imposed on the Orbiter.

a) The PLSS stowage/recharge station should allow for complete PLSS servicing including replacement of LiOH cartridges and batteries, removal of condensed water, and recharge of oxygen, water and battery while the PLSS remains in the stowage/recharge station.

b) The Orbiter should be capable of simultaneous servicing of both PLSS's.

15.2.4.1 Water Recharge

Table 15-2 summarizes the expendable water required to support the EVA requirements.

15.2.4.1 Water Recharge - Continued

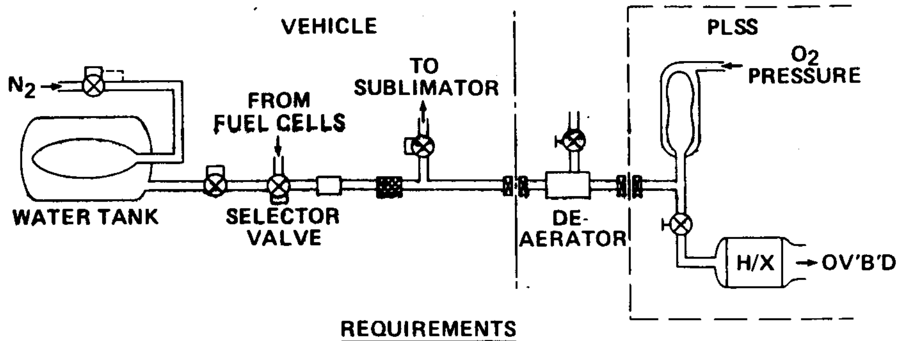
COOLING REQUIREMENTS FOR EVA OPERATIONS	
A. METABOLIC COOLING	1000 BTU/HR
B. BEAT LEAK	300 BTU/HR
C. LIOH COOLING	276 BTU/HR
D. ELECTRICAL (60 WATTS)	204 BTU/HR
TOTAL HEAT LOAD PER MAN-HOUR	1780 BTU/HR
WATER REQUIRED PER MAN-HOUR	1.73 LBS
TOTAL WATER FOR 32 MAN-HOURS	55.4 LBS
COOLING REQUIREMENT RESULTING FROM PRE-EGRESS CHECK-OUT	
A. FAN HEAT (10 WATT HOURS)	34 BTU
B. COMMUNICATIONS SYSTEM HEAT (6 WATT HOURS)	20 BTU
TOTAL PER MAN PER CHECK-OUT	54 BTU
TOTAL WATER PER MAN PER CHECK-OUT	0.05 LBS
TOTAL FOR SIX (6) CHECK-OUTS*	0.50 LBS
TOTAL WATER REQUIRED	
55.4 LBS + 0.50 LBS =	55.9 LBS

* ASSUMES DUAL EVA AND PLSS'S ARE FULLY CHARGED PRIOR TO LAUNCH.

TABLE 15—2. WATER REQUIRED TO SUPPORT EVA

Figure 15-11 schematically defines the recharge system and associated requirements. The vehicle portion of the schematic is representative of the Orbiter baseline system. The water temperatures and pressures are specified to ensure compatibility with the vehicle. The PLSS may require de-aeration of the expendable water depending on the type of expendable water PLSS subsystem employed. A flash evaporator system may require no de-aeration whereas a water boiler may require removal of a high percentage of dissolved gases. Detail requirements for the de-aerator (if required) can be established after selection of the PLSS heat rejection device.

15.2.4.1 Water Recharge - Continued



REQUIREMENTS

- QUANTITY
  - MAXIMUM PER RECHARGE — 8.06 LBS
  - MAXIMUM PER FLIGHT — 55.9 LBS
- SUPPLY PRESSURE — 33 PSIA
- SUPPLY TEMPERATURE — 35 TO 100°F
- QUALITY — PER NASA SPEC – PF-SPEC-1 CONTAINING:
  - DISSOLVED N_2 @ 33 PSIA
  - SILVER IONS 50 PPB

FIGURE 15–11. WATER RECHARGE

15.2.4.2 Oxygen Recharge

Table 15-3 summarizes the oxygen quantities required from the Orbiter to satisfy the EVA support requirements.

