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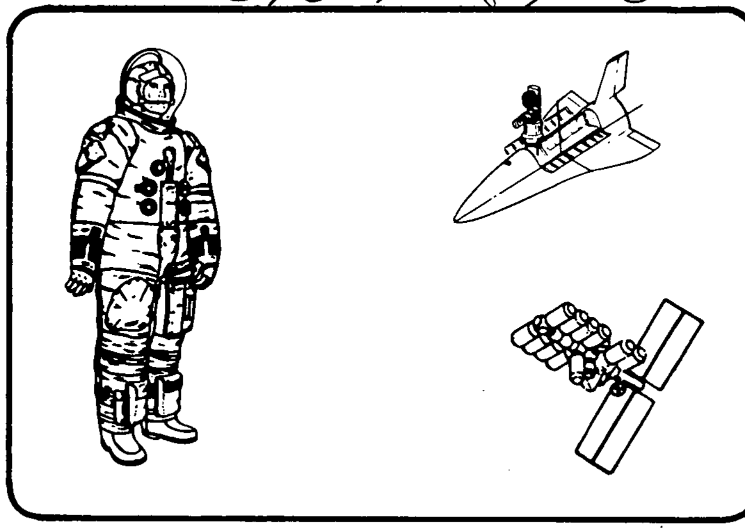

APPLICATION OF EVA GUIDELINES AND DESIGN CRITERIA

VOLUME I - EVA SELECTION/SYSTEMS DESIGN CONSIDERATIONS

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APPLICATION OF EVA GUIDELINES AND DESIGN CRITERIA

FINAL REPORT

CONTRACT NAS9-12997

VOLUME I - EVA SELECTION/SYSTEMS DESIGN CONSIDERATIONS

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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URS MATRIX

APRIL 1973

FOREWORD

This study contract (NAS9-12997) was awarded by NASA Johnson Space Center (JSC) to (1) provide information and data concerning orbital Extravehicular Activities (EVAs) in a format most useful to mission planners and experiment designers, (2) develop conceptual design(s) of versatile EVA workstations for future space application, and (3) initiate development of a model for estimating the impact of EVA costs on future payloads.

This report is presented in three volumes as follows:

Volume I:	EVA Selection/Systems Design Guidelines and Considerations
Volume II:	EVA Workstation Conceptual Design
Volume III:	EVA System Model

The report herein is a summary of the technical effort, an overview of the activities performed during the contract effort, and a presentation of the study results pertaining to the EVA Selection/Systems Design Criteria.

PREFACE

The United States' manned spaceflight programs prior to Skylab have qualified EVA as an operational technique for performing orbital and deep space mission functions outside the spacecraft. The Skylab program will capitalize on the established EVA techniques and equipment to retrieve solar astronomy experiment data contained in film magazines from the Skylab Apollo Telescope Mount (ATM). The Space Shuttle vehicle, which will begin orbital tests in the late 1970's, will afford the opportunity to perform a variety of tasks outside the spacecraft--perhaps more economically than any other method. Further, it is anticipated that spaceflights beyond the Space Shuttle and Modular Space Station will utilize manned EVA to great extents, and that each future mission will provide for backup and contingency operations to enhance mission success, including mandatory provisions for crewman safety and rescue.

Since the EVA capability currently appears to be a requirement for many future manned spaceflights, it is desirable to provide the mission planner and vehicle, experiment, and payload designers with information and data concerning the selection of man for extravehicular (EV) functions. This study provides an overview of the factors that must be considered when utilizing man as an EV method, the impact that man and EV equipment have on the mission, vehicle, and payload, and provides conceptual EV workstation designs for performing the EV functions. The study also initiates development of an EVA systems model to allow payload and experiment designers to assess the impact of EVA in terms of costs to future payloads.

In this volume, parameters that require consideration by the planners and designers when planning for <u>man</u> to perform functions outside the vehicle are presented in terms of the impact the extravehicular crewmen and major EV equipment items have on the mission, vehicle, and payload. Summary data on man's performance capabilities in the weightless space environment are also provided. The performance data are based on orbital and transearth EVA from previous spaceflight programs and earthbound simulations, such as water immersion and "zero-g" aircraft.

Several EV workstation concepts were developed and are documented in Volume II of this report. The workstation concepts were developed following a comprehensive analysis of potential EV missions, functions, and tasks as interpreted from NASA and contractor Space Shuttle and Space Station studies, mission models and reports. The design of a versatile, yet portable, EVA workstation is aimed at reducing the design and development costs for each mission and aiding in the development of on-orbit serviceable payloads. The replacement of dedicated EVA workstations with portable, modular units, which can readily be adapted to numerous worksites, represents a sizable cost savings to payloads using EVA.

The development of a model for estimating the impact of manned EVA costs on future payloads was initiated during the study. Basic information on the EV crewman requirements, equipment, physical and operational characteristics, and vehicle interfaces is provided. The cost model, being designed to allow system designers to quantify the impact of EVA on vehicle and payload systems, is addressed in Volume III.

ACKNOWLEDGEMENTS

The NASA Technical Monitor for this study was Mr. David C. Schultz, Chief, EVA and Experiments Branch (CG3), Crew Procedures Division, Flight Crew Operations, Johnson Space Center, Houston, Texas. Technical direction for the study was provided by Mr. Schultz; valuable assistance in obtaining information and data was supplied by personnel within the EVA and Experiments Branch. Appreciation is expressed to Dr. Stanley Deutsch, Director, Bioengineering Division, Office of Life Sciences, NASA Headquarters, for his worthy suggestions and assistance in arranging for the conduct of the study.

The contractor Principal Investigator for the study was Mr. Nelson E. Brown, Division Director, Life and Environmental Sciences Division, URS/Matrix Company, URS Systems Corporation. Principal contributors within the URS/Matrix Company were Dennis C. DeWitt and E. Rangel, Jr.

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ACRONYMS AND ABBREVIATIONS

ACS	Attitude Control Subsystem
AEPS	Advanced Extravehicular Protective System
AES	Advanced Extravehicular Suit
ALSA	Astronaut Life Support Assembly
AM	Airlock Module
AMRV	Astronaut Maneuvering Research Vehicle
AMS	Attached Manipulator System
AMU	Astronaut Maneuvering Unit
ASMU	Automatically Stabilized Maneuvering Unit
ASSY	Assembly
ATM	Apollo Telescope Mount
BSLSS	Buddy Secondary Life Support System
Btu	British Thermal Units
CCA	Communication Carrier Assembly
CCU	Crew Communication Umbilical
C&D	Controls and Displays
CEA	Control Electronics Assembly
cfm	Cubic Feet per Minute
CM	Command Module
CSM	Command Service Module
CTS	Contingency Transfer System
C&W	Caution and Warning
CWG	Constant Wear Garment
ECG	Electrocardiogram; (or) Evaporative Cooling Garment
EC/LSS	Environmental Control and Life Support System
ECS	Environmental Control System
ECS/LS	Extravehicular Control System/Life Support
EEG	Electroencephalograph
EHA	Electrical Harness Assembly
EKG	Electrocardiogram
ELSS	Extravehicular Life Support System

ACRONYMS AND ABBREVIATIONS (CONT'D.)

EMU	Extravehicular Mobility Unit
EV	Extravehicular
EVA	Extravehicular Activity
EVCS	Extravehicular Communications System
EVVA	Extravehicular Visor Assembly
FCMU	Foot Controlled Maneuvering Unit
FCS	Fecal Containment System
FTB	Film Transfer Boom
g	Gravity
GATV	Gemini-Agena Target Vehicle
HSD	Hamilton Standard Division
HHMU	Hand-Held Maneuvering Unit
IR	Infrared
ITMG	Integrated Thermal Micrometeoroid Garment
IVA	Intravehicular Activity
JSC	Johnson Space Center
kw	Kilowatt
LCG	Liquid Cooling Garment
LED	Light Emitting Diodes
LMSC	Lockheed Missiles and Space Company
LSS	Life Support System
MDA	Multiple Docking Adapter
MEED	Microbial Environment Exposure Device
MSFN	Manned Spaceflight Network
MWP	Maneuverable Work Platform
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
OBS	Operational Bioinstrumentation System
OPS	Oxygen Purge System
OWS	Orbital Workshop
PCU	Pressure Control Unit

ACRONYMS AND ABBREVIATIONS (CONT'D.)

PGA	Pressure Garment Assembly
PKG	Phonocardiogram
PLSS	Portable Life Support System
PSIA	Pounds per Square Inch Absolute
PSID	Pounds per Square Inch Differential
RF	Radio Frequency
RHC	Rotational Hand Controller
SAMS	Shuttle Attached Manipulator System
SCS	Suit Communications System
SEVA	Skylab Extravehicular Visor Assembly
SIM	Scientific Instrument Module
SLSS	Secondary Life Support System
SOAR	Shuttle Orbital Applications and Requirements
SOP	Secondary Oxygen Pack
STDN	Space Tracking and Data Network
STEM	Storable Tubular Extendible Member
TBD	To Be Determined
THC	Translational Hand Controller
TLSA	Torso Limb Suit Assembly
TYP	Typical
UCTA	Urine Collection Transfer Assembly
UV	Ultraviolet
V	Velocity

SECTION 1.0 INTRODUCTION

1.1 GENERAL STUDY OBJECTIVES

The overall objectives of the contract NAS9-12997, under which the study reported herein was conducted, comprise the following three areas:

- Expansion of EVA selection/systems design guidelines and considerations for application to future space missions.
- Conceptual design of a versatile EVA workstation to satisfy a wide range of future experiment and payload requirements.
- Initiate the development of a model for estimating the impact of EVA costs on payloads as an aid to experiment and payload designers.

This volume of the report presents the information and data developed in the expansion of EVA selection/systems design guidelines and considerations--the first of the three primary tasks listed above. The purpose of this task was to compile, develop, and format EVA information in a form most useful to that portion of the space community not directly involved in the extravehicular field. This report provides a general qualitative description of the many factors which are affected and areas that must be considered by the specification of EVA on future space programs. It was not within the scope of this effort to address the numerous elements of spaceflight that will be impacted by other potential methods/systems of performing a task outside a pressurized vehicle--nor was a trade study of EVA versus manipulators conducted. The intended user population includes those organizations engaged in experiment, payload, and vehicle design that have identified candidate operations to be performed outside the spacecraft. This part of the study encompasses the EVA field from a general point of view and is designed to aid the mission planner and experiment/payload designer by providing additional material for making decisions relative to selecting extravehicular techniques and configuring experiment/man interface hardware. This report does not attempt to identify or indicate the NASA center, organization, or personnel that may be involved when referring to the terms "mission planner and experiment/payload designer". These terms only refer to the assemblage of Government, industrial, institutional, or foreign organizations involved in developing a payload/vehicle to be included in the Space Shuttle Program with no connotations toward indicating a governing organization.

1.2 SCOPE OF STUDY AREA EFFORT

This segment of the study structures a list of EVA equipment design and selection considerations, generated during a previous contract, into a general EVA applications guidelines document. Emphasis is placed on the impact the crewman and EVA equipment impose on the mission, vehicle, and payload in terms of costs such as weight, volume, power, and crew time. Input data was obtained from a comprehensive review and analysis of the most current NASA and contractor documentation concerning the design and operation of EVA equipment for future space programs.

The EVA systems/equipment addressed in the study includes the following:

- Airlocks and Support Equipment
- Crewman Space Suits
- Extravehicular Life Support Systems
- Crew and Cargo Transfer Systems (Manned)
- EVA Workstations
- External Lighting
- Communications and Telemetry

There were several subtasks required prior to developing information concerning EV technique selection and hardware impacts. These subtasks included the following:

- Several governing parameters encompassing the selection of manned EVA were identified that require consideration early in the payload planning process. A qualitative discussion of these parameters was considered most beneficial to the potential users of EVA.

- Since the listing of "EVA System Design/Selection Considerations" (from a previous study which provides the basis for EVA data expansion) contained numerous entries, the listing was reduced to a manageable number common to the EVA systems and equipment addressed in this study.

- A listing of general EVA guidelines and constraints was developed from NASA Shuttle and Space Station documentation.

Other parameters concerning the selection of man for EV functions are discussed. These parameters include crew performance capabilities in weightlessness, crew physiological requirements, and special considerations such as crew safety and rescue.

1.3 BACKGROUND

1.3.1 Potential Applications of EVA

NASA's manned space programs of the 1970's have changed from activities aimed at qualifying man and equipment for spaceflight and lunar exploration to utilizing manned spaceflight to perform research and technology experiments in earth orbit. Several such experiments were conducted during the Apollo program. The Skylab program will go further with experiments such as the Apollo Telescope Mount (ATM) studies of the sun and, conversely, several studies of the earth's resources. Each of the previous programs will have added valuable knowledge about man in space, his spacecraft, the equipment he needs in space, his capabilities in the space environment, and the space environment itself.

The Space Shuttle will introduce the capability of placing experiment payloads into earth orbit for observation of the earth's surface, conduct of experiments and investigations of the space environment, and research into scientific and technological areas which capitalize on the unique characteristics of the weightless environment. The experiment payloads will vary in content and purpose from small, self-contained orbital laboratories to orbiting automated research satellites, and ultimately to payload modules forming a permanent orbiting Space Station.

The future orbital missions will present planners and designers with many new and unique payload support and servicing requirements. Several studies are currently being funded by NASA to define, in detail, mission descriptions and support operations for selected payloads. These studies are resulting in the identification of experiments/payloads that may require functions to be performed by extravehicular techniques. Man is one of the prime modes for carrying out these functions. Many preliminary trade studies must be performed, however, between candidate techniques before the most economical and dependable mode can be selected.

1.3.2 Previous Study Inputs

A previous study entitled "Extravehicular Activities Guidelines and Design Criteria", NASA Contract No. NAS8-27502, developed a compendium of data concerning manned spaceflight orbital EVA. The primary purpose of the document was to present the engineer, mission analyst, and designer with EVA information to efficiently aid in providing a potential solution to his extravehicular requirements. Upon completion of the study (NAS8-27502), it was considered that further study of those areas listed in Section 1.0, Subsection 1.1, would provide essential data relative to the planning of manned EVA on future space programs.

As a subtask on the previous contract, an extensive list of EVA design/selection considerations was developed to inform the planners and designers of the parameters that must be acknowledged when considering man for EV functions. These lists are contained in Appendix A for reference purposes and are used as a broad study base for information presented in this volume of the report.

1.4 STUDY GUIDELINES AND ASSUMPTIONS

When considering man as a candidate for quasi-defined (i.e., in the time frame of this study) operations outside the spacecraft, certain guidelines and assumptions are groundruled concerning the type of equipment to be used, the adequacy of current EV hardware, the design techniques employed on equipment being serviced, etc. Several guidelines and assumptions were established during the initial NASA-Contractor coordination meeting for conducting the study.

1.4.1 Study Guidelines

The following study guidelines were established in agreement with NASA-JSC.

- Current technology (1972) EVA systems and equipment will be assumed adequate in the areas listed:
  - Restraints (body, foot, etc.)
  - Cargo transfer systems
  - Communications and telemetry
  - Tools
  - Data/information management
  - Lighting
- Both portable life support systems and umbilical EVA life support systems will be considered in the study.

- Space suits in the 3.5-8.0 psi (.23-.56 kg./cm.^{2}) range will be considered in the study.

- Current EVA design constraints on workstations and man/system interfaces will be baselined.

1.4.2 Study Assumptions

- Mission planners and experiment designers only remotely associated with the EVA field will be the primary users of the study results.

- Experiments and payloads will be designed with ease of on-orbit servicing a consideration.

- Pressure suits operating in the 8 psi (.56 kg./cm.^{2}) range are at least as "mobile" as current 3.5 psi (.23 kg./cm.^{2}) suits.

- Life support systems will not increase or decrease appreciably in size and weight over state-of-the-art systems.

- Contamination from pressure suits will be controlled through methods which do not significantly impair suit mobility.

- EVA workstations can be delivered to the worksite and secured by either manipulators or EVA crewmen.

- One-man EVAs, with a vented standby crewman, will be permitted on future missions.

1.5 STUDY APPROACH

The basic study approach followed for the expansion of EVA Selection/System Design Guidelines and Considerations portion of the contract is shown graphically in Figure 1-1. The primary data sources for information were NASA/JSC

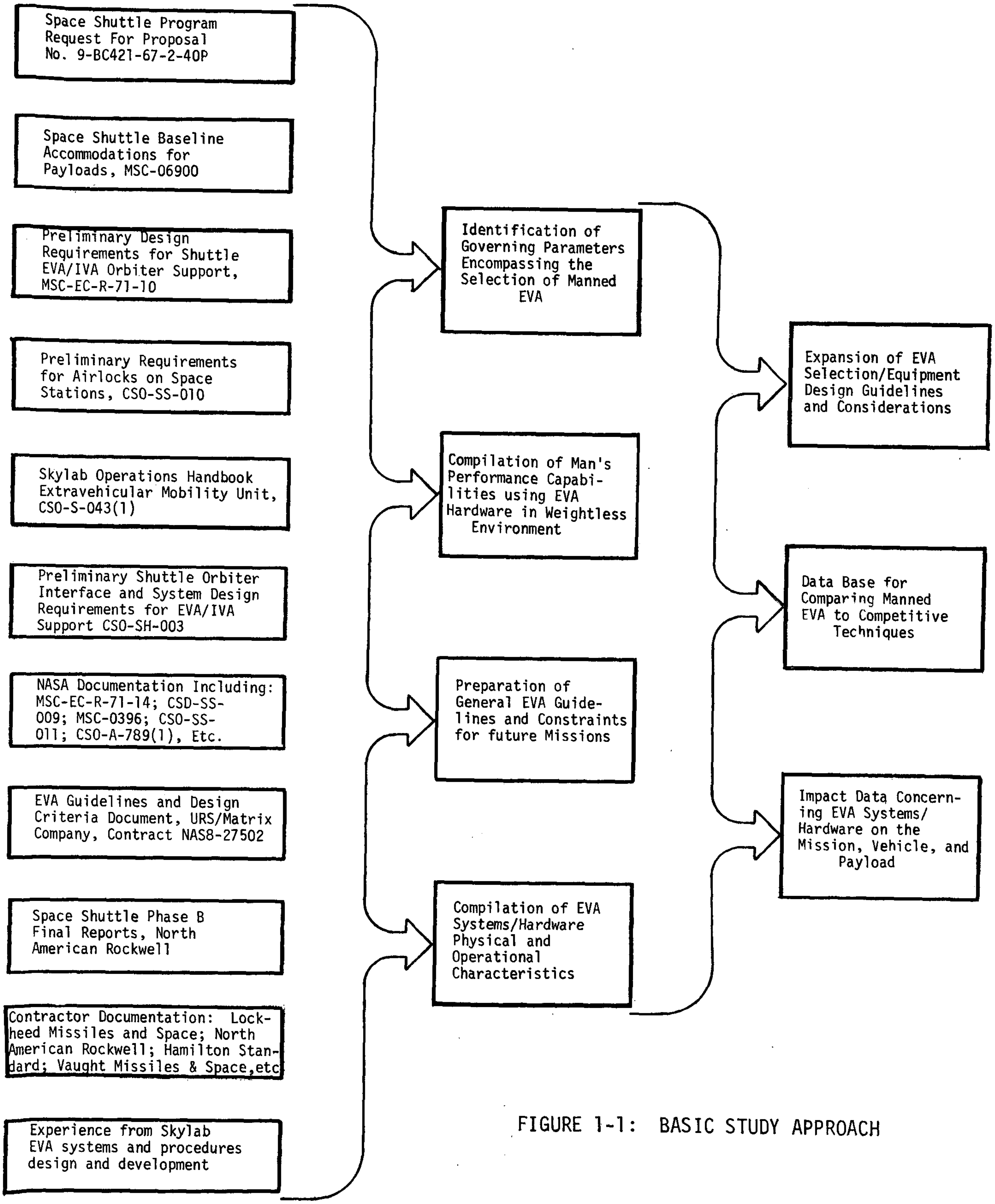

FIGURE 1-1: BASIC STUDY APPROACH

Space Shuttle and Space Station documentation, contractor reports, and URS/Matrix experience gained through development of Skylab EVA systems and procedures. The study was initiated with a review of EVA/IVA data applicable to future missions, then proceeded through analysis of EVA selection considerations, man's EVA performance capabilities, and EV systems' physical and operational characteristics. The study end products were finally developed from the data and information analyzed during the review. These end products included (1) expansion of EVA selection/system design guidelines and considerations, (2) a data base for comparing manned EVA to competitive techniques, and (3) impact data concerning EVA systems/hardware on the mission, vehicle, and payload.

The remaining sections of this report are comprised of the data and information developed to satisfy the study end products, and also contain relevant material developed during the conduct of the study.

SECTION 2.0 PAYLOAD SERVICING TECHNIQUES

2.1 CURRENT TECHNIQUES

NASA has been studying the economic merits of new transportation systems for spaceflight programs during the past several years. Considerable reductions in space transportation costs have been projected for new low-cost recoverable boosters and reusable Space Shuttle vehicles. Additional savings in experiment and payload costs could be realized by implementing low-cost techniques to service and reconfigure on-orbit a large quantity of various payloads. The Lockheed Missiles and Space Company (LMSC) has conducted studies (contracts NASW-2156 and NASW-2312) which considered the economic impact of both on-orbit servicing techniques and ground-based refurbishment. The on-orbit servicing studies were centered around the conceptual design philosophy of replaceable, standardized, modular hardware applicable to numerous payloads, and which could be economically replaced by man or machine systems. The LMSC study does not include analyses of the "technique" by which to perform the on-orbit functions, but develops a logical and viable approach to economical payload servicing.

There are a number of methods to be considered by the experiment and payload designers when addressing system operational life, experiment reconfiguration, and the various servicing aspects of each payload. Some of the methods used on previous spacecraft, and being considered for future programs to increase operational life and perhaps avoid servicing functions, include the following:

- Redundant systems as a backup to failure-likely components
- High tolerance, high reliability, "space qualified" component manufacturing and testing processes to decrease failure probability

- Design of highly reliable, single mission or expendable payloads of relatively short mission duration

Although redundant systems and highly reliable components are desirable for manned spacecraft, each of these methods has proven exceedingly expensive for experiment/payload application. Other less economically prohibitive methods are being studied for reconfiguring experiments and servicing payloads through both on-orbit and ground-based operations. These methods include manned, man-operated machine systems, and automatic systems. Several methods being considered are listed below:

- Utilize inherent spacecraft systems and equipment (e.g., airlocks, rescue and safety provisions) for manned extravehicular functions

- Develop vehicle-attached remote manipulator systems

- Develop free-flying teleoperator systems

- Provide pressurizable structures which allow manned intravehicular experiment servicing

- Design automatic systems for payload servicing

- Return payload to earth for servicing and updating

During the iterative design and development cycles of each experiment and payload, several of the above methods will receive some level of consideration. Initially, the designers will have the responsibility of transforming broad objectives into an acceptable profile and sequence of events against which the experiment/payload can be designed. Most often, incompatibilities will immediately arise between preferred equipment design and the operating capabilities of the supporting spacecraft and its equipment. Early trade-off studies are then initiated to arrive at a design compromise.

As the spacecraft hardware design solidifies, the designers will attempt to constrain their design to the spacecraft operating capabilities, ground support facilities, and flight software. During this phase of the experiment/payload design, the technique for performing servicing operations (if required) will be determined. Depending on the specific experiment/payload and its objectives, each of the servicing techniques listed previously will possess certain advantages regarding the spacecraft capabilities and ground support facilities. Trade-off studies are again required to select or design a method for effective and economical payload servicing. Some of the major considerations involved in selecting or designing a method/system to perform the servicing functions are contained in Table 2-1. The considerations list is aimed toward providing the experiment/payload designer with an initial insight of the major factors/parameters to be acknowledged, and later studied, prior to his selecting a servicing method or committing to an irreversible payload design. The table identifies considerations applicable to both the candidate servicing methods and the payload.

Table 2-1 is not intended to provide a total listing of all possible considerations applicable to the above areas. Many pertinent considerations will be identified by the experiment designers during the early payload development phase.

TABLE 2-1: PAYLOAD SERVICING METHOD SELECTION/EXPERIMENT DESIGN CONSIDERATIONS

SERVICING SYSTEM/METHOD CONSIDERATIONS	
• Availability of Qualified Systems and Components • System Development, Testing, and Qualification Costs • System Development Time • Expendable Requirements and Supporting Equipment • Classification of Service Tasks to be Performed (e.g., Module Replacement, Inspection, Monitor, Maintain, etc.) • Consumable Requirements and Supporting Equipment • Failure Probability of Automatic Systems • Control Systems for Free-Flying Units	• Capability Range of Various Systems • Quantity of Servicing Units Required • Training Requirements for System Operation • System/Technique - Weight - Size/Volume - Configuration • Contamination Sources • Safety
EXPERIMENT/PAYLOAD CONSIDERATIONS	
• Functional Design Life • Experiment/Payload - Weight - Size/Volume - Configuration - Component Accessibility • Payload Type (e.g., Free Flying, Attached, Sortie, Manned, Unmanned, Pressurized, Unpressurized, etc.) • Replacement Spares/Module Characteristics • Monitoring Requirements During Servicing	• Servicing Time Required • Servicing Fixtures, Tools, and Checkout System Required • Failure Probability of Automatic Systems • Training Requirements for Servicing • Contamination Sources • Location of Payload in/on Spacecraft • Payload Placement Schedule • Number of Identical Payloads Required • Safety

SECTION 3.0 GENERAL EVA GUIDELINES

3.1 INTRODUCTION AND BACKGROUND

Numerous guidelines and constraints have been established and enforced by NASA on the orbital extravehicular operations and EVA equipment since the early planning phase of the Gemini program. The early guidelines and constraints were established primarily to protect the EV crewman and his equipment, and to ensure the safety of other crewmen aboard the spacecraft during programs to establish EVA feasibility and evaluate EVA support equipment. As EVA experience and advanced support systems were developed, these guidelines and constraints were relaxed or modified to fit space programs designed to utilize EVA for accomplishing mission objectives. These programs used EVA primarily to retrieve experiment data in a variety of different forms, locations, and packaging arrangements.

The application of EVA is currently entering into an era of competition with other methods and techniques for economically performing spacecraft and payload functions. Therefore, EVA guidelines and constraints are presently being developed, and previous ones revised, to meet the requirements of the future programs. In terms of vehicle or payload servicing via EVA, crewman and equipment safety are the fundamental concerns followed by efficiently and economically performing the required function. The EVA guidelines and constraints for future missions are primarily based on the crewman's support equipment, vehicle support provisions, crewman capabilities, and safety. A listing of the general EVA guidelines and constraints being established for the Space Shuttle is contained in Section 3.2. All of the guidelines and constraints listed are not directly applicable to the candidate experiments and payloads but are of concern to the payload planners and designers in terms of potential design impacts. The list is inclusive of the guidelines and constraints currently established, independent of the spacecraft, payload, or EVA system affected.

Many of the guidelines and constraints were extracted directly from the Space Shuttle Program Request for Proposal, dated March 1972, and the Space Shuttle Baseline Accommodations for Payloads document, MSC-06900A. Other guidelines and constraints were established from the results of studies to identify future EVA applications and equipment requirements. Still others were adopted from previous space programs and revised for future applications.

The EVA guidelines and constraints contained in Section 3-2 do not constitute an official or complete listing adopted by NASA. Some of the guidelines are considered violable given sufficient justification, while the constraints are considered more rigid. Additional EVA guidelines and constraints will be established and others revised as EVA is applied to the future space programs. The guidelines and constraints are classified as follows:

A. CREWMAN
- Operational
- Physiological

B. EQUIPMENT
- General
- Life Support
- Airlocks and Hatches
- Workstations

C. MISSION

3.2 GENERAL EVA GUIDELINES

A. CREWMAN
- Operational

1. Properly trained personnel will be used for planned and unscheduled EV and IV activities.
2. EV/IV crewmen will be within the 5th to 95th percentile range.

3. The crewman will always be tethered (directly or indirectly) to the main vehicle; umbilicals and tethers will not constrain the crewman performing the EVA.

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

- Physiological

5. Minimum oxygen flow rate supplied to the crewman will be calculated using a respiratory quotient of 0.875.

6. A radiation dosimeter for EVA/IVA crewmen is required; the total allowed radiation dosage will not be exceeded.

7. Crewman heat storage per EVA/IVA will not exceed 300 BTU.

8. Provisions for prebreathing pure oxygen for three hours prior to EVA/IVA in a 3.7 psig (.26 kg./cm.^{2}) pressure suit must be provided; the 8.0 psig (.56 kg./cm.^{2}) suit has no prebreathing requirement.

B. EQUIPMENT

- General

1. EVA/IVA equipment should be provided to accommodate 2 men simultaneously.

2. EVA/IVA equipment will be stowed in a pressurized area.

3. EVA/IVA equipment containing potentially hazardous materials will be stored external to the crew compartment.

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

5. EVA/IVA equipment (including maneuvering units) shall not discharge contaminants which may adversely affect the primary vehicle external surfaces or experiment components.

6. EVA/IVA systems will be designed with adequate factors of safety to preclude any reasonable possibility of failure; all EVA/IVA equipment will have "fail-safe" capability as a minimum requirement.

7. Maneuvering systems critical systems will have a "fail-operational/fail-safe" capability.

8. A warning system will be included in the primary life support system equipment to alert the EVA/IVA crewman of an impending critical failure condition.

9. EVA/IVA support equipment will be ground maintainable, but not necessarily flight maintainable.

- Life Support

10. Primary life support equipment will be rechargeable/regenerable in flight.

11. Primary life support systems will provide sufficient expendables/consumables to complete EVA/IVA tasks.

12. Recharging/regenerating of EVA/IVA equipment will be accomplished without tools and in a pressurized area.

13. An independent emergency life support system with provisions to allow safe return of the EVA/IVA crewman to the primary spacecraft will be provided.

14. Equipment used only for IV emergency will not necessarily be rechargeable.

15. The same pressure suit will be utilized for both EVA and IVA. Lightweight IVA suits will be worn for emergency IV operations and suited development flights.

16. The maximum umbilical or tether-free length will be limited by umbilical/tether management and dynamic considerations.

- Airlocks/Hatches

17. The airlock will be used for EVA/IVA only and not be used as emergency shelter.

18. Final EVA equipment checkout will be performed in the airlock.

19. The airlock will accommodate two 95th percentile crewmen wearing pressure suits and other EVA support systems and equipment.

20. Airlock pressurization controls and instrumentation will be located to allow the EVA crewman to independently ingress the spacecraft (via his own airlock and hatch operations).

21. Airlock size will permit pressure-suited crewman operation of airlock controls.

22. The airlock will provide adequate lighting for airlock operations.

23. Hatches will be sized to accommodate a 95th percentile crewman wearing EVA equipment.

24. The outer airlock hatch will remain open during EVA/IVA.

- Workstations

25. All workstations will have provisions for crewman and equipment restraints; EV support equipment must be tethered at all times to the workstation, the vehicle, or the crewman.

26. Adequate lighting will be provided at all workstations.

27. Paths to workstations will be free from sharp protuberances, radiator surfaces, and other potentially hazardous objects or sensitive spacecraft surfaces during the EVA/IVA.

C. MISSION

1. EVA/IVA will be utilized for planned future missions, as required by the payload. As required by the primary spacecraft, EVA/IVA capability will be provided for unscheduled and contingency operations.

2. Space vehicle maneuvering will be minimized during unpressurized EVA/IVA.

3. For planned EVA/IVA, crewman assistance will be available for EVA/IVA equipment donning and checkout.

4. The maximum allowable EVA/IVA duration will be eight (8) hours per day.

5. The minimum interval between decompressions for a single crewman will be TBD hours.

6. Capability will be provided to allow pressure-suited crewman access to any unpressurized payload area.

7. Prebreathing, airlock, or other EVA/IVA operations will not cause the main cabin atmosphere parameters to exceed the design envelopes.

8. Two-way continuous communication capability between the EVA/IVA crewman and the primary vehicle is required; provisions will be made to permit two-way communications between the EVA/IVA crewman and the MSFN (Manned Space Flight Network) via the primary vehicle.

9. Both video and audio airlock-to-spacecraft communications will be provided.

SECTION 4.0 EVA TASK PROCEDURES SUMMARY

4.1 INTRODUCTION

Crewman activities involved in the preparation for, conducting, and terminating extravehicular operations consist of retrieving stowed components, preparing systems, donning and doffing EVA gear, systems checkout, materials handling, equipment stowage, etc. in conjuction with the scheduled EVA tasks. A minimum of two crewmen have been involved in the pre-EVA and post-EVA functions during previous extravehicular missions, and three (3) crewmen will participate during Skylab EVA. The current Space Shuttle Orbiter design guidelines specify provisions to support two EVA crewmen simultaneously, which would require a third crewman to monitor the EVA operations and support systems. The third crewman would be stationed inside the spacecraft partially suited for reacting to contingency or emergency situations.

However, one man EVA operations are being studied for the Shuttle Orbiter and other future missions in an effort to reduce the on-orbit EVA time, equipment, and stowage requirements per flight. One man EVA's would reduce the total number of crewmen involved in the EVA operations to two for many of the potential extravehicular tasks on future programs. The second crewman would monitor the EVA operations and support systems status, and serve as standby crewman for safety and rescue circumstances as in previous EVA missions. The second crewman may also be required to monitor the status of the payload being serviced during the EVA for information feedback to the crewman performing the task.

In addition to reducing the number of crewmen required to conduct and support EVA, efforts are being made to decrease the time and equipment required for pre- and post-EVA operations in the following areas:

- Consolidate stowed EVA equipment to one area near the EVA airlock

- Minimize/automate checkout tasks for pressure suits and life support systems
- Provide one-man quick don/doff pressure suits and life support systems
- Minimize EVA equipment servicing and recharge requirements
- Eliminate prebreathing requirements through high pressure space suits
- Minimize EVA airlock volume to conserve vehicle space and EVA expendables

Improvements in each of the above areas are expected to reduce considerably the pre- and post-EVA times and operations over previous EVA missions. The magnitude of the reduction in EVA crewman time requirements for future missions is expected to be 40-50% less than on the Skylab program.

4.2 EVA TASK SUMMARY

Table 4-1 summarizes the major tasks to be performed by the crewmen in order to satisfy a typical EVA mission in a future space program. The tasks refer to the required operations only. Task designations to individual crewmen are not specified. Table 4-1 is intended to familiarize the payload designer with the various operations and tasks required by the EVA crewmen (particularly pre- and post-EVA functions) and to aid in the design of compatible payload equipment and man/machine interfaces. A broad indication of the crewman's capabilities in a weightless environment can be derived from the table and applied to payload design. The sequence in which the tasks are performed will vary between EVA missions and will not directly correspond to the sequence depicted in Table 4-1.

TABLE 4-1: EVA GENERAL TASK SUMMARY

MODE	TASK	REMARKS
EVA PREPARATION		
SHIRTSLEEVE IVA	Translate to EVA equipment stowage area and stabilize	
↓	Ingress crewman restraints (if required)	Simple handholds may suffice
	Unstow pressure suit and transfer to donning station	
	Prepare suit donning station	Tasks vary with type suit used
	Unstow suit helmet and gloves	Usually placed in protective container
	Unstow liquid cooling garment (LCG) and remove crewman EVA gear	May consist of bioinstrumentation, communications, electrodes, etc.
SHIRTSLEEVE IVA	Install pressure suit in checkout restraints	Foot restraints used on Skylab

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONT'D.)

MODE	TASK	REMARKS
SHIRTSLEEVE IVA	Prepare suit for EVA • Open all zippers • Lubricate specified components as required • Remove H_2O and electrical connector caps and stow	Suit preparation varies between suits and length of time stowed in orbit
	Prepare helmet for EVA • Apply anti-fog solution • Attach EVA visor assembly to helmet	
	Unstow primary life support systems (LSS)	May consist of umbilical system or portable LSS on future missions
	Checkout and prepare LSS for EVA	Varies between systems
	Unstow contingency (backup) life support system	May consist of separate or LSS integrated units
SHIRTSLEEVE IVA	Checkout and prepare contingency LSS for EVA	Varies between systems

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONT'D.)

MODE	TASK	REMARKS
SHIRTSLEEVE IVA	Unstow payload servicing equipment and prepare for EVA as required	Depends on each payload requirement
	Prepare vehicle support systems and airlock for EVA	Consist of LSS, control and display panels, lights, tools, monitoring, etc.
	Doff constant wear clothing and stow	
	Don Fecal Containment System (FCS)	
	Don Urine Collection Transfer Assembly (UCTA)	
	Partially don liquid cooling garment (LCG) - lower half only	Requires additional tasks prior to full donning
	Prepare upper torso for bioinstrumentation system	Provides critical body function monitoring capability
SHIRTSLEEVE IVA	Don bioinstrumentation system	

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONT'D.)

MODE	TASK	REMARKS
SHIRTSLEEVE IVA	Don upper portion of LCG	
	Don lower portion of pressure suit	
	Connect and verify suit ancillary equipment secure	Includes UCTA, bioinstrumentation, LCG, etc.
	Don upper portion of pressure suit	
	Connect and activate interim LCG flow system	Provides body cooling prior to LSS activation (current systems)
	Don communications system	
	Don primary and secondary life support systems	May consist of umbilical or portable (LSS)
SHIRTSLEEVE IVA	Verify communications system operation	
SUITED IVA	Don helmet and gloves	
SUITED IVA	Activate and verify LSS operates as specified	Pressurize suit to operating pressure

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONT'D.)

MODE	TASK	REMARKS
SUITED IVA	Ingress EVA airlock and close "interior" hatch	
↓ SUITED IVA	Verify all airlock/vehicle/ EVA systems for "GO"	Final checkout of EVA system
EVA	Depressurize airlock and verify all EVA systems operational status	
	Open airlock external hatch and egress	
↓	Remove payload servicing equipment from airlock	
The following EVA operations are based on a hypothetical payload inspection and modular replacement task.		
EVA OPERATIONS		
EVA	Ingress payload bay	
↓ EVA	Unstow portable EVA work-station	Workstation may be deployed by the EVA crewman or manipulator arms

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONT'D.)

MODE	TASK	REMARKS
EVA	Translate with workstation to EVA worksite	Workstation may not be required for inspection, monitoring, or low force tasks
	Attach and deploy workstation	
	Ingress EVA workstation and prepare worksite/workstation	
	Inspect payload and attain access to replacement modules	May require opening/removing doors or panels
	Retrieve spent module(s) to be replaced and egress workstation	Modules may be handled by manipulator arms
	Translate with spent module to airlock and stow module	Modules may be handled by manipulator arm, thereby eliminating crewman cargo transfer requirements
	Retrieve new module and translate to EVA worksite	
EVA	Temporarily stow new module	Workstation ingress might be accomplished without stowing module

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONT'D.)

MODE	TASK	REMARKS
EVA	Ingress workstation and replace module	
	Verify replacement module	Audio and video contact with monitoring crewman/payload specialist
	Replace protective doors/ panel on payload	Quick release mechanisms normally used
	Repeat above procedures until EVA tasks are complete	
	Detach EVA workstation and fold into stowage configuration	
	Translate through payload bay and stow EVA workstation	Workstation may be stowed inside the airlock or in payload bay
	Egress payload bay and ingress airlock	
EVA	Prepare spent payload modules for vehicle ingress	May require temporary stowage, pressurizing, venting, etc.

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONT'D.)

MODE	TASK	REMARKS
EVA	Prepare airlock module for repressurization	
	Perform repressurization task sequence	
	Confirm repressurization sequence satisfactory	Monitor caution/warning indicators
EVA	Open airlock internal hatch and egress airlock into vehicle	
POST EVA		
SUITED IVA	Depressurize pressure suit	Use purge valve
	Doff EVA gloves	Temporarily stow EVA hardware
	Doff EVA helmet and visors	
	Disconnect and doff life support system (primary and secondary)	
SUITED IVA	Doff pressure suit and liquid cooling garment	Servicing of LCG required

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONT'D.)

MODE	TASK	REMARKS
SUITED IVA	Doff bioinstrumentation system	
	Doff fecal containment system (FCS) and urine collection transfer assembly (UCTA)	Servicing of LCG required
	Don constant wear garments (CWG) and inflight clothing	
SUITED IVA	Verify airlock hatch seal and airlock configuration	
SHIRTSLEEVE IVA	Initiate pressure suit drying operations	
SHIRTSLEEVE IVA	Recharge/service life support system(s) ● Portable LSS - Recharge oxygen - Recharge water/ice - Recharge battery - Checkout all systems ● Umbilical - Disconnect umbilical from LSS and panels - Checkout and service all systems	Servicing operations will vary for each LSS used

TABLE 4-1: EVA GENERAL TASK SUMMARY (CONCLUDED)

MODE	TASK	REMARKS
SHIRTSLEEVE IVA	Process UCTA and FCS units	
	Stow pressure suit ancillary equipment	Helmet, gloves, UCTA, FCS, bioinstrumentation system, SEVA, communications, etc.
	Complete suit drying operations and configure for stowage	
	Remove payload modules from airlock and process/stow	Process as required per payload
	Deactivate video monitoring systems	
	Verify all EVA equipment serviced and secured	Final check on equipment status
	Deactivate recording equipment	
	Debrief EVA operations and log data	Log required data for records
SHIRTSLEEVE IVA	End EVA mission	

SECTION 5.0 SYSTEMS CONSIDERATIONS APPLICABLE TO EVA

5.1 INTRODUCTION

Appendix A contains a comprehensive list of EVA selection/systems design considerations developed to identify the parameters that must be acknowledged when considering man for performing extravehicular functions. The considerations were developed by URS/Matrix during a previous contract (Extravehicular Activities Guidelines and Design Criteria, NASA-CR-2160, January 1973) to give planners and designers of future experiments and payloads an initial indication of the most "costly" aspects of using EVA. The considerations were developed based primarily on the required on-orbit EVA support equipment and its relation to the man, the spacecraft, and the payload. The major on-orbit EVA support equipment considered most common to all future extravehicular missions and included in the considerations listing are as follows:

- Crew Protective Systems (Space Suits)
- Environmental Control and Life Support Systems
- Crew and Cargo Transfer Systems
- EVA Workstations/Worksites
- Airlocks and Support Systems
- External Lighting
- Communications and Telemetry
- Data and Information Management

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Each of the EVA support equipment items listed above was subjected to an "EVA Selection/Systems Design Considerations" identification effort which resulted in numerous entries under each equipment item. A number of the considerations/entries are applicable to several or all of the EVA equipment items. Therefore, an EVA equipment considerations commonality chart, Figure 5-1, was developed based on the frequency distribution of the considerations across each of the major EVA equipment items. Several of the considerations appearing applicable only to specific EVA equipment or systems were regarded as essential and included in the chart. The commonality listing provides a manageable number of considerations/parameters to serve as a base for developing general information which associates the "costs" and impact of EVA to the mission, vehicle, and payload.

The EVA considerations are categorized into the following general classifications as applicable to the EVA areas:

- EVA Mission/Function
- Crewman Physiology/Performance
- Systems/Hardware/Equipment
- Spacecraft-Payload Systems/EVA Hardware Integration
- Special

Each of the EVA considerations is briefly discussed in the following paragraphs and Section 6.0 to provide the reader a somewhat qualitative description of the factors to be acknowledged when considering EVA as a means of performing operations outside the vehicle.

E

CONSIDERATIONS APPLICABLE TO EVA

SPACECRAFT-PAYLOAD SYSTEM/EVA HARDWARE INTEGRATION

- Vehicle Description/Accommodations
  - Vehicle Characteristics (General)
  - Time On-Orbit
  - On-Orbit Orientation
  - Total Vehicle Manpower
- EVA Translation Path
  - Translation Corridor to Worksite
  - Mobility Aids Along Path
- Crew Storage Provisions
  - Vehicle Stowage Volume
  - Volume Allocated to EVA
  - Stowage Environment

SYSTEMS/HARDWARE/EQUIPMENT

- EVA Qualified Hardware
- System Performance Characteristics
- System Flexibility
- System Reliability
- System Weight and Volume
- Equipment Operational and Shelf Life
- EVA Power Requirements
- Equipment Transportability
- Hardware Maintainability and Spares Requirements
- System Preparation Time
- System Expendables
- System Recharge, Collection and Drying
- Communications and Telemetry
- EVA Tools Considerations

EVA MISSION/FUNCTION

- EVA Function Definition
- EVA On-Orbit Time Requirements
- Frequency of EVA Operations
- EVA Scheduling
- Crewmen Required for EVA
- Translation Distance/Worksite Location
- Mass Handling Requirements

CREWMAN

- Crewman Safety Considerations
- EVA Performance Capabilities
  - Force Application
  - Reach Capability
  - Mass Handling Considerations
  - Mobility Considerations
  - Crewman Visibility
  - Crewman Comfort
  - EVA Monitoring Requirements
- Mission, Vehicle and Payload Impacts
  - Number of Crewmen Required
  - Duration of EVA
  - Frequency of EVA Operations
  - Total Manpower Required During EVA
  - Translation System to Worksite
  - Crewman Simulation and Training

SPECIAL

- Crewman Rescue

FIGURE 5-1: EVA CONSIDERATIONS COMMONALITY CHART

5.2 EVA MISSION/FUNCTION

The EVA considerations listed under the mission/function classification are concerned with the EVA impact to the total mission in terms of crewman time requirements and the additional support systems/hardware transported to orbit. EVA is weighed primarily against the decrease in on-orbit time that would be available for performing other mission/experiment functions and also the allocation of total payload weight, volume, expendables, etc. to EVA operations in lieu of providing additional scientific or developmental experiment programs. The weight, volume, etc. of EVA equipment is a primary factor only when the total payload(s) approaches the maximum (65,000 lbs. - 29,484 kg.) Shuttle Orbiter capacity.

5.2.1 EVA Function Definition

The type or characteristics of the EVA functions to be performed on a specific spaceflight mission are initially evaluated relative to crewman safety and crewman performance capabilities, followed by an evaluation of the impact of EVA on the mission, vehicle, and payload. The required extravehicular functions are identified or "designed" to be performed within the safety and capability limitations defined in Section 6.0 of this report. The EVA functions are then analyzed regarding their impact on the total mission and the "costs" to the vehicle and payload.

5.2.2 EVA On-Orbit Time Requirements

The time required for the EVA crewmen to prepare, conduct, and terminate extravehicular functions will impact the total spaceflight mission in the allocation of time available for required flight operations and supporting other primary experiment programs. The time required to perform the scheduled EVA tasks will also impact the vehicle and payload from the quantity of expendables and consumables required by the crewmen and life support systems (LSS) for EVA operations.

Preparation for EVA (pre-EVA) involves tasks such as equipment removal from stowage, equipment checkout, pressure suit and LSS donning, airlock preparation and depressurization, various checklist verification activities, etc. Other factors, including prebreathing pure oxygen for a specified interval to prevent decompression sickness (dysbarism), will be required if pressure suits below an operating pressure of 8.0 PSID (.56 kg./cm.^{2}) are used. Table 5-1 provides an abbreviated list of operations required during pre-EVA on future missions and includes a preliminary pre-EVA timeline (ref. 5.1). Table 5-1 is based on current pressure suits (nominal operation 3.7 PSID - .26 kg./cm.^{2}) which will require oxygen prebreathing if used on candidate future spacecraft. Table 5-2 provides a preliminary pre-EVA timeline based on pressure suits with an operating range between 8.0 and 14.7 PSID (.56 and 1.03 kg./cm.^{2}), with nominal operation being 8.0 PSID. Research and development for the design of pressure suits in the 8.0 to 14.7 PSID range was initiated in late calendar year 1972 and scheduled to be available for the early Space Shuttle flights (ref. 5.2).

The time required to perform the EVA tasks once outside the vehicle will impact the <u>mission</u> from the on-orbit manpower allocation point of view as in the crewman time required for pre-EVA functions. The length of time required outside the vehicle will also impact the <u>vehicle</u> through the quantity of LSS expendables and crewman consumables stowage volume needed during launch. The <u>payload</u> is affected by the EVA duration since the weight of crewman and LSS expendables and consumables are considered a part of the payload system.

The termination of extravehicular operations (post-EVA) requires on-orbit crewman time for repressurizing and safing the airlock, doffing the pressure suits, recharging LSS, stowing EVA equipment, etc. Tables 5-3 and 5-4 present the minimum required post-EVA operations for the 3.7 and 8.0 psi pressure suits, respectively. Preliminary post-EVA timelines, depicting the major task times, are included in the tables (ref. 5.1).

The timelines and operations/events shown in Tables 5-1 through 5-4 should be considered as general EVA operations applicable to a wide range of future

TABLE 5-1: PRELIMINARY PRE-EVA OPERATIONS AND TIMELINE FOR 3.7 PSID SUIT

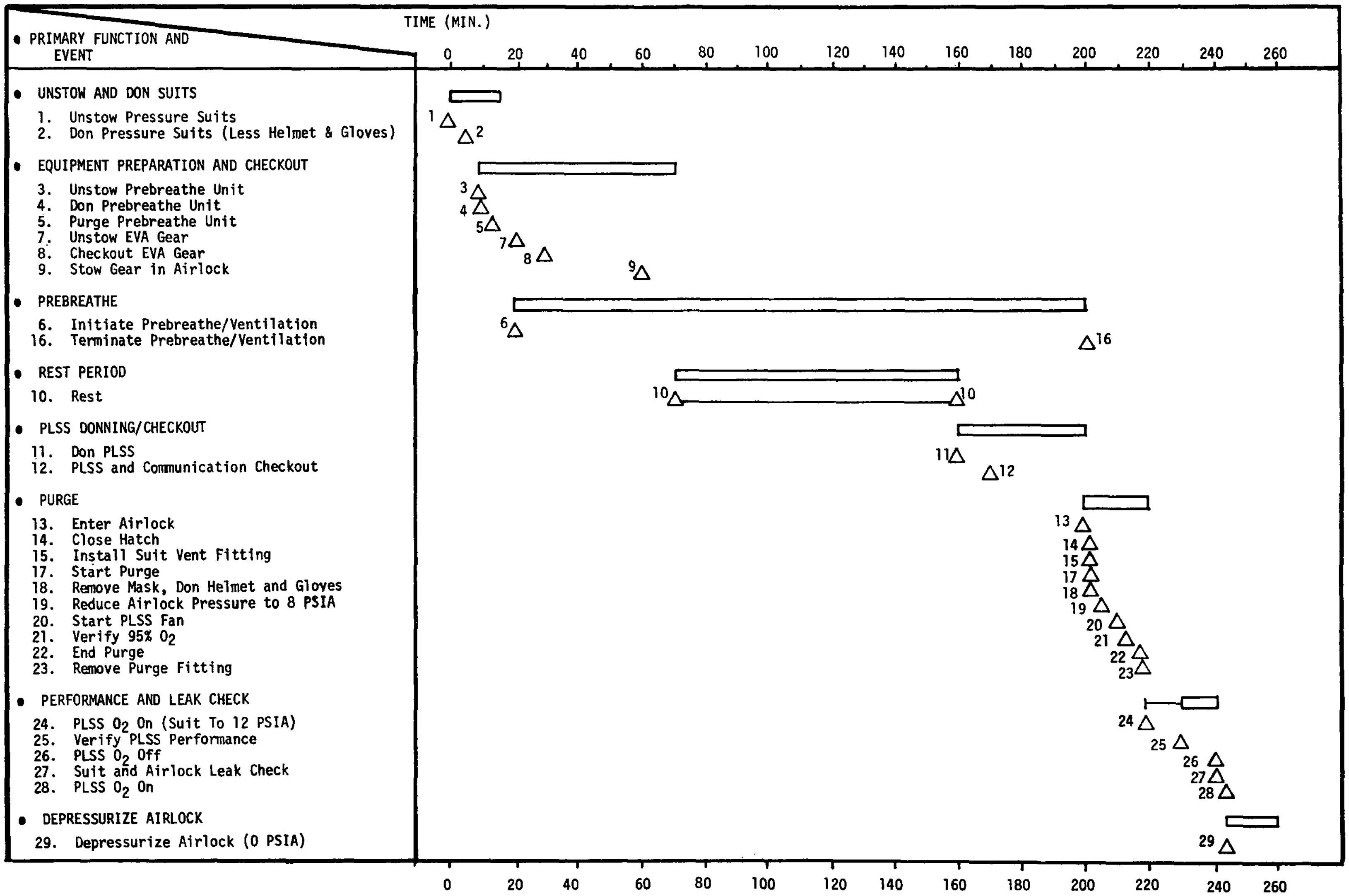


TABLE 5-2: PRELIMINARY PRE-EVA OPERATIONS AND TIMELINE FOR 8.0 PSID SUIT

PRIMARY FUNCTION AND EVENT	TIME (MIN.)
● UNSTOW EVA EQUIPMENT	
1. Unstow Suits and EVA Gear	
● EQUIPMENT CHECKOUT	
2. Preliminary Checkout of EVA Gear	
3. Return EVA Gear to Airlock	
● EQUIPMENT DONNING	
4. Unstow Suit Purge/Ventilation Hose	
5. Don Suits Less Helmet and Gloves	
6. Initiate Suit Ventilation	
7. Don PLSS	
● PLSS/COMMUNICATION CHECKOUT	
8. PLSS/Communication Checkout	
9. Install Suit Vent Fitting	
10. Don Helmet and Gloves	
11. Enter Airlock	
12. Close Hatch	
13. Terminate Suit Ventilation	
14. Start PLSS	
● LEAK CHECKS	
15. Depress Airlock to 12 PSI	
16. PLSS O_2 On (Suit to 20 PSI)	
17. Verify PLSS Performance	
18. PLSS O_2 Off	
19. Leakcheck Airlock and Suit	
20. PLSS O_2 On	
● DEPRESSURIZATION	
21. Depress Airlock	

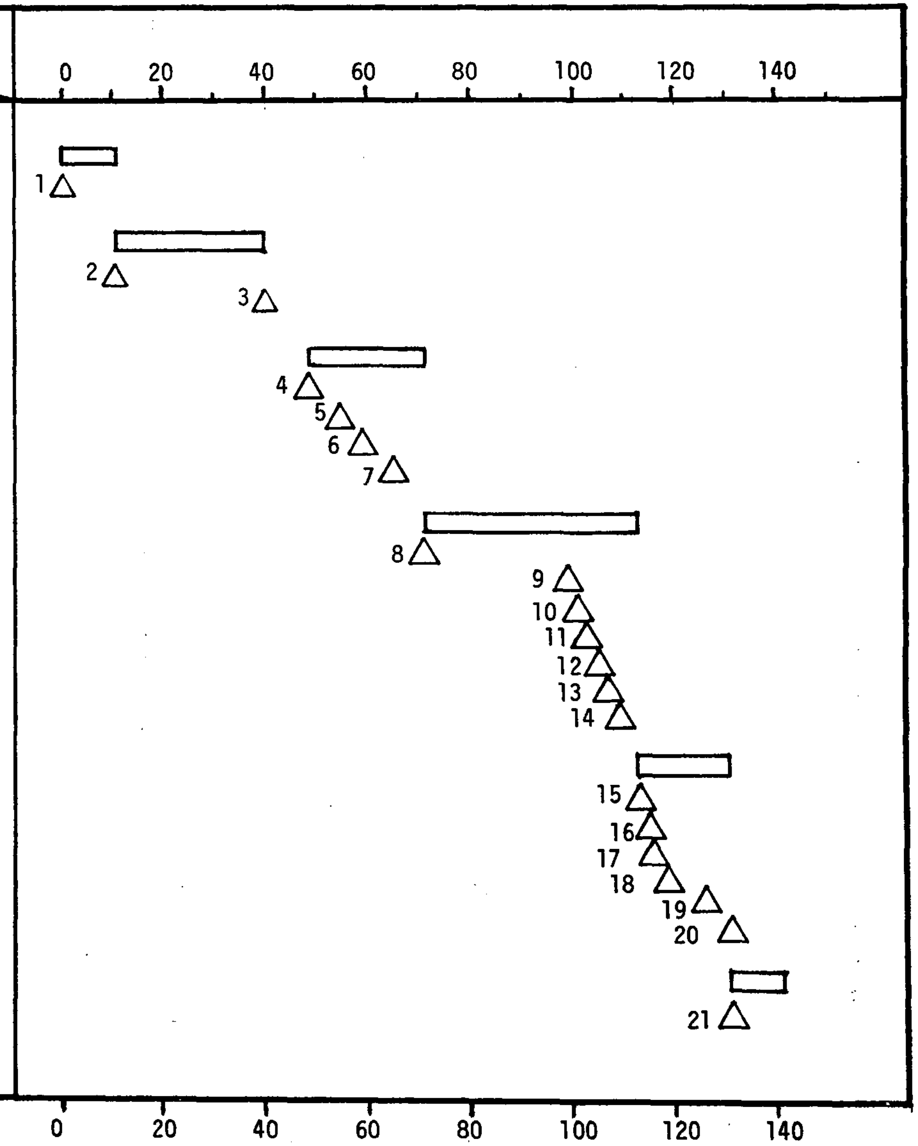


TABLE 5-3: PRELIMINARY POST-EVA OPERATIONS AND TIMELINE FOR 3.7 PSID SUIT

PRIMARY FUNCTION AND EVENT	TIME (MIN.)
• REPRESSURIZE AIRLOCK	
1. Enter Airlock	
2. Close EVA Hatch	
3. Repress Airlock	
• DOFF EVA GEAR	
4. Open Cabin Hatch	
5. Doff Suits and PLSS	
• RECHARGE EQUIPMENT	
6. Recharge PLSS (and Prebreather)	
• STOW GEAR	
7. Stow EVA Gear	
8. Configure Suits/PLSS for Drying	
9. Start Suit Drying	
10. End EVA Sequence	

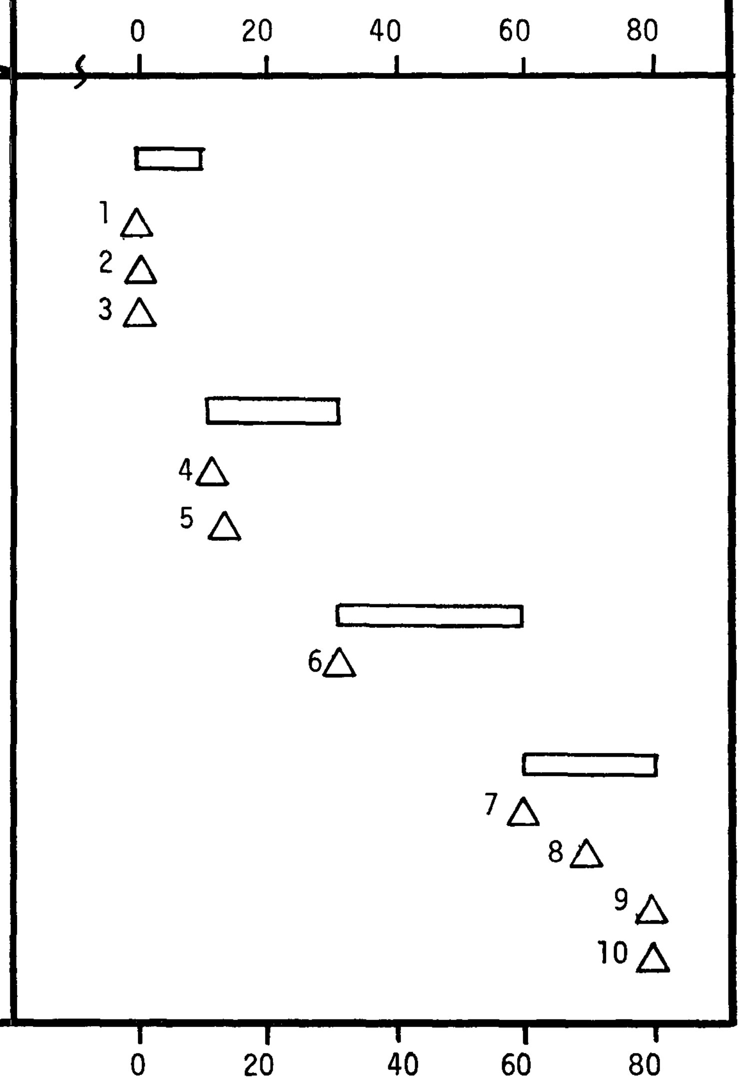
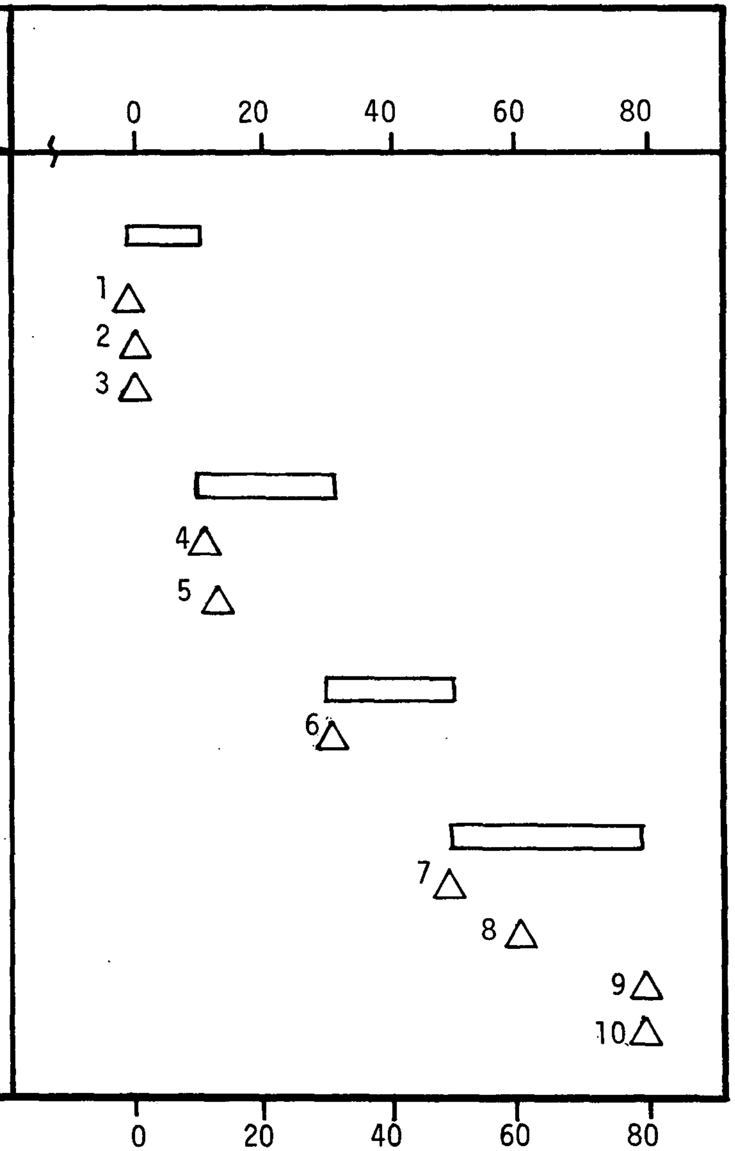


TABLE 5-4: PRELIMINARY POST-EVA OPERATIONS AND TIMELINE FOR 8.0 PSID SUIT

PRIMARY FUNCTION AND EVENT
• REPRESSURIZATION
1. Enter Airlock
2. Close EVA Hatch
3. Repress Airlock
• EQUIPMENT DOFFING
4. Open Cabin Hatch
5. Doff Suits and PLSS
• EQUIPMENT RECHARGING
6. Recharge PLSS
• GEAR STOWAGE
7. Stow EVA Gear
8. Configure Suits/PLSS for Drying
9. Start Suit Drying
10. End EVA Sequence



experiments and payloads. Each EVA mission will be somewhat unique in the supporting hardware requirements, replacement modules/cargo handled, payload equipment preparation, and data/equipment retrieved. Therefore, the crewman time required for pre- and post-EVA will vary between extravehicular missions. The preliminary timelines are based on simulations conducted during the Skylab Program using 1972 state-of-the-art pressure suits and support equipment, and projected to future missions assuming advanced EVA equipment. The total time required for the pre- and post-EVA appears excessive, particularly when prebreathing is required. However, through the use of suits operating at higher pressure (i.e., eliminate prebreathing), "rapid" don-doff suits and support systems, consolidated stowage of EVA equipment, etc. these times will be significantly reduced. The time estimates shown in Tables 5-1 through 5-4 represent worst-case conditions but should be used in timeline estimates for future EVAs until data on advanced extravehicular and Shuttle Orbiter systems become available.