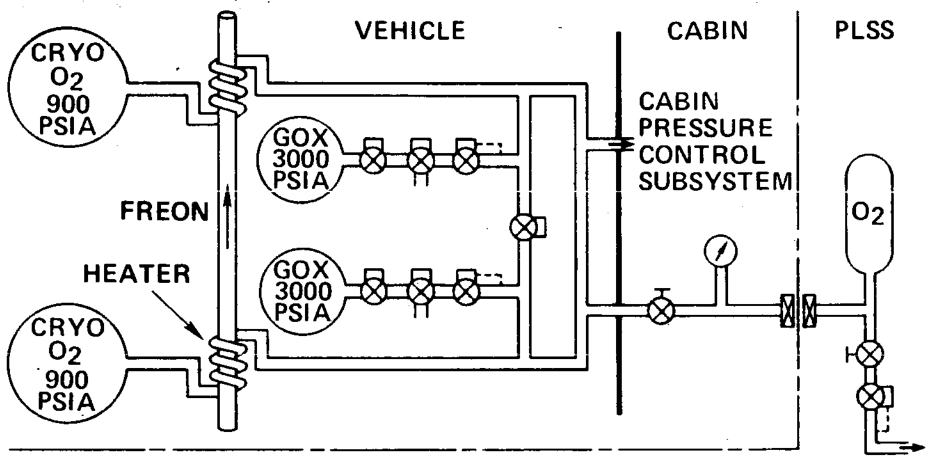
OXYGEN REQUIRED FOR EVA OPERATION	
A. METABOLIC CONSUMPTION	0.175 LBS/HR
B. SYSTEM LEAKAGE	0.0175 LBS/HR
TOTAL OXYGEN PER MAN-HOUR	0.1925 LBS
TOTAL OXYGEN FOR 32 MAN-HOURS	6.16 LBS
OXYGEN REQUIRED FOR PRE-EGRESS OPERATIONS	
A. METABOLIC DURING PRE-EGRESS CHECK-OUT	0.035 LBS
B. LEAKAGE CHECK	0.090 LBS
C. H_2O RESERVOIR PRESSURIZATION	0.058 LBS 0.058 LBS
TOTAL PER MAN PER CHECK-OUT	.183 LBS
TOTAL FOR SIX (6) CHECK-OUTS*	1.83 LBS
TOTAL OXYGEN REQUIRED	
6.16 LBS + 1.83 LBS =	7.99 LBS

* ASSUMES DUAL EVA'S AND PLSS'S ARE FULLY CHARGED PRIOR TO LAUNCH.

TABLE 15–3. OXYGEN REQUIRED TO SUPPORT EVA

15.2.4.2 Oxygen Recharge - Continued

The PLSS subsystem studies (Section 7.0) concludes that 900 psia is the perferred O_2 recharge pressure since it minimizes vehicle weight and volume penalties with an acceptable volume penalty to the PLSS. Figure 15-12 is a schematic representation of the oxygen recharge system which requires no changes to the baseline Orbiter O_2 supply subsystem.



REQUIREMENTS

• QUANTITY	
MAXIMUM PER RECHARGE	1.04 LBS
MAXIMUM PER FLIGHT	7.99 LBS
• PRESSURE	900 + 20 PSIA
• TEMPERATURE	80°F MAX
• QUALITY	MIL-O-27210B

FIGURE 15-12. OXYGEN RECHARGE

15.2.4.3 Battery Recharge

Table 15-4 summarizes the power to be supplied by the vehicle for PLSS battery recharges.

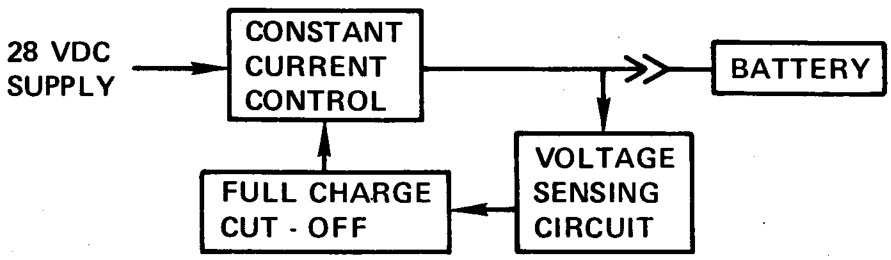
15.2.4.3 Battery Recharge - Continued

POWER REQUIRED FOR EVA OPERATION	
A. TOTAL PER MAN-HOUR	60 WATTS
B. TOTAL FOR 32 MAN-HOURS	1920 WATT HOURS
POWER REQUIRED FOR PRE-EGRESS OPERATIONS	
A. TOTAL PER MAN PER CHECK-OUT	16 WATT HOURS
B. TOTAL FOR SIX (6) CHECK-OUTS*	160 WATT HOURS
TOTAL POWER REQUIRED	
1920 WATT HOURS + 160 WATT HOURS	2080 WATT HOURS

* ASSUMES DUAL EVA'S AND PLSS'S FULLY CHARGED PRIOR TO LAUNCH.

TABLE 15—4. POWER REQUIRED TO SUPPORT EVA

Figure 15-3 is a schematic representation of a battery charger. It uses the constant current recharge method which is the perferred method for recharge of silver zinc batteries.



REQUIREMENTS

- POWER
  - MAXIMUM PER RECHARGE — 260 W - HOURS
  - MAXIMUM PER FLIGHT — 2080 W - HOURS
- CHARGING TIME — 16 HOUR MAX/BATTERY
- CHARGING METHOD — CONSTANT CURRENT
- CUT - OFF VOLTAGE — 18 - 24 VDC

FIGURE 15—13. BATTERY RECHARGE

15.2.4.3 Battery Recharge - Continued

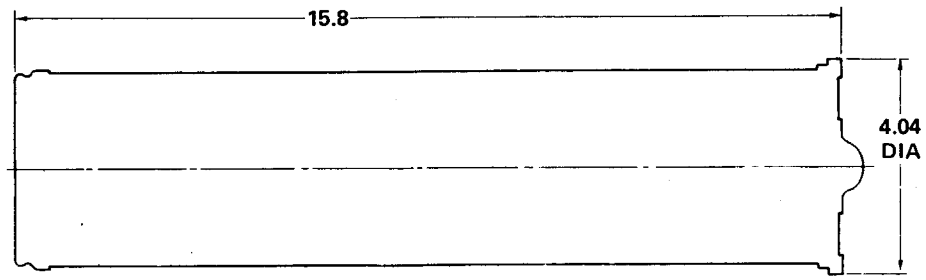
Completion of recharge is signified by a rapid increase of battery voltage which is used for battery charger cut-off. Since the optimum battery voltage is within the range of 13.5 to 18 volts, the cut-off voltage will range between 18.0 and 24 volts.

The weight and volume of a battery recharger are not affected significantly over the voltage ranges considered.

A charging time of 16 hours is required between EVA's for each battery. It is expected that the Shuttle flight will normally only require one EVA per day which is compatible with the 16 hour recharge capability. For those few flights where a higher EVA frequency is expected two (2) additional batteries can be stowed on the Orbiter and can be used for EVA while the other two batteries are being recharged.

15.2.5 LiOH Replacement

The replacement of LiOH cartridges following each EVA is accomplished by manually removing the cartridge, having an envelope as shown in Figure 15-14, and installing a new cartridge obtained from vehicle stowage.