5.2.3 Frequency of EVA Operations

The frequency of EVA operations, from the EVA equipment viewpoint, affects the mission, vehicle, and payload in the following areas:

- Crew time required for equipment preparation (addressed in Subsection 6.3.3)

- EVA equipment expendables, recharge, drying, and power requirements

- Crewman consumables stowage and weight

- Equipment spares and maintenance requirements

The crew time required to prepare and operate the extravehicular equipment is a necessary tradeoff independent of the method used in performing operations outside the vehicle. Any technique/method selected will require a finite amount of time to prepare equipment, and this time must be studied across all competing candidates. Trade-offs can then be made of EVA time versus other techniques and compared to the total mission time required for conducting additional experiments and mission operations. The frequency of EVA operations affects the vehicle with respect to the quantity of expendables and consumables needed to support EVA and the required stowage facilities on the vehicle. The stowage volume (e.g., additional containers, lockers, racks, etc.) of additional expendables and consumables required aboard each vehicle and the weight penalty to each payload are the basic parameters to be considered in association with the number of EVA missions per flight. Should the EVA frequency become numerous, stowage facilities for the EVA support equipment could present significant design problems which would require further trade-off studies involving various vehicle systems and structures.

Recharging the EVA portable life support systems and drying the pressure suits following each EVA must also be considered from the crew time and vehicle power requirements. Additional spare components for repair of EVA systems and equipment may be required should extravehicular operations occur frequently.

5.2.4 EVA Scheduling

The scheduling of EVA functions for compatibility with spacecraft maneuvering operations, the spacecraft orientation with respect to the sun/earth, and the space environment within the spacecraft orbit require consideration when designing payloads for EVA servicing. Spacecraft maneuvering operations (e.g., small ΔV, attitude stabilization) should be restricted or be minimal during EVA, particularly during the following activities:

- Crewman translation
- Cargo transfer
- Workstation deployment
- Payload retrieval
- Payload deployment
- Workstation ingress/egress
- Instrument calibration
- Fluid connect/disconnect

Prior to any spacecraft maneuvering operations, the EVA crewmen must be notified in sufficient time to avoid possible damage to the payload, loss of contact with the vehicle, and loss of data or equipment modules to deep space. Each EVA crewmen should verbally confirm a stabilized/restrained position for himself and the payload systems before the maneuvering operations are initiated.

The orientation and attitude of the spacecraft with respect to the sun, moon, and earth can produce an impact on extravehicular operations. The sources of illumination on an earth orbiting spacecraft can introduce lighting conditions varying from intense illumination and extreme contrasts to near total darkness. The complex illumination from the space elements may create visual problems for the EVA crewman, including object shape determination and distance judgement. Table 5-5 provides luminance values of several celestial bodies for intensity comparisons to readily known objects.

TABLE 5-5: LUMINANCE VALUES

	OBJECT VIEWED	VIEWED FROM	LUMINANCE
Celestial Bodies	Sun	Outside Earth's atmosphere	7×10^{8} mL
	Earth	Outside Earth's atmosphere	4.4×10^{8} mL
	Earth (dayside)	Earth orbital space	$(4.3 \text{ to } 9.4) \times 10^{3}$ mL
	Full Moon	Earth	8×10^{2} mL
	Pluto	Outside Earth's atmosphere	7×10^{0} mL
Common Objects	Upper limit of night vision		1×10^{-3} mL
	Snow in light of full moon		8×10^{-1} mL
	TV screen (B & W)		1×10^{1} mL
	White paper (in good reading light)		2×10^{1} mL

Requirements to expose EVA crewmen and equipment to extreme temperatures (e.g., inherent on the "light" and "dark" sides during earth orbit) for extended periods merit consideration when designing for extravehicular payload servicing. Unless dictated by the payload, scheduling of long duration extravehicular operations when the payload/vehicle is not directly exposed to sunlight is most desirable. Exposure of the pressure suit to elevated temperatures tends to decrease its useful life and increase the load on the life support system (LSS). Crewman comfort could also become a factor with a possible decrease in crewman performance. Studies of spacecraft on-orbit attitudes and orientations during each mission are required to "select" the optimum period to perform EVA. Slight changes in spacecraft attitude to gain a more compatible illumination and temperature environment for EVA should also be considered.

Artificial illumination of the EVA worksite area and translation paths is required during "dark side" earth orbital flights. The Shuttle Orbiter provides lighting for the general payload bay operations and crewman translation. However, additional lighting may be required for various experiment/payload EVA operations. The additional lighting may be supplied from either the payload or an EVA workstation. Dedicated lighting requirements are determined on an individual payload basis. Illumination levels for EVA are discussed in Subsection 7.8 of this report.

The space environment that will be encountered during future earth orbital flights is also significant to EVA from the hazards introduced by radiation and meteoroid concentrated areas. Scheduling of extravehicular operations when the spacecraft is near areas such as the South Atlantic Anomaly or aberrant meteoroid streams is to be avoided.

5.2.5 Crewmen Required for EVA

The number of EVA crewmen required in the servicing of an experiment, deployment/retrieval of a payload, or maintenance of the spacecraft systems will have an impact on the mission, the vehicle, and the payload. The mission will be affected through the availability of crewmen to perform all mission functions at the required time (see Section 6.3.1). While the crewman (or crewmen) is outside the vehicle, a minimum of one additional crewman is required to monitor EVA safety and payload status functions (i.e., those payloads/experiments being serviced). Depending on the EVA task characteristics, these monitoring tasks may be combined with the normal vehicle station keeping functions on the Space Shuttle. The Space Station and longer range programs should accommodate sufficient personnel to avoid simultaneous duties during extravehicular operations for those directly involved in EVA. During the planning and design of a mission utilizing EVA, specific attention must be directed to real-time inflight crewman operations and task timelines to ascertain that all mission functions can be performed at all times, in both nominal and contingency circumstances.

The number of crewmen with full EVA equipment required for an EV task affects the primary space vehicle design and operation in several areas. The greatest impact is in the total equipment required for the EV crewmen. Although the Shuttle payload is assessed with the weight "cost" of the EVA carry-on systems, the vehicle must provide adequate volume for permanent EV support systems, EV equipment/vehicle interface provisions, and stowage for the various carry-on systems and equipment. The major vehicle areas impacted by the number of EV crewmen are listed below:

- Quantity of EVA hardware
  - Weight
  - Stowage volume
  - Interfaces
- Airlock size and Configuration
- EV systems status monitoring
- Expendables
- Expendable stowage
- Equipment donning area
- Additional safety provisions

Each of the above parameters requires consideration, in view of the impact each additional EV crewman and equipment bring upon the vehicle, as trade-off studies are made to select the optimum method of performing functions outside the vehicle.

The various experiments and payloads aboard the vehicle at launch are also affected by the number of EV crewmen required. Since the EVA carry-on equipment and expendables are considered part of the payloads (with respect to weight and volume), each additional set of crewman equipment adds to the total payload weight for launch. This equipment, under current guidelines, includes the following (ref. 5.3):

- Pressure Garment Assembly (PGA)
- Environment Control/Life Support Systems (EC/LSS)
- Maneuvering Systems
  - Hand-Held Maneuvering Unit (HHMU)
  - Astronaut Maneuvering Unit (AMU)
- Tool Kits, Special Tools and Torquing Devices
- Crewman Restraints
- Portable Lights
- Crewman and Equipment Expendables
  - Oxygen
  - Nitrogen
  - Carbon Dioxide Control Equipment for PLSS
  - Recharge water for PLSS
  - All EVA Equipment Expendables and Spares

In the initial selection process of methods/techniques to perform EV functions, the payload designers must consider the weight and volume penalty of the EVA equipment and compare it to other options. Each of the options can then be assessed in terms of additional experiments and payload hardware that could be carried on a particular launch.

5.2.6 Translation Distance/Worksite Location

The location of the EVA worksites and the translation distance to the work areas are necessary considerations in the EVA support equipment selection process. These parameters will impact the mission, vehicle, and payload in the following areas:

- Type of EVA life support system
- Number and type of translation aids
- Cargo transfer system required
  - Hand carry
  - Manual assisted
  - Maneuvering unit
- Additional EVA lighting required
- Workstation required
  - Fixed
  - Portable
- Increase in EVA crewman and support crewman time

The above parameters impact the vehicle and payload initially from the volume required to incorporate/stow the EVA equipment on the vehicle and the equipment weight. The total mission is affected in terms of crewman time to translate between the worksites and the preparation/operation of the necessary EVA hardware. As an example, the payload worksite location may be a remote free-flying satellite (detached from the prime vehicle) requiring a self-contained maneuvering system, extensive cargo transfer, auxiliary lighting, EVA workstations, etc. Measurable crew time is required to prepare, checkout, and operate such equipment and must be justified against automatic and tele-operator systems.

The type of EVA life support systems used (both primary and contingency) will be a function of the distance from the EVA airlock and the location of the worksite. The types of life support systems (LSS) being considered for future EVA operations are portable life support systems (PLSS) and umbilical life support systems. Umbilical systems require interfaces with permanently installed Environmental Control/Life Support System (EC/LSS) in the vehicle or special provisions within the vehicle environmental control system. The EVA umbilical LSS appear most applicable where the distance from the airlock to the worksite does not exceed 60 ft. (18.3 m). Umbilical management becomes a factor at greater lengths. The umbilical LSS requires less space for the crewman to perform EVA operations since no gear is carried on the crewman's back as with the portable systems. Closed loop umbilical systems are applicable where payload contamination is of concern; the umbilical also eliminates the need for telemetry systems for monitoring critical body functions (i.e., uses hard wire system). An independent contingency LSS of approximately 30 min. duration is used with the umbilical EVA LSS. The umbilical LSS may encumber the EVA crewman in certain operations; however, unless translation to a free flying payload is required, a safety tether is used during all EVA operations independent of the LSS used.

Portable life support systems are completely self-contained units which operate independent of the vehicle environmental control system. Vehicle provisions for recharging/servicing the portable LSS are required. The portable systems are highly applicable in EVA functions where free-flying payloads are serviced and where moderately long distances are traversed. Current portable LSS have a duration in excess of 6 hours with the critical parameter being the water sublimator for crewman cooling functions. Due to the bulk of the portable LSS, more volume is required for working in and around the payloads than the umbilical systems. The weight and volume impact of the EVA life support systems are further discussed in later sections of the report.

The location, number, and type of crewman translation aids required to gain access and manually transfer equipment (e.g., replacement modules, workstations, tools, etc.) to the payload worksite are considerations in the selection of an extravehicular servicing technique. When considering man, unsupported by assist mechanisms, mobility aids in the form of handholds and handrails are required along the EVA translation path. Handrails or properly spaced handholds have proven adequate for crewman translation on previous EVA missions. Limited package/cargo transfer tasks using one handrail have also been performed on several of the Gemini and Apollo orbital flights. The arrangement or location of worksites and experiment equipment in a vehicle payload bay may require that mobility aids be attached to the payloads to provide stabilization or allow crewman passage to other worksites. The vehicle normally provides mobility aids for movement within the payload bay; however, the arrangement of multiple payloads or large diameter payloads may preclude the use of portions of these mobility aids on certain flights. Alternate translation paths over or around the payloads may require handholds and handrails which will impact the payload designs and weight. Each payload arrangement in which EVA is required should be considered relative to providing mobility aids in addition to those necessary for payload servicing.

The cargo/module transfer system required to support EVA is partially dependent upon the translation distance and the worksite location relative to the EVA airlock. Extendible cargo booms, endless clotheslines, and manual transfer methods have been utilized on previous EVA missions to transport data packages. Extendible booms and endless clotheslines are limited to line-of-sight transfers, while the crewman is constrained somewhat by the mass and volume of the packages. Cargo transportation to free-flying payloads that cannot be docked to the spacecraft may require a free-flying maneuvering device such as the current Astronaut Maneuvering Unit (AMU), Foot Controlled Maneuvering Unit (FCMU), or Maneuverable Work Platform (MWP). Man-rated maneuvering units have not been fully assessed for space work; however, the AMU and FCMU will be evaluated inside the orbital workshop on the Skylab program. Each cargo/module transfer task and the hardware required outside the vehicle must be independently evaluated with respect to the following:

- Payload location within the payload bay
- Free-flying satellite location with respect to the spacecraft
- Payload orientation within the payload bay or extending from the bay (i.e., attached to docking mechanism)

- Multiple payloads within the payload bay
- Clearance requirements between payloads and between the vehicle structure and the payloads located in the bay
- Size, mass, quantity, and frequency of modules being transferred
- Weight, volume, power, spares, servicing facilities, expendables, etc. required by the cargo/module translation/transportation hardware

The location of the payload to be serviced by EVA may require additional lighting, above that provided by the spacecraft, for "night side" operations.

Manipulative tasks located through an aperture in a payload, tasks located on the back side of equipment (i.e., opposite the light source), tasks located in shielded areas, etc. are candidates for supplemental lighting to be provided by the payload or from the EVA workstation. Each worksite must be evaluated to ensure adequate illumination levels for task performance and (video) monitoring requirements.

Spacecraft orientation with respect to the sun may also necessitate shielding or shading of payload components to prevent excessive glare and afford rapid hardware identification by the EVA crewman. As the angle of incidence of sunlight (essentially collimated) varies, significant differences in surface characteristics such as shadow shapes, luminance, and color will occur. Difficulty in properly identifying different shapes and surfaces may be encountered by the crewman. Similar lighting requirements will be necessary for both "night" and "light" sides of the orbit if teleoperators (fixed or free-flying) or manipulator arms are used to perform operations external to the vehicle. Since monitoring of servicing operations outside the vehicle is required, special lighting requirements are not unique to EVA but necessary, independent of the technique used.

The worksite location and configuration, and the tasks to be performed are the primary drivers in determining the requirement for an EVA workstation.

Translation distance to the worksite is also a consideration in the type of workstation selected. A free-flying satellite or payload extending perpendicular from the payload bay may require a simple EVA workstation that is fixed to the payload and can be deployed by the crewman when needed. Workstations may be transported to free-flying satellites via crewman maneuvering devices on advanced future missions. Tasks to be performed "inside" the payload bay may require portable workstation that can be attached on-orbit to the vehicle or payload. Workstations fixed to the payload or vehicle prior to launch may be applicable where the EVA tasks are concentrated to a limited number of locations.

Worksites initially proposed in locations with restricted access/working volume (e.g., near payload bay walls, between payloads) will require trade studies to determine the impact of worksite relocation, payload redocking, various servicing techniques, special tools, etc. Each proposed vehicle and payload worksite, in conjunction with each task, will require consideration/study on an individual basis. Workstation configuration as can be defined from current payload/vehicle requirements is the subject of Volume II of this report. Several EVA workstation conceptual designs, based on a preliminary analysis of present payload servicing requirements, are contained in the Volume II report.

The increase in crewman EVA time as a result of the translation distance to the worksite is considered significant only in requirements such as the following:

- Servicing of remote satellites requiring special crewman/cargo free-flying maneuvering units

- Numerous crewman translations between the EVA airlock and the worksite for transfer of replacement modules, tools, monitoring, etc.

The servicing of remote satellites requiring the use of free-flying maneuvering units is more costly to the payload due to the additional equipment involved. From the crewman-time-in-EVA standpoint, equipment in the maneuvering unit category will normally be stowed in the payload bay, and subsequently checked out, donned, serviced, and recharged in EVA. This prep/post time (in addition to actual translation and servicing time) must be considered in addition to the maneuvering weight, volume, and vehicle interface impacts. Several payloads currently proposed for Space Shuttle delivery are candidates for servicing via maneuvering units due to contamination critical equipment, payload configuration that prohibits docking to the vehicle, and payloads containing booms, solar arrays, etc. which are most accessible through the use of such units.

The number of trips required from the EVA airlock or module stowage area to the EVA worksite may require an excessive amount of the crewman's working time if only manual transportation is considered. Trade studies of man versus man-aided techniques (e.g., extendible booms, cargo trolleys, endless clotheslines) for transporting large quantities of cargo become necessary when the cost of crewman time and consumables balance the cost of systems development and the weight/volume of non-aided systems. Models or equations for calculating the break point of man versus man-aided or man-aided versus total automation, etc. are not likely to be developed due to the number of variables involved. Each EVA mission must be considered in separate study programs. Information on candidate cargo transfer systems applicable to the Space Shuttle Orbiter payload bay will be available from planned future studies.

5.2.7 Mass Handling Requirements

Mass handling requirements associated with the Space Shuttle payloads may range from transporting simple low mass inspection articles, to reconfiguring modularized payloads, to deploying/retrieving payloads of size and mass restricted only by the crewman's physical capability and vehicle capacity. Several methods of transporting cargo on previous EVA missions were mentioned in the previous subsection; these consisted primarily of man and man-aided mechanical techniques. These techniques remain valid and may have application on the Shuttle Orbiter and Space Station vehicles, particularly in supporting the modular replacement and satellite refurbishment type payloads. However, the previously developed systems were used to transport only a single package or small cluster of packages at a relatively slow velocity (5 in./sec. - 7.6 m/min. for the extendible booms) during each round trip. The endless clothesline was manually actuated and also relatively slow.

The primary package and payload handling techniques currently being considered by the Shuttle Orbiter consist of the EVA/IVA crewman and the Orbiter manipulator arms. The current level of definition/design of most payloads does not define the requirements for module handling/transfer. However, preliminary payload analyses indicate that an advanced, economical, and rapid cargo handling/transfer system may be required to handle the quantity of material to be transported on various Shuttle missions. This system(s) may take the form of a powered "trolley" unit that can be repositioned within the payload bay or a manually/electrically powered conveyor system readily attachable to the payload bay walls. The package handling and cargo transportation systems required for the Shuttle are candidates for future study programs. Reports should be available by late 1973.

5.3 SPACECRAFT-PAYLOAD SYSTEM/EVA HARDWARE INTEGRATION

The integration of EVA support equipment into the spacecraft will involve interfaces with several of the major vehicle subsystems. The degree of impact the EVA equipment integration introduces is dependent on the characteristics of the specific vehicle, the mission, and the EVA tasks required. Based on the variety of experiments/payloads tentatively scheduled for the Space Shuttle, modular (e.g., rack-mounted, replaceable consoles) EVA support equipment units to correspond with EVA requirements of each mission appear appropriate. The EVA requirements on the Space Shuttle missions will range from providing a contingency capability with no planned EVA task, to dedicated EVA systems technology development missions requiring direct involvement of four (4) crewmen. The modular EVA support equipment concept would allow "matching" EVA systems to specific mission requirements for efficient utilization of vehicle/payload volume and weight constraints.

The major vehicle subsystems affected by the EVA support equipment include the following:

- Structural (e.g., airlock, monitoring station, equipment stowage facilities)
- Power (e.g., lights, recharge stations, drying units)
- Environmental Control/Life Support System (e.g., umbilical LSS, suit ventilation prior to portable LSS operation)
- Hydraulic (e.g., water recharge of portable LSS, urine processing)
- Pneumatic (e.g., portable LSS recharge, airlock operation)
- Communications (e.g., telemetry, hardline, ground, other spacecraft)
- Data/Information Management (e.g., T.V., recorders, data dump)

5.3.1 Vehicle Description/Accommodations (Refs. 5.4 - 5.6)

Since the Space Shuttle Orbiter has been designated as the "workhorse" of future space programs, a general description of the accommodations available to support extravehicular operations are presented in the following paragraphs. The description is intended to provide potential users of EVA with an overview of the capabilities of the Shuttle Orbiter to support manned operations outside the vehicle.

5.3.1.1 Vehicle Characteristics (General)

The Shuttle Orbiter will provide an EVA capability for a minimum of two crewmen during all missions. Included in the accommodations are: (1) an EVA airlock, (2) systems/hardware stowage, (3) suit donning/doffing area, (4) LSS recharging station, (5) communications systems/circuits, (6) mobility/transfer aids, and (7) monitoring systems for on-orbit operations. The Shuttle Orbiter will provide the necessary support to perform seven 2-man EVAs of four-hour duration each as required during the 7-day orbital missions. One-man EVAs can also be conducted with crewman monitoring from within the Shuttle Orbiter by the onboard data system.

The EVA airlock for the Space Shuttle is located on the second level of the bi-level pressurized crew and passenger compartment (see Figure 5-2). The airlock provides access to the payload bay for EVA operations both with or without a payload docking module (see Figure 5-3). The EVA airlock hatch from the vehicle interior is 56 in. (1.4 m) by 40 in. (1.0 m); the payload bay/docking module hatch is 40 in. (1.0 m) in diameter. The "exterior" EVA hatch from the docking module to the payload bay is also 40 in. in diameter. The current airlock module size is 83 in. (2.1 m) long by 63 in. (1.6 m) in diameter. The Shuttle Orbiter provides functions for airlock support. The airlock support subsystem includes all hardware required to accommodate EVA and intravehicular suited activities, crewman payload access, and emergency breathing within the Shuttle Orbiter. The airlock volume is ventilated at all times by the Orbiter atmospheric revitalization subsystem.

The EVA systems/hardware stowage facilities are to be provided in the EVA airlock and the Orbiter cabin second level. An area below the second cabin level is provided for the Shuttle environmental control and life support equipment and additional stowage hardware. The lower level requires removal of floor panels for access. Pressure suit donning/doffing and EVA life support system (portable) recharging facilities are also provided in the airlock or on the second cabin level. The airlock pressurization/depressurization system is controllable from either the airlock or the Orbiter cabin. An emergency repressurization capability for rapid return to a safe environment in the event of an EVA system malfunction or as a backup to the normal airlock repressurization system is provided.

The Shuttle Orbiter EVA and Intravehicular Activity (IVA) equipment interfaces and services include provisions for complete recharge of the portable

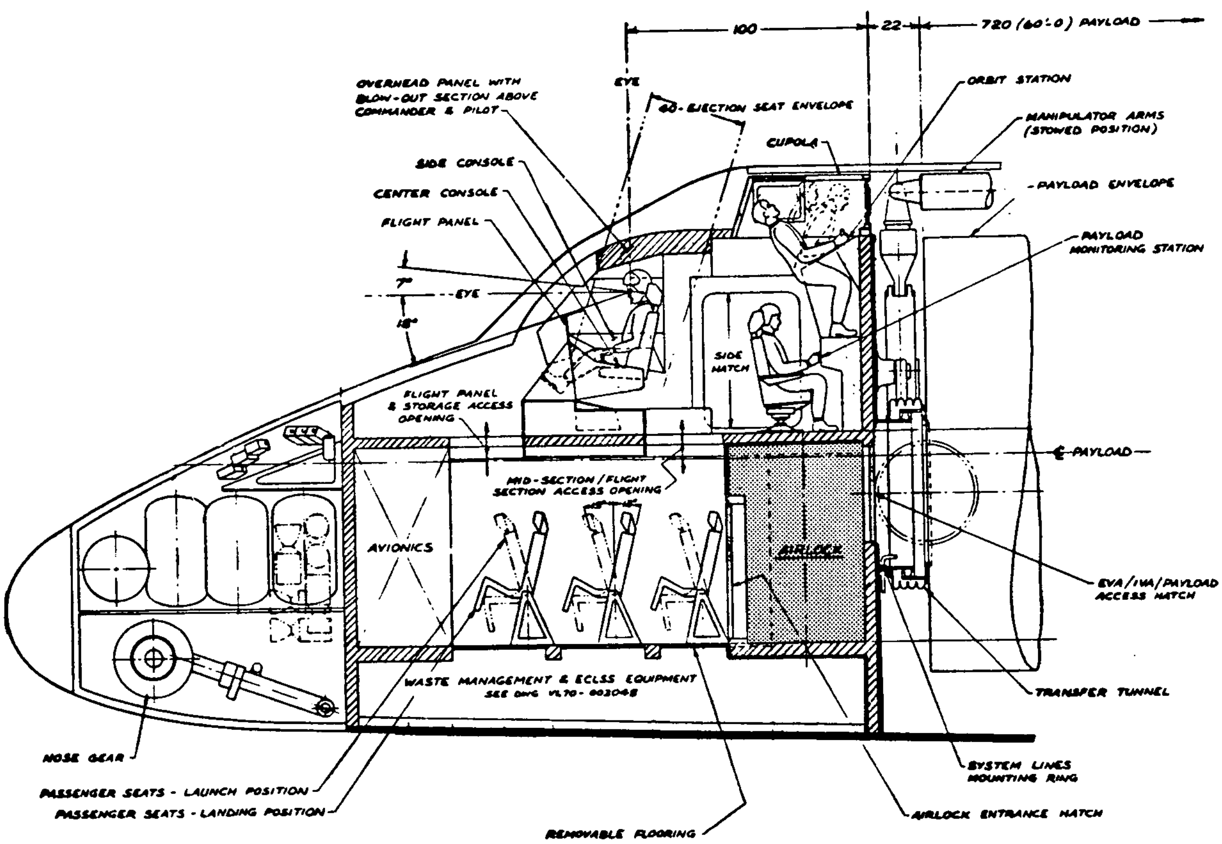


FIGURE 5-2: SPACE SHUTTLE EVA AIRLOCK LOCATION

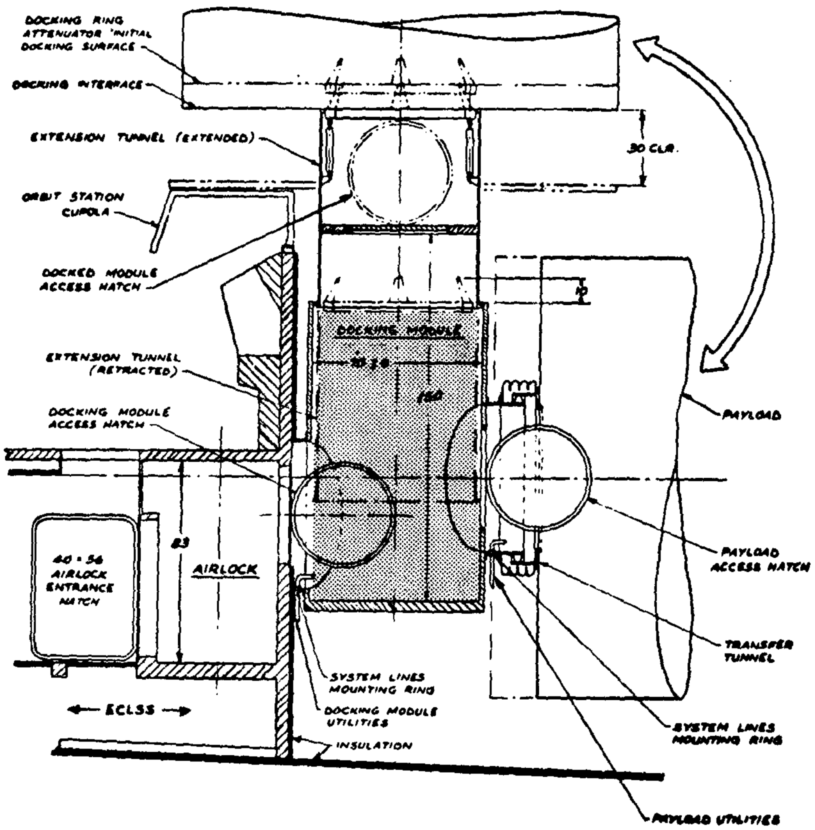


FIGURE 5-3: EVA AIRLOCK AND DOCKING MODULE ORIENTATION

life support systems, pressure suit drying, restraints and mobility aids, lighting, communications, EVA/IVA equipment donning/doffing and checkout, pressure suit gas ventilation, and liquid cooling garment water system.

During EVA the crewmen are monitored from within the Shuttle Orbiter by the onboard data system. The communications and tracking subsystem is part of the avionics system and provides the following:

A. Receiving and transmission of voice

B. Transmission of operational telemetry

C. Receiving, processing, and transmission of payload telemetry

D. Receiving, decoding, generation, and transmission of commands

E. Landing and atmospheric navigation sensor data

F. Transmission of television signals

G. Tracking passive targets

The comm/tracking subsystem provides the radio frequency (RF) interface between the orbiter and EVA crewmen, other orbiting vehicles (including communications relay satellites), and ground facilities. Ground communications facilities include the Space Tracking and Data Network (STDN) and AFSCF, Air Traffic Control facilities, and Orbiter vehicle landing site facilities.

Electrical power for operation of the major Shuttle Orbiter and payload systems is supplied by a hydrogen/oxygen fuel cell power plant system containing three (3) fuel cell subsystems. The fuel cell power system reactants and oxygen for the environmental control/life support system are supplied from super-critical cryogenic stowage tanks. Each of the fuel cell subsystems are rated at seven (7) kilowatts (kw) continuous power and 10 kw peak power. Two

10-ampere hour, nickel cadmium batteries provide emergency reset power for the main power generation and distribution equipment, and also for firing pyrotechnic devices. Two power plant subsystems have the capacity to support normal operational requirements, while one subsystem is adequate to provide fail-safe requirements. Under fail-safe operation, the one subsystem also provides one (1) kw average power to the payload.

During most of the mission, the Shuttle power plant system can provide an average of three (3) kw and a peak of six (6) kw to the payload, contingent on vehicle operations. Each power plant system (i.e., three total) provides voltage regulation with a range of 31.0 to 27.5 volts over a load range of 1.5 to 10.0 kw. For missions/payloads requiring an increase in total power or long duration missions, additional fuel cell reactants are carried in the payload bay. The expendables, their tankage, and plumbing to the Shuttle Orbiter interfaces are charged to the payloads. For extended duration missions electrical power consumables are estimated below for comparison to the baseline Shuttle requirements:

BASELINE

- 4 Men 7 Days
- 2 H_2 and O_2 Tanks
- 1 KW Avg to Payload
- 1 5 KW Peak to Payload
- 50 KWH Energy

7 DAY MISSIONS

- 2 Additional H_2 and O_2 Tanks
- 1280 KWH for Payload
- 932 lbs. for Dry Weight
- 1611 lbs. for Fluid Weight

30 DAY MISSIONS

- 7 Additional H_2 and O_2 Tanks
- 980 KWH for Payload
- 4180 KWH for Orbiter Energy
- 336 lbs. for ECLSS O_2
- 3537 lbs. for Dry Weight
- 5636 lbs. for Fluid Weight

5.3.1.2 Time On-Orbit

The Space Shuttle environmental control/life support system for nominal operations is sized to provide for a 4-man crew for 7 days, plus 96 hours for contingency operation, for a total of 44 man-days. The normal expendables stowage capacity is 42 man-days without modification to the Shuttle Orbiter; however, expendables over 28 man-days are considered part of the payload and are charged to payload weight. The Shuttle mission duration may be extended for up to 30 days by addition of expendables as payload weight and volume. A total of 10 crewmen and passengers (6 additional passengers) can be accommodated. During the normal 7-day mission, expendables for seven EVA airlock repressurizations are provided by the Shuttle Orbiter environmental control/life support (EC/LS) system. The EC/LS system consists of the following subsystems:

- Atmosphere revitalization
- Food, water, and waste management
- Active thermal control
- Airlock support

5.3.1.3 On-Orbit Orientation

The orientation of the Shuttle Orbiter with respect to the sun and other space bodies was briefly discussed in Subsection 5.2.4 of this report. This previous discussion was limited to considerations involving the EVA crewman and the affects of illumination levels, controls, object configuration determination, and radiation on task performance. Further discussion is merited concerning the temperature of EVA equipment being handled, hardware along the translation route, and ambient temperatures at the EVA worksites.

Preliminary temperature analyses were conducted (ref. 5.7) for the orbital conditions of a typical payload deployed from the Shuttle payload bay and a payload inside the bay. Ten (10) locations (see Figure 5-4) were identified for obtaining worst case hot environments, and contact temperatures with the Shuttle Orbiter oriented as shown in the figure were determined. A computer routine developed by Lockheed Missiles and Space Company (Lockheed Heat Rate Package - LOHARP) was used to obtain incident fluxes on all EVA crewman and spacecraft nodes which included self-blockage and multiple reflections. Additional analyses were conducted to include radiant emission interchange by spacecraft surfaces and to determine contact temperatures for the worst-case heating conditions. A steady-state adiabatic surface approximation was used for the heat radiation calculations. The payload dimensions used were 14 ft. (4.3 m) in diameter and 40 ft. (12.2 m) in length, with a radiator surface on the first 20 ft. (6.1 m) beyond the Shuttle cabin.

Maximum average incident flux values were obtained for the deployed and retracted payload modules, including both undegraded and degraded properties (see Figure 5-5). Incident flux at various solar and infrared (IR) wavelengths is shown in the figure. The worst-case for both solar and IR occurs with the EVA crewman in the payload bay and the payload module retracted. The high temperature average values are attributed to the cavity effects. Equipment surface (contact) temperatures of importance to EVA are also shown in Figure 5-5. Surface temperatures are estimated to reach 269°F in the payload bay and 285°F on the payload bay doors.

Cold case average fluxes and contact temperatures were calculated based on North American Rockwell Company cold case temperature profiles. In an orbit with the solar vector perpendicular to the orbit plane and the payload bay facing deep space, contact temperatures reach -263°F. In an identical

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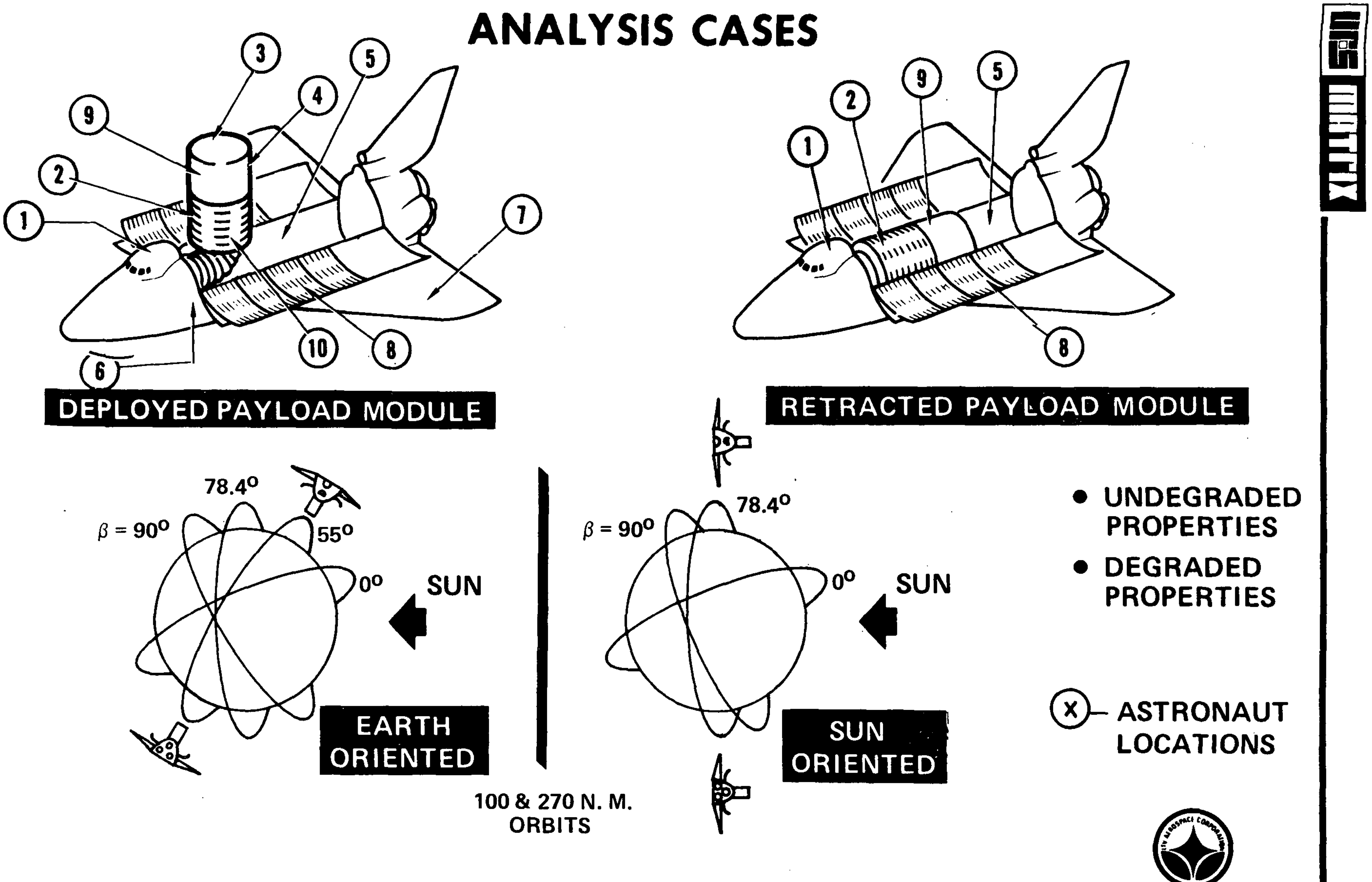


FIGURE 5-4: EVA TEMPERATURE ANALYSIS--LOCATION AND ORIENTATION

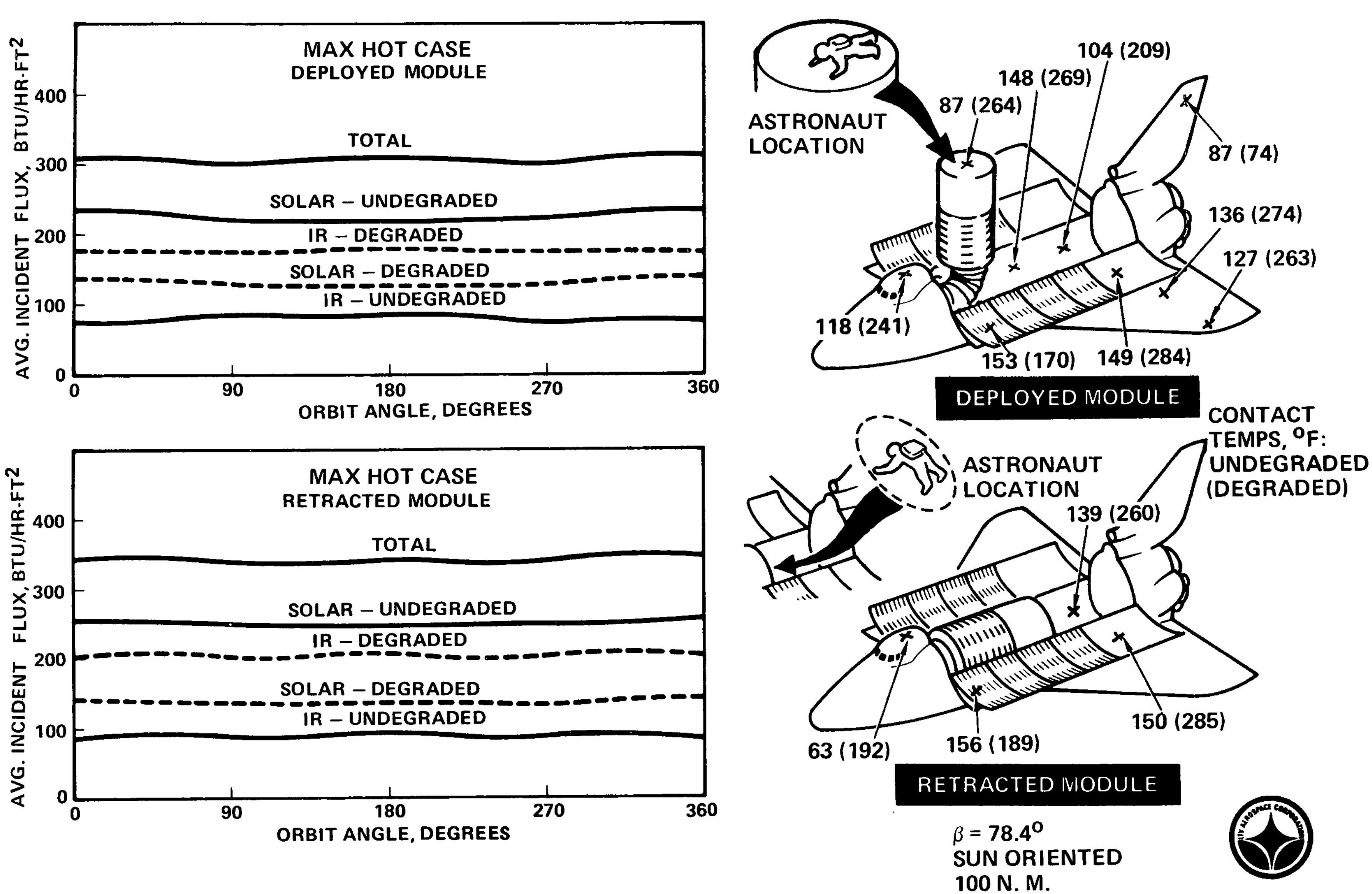


FIGURE 5-5: MAXIMUM AVERAGE FLUX AND CONTACT TEMPERATURES

orbit with the payload bay facing the earth, a minimum temperature of -281°F is reached on the underside of the Shuttle Orbiter.

The location of temperature sensitive payload equipment and equipment requiring EVA servicing must be considered in the initial phases of experiment and payload design.

5.3.1.4 Total Vehicle Manpower

The normal Shuttle Orbiter crew--a commander and a pilot--perform the Shuttle flight functions and manipulator operations while in orbit. Two additional crewmen make up the basic Orbiter manpower. Mission specialist and payload specialist are required to support the experiment and payload operations. Depending on the Orbiter/payload requirements, two crewmen will normally perform EVA/IVA operations. The payload specialist will not perform EVA functions unless contingencies exist. The operations and responsibilities of the Shuttle crewmen are discussed below:

COMMANDER -- The Commander is in command of the flight and is responsible for overall Space Shuttle, payload flight operations, and vehicle safety. The Commander is proficient in all phases of vehicle flight, payload manipulation, docking and subsystem command, control, and monitoring operations. He is required to be knowledgeable of payload and payload systems as they relate to flight operations, communication requirements, data handling, and vehicle safety.

PILOT -- The Pilot is second in command and is equivalent to the commander in proficiency and knowledge of the vehicle, payloads, and subsystems.

MISSION SPECIALIST -- The Mission Specialist is responsible for interfacing of payload and orbiter operations and the management of payload functions/operations. The Specialist is trained in vehicle and payload subsystems, flight operations, and payload communications data management. More than one Mission Specialist may be included in the crew when required by the payload.

PAYLOAD SPECIALIST -- The Payload Specialist is responsible for the applications, technology, and scientific payload/instruments operations. The Specialist has detailed knowledge of the payload/instruments, operations, requirements, objectives, and supporting equipment. More than one Payload Specialist may be included in the crew.

PASSENGER/OBSERVER -- Passengers/observers are personnel involved in experiment/payload design and data acquisition but have no active part in the Shuttle or payload operations.

5.3.2 EVA Translation Path

The EVA crewman translation path to the various worksites must provide sufficient volume to allow translation to avoid EVA equipment contact with surrounding vehicle equipment. Sharp corners and edges, hardware protrusions, and equipment arrangements that are candidates for LSS umbilical or safety tether entanglement, and pressure suit or life support system damage must be considered in establishing translation paths. The Shuttle Orbiter is responsible for providing a safe and sufficient translation corridor and mobility aids throughout the payload bay but does not include access to payload attached worksites.

5.3.2.1 Translation Corridor to Worksite

The translation path to the EVA worksite must provide a minimum of a 30 in. (.76 m) diameter corridor for the suited EVA crewman when using either a portable life support system or an umbilical system (see Figure 5-6). When ingressing/egressing an airlock or corridor normal to the initial direction of motion, a corridor approximately 30 in. (.76 m) by 50 in. (1.3 m) is required as shown in Figure 5-7 (ref. 5.1). The crewman ingress/egress arrangement and orientation will be a function of the Shuttle payload bay configuration and payload/experiment orientation within the bay.

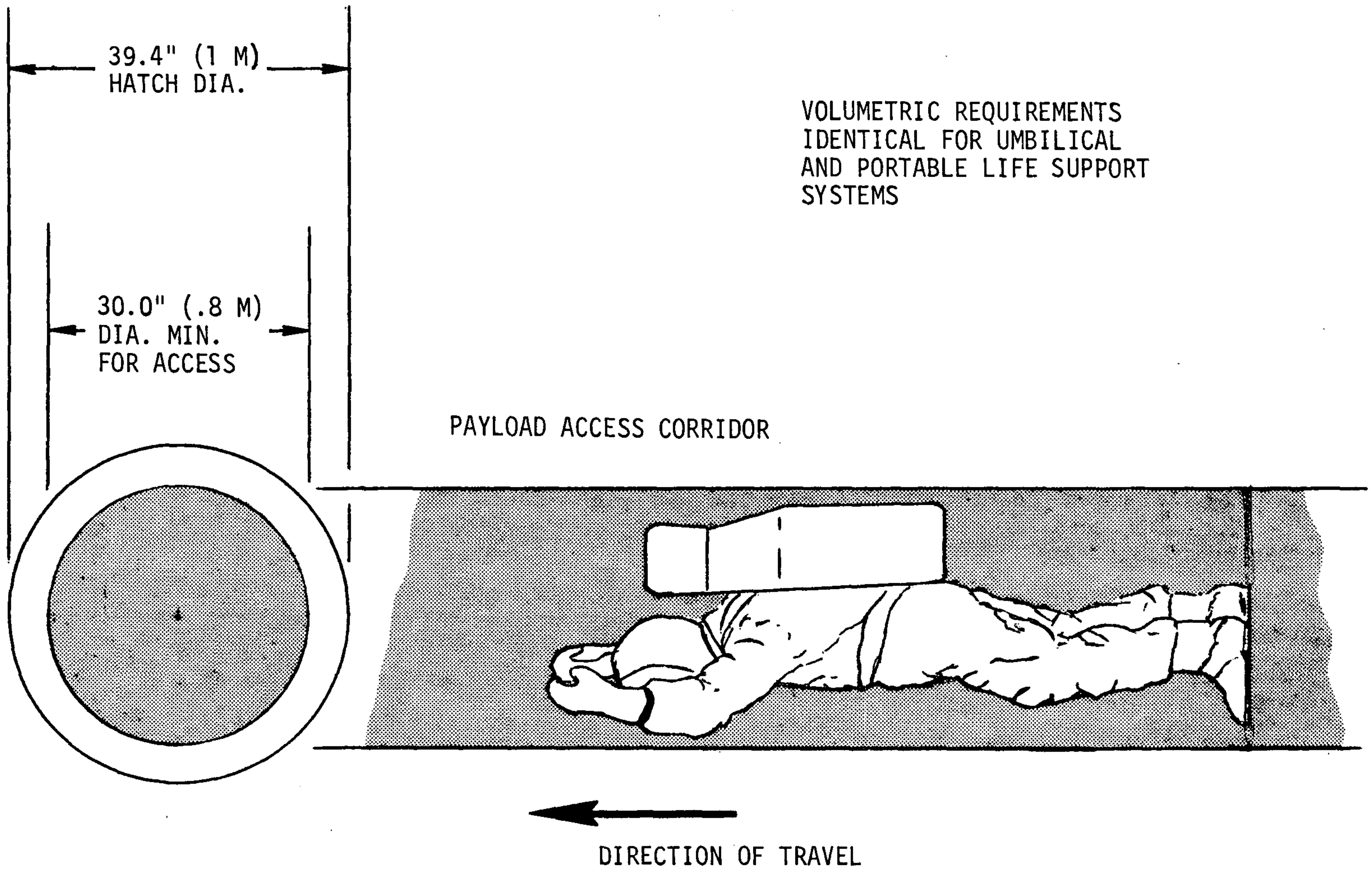


FIGURE 5-6: EVA CREWMAN TRANSLATION CORRIDOR

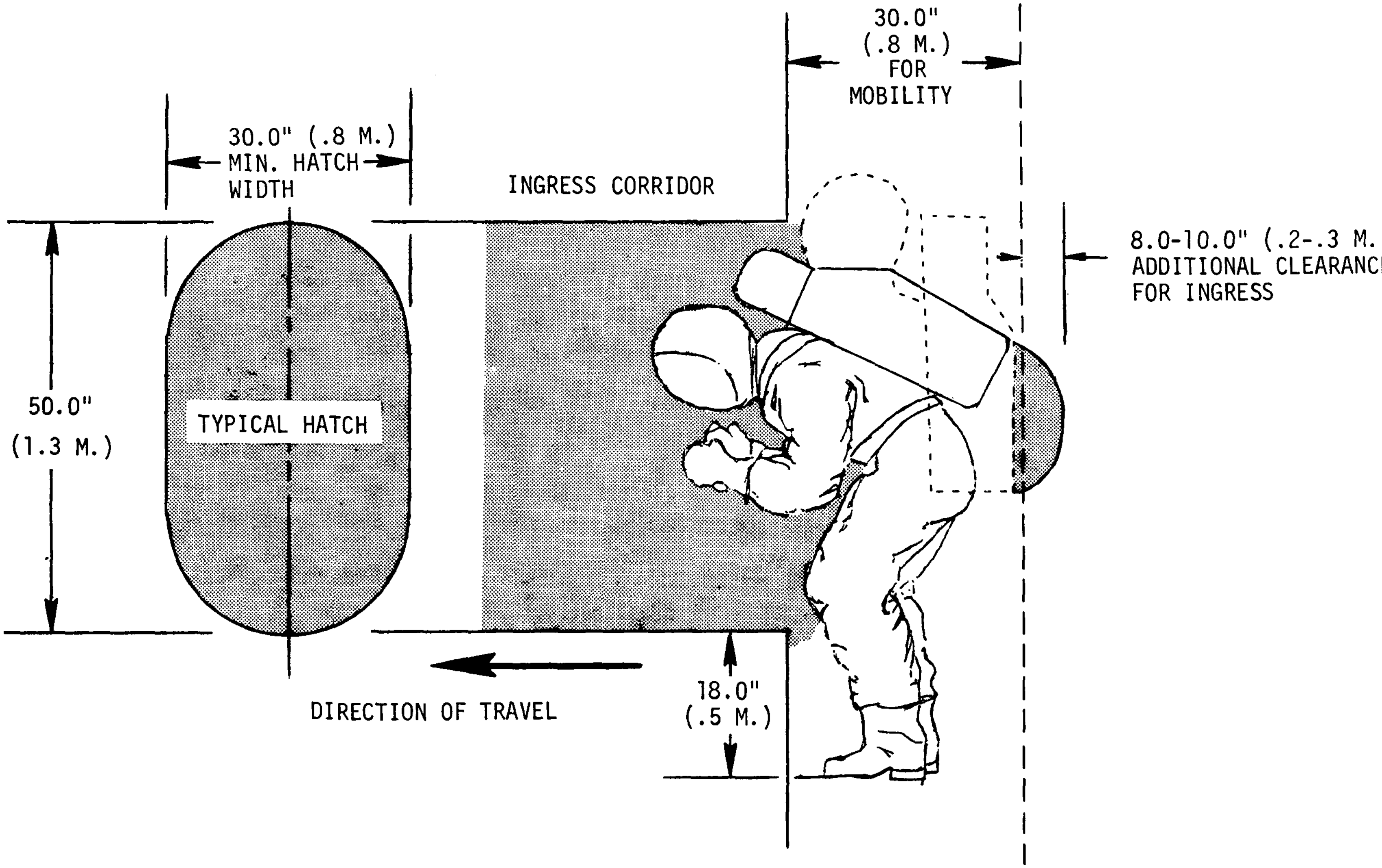


FIGURE 5-7: EVA CREWMAN ACCESS CORRIDOR--MOTION NORMAL TO CORRIDOR LONGITUDINAL CENTERLINE

5.3.2.2 Mobility Aids Along Path

The Shuttle Orbiter will provide mobility aids in the payload bay and on the Orbiter structure for EVA operations. The mobility aids include strategically located handholds, tether attach points, and foot restraints at required work areas. Adequate mobility aids must be provided by the payloads which require EVA operations such as maintenance, inspection, servicing, or payload deployment. Cargo/module transfer systems required by the payloads in addition to the Shuttle manipulator arms and crewman manual transfer are the responsibility of the individual payloads. Mobility aid quantity, configuration, and location, including special cargo transfer systems, will require study on each of the Shuttle missions requiring EVA or that are subject to contingency maintenance.

5.3.3 Crew Stowage Provisions

The stowage of crew provisions aboard the Shuttle Orbiter is primarily confined to the cabin lower deck, with some "low frequency use" items stowed below the lower deck. The upper level is dedicated to vehicle flight and payload operations. The crew provisions and off-duty habitability areas are located on the lower deck and arranged to facilitate multi-shift operations. Additional passenger accommodations can be accomplished within 24 hours by reconfiguring the lower level. Seats are readily attached to the deck floor for up to 6 additional passengers.

The Shuttle Orbiter crew stowage provisions and accommodations subsystem will include the following:

- All vehicle seats
- Stowage lockers for crew provisions and payload items:
  - Flight data files
  - Small experiments
  - Clothing
  - Tether and straps
  - Cameras and equipment
  - Survival equipment
  - Personal hygiene equipment
  - Miscellaneous loose items

The crew stowage and accommodations subsystem does not include the following:

- Environmental control/life support system expendables
- Portable fire extinguishers
- Waste management equipment
- Oxygen (O_2) contingency mask
- EVA "carry-on" equipment
- Food

Each of the above equipment items and stowage goods are handled individually or as part of the required support system.

5.3.3.1 Vehicle Stowage Volume

The stowage volume remaining in the Orbiter cabin after the installation of the required flight equipment (e.g., Flight operations, avionics, electrical power, communications, etc.) will be allocated to crew provisions and payload support equipment stowage. The total volume available and stowage location of each of the "loose" equipment items are not known at the present stage of development. The stowage facilities and arrangement for such equipment will be worked in much the same manner as the Skylab program, where compact stowage of items were individually "accommodated" to the available space. Each item and group of items constituting a system are stowed as near the associated operations as possible to avoid excessive crewman translation time (ref. 5.1).

Presently, hard mounting points for 125 ft.^{3} (3.3 m^3) of stowage lockers are provided by the Shuttle Orbiter (i.e., 170K dry weight vehicle). The volume of the lockers and crew stowage provisions, and the flight data files are provided by the Orbiter with no charges to the payload. The remaining stowable items are considered part of the payload equipment (ref. 5.1).

5.3.3.2 Volume Allocated to EVA

The total volume required for EVA equipment stowage, suit donning and drying, recharge stations, etc., based on the advanced systems (e.g., suits, LSS) being developed, is not precisely known as of early 1973. The preliminary EVA airlock designed to accommodate two fully EVA equipped crewmen, plus control panels and associated equipment, has a volume of approximately 150 $ft.^3$ (4.2 m^3). Estimated volume required for stowage of EVA equipment for two crewmen is approximately 25 $ft.^3$ (.7 m^3) based on previous missions and projected to the Space Shuttle systems. Early Shuttle airlock and EVA systems allotted 300 $ft.^3$ (8.5 m^3) in the cabin for all EVA associated operations and stowage including suit donning. However, if suit donning and suit and LSS stowage can be accomplished in the EVA airlock, the 300 $ft.^3$ will not be required. Volume sharing may also be feasible which will allow suit donning in the aisle space of the cabin lower deck (ref. 5.3).

Additional information concerning the volume requirements for EVA hardware stowage and operational functions will be available in mid-1973.

5.3.3.3 Stowage Environment

The stowage environment provided by the Shuttle Orbiter cabin will consist of an oxygen-nitrogen mixture at 14.7 psi (1.03 $kg./cm.^2$). The stowage areas exposed to the cabin environment will have the following characteristics:

- Oxygen partial pressure of 3.1 $\pm$ 0.1 psia (.29 $kg./cm.^2$)

- Carbon dioxide partial pressure of:
  - 5.0 mm Hg. (nominal)
  - 0 - 7.6 mm Hg. (range)

- Cabin temperature range of 65 - 80°F

- Crewman contact temperature 113°F maximum

- Humidity range TBD

Only nontoxic, nonflammable fluids and materials should be used in the pressurized inhabited and stowage areas within the cabin. Payloads and experiments requiring materials or equipment to be stowed in a special environment must be provided by the payload and are considered a part of the payload system.

5.4 SYSTEMS/HARDWARE/EQUIPMENT

The EVA considerations addressed in this subsection are concerned with the major equipment items necessary to conduct EVA. The availability, characteristics, and support requirements of the EVA systems are addressed from the viewpoint of their impact and costs to the vehicle and payloads. The major impact of the EVA equipment to the vehicle is in stowage volume, mounting provisions, and interface requirements (e.g., electrical, hydraulic, and pneumatic). The equipment impact to the payload is primarily the weight, access volume required, and EVA hardware integration (e.g., workstations, mobility aids, lighting). The impact to the mission involves crewman time and scheduling associated with EVA equipment preparation, donning/doffing, servicing, and stowing.

5.4.1 EVA Qualified Hardware

In considering the design of EVA hardware versus the selection of existing systems, consideration must be given to the cost, in both dollars and time, for developing and qualifying hardware for EVA. The testing and approval costs for qualifying new components and total systems for manned use in the space environment can readily become prohibitive to experiment designers. The utilization of existing EVA systems such as the pressure suit, life support systems, and cargo transfer systems are considered mandatory because of the safety and vehicle interface aspects in addition to the cost per unit. Equipment on the order of handrails, connectors, handles, lights, etc. can be designed and developed by the payload designer; however, many such items have been previously qualified through NASA. Utilization of these hardware items to the extent of designing the required payload areas to accept them will prove economical to the potential Shuttle user. Each experiment/payload must be considered on an individual basis to determine the applicability of the EVA hardware to that specific payload.

5.4.2 System Performance Characteristics

The performance characteristics of the major EVA support systems and equipment (i.e., pressure suits, life support system, and workstations) require assessment relative to their meeting the total EVA servicing requirements of the experiments/payloads. The pressure suit mobility and dexterity characteristics are assessed relative to the types of tasks (i.e., gross cargo handling to fine motor tasks) necessary to satisfy each payload or vehicle servicing operation. Since a distinct pressure suit will be developed and specified by NASA for use on the Space Shuttle Orbiter, the payload operations must be designed to be compatible with the pressure suit mobility characteristics. Detailed performance and physical characteristics of current pressure suits are presented in Section 7.3 of this report.

The most important performance characteristics of the EVA life support systems to the experiment/payload and vehicle systems designers are: (1) the heat removal capacity, and (2) the system duration in terms of crewman consumables and system expendables. The Space Shuttle EVA life support systems (LSS), as with the pressure suits, will be developed and selected by the NASA to meet the requirements of a wide range of candidate EVA missions. Portable, self-contained life support systems are currently being considered by the NASA. The payload and vehicle systems designers are concerned with the duration of the LSS in relation to the time required to perform the necessary payload servicing operations. Recharge of a portable LSS would be undesirable, if not prohibitive, midway through an EVA servicing mission. The elements which determine the portable LSS duration are these: (1) quantity of breathing oxygen, (2) carbon dioxide (CO_2) removal, (3) electrical power, and (4) sublimator feedwater in current portable LSS. (Advanced portable LSS may not use the sublimation technique to dissipate crewman-generated heat.) Umbilical LSS duration is primarily a function of stowed oxygen aboard and the CO_2 removal system used.

The capacity of the LSS to remove the quantity of heat generated by the crewman plus the influx of solar generated heat is of concern to the users of EVA. The LSS must maintain a viable and "comfortable" environment for the crewman during all normal and peak workload conditions associated with the payload and vehicle servicing operations. The total heat load associated with both the scheduled and contingency extravehicular operations are considered by the NASA in designing and specifying life support systems for the Space Shuttle. The experiment/payload designing teams (i.e., NASA and industry) are responsible for designing the EVA servicing operations to be compatible with the LSS capabilities. The physical and performance characteristics of state-of-the-art EVA life support systems are presented in Section 7.4 of this report.

The provisions available at each payload and vehicle worksite make up the most critical factor in assuring productive EVA operations. EVA missions on past space programs have verified the necessity of proper worksite provisions. Foremost in the provisions required at a worksite are crewman restraints and stabilization aids. The crewman must be adequately restrained to avoid expending time and energy while maintaining the proper attitude and location in performing servicing tasks. Workstations, either of a fixed or portable configuration, will be required at each worksite. The provisions furnished by the workstation at a particular worksite will vary with the payload and vehicle servicing requirements. A simple inspection task may require only handholds, whereas a modular replacement/servicing task may require a fixed workstation with a total complement of EVA supporting equipment. The major workstation support equipment options will include the following:

- Workstation ingress/egress aids
- Auxiliary lighting
- Temporary module stowage
- Crewman tether points
- Umbilical (LSS) restraint clip
- Working surface
- Foot restraints
- Camera (T.V., data collection)
- Tools
- Spare parts stowage
- Checklists
- Equipment tethers

Description information, functional capabilities, and physical characteristics of previous and proposed EVA workstation are contained in Section 7.5 of this volume of the report and Volume II of the total report. Volume II, "EVA Workstation Conceptual Design", is dedicated to the design and requirements of EVA workstations for future space programs.

5.4.3 System Flexibility

The capability of the EVA systems and equipment to meet the requirements of the various payload and vehicle servicing functions necessitates a highly flexible complement of EVA hardware. Design/selection of EVA systems and support hardware, dedicated to servicing a single or limited number of payloads or vehicle systems, appears impractical for Space Shuttle and future program application. The development costs and equipment interface problems associated with numerous dedicated EVA systems would be prohibitive to both the NASA and non-government space vehicle users.

From the EVA systems flexibility viewpoint, several of the major hardware items merit discussion. The EVA airlock is required to accommodate the total number of EV crewmen plus the various "cargo" requirements of the payloads for the transfer between the vehicle cabin and EV worksite. The airlock may also be required to support pressure suit and LSS donning, checkout, and servicing operations, provide EVA equipment stowage, provide emergency shelter, etc. The pressure suits must provide suitable mobility and dexterity to cover operations ranging from stationary monitoring to complex body and limb movements. The EVA life support system is required to provide environmental control at EV locations ranging from fixed workstations to free-flying maneuvering units, while allowing access to confined areas with varying contamination restrictions. The EVA workstations are required to provide restraints, tools, stowage, etc. for performing a large number of diversified tasks, while interfacing with a variety of differently configured payloads and vehicle worksites.

The Space Shuttle crew and "cargo" transfer systems must provide safe transfer of man and equipment to locations throughout the payload bay, exterior areas of the Shuttle Orbiter, and perhaps to remote free-flying satellites.

The cargo transfer systems are required to provide an efficient and effective means of transporting various quantities of mixed-size cargo to several locations during a single flight. EVA communications and telemetry systems must provide a network of equipment to permit voice and/or critical parameters to be transmitted between the EVA crewmen, spacecraft, and ground monitoring stations.

5.4.4 System Reliability

The reliability of EVA systems and hardware items is required to be among the highest of the spaceflight systems. The crewman's suit and equipment are subjected directly to the space environment during payload and vehicle servicing operations with no or, at best, limited protection by the vehicle. Redundant or backup systems are required, unless totally impractical for each EVA systems and hardware item critical to the safety of the crewman. Presentation, if available, of the probabilities for each of the EVA systems from all identifiable failure or hazards possibilities is beyond the scope of this report. Knowledge of such data is considered to be of limited value to the reader. General data are available on each major EVA system in Section 7.0 of this report.

5.4.5 System Weight and Volume

The weight and volume of the required EVA supporting equipment have previously been discussed relative to a total system impact on the vehicle and payload. Several major considerations relative to the EVA systems weights and volume of primary importance to the payload and vehicle systems designers, are listed below:

- EVA systems are designated as part of the payloads and are included in the total payload weight.
- The vehicle structure which houses the EVA equipment must be sized to adequately support the equipment during launch.

C[1]

- The weight (mass) of the EVA equipment should not seriously encumber the crewman during payload/vehicle servicing operations.
- EVA hardware being handled by the crewman should be sized (weight and volume) within the safe and efficient transfer/handling criteria established for one-man operations on the Shuttle Orbiter.
- The volume required for on-orbit EVA equipment stowage must be compatible with total vehicle stowage allocations.
- EVA hardware and experiment and vehicle systems replacement modules stowed inside the vehicle cabin must be designed to be transported through an EVA airlock shared by either one or two suited crewmen.

The dimensions, weights, and volumes of representative EVA systems and equipment are contained in Section 7.0 of this report.

5.4.6 Equipment Operational and Shelf Life

The operational and shelf lives of the EVA equipment being developed for the Space Shuttle program are not of major concern to the experiment/payload designer since the Shuttle Orbiter missions will initially be 7 days with possible growth to 30 days. These mission times would allow ground refurbishment of relatively short-lived EVA support systems. However, this would not be the case on programs such as the "permanent" Modular Space Station concepts where the EVA systems would remain on-orbit for a number of years. The EVA systems would then be replaced during replenishment of supplies to the total Space Station.

The design constraints concerning equipment life which are associated with the most safety critical EVA support systems are shown below (ref. 5.5):

- Primary Life Support Systems
  - Operational life: 6000 hours
  - Shelf life: 15 years

- Contingency Life Support Systems

  - Operational life: 300 hours
  - Shelf life: 15 years

- EVA/IVA Pressure Suits

  - Operational life: 500 hours
  - Shelf life: 4 years
  - Cycle life: 100,000 per suit joint

5.4.7 EVA Power Requirements

Several candidate EVA supporting systems and equipment items for the Space Shuttle will require either portable (battery) or vehicle power. The power requirements may be assoicated with real time operation of the EVA equipment or for functions such as suit drying or LSS battery recharge. The quantity of power required to support EVA on the Shuttle Orbiter is not currently available since many of the systems are in the conceptual stage. The power required for operation of the EVA equipment on previous programs has not significantly impacted the power supply/system. A listing of the EVA systems and equipment requiring electrical power is shown in Table 5-6.

5.4.8 Equipment Transportability

The number of candidate experiments and payloads currently scheduled for the Space Shuttle, the wide variety and configuration of the payloads, and the numerous payload combinations to be flown indicate a need for the EVA equipment to be highly transportable. The transportability requirement is applicable to both the equipment directly supporting the EVA crewman and the equipment required for experiment/payload servicing. Several recent payload requirements analyses (ref. 5.7) showed that a variety of hardware items of varying mass and size would require transportation to the payload and vehicle worksite during EVA servicing operations. Under current guidelines, this equipment will be

TABLE 5-6: EVA SYSTEMS REQUIRING ELECTRICAL POWER

EVA SYSTEM	POWER SOURCE
(a) Life Support System	
• Portable	Storage Battery
- Battery Recharge	Vehicle
• Umbilical	Vehicle
(b) Airlock	
• Lighting	Vehicle
• Controls and Displays	Vehicle
(c) Communications and Telemetry	
• Portable LSS	Battery and Vehicle
• Umbilical LSS	Vehicle
• Voice/Telemetry Recording	Vehicle
(d) EVA Workstation	
• Fixed-Lighting and Camera	Vehicle
• Portable-Lighting and Camera	Vehicle or Battery
• Workstation Powered Tools	Vehicle or Battery
(e) Crew/Cargo Transfer Systems	
• Extendible Transfer Booms	Vehicle
• Transfer Trolleys	Vehicle
• Astronaut Maneuvering Unit	Stowage Battery
- Battery Recharge	Vehicle
• Foot Controlled Maneuvering Unit	Stowage Battery
- Battery Recharge	Vehicle
• Maneuverable Work Platform	Stowage Battery
- Battery Recharge	Vehicle
(f) Miscellaneous	
• Lights-Translation Route	Vehicle
• Pressure Suit Drying	Vehicle
• T.V./Events Cameras	Battery/Vehicle

transferred from the stowage area by the EVA crewman and/or the Shuttle Orbiter manipulator or cargo transfer system. Ideally, each hardware item of size and mass which cannot be "attached" to the EVA crewman or contained in the EVA workstation stowage compartments should incorporate handling provisions to allow transport by both the EVA crewman and the designated manipulator/transfer system. A combination handhold-end effector mating connector would be required on the equipment to be transported. The Apollo EVA handhold configuration, being used on the Skylab program, also interfaces with the cargo (film magazines and containers) transfer system (film transfer booms).

EVA equipment transportability is of significance when the items require stowage inside the vehicle cabin. The equipment must initially be designed to be transferred from the pressurized cabin environment through either an EVA airlock or equipment transfer airlock. Considerations during equipment design such as equipment pressure venting, package size accommodated by the EVA airlock, and temporary stowage inside the airlock must be acknowledged.

The masses and sizes of packages that have been transported by a pressure suited crewman during previous EVA missions and during simulated zero-gravity studies are contained in Volume II of this report. Data on the equipment transporting capabilities of the manipulator/transfer system concepts for the Shuttle Orbiter were not fully defined for inclusion in this report.

5.4.9 Hardware Maintainability and Spares Requirements

The design of EVA support systems (e.g., life support system, suits) to accommodate on-orbit maintenance is considered with respect to early failure or damage to EVA systems. The repair of these systems is a factor in the EVA retrieval of scientific data as well as crew safety in the event an emergency vehicle transfer is required via EVA. Several factors require consideration when designing to include on-orbit maintenance of EVA systems. A listing of the major considerations is shown below:

- Quantity, weight, and volume of spare parts

- Vehicle stowage of replacement parts
- Modular component replacement concepts
- Work volume required for repair
- Test and checkout gear required
- Repair kits required
- Maintenance time required
- Number of crewmen required for maintenance
- Probability of successful on-orbit repair

5.4.10 System Preparation Time

The operations required to retrieve EVA system components from stowage, prepare the systems for donning, perform pressure integrity checks and final systems checkout functions have required a significant amount of crew time on previous space programs. The lengthy preparation times were attributed in part to the minimum cabin volume, the dispersed component stowage locations, and the number of manual preparation and checkout operations required. It is immediately obvious that providing sufficient working volume, central stowage of EVA hardware, and a reduction in the number of checkout operations (i.e., by automatic checkout systems) would reduce the crew time required. A summary of the operations required in the preparation for and termination of EVA is provided in Subsection 5.2.2 of this report.

Several of the obvious areas of consideration in designing for EVA on future programs include the following:

- Provide sufficient volume adjacent to the EVA airlock for centralized stowage of EVA gear, equipment donning/doffing, systems checkout, and equipment recharge and drying operations. This volume would be shared with other non-EVA functions when external operations are not being conducted.

- Provide adequate restraints and supporting crewmen to assist in the equipment preparation and checkout operations.

- Minimize or automate the number of EVA equipment checkout operations required.

- Provide sufficient airlock volume to minimize crewman position "jockeying" during airlock operations.

5.4.11 System Expendables

System expendables relative to EVA equipment primarily include those expendables associated with the crewman's portable life support systems (LSS). Current primary systems require water for sublimator operation which provides crewman and system heat removal functions, lithium hydroxide (LiOH) for carbon dioxide control, and charcoal for odor control. The portable life support systems also require vehicle power for stowage battery recharge; the pressure suits require vehicle power for suit drying operations. (These areas are covered in Subsection 5.4.12.) The oxygen (O_2) requirements are considered crewman consumables when associated with the primary portable life support systems and as system expendables when associated with umbilical (open loop-Skylab) and emergency (purge-type) life support systems.

The preliminary requirements/characteristics for EVA system expendables, based on current system projected for the Space Shuttle, are shown below (ref. 5.4 and 5.7):

- Lithium Hydroxide (LiOH) and Cartridge

  - Contains LiOH, charcoal, and particulate filter
  - One per system use per EVA

- Cartridge weight: ≈3.0 lbs. (1.4 kg.)
- Cartridge size: 15.8 in. x 4.04 in. dia. (.4 m x .1 m dia.)

• Water (H_2O) for Sublimator Operation

  - Recharge H_2O after each LSS use
  - Maximum H_2O required per recharge: 8.06 lbs. (3.7 kg.)
  - Supply pressure: 33 psia (2.3 kg./cm.^{2})
  - Supply temperature: 35 to 100°F

• Life Support Umbilical - Skylab System

  - Normal O_2 flow: 7.9 - 9.0 lb./hr. (3.6 - 4.1 kg./hr.)
  - Emergency O_2 flow: 12.5 - 14.0 lb./hr. (5.7 - 6.4 kg./hr.)
  - O_2 Pressure from vehicle: 55 - 176.2 psia (3.9 - 12.4 kg./cm.^{2})
  - Pressure to suit: 3.7 psia (.3 kg./cm.^{2})

• Emergency Life Support System - Preliminary

  - O_2 flow: 2.27 lbs. (1.0 kg.) per minute
  - Duration: 15 minutes

5.4.12 System Recharge, Collection and Drying

The EVA systems requiring recharge, water collection, or drying capabilities aboard the prime vehicle include the following:

• Portable life support sytem stowage battery recharge

• Condensed water (humidity control) collection from portable LSS

• Oxygen subsystem (crewman breathing) recharge for portable LSS

• Water recharge for sublimator operation

• Pressure suit drying following extravehicular operations

The preliminary requirements and considerations associated with EVA system recharge, collection, and drying operations are shown below (ref. 5.7):

- LSS Stowage Battery Recharge
  - Vehicle power required per recharge: 260 watt-hours (max.)
  - Charging time: 16 hr./batt. (max.)
- Condensed Water Collection
  - Water transferred per LSS use: 1.46 lbs. (.7 kg.) max.
- Breathing Oxygen Recharge
  - Oxygen required per recharge: 1.04 lbs. (.5 kg.) max.
  - Stowage pressure: 900 psia (63.3 kg./cm.^{2}) cryogenic O_2
  - O_2 recharge temperature: 80°F max.
- Sublimator Water Recharge
  - See Section 5.4.11 above
- Pressure Suit Drying
  - Suit drying time: 16 hours each
  - Vehicle power required: 35 watts
  - Suit drying system weight: 5.3 lbs. (2.4 kg.)
  - Drying system air flow rate: 7.5 ft.^{3}/min. (.2 m^3/min.)

It should be noted that the data contained in this Subsection (5.4.12) is based on preliminary studies using current information projected to future Space Shuttle requirements.

5.4.13 Communications and Telemetry

Based on current philosophy, voice communications and crewman and EVA systems status (either by telemetry or hard line) are required between the EVA crewmen and between the crewmen and the vehicle EVA monitoring station. Voice communications and telemetry are also required between the vehicle and ground monitoring stations and/or another space station. A communications network similar to the Apollo EVA concept is proposed for use on the Space Shuttle Orbiter. This system would provide two-way communications between EVA crewmen and with personnel within the Shuttle Orbiter. The Orbiter would relay voice and telemetry data to the ground stations and also receive voice communications from the ground. Voice communications via the vehicle systems between the ground and EVA crewmen would be provided. Additional information and data concerning communications and telemetry are provided in Subsection 7.7 of this report.

5.4.14 EVA Tools Considerations

The tools needed by the EVA crewman are a direct function of the vehicle and payload servicing requirements and the man/machine interface designs. The servicing requirements of the Shuttle Orbiter and associated payloads are not defined to a sufficient level of detail to permit identification/selection of tools at the present time (i.e., early 1973).

Experience from previous orbital EVA missions has indicated that most EVA tasks can be accomplished with appropriate hand tools if the crewman is properly restrained. The tools must, of course, be restrained/tethered to prevent loss into space. Many off-the-shelf industrial/mechanic tools can be used with minor modifications to improve handling and gripping with the EVA gloves.

Several power tools developed during the Apollo era are available and may be applicable for operations requiring repeated arm and wrist motions. Such repetitious motions are fatiguing during suited operations in the presently-available suits. Should future servicing operations require repeated arm/wrist motions, these previously developed power tools may be modified, thereby reducing research and development costs.

Although selected/modified for intravehicular operations on the Skylab program, most of the Skylab tools listed below can be used by the suited crewman in an extravehicular environment.

SKYLAB IVA TOOL LIST

- 1 Wrench, Adjustable
- 1 Pliers, Slip Joint
- 1 Pliers, Connector
- 1 Pliers, Needlenose
- 1 Pliers, Channel Lock
- 1 Cutter, Diagonal
- 1 Pin Straightener
- 1 Vise Grip
- 2 Screwdrivers, Standard
- 2 Screwdrivers, Phillips
- 1 Socket Wrench Set (15 pieces)
- 4 "C" Clamps
- 1 Mirror
- 1 Mechanical Fingers
- 1 Pinch Bar
- 1 Scissors
- 1 Crimper
- 7 Wrench, Open End/Box
- 1 Bench Vise
- 1 Spin Handle and 7 Allen Bits (plus 1 Square Bit)
- 1 Hammer, Ball-peen
- 3 Swiss Army Knives
- 2 Allen Wrenches
- Special Maintenance Tools

For the Skylab program, the tools are stowed in two five-drawer removable containers. The containers are designed to allow selection of a single tool from a drawer(s) or removal of the entire container for transport to the worksite. Each tool component is individually restrained in the container and equipped with tether attachments of velcro patches to avoid loss during use. Similar concepts may be applicable to the Shuttle Orbiter and future EVA programs.

5.5 SHUTTLE EVA CREWMAN RESCUE

Studies of Space Shuttle equipment, techniques, and procedures required to rescue the EVA crewman have not been completed for inclusion in this report. A set of requirements will be established as the vehicle EVA support systems are developed and EVA equipment/tasks are firmly identified. Numerous areas/ parameters require consideration during the establishment of EVA rescue criteria. Several items of importance are listed below:

- Type of "incident" causing contingency situation:
  - Explosion
  - Blocked access path
  - Pressure suit damage/failure
  - Life support system malfunction
  - Entanglement of umbilical
  - Loss of safety tether (no contact with vehicle)
  - EVA airlock systems/hatch failure
  - Crewman illness or partially incapacitated
  - Crewman unconscious
- "Equipment" available for rescue:
  - State of equipment readiness
  - Buddy Secondary Life Support System utilization
  - Crewman safety tether line
  - Tool requirements for rescue
  - Number of crewmen available for rescue (Status of IV crewmen)
  - Free-flying rescue units
  - Attached Manipulator System

The specification of EVA rescue criteria on previous space missions has resulted from a number of NASA and supporting contractor studies and panel meetings to determine the optimum systems and techniques. This procedure is expected to be followed for the Space Shuttle.

REFERENCES

5.1 Manned Spacecraft Center: Preliminary Design Requirements for Shuttle EVA/IVA Orbiter Support, MSC 01497, Internal Note MSC-EC-R-71-10, Houston, Texas, September 30, 1971.

5.2 Manned Spacecraft Center: Statement of Work for an 8.0 PSI Orbital EVA Space Suit Assembly (Feasibility Prototype), Crew Systems Division, Houston, Texas.

5.3 Manned Spacecraft Center: Space Shuttle Request for Proposal No. 9-BC421-67-2-40P, Houston, Texas, March 1972.

5.4 Hamilton Standard Division: Space Shuttle EVA/IVA Support Equipment Requirements Study, Midterm briefing to NASA-JSC, Houston, Texas, October 10, 1973.

5.5 Manned Spacecraft Center: Space Shuttle Baseline Accommodations for Payloads, Revision A, MSC-06900A, Houston, Texas, November 17, 1972.

5.6 Lyndon B. Johnson Space Center: Space Shuttle System Payload Accommodations, JSC-07700, Volume XIV, Houston, Texas, March 6, 1973.

5.7 Vought Missiles and Space Company: Study of Space Shuttle EVA/IVA Support Requirements, Midterm Briefing to NASA-JSC, Houston, Texas, October 1972.

B

SECTION 6.0 CREWMAN CONSIDERATIONS APPLICABLE TO EVA SELECTION

6.1 INTRODUCTION

Based on the potential contingency requirements and the rescue and safety aspects of spaceflight, all future manned spacecraft--according to current (1973) guidelines--must include provisions to allow the crewmen viable access to the vehicle exterior and free space. Since these safety provisions are mandatory, man has been assisted in remaining the prime economical candidate, relative to teleoperators, manipulators and automation, for performing mission functions external to the vehicle. In addition to man's dexterity, human judgment and "real-time" decision-making abilities, NASA's austere monetary budget during the early and mid-1970's has demanded an economical means of accomplishing experiment and mission objectives. To achieve this goal, ultimate utilization of manned EVA in conjunction with inherent on-board spacecraft systems and equipment is of prime interest.

NASA's resolution in reducing space transportation, payload, and experiment costs has been projected in several Payload Effects Analysis and Low Cost Payload Design Concept studies conducted by Lockheed Missiles and Space Company, et al., over the past several years. These studies revealed that substantial savings (perhaps up to 50%) may be realized on experiments and payload cost by fully implementing low-cost, refurbishable payload designs and Shuttle Orbiter equipment capabilities and operational techniques. A rational extension of using the Shuttle Orbiter to service (maintain, repair, reconfigure, update), in orbit, a large number of distinctive low-cost payloads (each designed for modular replacement) would be the standardization of (1) vehicle/payload subsystems and modular hardware and (2) the payload/satellite orbits to provide the Shuttle Orbiter cost-effective payload placements, retrieval, and revisits. Additionally, instead of designing a large number of mission-peculiar payloads/satellites, it appears most economical to design a small number of standard, modular serviceable, multiple-application payloads/satellites to perform the majority of all science and application missions.

The design of serviceable payloads/satellites from the man/system integration viewpoint, with the utilization of both manned EVA and inherent spacecraft equipment, is the current philosophy that must be considered throughout systems design and task performance mode selection (i.e., man, teleoperator, automation, etc.). The remainder of this document contains information and data to aid designers in their trade-off studies of various concepts, equipment, and modes of implementing the collection of scientific data from future space programs.

This section contains a qualitative description of crew-related considerations only. Those considerations dealing with the mission, systems, and other operational areas are discussed in Section 5.0 of this volume.

6.2 MAJOR CREWMAN CONSIDERATIONS GOVERNING THE SELECTION OF EVA

The purpose of this sub-section is to provide an initial insight, for the benefit of vehicle, experiment, and payload designers, into the major crewman-related parameters that govern the utilization of manned EVA for supporting mission objectives. The process of selecting EVA as a technique by which to perform an on-orbit operation involves the consideration of numerous factors. In early mission planning and in the experiment design for future space programs, the decision whether or not to utilize EVA frequently appears to be made on the basis that: (1) the EVA capability already exists on the vehicle, (2) that equipment components possess a low probability of failure, or (3) that other techniques may be more applicable. Each of these considerations are important; however, a systematic process for selecting a certain system or method to ensure mission success is required. Each potential method (see Section 2.0) of performing functions, usually considered to require operations outside the spacecraft, entails almost entirely different approaches, systems, and equipment. This document, however, considers only the man in performing extravehicular functions.

Three major parameters (see Table 6-1) are considered to govern the initial selection of manned EVA. These are (1) crewman safety, (2) crewman performance capabilities, and (3) the EV crewman impact on the mission, vehicle, and payload/experiment. The principal areas of the spaceflight mission or space elements affected by the parameters are also shown in the table.

TABLE 6-1: MAJOR CONSIDERATIONS GOVERNING SELECTION OF EVA

PARAMETER	PRINCIPAL AREAS AFFECTED		
	MISSION	VEHICLE	PAYLOAD
1. Crewman Safety	●		
2. Crewman Performance Capabilities			●
3. Impact to Mission, Vehicle and Payload	●	●	●
(a) Number of EVA Crewmen Required	●		●
(b) Duration of EVA	●	●	●
(c) Frequency of EVA Operations	●		●
(d) Total Manpower Required During EVA	●		●
(e) Translation System to Worksite		●	●
(f) Crewman Simulation and Training	●		●

The first two parameters are associated with the man, while the third is a major consideration regardless of the method used to accomplish extravehicular operations. The impacts (on the mission, vehicle, or payload) caused by the servicing system techniques being considered are weighed with respect to dollar cost to the specific mission and total space program; then trade-offs are made.

The three major parameters are presented in Figure 6-1 as a method or process to aid in systematically considering man for EVA. The process carries each potential EVA task through safety and crewman performance capabilities analyses, with respect to EVA mission requirements, before impact assessments are initiated.

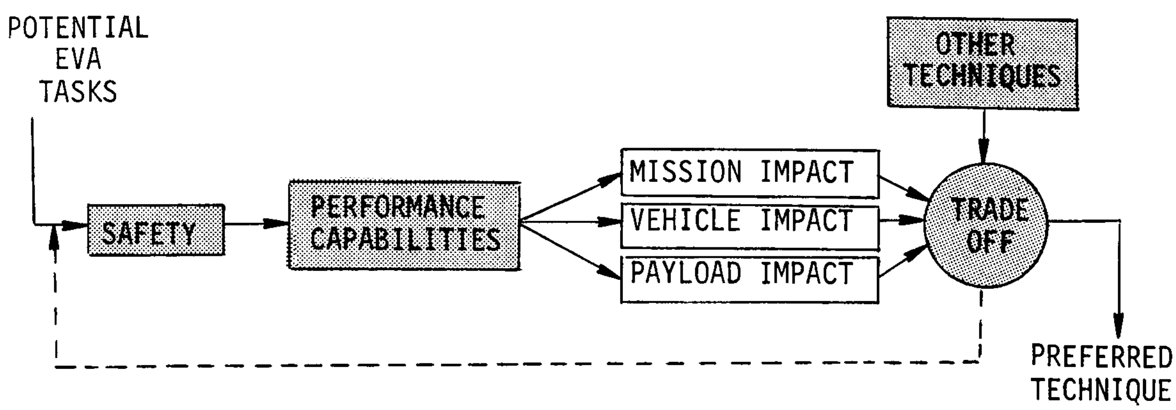


FIGURE 6-1: MANNED EVA INITIAL SELECTION PROCESS

Each of the major considerations governing the selection of EVA as shown in Table 6-1 are discussed in the following paragraphs.

6.2.1 Crewman Safety Considerations

The safety analysis may eliminate some potential EVA tasks on the basis of requirements such as radioactive materials handling, areas of high space radiation, or extreme translation distances. Table 6-2 contains a listing of the major safety parameters that require consideration at the beginning of the selection process.

TABLE 6-2: Major EVA Safety Considerations

SAFETY PARAMETER	REMARKS
Stored Energy Devices	Structural or mechanical devices that could be inadvertently actuated through mechanical or electrical interfaces (Deployment mechanisms, rotating elements, spring loaded devices, etc.)
Pyrotechnic Devices	Explosive devices that if actuated could cause injury to EVA crewmen (Explosive release systems, bolts, etc.)
Fluid Handling	Handling of fluids not compatible with EVA support systems and equipment
Radioactive Material	EVA in areas exposed to radioactive sources such as nuclear systems, areas of high radioactive material in space, etc.
Spacecraft Equipment	Spacecraft equipment such as protrusions, sharp edges, and corners that could cause damage to EVA equipment (i.e., suits, life support systems, tethers, etc.)
Cargo Size/Mass	Handling cargo with size or mass properties that may impair control or visibility
Distance From Spacecraft	Remote EVA tasks requiring extensive safety and rescue capabilities
Moving Parts	Structural or mechanical rotating devices or linkages in motion during EVA
Unstable Structures and Payloads	Structures or payloads not rigidly secured to the primary vehicle or payload system
Illumination	EVA work areas and translation routes insufficiently illuminated

Each candidate EVA mission and the major functions and operations within the mission are to be evaluated using the considerations in Table 6-2 as general guidelines. Since the EVA missions, interface hardware, and vehicle equipment vary widely, a process or methodology for evaluating the safety considerations would be difficult to format. The individual missions could best be handled from the designer's general knowledge of potential hazards to man in earth and space environments with assistance from specialists in EVA. Information concerning general aspects of crewman safety can be obtained from the NASA/JSC Director of Safety, Reliability and Quality Assurance--Program Management Safety Office. Specific questions concerning crewman safety in the extravehicular environment can be directed to specialists in the EVA field through the Program Management Safety Office. Each safety consideration should be addressed by the designer/planner before proceeding to the second major governing consideration--Crewman Performance Capabilities.

6.2.2 Crewman EVA Performance Capabilities

The potential EVA functions remaining after the safety analysis are evaluated on the basis of man's capabilities in EVA. Some EVA tasks may be eliminated through the crewman capabilities analysis because of requirements such as accessibility, extreme force, mobility, etc. The crewman's performance capabilities in the EVA environment are highly dependent upon the support provided. In addition to the proper space suits and life support systems, support hardware such as mobility aids, restraint equipment, transfer systems (crew and cargo), and worksite provisions (tools, lighting, etc.) are mandatory for satisfactory task performance. Table 6-3 (refs. 6.1-6.4) provides a summary of performance capabilities that have been satisfactorily demonstrated in free space and during earth-based simulations. The earth-based simulations considered most valid are the water immersion and parabolic aircraft simulation techniques.

Table 6-3 does not attempt to list every task performed during previous EVAs or during simulations but only selected functions that indicate the range of capabilities proven thus far. The entries in the table are representative

TABLE 6-3: SUMMARY OF EVA PERFORMANCE CAPABILITIES

FUNCTION/TASK PERFORMED	ON PREVIOUS SPACEFLIGHTS	DURING GROUND-BASED SIMULATIONS
INGRESS/EGRESS		
• Hatch	Less than 2 min. required; no cargo. Less than 4 min. required; with cargo.	Skylab EVA hatch: less than 2 min., 24" to 31" x 34" (.61 to .79 x .86 m)
• Workstation	Less than 2 min. required; with handholds and foot restraints.	
WORKSITE ACTIVITIES		
• Force Application	Using Gemini foot restraints-- Apply 200 in.-lbs. (2.3 kgm) torque; using 9 in. (22.9 cm) wrench. Apply 100 in.-lbs. (1.2 kgm) torque; using 5 in. (12.7 cm) wrench. Apply 25 lbs. (11.3 kg) force.	Using Skylab foot restraints-- Apply 60 lbs. (27.2 kg) force, forward; 28-52 in. (.7-1.3 m) above foot restraints. Apply greater than 60 lbs. (27.2 kg), pulling; on lever 1 ft. (.3 m) above foot restraints. Horizontal pulling forces greater than pushing forces.
• Motor Processes	Align connectors Cut electrical connectors Fluid quick-disconnect hookup Photography Unstow: oxygen hose, AMU control arm Connect tether hooks Attach spacecraft (GATU) tether Tighten Saturn bolt (with tools) Wipe Command Module Pilot's window	Visually align Apollo Telescope Mount canister Actuate electrically-powered control devices Align/actuate 16 mm camera

TABLE 6-3: SUMMARY OF EVA PERFORMANCE CAPABILITIES (Cont'd.)

FUNCTION/TASK PERFORMED	ON PREVIOUS SPACEFLIGHTS	DURING GROUND-BASED SIMULATIONS
WORKSITE ACTIVITIES (Cont'd.)	Torque bolthead Remove cutters from suit pouch Inspect equipment Evaluate Velcro pad Evaluate handholds Evaluate life support activities Deploy, conduct, and retrieve MEED experiments	
• Mass Handling	Mount cameras Deploy telescoping handrail Change EVA camera film Install camera Retrieve 85-lb. (38.6 kg) camera Retrieve 27-lb. (12.2 kg) camera cassette Retrieve micrometeorite package Prepare Astronaut Maneuvering Unit (AMU)	Package handling, sized to 30 x 24 x 16 in. (.8 x .6 x .4 m) Deploy/actuate package transfer systems Manage umbilical Actuate film magazine access door Deploy mechanical booms/arms Retrieve/replace film magazines/cassettes Deploy/retrieve 16 mm camera
CREWMAN TRANSLATION		
• Distance/Velocity	Translate 10 ft. (3.05 m) using single handrails/handholds Completion of three round trips of 20 ft. (6.1 m) each (plus activities) completed in 38 min. Evaluate umbilical (tether dynamics)	IVA translation velocity 1.0 to 2.0 ft/sec (.3 to .6 m/sec), single handrail EVA translation velocity 1 ft/sec (.3 m/sec), single handrail 30 ft. (9.1 m)-translation

TABLE 6-3: SUMMARY OF EVA PERFORMANCE CAPABILITIES (Cont'd.)

FUNCTION/TASK PERFORMED	ON PREVIOUS SPACEFLIGHTS	DURING GROUND-BASED SIMULATIONS
CREWMAN TRANSLATION (Cont'd.) • Cargo Transfer/ Mass Handling	Transport 85-lb. (38.6-kg) camera 10 ft. (3.0 m) Transport 27-lb. (12.2-kg) camera 10 ft. (3.0 m) Evaluate Hand-Held Maneuvering Unit (HHMU) Retrieve package from remote vehicle	Crewman with cargo translation velocity of .5 to 1.0 ft/sec (.15 to .30 m/sec), single handrail Crewman with 1650-lb. (744.1-kg) package (142 ft^3; 4.02 m^3): translation velocity of .3 ft/sec (.09 m/sec), dual handrails; velocity of .2 ft/sec (.06 m/sec) single handrail. Realistic average translation rate of .75 ft/sec (.229 m/sec) with 320-lb. (145.9-kg) mass Two-man deployment of simulated 8500-lb. (3855.6-kg) payload--3.5 ft (1.07 m) dia. x 19 ft (5.8 m); masses to 65,000 lbs. (29,484 kg) being considered for future deployment

of functions performed to satisfy specifically designed tasks on past EVA missions and simulations for the Skylab and Shuttle programs. Capabilities far in excess of those demonstrated to date are expected to be routine operations on future missions. A checklist of crewman performance considerations for comparison to candidate EVA task requirements is contained in Table 6-4. Subsequent paragraphs address performance capabilities for force, reach, mass handling, mobility, visibility, crewman comfort and monitoring requirements.

6.2.2.1 Force Application

Based on an analysis of future payload servicing requirements for EVA workstation conceptual design (Volume II of this report), the EVA crewmen will be required to exert a large number of forces varying in magnitude and direction. The magnitude and direction of forces that can be applied by the fully equipped EVA crewman will be slightly impaired due to the restrictions imposed by the pressure suit and life support systems. However, the major consideration in EVA crewman force application capability is properly restraining the crewman for each force requirement. Given proper restraints, the magnitude of force (unsustained) that can be applied by the EVA crewman will not vary considerably from his capabilities in an earth environment. However, sustained forces and repeated force application, using wrist and arm motions, require the crewman to continuously overcome the inherent pressure suit resistance in addition to the work forces. Such operations eventually become fatiguing to the crewman. The direction of force that can be applied by the EVA crewman is, of course, a direct function of the task location relative to crewman accessibility and orientation. The worksite should provide adequate maneuvering volume to allow complete access to the task.

The level of "restrictions" and "encumbrances" associated with the current and conceptual EVA pressure suits is not considered a major factor in task performance when present technology is applied to the design of the man/equipment interface and task manipulations. The crewman restrictions linked to the earlier space suits (i.e., Gemini) are no longer inherent in the current suits. The mass and volume of EVA life support systems, however, must be considered

TABLE 6-4: CREWMAN PERFORMANCE CONSIDERATIONS CHECKLIST

CREWMAN PERFORMANCE CHECKLIST			
• Ingress/Egress Requirements			
- Restraint Systems	☐		
- Hatches	☐	- Work Stations	☐
- Passageways	☐	- Between Structural Members	☐
• Translation			
- Manual[1]	☐	- Automated[3]	☐
- Manual Aided[2]	☐	- Free Flying Unit[4]	☐
• Cargo Transfer			
- Manual	☐	- Automated	☐
- Manual Aided	☐	- Free Flying Unit	☐
• Package and Module Handling			
- Size	☐	- Volume	☐
- Mass	☐		
• Force Application			
- Sustained	☐	- Direction	
- Impulse	☐	(a) Up/Down	☐
- Torque	☐	(b) Fore/Aft	☐
- Magnitude	☐	(c) Lateral	☐

TABLE 6-4: CREWMAN PERFORMANCE CONSIDERATIONS CHECKLIST (CONT'D.)

CREWMAN PERFORMANCE CHECKLIST			
• Illumination Requirements for Task Performance			
- Brightness		- Hand Held	
- Fixed		- Body Mounted	
- Glare Avoidance		- Adjustable	
• Mobility Requirements			
- Whole Body		- Limbs	
(a) Rotational		(a) Direction	
(b) Translational		(b) Range	
• Task Classification			
- Gross Manipulative		- Fine Manipulative	
• General			
- Task Duration		- Task Difficulty	
- Crewman Comfort		- Task Frequency	
- Food and Water Requirements			

1. Unassisted crewman transfer using handrails, handholds, etc.
2. Crewman assisted by "endless" clotheslines, extendible booms, etc.
3. Crewman assisted by powered trolley, powered booms, etc.
4. Crewman self-contained maneuvering systems.

relative to optimum worksite access for maximum force application. The range of force magnitudes, varying with direction and crewman restraint systems, that can be applied in the EVA environment is not available. The forces that have been applied by the EVA crewmen on previous EVA programs are shown in Table 6-3, "EVA Performance Capabilities Summary".

6.2.2.2 Reach Capability

The reach capability of the fully equipped EVA crewman requires consideration when designing payloads and vehicle systems for EVA servicing. The crewman's functional reach is certainly a function of his physical stature and ranges from 21.2 in. to 25.3 in. (.53 m - .64 m) depending somewhat on the percentile of the man (ref. 6.5). Functional reach for purposes of this document is defined as the distance from the crewman's palm to the nearest interference point (either the chest or EVA support gear) when reaching forward with the crewman standing erect and the right arm extended horizontally to its maximum length. Factors other than man's "arm length" require consideration when using man to perform EVA operations. The pressure suit and front mounted life support system hardware will restrict the crewman's functional reach. The crewman's (50 percentile) functional reach with Skylab pressure suit and umbilical life support system is approximately 23 inches (.58 m).

In considering the EVA crewman's reach capabilities when stabilized at a worksite, the type of restraint system used is of primary importance. Foot restraints of the Apollo and Skylab configuration offer greater latitude in reach capability than systems that restrict torso movement (e.g., body tethers). Foot restraints in a weightless environment allow the crewman to "pivot" about the ankles; and the reach envelope is limited only by the crewman's agility.

In designing vehicle systems and payloads which require reaching into an aperture, the work surface should generally be positioned as close to the exterior surface of the item being serviced as design will allow. In addition to simplifying the crewman's tasks, discretion in positioning hardware within the payload to be serviced would reduce the probability of damage to the crewman's EVA equipment (e.g., suit, helmet, LSS) and payload interfaces through inadvertent contact.

6.2.2.3 Mass Handling Considerations

The design of modules/cargo requiring transportation to and from a work-site by the EVA crewman should consider the package size, mass, handhold location with respect to the mass center of gravity (CG), and the number of crewmen involved in transfer operations. The package size should not limit crewman visibility during transfer operations, particularly for one man transportation tasks. No limits have been established for the size of packages that can be safely handled by the EVA crewmen on future EVA missions. Each package size and configuration will possess different handling characteristics and require individual consideration. One man package transfer simulations have been conducted on the KC-135 "zero-g" aircraft with packages having frontal dimensions of 40 in. by 30 in. (1.02 m by .76 m) without significant visual problems.

The mass that can safely be handled by EVA crewmen, as in the case of package size that can be transported, has not been established. Packages of approximately 85 lbs. (38.6 kg.) have been manually transported on the Apollo program while simulation programs have successfully handled 8500 lbs. (3856 kg.). Additional simulations are scheduled to handle up to 65,000 lbs. (29,484 kg.). An important factor to consider in EVA package handling/transfer is the package velocity should decrease with increased mass to assure safe handling operations.

The location of handholds or transfer points with respect to the package mass center of gravity is important in the design of equipment for EVA transfer. The mass moment of inertia about the package handle is the limiting factor in "controlled" transfer operations. Many variable factors such as crewman strength, mobility aids, package configuration, transfer velocity, spacecraft perturbation, etc. are required to determine the maximum mass moment of inertia for safe and efficient transfer/handling operations for a specific application. Upper limits have not been established.

The number of crewmen involved in the EVA equipment handling functions should be considered when designing transportable EVA hardware. Two crewmen as opposed to only one will allow larger and more massive packages to be handled. The time required for transfer operations will be reduced, and the safety of both the crewmen and equipment will be enhanced where large, massive packages are involved. Other areas of consideration associated with equipment handling include providing crewman mobility aids compatible with package characteristics and the package-to-crewman/spacecraft safety tether requirements.

6.2.2.4 Mobility Considerations

The mobility characteristics of the EVA crewman are dependent upon: (1) the EVA pressure suit, (2) the mobility aids, and (3) the life support system provided to perform the EVA functions. The total mobility of the pressure suit is dependent upon the independent joint mobility and the "fit" of the suit to the crewman. The pressure suit joints include the shoulder, waist, elbow, hip, knee, and ankle. Joint mobility design requirements for the 8.0 psia (.56 kg./cm.^{2}) pressure suit currently under development are shown in Figure 6-2. The design of EVA serviceable hardware and equipment operations are required to fall within these mobility guidelines.

The necessity of providing adequate mobility aids and restraint systems to enhance the performance of EVA has been discussed in a previous section and will not be repeated here. The life support system required by the crewman can affect the overall mobility of the EVA crewman. An umbilical life support system requires "management" of the umbilical during translation to avoid entanglement with surrounding equipment and limits the to-from transfer route. The portable life support systems increases the mass and redistributes the center of gravity of the man/system unit which must be acknowledged by the crewman during translation and worksite activities.

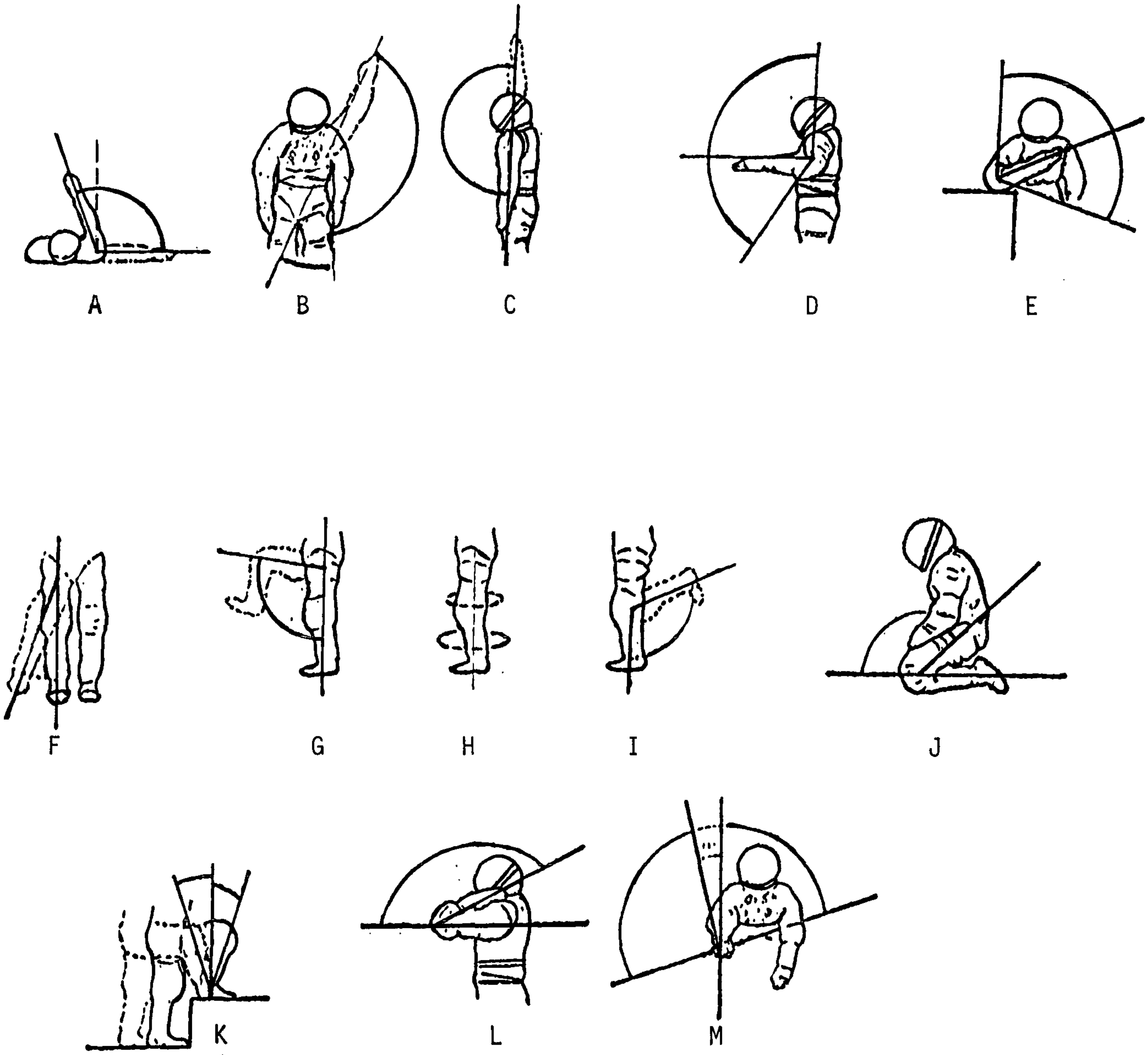


FIG.	SUIT JOINT	TORQUE (FT.-LB.)	ANGLE OF MOTION (DEGREE)
A	SHOULDER ADDUCTION/ABDUCTION	1	105
B	SHOULDER (LATERAL/MEDIAL) MOVEMENT	1/1	150/30
C	SHOULDER FLEXION/SHOULDER EXTENSION	1	180
D	SHOULDER ROTATION (X-Z PLANE)/(DOWN-UP)	0.1/0.1	80/90
E	SHOULDER ROTATION (Y-Z PLANE)	0.1	130
F	HIP ADDUCTION (LEG STRAIGHT)	1	60
G	HIP FLEXION	1	160
H	HIP ROTATION	1	110
I	KNEE MOBILITY FLEXION-STANDING	1	120
J	KNEE FLEXION-KNEELING	2	170
K	ANKLE EXTENSION/FLEXION	1/1	45/45
L	ELBOW FLEXION/EXTENSION	1	150
M	FOREARM MOBILITY WRIST ROTATION	0.1	180

FIGURE 6-2: 8.0 PSI SUIT JOINT MOBILITY REQUIREMENTS

6.2.2.5 Crewman Visibility

Crewman visibility during both "light" side and "dark" side orbital extravehicular operations requires consideration early in the planning and design phase of the vehicle systems and payloads to be serviced EVA. The major factors contributing to possible visibility restrictions during EVA are: (1) extreme brightness during the "light" side of the orbit, (2) characteristics of collimated light from the sun, (3) insufficient "dark" side illumination, and (4) suit helmet visor worn to prevent eye damage during intense illumination periods.

The extreme brightness, and the ultraviolet (UV) and infrared (IR) rays existing in the space environment, require the use of a protective visor during EVA. The visor assembly is worn over the basic helmet protective shell and contains sufficient visor and "blinder" inserts for adequate protection during orbital EVA. The visor and blinder inserts are adjusted by the EVA crewman as required at the various worksites.

The essentially collimated light from the sun and the illumination complexity introduced by other heavenly bodies may create visual problems for the EVA crewman. The determination of true object shape in a collimated light field is more difficult than in normally dispersed light. Distance judgement in a collimated or complex lighting environment can also be more difficult. A summary discussion on the illumination characteristics of earth orbital lighting can be found in reference 6.4.

Artificial lighting from the Shuttle Orbiter, payloads, or EVA workstation is required during "dark" side orbital extravehicular servicing operations. The Shuttle Orbiter will provide sufficient illumination for general EVA operations in the payload bay; however, concentrated lighting required at the worksite will be supplied by the payload or EVA workstation. The general illumination levels specified for the Skylab program were as follows: (1) a minimum of 2.0 ft. lamberts along all EVA translation routes, and (2) a minimum of 5.0 ft. lamberts illumination at each prepared worksite. These illumination levels should be sufficient for the Space Shuttle and future space programs. Unprepared worksites requiring additional lighting may best utilize portable light assemblies. Additional information/data concerning EVA lighting on the Shuttle Orbiter can be found in Section 7.8 of this report.

6.2.2.6 Crewman Comfort

The comfort of the crewman while performing in the extravehicular environment can be a factor in efficient task performance. Several factors which will contribute to crewman discomfort, if not properly controlled, include the following:

- Pressure points caused by an improperly fitted pressure suit
- Insufficient or unattended pressure suit oxygen or water flow for maintaining body temperature control
- Workload control to maintain proper metabolic loading and body heat stowage

Each of the pressure suits are "custom fitted" to the crewman prior to vehicle launch. Ideally each suit would provide maximum comfort; however, sufficient time, volume, and assistance (if necessary) must be provided to allow proper donning and checkout of the suit and attached LSS. All areas of suit/LSS discomfort should be corrected prior to cabin egress for planned EVA operations. Emergency suited conditions dictate the most comfort attainable in the available donning time.

In the early EVA systems development flights, estimates of the heat load produced by the crewman and equipment were too low. Subsequently, the crewman overloaded the LSS system, and performance was degraded. This condition was immediately corrected through increasing the capacity of the LSS and introducing the liquid cooling garment. In state-of-the-art life support systems, human endurance rather than LSS capacity is the limiting factor. However, sufficient control of the LSS must be maintained by the crewman to avoid uncomfortable temperature peaks during work-rest periods and to compensate for the temperature changes (i.e., heat transfer through the suit) between "light" and "dark" orbital EVA operations.

Maintaining the crewman within his thermal physiological tolerance limits is of concern during EVA. Workload control in conjunction with the life support system, provides sufficient means to maintain the EVA crewman within comfort limits. In the normal comfort state, man maintains a skin temperature of 98.6 $\pm$ 0.9° F. His thermoregulatory system attempts to maintain a deep body temperature of approximately 98.6° F. The principal mechanisms of achieving a balanced state of comfort are by changing the rate of sweat production and the amount of blood flow to the skin area. Varying the ambient temperature that the body "sees" or increasing the crewman's metabolic rate (i.e., by increasing the workload) will affect this balanced state of comfort. The amount of heat stored in the body as a function of workload must be considered in "designing" for crew comfort. The crewman body heat storage is limited to 300 BTUs during EVA. Figure 6-3 shows the effects of body heat storage on crewman performance over a period of time. The body is capable of storing the 300 BTUs of heat over somewhat long periods of time with no adverse affect on performance. However, as the chart indicates, exceeding the capacity of the body for heat storage over a given time period can not only prohibit the crewman from performing EVA tasks at his maximum efficiency but can lead to early termination of EVA servicing operations.

6.2.2.7 EVA Monitoring Requirements

The monitoring of the EVA crewman on the Space Shuttle and future missions currently appears to be limited to assuring crew safety and well-being. Preliminary monitoring requirements are listed below (ref. 6.6):

- Pressure suit primary oxygen (O_2) pressure
- Oxygen flow rate

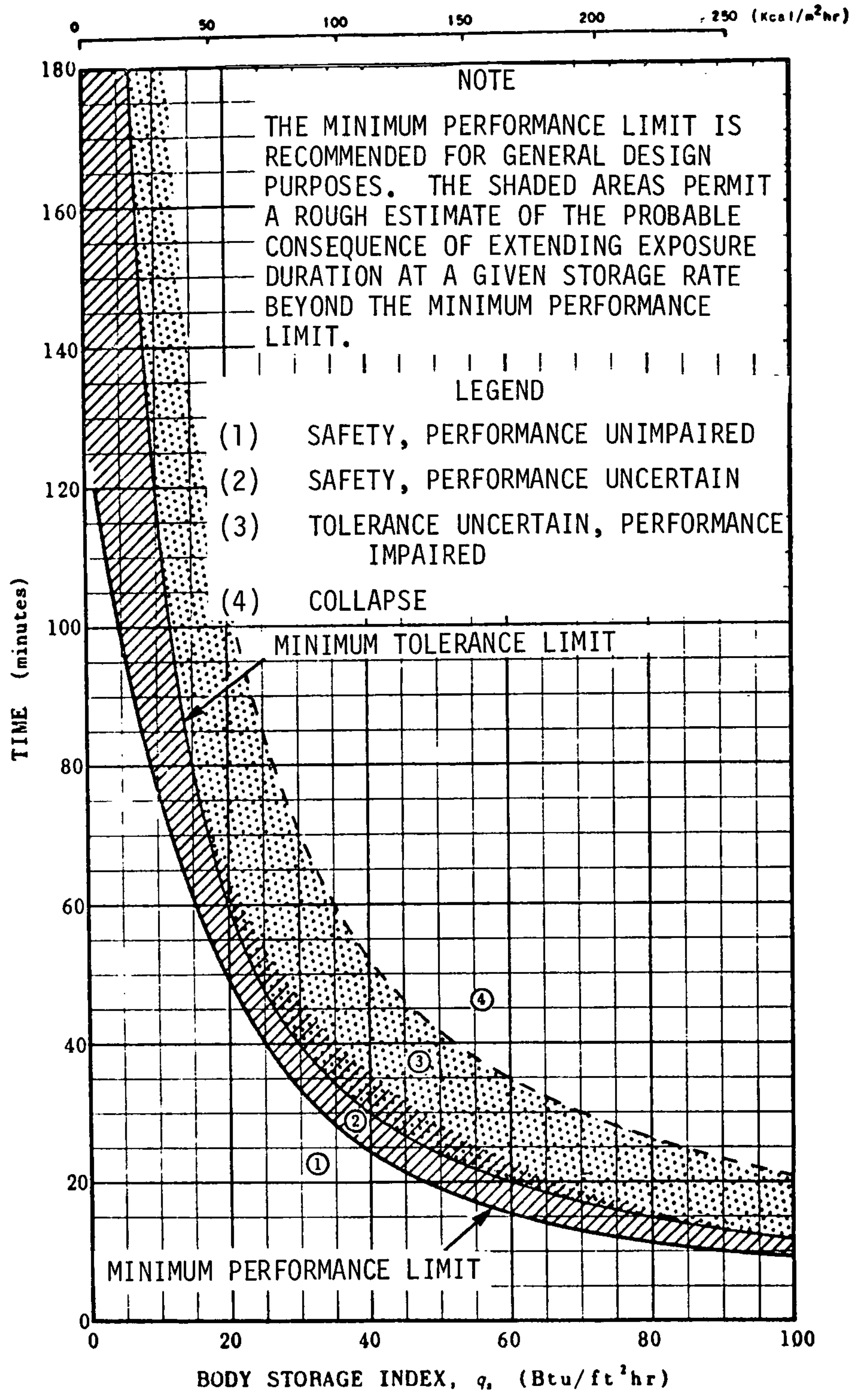


FIGURE 6-3: THERMAL PERFORMANCE AND TOLERANCE LIMITS

- Carbon dioxide (CO_2) vent flow
- Crewman heart rate
- Time in EVA
- LSS battery voltage (portable LSS)
- Voice transmission
- LSS heat sink status

Metabolic load predictions through real-time heart rate monitoring will be used to control work rate as in previous EVA programs. A minimum of ten (10) telemetry channels from each EVA crewman has been proposed by Space Shuttle EVA/IVA requirements studies (ref. 6.7).

6.3 MISSION, VEHICLE, AND PAYLOAD IMPACTS

Since the Space Shuttle Program presently constitutes development of the major U.S. space vehicle for the next two decades, attention is directed toward the EVA support systems provided by the Shuttle Orbiter and those considered part of the payloads. The equipment considered part of the payloads usually represent carry-on hardware such as space suits, life support systems, and expendables. The Space Station, scheduled for initial build-up through modular shuttle orbiter payloads in 1985, is expected to provide EVA support systems, equipment, and expendables supplied between the Orbiter and the payloads, the payload planners and designers will be required to consider the basic EVA associated parameters that impact the mission, vehicle, and payloads. These parameters should be considered after the crewman safety and performance capabilities assessments are complete.

The current NASA documentation that has control over the Shuttle Orbiter configuration and accommodations between the Orbiter and payloads consists of the Space Shuttle Program Request for Proposal (RFP) 9-BC421-67-2-40P, March 1972, and the Space Shuttle Baseline Accommodations for Payloads document, MSC-06900A. The RFP with any subsequent revisions is the primary controlling source document. The Space Shuttle preliminary design phase initiated in September 1972 will provide in-depth information on Orbiter characteristics and may, if required, propose modifications to certain of the initial guidelines. The Shuttle program configuration description and requirements sections of these documents specify the EVA accommodation equipment to be provided by the Shuttle Orbiter and the payload. A summary of the EVA accommodations between the Orbiter and payload, as depicted in the configuration control documents above, is contained in Table 6-5.

The parameters impacting the mission, vehicle, and payload are not limited to the Shuttle Orbiter and its associated payloads--they are equally applicable to any future mission considering EVA functions. A summary expansion of each of the parameters listed in Table 6-1 is contained in subsequent paragraphs. It should noted that many of the parameters to be considered are required, whether or not EVA is used as the primary mode to accomplish mission objectives. The crewman safety/rescue requirements in the event of spacecraft disablement, and the probable manned backup to teleoperator or automated systems, already provide the means to attain access to the vehicle exterior and to many payload areas that may require servicing. Detailed information will be contained on these and other impact parameters in later sections.