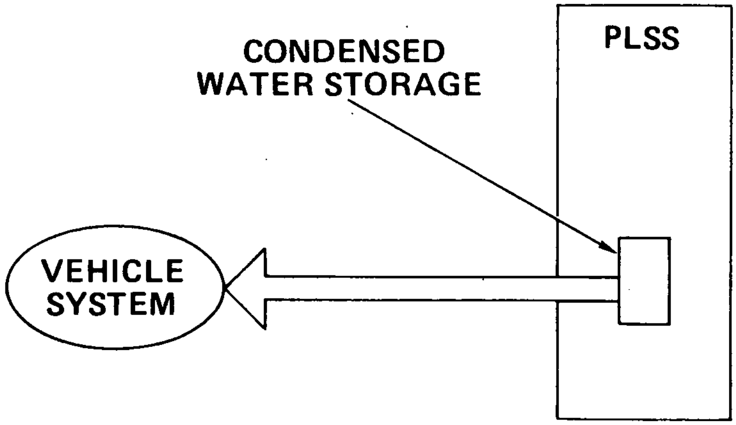


ESTIMATED WEIGHT 3.0 LBS

FIGURE 15—14. LiOH CARTRIDGE ENVELOPE

15.2.6 Condensed Water Collection

During EVA operations, humidity control is achieved by condensing the excessive water vapor, separating the condensed water from the suit ventilation flow and then storing the condensate within the PLSS. As part of PLSS servicing following each EVA, the condensed water must be removed from the PLSS and delivered to the vehicle. Figure 15-15 shows the quantities of water to be transfered. It is based on manned test data obtained from the Apollo Program which used a system similar to the system recommended for Shuttle EVA.



QUANTITIES

MAXIMUM PER TRANSFER	1.46 LBS
MAXIMUM PER FLIGHT	11.6 LBS

FIGURE 15–15. CONDENSED WATER COLLECTION

15.3 Stowage Requirements

The purpose of this section is to identify the EVA equipment to be stowed on board the Orbiter. The equipment size, weight perferred stowage location and any potential stowage constraints are identified.

15.3 Stowage Requirements - Continued

Table 15-5 identifies the equipment, quantities and the perferred locations for stowage for the major items of the EVA system. The locations specified are intended to allow for crewman donning or usage immediately after removal from stowage thus minimizing the number of interim stowage provision and equipment restraints. The following paragraphs provide further information for stowage of the items listed in Table 15-5.

EQUIPMENT DESCRIPTION	QUANTITY PER FLIGHT	PERFERRED LOCATION	REMARKS
EVA PRESSURE SUITS	2	CABIN	
EMERGENCY IV SUITS	ONE PER CREWMAN	CABIN	THE QUANTITY ASSUMES THAT THE EVA SUIT IS NOT USED FOR EMERGENCY IV.
LIQUID COOLING GARMENT	2	CABIN	
URINE COLLECTION ASSEMBLY	2	CABIN	
PRIMARY LIFE SUPPORT SYSTEM	2	CABIN	
EMERGENCY LIFE SUPPORT SYSTEM	2	CABIN	
LIOH CARTRIDGES	10 MAXIMUM	CABIN	QUANTITY VARIES ON EACH FLIGHT. THE QUANTITY SHOULD SUPPORT ALL PLANNED EVA'S PLUS ONE DUAL UNSCHEDULED EVA.
BATTERIES	2 MAXIMUM	PAYLOAD BAY	BATTERY STOWAGE REQUIRED ON THOSE FLIGHTS WITH LESS THAN 16 HOURS BETWEEN EVA'S.
SUIT VENTILATOR	2	CABIN	
PORTABLE LIGHTING UNIT	2	AIRLOCK	
MANIPULATOR WORK PLATFORM	1	PAYLOAD BAY	
EVA TOOLS			AS REQUIRED BY PAYLOAD

TABLE 15—5. STOWAGE LIST

15.3.1 Pressure Suit Stowage

Tables 15-6 and 15-7 lists the items of the EVA pressure suit and the Emergency IV suit respectively which can be stowed separately. The helmets and EV visors should be stowed such that scratch and impact protection is afforded to the visors. Stowage envelope for the pressure suits is not specified since the soft flexible garment can be stowed unforlded or folded in a variety of configurations. The helmet can be stowed within an envelope of 12 in. x 12 in. diameter. Some volume savings may be realized by stowing the communications carrier within the helmet and the EV visors attached to the helmet.

15.3.1 Pressure Suit Stowage - Continued

ITEM	WT (LBS)	STOWAGE VOLUME
• TORSO LIMB ASS'Y UPPER TORSO LOWER TORSO ITMG ELEC HARNESS RELIEF VALVE PURGE VALVE	46.7	6.0 FT^3
• GLOVES	3.0	WITHIN SUIT
• HELMET	2.7	1700 IN^3
• EV VISOR	5.7	3600 IN^3
• HEADSET & MIKE	1.6	WITHIN HELMET
TOTAL	65.0	

TABLE 15–6. EVA/IVA SUIT

ITEM	WT (LBS)	STOWAGE VOLUME
• TORSO LIMB ASS'Y UPPER TORSO LOWER TORSO ELECTRICAL HARNESS RELIEF VALVE PURGE VALVE	12.8	2.0 FT^3
• GLOVES	2.4	WITHIN SUIT
• HEADSET & MIKE	1.6	WITHIN HELMET
TOTAL	19.0	

TABLE 15–7. EMERGENCY IV SUIT

15.3.2 Undergarment Stowage

Envelopes and weights of the Liquid Cooling Garment (LCG) and the Urine Collection Assembly are defined in Table 15-8.