6.3.1 Number of EVA Crewmen Required

The total number of crewmen required (from the crewman's performance capabilities aspect) to conduct an extravehicular mission is dictated, within limits, by the specific payload and tasks to be performed. Crewman requirements in terms of EVA equipment impact on the vehicle and payloads were discussed earlier. EVA on previous space programs has utilized a minimum of two crewmen completely equipped for EVA duties. The two-man EVA requirement was a result of both the spacecraft configuration and the task complexity. On the Gemini and Apollo program, the entire vehicle cabin was depressurized thereby subjecting

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS

SHUTTLE DOCUMENT:
Space Shuttle Program Request For Proposal - No. 9-BC421-67-2-40P, March 1972

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• The cabin accommodations shall support EVA/IVA activity with necessary carry-on equipment chargeable to payload; i.e., suits, umbilicals, etc.	IV - 9	1.3.0.1-4
• The Orbiter shall have the capability to support the survival of a four-man crew for 96 hours after an in-orbit contingency, assuming reduced consumption rates as appropriate, and with the crew in a resting level of activity and the vehicle essentially powered down.	IV - 13	1.3.0.17
• Two-way voice communications shall be provided between: - The Orbiter and EVA crewmen - EVA crewmen and the space network via the Orbiter relay	IV - 26	1.3.4.2.3
• A mission specialist console shall be provided for monitoring and control of payloads. Displays and controls provided at the mission specialist station include an audio communications panel with audio channel selector for communications with crewman, personnel in payload bay, EVA personnel, personnel in free-flying payload, or the ground.	IV - 27	1.3.4.3.4-d

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Program Request For Proposal - No. 9-BC421-67-2-40P, March 1972

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• Environmental Control/Life Support System (EC/LSS): The Contractor shall provide the life support for the flight personnel and environmental control for the Orbiter Vehicle during all mission phases. The EC/LSS shall provide the life support environment required to provide a shirtsleeve environment for the crew. The EC/LSS shall perform the major functions of atmosphere revitalization; active thermal control; and water, waste, and food management, and atmosphere monitoring to include contaminate detections. Provisions shall also be made for support to extravehicular/intravehicular activity (EVA/IVA). The EC/LSS shall have the following requirements: - Total pressure requirements shall be a nominal 14.7 psia, using a two-gas system composed of nitrogen and oxygen. - The partial pressure of oxygen shall be 3.1 ± 0.1 psia. Carbon dioxide partial pressure shall be: a. Nominal : 5.0 mmHg b. Range : 0 - 7.6 mmHg - Provisions shall be made for connecting oxygen mask assemblies for EVA/IVA oxygen prebreathing and emergency conditions.	IV - 31	1.3.5
• Expendables and EVA/IVA suits to support EVA/IVA operations shall be provided at the expense of payload weight. Applicable design requirements are as follows:	IV - 32	1.3.5.9,11

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Program Request For Proposal - No. 9-BC421-67-2-40P, March 1972

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
- An EVA/IVA service and recharge station to support storage, recharge, checkout, and donning of EVA/IVA equipment shall be provided.		
- Adequate EC/LSS expendables to provide for seven airlock pressurizations and seven EVA equipment recharges shall be provided.		
- Provisions shall be made for one cabin repressurization in the event of an emergency.		
• An airlock shall be provided and sized to accommodate two-man EVA operations without the necessity for cabin decompression.	IV - 32	1.3.6.1.3
• Hatches shall be designed to be opened externally and such that latch/unlatch operations can be performed from either side of the hatch. A means for pressure equalization and a display of pressure delta across the hatch shall be provided. The hatches required for emergency egress shall not result in damage to the vehicle primary structure and pressure equalization shall not be required for emergency egress.	IV -33	1.3.6.1.8
• Crew and Cargo Transfer: The Orbiter Vehicle shall be designed to allow (shirtsleeve) access to pressurized payload modules and pressure suit access to the unpressurized payload bay in flight.	IV - 33	1.3.6.2.2
• Payload Retrieval: For retrieval of payloads, the Orbiter shall be capable of transmitting commands to a payload to maneuver and configure the payload for retrieval. Additionally, as a design objective, the Orbiter shall provide standard interface connectors for electrical power, communications, caution	IV - 38	1.3.8.1.5

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Program Request For Proposal - No. 9-BC421-67-2-40P, March 1972

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
and warning, and fluid interfaces which may be engaged and disengaged without EVA. To accommodate their retrieval and stowage in the payload bay, the payloads shall provide compatible mechanical, electrical, and fluid interfaces.		
• Payload Handling Station: The payload handling station shall provide the flight crew with the controls, visibility, and displays required to deploy and retrieve payloads. This station shall be capable of being manned by one flight crewman in a shirtsleeve environment and provide visual access to the payload supports and deployment/retrieval mechanism attachment points.	IV - 43	1.3.8.7.2
• Illumination: The Orbiter shall provide a lighting system for illumination to support Orbiter/payload operations external to the Orbiter and inside the payload bay. The external lighting system shall provide illumination for payload deployment, docking, and retrieval operations. Payload bay illumination shall be provided for payload inspection, attached payload operations, payload latching, and payload release. The illumination system within the cabin shall provide illumination for each payload display and control station which is compatible with the crew compartment illumination requirements.	IV - 43	1.3.8.7.3

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION PAGE	REFERENCE LOCATION SECTION
• PAYLOAD OPERATIONS Payload operations during the orbital mission phase may be performed with the payload attached in the payload bay, attached to the orbiter and out of the payload bay, or deployed and released from the orbiter. Payload operations, which may require radio frequency (RF) and/or hardline interface between the payload, the orbiter vehicle, and sometimes the ground, are concerned with such functions as command and control, data transfer, monitoring and checkout, tracking and ranging, and inspection. Payload operations, which normally require some physical interface between the payload and the orbiter vehicle, are concerned with such functions as deployment, erection or release, logistics, maintenance, servicing, retrieval, retraction, and stowage.	2 - 8	2.4
• PAYLOAD MONITORING AND CHECKOUT The orbiter will have provisions for monitoring all safety-of-flight parameters generated by the payload. These parameters are displayed to the flight crew and mission specialists. In addition to the safety-of-flight parameters, payload peculiar parameters can be displayed to the mission specialist on the general purpose displays, or through payload-supplied mission peculiar displays to the payload specialist. Prior to payload operation or deployment, functional checkout can be accomplished by use of programs stored in the memory of the computer used for payload checkout. Manual insertion of payload data/commands into the computer can be made through the keyboard. Dedicated payload displays and controls can also be used in conjunction with payload checkout. Visual inspection and manual assistance by the crew can be accomplished by extravehicular activity (EVA).	5 - 2	5.3

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• EXTRAVEHICULAR ACTIVITIES	5 - 4	5.6
Extravehicular activity (EVA) is any in-space activity which requires a crewman (or passenger) to depart the normally pressurized cabin of the shuttle and enter an unpressurized environment. The orbiter provides the capability to perform seven 2-man, 4-hour EVAs. Although 2-man EVAs are the nominal mode, single man EVAs can be accomplished. The EVA expendables and EVA equipment weights are chargeable to the payload weight. During EVA, crewmen are monitored from within the orbiter by the shuttle onboard data system. The nominal EVA system does not require umbilical support from the vehicle; however, the EVA crewmen must be tethered. This system evaporates water for cooling purposes. For payloads sensitive to water vapor a non-venting EVA system is available, but this system is constrained by a water cooling umbilical. A manipulator-attached EVA crewman work platform is available for payloads. If forces must be applied by the EVA crewman to the payload, the payload must provide restraint for either the EVA crewman or the EVA platform. The weight and volume of this platform is chargeable to payload. Those payloads that provide EVA work areas must consider the following in their design: a. Have handholds, guide rails, tether attach points, and proper lighting along EVA routes and at work stations. b. Foot restraints are needed where pushing, pulling, or torque actions are planned. c. EVA routes must be planned and free from dangerous, sharp, or easily damaged objects.	5 - 5	

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• PAYLOAD BAY	7 - 1	7.1
The payload bay has a clear volume of 15 feet diameter by 60 feet length for missions not requiring docking. Docking missions require (TBD) feet of bay length to accommodate the docking module. This volume is basically a payload dynamic envelope within which the payload must remain during the entire flight regime. This envelope is penetrated by the necessary payload structural attachments and umbilicals which extend outside the envelope to interface with the orbiter. The clearance envelope between the payload envelope and the orbiter structure is provided by the orbiter to avoid orbiter deflection and deployment interference between the orbiter and the payload.	7 - 2	
For the purpose of uniformity, a coordinate system has been established for the space shuttle program.		
• PAYLOAD STRUCTURAL ATTACHMENT	7 - 2	7.2
Payload structural accommodations provide a 3-points-in-plane across the cargo bay positioned at 14 locations along the length of the bay. This design reduces payload weight and complexity and provides flexibility for accommodating a wide spectrum of payloads. Alignment of the payloads is maintained within 0.5 degree of the orbiter's reference system. The fittings along the upper door frame are capable of reacting loads in the ±X and ±Z planes, while the lower keel fitting reacts loads in ±Y plane only. A 4-point retention concept is used.		

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• <u>PAYLOAD DEPLOYMENT/RETRIEVAL MECHANISM</u> A payload is retrieved in three basic steps: (1) transmission of commands for stabilization, orientation for manipulator attachment, retracting solar arrays, antenna, etc.; (2) manipulator engagement, translation, and securing in the payload bay; and (3) connection of payload utilities, e.g., caution/warning, power, data, and fluid/gas venting when required. Payload retrieval involves the combined operations of rendezvous, stationkeeping, and manipulator arm control. The baseline system employs TACAN for range information, star sensors for angle information, the IMU for maneuver sensing, and relies on manual control for shortrange stationkeeping and manipulator drive operation. Although the majority of cases involve active payloads with no time constraints, the orbiter has single-orbit payload retrieval and passive target retrieval capabilities. When these requirements are not both imposed on the same mission, the baseline approach is satisfactory. Passive rendezvous can be accomplished manually from a standoff distance greater than the uncertainty about target and orbiter position at periods of proper lighting conditions, fast rendezvous is considered possible with active targets. During a capture sequence, the vehicle and manipulators are controlled from the forward and aft top deck stations, respectively. Once a stationkeeping position is achieved, a standard manipulator trajectory for arm deployment to a position short of the payload is commanded and monitored by the payload handling station operator.	7 - 12	7.3

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION PAGE	REFERENCE LOCATION SECTION
Next, the crewman, utilizing direct and TV viewing, operates the 3-axis manipulator arm controllers. He commands rates of the arm and effectors in translation and rotation. The payload monitor/payload handling computer transforms simple commands into appropriate rates of the seven arm joints until proper engagement is made. Inasmuch as crew performance under defined time constraints and sensor performance is critical, realistic laboratory simulations will be employed to verify operations for all mission requirements. Should additional sensors be recommended to achieve desirable performance margins (e.g., laser radar for fast rendezvous with a passive target) these will be incorporated as payload unique items.		
• PAYLOAD BAY HATCH	7 - 17	7.4
The payload bay hatch is located on the vertical centerline of the vehicle and has a 40-inch clear opening. This opening is sized to allow a TBD-inch object to be removed from or to a pressurized payload. The size object that can be moved from or to an unpressurized payload is a function of airlock volume. Since the shuttle contains only one airlock exit hatch, a pressurized payload that required EVA operations must be isolatable from the shuttle cabin during EVA. Missions with planned docking will have a docking module attached to the payload bay hatch. Pressurized payloads will interface with the docking module hatch and again must be isolatable for EVA. The ability to disconnect a pressurized payload from the payload bay hatch during flight must be maintained to provide for rescue.		

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• DOCKING MODULE Docking of the orbiter to another orbital element is accomplished by the installation of the docking module in the payload bay. This module is attached to the orbiter airlock/payload bay hatch located on the forward bulkhead of the payload bay. Docking is accomplished by the extension of the docking ring approximately 30 inches above the orbiter mold line and engagement of the docking mechanism to another orbital element. Access through the docking module either to the payload bay or to an attached habitable module in the payload bay is provided by a 40-inch clear diameter hatch located on the centerline of the payload bay.	7 - 17	7.5
• NASA PAYLOAD SUPPORT The orbiter will transmit voice and digital data to a payload and will receive voice and digital data from a payload via hardwire or RF communication links. The orbiter will transmit commands at a 2 Kbps rate (generated on-board) and voice, onboard or relayed, to an attached payload via the hardwire communication link. The orbiter will receive, and relay, voice, analog data, and digital data (at rates up to 256 Kbps) from an attached payload via the hardwire communication link. The orbiter RF communication link will transmit commands at a 2 Kbps rate (generated onboard) or voice, onboard or relayed, to a detached payload. The orbiter RF communication link will receive and relay voice or digital data (realtime or recorded at rates up to 2 Kbps from a detached payload.	8 - 12	8.3.4

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION PAGE	REFERENCE LOCATION SECTION
• VHF VOICE TRANSCEIVER The VHF AM/FM voice transceiver will provide multichannel coverage from 118 to 150 MHZ with either amplitude or frequency modulation of the voice on a carrier. Control panels located in the crew stations will enable the crew to select the desired frequencies on each transceiver. The transceivers will provide for (1) simplex voice communications with commercial air traffic control facilities during energy management, final approach, landing and ferry, (2) duplex voice (backup to S-band voice in orbit) between the orbiter and an STDN by transmitting on one transceiver (136 to 138 MHZ) and receiving on another (144 to 150 MHZ), (3) international rendezvous and docking mission simplex voice communications on 121.75 MHZ (FM), (4), duplex EVA communications between two EVAs and the orbiter, and (5) duplex voice or command and low rate telemetry communications with a detached payload.	8 - 13	8.3.5.1
• ATMOSPHERIC O_2/N_2 SUPPLY AND PRESSURE CONTROL This section provides and controls the oxygen and nitrogen (except cryogenic oxygen storage which is the responsibility of electrical power generation subsystem) required for pressurization of all orbiter compartments to 14.7 psia, for seven airlock repressurizations (except emergency repressurization of extravehicular airlock), and for resupply of extravehicular life support systems for seven excursions.	12 - 2	12.1.2

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• AIRLOCK SUPPORT SUBSYSTEM The airlock support subsystem contains the systems required to provide EVA, payload bay access, and emergency breathing within the shuttle. The subsystem provides access from the cabin to free space, pressurized or unpressurized payloads, and the docking adapter. Transfer from a contaminated environment to an uncontaiminated environment without containinating the clean environment is provided. To perform these functions the airlock support subsystem contains an airlock, hatches, press/depress system, EVA/IVA equipment interfaces and services, and ventilation system. The airlock volume is sized to allow two EVA crewmen to transfer from or to the cabin with a TBD sized object. The press/depress system is controllable from either the airlock or the cabin. There is emergency repressurization capability for rapid return to a safe pressure in the event of an EVA system malfunction or to back up the normal repress system. The EVA/IVA equipment interface and services include provisions for complete recharge of the EVLSS, suit drying, EVA equipment donning and checkout, restraints, mobility aids, lighting, communications, liquid cooled garment water system, and suit gas ventilation. Besides suit gas ventilation, the airlock volume is kept ventilated at all times by the atmospheric revitalization subsystem. An extendable transfer tunnel kit or docking module mounted on the aft side of the bulkhead separating the crew compartment and payload bay, provides in-flight access between these two areas. The tunnel is extendable to mate with pressurized payload modules for the shirtsleeve access mode of operation. Access to the unpressurized area of the payload bay is achieved with the airlock or the airlock and docking module. The crew compartment interface with the transfer tunnel is via the airlock through an access hatch in the aft cabin bulkhead. The tunnel is retractable for clearance during payload loading or deployment.	12 - 5	12.4

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• PAYLOAD HANDLING STATION The payload handling station has, in addition to direct vision, a minimum of five closed circuit TV cameras and two TV monitors. The cameras, located near the terminator of each manipulator arm, ensure a closer image of the target so that final closure and attachment may be accurately controlled. Two TV cameras are mounted in the payload bay and provide remote reviewing of the payload attachment and release and stowage operations as well as general viewing of the entire area. The fith camera is used within the docking module and mounted on the centerline of the docking axis at the docking port window to aid the manipulator operator to monitor alignment and range/range rate during manipulator controlled docking operations. The exterior lighting system fulfills requirements for orbital visual acquisition and tracking, determination of gross attitude, relative attitude and alignment, and gross range and range rate of payloads during terminal rendezvous, docking, deployment, and retrieval operations under all space lighting conditions. Type of lamps and their locations are shown in Figure 6-4.	13-8	13.5

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
• SUPPORTS AND RESTRAINTS	13 - 10	13.6.1
Mobility aids are provided in the payload bay and orbiter structure. These mobility aids include strategically located handholds, tether-attachment points, and foot restraints at work areas. Similar mobility aids should be provided on payloads which require EVA/IVA crew operations such as maintenance, inspection, or deployment.	13 - 11	
The EVA capability for a minimum of two crewmen is provided by the orbiter. To support EVA, the orbiter has an airlock EVA equipment storage and donning area, extravehicular life support system (EVLSS) recharging station, crew mobility aids, and the necessary communication circuits and monitoring systems for on-orbit operations. The EVA equipment and expendables are available and are chargeable to the payload. This EVA equipment includes (1) pressure garment assemblies (PGAs); (2) EVLSSs; (3) maneuvering systems; (4) tool kits; (5) restraints; and (6) portable lights. Standard tools and a torquing device are included in the tool kit. Specialized tools and tool adapters are provided by the payload.		
The following items must be considered in payload design to ensure compatibility with the EVA crewman to obtain maximum utility from time spent in EVA.		
a. Handholds or guiderails are provided along the EVA traverse wherever required.		
b. Foot restraints and tether-hook attach points are provided at work stations or wherever pulling, pushing, or torquing actions are required.		

TABLE 6-5: EVA SUPPORT ACCOMMODATIONS BETWEEN SHUTTLE ORBITER AND PAYLOADS (CONT'D.)

SHUTTLE DOCUMENT:
Space Shuttle Baseline Accommodations For Payloads--MSC-06900A

SHUTTLE ORBITER - PAYLOAD ACCOMMODATIONS	REFERENCE LOCATION	
	PAGE	SECTION
c. Maximum force and torque capabilities for the restrained EVA crewmen are: Torque - (TBD) foot/pounds Force pull - (TBD) pounds Force push - (TBD) pounds d. Reach mobility and visibility are considered in work station design. Tool and controls must be compatible with the gloved hand. e. Maximum envelope dimensions of the PGA/PLSS are shown on Figure 6-5. (NOTE: These dimensions are subject to change pending advanced PGA/PLSS development.) f. Lighting levels are compatible with the tasks to be performed. g. Sharp or dangerous objects are eliminated from the EVA route. Payload weight which can be transferred by the crewman is dependent upon the physical configuration of the payload and the method transfer.		

	APPLICATION	QUANTITY	TYPE
1	ATTITUDE AND RUNNING LIGHTS	13	LOW VOLTAGE AC, TUNGSTEN HALOGEN LAMPS
2	ACQUISITION TRACKING ANTICOLLISION LIGHTS	2	XENON FLASHING (MODIFIED APOLLO)
3	DOCKING LIGHTS SPOTLIGHT (a)	2	LOW VOLTAGE AC, TUNGSTEN HALOGEN LAMPS, 15K BCP
	FLOODLIGHT (b)	1	LOW VOLTAGE AC, TUNGSTEN HALOGEN LAMP
4	EVA LIGHTS	2 (OR AS REQMTS. DICTATE)	LOW VOLTAGE AC, TUNGSTEN HALOGEN LAMPS, 100 WATTS
5	PAYLOAD BAY FLOODLIGHTS	4	75 WATT FLUORESCENT
6	MANIPLATOR ARMS SPOTLIGHTS	2	LOW VOLTAGE AC TUNGSTEN HALOGEN, 100 WATTS
7	LANDING LIGHTS	2	700K BCP QUARTZ, SEALED BEAM

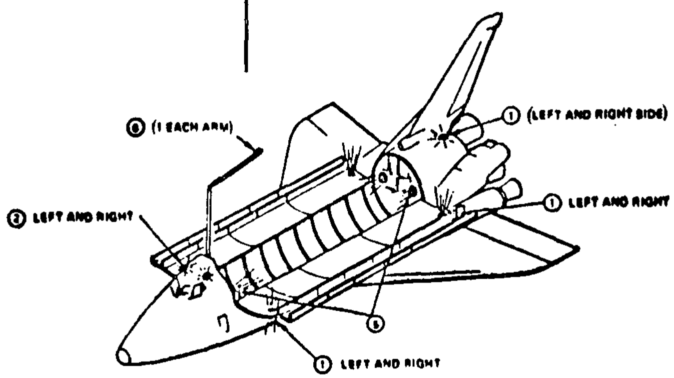
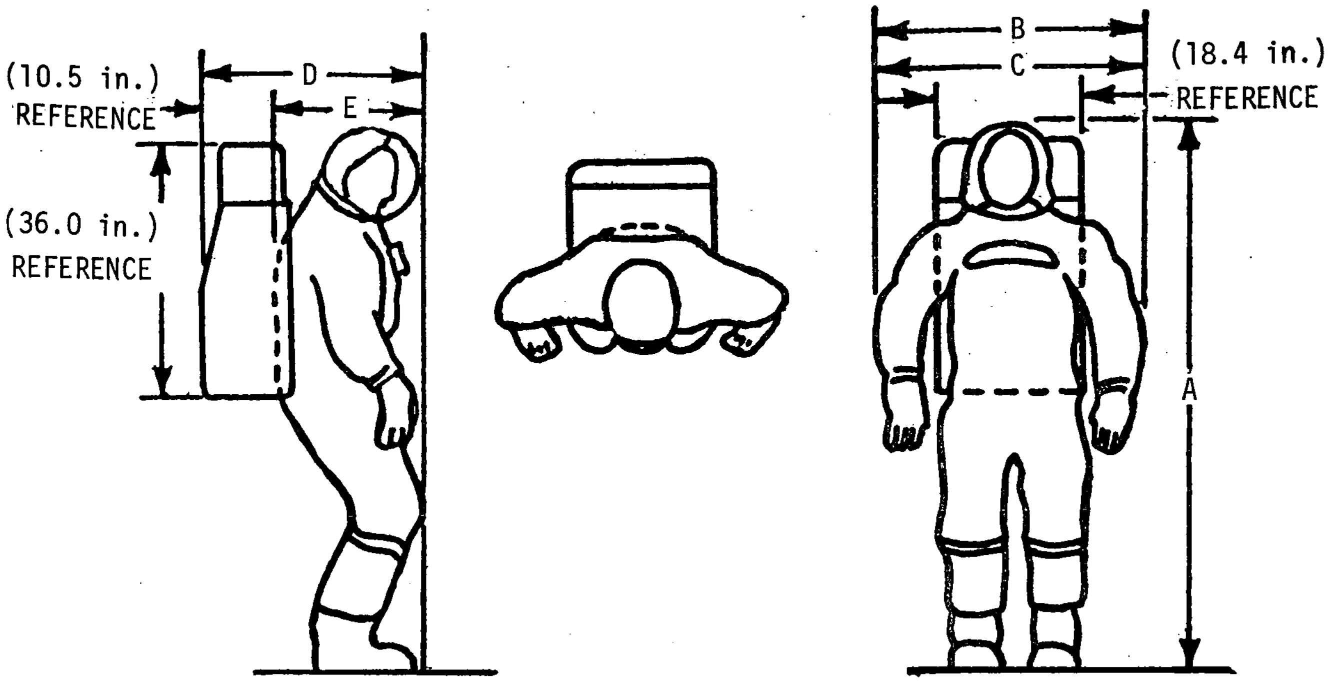


FIGURE 6-4: SHUTTLE ORBITER LAMP LOCATIONS AND QUANTITY



DIMENSION (in.)*	PERCENTILE MAN	
	5%	95%
A - Height	67.5**	75.5**
B - Maximum Breadth at Elbows (Arms Relaxed)	-	29.4
C - Maximum Breadth at Elbows (Arms at Side)	-	26.4
D***Maximum Depth with Portable Life Support System (PLSS) and Backup Oxygen (OPS)	26.0	28.4
E***Maximum Depth without PLSS/OPS	15.5	17.9
Weight (lb), with PLSS/OPS	316.0	385.3
Weight (lb), without PLSS/OPS	190.3	259.6

Notes:

* Measurements made on A7L PGA, pressurized to 3.75 psig
** Dimensions shown are in units of inches
*** To obtain envelope dimensions, 2 inches have been added to maximum chest depth of suited/pressurized crewman for PLSS control box.

FIGURE 6-5: PRESSURE SUIT AND LIFE SUPPORT SYSTEM MAXIMUM ENVELOPE DIMENSIONS all crewmen to the space environment. On the current Skylab Program two EVA crewmen are required to perform the scheduled tasks, with a third crewman (inside) partially suited for contingency operations. However, for EVA on future programs, the current (1972) guidelines are designed to minimize the number of crewmen per EVA without jeopardizing safety or affecting task performance. One man EVA's plus a second partially suited standby crewman for contingency situations is permissible on future missions (i.e., 1972 guidelines). Each candidate EVA mission should be studied to determine payload design techniques and task operations that will result in minimizing the number of EVA and supporting crewmen required.

In terms of impacting the space mission, vehicle, and payload, the number of crewmen required on-orbit to perform, conduct, and support EVA operations are weighed against competitive techniques in the following areas:

(1) Crewman time required per mission

(2) Vehicle volume required for equipment donning/doffing, servicing, and stowage

(3) Ancillary equipment weight considered part of the payload

The time required by the crewmen for pre- and post-EVA tasks was discussed in earlier sub-sections. This pre- and post-EVA time plus the actual EVA task time are compared to the EV crewman time required to initiate, checkout, control, monitor, service, and terminate operations associated with techniques such as teleoperators or automated systems. Each candidate mission requiring external operations must also be individually studied with respect to primary and backup techniques for each task.

The volume required on the spacecraft for installing, servicing, and stowing EVA systems and crewman supporting hardware is compared to the volume required by other candidate payload servicing techniques in order to establish data points in technique selection studies. The EVA equipment weight considered part of the payload that utilizes EVA is handled in the same manner as the required spacecraft volume. The weight of the EVA equipment is compared to the weight of other techniques in trade studies to determine the most economical method of task performance outside the pressurized vehicle cabin.

6.3.2 Duration of EVA

The duration of each manned EVA will affect the spaceflight mission primarily from the in-flight manpower time allocation point of view. The time required for EVA preparation, actual EVA time, and post EVA functions must be compared to crewman time to checkout, operate, monitor, and shutdown operations associated with other candidate systems. These times must then be compared to the additional crewman time that may have been available to perform additional experiments or required mission functions. Trade studies are then conducted.

The vehicle is affected by the duration of EVA in the quantity of expendables and consumables carried on a specific flight and the stowage facilities required. These expendables and consumables are those utilized by the crewman and his life support systems and are a direct function of the number of crewmen required in EVA.

The payload is also affected by the duration of EVA: in this case from the standpoint of the expendables and consumables being considered part of the total payload weight. The weight of these expendables subtract directly from the weight allowable for experiments or payload systems as would propellant for a teleoperator system.

The duration of EVA with regard to the capabilities of the life support systems and crewman protection equipment is not considered a major factor during future EVA missions. Current technology in EVA hardware, from the duration/capacity to support extended missions, has equaled or exceeded the physiological and endurance capabilities of the crewman.

E

6.3.3 Frequency of EVA Operations

The frequency of extravehicular operations required by the experiments and payloads are significant due to the crewman time required for pre- and post-extravehicular tasks and conduct of EVA, the expendables and consumables required for each EVA, and the quantity of EVA support equipment required per spaceflight mission. The pre- and post-EVA tasks must be repeated for each EVA mission. The pre- and post-EVA time combined with the time required to perform the extravehicular tasks may become excessive unless provisions are made during the initial payload design. Based on current and projected EVA equipment operations, a maximum of one EVA per each 24 hour mission period should not be exceeded. More frequent EVA's may become a reality pending advanced extravehicular systems development (e.g., suits, LSS, airlocks, workstations, etc.). Multiple payloads aboard a single vehicle should be designed/selected to permit performing the maximum number of EVA operations across all payloads during each EVA mission. Frequency of EVA operations in terms of the equipment impact on the vehicle and payload are discussed in Section 5.2.3 of this report.

6.3.4 Total Manpower Required During EVA

The total manpower required from the space vehicle to conduct and support exterior operations is a primary consideration when assessing the techniques available for accomplishing on-orbit tasks. Some techniques may require functions where a large percentage of the crewmen would be dedicated to periodically supporting the operations outside the vehicle. In programs such as the Space Shuttle where numerous experiments may be aboard a single flight, several experiments will be conducted simultaneously; since the flight duration is only seven (7) days, crewman time is extremely valuable. Therefore, methods of accomplishing the EV tasks must be evaluated in terms of crewman time versus the "cost" of other systems (i.e., technology, development, testing, and qualifying costs plus the weight, volume, and power impacts on the vehicle and payloads).

Orbital and transearth EVA on space programs through Skylab have used a minimum of two men during the EVAs. During the Gemini and Apollo programs, one crewman usually performed the majority of EV functions while the remaining crewman (or crewmen) monitored EV and spacecraft systems or assisted EV operations from the spacecraft hatch. Each crewman was essentially "EVA" since the total vehicle was subjected to the space environment. During planned Skylab EVA, two crewmen with about equal workloads will perform the required EV functions, while the third crewman will monitor EV and spacecraft systems from inside the vehicle. The third crewman will be in a partially space-suited condition for reacting to contingency situations.

The Space Shuttle is currently considering baselining one man EVAs, contingent on the task requirements, with a second "standby" crewman in a semi-suited status inside the pressurized vehicle. The second crewman may monitor the EV operations, EV crewman support systems status, and the status of the experiments or payloads being serviced on an integrated control/display panel. Such a safety backup and crewman monitoring arrangement would permit the two remaining crewmen to perform other functions associated with the payloads or spacecraft. (Under current guidelines the normal number of personnel aboard the Shuttle Orbiter is four (4). These include the commander, pilot, mission specialist, and payload specialist.) When two EVA crewmen are required, a third backup crewman should be capable of performing the required monitoring functions, thereby permitting the fourth crewman to perform other duties. Only during EVA's that are dedicated to conducting experiments for developing EVA equipment and advanced operational techniques should the full Shuttle crew be required to assist in the EV operations. Experiment programs such as the development and evaluation of advanced Astronaut Maneuvering Units (AMU) and Maneuverable Work Platforms (MWP), or the on-orbit construction of large structures (i.e., Antennae), may require as many as four (4) crewmen intermittently for the total program. For EV missions requiring several crewmen, volume is available within the Shuttle Orbiter for additional payload specialists. Their weight, consumables, support systems, equipment, and expendables are considered part of the payload.

Each potential manned EVA mission should be considered with respect to the total manpower required during EVA operations and assessed against the costs (to the vehicle and payload) of the manpower, systems, and equipment required by competitive techniques.

6.3.5 Translation System to Worksite

The translation system/equipment required to gain access to the exterior worksite, either from the EVA crewman or the manipulator payload servicing aspect, will be a significant impact to the spacecraft and payloads. A manipulator system will require a number of subsystems which will interface with various equipment and structures of the vehicle and payloads. The major manipulator subsystems required for crewman/cargo handling include the following:

- Operator/conductor station
- Presentation subsystem (e.g., T.V., status feedback)
- Man-rated manipulator structure (e.g., arms, joints)
- Manipulator end effectors (i.e., grappler)
- Controller subsystem (e.g., operating devices, equipment, control units, input command resolver)
- Crewman work platform (i.e., workstation attached to manipulator)

The total manipulator system will require a combination of structural, hydraulic, electrical, pneumatic, and visual interfaces within the vehicle and on the payload. These interfaces are too numerous and premature for discussion in this report.

As a minimum, the EVA crewman will require a manual translation system to the worksites. This system may consist of a combination of handholds and handrails for access to worksites within the payload bay or Shuttle attached payloads. Manual-assisted and powered devices may be required where package/module transfer tasks are required. These manual-assisted transfer/translation devices may range from manually actuated "clothesline" systems to electrically powered transfer booms to captive trolley systems. These EVA crewman translation/transportation systems will also require a combination of structural, electrical, and visual interfaces with the vehicle and payloads.

Translation systems for servicing remote free-flying satellites that cannot be docked to the parent vehicle will require a free-flying maneuvering device that will transport both the crewman and necessary servicing hardware. Several candidate maneuvering systems are available and are being tested on the Skylab programs for application to future space programs. Candidate crewman translation systems are further discussed in Subsection 7.6 of this report.

6.3.6 Crewman Simulation and Training

In the development of systems and techniques for efficient EVA servicing of future vehicles and payloads, simulation provides the means to identify, study, and resolve problems that evolve during each system and technique development phase. Simulation and training are required to permit the selection of the most efficient systems, to enhance crew safety, and to increase the probability of mission success. Once the optimum combination of systems and techniques has been developed, system verification programs should be conducted using high fidelity mockups and realistic simulated environments. Crewman training can then be initiated in these same environments using prototypes of the flight hardware, modified only to accommodate the simulation facilities.

The simulation and training facilities used for development and verification of orbital EVA systems and techniques are of two classes: (1) gravity-related and (2) atmosphere-related. The gravity-related facilities include the following:

- One-gravity (1-g)
- Multiple degree of freedom (MDF)
- Water immersion - Neutral buoyancy (NB)
- Parabolic flight (KC-135 aircraft)

The atmosphere-related or environment-related facilites consist primarily of various thermal/vacuum chambers. Thermal/vacuum testing is a fundamental phase of space suit, life support system, and airlock systems development, evaluation and verification in association with extravehicular activities. In addition to equipment testing, thermal/vacuum chambers provide familiarization for flight crews in a simulated space environment--with the exception of a weightless condition. The thermal/vacuum simulation and training exercises allow the crewmen to operate the EVA systems under "space" conditions and provide an increased confidence in the equipment and procedures/techniques to be used during vehicle and payload servicing operations.

Depending on the critical nature of the hardware item or technique with respect to crew safety or mission success, each area/element associated with EVA is subjected to most of the above simulation facilities during its development cycle. Simulation and crew training is a mandatory requirement for most operations performed in the space environment, particularly outside the vehicle cabin. The degree of simulation and training required is determined from the critical nature of each system or operation. Simulation and training requirements measured in time increments cannot be readily adapted to charts or satisfactory algorithms developed to cover all variables. Summary information on each of the simulation and training facilities/techniques can be found in reference 6.4.

REFERENCES

6.1 Manned Spacecraft Center: Summary of Gemini EVA, R. M. Machell (ed.), NASA SP-149, Houston, Tex., 1967.

6.2 "Worden Takes First Deep Space Walk", Aviation Week and Space Technology, August 9, 1971.

6.3 Manned Spacecraft Center: Gemini Summary Conference, NASA SP-138, Houston, Tex., February 1-2, 1967.

6.4 Brown, N. E., T. R. Dashner, and B. C. Hayes, Extravehicular Activities Guidelines and Design Criteria, NASA-CR-2160, January 1973.

6.5 Marshall Space Flight Center: Human Engineering Design Criteria Standard, MSFC-STD-267A, Huntsville, Alabama, September 23, 1966.

6.6 Vought Systems Division (LTV), Study of Space Shuttle EVA/IVA Support Requirements, Final Briefing to NASA-JSC, February 1973.

6.7 Hamilton Standard Division, Space Shuttle EVA/IVA Support Equipment Requirements Study, Final Briefing to NASA-JSC, March 1973.

SECTION 7.0 EVA SYSTEMS AND EQUIPMENT

7.1 INTRODUCTION

The previous sections of this report were concerned primarily in presenting the reader with an overview of the broad aspects and considerations of using man to perform on-orbit tasks outside the spacecraft cabin. A general overall knowledge of these considerations is required by the planners and designers of experiments, payloads, and primary vehicle subsystems in order to initially assess the feasibility of designing their equipment around EVA servicing. The performance capabilities of the crewmen in the weightless environment were also presented in previous sections of the report. Knowledge of man's capabilities in the extravehicular space environment is mandatory for planners and designers in their development of EVA serviceable payloads.

The next essential step in providing information to the potential users of EVA on the Space Shuttle and future programs is to identify and describe the equipment required aboard the prime vehicle to support the extravehicular operations. The characteristics of the required EVA support equipment in terms of operational capabilities, quantities, weights, dimensions, volumes, and equipment interfaces are among the primary factors in the selection and comparison of candidate extravehicular servicing techniques. The development status of new and advanced EVA systems and support equipment should also be readily available to the users of EVA.

The following subsections discuss the major EVA supporting hardware with respect to their physical, operational or performance characteristics. These general characteristics are presented in a narrative format supported by tables, charts, and figures, as required. Detailed information/characteristics concerning the operation of subsystems or components are not contained in this report. Such level of detail will be left to documentation specifically concerned with the design of the specific EVA equipment subsystems. The following EVA support equipment catagories will be discussed:

- Airlocks
- Pressure Suits
- Life Support Systems
- Worksites and Workstations
- Lighting
- Crew and Cargo Transfer
- Communications and Telemetry

The information presented on the EVA systems is not consistently formatted but presented in a manner considered most beneficial and readily usable by the Shuttle user population.

7.2 AIRLOCK

7.2.1 Introduction

The purpose of this section of the study is to identify and summarize available data/information concerning the space vehicle airlock and its impact on EVA payload and vehicle servicing. The data includes the configuration of the airlock, associated support subsystems, IVA/EVA interfaces, and unique considerations that must be acknowledged during the initial planning stages for a manned spaceflight. The MSC Space Shuttle Baseline Accommodations for Payloads document and the Space Shuttle Program Request for Proposal (No. 9-BC421-67-2-40P) describe the baseline configuration of the Shuttle system consistent with the current program requirements of the NASA Space Shuttle office. The design guidelines specified in these documents require the Shuttle Orbiter to provide an airlock(s) permitting EVA access to the payload bay, shirtsleeve access to pressurized payloads, and EVA/IVA access to other manned or unmanned orbital elements or another orbiter vehicle. The airlock(s) permitting EVA access to the Shuttle payload bay and to "free space", for either planned or contingency extravehicular functions, are of primary interest concerning the airlock integration into and impact upon the Shuttle Orbiter and payloads.

Space station EVA airlock requirements, as in the case of the Space Shuttle, have not been clearly defined at the present. Documentation developed by

NASA/JSC has, however, identified preliminary requirements for EVA airlocks on space stations to serve as guidelines for use in the design of environmental control/life support systems and crew/cargo transfer interfaces with the space station airlocks. Equipment configurations and specifications for future space vehicle airlocks will be developed as a result of the present and proposed Space Shuttle studies. Since the Shuttle program will be the forerunner in the development of EVA airlocks for future missions, particular emphasis in this study is directed to the Shuttle Orbiter airlock design requirements.

7.2.2 Airlock - General

An EVA airlock is a special purpose intermediate man-rated chamber, pressurizable compartment, individual module, or an appropriate combination thereof, designed to provide pressure suited access between a pressurized space vehicle and an unpressurized area or free space. The airlock contains the necessary systems and provisions required to support the extravehicular operations, including safety equipment.

Pressure suited activities within the confines of an unpressurized vehicle structure are classified as IVA and are supported by the EVA airlock. EVA is applied to activities conducted outside the space vehicle pressure hull or where access to free space is not prohibited (ref. 7.1).

The sketches shown in Figure 7-1 represent the most current conceptual design for a cylindrically-shaped airlock and its general location within the internal configuration of the Shuttle Orbiter. The two hatches, one oriented to the payload bay and the other to the crew compartment, are indicated in the figure. The control panel and two fully suited crewmen are also noted.

7.2.3 Shuttle Airlock Guidelines

For the purpose of this study, the guidelines and constraints established by the NASA Shuttle program documents are used as a reference base. The general guidelines developed early in the Shuttle program planning phase are listed below:

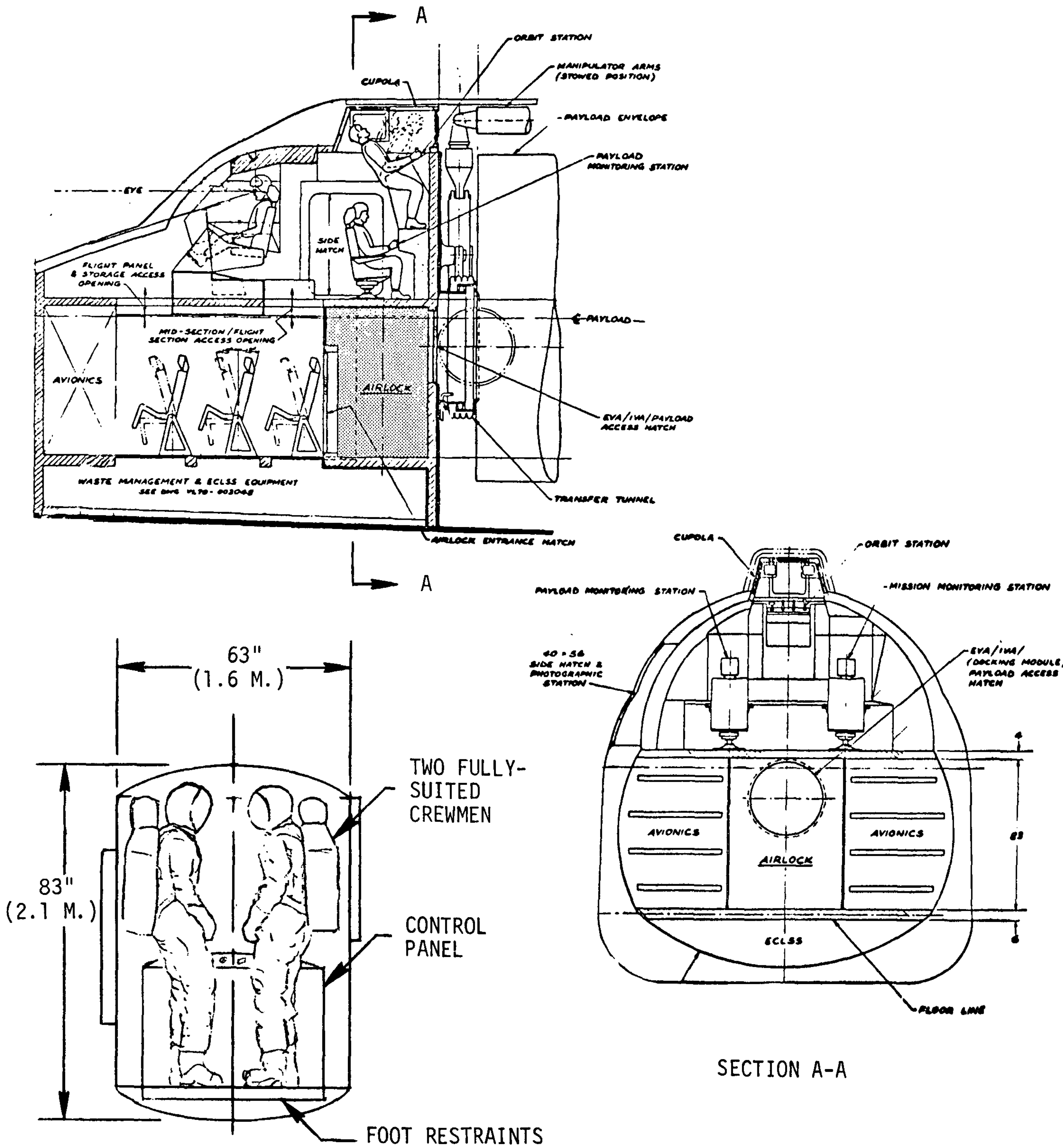


FIGURE 7-1: SPACE SHUTTLE EVA AIRLOCK

- The airlock must be sized to accommodate two-man EVA operations without depressurizing the Orbiter crew compartment/cabin.
- EVA capability must exist even though a docking module is attached to the Shuttle docking port.
- The airlock must provide EVA/IVA access to the payload bay with the payload doors closed, as well as external access to the Orbiter.
- The majority of the pre- and post-EV/IV activities will be performed in the airlock.
- The quantity of EVA expendables, stowage requirements, recharge and drying provisions will be dependent upon the scheduled number of dual EVAs per mission.
- The airlock must provide sufficient room to exchange positions with suited companion.
- The airlock will not be configured for use as a refuge in the event of an Orbiter cabin failure.
- The airlock volume will be sized to allow two EVA crewmen with full gear to transfer from or to the vehicle cabin with a TBD size package.
- The airlock pressurization/depressurization system will be controllable from either the airlock or the cabin.
- Emergency repressurization capability will be provided for rapid return to a safe pressure in the event of an EVA support system malfunction or as a backup to the primary repressurization system.
- The airlock volume will be ventilated at all times (except during EVA) by the vehicle atmospheric revitalization subsystem.

The airlock guidelines and configuration are based on the Space Shuttle vehicle as defined in the North American Rockwell technical proposal SD-72-SH-58-3, Volume 3, with modifications as amended by contract NAS9-14000 and ATP (Authority to Proceed) ground rules. The guidelines cited above were taken from references 7.2 through 7.4.

7.2.4 Major Airlock Subsystems

The EVA airlock system is supported by a number of subsystems and equipment that must be considered during airlock design and integration into the space vehicle. The major subsystems are listed in Table 7-1 and include those subsystems and equipment required to support both umbilical and portable life support system (PLSS) EVA/IVA operations. Table 7-1 also indicates the airlock subsystem interfaces to be considered regarding primary spacecraft systems and structures. Additional information and preliminary data concerning spacecraft/ airlock subsystems are contained in the following paragraphs.

7.2.5 Airlock Design

The general requirement for an airlock having been defined, the primary emphasis is on designing an airlock that can be integrated into the spacecraft with an acceptable level of impact to the vehicle, payload, and mission.

The data contained herein is an expansion of existing design information and the identification of additional areas that will require consideration during the development of the airlock. Since the Shuttle EVA airlock configuration, equipment, and specification are not firm, this information should be used for guideline purposes only.

7.2.5.1 Airlock Subsystems Overview

The major subsystems that are applicable to the EVA airlock and which the designers must acknowledge, as a minimum, are discussed in the following paragraphs and presented in Table 7-2. For the purpose of this study, both the

TABLE 7-1: EVA AIRLOCK SUBSYSTEMS AND INTERFACE CONSIDERATIONS

AIRLOCK SUBSYSTEMS \ VEHICLE IMPACT	MECHANICAL			STRUCTURAL		ELECTRICAL			PNEUMATIC					HYDRAULIC						OTHERS			
	WEIGHT	VOLUME	CONFIGURATION	LOCATION	PHYSICAL INTERFACE	WATTS/HR.	VOLT/AMP/φ	TYPE (AC-DC)	GAS TYPE	QUANTITY	PRESSURE	FLOW RATE	TEMPERATURE	FLUID TYPE	QUANTITY	PRESSURE	FLOW RATE	TEMPERATURE	PURITY	CONTROLS	DISPLAYS	DATA PROCESSING	PROCEDURES
PRESSURE HULL	●	●	●	●	●																		●
HATCHES	●	●	●	●	●																●		
ENVIRONMENTAL	●	●		●	●				●	●	●	●	●								●		
THERMAL	●	●		●	●																●		
SAFETY/HAZARD	●	●	●			●	●	●	●		●		●								●		
COMMUNICATIONS	●	●		●	●	●	●	●												●	●	●	
STABILIZATION AIDS	●																						
MOBILITY AIDS	●	●		●	●																		
ILLUMINATION	●	●				●	●	●															
UMBILICAL STOWAGE	●	●	●		●																		
EQUIPMENT STOWAGE	●	●	●		●																		
DISPLAYS-AIRLOCK STATUS	●	●		●	●	●	●	●			●		●								●		
CONTROLS-AIRLOCK	●	●	●																	●			
CONTROLS-SUIT SYSTEMS																							
• PGA USING LSU	●					●	●	●	●	●	●	●	●	●	●	●	●	●	●				
• PGA VENTING	●					●	●	●	●	●	●	●	●										
• LSU DRYING	●					●	●	●	●	●	●	●	●										

TABLE 7-2: AIRLOCK SUPPORT SUBSYSTEMS AND EQUIPMENT

AIRLOCK SUBSYSTEMS	DESIGN CHARACTERISTICS	INTERFACES/ SUPPORTING FUNCTIONS	COMMENTS	REFERENCES
PRESSURE HULL	• Dimensions 63"d x 83"h • Cylindrical shape • Non-flammable material	• Accommodate two 95th percentile crewmen in pre and post EV/IV activities • Stowage facilities for EVA equipment • Drying facilities (PGAs) • Cargo handling unit • Suit ventilation • PGA umbilical cooling • PLSS water recharge • PLSS oxygen recharge • PLSS battery recharge • PLSS condensed water collection • PLSS RF hardline for comm verification • Post EVA PGA waste management	• Devices and facilities recessed flush with internal airlock surface must not affect structural integrity of hull. • The magnitude of stowage and support facilities required for EVA may necessitate relocation of some activities into the cabin compartment.	• Manned Spacecraft Center: Preliminary Design Requirements for Shuttle EVA/IVA Orbiter Support, MSC-01497, September 1971 • MSC-06900A, Space Shuttle Baseline Accommodations for Payloads, Nov 1972 • Space Shuttle EVA/IVA Support Equipment Requirements Study, Mar 1973, Hamilton Standard • MSC-04645, CSD SH-003, Preliminary Shuttle Orbiter Interface and System Design Requirements for EVA/IVA Support, Feb 1972.
HATCHES	• Two hatches - rectangular 40"x56" to cabin and circular 40"d to payload • Handles for hatch operation provided on both sides of hatch • Hatches to cabin and to payload swing outward from airlock • Viewports located on hatches for viewing airlock interior • Pressure equialization valve operable from botn sides of each hatch	• Entrance and exit by 95th percentile crewman • Operation by suited crewman without special tools	• In event of an airlock contingency, either hatch open time should be maximum of 20 sec. • During EVA, hatch to the payload will remain open. • Leakage rate from cabin through cabin hatch should approach zero. • Emergency procedures are defined in the event a failure in airlock-to-cabin hatch results in rapid depressurization of the cabin compartment.	• MSC-04645, CSD-SH-003, February 1972, Preliminary Shuttle Orbiter Interface and System Design Requirements for EVA/IVA Support • MSC-06900A, Space Shuttle Baseline Accommodations for Payloads, Nov 1972 • Space Shuttle EVA/IVA Support Equipment Requirements Study, Mar 1973, Hamilton Standard

TABLE 7-2: AIRLOCK SUPPORT SUBSYSTEMS AND EQUIPMENT (CONT'D.)

AIRLOCK SUBSYSTEMS	DESIGN CHARACTERISTICS	INTERFACES/ SUPPORTING FUNCTIONS	COMMENTS	REFERENCES
HATCHES (CONT'D.)	• Hatch to payload will contain adequate environmental and meteoroid protection.		• Considerations be given to interlocking the two hatches so one cannot be opened until other is locked	
PRESSURIZATION	• Pressurization/depressurization rates - Nominal - 0.02 to 0.1 psi/sec. - Maximum - 1.0 psi/sec. • A separate emergency repressurization capability	• This system is controlled from either the airlock or cabin.	• Revitalization of airlock atmosphere will depend upon mixing with cabin atmosphere whenever interior airlock hatch is open	• MSC-06900A, Space Shuttle Baseline Accommodations for Payloads, Nov 1972 • Space Shuttle EVA/IVA Support Equipment Requirement Study, Mar 1973, Hamilton Standard
SAFETY/HAZARD	• Guard railings placed around the circumference of the control panel and/or individual guards to prevent accidental actuation of switches • Hatch handle design should prohibit inadvertent actuation by crewmen. • Airlock interior should be free of sharp, pointed or easily damaged surfaces.	• Safety precautions and procedures will be adhered to during EVA preparation. • All loose equipment will be restrained or stowed.	• In the event of airlock contamination, survival may depend on rapid evacuation to cabin and isolation of airlock. • Fire fighting equipment should be stowed in the airlock or near vicinity.	• MSC-06900A, Space Shuttle Baseline Accommodations for Payloads, Nov 1972 • MSC-04645, CSD-SH-003, Preliminary Shuttle Orbiter Interface and System Design Requirement for EVA/IVA Support, Feb 1972
COMMUNICATIONS TELEMETRY	• Provide RF hardline communications line and link up capability from PLSS to airlock controls and displays panel • Voice communications capability provided between airlock and cabin	• Suited crewman to verify PLSS primary (duplex) and backup (simplex) systems prior to EVA • Two-way voice communications will be maintained with the crewmen in airlock and those in cabin.	• Communications maintained via RF or hardline during all pre and post EV/IV activities in the airlock • Critical suit parameters should be continuously monitored during suited mode in the airlock.	• MSC-06900A, Space Shuttle Baseline Accommodations for Payload, Nov 1972 • Space Shuttle EVA/IVA Support Equipment Requirements Study, Hamilton Standard, Mar 1973

TABLE 7-2: AIRLOCK SUPPORT SUBSYSTEMS AND EQUIPMENT (CONT'D.)

AIRLOCK SUBSYSTEMS	DESIGN CHARACTERISTICS	INTERFACES/ SUPPORTING FUNCTIONS	COMMENTS	REFERENCES
COMMUNCATIONS TELEMETRY (CONT'D.)	• For crewman on an umbilical, a series of parameters will be monitored during EVA and transmitted via hardline through airlock C&D panel.			• Study of Space Shuttle EVA/IVA Support Requirements, Feb 1973, Vought Systems Division
STABILIZATION AND MOBILITY AIDS	• Restraint equipment will be included as follows: - Foot restraints (2 sets) - Waist tether attach points at convenient locations internally - Handholds or rails provided internally in the vicinity of hatches, C&D panel, and support facilities - Handholds or rails provided externally around hatches	• Crewmen require restraint equipment for dwell time, airlock operation and aids for general movement within the airlock. • During EVA the crewman will be tethered to an attach point in the vicinity of the external hatch.	• Foot restraints could be movable to allow crewman 360° rotational movement without loss of restraint.	• MSC-06900A, Space Shuttle Baseline Accommodations for Payloads, Nov 1972 • MSC-07387, Crew Station Specification, Oct 1972 • Space Shuttle EVA/IVA Support Equipment Requirements Study, Mar 1973, Hamilton Standard • Study of Space Shuttle EVA/IVA Support Requirements, Feb 1973, Vought Systems Division
ILLUMINATION	• Lighting devices flush mounted with impact protection on the interior airlock wall providing 5 ft.-L. (min.) illumination • Integral lighting will be provided for the C&D panel at 2 ft.-L. max. with dimming capability to zero. • Portable lights for EVA (2) may be provided and stowed in the airlock.	• Crewmen will be provided with capability to control airlock general lighting externally in the vicinity of the hatches, at the C&D airlock and cabin panels.	• General illumination must be sufficient to eliminate requirements for utility lighting. • Provisions for emergency lighting should be included in the design.	• SC-L-0002, November 1971, General Specification Lighting, Manned Spacecraft and Related Flight Crew Equipment Functional Design • MSC-06900A, Space Shuttle Baseline Accommodations for Payloads, Nov 1972 • MSC-07387, Crew Station Specification, Oct 1972

TABLE 7-2: AIRLOCK SUPPORT SUBSYSTEMS AND EQUIPMENT (CONT'D.)

AIRLOCK SUBSYSTEMS	DESIGN CHARACTERISTICS	INTERFACES/ SUPPORTING FUNCTIONS	COMMENTS	REFERENCES
STOWAGE	• Stowage facilities must be sufficient to accommodate at minimum the following items: - 2 PGAs for 95th percentile crewmen - 2 Portable LSS or 2 umbilicals (60 ft.-183 m.) - 2 EV/IV support equipment - 2 Tool kits including tools for emergency removal of hatch - 2 Waist restraint tethers - 2 RF hardline - 2 Portable lights - 2 PGA maintenance kits - 2 Suit ventilators - 5 Trash bags	• Stowage needs depend on crewman pre and post EV/IV activities conducted in the airlock. Accordingly the list of equipment will change with variations in EVA requirements or functions	• With the limitation on airlock space evaluation and priority systems may be instituted to determine which equipment must be stowed in airlock and those items that can be transferred to cabin. • Trade-offs may also be required for temporary stowage accommodations inside airlock.	• NASA CR-2160, Extravehicular Activities Guidelines and Design Criteria, Jan 1973, URS/Matrix • Space Shuttle EVA/IVA Support Equipment Requirements Study, Mar 1973, Hamilton Standard • Study of Space Shuttle EVA/IVA Support Requirements, Feb 1973, Vought Systems Division
CONTROLS AND DISPLAYS	CONTROLS - • Decompress/Recompress rates • Overpressurization • Hatch lock/unlock DISPLAYS • Airlock pressure • Hatch lock/unlock indicators • Hatch ΔP indicators	• The EVA crewman should have capability to initiate and control airlock depressurization and repressurization. • A separate EVA/IVA control panel may be provided for each crewman.	• Control operation should not require special tools. • Controls and displays should be kept minimum (i.e., only those required for safety monitoring and EV/IV operation success) • Panels should not impede the movement of suited crewman.	• MSC-06900A, Space Shuttle Baseline Accommodations for Payloads, Nov 1972 • MSC-07387, Crew Station Specification, Oct 1972 • Study of Space Shuttle EVA/IVA Support Requirements, Feb 1973 Vought Systems Div
SUIT SYSTEMS: PGA/UMBILICAL	• Umbilical LSS will connect to life support connector on airlock control panel. (EVA duration - 4 hrs.)	• Life support essential elements will be provided by the space vehicle system.	• The crewman encounters umbilical management problems at umbilical lengths greater than 60 ft.	• NASA CR-2160, Extravehicular Activities Guidelines and Design Criteria, Jan 1973, URS/Matrix

TABLE 7-2: AIRLOCK SUPPORT SUBSYSTEMS AND EQUIPMENT (CONT'D.)

AIRLOCK SUBSYSTEMS	DESIGN CHARACTERISTICS	INTERFACES/ SUPPORTING FUNCTIONS	COMMENTS	REFERENCES
SUIT SYSTEMS: PGA/UMBILICAL (CONT'D.)	• Stowage facilities will be provided for 2 umbilicals 60' in length.	• Critical parameters will be monitored at cabin C&D panel. • Crewmen will be in continuous voice communications.		• Study of Space Shuttle EVA/IVA Support Requirements, Vought Systems Div, Feb 1973
SUIT SYSTEMS: PGA/PLSS	• Servicing equipment for PLSS may be located inside airlock: - O_2 recharge - LiOH replacement - Water recharge - Battery recharge - Condensed water collection	• PLSS (2) stowed and recharged in the airlock	• PLSS provides greater flexibility and freedom of movement during EVA over umbilical. However PLSS must be recharged after each EVA or prior to next EVA. • An emergency or secondary life support system must provide crewman with a backup system for safe return in event of a PLSS failure. An integrated PLSS/ELSS backpack has been proposed.	• Space Shuttle EVA/IVA Support Equipment Requirements Study, Hamilton/Standard, Mar 1973 • Study of Space Shuttle EVA/IVA Support Requirements, Feb 1973, Vought System Div
PGA VENTILATOR/ DRYER	• The airlock may provide a suit ventilator integral with the airlock. • Portable unit size may be approximately 1000 in.^{3} (16,390 m^3) and weigh 7 lbs. (3.2 kg.).	• Primary function would be to supply crewman cooling during EVA preparation • Secondary uses would be as suit dryer or vacuum cleaner	• The portable unit may further impact the airlock stowage requirements previously identified. • Weight impact for a separate unit also requires evaluation. • For an integral unit, two short umbilical lines would be provided and stowed in the airlock.	• Space Shuttle EVA/IVA Support Equipment Requirements Study, Hamilton Standard, Mar 1973 • Study of Space Shuttle EVA/IVA Support Requirements, Feb 1973, Vought System Div

umbilical and portable life support subsystems have been included:

- Pressure Hull - The size of the airlock becomes one of compromise between satisfying its internal accommodation requirements (i.e., number of crewmen, stowage, controls, support facilities) and one of minimizing the impact on the volume allocation for other vehicle systems and the cabin compartments. The capacity of the airlock pumpdown system in proportion to airlock size becomes a limiting factor.

- Hatches - The airlock contains two hatches to allow the transfer of a crewman from a pressurized environment to the space environment. The size of the hatches must be sufficient to accommodate the passage of a 95th percentile suited crewman and hardware/modules for servicing of payloads and vehicle systems. The airlock hatches should also contain observation windows from which to observe the maximum interior volume.

- Pressurization - The airlock does not have a separate environmental or thermal control system but is dependent on the vehicle system for the revitalization of the airlock atmosphere via the open interior cabin hatch. A pressurization/depressurization system provides control from either the airlock or the cabin and an emergency repressurization capability for rapid return of pressure in the event of an EVA system malfunction.

- Safety & Hazard - The internal configuration of the airlock should be designed to meet the safety requirements established for the space vehicle and airlock, in particular. The supporting subsystems and loose equipment transferred into or through the airlock should be free from dangerous, sharp, or easily-damaged surfaces. Switch guards, impact devices, or some types of protective hardware should be installed, as required, to prevent accidental actuation or damage by the crewman. All materials used in the construction of the airlock or in the equipment transferred through the airlock should meet the flammability and outgassing requirements for flight.

- Communications/Telemetry - The crewmen in the cabin rely on voice communications for maintaining contact with the crewmen in the airlock. As part of the pre-EVA checkout procedure each crewman connects an RF hardline from the PLSS to the monitoring station for verifying the operational status of the backpack communications and telemetry circuits. If the crewman utilizes an umbilical for EVA, hardlines for voice, bio-med, and suit parameters should be included in the communications system.

- Stabilization & Mobility Aids - Foot restraints should be provided for each crewman in the airlock. Handholds, guide rails, and tether attach points should be located in the airlock, as required, to assist the crewman in the performance of tasks associated with EV/IV activities. These aids can also be used as temporary equipment restraints.