ITEM	WEIGHT	VOLUME
LIQUID COOLING GARMENT	4.6 LBS	440 CU. IN.
URINE COLLECTION ASSEMBLY	0.7 LBS	48 CU. IN.

TABLE 15-8. UNDERGARMENTS STOWAGE

The LCG stowage location should preclude exposure of the garment to cold walls which could result in freezing of the contained water.

15.3.3 Life Support Systems Stowage

Study results indicate that integration of the PLSS and ELSS into a single package is the preferred approach for minimizing the weight and volume penalties to the EVA system and the vehicle. Secondly, this approach minimizes equipment handling during EVA preparation and ground operations. Table 15-9 defines the weights and stowage envelope for an integrated PLSS/ELSS and for separately packaged units. The values represent fully charged units with umbilicals and support harnesses for suit attachment.

The primary environmental constraint for stowage of these items is to preclude freezing of the contained water. As discussed previously, the stowage station should also allow for recharge of the units while stowed and it can also be used as a donning station.

15.3.3 Life Support Systems Stowage - Continued

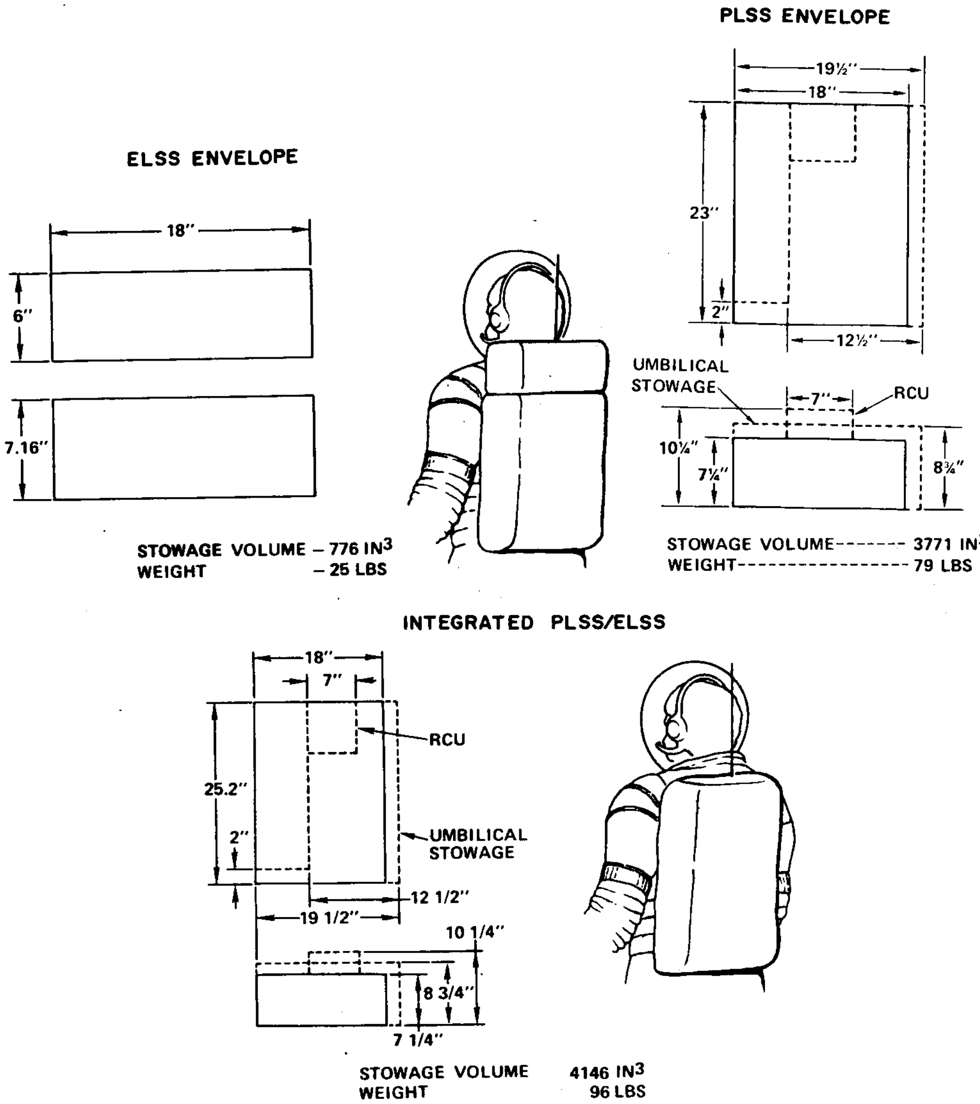


TABLE 15–9. LIFE SUPPORT SYSTEMS STOWAGE

15.3.4 LiOH Cartridge and Battery Stowage

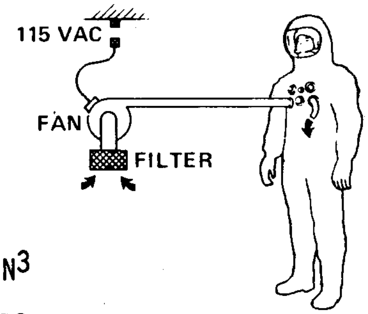
The stowage weights and envelopes for the PLSS LiOH cartridge and batteries are specified in Table 15-10. The battery stowage is required only on flights with less than 16 hours between EVA's which is the maximum time required to completely recharge the PLSS batteries.

ITEM	WEIGHT LBS	VOLUME CU. IN.
LIOH CARTRIDGE	3.0	SEE FIGURE 15-14
BATTERY	8.8	185

TABLE 15—10. LiOH CARTRIDGE AND BATTERY STOWAGE

15.3.5 Suit Ventilator Stowage

Table 15-11 defines the weight and stowage volume of the suit ventilator including a power cable 23 feet in length to allow crewman movement about the lower cabin and airlock.



STOWAGE VOLUME: 1350 IN^3

WEIGHT: 7 LBS

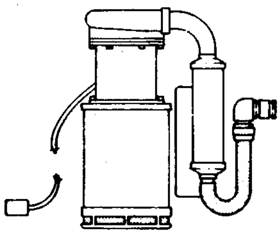


TABLE 15—11. SUIT VENTILATOR STOWAGE

15.3.6 Manipulator Work Platform

The Orbiter should provide for stowage of a work platform for crewman restraint and translation while performing EVA tasks. It is estimated that the manipulator work platform discussed in Section 12.0 can be stowed within an envelope of 20" x 8" x 48" and will weigh less than 60 pounds. However, additional design effort is required to establish firm stowage requirements.

15.3.7 EVA Tools

The tools required for EVA crewman use may be stowed in the cabin, payload, payload bay or on the exterior of the payload. The weights and volumes of these items may vary significantly on each flight depending on the payload requirements. Therefore, tool definition and stowage requirements should be specified as part of payload definitions.

15.4 Communications and Monitoring

As indicated by Figure 15-16, the Orbiter should have the capability to:

a) Receive and transmit RF two-way voice communications between two EVA crewmen and Orbiter personnel

b) Relay EVA crewmen voice communications between ground and other spacecraft personnel

c) Transmit any alerts initiated by ground or vehicle personnel to the EVA crewmen.

These requirements impose negligible impacts to the Orbiter since payload requirements establish the above communications capability.