- Illumination - The general illumination guidelines for the airlock lighting are contained in Subsection 7.8 entitled "EVA Lighting". It should be noted that some of the airlock lighting devices should be connected in parallel to a separate circuit for emergency lighting in the event of a main power failure.

- Stowage - The task functions to be performed in the airlock and planned EVA servicing determine for the most part the loose equipment to be accommodated or stowed in the airlock. Since the airlock volume and stowage facilities are rather limited, it may be necessary to transfer some of these functions and equipment to the cabin compartment. If loose hardware is stowed in the airlock at launch, the stowage facilities (i.e., containers, cushions, straps, retention points) must be designed to withstand launch loading.

- Controls & Displays - The airlock Controls and Display Panel should be configured for monitoring and managing critical airlock functions in support of EVA servicing. The design and location of the panel should be arranged for a minimum of interference with the movement of a suited crewman and remain convenient for crewman operation.

- Suit Systems - As indicated previously, a reference is made to both a vehicle-dependent umbilical and a PLSS for EVA. Until the selection of the method is made for the Shuttle Orbiter, both systems should be considered and documented. In either case after each EVA, each PGA requires drying before it can be used for the following EVA. A ventilating unit or ventilating capability within the airlock is required for the dual purpose of supplying crewman cooling during EVA preparation as well as drying the PGA. To complete the drying process, several desiccant bags should be stowed in the vehicle and used to remove the last traces of moisture in the suit.

7.2.6 Future Considerations

Initial planning indicates that space vehicles after the Shuttle Orbiter will contain two and, perhaps, more airlocks. These will be strategically located and designed with greater flexibility to accommodate the expanding role of EVA on longer duration missions.

Technology advances will also be made in the EVA support systems and equipment to reduce the pre- and post-EV activities so that a crewman may devote more time to productive functions.

In almost all cases, the airlock designers will be limited by weight and volume; this becomes a restriction on hull size and the flexibility and capability of the supporting subsystems. However, in this type of situation the new and improved ideas, methods, and designs are created to enhance the EVA operation without jeopardizing the safety of the crewman.

7.3 PRESSURE SUITS

7.3.1 Introduction

The purpose of a pressure suit designed for space flight is to provide the crewman with a habitable environment and afford him protection from the following:

- A low ambient pressure
- Extreme thermal environment
- The lack of a breathable gas
- Micrometeroid impact

In addition, the pressure garment must provide the EVA crewman with sufficient mobility, dexterity, and visibility to perform required activities during planned, unscheduled, and contingency modes of mission operations.

From these fundamental considerations the designers produced a pressure suit for the Apollo Program which continued to be improved upon throughout its application on the Skylab Program. The most recent model designated the A7LB Pressure Garment Assembly (PGA) will be covered in subsequent paragraphs.

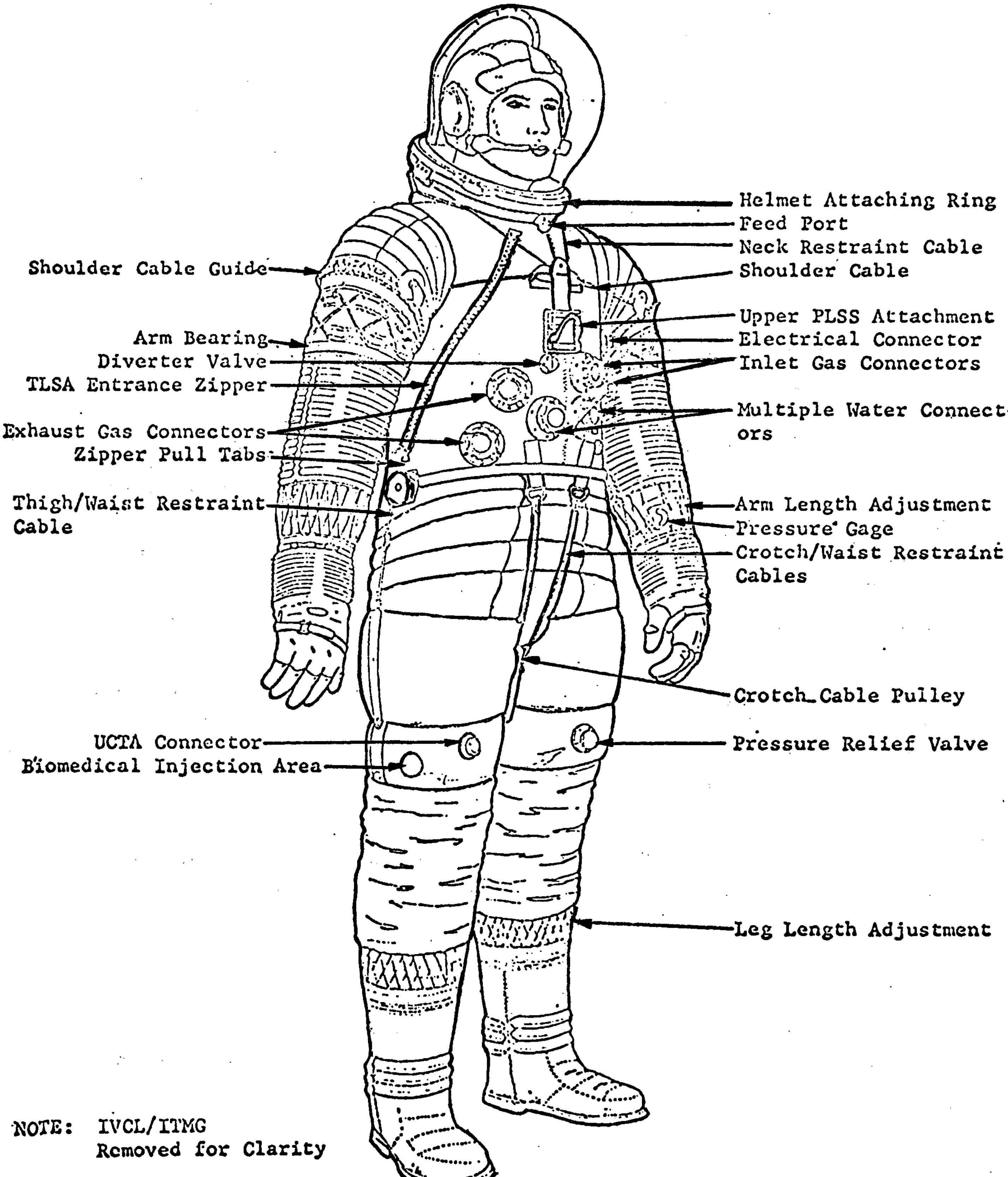
A portion of this section will also cover the rationale for progressing into another generation of pressure suits and the pertinent features of the suit that is now being developed for the Space Shuttle program.

7.3.2 A7LB Pressure Suit

The current A7LB pressure suit has been designated for the Skylab missions based in part on its proven capability in space. This suit evolved from an earlier version known as the A7L which was modified to provide greater mobility and flexibility, particularly in the areas of the waist, neck, arm, and shoulder.

The A7LB PGA (see Figure 7-2) is a pressurizable anthropomorphic structure designed to accommodate normal body movements at low torque rates. The pressurized portion of the assembly consists of a torso limb suit assembly (TLSA), detachable gloves and helmet.

Convoluted joints provide for low torque body movements and permit a near constant volume displacement during normal joint flexure. Longitudinal cables extend across each convolute and sustain its axial loads. The neck, waist, shoulder cone, and ankle convolutes are of the constricted restraint type; and



NOTE: IVCL/ITMG Removed for Clarity

FIGURE 7-2: A7LB PRESSURE GARMENT ASSEMBLY the shoulder, elbow, knee, waist, and thigh joints are single wall bellow-like structures.

The breathable gas used for respiration, pressurization, and ventilation purposes is distributed within the PGA through non-crushable ducts. Inlet and outlet connectors (two pair for EV and one pair for IV) are the interfaces between the suit and the life support system. A diverter valve is used to direct the gas flow into the helmet through the vent duct or divide the flow between the helmet and torso ducts at the discretion of the crewman. The ventilating gas flows over the body to all extremities, removes body gases, toxicants and heat, and is expelled through the PGA exhaust gas connector. Specific pressurization and ventilation data is referenced in Table 7-3.

A textured nylon fabric is bonded to the inner surface of the TLSA to protect the bladder from scuffs, abrasions, and snags. A light weight multi-laminate assembly (see Table 7-4) designed to fit over the TLSA provides thermal, micrometeoroid, and puncture protection during EVA. A separate intravehicular cover layer is provided on the IV configured torso limb suit during IVA and affords protection against excessive heat and flame impingement.

A receptacle is also provided on the PGAs for connecting the spacecraft liquid cooling system to the liquid cooling garment (LCG), which is worn under the torso limb suit. The function of the LCG is to remove metabolic heat from within the PGA.

Biomedical data, suit parameters, and communications are transmitted by way of a separate connector on the PGA that interfaces electrically with the spacecraft.

Permanent and detachable pockets for stowage of loose hardware such as tools, scissors, sunglasses, pen, penlight, sliderules, and check lists are provided as part of the PGA. The detachable pockets are usually removed prior to EVA.

TABLE 7-3: PRESSURIZATION AND VENTILATION DATA FOR THE A7LB PRESSURE SUIT

SUIT PARAMETER	VALUE
Operating pressure range	0 - 4.00 psig (0 - .3 kg/cm^2)
Structural test pressure	6 psig (.4 kg/cm^2)
Proof test pressure	8 psig (.6 kg/cm^2)
System pressure drop:	
6.0 cfm (2832 cc/sec) flow @ 3.75 psig (.3 kg/cm^2)	5.3 inches of water
12.0 cfm (5664 cc/sec) flow @ vent pressure	15.1 inches of water
12.0 cfm (5664 cc/sec) flow @ 3.75 psig (.3 kg/cm^2)	15.1 inches of water
Relief pressure:	
Increasing (open)	4.8 to 5.5 psig (.3 to .4 kg/cm^2)
Decreasing (close)	4.7 psig (.3 kg/cm^2)-- max. leakage of 2.0 scc/min.
Pressure gauge, indicating range	2.5 to 6.0 psig (.2 to .4 kg/cm^2)
Leakage rate, pre-flight	180 cc/min. @ 3.7 psia (.3 kg/cm^2) max.

TABLE 7-4: COMPARISON OF A7LB LUNAR AND ORBITAL ITMG

Typical A7LB ITMG Layup

T-162 Teflon Layer

4484A Super-Beta Layer

3 Layers Beta Marquisette

2 Layers 1/2 Mil Aluminized Kapton Film-Gridded (Kapton is crosshatched with 1/4" strips of Kapton tape to provide rip-stop capabilities)

5 Layers Perforated Aluminized (Aluminized both sides) Mylar

5 Layers Nonwoven Dacron

Neoprene Coated Rip-stop

Typical Orbital ITMG Layup

T-162 Teflon Layer

4484A Super Beta Layer

3 Layers Gridded/Krinkled *1/2 Mil Double Aluminized Kapton (Aluminized both sides)

2 Layers Sized Beta Marquisette (Kel F 800)

Neoprene Coated Nylon Rip-stop

* 1/2" strips of Kapton tape prestretched across Kapton in gridded pattern.

The helmet is a bubble-shaped pressure vessel composed of a clear lexan material bonded to a machined and anodized aluminum ring. Provisions for emergency feeding and valsalva (equalizing ear pressure) are designed into the helmet. A visor assembly which attaches to the helmet slides over the clear surface and provides ultraviolet, thermal-micrometeoroid, and solar protection for the crewman during EVA.

The EV gloves are multilayered in construction and, like the helmet, are detachable from the PGA. Each glove is designed to maintain the temperature within the glove between 60° and 130°F.

Recent modifications were made to the A7LB EV gloves in the following areas:

- Improved donning/doffing by enlarging the wrist disconnects and convolutes.
- Improved dexterity by the addition of curved fingers, thumb extensions, and custom-fitted external palm restraints.

Table 7-5 provides the performance criteria (e.g., complex movements of the fingers, hand, and wrist) that the EVA glove must provide for general servicing tasks. A separate pair of gloves with lesser insulating properties than the EVA gloves will be provided for intravehicular tasks.

Each PGA is individually sized to the assigned crewman. The suit is tailored as closely as possible to actual body contours with flexible joints provided at natural body break points to enhance mobility and reduce excessive bulk. A list of the body movements that can be exercised by an A7LB suited crewman is contained in Table 7-6. Some pictorial representations of the suited body movement limits are included in Figures 7-3 through 7-6.

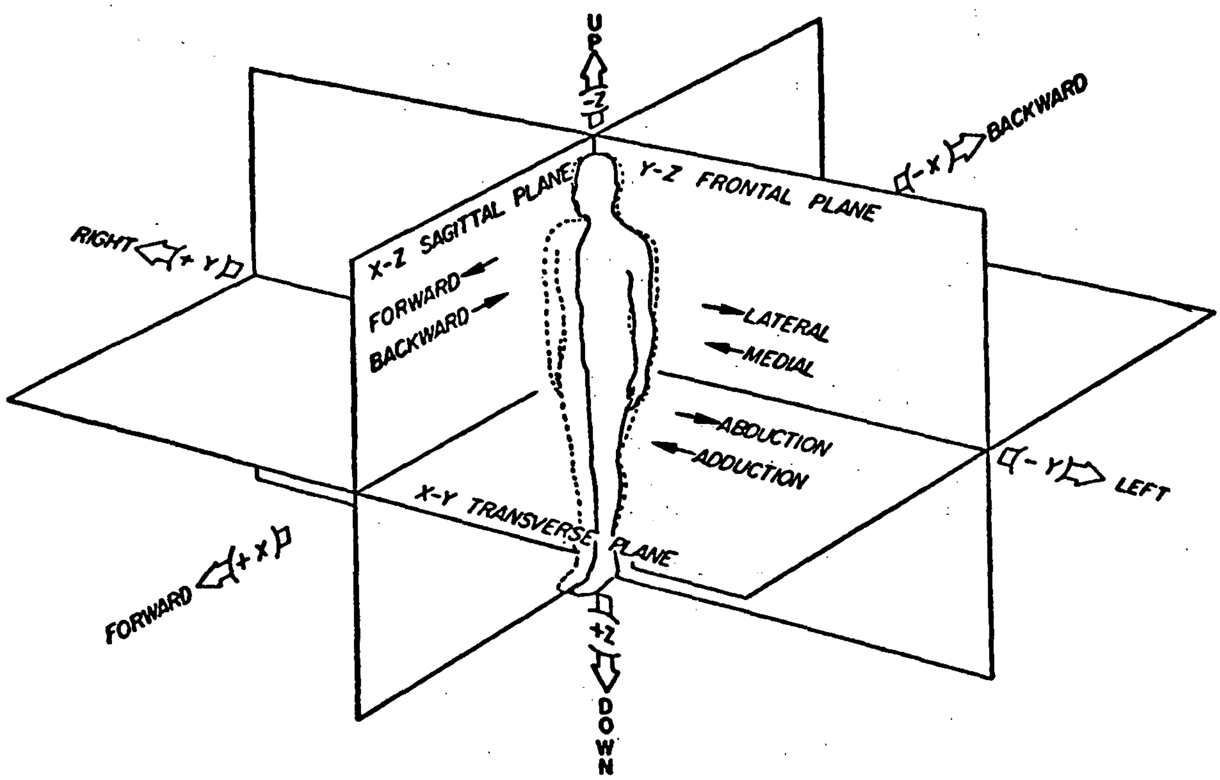
The information/data provided in this subsection was derived from references 7.5 through 7.11. Detailed A7L and A7LB pressure suit information concerning

TABLE 7-5: PERFORMANCE CRITERIA FOR THE A7LB GLOVE

OPERATIONS OR MOTIONS	REQUIRED PERFORMANCE CRITERIA
Finger: Pushbutton Ops.	Operate pushbutton within panel of pushbuttons
Finger: Pulling Ops.	Operate T-handle control Operate D-handle control Operate ring handle control
Grasp	Use a screwdriver Use pliers Use crescent wrench Use socket wrench
Wrist Movements	Move wrist side to side while opening and closing fingers Move wrist up and down while opening and closing fingers
Whole Hand Movement	Hold hand at any desired position
Thumb	Operate thumbwheel
Hand Rotation	Operate discrete position rotary switch
Palmar	Write legibly with pencil Operate .375 inch dia. rotary knob Utilize small screwdriver
Tip Prehension	Pick up small objects such as: Small screws Small rocks
Lateral Prehension	Operate 2 and 3 positions Toggle switches: Vertically Horizontally

TABLE 7-6: BODY MOVEMENTS IN A7LB SUIT AT 3.75 PSIA

WAIST	
Forward Flexion (See Figure 7-3)	120 degrees
Left Lateral (See Figure 7-4)	35 degrees
Right Lateral	35 degrees
Rotation Right	5 degrees
Rotation Left	5 degrees
NECK	
Flexion Forward	10 degrees
Flexion backward (See Figure 7-5)	30 degrees
LEG	
Step Height (See Figure 7-6)	20 inches



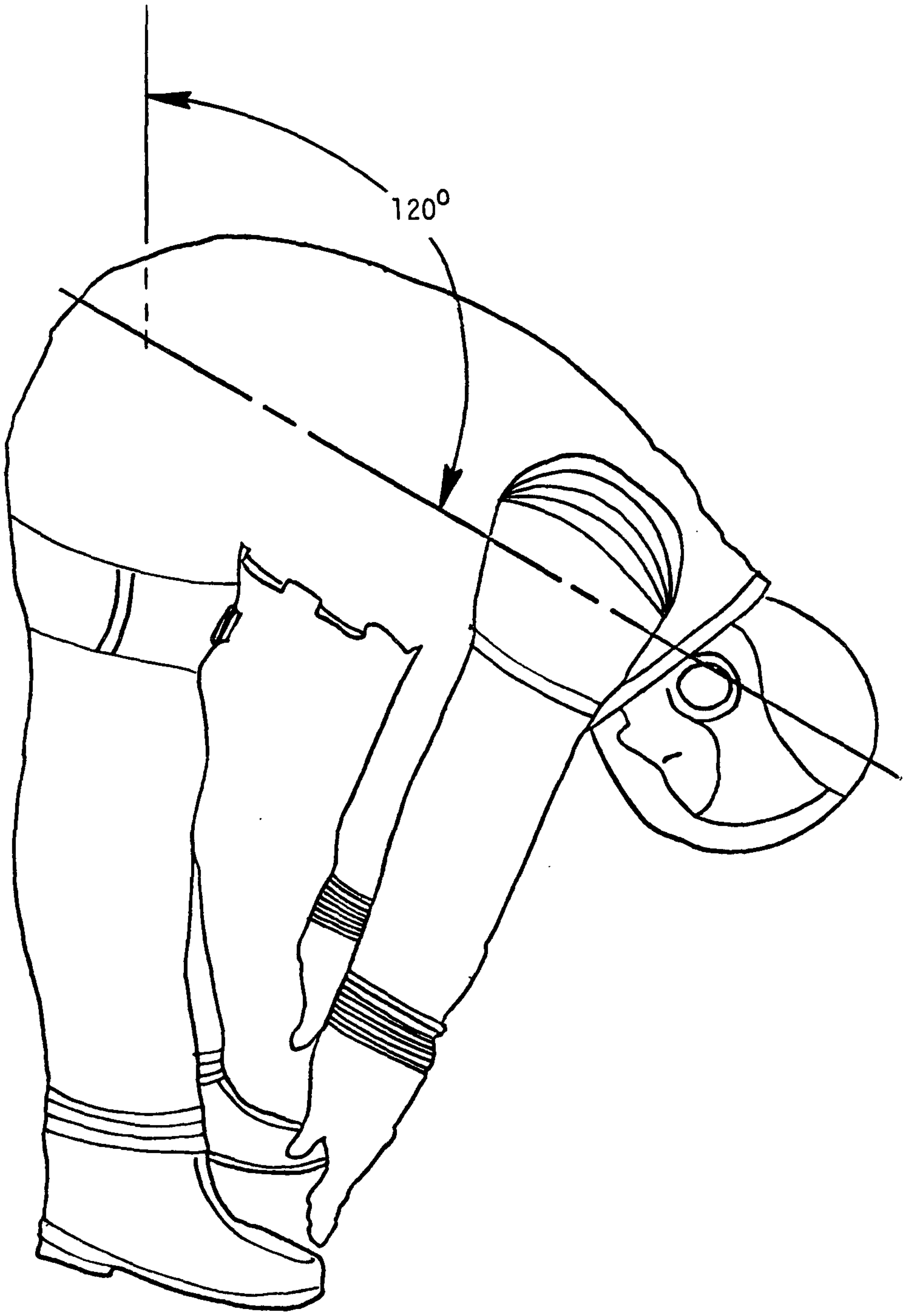


FIGURE 7-3: FORWARD FLEXION

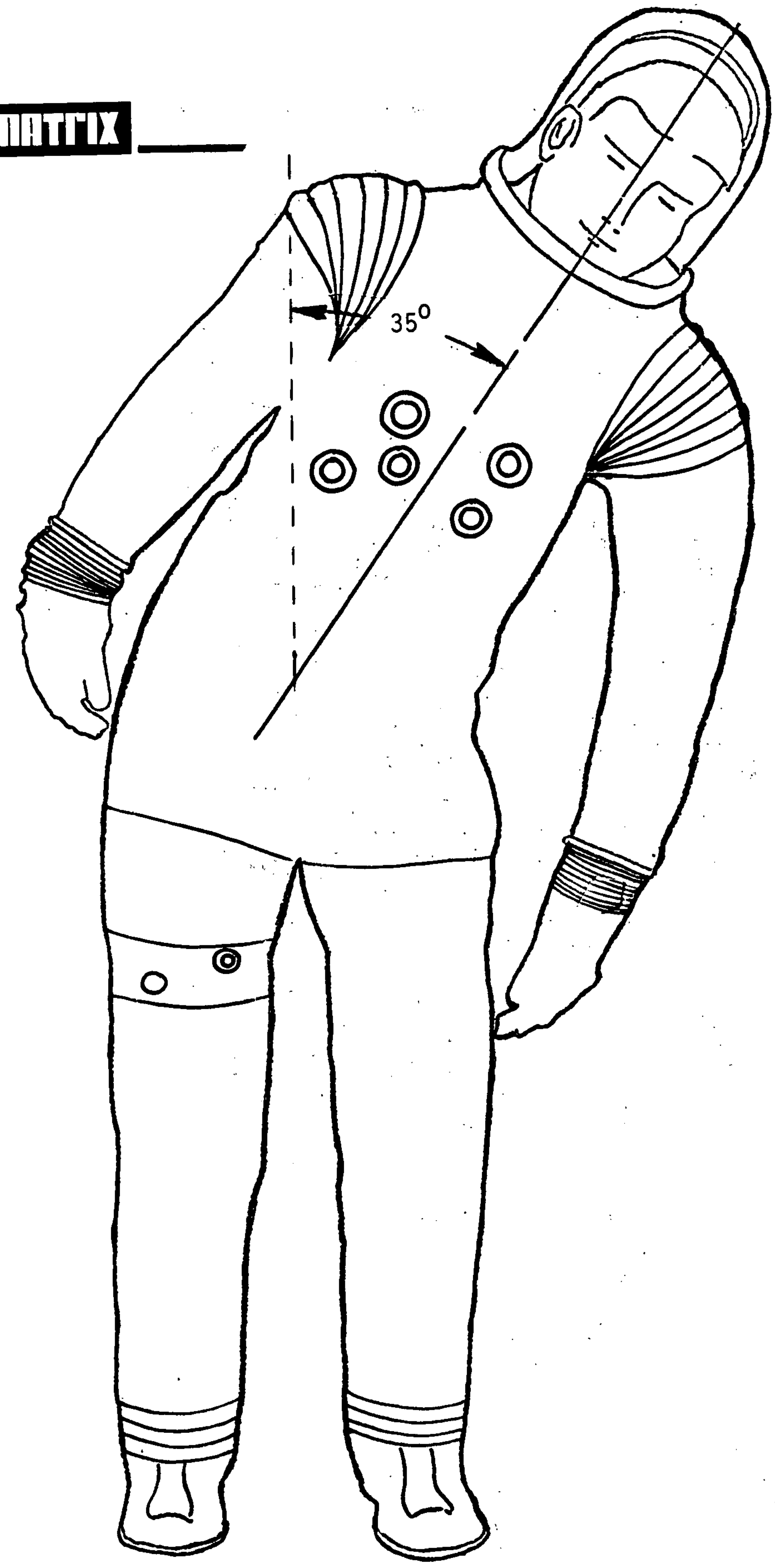


FIGURE 7-4: LEFT LATERAL

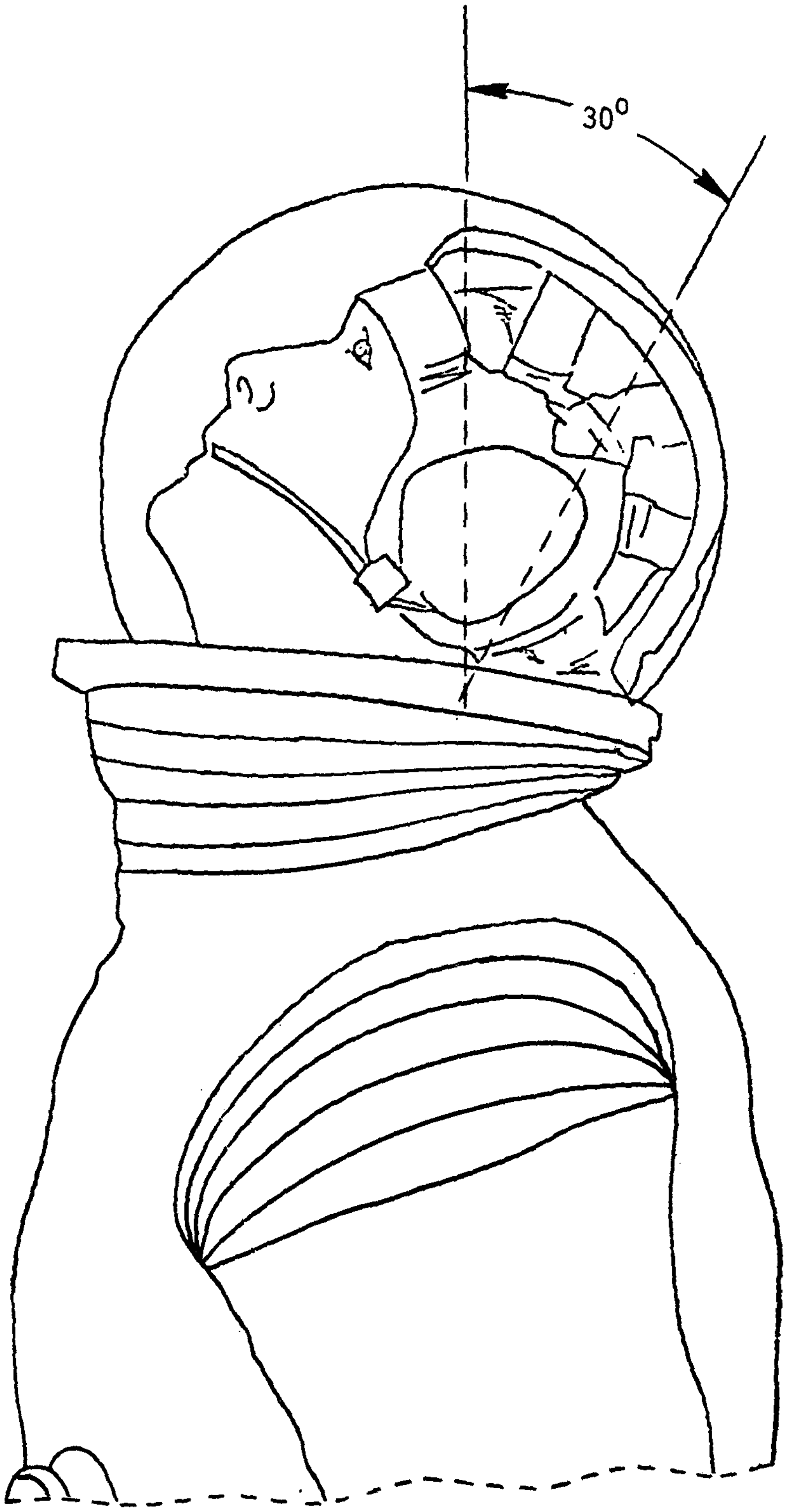


FIGURE 7-5: NECK FLEXION BACKWARD

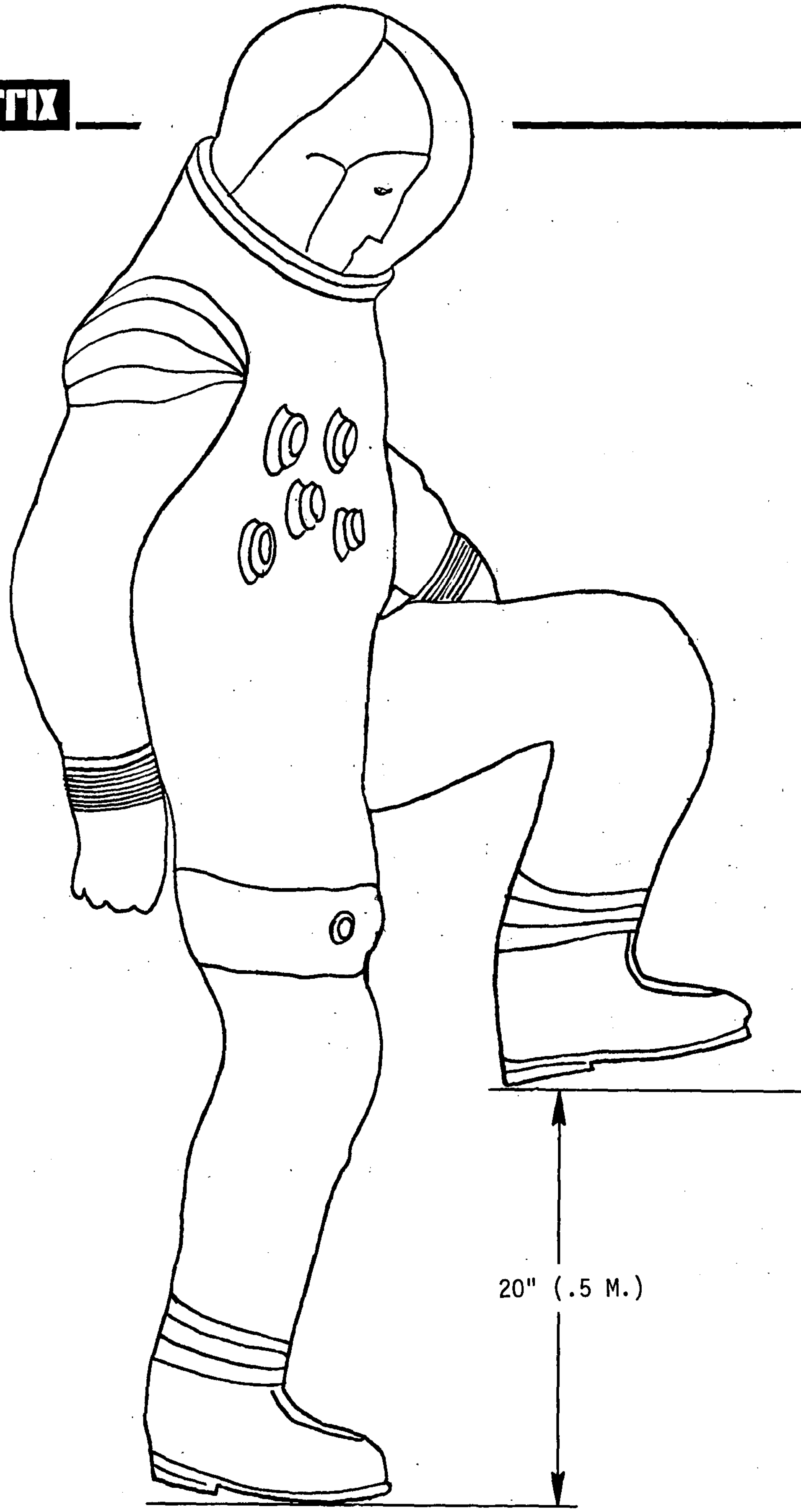


FIGURE 7-6: STEP HEIGHT

the physical, operational, and performance characteristics can be obtained from these sources, if required.

7.3.3 Space Suits and Support Hardware

The A7LB pressure suit components and supporting equipment (see Figure 7-7) that will be used during Skylab extravehicular operations are listed in Table 7-7. The suit components and equipment items are separated into the following major categories.

- Primary don/doff items
- Secondary don/doff items
- Stowage support equipment
- Maintenance, don/doff, and drying support items

The pressure suit equipment breakdown is included to provide mission planners and designers an overview of the total equipment items associated with the pressure suits. Each of the suit equipment items must be stowed aboard the spacecraft either as a unit or equipment package. Table 7-7 contains the part number, size/volume, weight and spaceflight program of each of the suit equipment items (ref. 7.12). The table also contains the number of items allocated for each of the EVA crewmen on previous programs and estimates for the Space Shuttle Program. The weight, volume, and number of suit support items per crewman are not expected to vary significantly between former suits and those being developed for the Space Shuttle. The total extravehicular mobility unit (EMU) for use on the Skylab Program is shown in Figure 7-8. Additional information including systems interfaces, displays, stowage, etc. is contained in the figure.

7.3.4 Advanced Space Suit

Space suits developed for a program can continue to be improved to satisfy varying requirements up to a point. However, advances in suit technology and materials eventually begin to surpass the design limits of

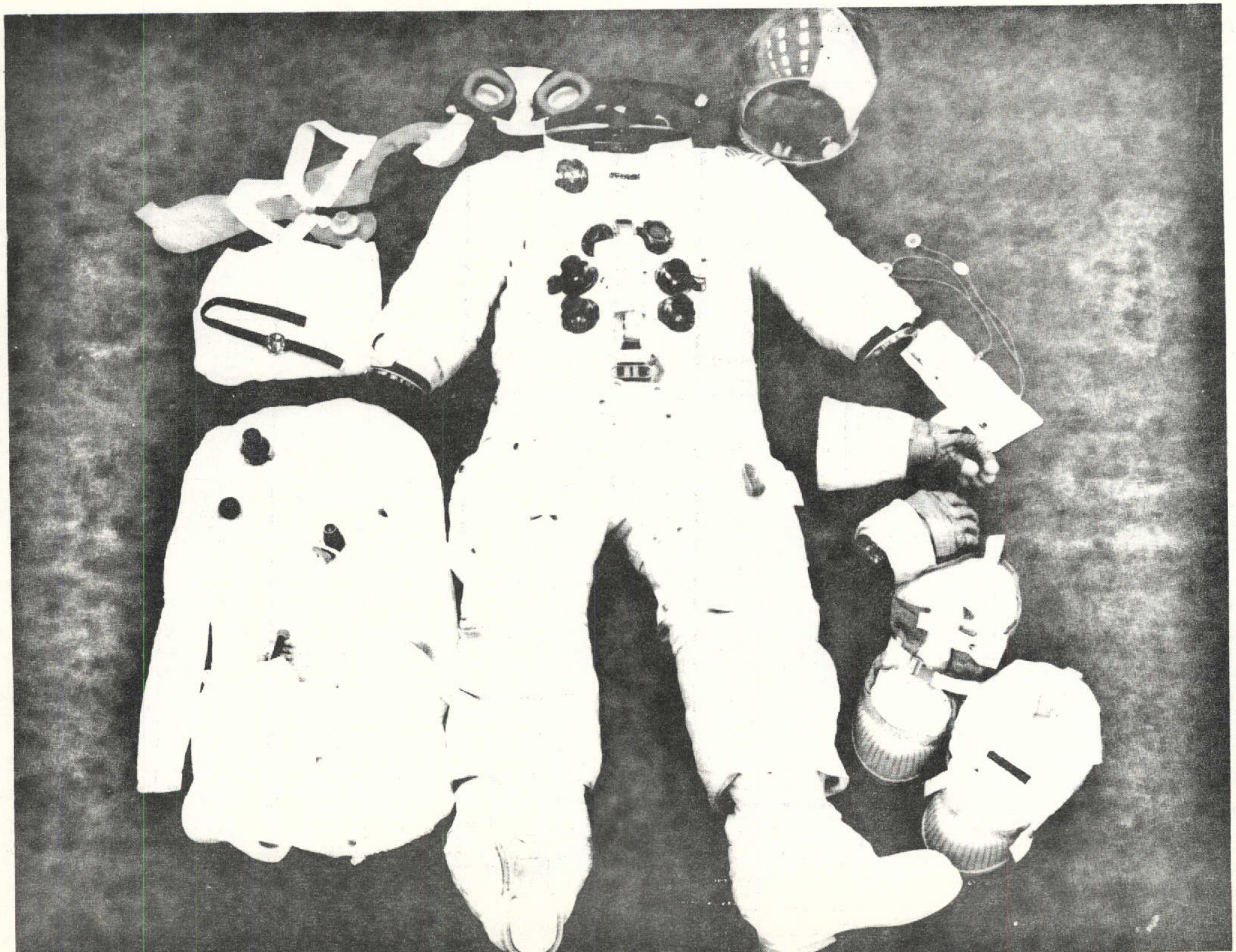


FIGURE 7-7: A7LB SUIT AND MAJOR SUPPORT HARDWARE

TABLE 7-7: SPACE SUITS AND SUPPORT HARDWARE

PRIMARY DON/DOFF ITEMS	PART NUMBER	DIMENSION/VOLUME		WEIGHT		UTILIZATION			ITEM ALLOCATION PER PROGRAM		
		in/ft^3	m/m^3	lbs	kgs	Apollo	Skylab	Shuttle	Apollo Program Description: • 1 and 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 8 hour EVA(s) • < 15 days	Skylab Program Description: • 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 3 hour EVA(s) • > 25 < 60 days	Shuttle (Estimated) Program Description: • 1 and 2 man EVA(s) • 1 to 8 EVA(s) • 1 to 8 hour EVA(s) • < 10 days
Pressure Garment Assembly① (8 psi)	Being Developed	Max 6 cu ft	Max .17 cu m	Max 40	Max 18.16			•			One per EVA Crewman
Helmet	AES Program							•			One per EVA Crewman
Gloves (EV)	Being Developed							•			One pair per EVA Crewman
Pressure Garment Assembly① (3.75 psi)	A7LB-100006-TBD	15x26x48 (Max 10.8 cu ft)	.38x.66x1.22 (Max .31 cu m)	49.3	22.38	•			One per L-EVA② Crewman		
	A7LB-100006-TBD	"	"	46.3	21.02		•			One per Crewman	
	A7LB-100008-TBD	"	"	43.1	19.56	•			One per T-EVA③ Crewman		
Helmet	A7LB-102053-03/04			2.7	1.22	•			One per Crewman		
	A7LB-102053-06/09			2.7	1.22		•			One per Crewman	
Gloves (EV)	A7LB-203034-15/16			2.9	1.31	•			One pair per L-EVA Crewman		
	A7LB-203034-13/14			2.7	1.22	•	•		One pair per T-EVA Crewman	One pair per Crewman	
Gloves (IV)	A7LB-103011-07/08			2.1	.95	•	•		One pair per Crewman	One pair per Crewman	
Urine Collection Transfer Assembly	14-0108-02			.5	.23	•			One per T-EVA Crewman		
	14-0108-04	12x12x2	.3x.3x.05	.5	.23	•	•	•④	One per L-EVA Crewman	One per Crewman per EVA	
Bioinstrumentation Assembly	SEB-42100083-308			1.1	.50	•		•	One per Crewman		One per EVA Crewman
Operational Bioinstrumentation System	8402330100-019			1.1	.50		•			One per Crewman	
Bio-Belt Assembly	SEB-13100084-204			.3	.13	•		•	One per Crewman		One per EVA Crewman
	SEC-13100148-301	4.6x1.5x10.9	.12x.04x.28	.3	.13		•			One per Crewman	
Suit Electrical Harness	A7LB-109040-01			.4	.18	•			One per L-EVA Crewman		
	A7LB-109040-02			.4	.18	•		•	One per T-EVA Crewman		One per EVA Crewman
Suit Harness	84000095200-029			.5	.23		•			One per Crewman	
Bio-Harness	A7LB-109043-01			.2	.09	•		•	One per Crewman		One per EVA Crewman
Communications Carrier Assembly (CCA)	16536G-04			1.6	.72	•		•	One per Crewman		One per EVA Crewman
	16536G-07	10x8x4	.25x.2x.1	1.6	.72		•			One per Crewman	
Eartube (CCA)	75101-380 or 3			n⑤	-	•		•	One pair per CCA		One pair per CCA
	75101			n	-		•			One pair per CCA	
Earmold (Right and Left)	SEB-42100104002/3			n	-	•	•	•	One pair per CCA	One pair per CCA	One pair per CCA
Fecal Containment Subsystem (FCS)	A6L-501000-05	10x7x2	.25x.18x.05	.5	.23	•	•	•	One per Crewman	One per Crewman per EVA	One per EVA Crewman per EVA
Lunar Extravehicular Visor Assembly (LEVA)	A7L-205000-11			5.7	2.58	•			One per L-EVA Crewman		
Skylab Extravehicular Visor Assembly (SEVA)	A7LB-509000-01	11x11.5 Dia.	.28x.29 Dia.	4.9	2.22		•			One per Crewman	
Extravehicular Visor Assembly (EVVA)	AES Program⑥			4.0	1.81			•			One per EVA Crewman
Liquid Cooling Garment (LCG)	A6L-400000-19	12.5x10x3.5	.32x.25x.09	4.4	1.99	•	•	•	One per L-EVA Crewman	One per Crewman per EVA	Min. one per EVA Crewman per flight
Constant Wear Garment (CWG)⑦	SEB-13100061-209	10x8x2.5	.25x.2x.06	.8	.36	•			One per T-EVA Crewman		
CWG Electrical Harness	A6L-507000-03			.4	.18	•			One per Crewman		

FOOTNOTES OR REMARKS

① Volume includes Helmet/Gloves

② Lunar EVA

③ Trans-earth EVA

④ Suggested utilization

⑤ Negligible: <.1 lbs

⑥ AiResearch Program: Advanced Extravehicular Suit

⑦ The CWG, instead of the LCG, was worn by the Apollo Trans-earth EVA Crewman. The CWG is worn during low-metabolic pressure suited intravehicular activities (IVA)

TABLE 7-7: SPACE SUITS AND SUPPORT HARDWARE (CONT'D.)

SECONDARY DON/DOFF ITEMS	PART NUMBER	DIMENSION/VOLUME in/ft3	DIMENSION/VOLUME m/m3	WEIGHT lbs	WEIGHT kgs	UTILIZATION Apollo	UTILIZATION Skylab	UTILIZATION Shuttle	ITEM ALLOCATION PER PROGRAM: Apollo	ITEM ALLOCATION PER PROGRAM: Skylab	ITEM ALLOCATION PER PROGRAM: Shuttle (Estimated)	FOOTNOTES OR REMARKS
									Program Description: • 1 and 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 8 hour EVA(s) • < 15 days	Program Description: • 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 3 hour EVA(s) • > 25 < 60 days	Program Description: • 1 and 2 man EVA(s) • 1 to 8 EVA(s) • 1 to 8 hour EVA(s) • < 10 days	
Checklist Pocket	A7LB-201153-01			.3	.13	•			One per T-EVA(1) Crewman			(1) Trans-earth EVA
	A7LB-201155-01			.8	.36	•			One per L-EVA(2) Crewman			
	A7LB-201155-01	5x4x1.1	.13x.1x.03	.4	.18		•	•(3)		One per Crewman	One per EVA Crewman	
Data List Pocket	A7LB-201121-01/03			.8	.36	•			One per T-EVA Crewman			(2) Lunar EVA
	A7LB-201156-01			.4	.18	•		•	One per L-EVA Crewman		One per EVA Crewman	
	A7LB-201156-01	9x8x3	.23x.2x.08	.8	.36		•			One per Crewman		(3) Suggested utilization
Scissors Pocket	A7LB-201175-01	3.2x2.5x.08	.08x.06x.002	.1	.04	•	•	•	One per Crewman	One per Crewman	One per EVA Crewman	
Passive (Radiation) Dosimeter	SEB-12100045-201			n(4)	-	•			Three per crewman			(4) Negligible: <.1 lbs
	-			n	-		•	•		One per Crewman	One per EVA Crewman	
Personal Radiation Dosimeter	SEB-16100703-201			.4	.18	•			One per Crewman			(5) Minimum
	SEB-16100703-202	2.2x.8x3.13	.05x.02x.08				•	•		One per Crewman	One per EVA Crewman	
Wristlets				n	-	•	•	•	Crewman preference	Crewman preference	Crewman preference	(6) Because of a varied number of EVA(s)/tasks per flight, this type of checklist may be required
Comfort Gloves				n	-	•	•	•	Crewman preference	Crewman preference	Crewmen preference	
Watchband	SEB-12100030-201			n	-	•			One per L-EVA Crewman			
	SEB-12100030-202			n	-	•	•	•	One per Crewman	One per Crewman	One per EVA Crewman	
Chronograph	SEB-12100039-001			.1	.04	•			One per Crewman			
	SEB-12100039-002			.1	.04		•	•		One per Crewman	One per EVA Crewman	
Wrist Mirror	SDB-12100086-001			n	-	•			One per L-EVA Crewman			
In-Suit Drinking Device	14-0151-02	15x11.5x1	.37x.29x.02	.3	.13	•	•	•	One per L-EVA Crewman per EVA	One per EVA Crewman per EVA	One per EVA Crewman per EVA	
Penlights	ACR-FA-5	5.16x1.03 Dia.	.13x.02 Dia.	.3	.13	•	•	•	One per Crewman	One per EVA Crewman per EVA	One per EVA Crewman per EVA	
Scissors	SDB-42100059-202			.5	.23	•	•	•	One per Crewman	One per Crewman	One per EVA Crewman	
Data Recording Pens	SEB-12100051-204	5.21x.52 Dia.	.13x.01 Dia.	n	-	•	•	•	One per Crewman per flight (min)(5)	One per Crewman per flight (min)	One per EVA Crewman per flight (min)	
Pencil	SEB-12100081-301	5.07x.4 Dia.	.12x.01 Dia.	n	-	•	•	•	"	"	"	
Marker Pen	SEB-12100082-301	5.2x.55 Dia.	.13x.01 Dia.	n	-	•	•	•	"	"	"	
EVA Cuff Checklist	SEB-33100302-302	3x3.25x.5	.07x.08x.01	.3	.13	•		•	One per L-EVA Crewman per EVA		(Min)(5) One per EVA Crewman per EVA(6)	
Retractable EVA Tether	SEB-33100291-305			.2	.09	•			One per L-EVA Crewman			
EVA Waist Tether	SEB-33100192-308			.6	.27	•			One per flight			
EVA Wrist Tether							•			One per EVA Crewman		

TABLE 7-7: SPACE SUITS AND SUPPORT HARDWARE (CONT'D.)

	STOWAGE SUPPORT EQUIPMENT	PART NUMBER	DIMENSION/VOLUME in/ft^3	DIMENSION/VOLUME m/m^3	WEIGHT lbs	WEIGHT kgs	UTILIZATION Apollo	UTILIZATION Skylab	UTILIZATION Shuttle	ITEM ALLOCATION PER PROGRAM: Apollo	ITEM ALLOCATION PER PROGRAM: Skylab	ITEM ALLOCATION PER PROGRAM: Shuttle (Estimated)
										Program Description: • 1 and 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 8 hour EVA(s) • < 15 days	Program Description: • 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 3 hour EVA(s) • > 25 < 60 days	Program Description: • 1 and 2 man EVA(s) • 1 to 8 EVA(s) • 1 to 8 hour EVA(s) • < 10 days
Containers	Pressure Garment Assembly (PGA) Container	V36-601510-201			8.1	3.67	•		*	One per flight(1)		
Containers	PGA Container (L)	V56-601010-11	11.5x22x33	.29x.55x.83	1.5	.68		•			Only one container per Crewman	
Containers	PGA Container (C)	V56-601010-21	11.5x22x33	.29x.55x.83	1.5	.68		•				
Containers	PGA Container (R)	V56-601010-31	11.5x22x33	.29x.55x.83	1.5	.68		•				
Containers	Helmet & LEVA(2) Interium Stowage Container Assembly	SEB-33100794-301			1.4	.64	•			One per flight(3)		
Containers	Penlight Container	V36-787800			.3	.14	•			One per flight(1)		
Containers	Heel Restraint Container	V36-787808			.1	.04	•			One per flight(1)		
Containers	EVA Equipment Container	V36-787833-201			1.3	.59	•			One per flight(1)		
Bags	In-Flight Helmet Stowage Bag	SEB-13100077-206			.6	.27	•			One per Crewman(1)		
Bags	Helmet Stowage Bag	A6L-502000-13			1.3	.59	•			One per L-EVA Crewman		One per EVA Crewman
Bags	Helmet Stowage Bag	SEB-13100077-207			.7	.32		•	*		One per Crewman	
Bags	SEVA(4) Stowage Bag	A6L-502030-01			2.9	1.31		•	*		One per Crewman	One per Crewman
Bags	Earmold/Eartube Bag	SEC-12100244-301			n(5)	–		•			One per Program(6)(7)	
Bags	Temporary Stowage Bag	V36-601015-301			1.7	.77	•			Five per flight(1)		
Bags		V36-601015-401	12x2.5x6.5	.3x.06x.16	1.7	.77		•	•(8)		Eleven per Program(7)	(Min)(9) One per EVA Crewman
Bags	Accessory Bag	SEB-13100114-701			.3	.14	•	•	•	One per Crewman	One per Crewman	One per EVA Crewman
Tethers/Straps	Wrist Tether	SEB-33100852-301			.3	.14	•		•	One per flight(1)		
Tethers/Straps	IV Crewman Tether	V36-601630			.4	.18	•		•	One per flight(1)		
Tethers/Straps	Utility Strap	V36-788020-11			n	–		•	•		48 per Program	
Tethers/Straps	Bungee Cord	V36-601170-41			.1	.04	•		•	Three per flight(2)		
Tethers/Straps	LCG(10) Retention/Retaining Strap	V56-786565			.2	.09		•	•		Two per Program(7)	
Tethers/Straps	PGA Tie-Down Strap	V56-601061			.1	.04		•			Two per PGA	
Tethers/Straps	EMU(11) Kit Strap Assembly	V56-786551-91			.3	.14		•			One per flight(1)	
Tethers/Straps	EMU Kit Strap Assembly	V56-786551-181			.1	.04		•	•		Three per Program(7)	

FOOTNOTES OR REMARKS

* Some type of this item should be provided
(1) Stowed in Command Service Module (CSM)
(2) Lunar Extravehicular Visor Assembly
(3) Stowed in Lunar Module (LM)
(4) Skylab Extravehicular Visor Assembly
(5) Negligible: < .1 lbs
(6) Contains spare Earmolds/Eartubes
(7) Stowed in Skylab OWS
(8) Suggested utilization
(9) Minimum
(10) Liquid Cooling Garment
(11) Extravehicular Mobility Unit

TABLE 7-7: SPACE SUITS AND SUPPORT HARDWARE (CONT'D.)

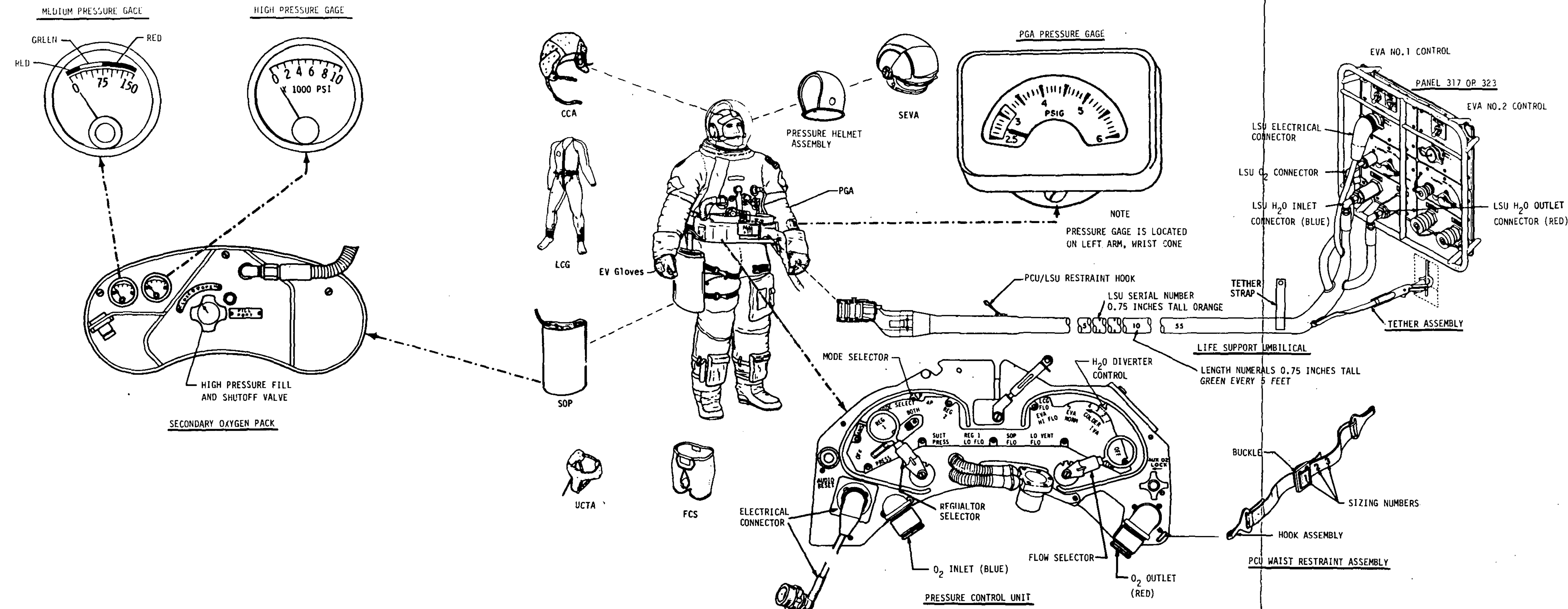
	MAINTENANCE, DON/DOFF, AND DRYING SUPPORT ITEMS	PART NUMBER	DIMENSION/VOLUME		WEIGHT		UTILIZATION			ITEM ALLOCATION PER PROGRAM		
			in/ft^3	m/m^3	lbs	kgs	Apollo	Skylab	Shuttle	Apollo: Program Description: • 1 and 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 8 hour EVA(s) • < 15 days	Skylab: Program Description: • 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 3 hour EVA(s) • > 25 < 60 days	Shuttle (Estimated): Program Description: • 1 and 2 man EVA(s) • 1 to 8 EVA(s) • 1 to 8 hour EVA(s) • < 10 days
Maintenance and Don/Doff Support Equipment	PGA[1] OWS[2] Maintenance Kit	A7LB-508000-01	.235 cu ft	.006 cu m	4.7	2.13		•	*		One per Program	One per flight
	EMU[3] Maintenance Kit	A6L-503000-11			.5	.23	•			One per Crewman[4]		
		A6L-503000-11			.6	.27		•	*		One per flight	One per flight
	Donning Lanyard	A7L-101033-02			.1	.04	•			One per flight[5]		
	OBS[6] Electrode Assembly Kit	SJC-42100654-301	5x5.5x2.5	.13x.14x.06	1	.45		•	*		One per Program	
	Tissue Dispenser	SEB-42100086-203			1.4	.64	•			Eight per flight		
Don/Doff Support Hardware	Electrical Connector Cap[7]	A7L-101118-01			n[8]	-	•	•		One per Crewman	One per Crewman	
	UCTA[9] Clamp	14-149-01	3x2.5x.5	.07x.03x.01	n	-	•	•	•	One per Crewman	One per Crewman per EVA	(Min) One per EVA Crewman
		14-149-01	3x2.5x.5	.07x.03x.01	n	-	•			One per L-EVA[10] Crewman		
	Protective CWG[11], Bio-Harness Connector Cap	351-B-101			n	-	•			One per Crewman		
	Electrical Connector Cover (CWG)	351-B-101			n	-		•			One per Crewman	
	H_2O Connector Plugs	A7L-101035-01			.1	.04	•			One per L-EVA Crewman		
	LCG[12] Adapter	A7LB-109042-02			.2	.09	•			One per L-EVA Crewman		
Drying Support Equipment	Desiccant Bags[13] (Reusable)		~84x1 Dia.	~2.10x.03 Dia.	2.2	.99		•	•		2 per suit (Program total 12)	(Min)[14] 2 per suit
	Dryer (Blower Motor)		~12x12x16	~.30x.30x.40	17.8	8.08						
	Blower Motor with the following: - Adapter Manifold - Flex Hose (~10')				18.3	8.31		•	•		One per Program	One per flight
	Gas Outlet Adapter							•			One per Program	

FOOTNOTES OR REMARKS

* Some type of this item should be provided

1. Pressure Garment Assembly
2. Orbital Workshop
3. Extravehicular Mobility Unit
4. One stowed in Command Service Module (CSM); two stowed in Lunar Module (LM)
5. Stowed in LM
6. Operational Bio-Instrumentation System
7. Used in conjunction with suit harness
8. Negligible: <.1 lbs
9. Urine Collection Transfer Assembly
10. Lunar EVA
11. Constant Wear Garment
12. Liquid Cooling Garment
13. Bags must be dried before reuse
14. Minimum

SKYLAB EXTRAVEHICULAR MOBILITY UNIT (EMU)



SYSTEMS INTERFACES

CM

POWER:	25 TO 30 VDC 2 AMP MAX.	BUS A OR B
OXYGEN:	95 + 5 PSIG	FLOW CONDITIONS
	115 PSIG MAX.	NO FLOW
	150 PSIG MAX.	RELIEF PRESSURE
	10 TO 13 LB/HR	FLOW
	35° TO 70° F	INLET TEMPERATURE

WATER NOT AVAILABLE

AM

POWER:	25 TO 30 VDC 2 AMP NOMINAL	BUS 1 OR 2
OXYGEN:	125 + 10 PSIA	NOMINAL FLOW CONDITIONS
	176 PSIA MAX.	NO FLOW
	165 MAX. PRESS	WITH 8LB/HR FLOW
	65 PSIA MIN.	INTERFACE PRESS., FUNCTIONAL UMBILICAL 9 LB/HR (ONE BROKEN UMBILICAL)
	40° TO 90° F	INLET TEMPERATURE
	22.7 LB/HR MAX.	FLOW TOTAL FOR NOMINAL PRESSURE (13.8 LB/HR AT ONE STATION, 9.0 LB/HR AT OTHER STATION)
WATER:	27.5 PSIA MAX	NOMINAL
	37.2 PSIA	BLOCKED RETURN LINE
	200 LB/HR	FLOW RATE
	280 LB/ HR	FLOW RATE
	41° TO 49° F	INLET TEMPERATURE WITH MAX. HEAT LOSS OF 300 BTU/HR IN LSU/PCU/LCG

DATA REQUIREMENTS

INSTRUMENTATION/TELEMETRY

PGA PRESSURE GAGE
PGA GAS SUPPLY TEMPERATURE (TM)
PGA GAS RETURN TEMPERATURE (TM)
PCU WATER RETURN TEMPERATURE (TM)
PCU WATER SUPPLY TEMPERATURE (TM)
SOP SUPPLY FLOW
LOW VENT FLOW
REG. NO. 1 LOW FLOW
SUIT PRESSURE HIGH OR LOW

ONBOARD BIOMED INSTRUMENTATION SYSTEM (OBS)

CARDOITACHOMETER (CTM)
ELECTROCARDIOGRAPH (ECG)
IMPEDENCE PNEUMOGRAPH (ZPN)
BODY TEMPERATURE (BTMS)
SUBJECT IDENTIFICATION (SID)

SUPPORT EQUIPMENT/HARDWARE

AM-ECS, CM-ECS
M-509
T020
D024

OPERATIONAL CONSTRAINTS

LOSS OF POWER TO PCU AFFECTS COM, C_2W INDICATORS, OBS AND NOT H_2O OR O_2 FUNCTION.

DISPLAYS

PRESSURE GAGE
LOW VENT FLOW WARNING LIGHT
SECONDARY OXYGEN FLOW WARNING LIGHT
REGULATOR NO. 1 LOW FLOW WARNING LIGHT
SUIT PRESSURE WARNING LIGHT, HIGH & LOW
SOP HIGH PRESSURE GAGE
SOP MEDIUM PRESSURE GAGE

CONTROL FUNCTIONS

TWO POSITION VENTILATION DIVERTER VALVE, VERTICAL (EV) HORIZONTAL (IV).
PRESSURE RELIEF VALVE, PRESSURE GARMENT ASSEMBLY.
PRESSURE RELIEF VALVE, SECONDARY OXYGEN PACK.
REGULATOR SELECTOR SUIT PRESSURE
MODE CONTROL SELECTOR
FLOW CONTROL SELECTOR
LCG WATER DIVERTER VALVE
SECONDARY OXYGEN SHUT-OFF VALVE

CREW TASKS

DON EMU
DOFF EMU
CONNECT LSU OR UMBILICAL TO ECS
PERFORM EXPERIMENTS EVA AND IVA
CHARGE PCU/LSU
DESERVICE PCU/LSU
FILL WATER DRINK BAG

ALSA STOWAGE

2 PCU'S (DRY) OWS, 2 PCU'S (WET) PER CSM, 8 TOTAL
2 SOP'S MDA & OWS, 2 SOP'S PER CSM, 8 TOTAL
4 LSU'S (DRY) OWS, 2 LSU'S (WET) AM, 6 TOTAL

PCU WARNING ALARM SYSTEM SUMMARY

C & W INDICATORS	INDICATION OF	DISPLAY	PCU WARNING TRIP POINT	WARNING RESET POINT
SOP FLO	SECONDARY OXYGEN SUPPLY FLOW INITIATED	AUDIO & VISUAL (SOP)	0.05 TO 0.20 LB/HR ON INCREASING FLOW	0.05 LB/HR MIN. ON DECREASING FLOW
LO VENT FLO	LOW TOTAL OXYGEN VENTI-LATION FLOW RATE TO CREWMAN	AUDIO & VISUAL (VENT)	4.5 TO 5.7 LB/HR ON DECREASING FLOW	5.7 LB/HR MAX. ON INCREASING FLOW
REG. 1 LO FLO	LOW FLOW PROCEEDING THROUGH PRIMARY CONTROL REGULATOR	AUDIO & VISUAL (REG)	2.75 TO 3.75 LB/HR MAX. ON DECREASING FLOW *	3.75 LB/HR MAX. ON INCREASING FLOW
SUIT PRESS	LOW OR HIGH SUIT PRESS-URE AS MEASURED DOWN-STREAM OF SUIT	AUDIO & VISUAL (PRESS) AUDIO & VISUAL	2.7 TO 3.0 PSID ON DECREASING PRESS. 4.17 TO 4.53 PSID ** (HIGH) ON INCREASING PRESS.	3.0 PSID MAX ON INCREASING PRESS. 4.17 PSID MIN. ON DECREASING PRESS.

*SIGNAL SENT FROM TRANSDUCER TO CONTROL MODULE IS DELAYED 5 SECONDS WITHIN THE CONTROL MODULE LOGIC BEFORE WARNING INDICATION IS GIVEN, THUS ELIMINATING FALSE WARNING TONES DUE TO TRANSIENT FEEDBACK CONDITIONS FROM SUIT PRESSURE VARIATIONS DUE TO SUIT VOLUME CHANGES WITH CREWMAN'S ACTIVITIES.

**CREWMAN UTILIZES SUIT PRESSURE GAGE TO DETERMINE PRESSURE LEVEL.

PCU FLOW CONTROL FEATURES		
OFF	ABS OR P	0 (ONLY IF REG'S ARE "OFF")
IVA	P	10.9 TO 13.7 LB/HR (NOMINAL) AT 5.0 PSIA AMBIENT AND PCU PRESSURE AT 3.42 TO 3.80 PSID
EVA NORM	ABS	10.0 TO 14.5 LB/HR AT 5.0 PSIA AMBIENT, PGA VENT 7.9 TO 9.0 LB/HR AT 0.0 PSIA AMBIENT
EVA HIGH FLOW	ABS	12.5 TO 14.0 LB/HR AT 0.0 PSIA AMBIENT

PREPARED BY: H. L. [signature]
APPROVED BY: [signature] 2/2/72
APPROVED BY: W. W. [signature] 2/2/72
REVISION DATE: 2-2-72

NASA MSC

FIGURE 7-8: SKYLAB EXTRAVEHICULAR MOBILITY UNIT USING A7LB SUIT

FOLDOUT FRAME 1

FOLDOUT FRAME 2

the suit, and it becomes necessary to consider a new generation of space suit to meet new space programs.

From several studies undertaken by space suit designers, the following requirements for an advanced space suit were identified:

- Operating Pressure - 8 PSIA
- Leakage Rate - 80 SCC/Min at 8 PSIA, Max.
- Materials
  - High Strength
  - Nonflammable in One Atmopshere Air
- Quick Donning
- Useful Life - 8 Years
- Joint Cycle Life
  - Upper Torso Joints - 200,000 Cycles
  - Lower Torso Joints - 100,000 Cycles
- Structural Design Factors
  - Design - 1.5 x 8.0 = 12 PSIG (.84 kg./cm.^{2})
  - Proof - 2.0 x 8.0 = 16 PSIG (1.1 kg./cm.^{2})
  - Burst - 2.5 x 8.0 = 20 PSIG (1.4 kg./cm.^{2})
- Vent System Pressure Drop
  - 1.8 Inches of H_2O Max
  - At 5.5 ACFM and 8 PSIA
  - (Excluding Connectors)
- EVA/IVA Suit Must Withstand Contact With Surfaces With a Temperature of -263°F To +285°F
- Interior Surface Temperature Range: 39°F To 113°F
- Suit Mounted Equipment
  - Pressure Gage
  - Helmet/Helmet & Torso Vent Diverter Valve
  - Active Radiation Dosimeter (EVA/IVA Suit Only)
  - Feed Port in Helmet
  - Urine Transfer Device

One of the first considerations for a new suit was operating pressure. At ambient earth pressure, the human body is saturated with nitrogen, and as the ambient pressure is decreased, the lower pressure can allow some nitrogen to come out of solution and result in the formation of bubbles in the blood stream. Such a condition can cause dysbarism (decompression sickness); however, this can be averted by breathing 100% oxygen for specified periods of time prior to exposure at a lower ambient pressure. This oxygen breathing process is known as "pre-breathing".

On the Apollo flights, the reduction of the cabin ambient pressure to 5 psia (.35 kg./cm.^{2}) and a further reduction to 3.7 psia (.26 kg./cm.^{2}) during EVA required that the crewman prebreathe between 2 and 3 hours prior to launch and before exposure to the lower pressure.

Skylab will also operate at 5 psia. However the Shuttle Orbiter will be maintained at 14.7 psia (1.0 kg./cm.^{2}) (20% oxygen, 80% nitrogen). As indicated on Table 7-8 the selection of 8 psia (.56 kg./cm.^{2}) as the operating pressure for the Shuttle space suit would completely eliminate the pre-breathing requirement prior to EVA. This 8 psia level would also provide the IV and EV crewman with the greatest margin of safety during a depressurization contingency where time would not permit pre-breathing. After extensive consideration of the many aspects of the pressure problem, the design goal for the Shuttle space suit was set at 8 psia, a most significant requirement.

TABLE 7-8: GENERAL NASA-ACCEPTED PREBREATHING TIMES

TRANSFER FROM	TRANSFER TO	REQ'D. TIME (HOURS)
14.7 psia (3.2 ppO_2)	8.0 psia (100% O_2)	0
14.7 psia (3.2 ppO_2)	8.0 psia (3.5 ppO_2)	0
14.7 psia (3.2 ppO_2)	5.0 psia (100% O_2)	3
14.7 psia (3.2 ppO_2)	5.0 psia (100% O_2)	3
14.7 psia (3.2 ppO_2)	3.7 psia (100% O_2)	4
8.0 psia (3.5 ppO_2)	3.7 psia (100% O_2)	1-2
8.0 psia (3.5 ppO_2)	5.0 psia (100% O_2)	1-2
5.0 psia (100% O_2)	14.7 psia (3.2 ppO_2)	0
5.0 psia ($\approx$100% O_2)	3.7 psia (100% O_2)	0
5.0 psia (3.5 ppO_2)	3.7 psia (100% O_2)	1-2
pp - partial pressure		

The approach in the development of this new space suit begins with an evaluation of the latest research in various types of advance pressure suits, selecting the outstanding features and molding these into a state-of-the-art suit design. An artist's concept of a prototype for the 8 psia suit is shown in Figure 7-9.

The design, development, and fabrication of a new space suit is a complicated process involving an in-depth evaluation of numerous considerations. In this section the reader will be exposed to some of the areas that require special emphasis by the suit designer and user.

The selection of optimum suit materials for each application must satisfy established requirements based on the environment in which the suit will be subjected. For example:

- Pressure Restraint Materials
  - Strength/weight and modules
  - Durability
  - Tear resistance
  - Resistance to temperature and pressure extremes
  - Chemical resistance
  - Flammability and off-gassing
  - Shelf life and service life
  - Ease of fabrication
- Pressure Bladder Materials
  - Tensile and elongation properties
  - Tensile set resistance
  - Tear and puncture resistance
  - Low permeability
  - Age resistance
  - Ease of fabrication
  - Resistance to temperature extremes

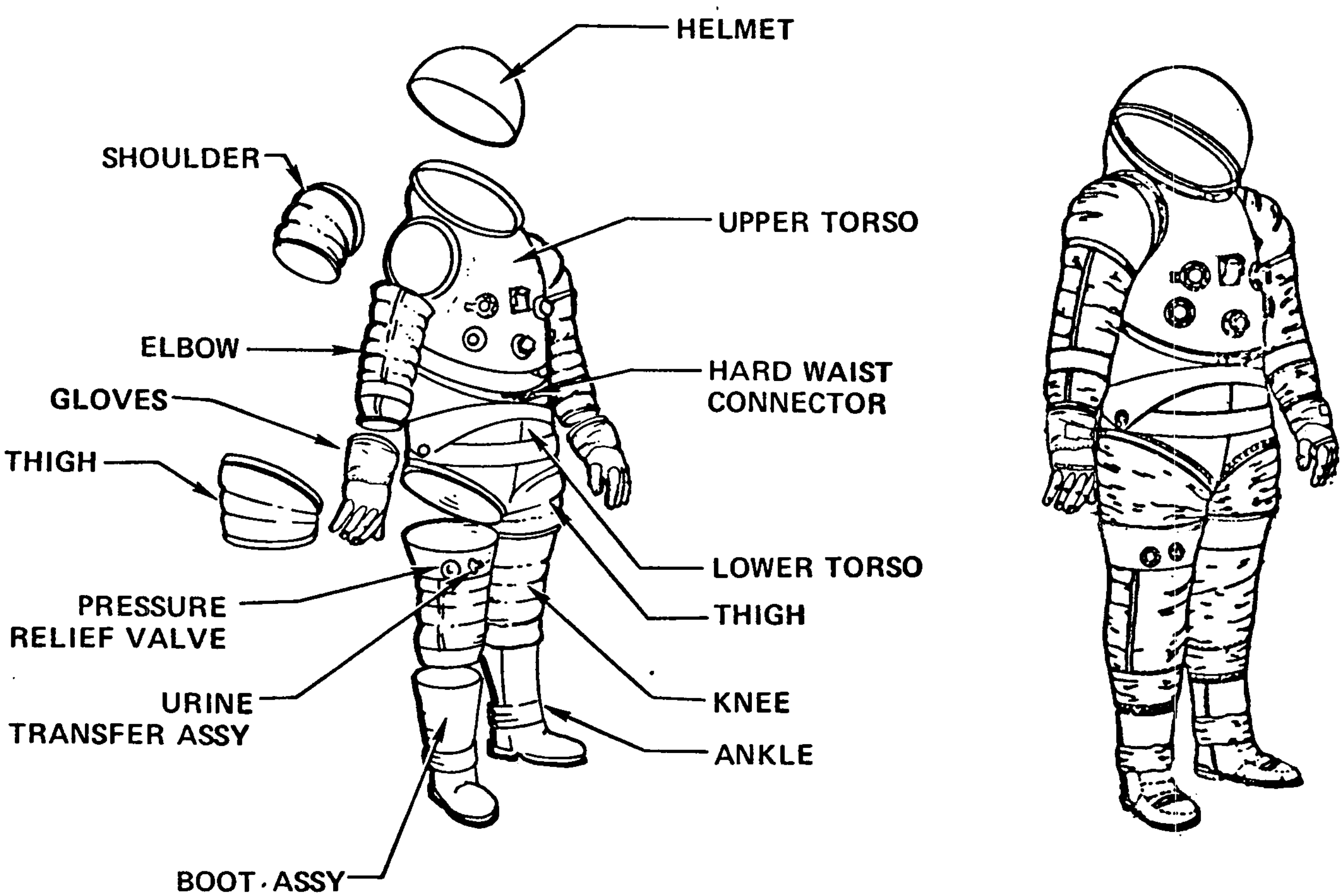


FIGURE 7-9: 8 PSIA EXTRAVEHICULAR SUIT

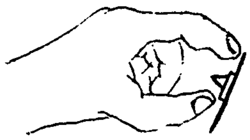
- Helmet & Visors
  - Optical clarity
  - Structural integrity
  - Shelf life and service life
  - Abrasion resistance
  - Folding and flex endurance
  - Resistance to cracking and crazing
- Boot Sole
  - Light weight
  - Durable
  - Chemical and age resistant
  - Flame resistant
  - Easy to manufacture
  - Resistant to flex cracking

Flammability is a requirement that is being reevaluated in light of the change in operating pressure (14.7 psia) and oxygen/nitrogen mixture (≈20% O_2 - 80% N_2) on the Shuttle Orbiter. Many of the non-flammable materials presently utilized are expensive, difficult to process and marginally acceptable based on other critical parameters. Therefore, reduction of the flammability requirements would permit the selection over a greater number of materials which offer distinct advantages in performance, strength and cost. The off-gassing characteristics of all materials must still continue to be evaluated in all exposure environments. This is necessary because the combination of pressure, temperature and atmosphere affect the degree and rate of materials off-gassing.

The design of the glove should provide the greatest amount of dexterity combined with low torque during EVA. Figure 7-10 illustrates the EVA hand dexterity requirements. As the glove is constructed and the multi-layers of thermal insulation and pressure materials are added, the degree of dexterity decreases. It becomes a problem of trade-off and compromise between minimum acceptable protection and sufficient dexterity to perform the assigned tasks. Some degree of dexterity can be recovered if each glove is custom fitted for each crewman.

TYPES OF HAND AND/OR FINGER PREHENSION

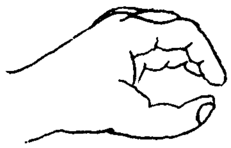
PALMAR



RELATED TASKS

1. Writing
2. Using rotary
3. Using small screwdriver

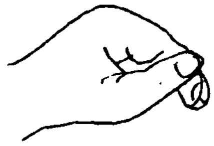
TIP



RELATED TASKS

1. Picking up small objects
2. Using tweezer
3. Winding electrical insulating tape
4. Using twine or heavy lacing tape

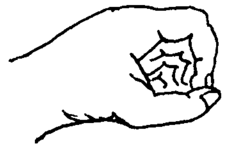
LATERAL



RELATED TASKS

1. Using rotary
2. Using toggle switch

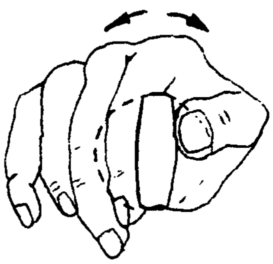
GRASP



RELATED TASKS

1. Using pliers
2. Using wrenches
3. Using screwdriver
4. Using handles and levers
5. Using handholds and handrails
6. Ingress and egress Shuttle couch or airlock
7. Using torque wrench

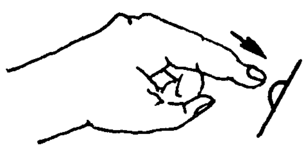
OTHER TYPES OF REQUIRED HAND/FINGER OPERATIONS



HAND ROTATION

RELATED TASKS

1. Removal of screws or nuts
2. Satellite component removal



FINGER PUSHBUTTON OPERATIONS

FINGER-PULLING OPERATIONS

RELATED TASKS

1. Removal and installation of experiment modules during maintenance
2. Removal and installation of quick-release pins

FIGURE 7-10: EVA HAND DEXTERITY REQUIREMENTS

The most noticeable feature of the new suit concept is the hemispherical configured helmet. A comparison with the domed shaped Apollo helmet (see Table 7-9) was prepared and based, to some extent, on the advantages noted. This configuration will be fabricated and evaluated for flight on the Shuttle Orbiter.

On the Apollo flights the pressure suits were custom fitted to each astronaut; however, for the Shuttle Program an alternate method of suit sizing has been proposed. This suggestion is based on a study conducted of the astronauts' sizing history. The results indicated that a nine unit torso sizing system with a common sized hard waist disconnect/entry and a one inch adjustment in the buttock circumference would permit a nominal fit for approximately 85% of the crewmen. The remainder would require slight variation adjustments and in some extremes a custom fitted suit.

Utilization of this approach would minimize the problems of documentation, identification, and in process tracking and maximize the efficiency of cutting, stitching, and assembly operations. As indicated previously, the gloves would continue to be custom fitted for retention of mobility. From the sizing history study it was also determined that at least a five size boot system would be required to accommodate the crewmen.

The reliability goals set for the 8 psia pressure suit include an 8 year component life for soft goods, a high EVA suit cycle life for suit joints (100,000 minimum) and design features that permit the crew to perform their assigned tasks during all modes of operation. Realistic safety factors for all suit cycling requirements should be employed in each design, and extensive component testing used to verify the designs. Cost will be a rigid limiting factor; therefore, standard parts should be used and components from previous programs which have a history of high reliability should be modified to meet the new requirements.

TABLE 7-9: HELMET CONCEPT COMPARISON

HEMISPHERICAL HELMET	
ADVANTAGES	DISADVANTAGES
A. Excellent visibility - (no need for suit neck mobility). B. Can better withstand pressures above 8 psid. C. Easy to manufacture (Lower cost). D. Easy donning - fits all head sizes. E. No vent ducting required in helmet for CO_2 washout. F. Can be rotated in neck ring if scratches occur in line of vision. G. Will readily permit integration with visor assembly.	A. Large bulky neck ring due to large diameter. B. Not certification tested for any mission. C. Heavier.
APOLLO/SKYLAB CONFIGURED HELMET	
A. Qualified for Apollo/Skylab Missions. B. Small neck ring will provide least amount of interference in close areas.	A. Difficult to manufacture. B. Difficult to integrate visor assembly. C. Programs have demonstrated difficult donning for several crewmen due to varying head sizes. D. Configuration is marginal structurally at pressures above 8 psi. E. Restricted visibility - thereby required neck mobility in the A7LB-EV suit. F. Requires vent ducting in helmet due to shape to provide proper CO_2 washout. G. More visual distortion than AES type helmet.

Based on previous test data, suit designs such as pressure sealing zippers, sliding cables and integrated dipped convolutes are not readily adaptable to shuttle suit design requirements. More reliable concepts such as couplings, bearings and specially constructed convolutes are being recommended for the 8 psia pressure suit. For example, a hard disconnect for suit entrance or closure is being recommended for the new suit as opposed to zipper or roll seal entrance systems based on the information contained in Table 7-10 (ref. 7.13 and 7.14).

A prototype 8 psia pressure suit is scheduled to undergo an evaluation program in late 1973 or early 1974. Additional information concerning the capability to perform Shuttle vehicle and payload EVA servicing functions, using the advanced suit, will be available to the mission and payload planners and designers upon completion of the evaluation program.

7.4 EVA LIFE SUPPORT SYSTEMS

7.4.1 Introduction

The life support systems designed for use in the orbital extravehicular environment have consisted of two basic types: (1) self-contained units carried by the EVA crewman and (2) umbilical systems where the crewman must remain tethered to the vehicle. The umbilical life support system (LSS) is a vehicle-dependent type which utilizes consumables stored aboard the spacecraft. The self-contained portable life support system (PLSS) incorporates the crewman consumables and system expendables within the unit.

The EVA life support systems are required to provide the following basic physiological essentials:

- Space suit pressurization
- Suit pressure control
- Oxygen (O_2) for respiration
- Removal of carbon dioxide (CO_2)

TABLE 7-10: SUIT ENTRY COMPARISONS

HARD WAIST DISCONNECT ENTRY	
ADVANTAGE	DISADVANTAGE
A. Easy to don. B. Low leakage. C. Reliable seal at all pressures discussed within this report. D. More adaptable to changes. E. Sizing capabilities. F. Easy maintenance and replacement. G. High cycle life.	A. Heavier in weight. B. Bulky and uncomfortable when unpressurized or in the seated position. C. Costly. D. Increases stowage volume.
ZIPPER ENTRY	
A. Light weight. B. Comfortable when in seated position due to flexibility and no protrusions.	A. Leakage is much higher than hard ring entry. B. Difficult to don depending on the zipper routing and tightness of suit fit. C. Zipper design is less reliable than the hard ring entry especially at pressures greater than 4.0 psi. D. Can hang up if user is not familiar with donning operation. E. Very low cycle life.
ROLL SEAL ENTRY	
A. Soft, comfortable interface with crewman. B. Inexpensive. C. Very adaptable to sizing changes.	A. Difficult to don without assistance. B. Higher leakage than hard waist disconnect. C. Less reliable than hard waist disconnect. D. Lower cycle life than hard waist entry.

- Removal of odors and other contaminants
- Temperature and humidity control

In addition to the above basic requirements, other supporting provisions are normally integrated into the EVA life support systems. These ancillary provisions are primarily associated with safety and crewman comfort in lieu of providing a viable environment. The major auxiliary provisions are listed below:

- Portable life support system
  - Water circulation system for body heat removal through a liquid cooling garment.
  - Radio frequency communication system.
  - Telemetry system for crewman physiological and LSS systems status monitoring.
  - Caution and warning system for critical function enunciation.
- Umbilical life support system
  - Hardline communication system
  - Liquid cooling garment, water circulation system
  - Hardline crewman physiological and LSS systems status monitoring
  - Caution and warning

In the event of primary life support system failure, small self-contained oxygen/pressurization systems are provided for all EVAs. The backup units are basically oxygen purge systems with sufficient suit pressurization and O_2 flow to maintain CO_2 levels within physiologically tolerable limits for a short time. The capacity of the backup LSS units are sized to the EVA mission characteristics and have ranged from about 9 to 30 minutes duration (ref. 7.1).

Several EVA life support systems were developed for the Gemini and Apollo programs. However, these somewhat obsolete systems will not be discussed; only those systems currently being considered for future programs will be addressed.

7.4.2 Umbilical Life Support Systems

Umbilical life support systems used on previous EVA missions were of the open and semi-open ventilation types which release O_2 to the space environment during EVA operations. The Skylab orbital system is an example of an open type umbilical LSS, whereas the later Gemini LSS were of the semi-open-loop type. For Skylab EVA an Astronaut Life Support Assembly (ALSA) will be used. The ALSA consists of three primary components: (1) a 60 ft. (18.3 m) life support umbilical, Figure 7-11; (2) a Pressure Control Unit (PCU); and (3) a Secondary Oxygen Pack (SOP), Figure 7-12. The space suit configuration with the ALSA EVA system is shown in Figure 7-13. The life support umbilical supplies oxygen, water, and electrical power from the spacecraft systems. The Pressure Control Unit is mounted on the front of the crewman's suit near the waist and provides LSS control and warning systems for oxygen and LCG water supplied from the spacecraft. The Secondary Oxygen Pack is a backup LSS unit and supplies 30 minutes of reserve oxygen. The SOP is strapped to the crewman's right leg during EVA (ref. 7.15).

The EVA umbilical is intended to be used as a primary LSS; however, in contingency situations the umbilical can be used within a toxic or partially pressurized environment either inside or outside the vehicle. The umbilical also contains an integral safety/restraint tether for EVA use. The Skylab program uses the most advanced umbilical life support system and will require only minor modifications (if any) to interface with future systems.

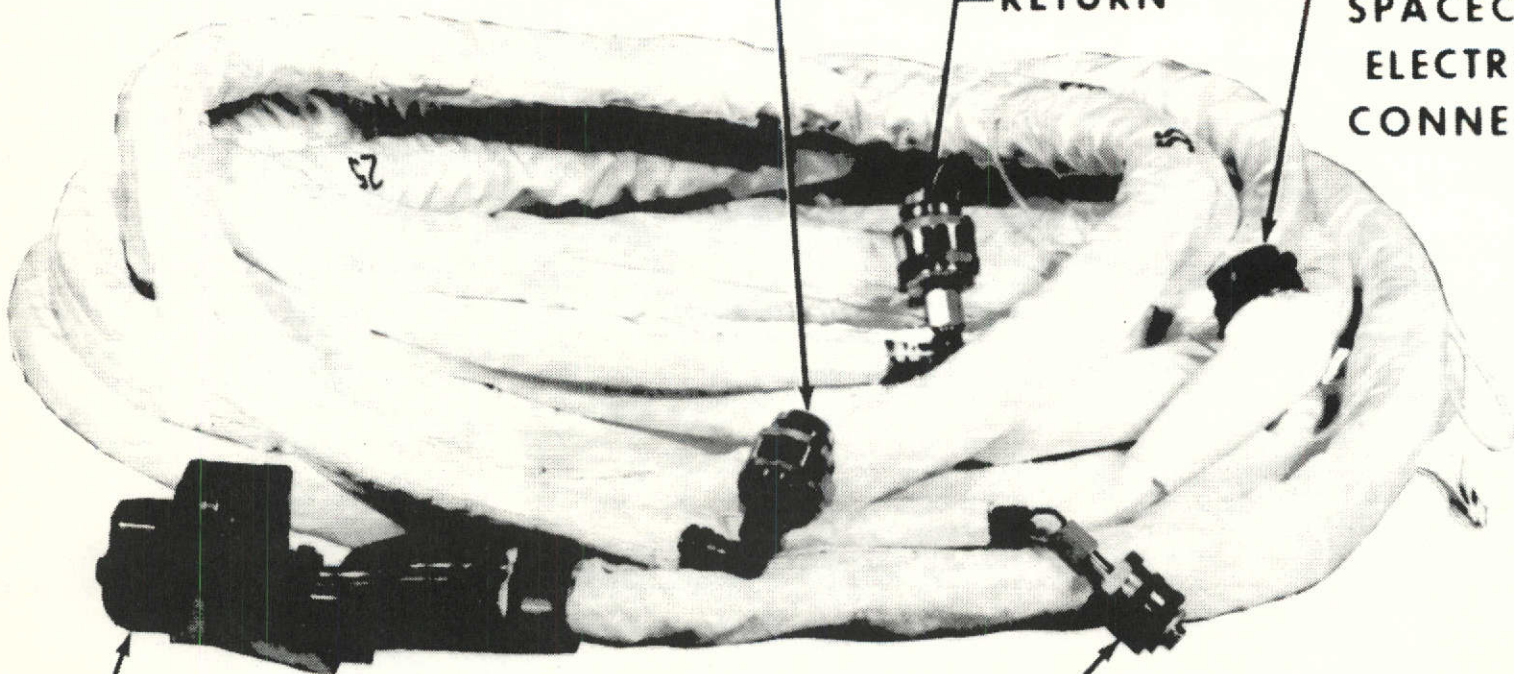


FIGURE 7-11: SKYLAB LIFE SUPPORT UMBILICAL

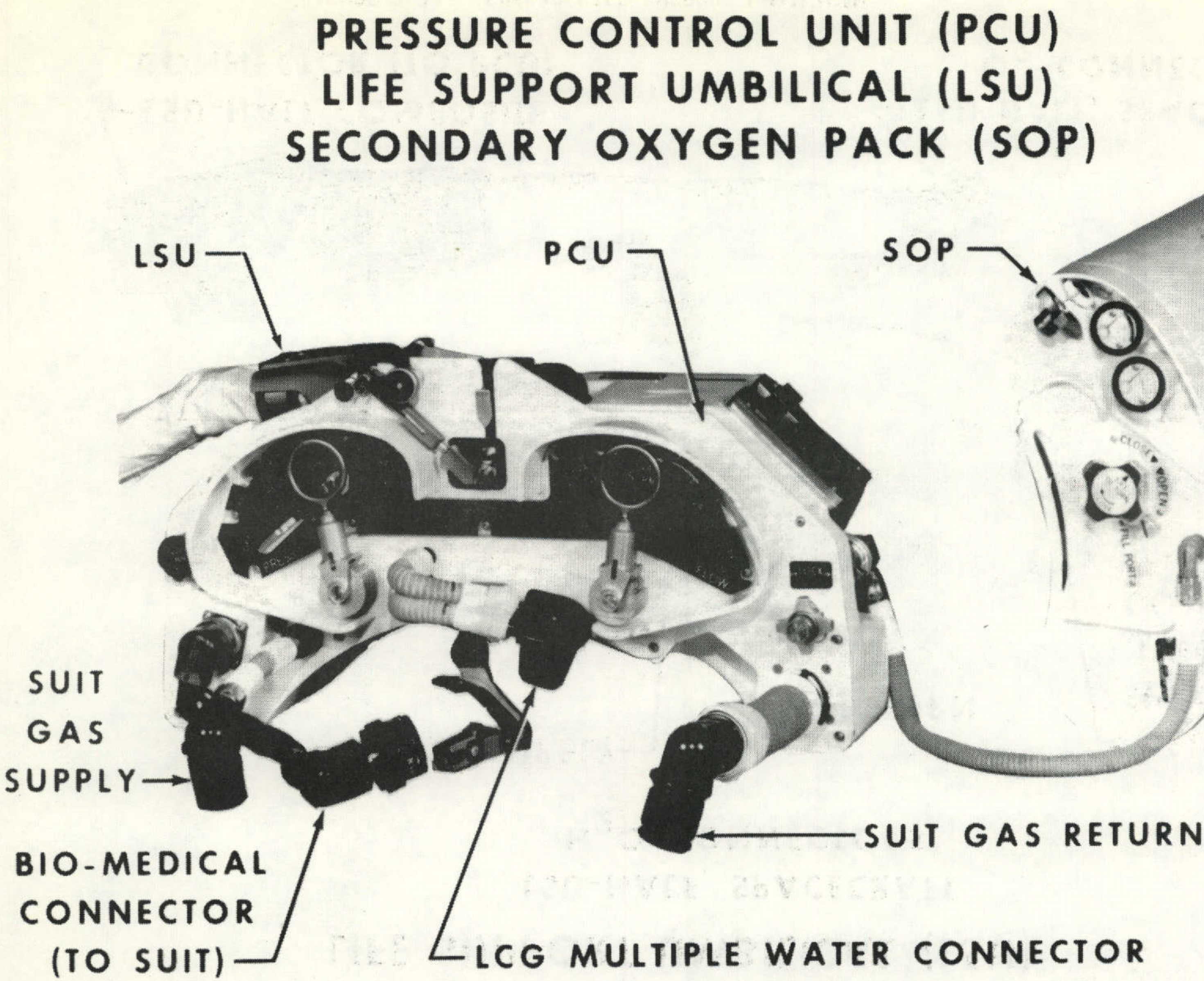


FIGURE 7-12: SKYLAB PRESSURE CONTROL UNIT AND SECONDARY OXYGEN PACK

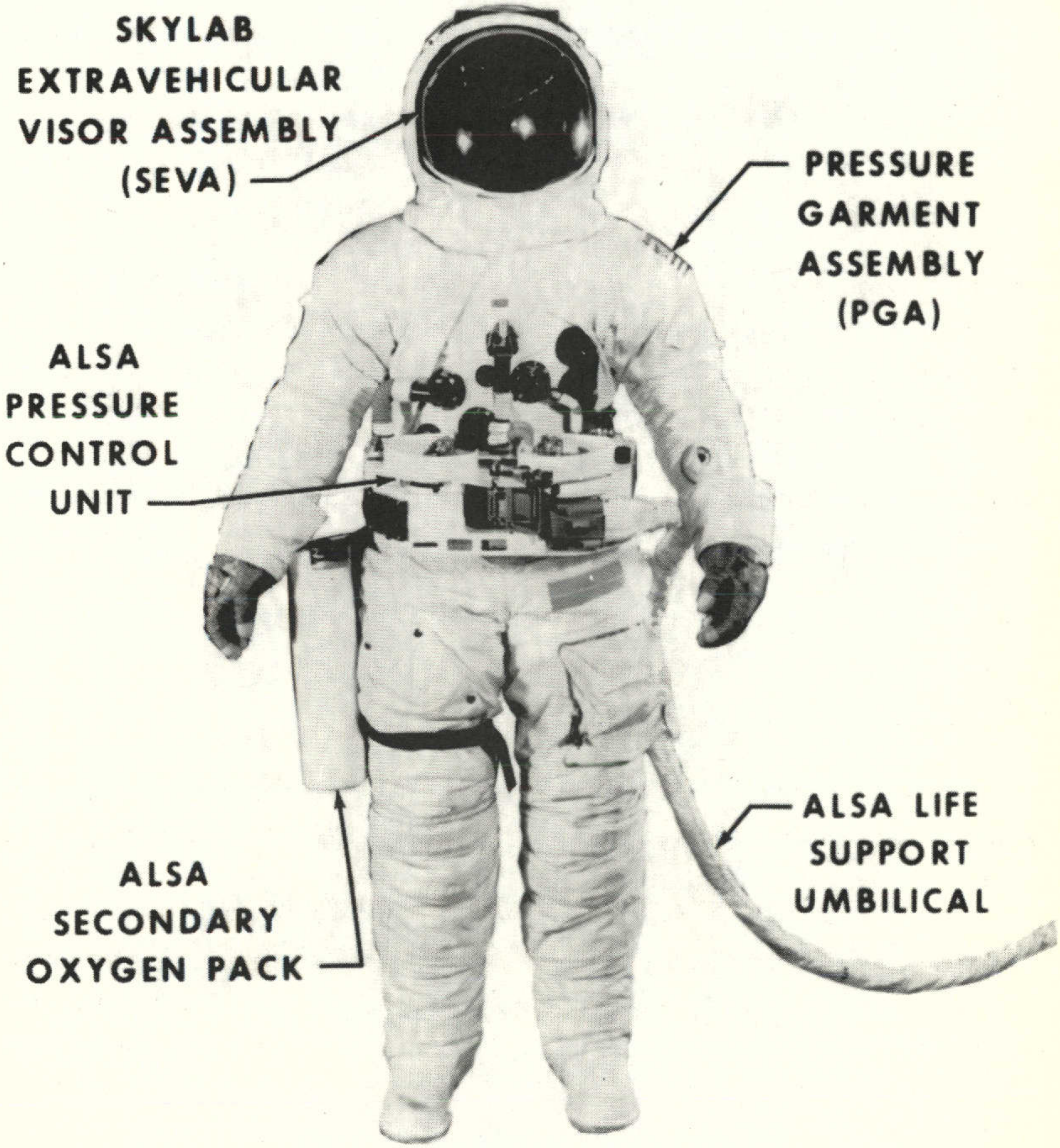


FIGURE 7-13: SKYLAB UMBILICAL LIFE SUPPORT ARRANGEMENT

The Skylab umbilical life support system's basic characteristics are summarized in Table 7-11. Additional data are contained in Table 7-12 for the umbilical and portable system components. This table provides background information on the utilization of umbilical life support systems for the U.S. space programs including the quantities required per EVA or for the entire mission. Table 7-12 is intended to aid the reader in integrating a total EVA system into the various vehicle and payload designs.

It is anticipated that both the umbilical and portable LSS will have applications on future space programs requiring EVA. In considering an umbilical system, it should be noted that umbilical management may become a problem when the length exceeds 60-75 ft. (18.3-22.8 m). Potential problems may include: (1) management during EVA translation and worksite operations, (2) entanglement with equipment along the translation route, (3) internal stowage volume, and (4) oxygen and water "pumping" and "purging" systems designs due to the frictional forces in the long length small diameter tubes. Specific data on the design of the umbilical life support hardware is beyond the scope of this report--the reader is referred to specific hardware end item specifications.

7.4.3 Portable Life Support Systems

The basic portable life support system used throughout the Apollo lunar exploration program (see Figures 7-14 and 7-15) is the only currently approved portable system for orbital EVA operations. However, other systems are presently being studied and will be discussed in later subsections. The portable systems used thus far have relied on stored expendables to accomplish all environmental control functions. Oxygen is provided by high pressure stowage bottles, and carbon dioxide is removed by lithium hydroxide. Sublimators use stored water to reject crewman and system heat, and condensates are collected for humidity control.

The portable LSS units are basically two-loop closed systems--oxygen and water. The oxygen circulation loop provides thermal and composition control

TABLE 7-11: SKYLAB EVA UMBILICAL LIFE SUPPORT SYSTEM CHARACTERISTICS

UMBILICAL SUBSYSTEM / PARAMETER	WEIGHT		VOLUME		DIMENSIONS		SYSTEM CHARACTERISTICS
	lb.	kg.	in.^{3}	cm.^{3}	in. (ft.)	m	
Life Support Umbilical	50.0	22.7	-	-	60 (ft.) length	18.3m length	• O_2 pressure to PCU: 55 to 120 psia • O_2 pressure drop: 10 psid • O_2 operating temperature: 40° to 90° • O_2 umbilical exposure limits: -200° to 300°F • H_2O pressure (max.): 28.5 psi • H_2O flow rate: 200 lb./hr. (min.) 250 lb./hr. (max.)
Pressure Control Unit	26.2	11.9	1147	18,787	18.2 x 9.7 x 6.5 (max.)	.46 x .25 x .16	• O_2 pressure to suit: 3.7 psia • O_2 flow: - 7.9 to 9.0 lb./hr. (normal) - 12.5 to 14.0 lb./hr. (emergency) • Dumps O_2, CO_2, and contaminants to space • Maintains CO_2 buildup below 7.5 mm Hg. • Supplies 700 to 1600 Btu/hr.
Secondary Oxygen Pack	44.1	20.0	959	15,708	15.5 x 11.25 x 5.5	.39 x .28 x .14	• O_2 pressure to suit: 3.7 psia • O_2 flow: - 7.9 lb./hr. for 30 min. - 13.1 lb./hr. for 18 min. - 3.95 lb. of usable O_2 • Automatic flow in event of failure • 6000 psi (422 lbs./cm.^{2}) tank pressure

TABLE 7-12: EVA LIFE SUPPORT SYSTEMS AND EQUIPMENT

	PRIMARY DON/DOFF ITEMS	PART NUMBER	DIMENSION/VOLUME in/ft³	DIMENSION/VOLUME m/m³	WEIGHT lbs	WEIGHT kgs	UTILIZATION Apollo	UTILIZATION Skylab	UTILIZATION Shuttle	ITEM ALLOCATION PER PROGRAM: Apollo — Program Description: • 1 and 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 8 hour EVA(s) • <15 days	Skylab — Program Description: • 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 3 hour EVA(s) • >25 <60 days	Shuttle (Estimated) — Program Description: • 1 and 2 man EVA(s) • 1 to 8 EVA(s) • 1 to 8 hour EVA(s) • <10 days
Primary Systems	PLSS(1)/EVCS(2) Assembly	SEB-11100066-145	26.0x17.8x10.5	.66x.45x.27	94.4	42.85	•			One per Commander		
		SEB-11100066-148			94.5	42.90	•			One per LM(3) Pilot		
	PLSS(4)	SV-706100-7-19					•			One per L-EVA(5) Crewman		
	EVCS-1(4)	8358750-503					•			One per Commander		
	-2(4)	8358751-504					•			One per LM Pilot		
	PLSS-7 Battery(4)	SV-722862-3	6.5x4.75x6.0	.16x.12x.15	8.2	3.72	•			One per L-EVA Crewman per EVA		
	PLSS LiOH(6) (-7) Cartridge(4)	SV-710854-11	15.8x4.4 dia.	.40x.11 dia.	4.6	2.08	•			One per L-EVA Crewman per EVA		
Secondary Systems	Oxygen Purge System	SV-730101-3-10			34.0	15.44	•		*	One per L-EVA Crewman		
	Secondary Oxygen Pack	132730-4	15.5x11.25x5.5	.39x.28x.14	44.1	20.02		•			One per Crewman	
	Buddy SLSS Assembly	SV-729602-9			7.1	3.22	•			One per pair of L-EVA Crewman		
Umbilicals	Oxygen Umbilical - Left	V36-601207-51			7.8	3.54	•			Each CSM(7) Crewman is assigned only one of the three umbilicals		
	- Center	V36-601207-61			8.1	3.68	•					
	- Right	V36-601207-71			11.8	5.36	•					
	Apollo EVA Umbilical Assembly	V36-710100			14.3	6.49	•			One per T-EVA(8) Crewman		
	Life Support Umbilical (Wet)	132826-02	Length-60 ft	Length 18 m	54.5	24.74		•			Only one per each EVA Crewman	
	(Dry)	132826-02			48.7	22.11		•				
	Oxygen Umbilical Hose Clamp	V-36-601082			.1	.05	•			One per Crewman		
Regulators	PLSS Remote Control Unit	SV-721783-14			5.3	2.41	•			One per L-EVA Crewman		
	Pressure Control Unit (Wet)	132728-04			26.7	12.12		•			Only one per each EVA Crewman	
	(Dry)	132728-04			26.2	11.89		•				

FOOTNOTES OR REMARKS

* Some type of this item may be required
(1) Portable Life Support System
(2) Extravehicular Communications System
(3) Lunar Module
(4) Individual item weights reflected in total PLSS/EVCS Assembly weight
(5) Lunar EVA
(6) Lithium Hydroxide
(7) Command/Service Module
(8) Trans-earth EVA

TABLE 7-12: EVA LIFE SUPPORT SYSTEMS AND EQUIPMENT (CONT'D.)

	MISCELLANEOUS ITEMS	PART NUMBER	DIMENSION/VOLUME in/ft3	DIMENSION/VOLUME m/m3	WEIGHT lbs	WEIGHT kgs	UTILIZATION Apollo	UTILIZATION Skylab	UTILIZATION Shuttle	ITEM ALLOCATION PER PROGRAM: Apollo	ITEM ALLOCATION PER PROGRAM: Skylab	ITEM ALLOCATION PER PROGRAM: Shuttle (Estimated)
										Program Description: • 1 and 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 8 hour EVA(s) • < 15 days	Program Description: • 2 man EVA(s) • 1 to 3 EVA(s) • 2 to 3 hour EVA(s) • > 25 < 60 days	Program Description: • 1 and 2 man EVA(s) • 1 to 8 EVA(s) • 1 to 8 hour EVA(s) • < 10 days
Stowage Support Equipment	Buddy SLSS(1) Assembly Stowage Container	LDW340-58464-3-1			3.0	1.36	•			One per flight(2)		
	Umbilical/Tether Container	V36-787816			1.6	.73	•			One per flight(3)		
	PLSS/LiOH Cartridge Container Assembly	SEB-11100112-301			6.8	3.09	•			Four per flight(2)		
	PLSS/LiOH (Protective) Container Assembly	SV-723240-1					•			Four per flight(2)		
	Pressure Control Unit Container	V56-786502-11	19.1x10.96x9.96	.48x.27x.25	8.0	3.63		•			Two per flight	
	Secondary Oxygen Pack Container	V56-786503			9.3	4.22		•			Two per flight	
	MDA Umbilical Container	V56-786504-71	25.0x8.0 Dia.	.63x.20 Dia.	.3	.14		•			One per flight	
Maintenance Equipment	OPS(4) Antenna Repair Kit	SV-748660-1			.6	.27	•			One per flight(5)		
Don/Doff Support Hardware	Gas Connector Cover	SEB-13100219-301			*		•			One per L-EVA Crewman		
	MWC(6) Dust Cover	SEB-13100230-301			*		•			One per L-EVA Crewman		
	Electrical Connector Dust Cover	SEB-13100232-302			*		•			One per L-EVA Crewman		
	PLSS Oxygen Vent Cap	LSC-3303200-9			.1	.05	•			One per flight(5)		

FOOTNOTES OR REMARKS

*Individual item weight reflected in total PLSS/EVCS Assembly weight

(1) Secondary Life Support System

(2) Stowed in the Lunar Module

(3) Stowed in the Command Module

(4) Oxygen Purge System

(5) Stowed in the Lunar Module

(6) Multiple Water Connector

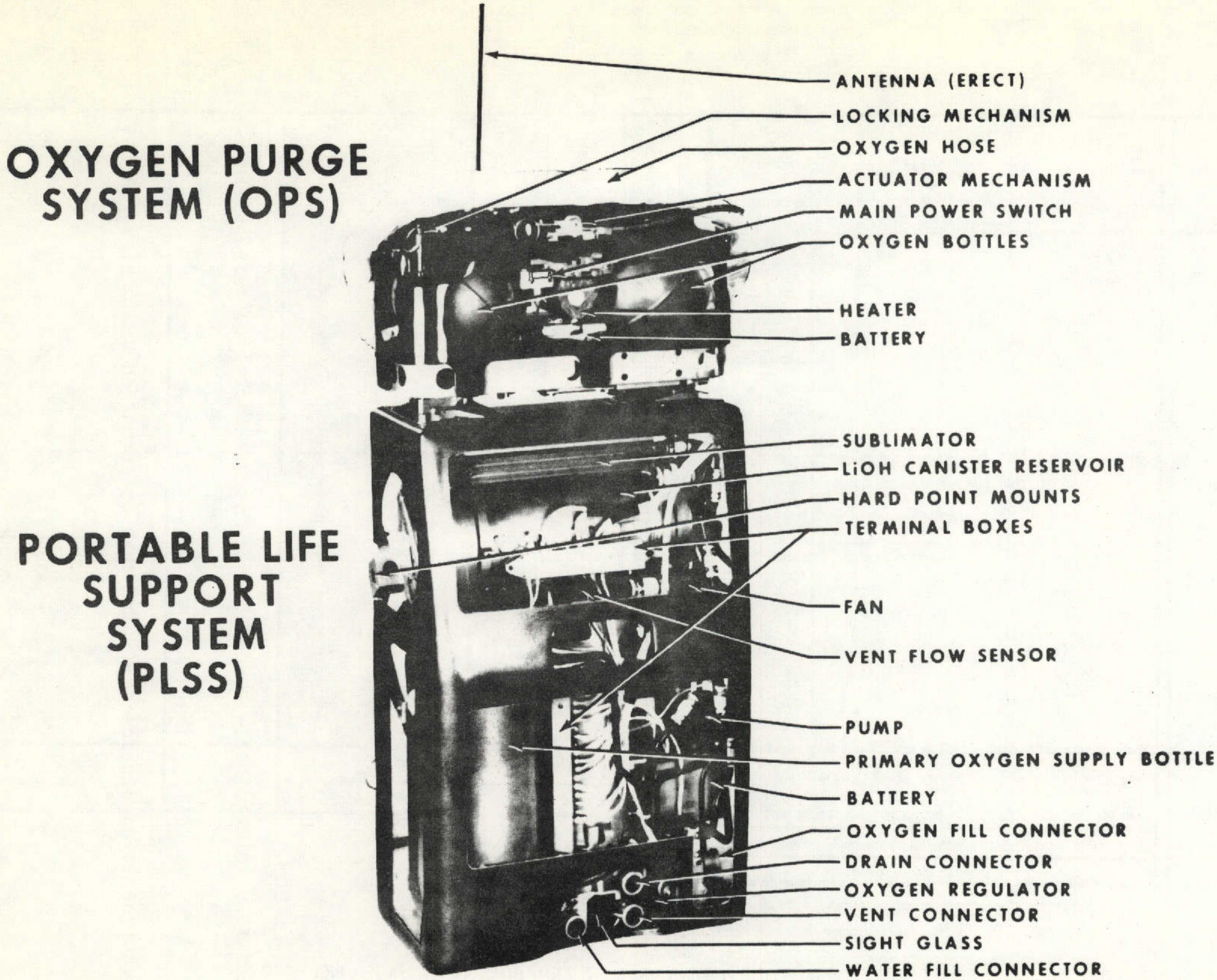


FIGURE 7-14: PORTABLE EVA LIFE SUPPORT SYSTEM--PROTECTIVE COVER REMOVED

FIGURE 7-15: PORTABLE LIFE SUPPORT SYSTEM--LUNAR APPLICATION

in the suit, and the water loop provides body heat removal through the use of liquid cooling garment. The water loop also provides system component cooling. To complete the total LSS package, a power supply (storage battery), communications system, telemetry system, caution and warning indicators (audio and visual), and system controls are incorporated. The current portable LSS can support metabolic loads ranging from 400 Btu/hr. to short-term peaks of 2000 Btu/hr. The current portable systems are rate sensitive with regard to expendables depletion and will not provide cooling until the airlock is depressurized to permit sublimator operation. The portable system being considered for use on the Space Shuttle is designated the -7 portable life support system (PLSS).

An Oxygen Purge System (OPS) is used in conjunction with the -7 PLSS to provide emergency oxygen in the event of primary LSS failure. The OPS is normally attached on top of the PLSS (see Figure 7-14) but can be mounted at various places on the suited crewman. The OPS will provide oxygen for a period of 30 minutes with a heat removal capacity of 800 Btu/hr. Should one of the water cooling systems malfunction during dual EVAs, a Buddy Secondary Life Support System (BSLSS) is being considered for Space Shuttle Application (see Figure 7-16). The BSLSS consists of a pair of water umbilical hoses with a standard connector on one end and a dividing connector at the other. The water flow from one PLSS is shared by two crewmen when the BSLSS is used. In addition to the dual hoses, the BSLSS unit includes a tether strap, two snap hooks, and an insulation sheath. This backup system was available for the later Apollo lunar missions.

The basic characteristics of the -7 PLSS and backup systems are summarized in Table 7-13. Additional subsystem level data are provided in Table 7-12 for those readers requiring information relative to the number of PLSS hardware items required per EVA crewman or for a total mission. Table 7-12 information is based on previous EVA missions.

In considering current portable life support systems, the following factors must be acknowledged:

TABLE 7-13: EVA PORTABLE LIFE SUPPORT SYSTEM (-7 PLSS) CHARACTERISTICS

PARAMETER / PORTABLE LIFE SUPPORT SYSTEM	WEIGHT		VOLUME		DIMENSIONS		SYSTEM CHARACTERISTICS
	lb.	kg.	$in.^3$	m^3	in.	m	
-7 Portable LSS	103	46.7	5100	83,589	26.0 x 17.8 x 10.5	.66 x .45 x .27	• Provides O_2, H_2O circulation, communications and telemetry, CO_2 and humidity control • O_2 flow: 0 to 3.8 lb./hr. at 3.75 to 4.05 psia • O_2 storage: 1410 psia at 70°F • Capacity: 12-0 Btu/hr. for 6 hrs., 2000 Btu/hr. short term • 30 Channel telemetry system • Maintains CO_2 below 7.5 mm Hg. for 6 hrs. at 1200 Btu/hr.
Oxygen Purge System - OPS	34	15.4	1400	22,946	-	-	• Operating temperature range: -130 to +130°F • O_2 flow: 4.0 lb./hr. (normal) 8.0 lb./hr. (high) • Usable O_2: 5.8 lb. • Contains two spherical O_2 stowage tanks: - 5.8 lbs. of O_2 at 5880 psia and 70°F - tank pressure: 0 to 6750 psia
Buddy Secondary LSS	7.1	3.2	-	-	-	-	• Provides H_2O cooling for LCG to failed PLSS water loop • H_2O flow of one PLSS shared by two crewmen

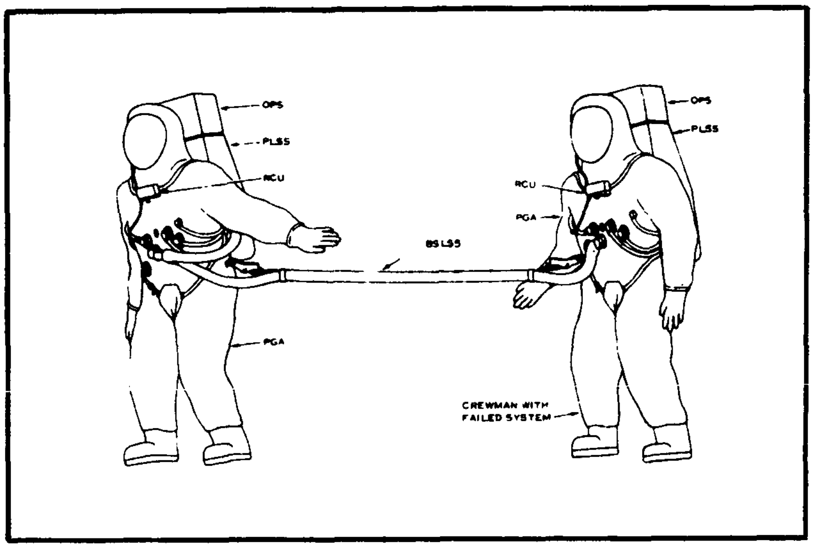


FIGURE 7-16: BUDDY SECONDARY LIFE SUPPORT SYSTEM

- Unit does not provide cooling until subjected to the vacuum environment.
- Oxygen and water recharge facilities are required aboard the vehicle.
- Battery recharge is required after each use.
- Lithium hydroxide replacement after each use.
- Vehicle water collection system for condensed water (humidity control condensate).
- Access volume may be increased over umbilical LSS due to dimensions of PLSS.

Advanced EVA portable life support systems may eliminate some of the above requirements/impacts. However, design has not been initiated for development of such systems; only concepts have been studied.

7.4.4 Advanced Portable Life Support Systems

Several EVA portable life support system preliminary designs have been studied for application to the Space Shuttle (ref. 7.16 and 7.17). Prior to the conceptual designs, two independent studies were conducted to determine the EVA primary and contingency life support system requirements for Space Shuttle vehicle and payload servicing. The requirements identified as a result of the LSS portion of the studies are shown in Figures 7-17 and 7-18 for the primary and contingency systems, respectively.

A number of primary life support system options were addressed during the aforementioned studies (i.e., Space Shuttle EVA/IVA support system requirements). Each of these options used high pressure oxygen stowage with the major system variations being in the method of heat rejection from the crewman and LSS equipment. The following subsystems for maintaining thermal control were the major candidates considered:

- Flash evaporators
- Water boiler
- Water sublimator (current systems)
- Modular ice pack (non-venting operation only)

The flash evaporator and modular ice pack subsystems, along with the current water sublimators, have received primary study emphasis during the initial EVA LSS requirements studies.

The physical characteristics of the primary LSS concept developed by the Hamilton Standard Division are shown in Figure 7-19. The system used a flash evaporator subsystem and meets the requirements specified for Shuttle EVA. The schematic diagram of the LSS concept is shown in Figure 7-20. An emergency

SPACE SHUTTLE EVA PORTABLE LIFE SUPPORT REQUIREMENTS COMPARISON

HAMILTON STANDARD DIVISION

• Duration	4 Hours
• Metabolic Loads	1000 Btu/hr. avg., 1500 Btu/hr. peak
• O_2 Supply	1.04 Lbs.
• Pressure Control	8.2 $\pm$ 0.2 Psi
• CO_2 Control	7.6 mm Hg Max.
• Contaminant Control	0.19 Lbs. Charcoal 28 Micron Filter
• Humidity Control	50°F Dew Pt. Max.
• Ventilation	6 ACFM Min.
• Voice Communications	Primary: Duplex Back-Up: Simplex
• Life	Shelf: 15 Yrs. Operational: 6000 Hrs.

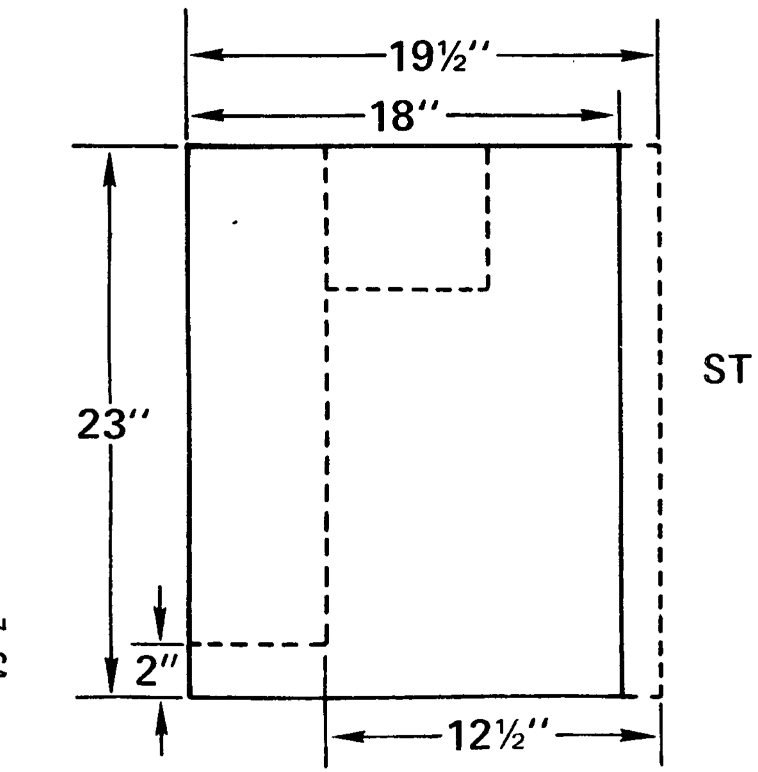
VOUGHT SYSTEMS DIVISION

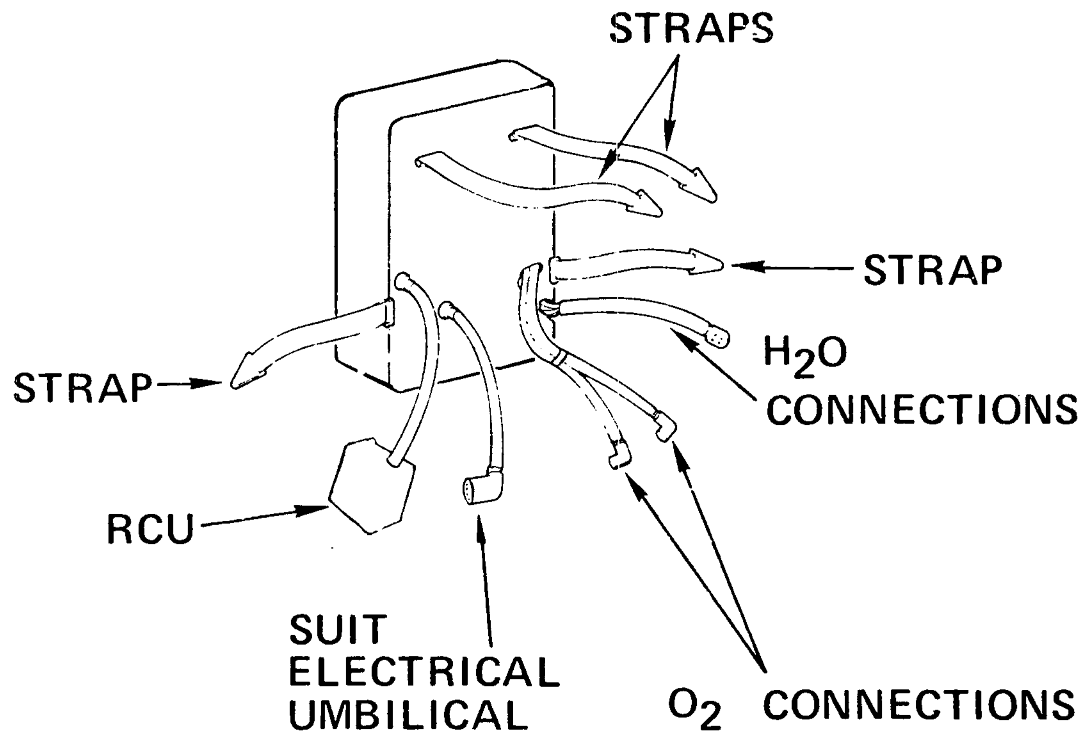
• Duration	4.0 Hours
• Metabolic Rates	
- Minimum	400 Btu/hr.
- Shuttle Flight EVA Avg.	800 Btu/hr.
- Single EVA/IVA Max. Avg.	1000 Btu/hr.
- Maximum for 1/2 Hour or Less	2000 Btu/hr.
• Thermal Storage in Crewman	$\pm$100 Btu/hr.
• Carbon Dioxide Partial Pressures	
- Nominal	5 mm Hg.
- Average	7.6 mm Hg.
- Maximum for Less Than 30 min.	15.0 mm Hg.
• Ventilation Loop Flow Rate	5.5 ACFM
• Suit Pressure	8.0 Psia
• Communications	
• Multiple Use	
- During a Shuttle Flight	
- Multiple Shuttle Flights	
- Different Crewmen	
• Environmental Heat Leak to EMU	+300 Btu/hr. -375 Btu/hr.