15.4 Communications and Monitoring - Continued

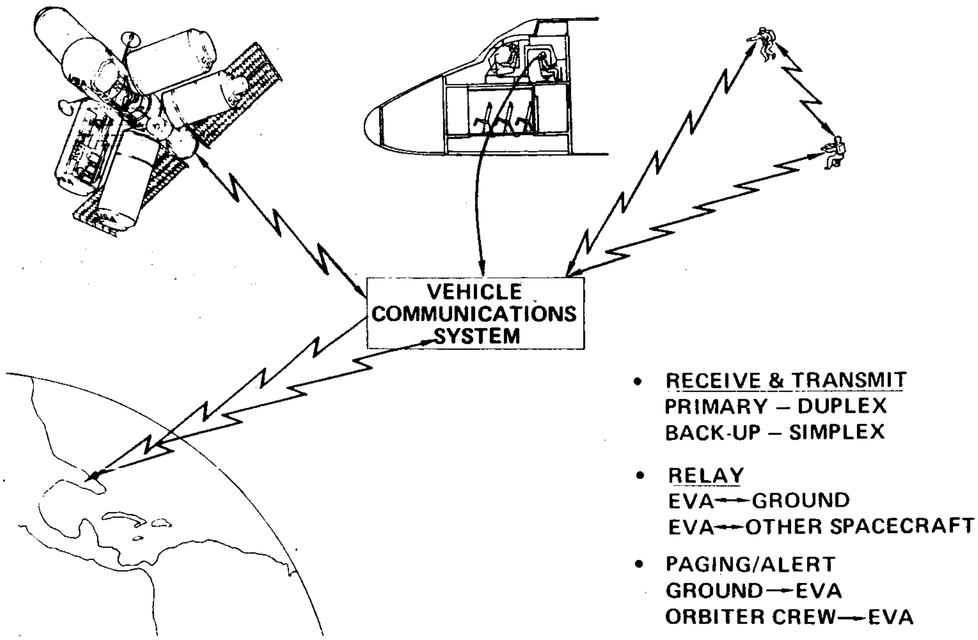


FIGURE 15–16. COMMUNICATIONS REQUIREMENTS

Figure 15-17 identifies the vehicle requirements for support of EVA telemetry data. The telemetry requirements provide the following capability:

a) Receive approximately ten (10) parameters of telemetry data from each of two EVA crewmen simutaneously.

b) Relay telemetry data to ground

c) Store telemetry data

d) Provide for the simultaneous display of telemetry data from each crewman

e) Provide caution and warning indications when telemetered parameters exceed pre-established limits.

15.4 Communications and Monitoring - Continued

PARAMETER	CREWMAN # 1	CREWMAN # 2
SUIT PRESS	8.10 ●○	8.08 ●○
VOLTS	17.3 ●○	17.0 ●○
AMPS	3.2 ●○	3.1 ●○
═══	═ ●○	═ ●○
═══	═ ●○	═ ●○
═══	═ ●○	═ ●○
═══	═ ●○	═ ●○
═══	═ ●○	═ ●○
═══	═ ●○	═ ●○
O_2 PRESS	120 ○●	350 ●○

- RECEIVE T/M DATA FROM TWO CREWMEN
  — EVA→ORBITER
- RELAY
  EVA→GROUND
- DISPLAY
  — T/M PARAMETERS
- CAUTION & WARNING

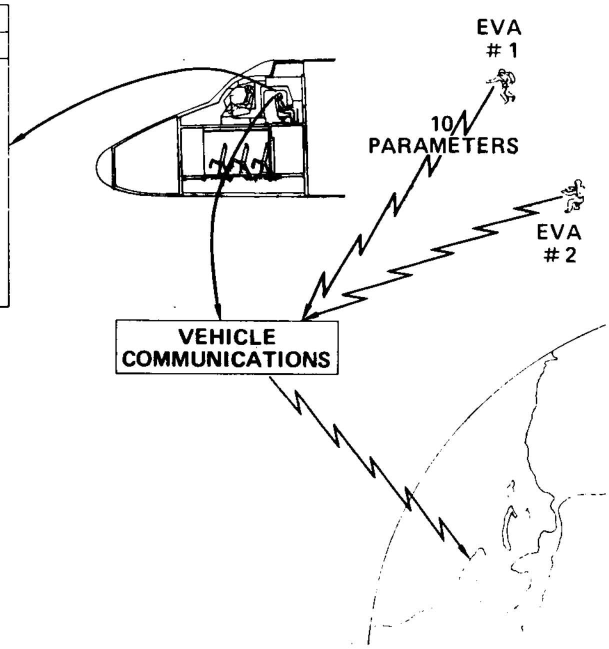


FIGURE 15—17. TELEMETRY REQUIREMENTS

Again, the Orbiter payload telemetry requirements provides basic capability for the Orbiter to satisfy the EVA telemetry requirements. Although this requirement is not considered mandatory, it should be utilized to provide maximum system flexibility as discussed in Section 7.0 of this report.