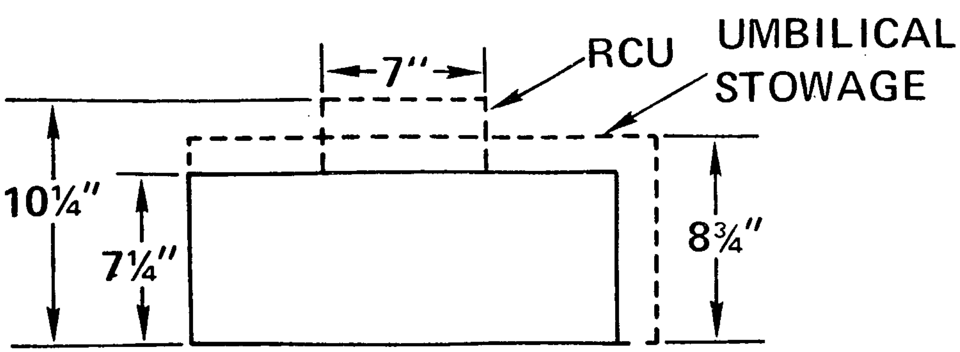
FIGURE 7-17: REQUIREMENTS COMPARISON FOR SHUTTLE PORTABLE LSS

SPACE SHUTTLE EVA EMERGENCY LSS REQUIREMENTS COMPARISON			
HAMILTON STANDARD		VOUGHT SYSTEMS DIVISION	
• Duration	15 Minutes	• Reserve O_2 for Suit Leak	3.75 Lbm. usable O_2
• Metabolic Load	1600 Btu/hr.	• CO_2 Level Inspired	15 mm Hg. or less
• Pressure Control	8.2 $\pm$0.2 Psi	• Metabolic Rate	1200 Btu/hr.
• CO_2 Control	15 mm Hg Max.	• Environmental Heat Leak to Suit	+220 Btu/hr. -280 Btu/hr.
• Ventilation	3.2 ACFM Min.	• Crewman Thermal Storage	$\pm$300 Btu/hr.
• O_2 Supply	2.27 Lbs. Min. Usable	• Failure in Any EVLSS Subsystem	Redundant Emergency Provisions
• Thermal Control	300 Btu Max. Heat Storage	• Duration	24 Minutes
• Visual Displays	O_2 Supply Pressure O_2 Regulated Pressure	• Suit Pressure	8.0 Psia
• Life	Shelf: 15 Yrs. Operational: 300 Hours		

FIGURE 7-18: REQUIREMENTS COMPARISON FOR SHUTTLE EMERGENCY LSS

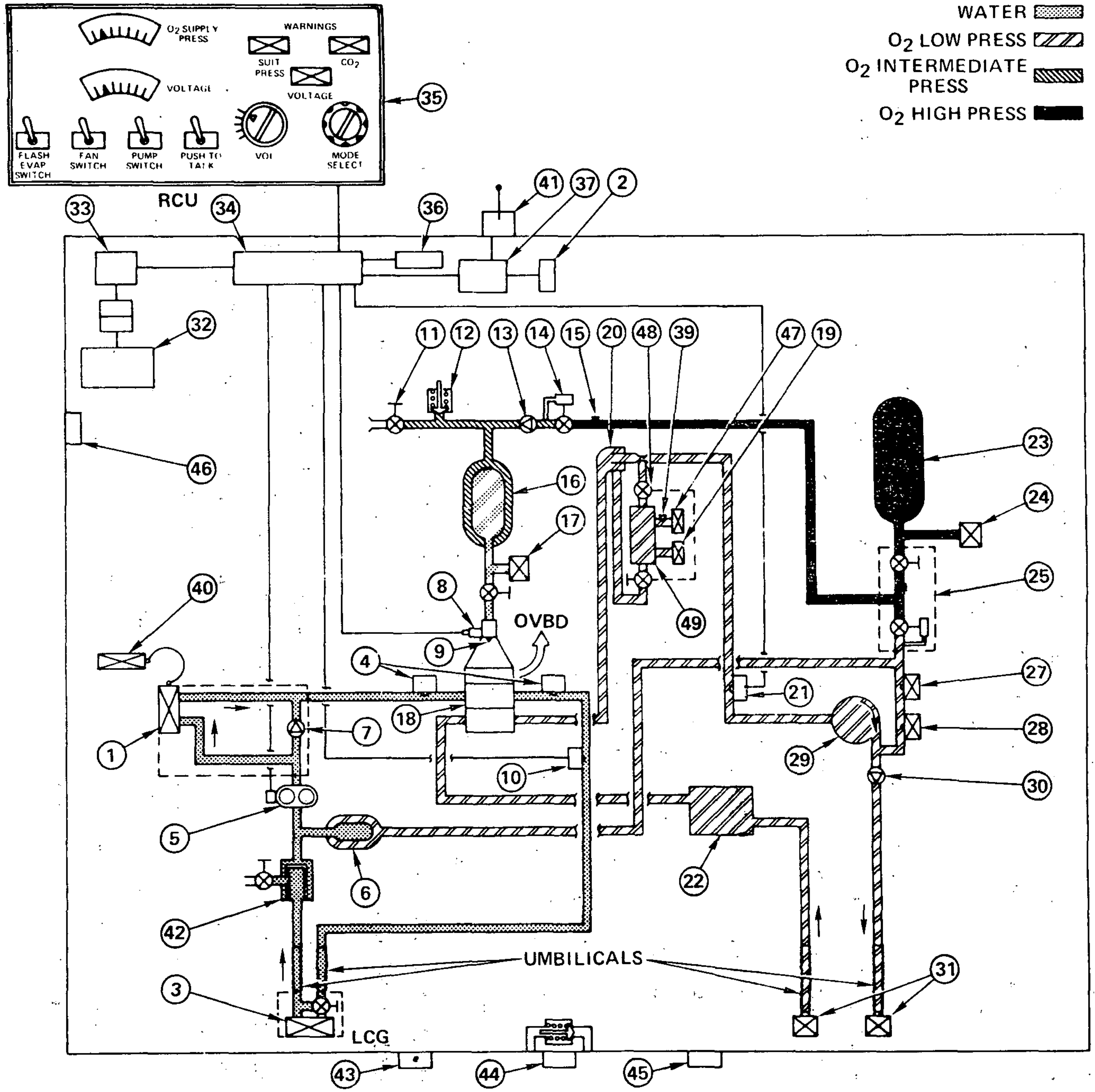






STOWED VOLUME	3771 IN.^{3}	(26,510 CM.^{3})
DONNED VOLUME	3000 IN.^{3}	(21,090 CM.^{3})
WEIGHT	79 LBS.	(35.8 KG.)

FIGURE 7-19: PRIMARY LSS SYSTEM CONCEPT--PHYSICAL CHARACTERISTICS (HSD)



ITEM	PART NAME
1	MULTIPLE H_2O FEMALE DISCONN
2	SUIT ELEC UMBILICAL
3	MULTIPLE H_2O MALE DISCONN
4	H_2O ΔT TRANSDUCER
5	PUMP MOTOR ASSY
6	ACCUMULATOR
7	CHECK VALVE
8	SOLENOID
9	NOZZLE VALVE
10	TEMP SENSOR
11	S/O VALVE
12	RELIEF VALVE
13	CHECK VALVE
14	PRESS REG
15	FLOW LIMITER
16	H_2O RESERVOIR
17	FILL CONN
18	EVAPORATOR HX
19	DRAIN CONN
20	H_2O SEPARATOR, 1ST STAGE
21	TEMP TRANSDUCER
22	LiOH CANISTER
23	OXYGEN BOTTLE
24	O_2 FILL CONN
25	O_2 REG & S/O ASSY
27	PGA PRESS DIFF SWITCH
28	PGA PRESS DIFF TRANS
29	FAN/MOTOR ASSY
30	CHECK VALVE
31	O_2 CONNECTORS
32	POWER SUPPLY
33	CURRENT SENSOR
34	TERMINAL BOX
35	REMOTE CONTROL UNIT
36	ELECTRONIC CONTROLLER
37	COMMUNICATIONS
39	ORIFICE
40	H_2O CONN STOWAGE CAP
41	ANTENNA
42	GAS SEPARATOR
43	O_2 INLET CONN STOWAGE PLATE
44	O_2 OUTLET CONN STOWAGE PLATE
45	PLSS/PGA ELEC UMBILICAL STWG PLT
46	BATT CABLE STOWAGE PLATE
47	PRESSURE PORT
48	S/O VALVE, DOUBLE BANK
49	H_2O SEPARATOR, 2ND STAGE

FIGURE 7-20: PRIMARY LSS SCHEMATIC (FLASH EVAPORATOR OPTION)--HSD

LSS unit concept was also considered by Hamilton Standard. This unit consists of an open-loop oxygen purge system of 15-minutes duration. The emergency system envelope is approximately 18.0 x 7.2 x 6.0 in. (.46 x .18 x .15 m) and weighs about 25 lbs. (11.3 kg.). The unit volume is 776 in.^{3} (12,719 cm.^{3}).

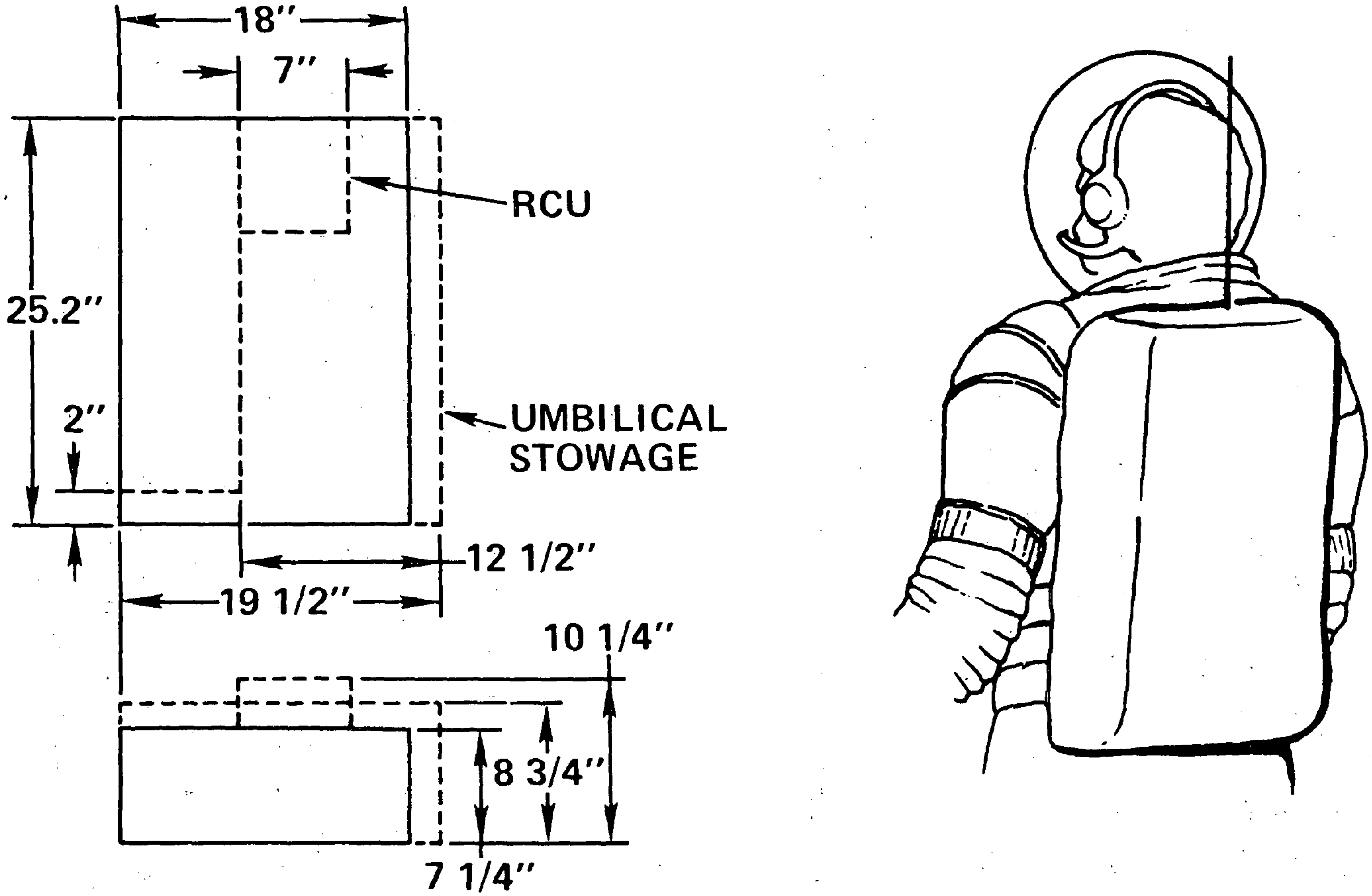
The integration of the primary and emergency life support systems was also considered in the Hamilton Standard study. By integrating the systems, approximately 480 in.^{3} (7,867 cm.^{3}) and 8 lbs. (3.6 kg.) were eliminated from the separate units in addition to several physical and functional interfaces between the two units and the vehicle stowage and recharge facilities. The integrated portable LSS, as recommended by Hamilton Standard, is shown in Figure 7-21. Physical characteristics of the integrated unit are included.

The Vought Systems Division of LTV also conducted studies associated with Space Shuttle EVA requirements. The EVA life support system options considered in the LTV study included the following:

- All umbilical
- Umbilical/vent
- Umbilical/non-vent
- Portable vent/non-vent (Integral)
- Portable vent/non-vent (Detached)
- Modular ice pack vent/non-vent

The umbilical LSS concepts were considered to introduce umbilical management problems and were not capable of servicing all EVA Shuttle areas. The umbilical systems were eliminated from competition early in the LTV study.

The EVA primary life support system recommended by LTV consists of a portable unit utilizing a flash evaporator for heat rejection during the vented mode. The non-vented mode would use a modular ice pack for thermal control. In the vented mode, the flash evaporator exhausts the by-products to space, which could contaminate sensitive experiments. The modular ice pack system allows flash evaporator bypass for contamination sensitive areas for a one hour period per ice pack unit.



	STOWAGE VOLUME	DONNED VOLUME	WEIGHT
PRIMARY AND EMERGENCY LSS	4547 in.^{3} (74,525 cm.^{3})	3776 in.^{3} (61,888 cm.^{3})	104 lbs. (47.2 kg.)
INTEGRATED LSS	4146 in.^{3} (67,953 cm.^{3})	3300 in.^{3} (54,087 cm.^{3})	96 lbs. (43.5 kg.)

FIGURE 7-21: SHUTTLE TOTAL EVA LSS INTEGRATION CONCEPT--CHARACTERISTICS (HSD)

The orientation of the LSS hardware on the suited crewman is shown in Figure 7-22. Physical characteristics of the primary LSS and the modular ice pack are also shown on the figure. Functional diagrams of the primary LSS system and emergency unit are contained in Figure 7-23. An emergency oxygen pack for use with the LTV primary LSS was also considered by LTV. The system is essentially an O_2 stowage/purge system as in previous concepts. Characteristics of the system are shown in Figure 7-22. The emergency oxygen pack is sized for 24 minutes operation.

Since each of the life support systems discussed above are in the conceptual phase, detailed information on the physical, operational, and performance characteristics are not available. Further study by the NASA and industry is required before the final EVA life support system selection will be made.

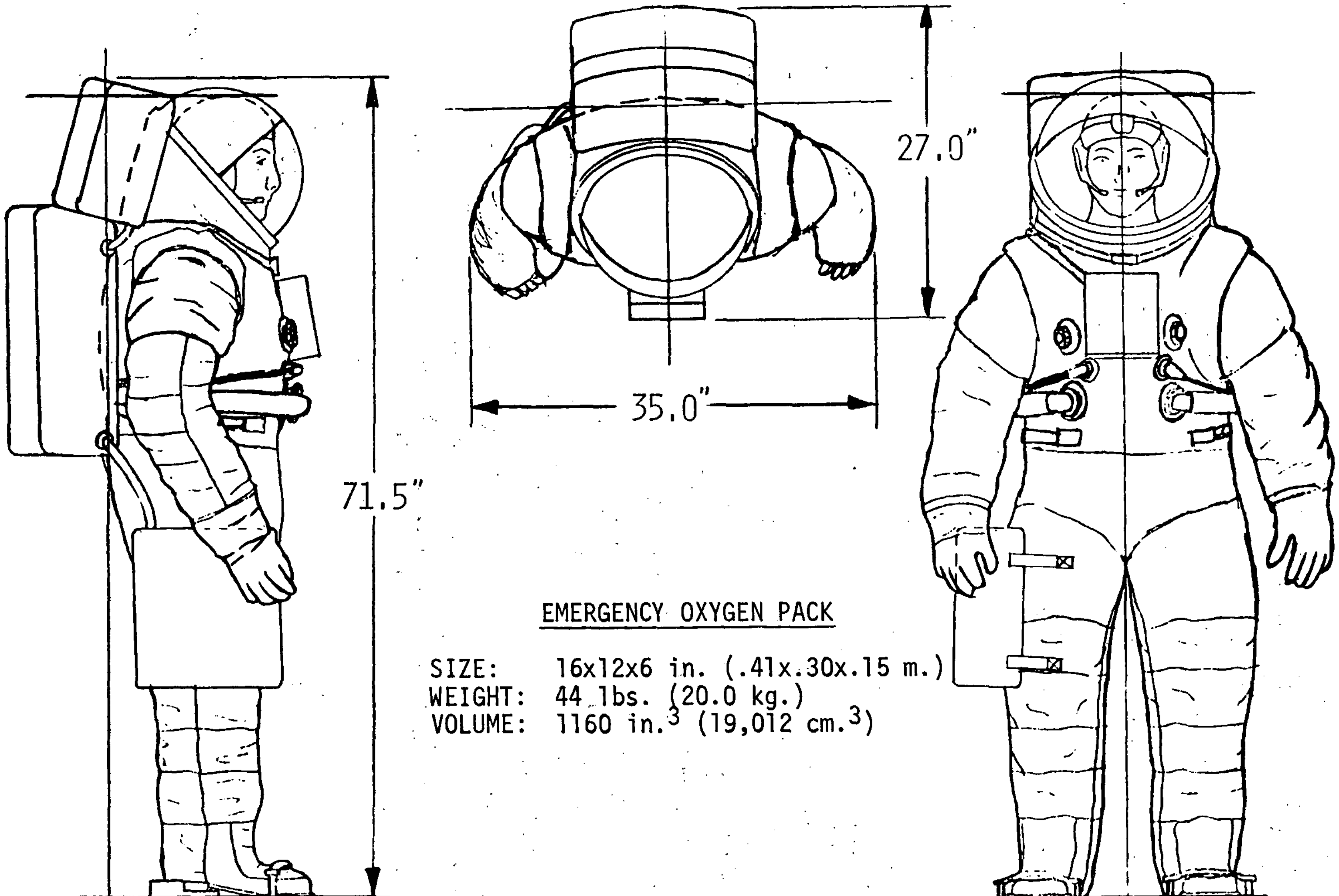
The information and characteristics presented for the Space Shuttle EVA life support system were derived from preliminary data contained in references 7.16 and 7.17.

7.5 WORKSITES AND WORKSTATIONS

7.5.1 Introduction

The orbital EVA missions conducted on previous space flights demonstrated that many diversified operations can be effectively conducted outside the spacecraft if one fundamental item is provided: adequate equipment to support the EVA crewman at each worksite, particularly restraint equipment. In the weightless (zero-g) environment the EVA crewman must have a sufficient means of reacting all forces applied by him to any object.

Unlike the earth environment, in weightlessness all crewman task performance must be evaluated in terms of specific forces required over specific time intervals to determine the precise requirements for restraints. Tasks requiring low force applications for short time periods (e.g., inspection, switch



EMERGENCY OXYGEN PACK

SIZE: 16x12x6 in. (.41x.30x.15 m.)
WEIGHT: 44 lbs. (20.0 kg.)
VOLUME: 1160 in.^{3} (19,012 cm.^{3})

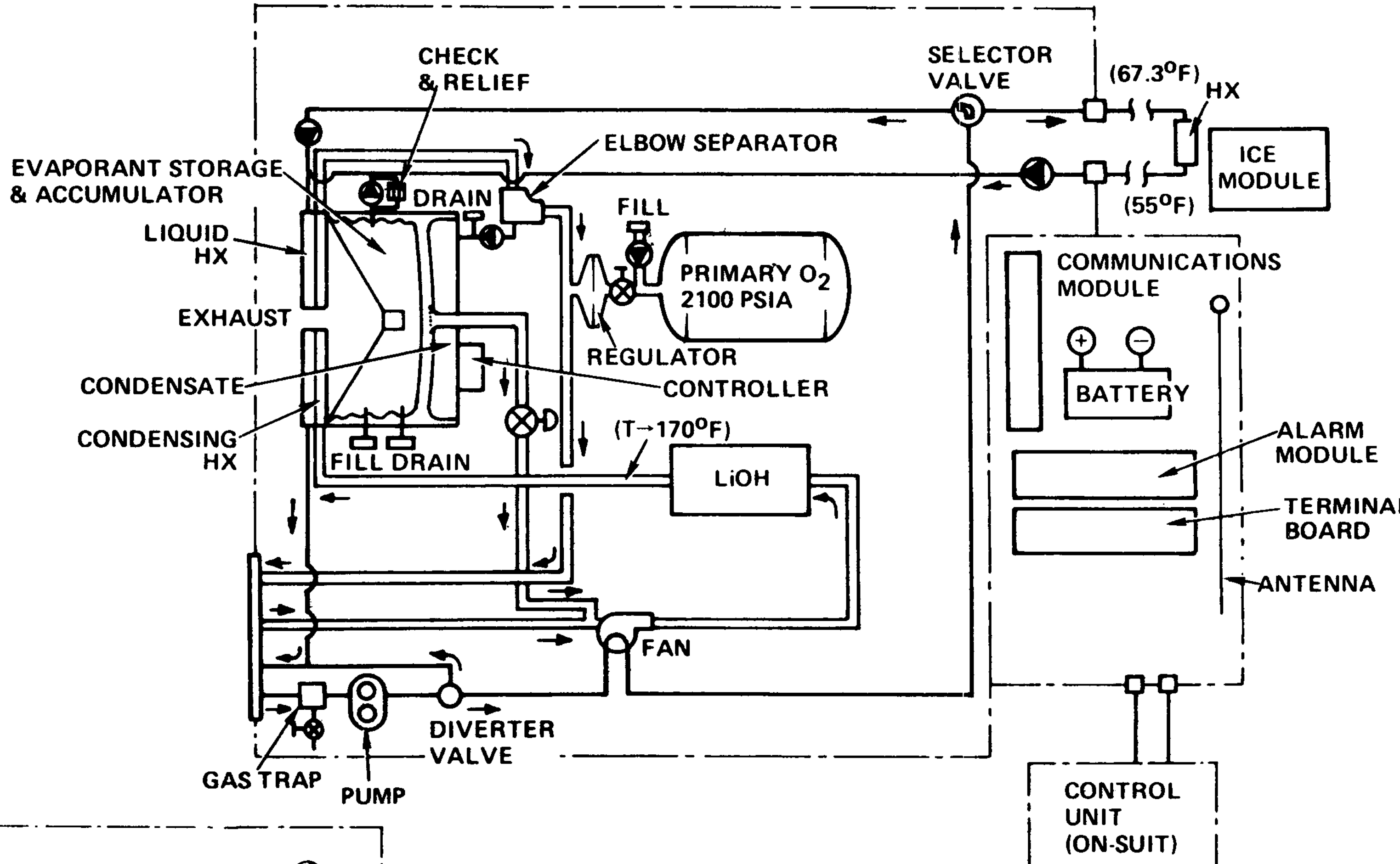
PRIMARY LSS

SIZE: 23.4x16.0x9.4 in. (.59x.41x.24 m.)
WEIGHT: 91 lbs. (41.3 kg.)
VOLUME: 3635 in.^{3} (59,578 cm.^{3})

ICE PACK

SIZE: 13.5x13.5x4.5 in. (.34x.34x.11 m.)
WEIGHT: 33 lbs. (15.0 kg.)
VOLUME: 890 in.^{3} (14,587 cm.^{3})

FIGURE 7-22: LSS HARDWARE LOCATION ON SUITED CREWMAN--LTV CONCEPT



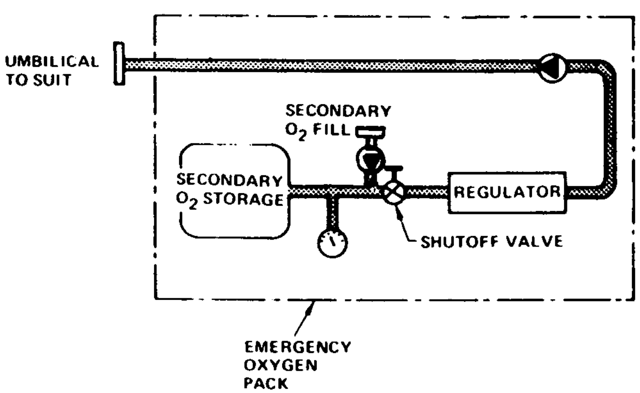


FIGURE 7-23: PRIMARY AND SECONDARY LSS SCHEMATIC--LTV SHUTTLE CONCEPTS

actuation) may not require specialized restraints, while high force applications or low force for extended periods in EVA will require special restraint systems. High force applications on orbital missions have previously been limited to the ability of the EVA crewman to provide peak and sustained forces. These applications have been the subject of considerable study by NASA and various contractors; however, force thresholds are not properly defined or measured by this method, particularly since they are strongly task dependent. Therefore, each candidate EVA task must be studied to determine the "type" of workstation most suited to the task requirements (ref. 7.18).

7.5.2 General EVA Workstation Types

EVA worksites for future space programs have generally been classified as prepared and unprepared. Each class is defined below:

Prepared Worksite: A worksite in which the location and the EVA operations to be performed are established during the equipment design and development phases. The site contains all EVA supporting hardware to perform the required tasks.

Unprepared Worksite: A worksite in which no special restraints or equipment is provided for conducting extravehicular operations. The location may or may not be predetermined prior to EVA since unprepared worksites are generally sites of unplanned operations.

Prepared worksites may incorporate a fixed EVA workstation or provisions for attaching portable workstations. The fixed workstations on previous spaceflights were designed concurrently with the systems/equipment requiring EVA and were dedicated workstations. Future programs are studying EVA workstation concepts which will allow attachment of a versatile workstation to a number of worksites prior to launch or installing a portable workstation on-orbit.

7.5.3 Worksite Requirements

The development of worksites beginning with the Gemini Program and continuing through Skylab has generated a set of worksite baseline requirements criteria. This criteria has been developed into a checklist for use by planners and designers requiring EVA (see Figure 7-24). Based on the specific task to be performed, the checklist may be used to identify the characteristics and hardware items required for each task. The appropriate requirements can then be incorporated into the design of a fixed workstation or the equipment selected for incorporation into a "modular" workstation (ref. 7.1).

7.5.4 EVA Workstation Design

EVA workstation designs have ranged from simple handholds and foot stirrups (see Figure 7-25) to elaborate workstations containing numerous aids for restraining and assisting the crewman during task performance (see Figure 7-26). The preliminary workstation concept shown in Figure 7-26 is intended to be attached to a Shuttle Orbiter manipulator arm (i.e., Attached Manipulator System - AMS) and controlled by the EVA crewman during translation. The manipulator controls would retract to a stowed postion to permit access to the work areas. A number of similar preliminary manipulator arm concepts have been proposed for Shuttle Orbiter payload servicing.

Volume II of this report is devoted to the analysis of future space vehicles and their payloads to determine the EVA workstation requirements. Conceptual designs of versatile EVA workstations are included in the volume. A guideline assumed in the development of the workstations required the workstations to be hard mounted prior to vehicle launch or transported to the worksite either by the crewman or manipulator arms. The results of the above analysis and EVA workstation conceptual designs will not be presented in this Section--the reader is referred to Volume II of this report, "EVA Workstation Conceptual Design".

STABILIZATION

- Type of Stabilization
  - Restraint
  - Handhold/foothold
  - Both restraints and hand/foothold
  - Cage
  - Portable or fixed
- Restraint Location
  - Waist
  - Foot
  - Other body attachment (chest, knee, etc.)
- Restraint Type
  - Rigid
  - Flexible
  - Rigidized
  - Retractable - spring loaded
- Handhold/Foothold Characteristics
  - Length
  - Hand/foot clearance
  - Location
  - Relation to restraints
- Restraint Fastener
  - Quick disconnect
  - Positive feedback of activation
- Restraint Adjustments
  - Disconnect/connect
  - Tighten/loosen
- Safety Considerations
  - Backup tether
  - Restraints - footholds don't themselves become hazards

EQUIPMENT MOUNTING

- Umbilical Secure
- Temporary Storage of Equipment
  - Tools
  - Samples
  - Data recording equipment

FORCE

- Type of Force
  - Sustained
  - Impulse
- Direction of Force
  - Up/down
  - Lateral
  - Fore/aft
  - Rotational
- Magnitude of Force
- Counterforces

SITE ACTIVATION

- Type of Activation
  - Remote
  - Local - pre-entry
  - Local - post-entry
- Operations
  - Activation of light sources
  - Configuration of structures
  - Selection of operational modes
  - Decision to enter site

SITE LOCATION

- Type of Location
  - Whole body in free space
  - Body partially in free space - partially in confined space
  - Within unpressurized vehicle
  - Transportable site - as an end of sepentuator or portable workstation
- Relationship to Vehicle
  - Immediately adjacent to vehicle structures
  - Removed from vehicle
  - Line of site or hidden

SITE ENTRY

- Clearance of Entry
  - Whole body
  - Limb
  - Encumbered - unencumbered
- Provisions for Emergency Escape
- Safety Hazards Around Entry
  - Protuberances
  - Moving parts
  - Unstable structures
  - Sensitive areas
- Visibility of Entry
  - Color coding of translation aids - handholds, foot restraints
  - Lighting of entire entrance
  - Lighting of worksite within entry
- Body Orientation to Entrance at Entry
  - Always head first or frontal
  - Sideways entry is acceptable if entrance and worksite are in the field of view during actual entry
- Umbilical Dynamics

LIGHTING

- Type
  - Body mounted
    - Wrist
    - Helmet
    - Chest
  - Hand held
  - Removable
  - Fixed
- Number of Lights
- Location of Lights
- Field of View
- Brightness
- Avoidance of Glare
- Color
- Adjustments
  - Direction
  - Brightness
  - Field of view size
  - Number of lights
  - Location
- Power Requirements

ASTRONAUT/WORKSITE INTERFACE

- Type of Site
  - Unconfined
  - Semiconfined
  - Confined
    - Limbs
    - Whole body
      - body clearances
      - presence of protuberences
- 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

MOBILITY

- Motions Required in Worksite
  - Whole body
    - Rotational
    - Translational
      - lateral
      - front-back
      - up-down
      - twisting
  - Limbs
    - Direction of motion
    - Range of motion
- Extent of Motion
- Frequency of Motions

CONTROL/DISPLAY

- Nominal Operational
  - Location
  - Size
  - Type
  - Operating characteristics
  - Number
  - Illumination
  - Labelling
  - Orientation
  - Relation of controls to displays
- Contingency Operation
  - Alarms
  - Malfunction detection
  - Fault isolation
  - Checkout

SITE OCCUPANCY

- Duration
- Frequency - number of times during EVA and during one mission
- Number of similar sites

FIGURE 7-24: WORKSITE REQUIREMENTS CHECKLIST

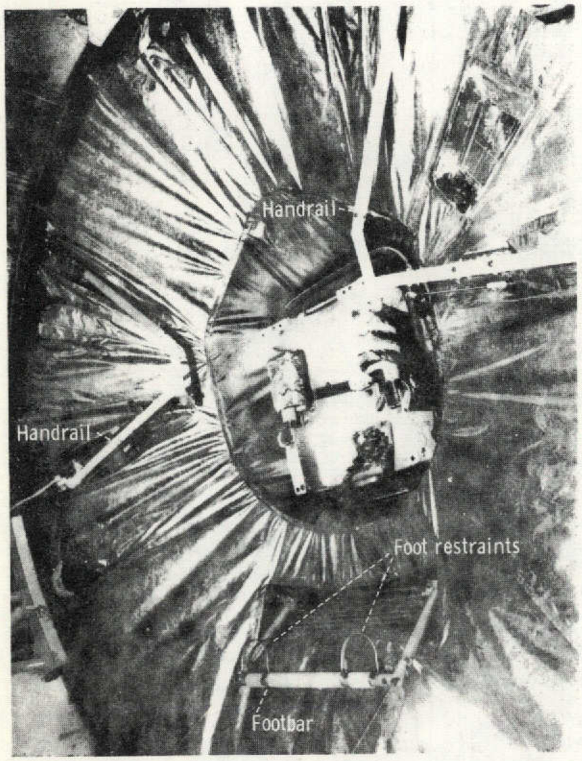
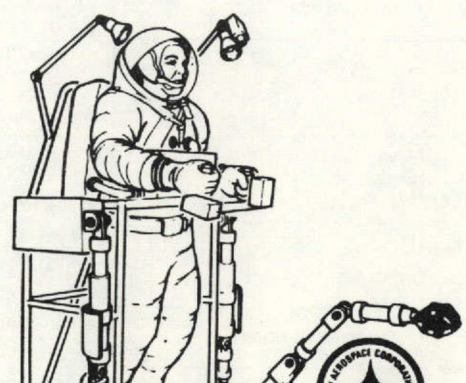


FIGURE 7-25: GEMINI EVA WORKSTATION AIDS--FOOT STIRRUPS AND HANDRAILS

FIGURE 7-26: EVA WORKSTATION CONCEPT--INCLUDING MANIPULATOR ARMS AND EQUIPMENT



7.6 LIGHTING

7.6.1 Introduction

Only preliminary information is available concerning lighting and illumination levels on the Space Shuttle Orbiter--particularly lighting associated with the extravehicular crewman's activities and translation route. The information presented in the following subsections was obtained from Apollo and Skylab program documentation and applied to the Shuttle Orbiter. The material to follow is primarily concerned with lighting required to perform tasks inside the vehicle cabin in support of EVA, and EVA operations on the "dark side" of the earth orbit.

7.6.2 EVA/IVA Lighting - Internal

The space vehicle internal lighting system must provide general illumination of sufficient level (5 ft.-L. min.) to allow crewmen visual access to interior vehicle surfaces and to facilitate removal, from the stowage compartment, those items of crew equipment required for IVA or EVA. The lighting in the stowage areas should be adjustable in intensity from 5 to 15 ft.-L. to eliminate shadowing and to illuminate dark areas. General lighting (5 ft.-L.) strategically located along the crewman's egress route from the cabin compartment to the airlock hatch is required to provide safe EVA crewman (suited) transfer.

7.6.3 Airlock Lighting

General illumination of at least 5 ft.-L. should be provided in the airlock during EV or IV activities. The individual light fixtures should be designed with impact protection devices to avoid possible damage from equipment. Each flush-mounted fixture and protection device will aid in preventing the crewman from injury while also lessening possibilities of light damage from the crewman in the confined cabin space. The fixture design should direct the light into the desired area with no visual discomfort to the crew members.

The on/off controls for the lighting should be located on the airlock control panel, main cabin control panel and externally adjacent to the hatches. The designated number of lights should be so arranged to preclude the requirement for utility lights in the airlock (ref. 7.19).

Integral lighting provides the primary means of illuminating the airlock Display and Control (D/C) panel with the capability for variable dimming down to zero. It should be noted that dimming must be free of detectable flicker at any brightness level, and the brightness level cannot interfere with instrument operation. The instruments and meter glass should be designed so as not to produce parallax, distortion or undesirable reflections. Anti-reflection coatings may be applied to glass or glass-like surfaces. Material which can shatter or splinter upon impact will not be used on any instruments which require a glass cover in the control and display panel. This same recommendation applies to any lighting device in the space vehicle.

7.6.4 EVA Lighting - External

Illumination must be provided along the EVA transfer routes to the Shuttle bay worksite areas at a minimum brightness of 2 ft.-L. These lights should be stationary and operate at a fixed brightness level. The EVA crewman may also be provided with a portable battery-operated light source for additional illumination. This item of crew equipment must be tethered to the crewman or temporarily restrained with velcro contact strips enroute to and at the EVA payload worksite. In the event of a contingency which requires inspection or repair activities on the space vehicle exterior, adjustable light fixtures may be provided. These devices should be capable of floodlighting any designated area of the vehicle's surface.

7.6.5 Shuttle Payload Bay Lighting

The payload lighting system should provide sufficient intensity to illuminate the overall payload bay. Based on the NASA information available during preparation of this report, the following preliminary requirements for

Shuttle payload lighting have been defined, with the qualification that present studies and subsequent simulated tests may cause these requirements to be revised:

- Five general light source assemblies shall be provided along the sides of the payload bay, three to starboard and two to port and approximately six feet above the payload bay floor level.
- Each light source-assembly shall consist of two lamps behind a Fresnel lens diffusing surface.
- Each lamp shall operate and produce acceptable illumination at supply voltages (nominally 28 vdc) of 23 to 30.5 VDC and shall produce no less than 25 lumens per watt.
- One lamp of each assembly shall be connected in a lighting circuit; the remaining lamps shall be connected in a second independently controlled circuit.
- Using a fore/aft perpendicular plane as a reference, either lighting circuit shall produce at least 25 foot-lamberts, and both lighting circuits shall produce at least 40 foot-lamberts of illumination on that portion of the plane within the bay.
- On-off control of each lighting circuit shall be from the payload handling station or the airlock.

Four supplementary spotlight sets may also be provided, one each for the TV camera systems mounted fore and aft of the payload and one on each of the Shuttle-attached manipulator arms. Control for these sets will be located at the payload handling station. Although these lights can provide additional illumination in a selected area of interest, they should not be considered in the design for fixed payload lighting (ref. 7.2 and 7.4).

7.6.6 Emergency Lighting

Emergency lighting should be provided in case of primary power failure. This system should be isolated on a separate bus from the main power source and should actuate a portion of the general illumination lights in the crew compartment, stowage area, egress routes, passageways airlock, ingress route, and payload bay at a minimum brightness level of 2 ft.-L. The design should designate a required number of lights from the general illumination system to be operational in less than ten seconds after the emergency lighting switch(es) has been activated. These switches should be installed in accessible locations and readily recognizable by form.

7.6.7 Supplementary Lighting Information

A list of definitions and pertinent data (see Table 7-14) has been compiled. Although incomplete, it will provide additional information to assist the planner in a better understanding of Shuttle lighting requirements.

Table 7-15 has been prepared to identify EVA lighting guidelines for each of the activities discussed in this subsection.

Under the present guidelines the pre- and post-EV/IV activities, including pressure suit donning/doffing, drying the pressure suit and recharge of the life support unit, will be accomplished under the lighting levels specified for the airlock. However, if the EVA associated operations are transferred to a separate area away from the airlock, the same guidelines for adequate lighting would apply (ref. 7.19).

TABLE 7-14: SUPPLEMENTARY INFORMATION

METERIC CONVERSION

All lighting units in this section are in the American units because all presently used instruments are either calibrated to foot candles or foot lamberts. Listed below are the conversion factors to be used for obtaining the values of Internal System of Units (SI):

Multiply	By	To Obtain
Foot candle	1.076×10^{1}	Lux
Foot lambert	3.426	Candela per sq. meter
Candle power	1.2566×10^{1}	Lumen
Foot lambert	1.076	Millilambert

DESIGN AND CONSTRUCTION

The following methods for interior and exterior lighting are recommended to be used singularly or in combination.

- Luminescent light - self-radiating
- Incident lighting - direct, indirect
- Back lighting - transillumination

The illumination source can be incandescent, electroluminescent, light emitting diodes, (LED), or any other source where the brightness and other design requirements can be met.

FLOODLIGHTING

Light provided by a fixture separated from a display, indicator or panel assembly.

GLOSS

Brightness or luster of a surface that approaches closely the condition of specular reflection as opposed to a diffused surface (matt). A gloss number is the ratio of specularity related to a diffused surface reference.

ILLUMINATION

The amount of light falling on a unit area measured in foot candles.

INTEGRAL LIGHTING

That lighting which originates within a display, indicator or panel assembly.

TABLE 7-14: SUPPLEMENTARY INFORMATION (CONT'D.)

LUMINANCE

Brightness of the reflected light from a surface given off in the direction of the observer; expressed in foot lamberts.

CANDLEPOWER

Luminous intensity of any light source.

BRIGHTNESS

Luminance emitted from a surface in luminous flux per steradian solid angle per unit area of source; measured in foot lambert (ft.-L.).

TABLE 7-15: SPACE VEHICLE EVA LIGHTING GUIDELINES

ACTIVITY	LIGHTING		REMARKS
General Illumination			
• Passage Ways	Incandescent	5 Ft.-L.(Min.)	
• Egress Routes	Incandescent	5 Ft.-L.(Min.)	
Stowage Areas	Combination-Fluorescent Incandescent	5-15 Ft.L.	Adjustable Intensity
Airlock			
• General-Interior	Combination	5 Ft.-L.(Min.)	
• D & C Panel	Integral	2 Ft.-L.Max.*	Adjustable Intensity
EVA Lighting			
• Transfer Routes	Incandescent	2 Ft.-L.(Min.)	
• Payload Bay	Incandescent	25 or 40 Ft.-L.	Two Circuits
• Portable	Battery	TBD	
Supplementary			
• T.V. Spotlight Sets	Incandescent	25-50 Ft.-L.	
Contingency	Incandescent	50 Ft.-L.	Exterior Floodlighting
Emergency	Combination	2 Ft.-L.(Min.)	

*NOTE: Certain displays and warning indicators may require higher intensity levels.

7.7 CREW AND CARGO TRANSFER SYSTEMS

7.7.1 Introduction

Numerous methods have been devised for the EVA translation of crewmen and transfer of cargo, some of which have been successfully flight tested. The better known systems as well as unique hardware innovations for Skylab and, perhaps, applicable to the Shuttle Orbiter will be discussed in this section.

Although many of the previously conceived ideas have been discarded as being too bulky, ineffective or inefficient, it is possible that a variation or combination of those methods would result in a better EVA approach on future space missions.

The movement of crewmen and large quantities of cargo over a wide range of distances on future missions will necessarily require more advanced techniques and equipment than have been developed thus far.

7.7.2 Translation of Crewman

- Manual (Handholds/Handrail) - Most EVA crewman translation has been achieved by pre-installed handholds. This device is generally a single unit rectangular metal rail mounted about 3 inches above the surface of the vehicle and attached to the surface at both ends.

  The handrail is a continuation of the handhold configured in single or parallel units 18 to 20 inches apart. The length is variable depending upon the application. The general design characteristics for these items have been compiled in Table 7-16.

- Adhesive Devices - This concept encompasses both chemical and electrical devices. Chemically activated adhesive pads are capable of producing attachment forces of 400 psi or greater; however, they also

TABLE 7-16: EVA HANDHOLD AND HANDRAIL CHARACTERISTICS

DEVICE	DESIGN CHARACTERISTICS					
	SHAPE / GRIP CROSS SECTION	LOAD LIMITS (LBS)	TYPE OF LOAD	DIRECTION OF LOAD	ALLOWABLE DEFLECTION (INCHES)	REMARKS
HANDHOLD	RECTANGULAR / 1.25X.62 INCHES .25 IN CORNER RADIUS	600	CONCENTRATED	IN ANY DIRECTION	0.5	• MUST PROVIDE NO LESS THAN 5.5 INCHES OF STRAIGHT GRASPING SURFACE
HANDRAIL	RECTANGULAR / 1.25X.62 INCHES .25 IN CORNER RADIUS	600	CONCENTRATED ON MOST CRITICAL 2 INCHES OF MEMBER	IN ANY DIRECTION	1.0	• RAISED DISTANCE FROM VEHICLE SURFACE MUST BE NO LESS THAN 2.5 INCHES TO INSURE GLOVE CLEARANCE

have the disadvantage of altering the surface of the vehicle. Another device in this same group utilizes electroadhesive forces which offers a potential means of adhering to any conductive surface. This provides the EV crewman virtually unlimited maneuvering and position capability without altering the contact surface. An electroadhesive device is illustrated in Figure 7-27. One disadvantage is that current electro-adhesive devices require flat surfaces for optimum operation (ref. 7.1).

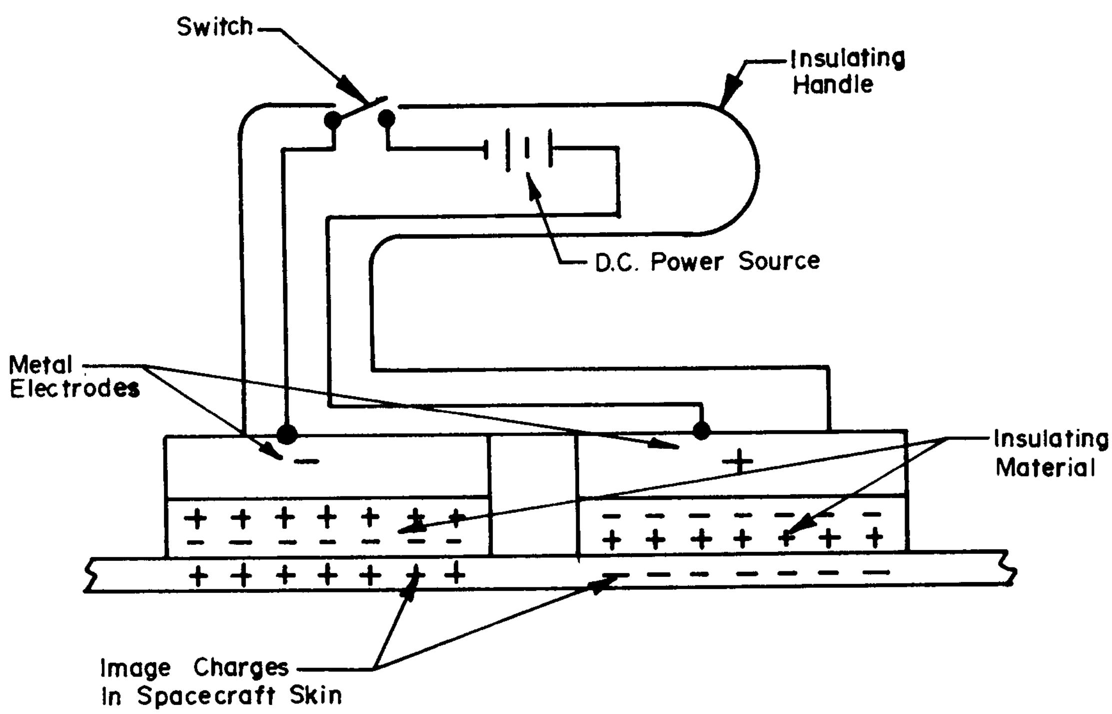


FIGURE 7-27: ELECTROADHESIVE DEVICE

- Maneuvering Devices - Maneuvering equipment can be classified into two categories: (1) automatically stabilized devices and (2) unstabilized or manually controlled units. The automatically stabilized devices are equipped with attitude rate feedback sensors which provide automatic attitude stabilization (via the Reaction Control System). The manually controlled units rely on man for rate sensing and initiation of stabilization torques from thrusters which are directionally aimed by the crewman.

- Handheld Maneuvering Unit (HHMU) - An early version of a manually controlled device was tested and evaluated on previous space flights. The results established the feasibility of the HHMU and aided in the development of the hardware which was designed for Skylab (see Figure 7-28 and 7-29). This unit, however, will be evaluated only in IVA as part of Skylab Experiment M509--Astronaut Maneuvering Equipment.

  The HHMU operation is initiated when the crewman points the unit in the desired direction of movement, squeezes the trigger mechanism resulting in the release of a high pressure gas (nitrogen) through the pusher and tractor type thrusters. Table 7-17 contains HHMU thruster characteristics (ref. 7.20).

TABLE 7-17: HHMU THRUSTER CHARACTERISTICS

PARAMETER	TRACTOR	PUSHER	UNIT
Number of thrusters	2	1	-
Maximum thrust	1.5 ± 0.125	3 ± 0.25	lb
Specific impulse	TBS	TBS	sec
Nitrogen flow rate	0.024	0.044	lb/sec
Throat area	0.012	0.0204	in^2
Exit area	0.033	0.0616	in^2
Expansion ratio	2.75	3.02	-
Cant angle	10	N/A	deg

- Astronaut Maneuvering Unit - The Skylab Automatically Stabilized Maneuvering Unit (ASMU) is a back mounted device which will also be tested under IVA conditions as part of Skylab experiment M509. Astronaut attitude control forces can be generated by various firing combinations of 14 cold gas thrusters (see Table 7-18) or by control

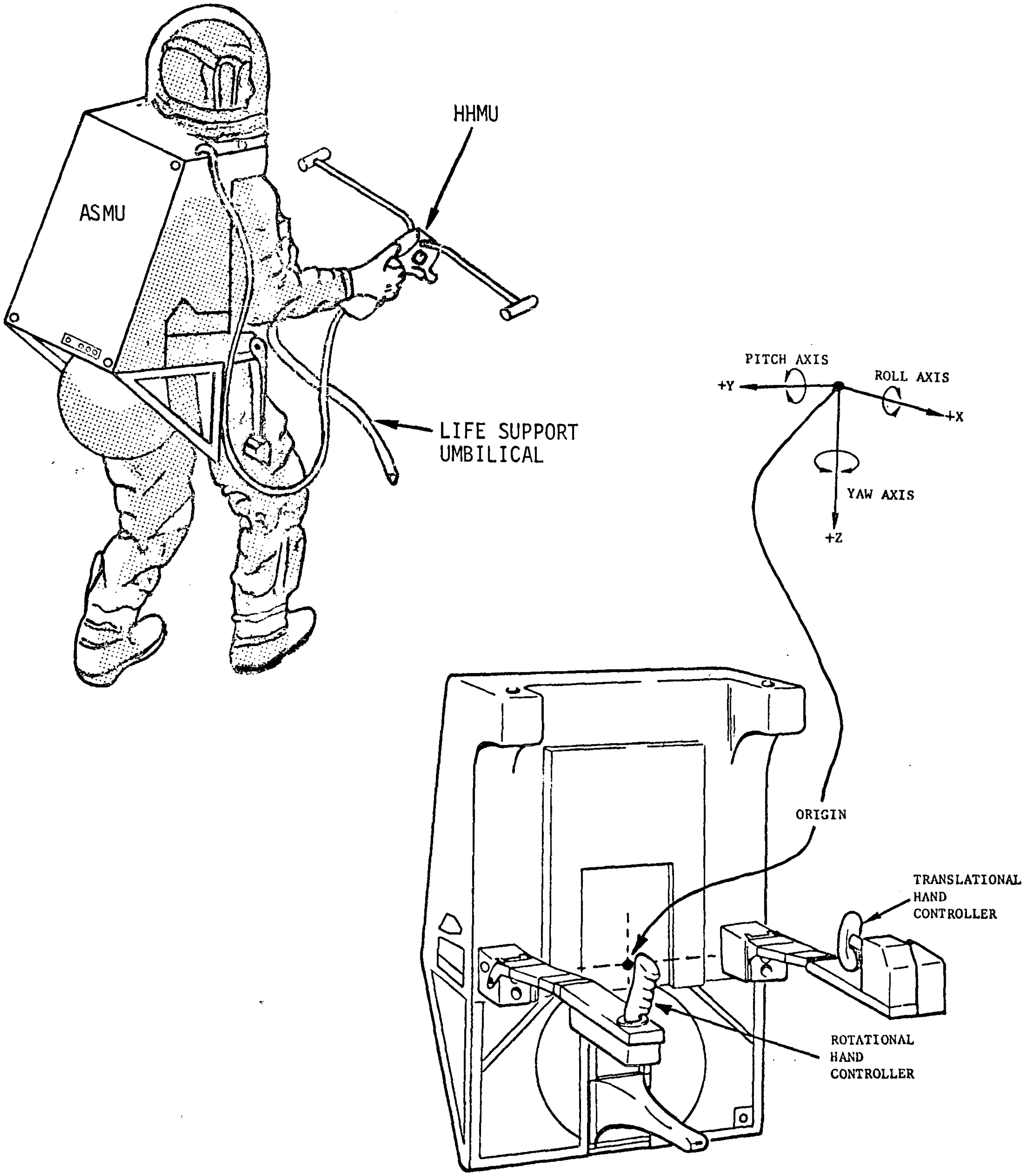


FIGURE 7-28: SKYLAB EXPERIMENT M509

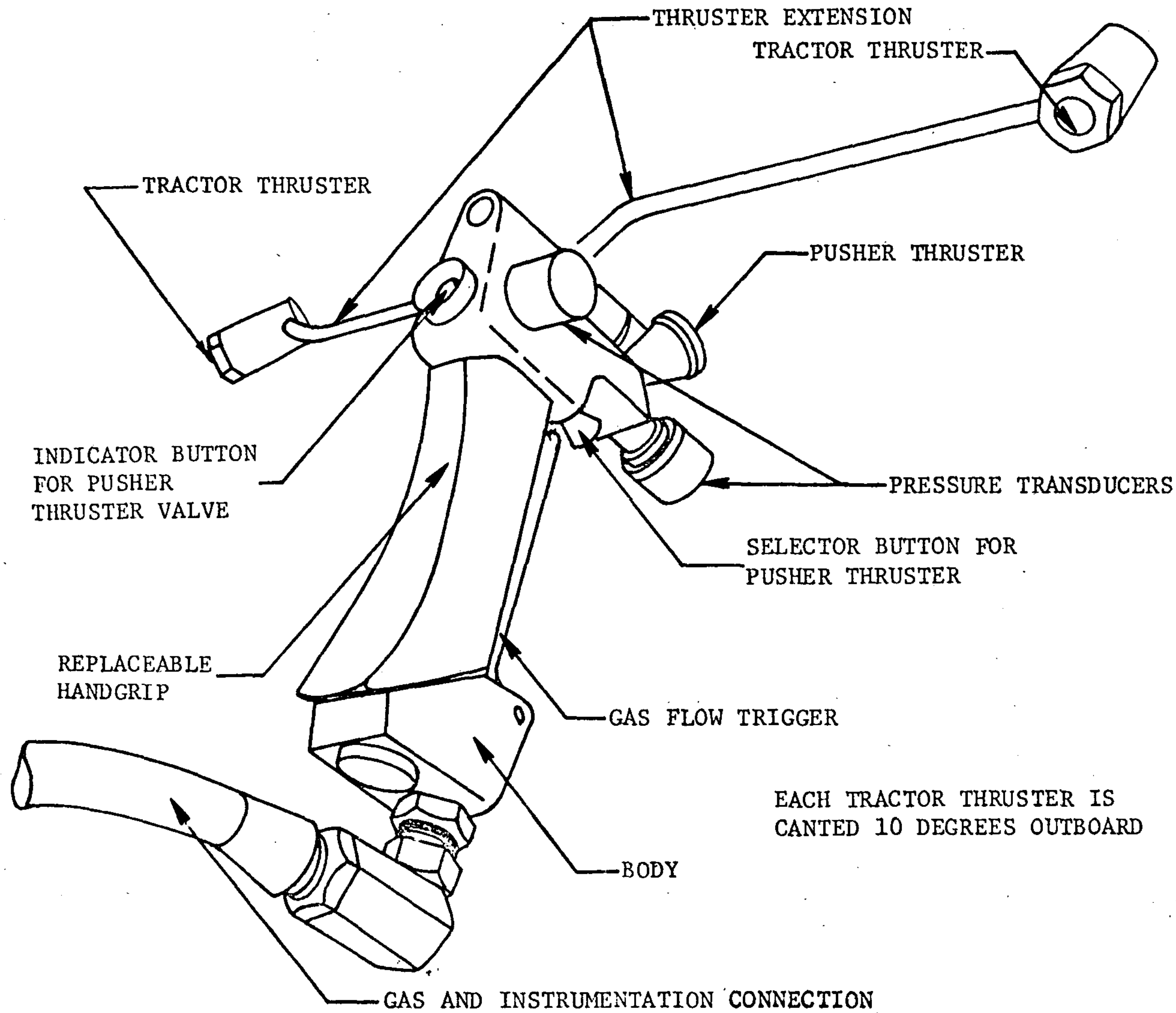


FIGURE 7-29: SKYLAB M509 HAND-HELD MANEUVERING UNIT

TABLE 7-18: ASMU THRUSTER CHARACTERISTICS

PARAMETER	THRUSTERS 1.25 lb*	2.15 lb*	2.35 lb*	4.3 lb	Unit
Thrust variation	±0.125	±0.0215	±0.235	±0.430	lb
Number of thrusters	4	4	4	2	--
Specific impulse	52 ± 2	52 ± 2	52 ± 2	52 ± 2	sec
Minimum impulse (±27%)**	0.035	0.060	0.066	0.100	lb-sec
Nitrogen flow rate***	0.023 ±0.005	0.04 ±0.006	0.042 ±0.006	0.08 ±0.01	lb/sec
Throat area	0.00716	0.0177	0.018	0.0288	in^2
Exit area	0.023	0.0479	0.0504	0.087	in^2
Expansion ratio	3.2	2.7	2.8	3.02	--

*Always operated in pairs
**Assumes 20-msec command
***Calculated from listed thrust and specific impulse

moment gyros. Thus, the crewman is provided with powered translational and rotational maneuvering capabilities in six degrees of freedom (X, Y, Z, pitch, roll, & yaw) within three operational modes: Direct, Rate Gyro, and Control Moment Gyro.

In the direct mode the astronaut is completely dependent on visual cues for position and attitude rates. Thrusters provide constant translation and rotational accelerations about a fixed body axis. The rate gyro mode employs the same thruster configuration and performance characteristics as the direct mode but has automatic rate gyro stabilization and attitude hold within certain design limits (i.e., deadbands). Any drift outside these limits causes the unit to operate automatically for return to the deadband. The control moment gyro is similar to the rate gyro mode, except that reaction control is provided through momentum exchange instead of mass expulsion (ref. 7.20).

- Foot Controlled Maneuvering Unit (FCMU) - This device offers a combination of simplicity, reliability, and "hands-free" operation not provided in the other types of maneuvering units.

  As illustrated in Figure 7-30, the crewman straddles the FCMU and inserts his boots into the foot pedal assemblies. Each foot pedal, which is connected to a 4 nozzle thruster assembly, is mechanically controlled by the foot movements of the crewman. The movements cause the thrusters to be actuated, allowing the crewman to control his attitude about three axes and to translate along the vertical body axis. The propellant supply on the backpack provides nitrogen to the thrusters via the propellant umbilical. Thruster characteristics and system dynamics data are shown in Tables 7-19 and 7-20 (ref. 7.21).

- Manipulator/Work Platform - This concept, which has been discussed for Shuttle evaluation, would involve the integration of a manipulator system with a work platform (see Figure 7-31). The resultant combination would provide the capability for transporting the EVA crewman to and from any payload worksite within the operating limits of the manipulator.

  The work platform design would include the following: (1) maneuvering controls and alarm console, (2) docking arms with locking capability after the assembly is attached to the worksite, (3) crewman restraints; foot, handhold, and tether tie points, (4) cargo/spare parts rack, (5) power outlets and power tools, (6) lighting devices, (7) hand tools and rack, (8) diagnostic/checkout panel, and other equipment required for EVA payload servicing. A T.V. camera and monitor would enable a second crewman to monitor the EVA operation in real time and provide support as required (ref. 7.16).