The operational frequencies of the EVA system were not defined as part of this study. Consideration must be given to all space systems including satellites, free-flyer, space stations as well as the Orbiter Communications requirement to establish non-interferring frequency assignments. It is anticipated that the frequencies used for the Shuttle EVA/IVA system will be similiar to those employed for the Apollo EVA system.

The Orbiter Antenna system should ensure line-of-site communication with an EVA crewman at all times while performing tasks including payload maintenance and conduct of experiments.

15.5 Airlock Requirement

The requirements for the airlock are summarized in Table 15-12.

SIZE - ACCOMMODATE TWO 95TH PERCENTILE CREWMEN	HATCHES • INGRESS/EGRESS BY 95TH PERCENTILE CREWMAN • OPERABLE FROM BOTH SIDES
DECOMPRESS/RECOMPRESS RATES • DECOMPRESSION RATE: 1.0 PSI/SEC MAX • RECOMPRESSION RATE: 0.1 PSI/SEC MAX	LIGHTING • 5 FOOT LAMBERTS MIN.
CONTROLS • DECOMPRESS/RECOMPRESS RATES • HATCH LOCK/UNLOCK	MOBILITY AIDS • FOOT RESTRAINTS • HAND HOLDS/RAILS • WAIST TETHER
DISPLAYS • AIR LOCK ABS. PRESSURE • HATCH LOCK/UNLOCK INDICATORS • HATCH ΔP INDICATORS	SUPPORT SYSTEMS • RF HARDLINE • LIQUID COOLING SYSTEM • VENTILATOR POWER SOURCE

TABLE 15-12. AIRLOCK REQUIREMENTS

The baseline airlock size is 63 inches in diameter by 83 inches long. Tests conducted at NASA/MSC indicate that this size is adequate for use by two large suited crewmen provided that no large cargo packages are present. The results of the task analysis indicates that relatively small packages, i.e., film cassettes, are to be transfered through the airlock with the EVA crewmen. The baseline hatch sizes of 40 inches diameter and 40 inches by 56 inches is also adequate for crew and equipment transfer.

The recompression rate is based on the physiolocial limits of the crewman. The decompression rate is based on the standard used by the U.S. Air Force in training personnel for rapid decompression exposure.

15.5 Airlock Requirements - Continued

The EVA crewman should have complete control of airlock operation including the initiation of depressurization and repressurization. The locking, unlocking, opening and closing of all airlock hatches should be possible from either the interior or exterior of the airlock.

During airlock operations, the EVA crewmen should have visual access of the displays listed in Table 15-12 to verify the airlock pressure level and hatch status.

The lighting and mobility aids are required to support EVA operations as well as shirt sleeve operating modes. These provisions may be combined to allow a single restraint capable of supporting all modes of airlock operations. For example, the Skylab foot restraints can be used for both shirt sleeve and suited operations.

The support systems for RF hardline, liquid cooling and a power outlet for the suit ventilator were discussed in Section 15.2.

15.6 Summary

The following vehicle interface requirements are recommended for support of EVA/IVA operations:

a) The orbiter should be capable of supporting a maximum of thirty-two (32) man-hours of EVA and six (6) airlock depressurizations/repressurizations.

b) Orbiter support provisions are required in the lower cabin for EVA/IVA equipment stowage, donning, doffing and recharge. This should be accomplished in common stowage/recharge/donning stations and should provide for simultaneous servicing as opposed to sequential servicing.

c) A 115 vac power source is required in the lower cabin and airlock for ventilator operation.

d) A liquid cooling capability is recommended for support of EVA preparation and Emergency IV.

e) The airlock should have a RF hardline.

f) The Orbiter Communications System should be capable of transmitting, receiving and relaying voice communications between EVA crewmen, the Orbiter, Ground and other Shuttle related manned space vehicles.

g) The Orbiter should be capable of receiving, relaying, storing and displaying telemetry data from two (2) EVA crewmen simultaneously.