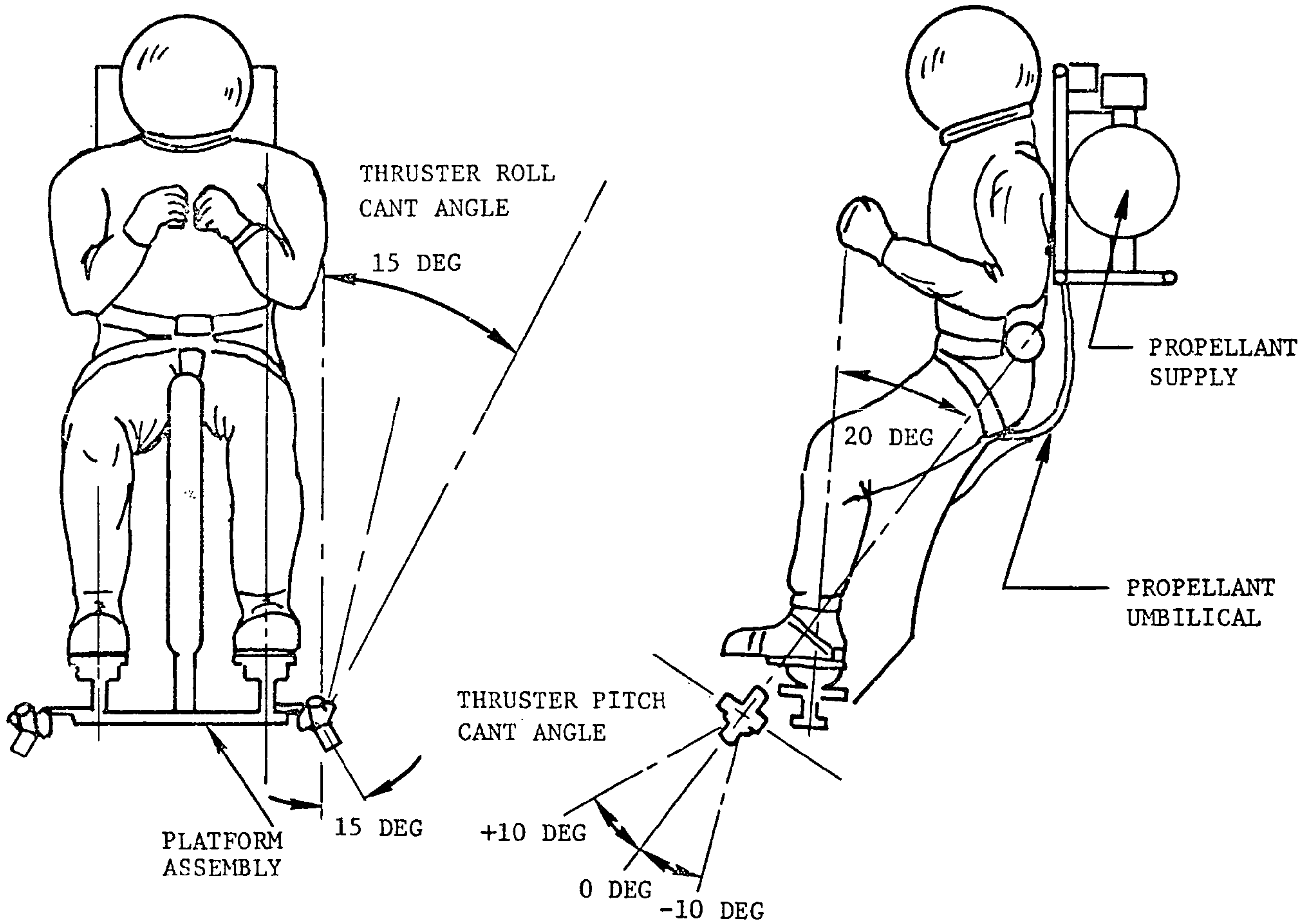


FIGURE 7-30: FOOT CONTROLLED MANEUVERING UNIT (FCMU)

- Maneuverable Work Platform (MWP) - Combining the work platform with a maneuvering unit provides a greater operating radius for the EVA crewman. Distance and duration would be dependent on the expendables of the propulsion system and the crewman's life support unit. An artist's concept of an MWP is referenced in Figure 7-32. The capability of such a device could be designed to include most of the following elements: (1) forward control module with remote control features, (2) spare parts module, (3) collapsible cargo frame, and (4) aft module for electronics and antenna arrays. A desirable innovation of the MWP is the proposed variable geometry cargo frame which can be rapidly assembled by means of quick disconnect structural joints. In an extended configuration the frame could be used as scaffolding at the worksite.

TABLE 7-19: FCMU THRUSTER SET CHARACTERISTICS

Thruster Parameter	Value	Unit
Flow Rate, Nitrogen (Max.)		
Rotational (Pitch)	0.0108	lb/sec
Translational	0.036	lb/sec
Thrust		
Rotational (Pitch)	0.6	lb
Translational	2.0	lb
Specific Impulse (Nominal)	56	sec
Minimum Impulse	0.01	lb-sec
Operating Life (per thruster)	25,000	cycles

TABLE 7-20: FCMU/CREWMAN SYSTEM DYNAMICS*

Parameter	Value	Unit
Rotational Acceleration	4.0 $\pm$0.4	deg/sec^2
Translational Acceleration	0.1 $\pm$0.01	ft/sec^2

*200- to 215-pound baseline crewman

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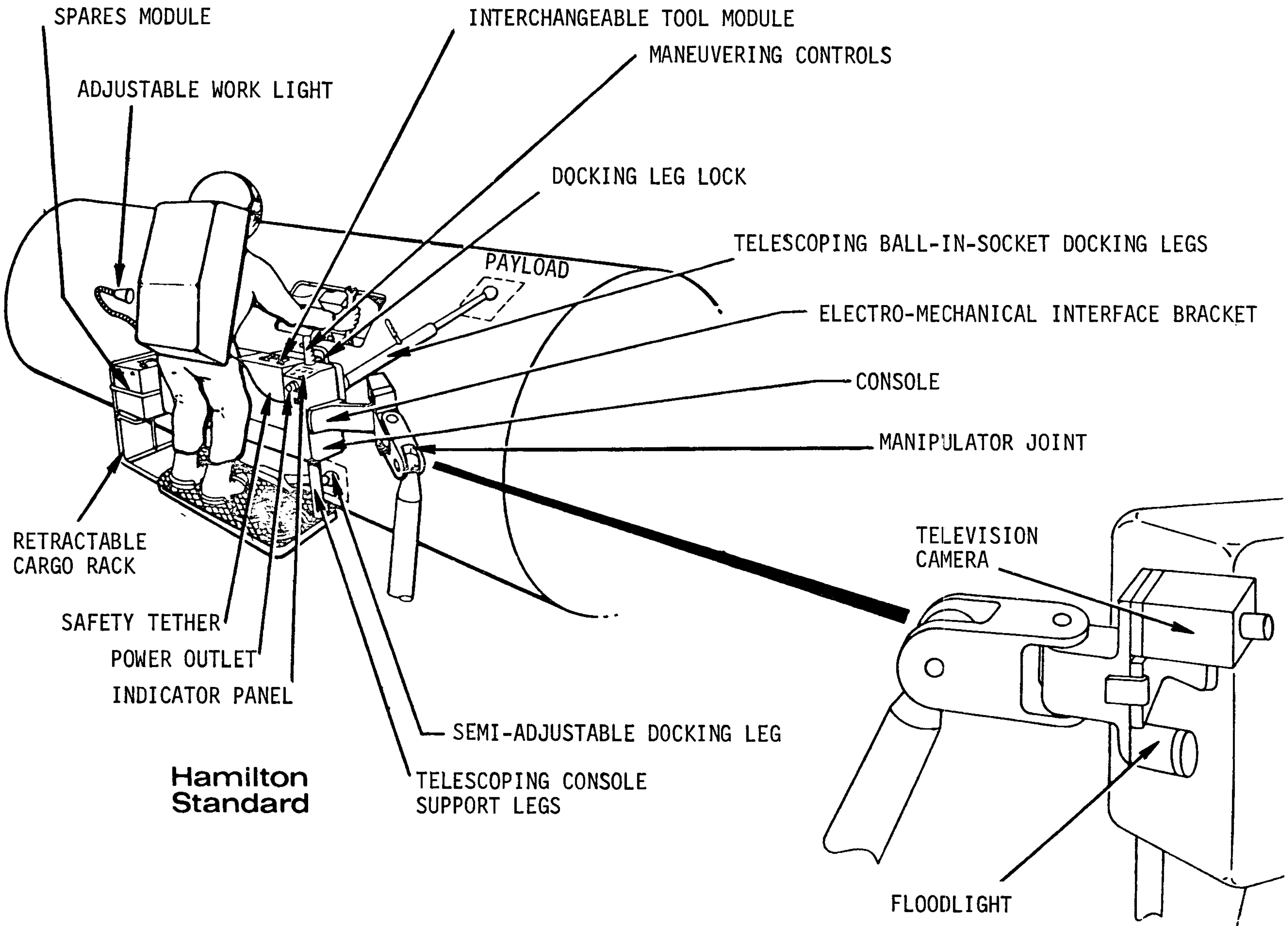


FIGURE 7-31: MANIPULATOR/WORK PLATFORM

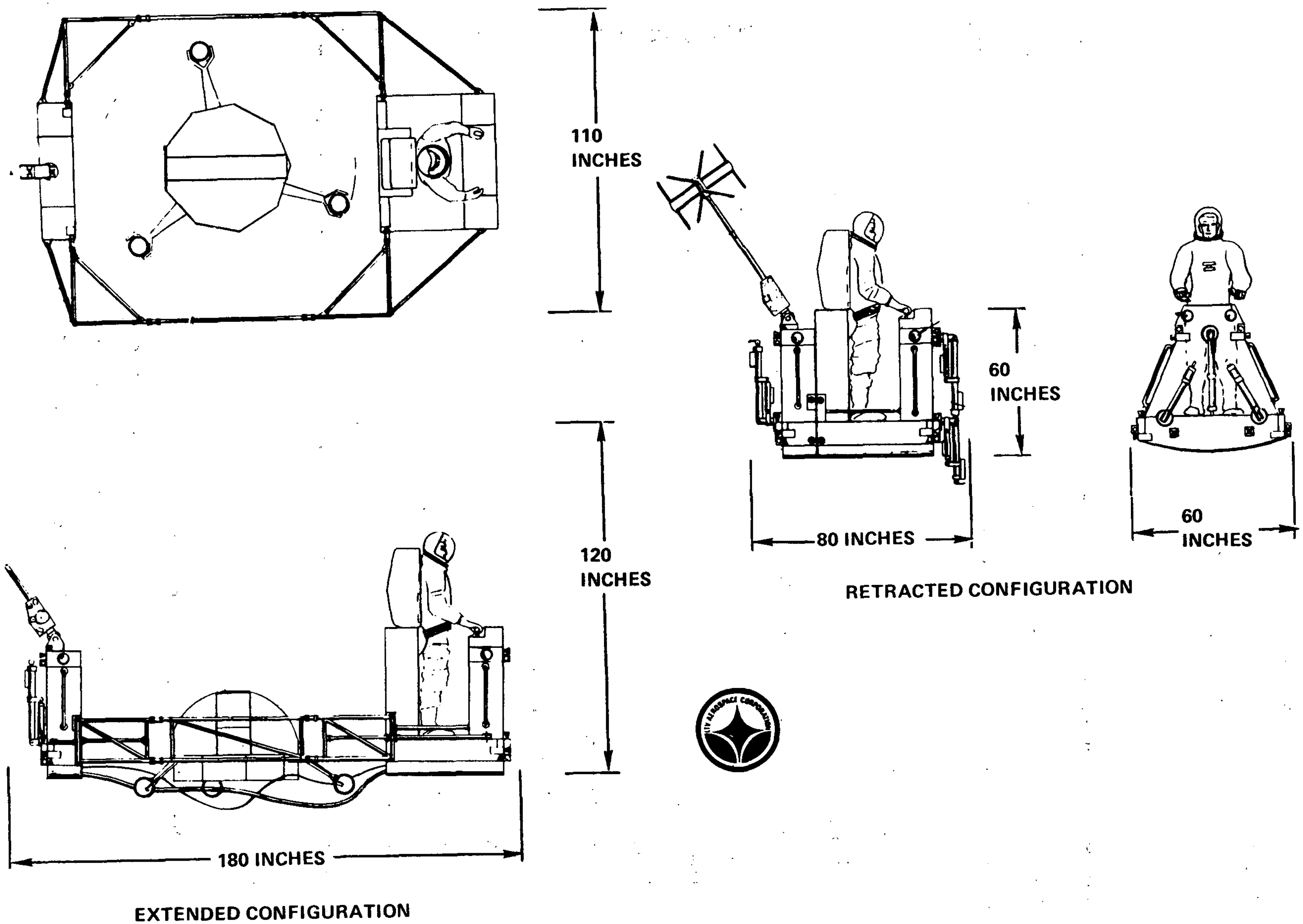


FIGURE 7-32: MANEUVERABLE WORK PLATFORM

A docking system is composed of grappler arms and anchors to restrain the MWP during payload servicing. A list of design characteristics are shown in Table 7-21 (ref. 7.22).

TABLE 7-21: MWP DESIGN CHARACTERISTICS

MWP DESIGN CHARACTERISTICS	
PARAMETER	VALUE
Weight	1600 lbs. -- 725.8 kg.
Volume	140 ft.^{3} -- 4.0 m.^{3}
Dimensions	5'x4'x7' -- 1.5x1.2x2.1 m.
Support Equipment Weight	2000 lbs. -- 907.2 kg.
Support Equipment Volume	186 ft.^{3} -- 5.3 m.^{3}
Propellant	Nitrogen
Power	600 watts
Data Requirements	8000 bits/sec
Voice Communications	yes
Radar	yes
Television	yes
External Lighting	yes

7.7.3 Transfer of Cargo

Many of the various methods for crew translation can also be used concurrently to transfer cargo. In each concept under the previous subsection, cargo transfer is possible--even if the crewman uses handrails in which case a wrist tether with a cargo attachment device would probably be employed.

In this section the prime consideration is the movement of cargo from a stowage to a service area.

- Manual Cargo Transfer - A definition for this type of transfer is the unassisted movement of cargo from point to point while attached to the crewman along the entire route. The cargo may be hand held or attached to the crewman by rigid or flexible devices. The configuration of these devices could take the form of personnel harnesses, backpacks, waist belts, tethers, or adjustable frames. Of the many conceptual designs proposed and evaluated, the best known is probably the wrist tether (see Figure 7-33). This unit/technique has been used on the Apollo program.

- Clothesline - The clothesline cargo transfer system consists of a continuous loop of highly flexible line with pulleys or rings to secure the clothesline to the vehicle and hooks to attach the cargo to the clothesline. Depending on the application, a cargo frame may be attached to the clothesline with clamping devices and guide units for providing two-axis stability.

  The contingency (or backup to the boom) cargo transfer system supplied on Skylab consists of two endless clothesline units. The transport lines are driven through two rings that act as sheaves for the clothesline. Hooks are used for attaching the cargo and as retention points between the rings and the surface of the vehicle. A tensioning strap is also included between the cargo attach hooks to maintain tautness in the system (ref. 7.23).

- Tubular Extendible Members - This type of device (see Figure 7-34 and Table 7-22) consists of a continuous strip(s) of resilient spring metal which has been treated for maximum flexibility and which possesses various characteristics when unfurled. Storage of the member(s) is accomplished by coiling the metal strip around or into a cylindrical drum which rotates for extension and retraction.

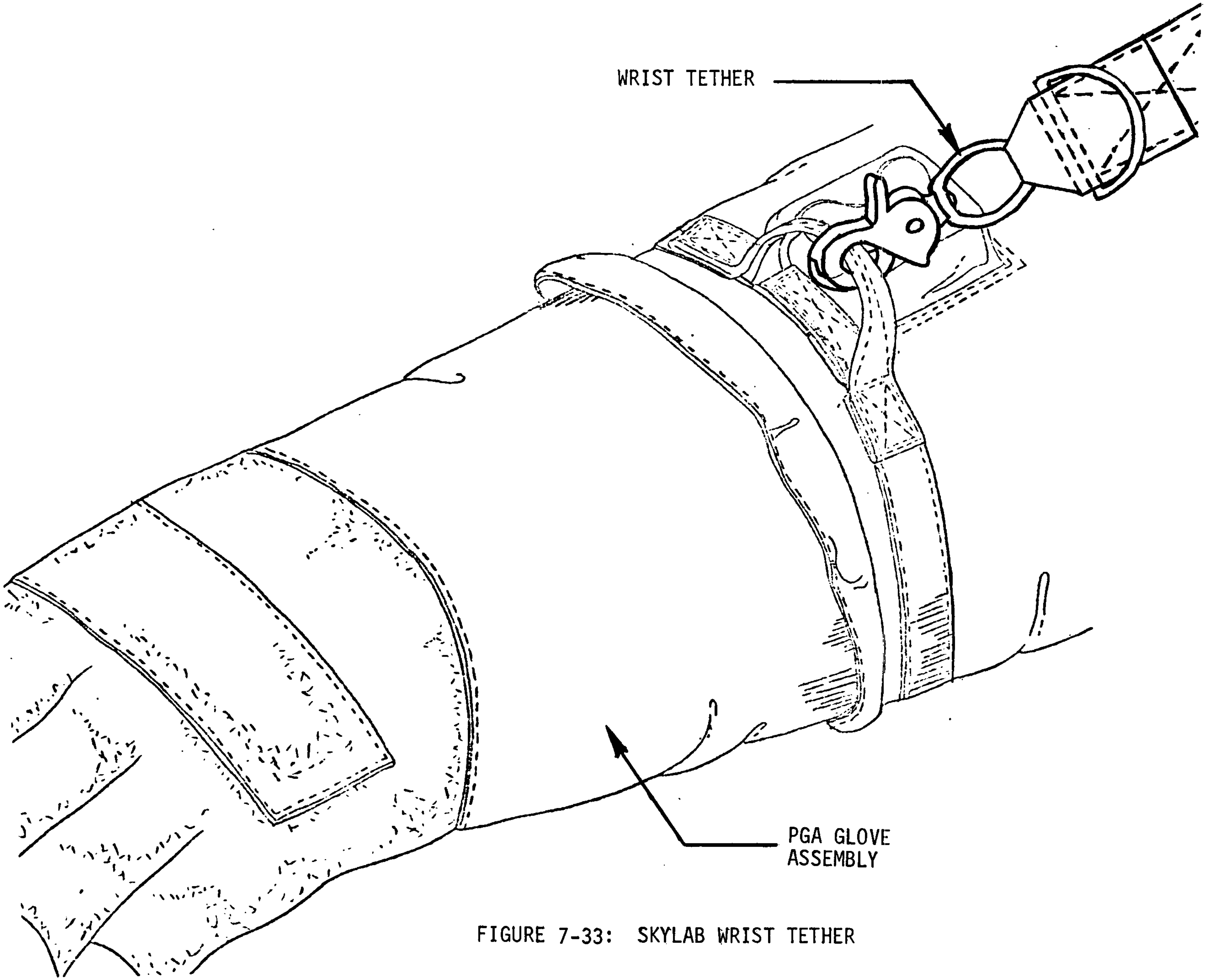
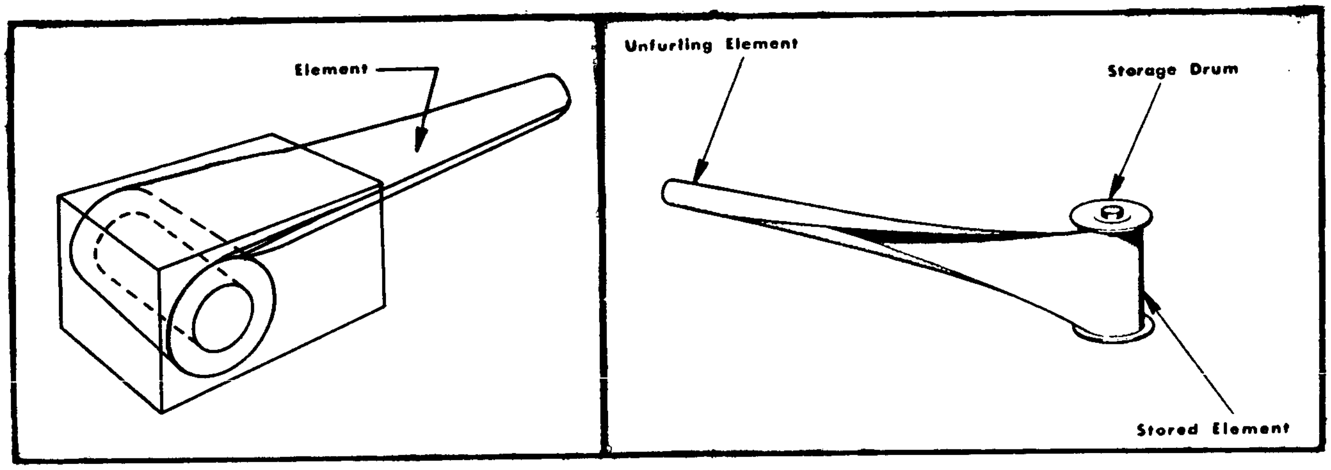


FIGURE 7-33: SKYLAB WRIST TETHER

TABLE 7-22: TUBULAR EXTENDIBLE MEMBER CHARACTERISTICS

BOOM DESIGN CHARACTERISTICS	
PARAMETER	VALUE
Weight	85 lbs. -- 38.6 kg.
Volume	3900 in.^{3} -- 63,921 cm.^{3}
Dimensions	25x13x12" -- 63.5x33.0x30.5 cm.
Boom Diameter	1.67" (each boom) -- 4.24 cm.
Element Thickness	7.5 mil -- 19.1 x 10^{-3} cm.
Boom Extension	28.6' -- 8.72 m.
Element Configuration	Figure 8
Element Material	Beryllium Copper
Actuation Method	Electric or manual
Extension rate	5 in./sec. -- 12.7 cm./sec.
Retraction rate	5 in./sec. -- 12.7 cm./sec.
Power	75 watts



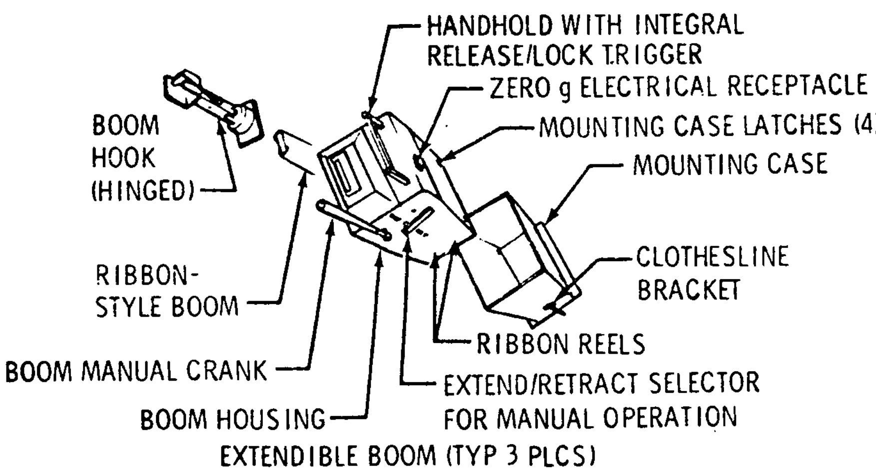


FIGURE 7-34: SKYLAB FILM TRANSPORATION BOOM

The cylindrical drum diameter is designed so that the elastic limit of the metal strip or element is not exceeded as it is coiled on the drum. Consequently, no permanent strain is introduced in the element. The strength characteristics of the unfurled or extended strip are provided by the type of configuration, amount of overlap and the number of elements. In its unfurled configuration, the element is free of stress. The advantage becomes one of being able to operate over relatively large distances with equipment which requires little stowage volume.

Two extendible members (Film Transportaion Booms) will be used during the Skylab EVA missions for transferring cargo between the Apollo Telescope Mount experiment canister and the Airlock Module. The booms are mounted in receptacles outside the vehicle and are prealigned to receive cargo from two separate EVA workstation. Each device is electrically driven; however, it can be manually operated. The cargo is attached to a fixed boom hook which secures and restrains the cargo movement sufficiently to restrict momentum buildup during transfer operations.

- Cargo Transfer Rails - A system of single or dual rigid rails, depending on the size and configuration of the cargo, could be effectively used for cargo transport from the Shuttle payload bay to a storage area or points between. Figure 7-35 illustrates how a pallet with guide rails would transfer a load of cargo along the rails in either direction. The system could be designed for motor drive, manual actuation or movement with tether lines. This concept has not been tested in flight; however, prototypes have been fabricated and the results demonstrate its simplicity and reliability. It is also feasible that the pallet would be utilized to accommodate an EVA crewman for translation to the worksite (ref. 7.1).

- Attached Manipulator - One of the most current developments in the field of cargo transfer and servicing is the attached manipulator system being proposed for the Shuttle Orbiter (see Figure 7-36). For the Shuttle Program, the manipulator system has been defined as a mechanical device capable of locating and orientating an end effector in space to perform useful work. An in-flight console operator will communicate motion to the manipulator by using the controller to input commands to the manipulator control system. These commands will, in turn, be directed to the appropriate manipulator drive motor for movement in the desired direction.

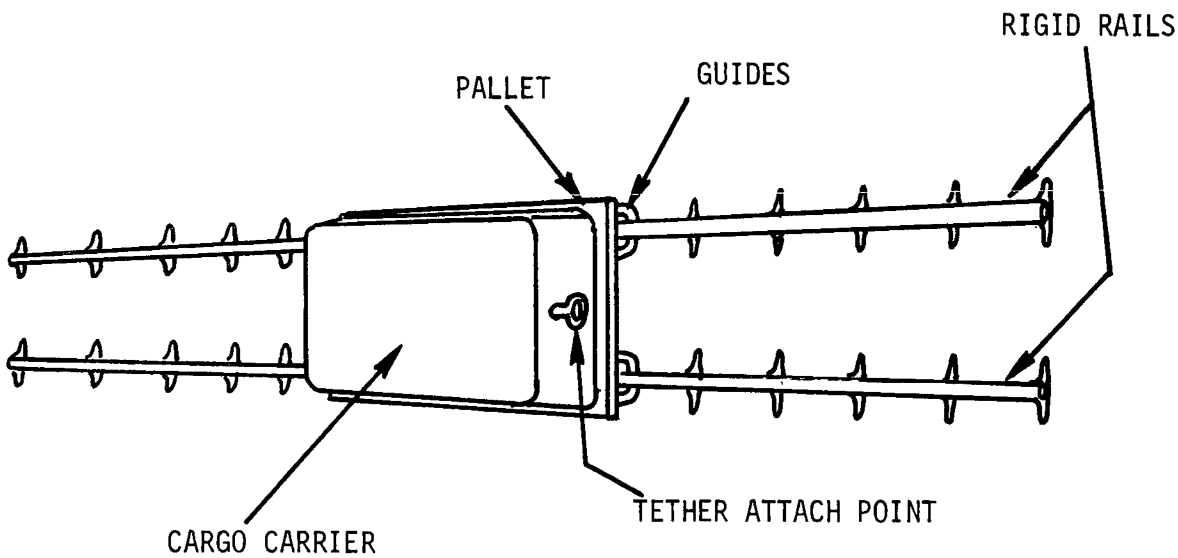


FIGURE 7-35: CARGO TRANSFER RAILS CONCEPT

The major concern in the design of a manipulator controller is the selection of the control system. The primary concern is one of designing/selecting a control system which will maximize the operator's ability to predict and control the manipulator's position and orientation. Studies have determined that for an "ideal" control system (where "ideal" is defined as a system which can perfectly track the operator's input commands), the preferred ranking is: (1) position, (2) rate and (3) acceleration control. This ranking minimizes the number of mental integrations required of the operator in controlling the manipulator system. The manipulator system currently in the initial concept phase for Space Shuttle application is designated the Shuttle Attached Manipulator System (SAMS). The intended functions of the Attached Manipulator System (AMS) vary from payload/vehicle servicing tasks to deployment and retrieval of satellites/laboratories

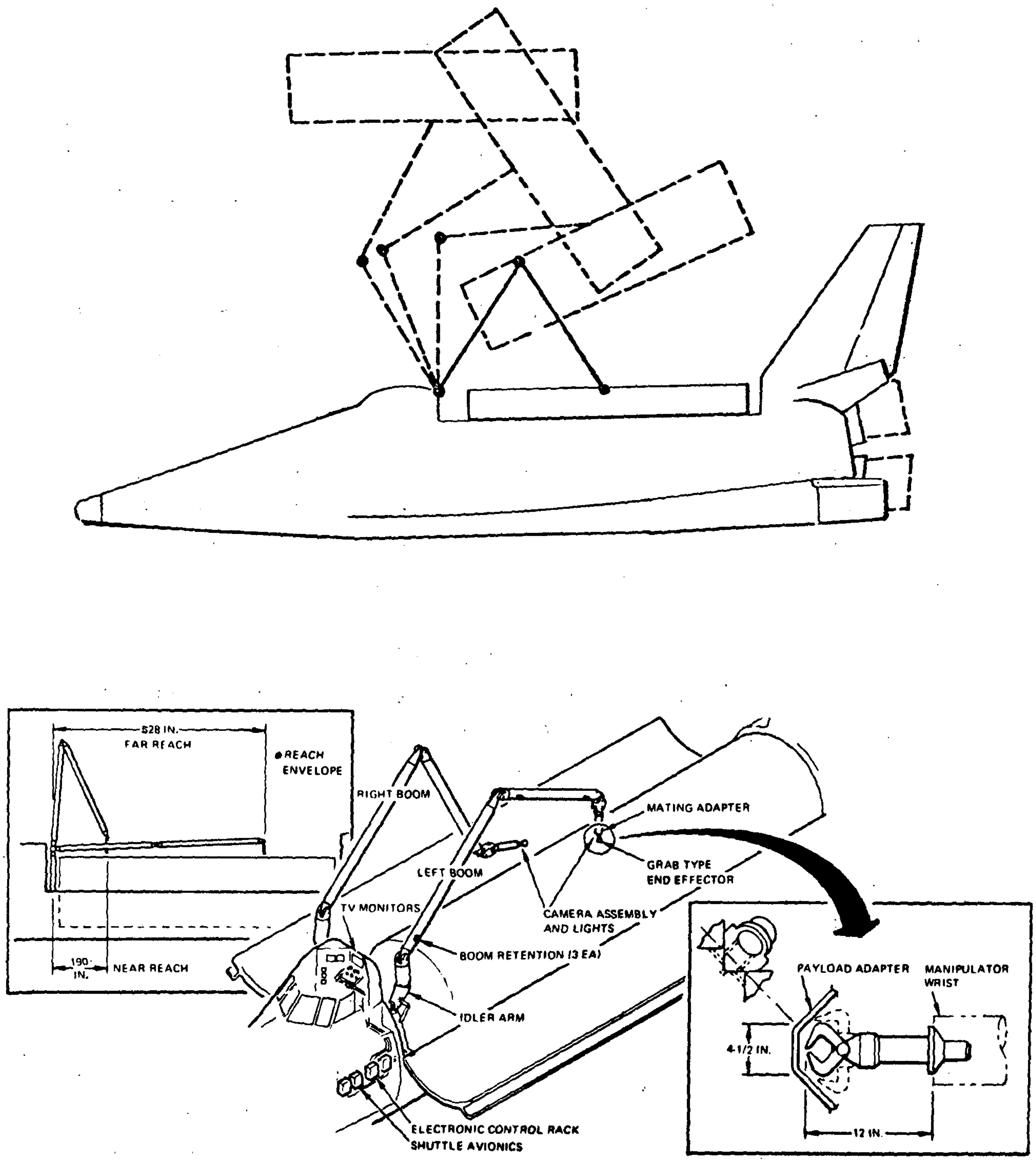


FIGURE 7-36: SHUTTLE ORBITER ATTACHED MANIPULATOR SYSTEM

ranging from 700 to 65,000 lbs. (317 to 29,500 kg.). Preliminary characteristics of the AMS concept are shown in Table 7-23 (ref. 7.2).

In evaluating the manipulator system for a space vehicle the following design objectives evolve. This is not considered a complete list, but will provide the designers with several initial considerations (ref. 7.25).

a. Limited Control Space: Crew station weight and volume restrictions have established a limitation on control space for manipulator operation.

b. Precise Control: Accuracy requirement for precise control is one of the most important manipulator criterion. As the level of accuracy decreased, large corresponding decreases in manipulator control have been observed during prototype tests.

c. Natural Movements: Spatial correspondence should exist between the operator's wrist orientation and the orientation of the end effector. Additionally all motions of the controller must be within the range of man's dynamic motion.

d. Single Handed Control: It is desirable to provide single handed control to allow the crewman freedom for manipulation of other associated controls (video, lighting communications, etc.) required during the transfer and servicing functions.

The approach of using manipulator systems for space work is in the initial concept phase and will require many refinements during development iterations to satisfy future satellite/payload deployment and retrieval requirements. The scope of manipulator application on the Space Shuttle and future space programs appear extensive, particularly for performing operations in conjunction with the EVA crewman. Consideration must be given to integrating the two technologies in order to meet the complex servicing requirements of candidate experiments and payloads on future missions.

TABLE 7-23: SHUTTLE ATTACHED MANIPULATOR CHARACTERISTICS

PARAMETER	MEASURE
Translation velocity	0 to 0.2 ft./sec. (65,000 lb. load) 0 to 2.0 ft./sec. (no load)
Rotation velocity	0 to 0.2 deg./sec. (65,000 lb. load) 0 to 3.0 deg./sec. (no load)
Acceleration rate	0 to 0.005 ft./sec.^{2} (65,000 lb. load) 0 to 0.5 ft./sec.^{2} (no load)
Deceleration rate	0 to 0.005 ft./sec.^{2} (65,000 lb. load) 0 to 1.0 ft./sec.^{2} (no load)
Reach distance	40 feet (approx.)
Reach angle	limited only by interference with Orbiter structure
Tip position accuracy	$\pm$ 2 inches
Orientation accuracy	$\pm$ 0.1 degree
Tip force	10 to 20 lbs.-force
Tip deflection	0.1 in./lb. tip force
Force feedback	4 to 5 lbs.
Visibility	direct or TV combination

7.8 COMMUNICATIONS AND TELEMETRY--EVA

7.8.1 Introduction

Crewmen involved in EV/IV activities will develop certain physiological and performance characteristics which differ from those on earth due to the weightless space environment. It was determined early in the space program that certain parameters should be monitored and telemetered to earth. Subsequent evaluation of this data assisted in the development of EVA hardware and advancement of the EVA technique.

This section will address the telecommunications aspects of the EVA operation. If the EVA crewman utilizes a portable life support system, the communications/telemetry concept for Shuttle Orbiter will probably be similar to that employed on the Apollo lunar surface exploration missions. An umbilical supported EVA will employ a concept similar to the one being programmed for Skylab.

7.8.2 EVA/Umbilical Telecommunications

The following is a description of the telecommunications configuration which will be used for the umbilical-supported Skylab EVA operation.

The audio subsystem in conjunction with the Space Suit Communications system (see Figure 7-37) provides voice contact between the EVA crewmen, the Skylab Cluster personnel, and the ground tracking network. All real time voice transmissions to the ground network are relayed by the CSM S-band. If the vehicle is not in contact with a ground station, voice information is recorded on tape for delayed transmission. The Skylab Telemetry Transmitters, controlled either onboard or by ground command, also permit the transmission of biomedical data and suit parameter readings in real time or tape-recorded delayed time (ref. 7.26).

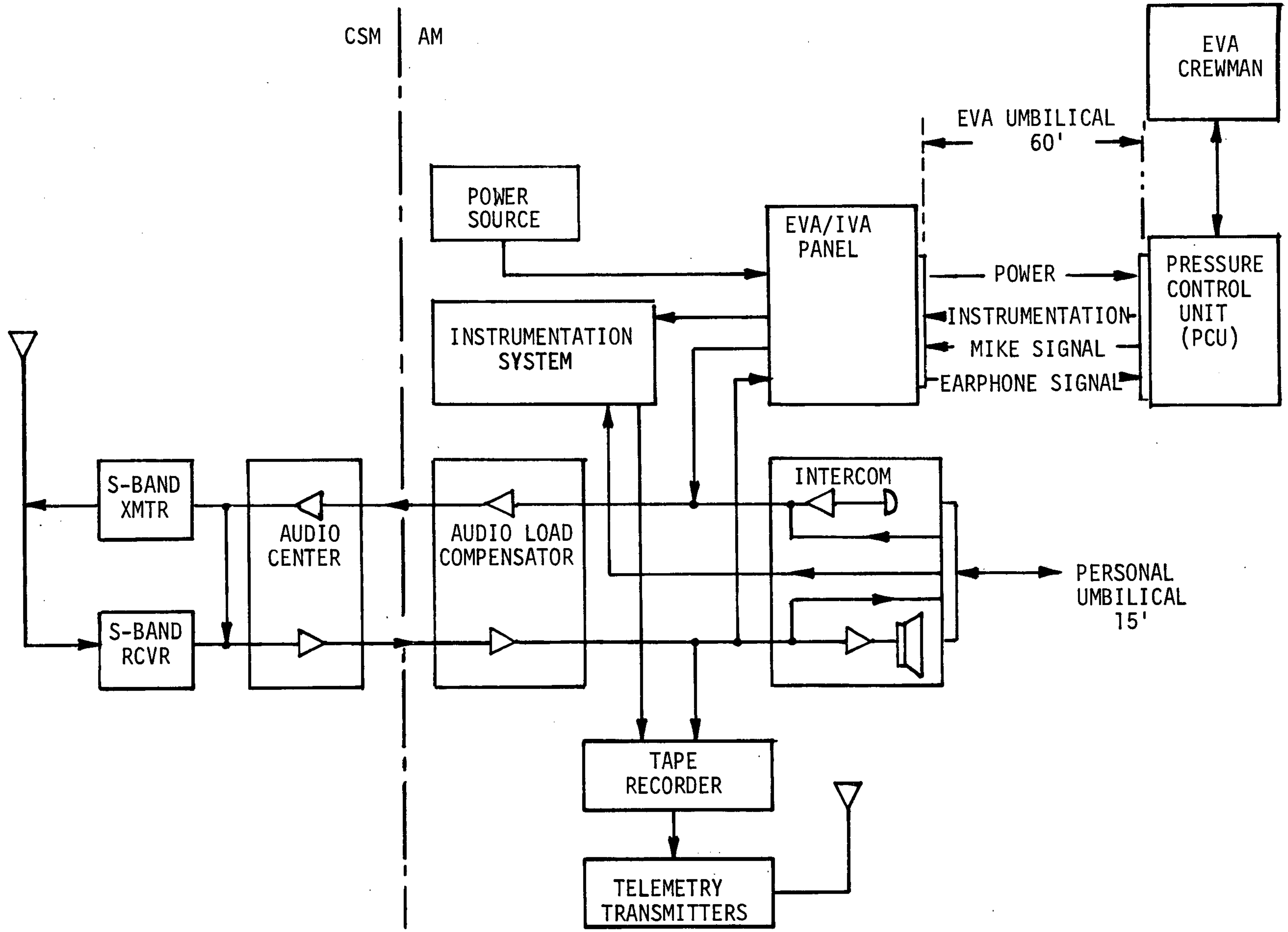


FIGURE 7-37: SKYLAB TELECOMMUNICATIONS SUBSYSTEM

The Skylab Operational Bioinstrumentation System (OBS) was designed to be individually adjustable for monitoring the physiological functions of each crewman during specified periods of the mission (see Table 7-24). Concurrently other sensors measure selected suit parameters for telemetering to earth. These are identified below and in Figure 7-38 (ref. 7.20).

- Suit Outlet Gas Temperature
- Suit Inlet Gas Temperature
- LCG Inlet Temperature
- LCG Outlet Temperature
- Suit Pressure

A third set of sensor readings are also monitored of the Umbilical Pressure Control Unit (PCU). The control module within the PCU activates appropriate warnings based on signals from sensors indicating the following events:

- Low or high suit pressure
- Regulator 1 low flow*
- Secondary oxygen pack flow
- Low vent flow*

The control module signal conditioning and logic provides a warning tone modulated and transmitted to the suited crewman if any of the above events occur. Coincident to the warning tone, the appropriate event warning message on the display panel (mounted on top of the PCU and visible to the suited crewman) will illuminate.

The suited crewman may turn off the warning tone by depressing the AUDIO-RESET switch located on the top left of the PCU. However, the tone will come back on with the occurrence of a second event. The illuminated warning message, however, will stay illuminated as long as the off-nominal event exists.

*Signal sent from transducer to the control module is delayed 5 ±1 seconds within the control module logic before warning indication is given, thus eliminating false warning tones due to transient feedback conditions from suit pressure variations due to suit volume changes with crewman's activities.

TABLE 7-24: OBS CHARACTERISTICS

OBS Component Parameters				
Component	Monitored	Measurement Range	Output Level (Vdc)	Accuracy
ECG	Heart Action	N/A	0 to 5 $\pm$0.25	N/A
ZPN	Respiration Range	3 to 9 ohms (transthoracic impedance)	0 to 5 $\pm$0.25	N/A
CTM	Heart Beat	30 to 200 beats per minute	0 to 5 $\pm$0.25	2% F.S.

OBS Sample Rates		
Measurement	Sample Rate (sps)	Record on Tape
ECG	320.0	Yes
ZPN	80.0	Yes
CTM	10.0	Yes
SID	1.25	Yes

ECG - Electrocardiograph
ZPN - Impedance Pneumograph
CTM - Cardiotachometer
SID - Crewman Identification

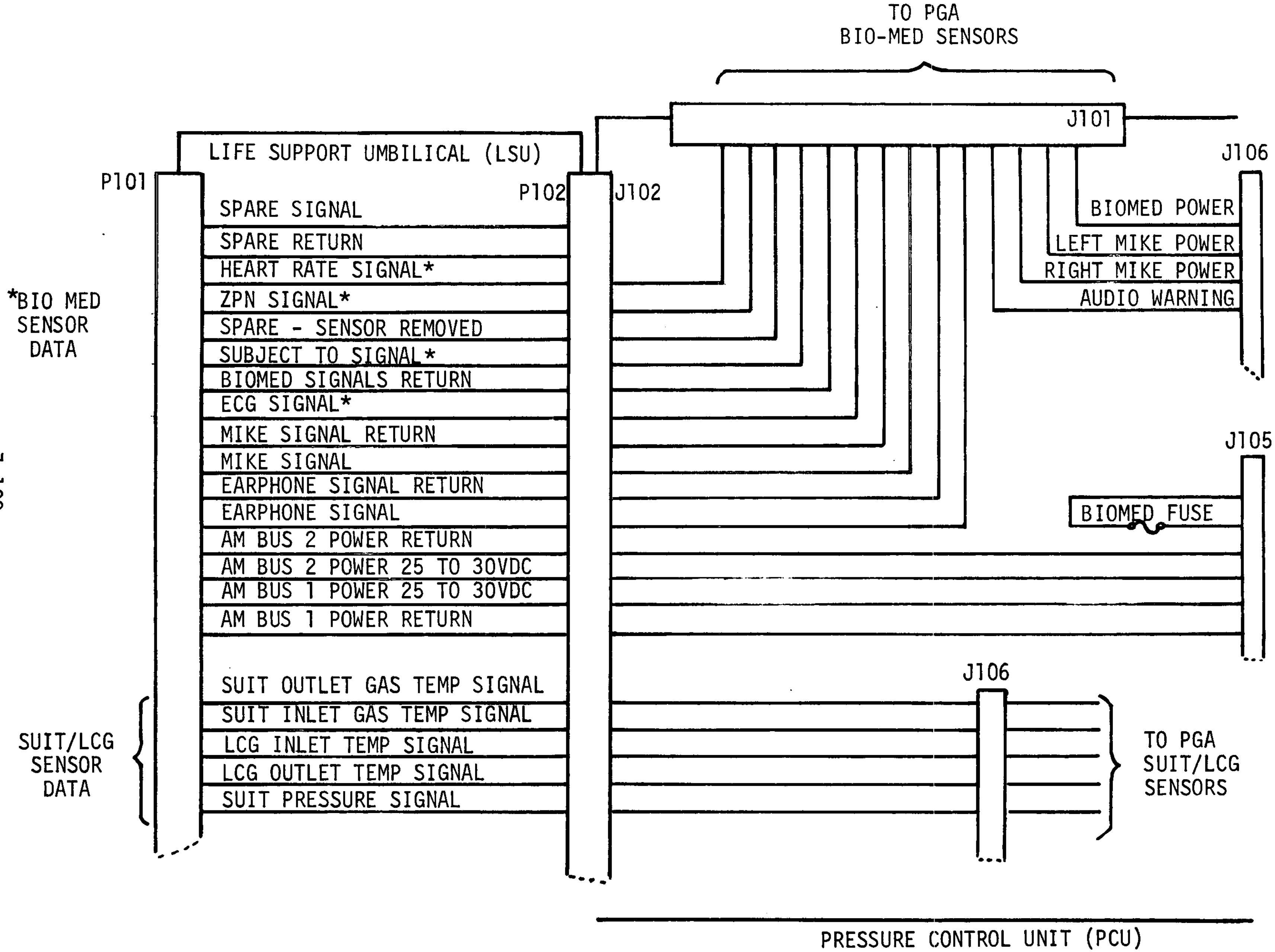


FIGURE 7-38: MONITORED DATA

All warning message lamps and their respective lamp drivers, the warning logic, and warning tone generator may be tested by depressing the test switch located on the bottom right of the PCU. However, the TEST switch cannot be actuated with a PGA gloved hand.

7.8.3 Airlock Communications

During the period of EV/IV activity in the Shuttle airlock two-way communication will be used to establish and maintain contact with cabin personnel. The voice contact is essential not only from a safety standpoint but also for monitoring the crewman's status and performance.

During a portable LSS-supported Shuttle EVA an RF hardline connected between the portable LSS and the airlock panel may be required if RF transmission through the airlock structure becomes prohibitive. If direct RF voice contact with the portable LSS is not possible because of the airlock's metallic structure, this could be circumvented by the installation of an antenna system inside the airlock linked to the vehicle communications center. The hard-line arrangement, however, would allow pre-EVA verification of the portable LSS communications and provide voice contact with the monitoring personnel. If the EVA crewman utilizes an umbilical LSS, this becomes his link for maintaining two-voice communications with the monitors (ref. 7.2).

7.8.4 EVA/Portable LSS Telecommunications

The portable LSS Extravehicular Communications Subsystem (EVCS) configuration includes the following equipment:

- Two AM Transmitters
- Two AM Receivers
- One FM Receiver
- Signal Conditioners
- Telemetry subsystem
- Warning subsystem

During normal mission operations with two crewmen EVA in the payload bay area, the telecommunications concept would be similar to the one illustrated in Figure 7-39.

The EVCS also provides voltage regulated power for the Remote Control Unit (RCU) and the transducers of the instrumentation subsystem. The following is a tentative list of portable LSS, Biomed, and PGA sensor signals that could be monitored, measured, displayed and/or telemetered to earth.

Instrumentation	Type of Signal
PGA pressure	TM, warning
LCG inlet temperature	TM
LCG differential temperature	TM
Low vent flow	Warning
O_2 bottle pressure	TM
High primary O_2 flow	Warning
Feedwater pressure	TM, warning
Sublimator outlet gas temperature	TM
Battery voltage	TM
Battery current	TM
CO_2 level	TM
ECG	TM
ZPN	TM
CTM	TM
SID	TM

The Remote Control Unit mounted on the chest of the PGA contains displays and controls similar to those illustrated in Figure 7-40.

The function of the Push-To-Talk switch is to override the voice-operated switch normally used in the communications system. The mode selector switch provides the crewman with the following options:

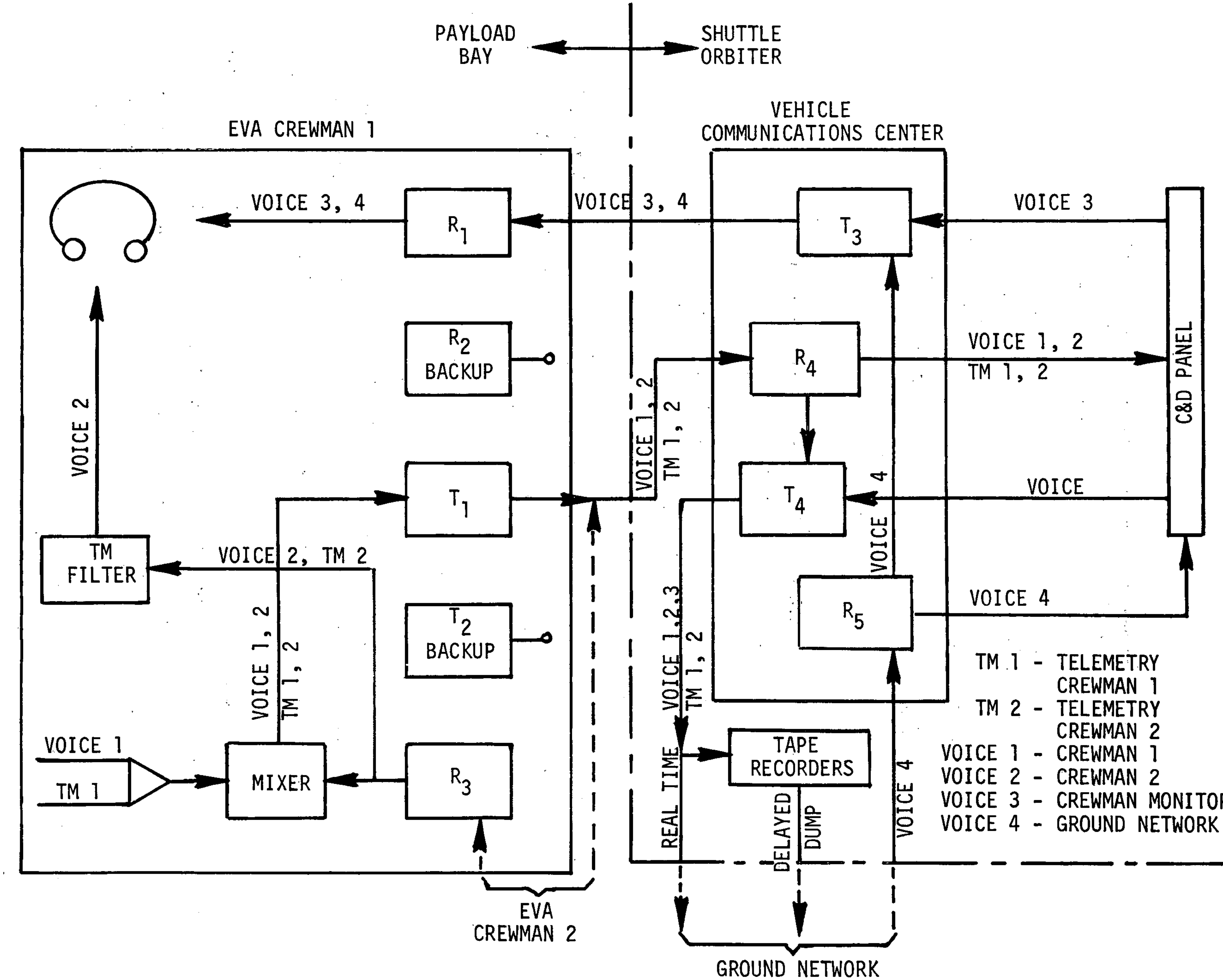
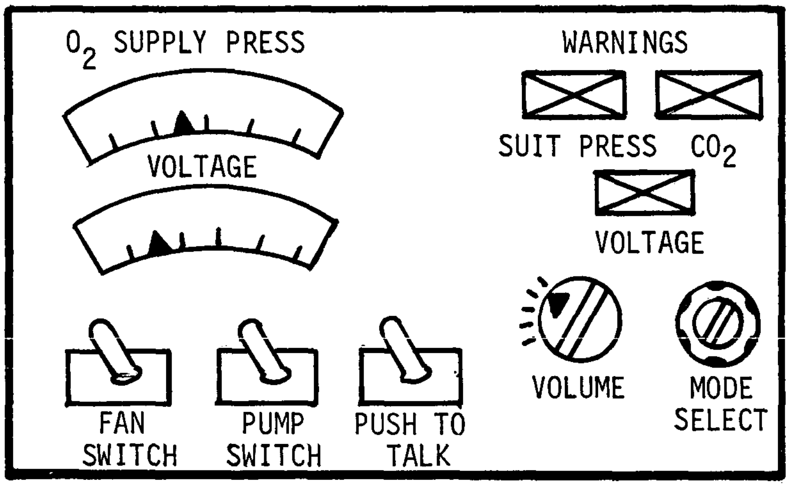


FIGURE 7-39: PLSS/EVCS RF LINKS



REMOTE CONTROL UNIT

FIGURE 7-40: TYPICAL REMOTE CONTROL UNIT FOR SPACE SUIT--NOTE COMMUNICATIONS

- MAIN-VOX (Voice actuated transmitter) mode: The first syllable of a voice transmission automatically actuates the transmitter. Transmission and reception can occur simultaneously.

- OFF-VOX is grounded: no voice transmission occurs.

- MOM - Momentary voice communication: Voice transmission and reception is maintained as long as the switch is held in the MOM position. Upon release, the switch automatically returns to OFF-VOX.

An alarm tone functions in all modes of operation to warn the EVA crewman if certain parameters fall outside desired limits which may indicate a potentially dangerous condition. At the same time, small warning "flags" or indicators will provide the crewman with a visual identification that a problem exists. The audible warning will continue for approximately 10 seconds and then automatically stop; however, the warning flag will continue as long as the problem exists. The EVCS has 30 channels: 26 for telemetering, 2 for calibration and 2 for synchronization with the ground network (ref. 7.26).

Several television cameras will be installed around the pheriphery of the payload bay and on the manipulator arms. A minimum of two, installed at each end of the payload bay, will be used to monitor the safety and performance of the EVA crewmen. Close-up viewing of the servicing functions will be provided by TV cameras mounted on the work platform or EVA workstation.

REFERENCES

7.1 URS/Matrix Company: Extravehicular Activities Guidelines and Design Criteria, NASA CR-2160, Huntsville, Alabama, January 1973.

7.2 Manned Spacecraft Center: Space Shuttle Baseline Accommodations for Payloads, MSC-06900A, Houston, Texas, November 17, 1972.

7.3 Manned Spacecraft Center: Preliminary Design Requirements for Shuttle EVA/IVA Orbiter Support, MSC-01497, Internal Note MSC-EC-71-10, September 30, 1971.

7.4 Manned Spacecraft Center: Space Shuttle Program Request for Proposal No. 9-BC421-67-2-40P, Houston, Texas, March 1972.

7.5 Manned Spacecraft Center: Performance and Design Requirements for Skylab Extravehicular Mobility Unit, Master End Item Specification, CSD-S-D14, MSC-02806, October 6, 1971.

7.6 Manned Spacecraft Center: Extravehicular Mobility Unit for Lunar Module Crewman (EMU/LM) Apollo J-Missions, Master End Item Specification Performance/Design and Product Configuration Requirements, CDS-A1059, Houston, Texas, May 1968.

7.7 Manned Spacecraft Center: Model A7L Space Suit, Apollo Block II, Contract End Items Familiarization and Operations Manual, Contract No. NAS9-6100, Doc. #8812700149A, Houston, Texas, November 21, 1968.

7.8 ILC Industries, Inc.: Model A7L Advanced Extravehicular Pressure Garment Assembly, unpublished presentation, 1969.

7.9 Litton Systems, Inc.: Torso Limb Assembly (TLA) for Advanced Extravehicular Space Suit (AES), Part I: Performance Design Requirements, Master End Item/Contract End Item Detail Specification (Prime Equipment), CEI No. SD08, Spec. No. 241901, Contract No. NAS9-7533, February 16, 1970.

7.10 ILS Industries, Inc.: A7LB Pressure Garment Assembly with Integrated Thermal Meteoroid Garment for Apollo Extravehicular Mobility Unit, Contract End Item Specification, CEI No. 3001 B, Rev. A, Dover, Del., January 30, 1970.

7.11 AiResearch Manufacturing Co.: Torso-Limb Assembly (TLA) for Advanced Extravehicular Space Suit (AES), Master End Item/Contract End Item Specification (Prime Equipment), Part I, MEI/CEI No. 958567A, Contract No. NAS9-7555, January 15, 1970.

7.12 Manned Spacecraft Center: Skylab Stowage List, Command Modules 116, 117, 118, Skylab Missions 1/2, 1/3, 1/4, I-SL-003, March 16, 1973.

7.13 ILC Industries, Inc.: Requirements Study for Space Shuttle Pressure Suit, Final Report, ER-051-01, December 19, 1972.

7.14 Manned Spacecraft Center: Statement of work for an 8.0 PSI Orbital EVA Space Suit (Feasibility Prototype), Crew Systems Division.

7.15 Manned Spacecraft Center: Skylab Operational Data Book, Volume V, MSC-01549, Houston, Texas, October 1970.

7.16 Hamilton Standard Division: Space Shuttle EVA/IVA Support Equipment Requirements Study, Final Briefing to NASA-JSC, Houston, Texas, March 22, 1973.

7.17 Vought Missiles and Space Company: Study of Space Shuttle EVA/IVA Support Requirements, Final Briefing to NASA-JSC, Houston, Texas, February 1973.

7.18 URS/Matrix Company: Study of Astronaut Restraints and Mobility Aids in a Weightless Shirtsleeve Environment, Contract NAS9-12574, September 27, 1972.

7.19 Wheelwright, C. W., General Specifications for Spacecraft Lighting, SC-L-0002, Manned Spacecraft Center, Houston, Texas, November 1971.

7.20 Manned Spacecraft Center: Skylab Operational Data Book, Volume I, MSC-01549, Houston, Texas, April 5, 1971.

7.21 Manned Spacecraft Center: Skylab Experiment Operations Handbook, Volume 1, Experiments Descriptions, MSC-00924, March 17, 1972.

7.22 NASA: Reference Earth Orbital Research and Applications (Blue Book), NHB-7150.1, January 15, 1971.

7.23 Martin Marietta Corporation: Skylab Operations Handbook, Contract No. NAS8-2400, Houston, Texas, July 19, 1972.

7.24 Martin Marietta Corporation: Attached Manipulator System Design and Concept Verification for Zero-g Simulation, Technical Progress Briefing, November 1972.

7.25 URS/Matrix Company: A Study of Teleoperator Systems Performance Requirements, Final Report, Huntsville, Alabama, November 18, 1972.

7.26 McDonnell Douglas Corporation: MDA/AM/OWS Instrumentation System, Document 6079, Houston, Texas, September 1971.

7.27 Hamilton Standard Division: Apollo Portable Life Support and Oxygen Purge Systems, B-231A, Windsor Locks, Conn., (not dated).

APPENDIX A EVA SELECTION/SYSTEMS DESIGN CONSIDERATIONS LISTS

In the selection of a method/system to perform experiment operations or payload servicing functions external to the spacecraft, and in the design of the experiments/payloads to interface with the selected technique, numerous considerations must be acknowledged in regard to the man, the mission, the spacecraft, and the total program. Regardless of the method or system being considered to perform the external functions, each candidate is required to undergo trade studies involving "costs" (weight, volume, crew time, power) to the mission, spacecraft, and payload.

When studying man as a candidate for extravehicular operations, initial considerations involve crewman safety and his capabilities in the weightless environment. Once the safety and capabilities are assured within the task requirements, on-orbit EVA support systems and equipment are considered relative to their integration and impact on the applicable spacecraft or payload. A somewhat extensive listing of considerations (Extravehicular Activities Guidelines and Design Criteria, NASA-CR-2160, January 1973) was developed under a previous contract to provide the mission planners and payload designers an initial indication of the major parameters to be addressed when considering manned EVA.

The considerations lists were based on the major on-orbit support systems and equipment required to conduct manned operations outside the vehicle. A separate list of considerations applicable to the following EVA systems is contained in Table A-1:

- Environmental Control and Life Support Systems
- Crew Protective Systems (Space Suits)
- Airlocks and Support Equipment

- Crew and Cargo Transfer Systems
- EVA Worksite/Workstation
- External Lighting
- Communications and Telemetry
- Data/Information Management

The considerations contained in the lists are further classified into the following general categories:

- EVA Mission/Function
- Spacecraft Hardware/Systems Integration
- Crew Physiology/Performance
- Subsystem Hardware/Equipment
- Familiarization/Simulation/Training
- Special

Each of the EVA Selection/Systems Design Considerations lists applicable to their specific experiment requirements should be reviewed by the payload designers during the initial studies to select an "extravehicular" servicing technique. A number of the considerations are common to each listing and have been arranged into a considerations commonality listing, with a brief discussion of each consideration, in Sections 5.0 and 6.0 of this report.

TABLE A-1: EVA Systems Design/Selection Considerations

SYSTEM NOMENCLATURE: EC/LSS - UMBILICAL AND PORTABLE

EVA MISSION/FUNCTION

- EVA Mission Definition
- Frequency of EVA Operations
- Tool Requirements (Manual/Powered)
- Number of Crewmen Required at Worksite
- Number of Times Task is Performed

SPACECRAFT HARDWARE/SYSTEMS INTEGRATION

- Vehicle Description/Characteristics
- Location of EVA Worksite
- Spacecraft Manpower Support Requirements
- Translation Path to EVA Worksite
- Equipment Along Translation Route
- Umbilical/Tether Entanglement Characteristics
- Power Requirements from Spacecraft
- External Lighting Requirements
- Airlock Volume/Dimensions
- Airlock Hatch Size
- EC/LSS - Spacecraft Interface Requirements
- Spacecraft Interface Requirements
- Tool Interface Requirements
- Stowage Volume Required for Units
- Stowage Environment/Atmoshpere Required for Units
- Stowage Volume Required for Support
- Workstation Ingress/Egress Volume Available
- Working Volume Available at Worksite

CREW PHYSIOLOGY/PERFORMANCE

- Number of Crewmen Required for EVA Tasks
- EC/LSS Expendables Requirements
- System Donning/Doffing Time
- Number of Crewmen Required to Don/Doff
- Telemetry Requirements
- Environmental Monitoring Requirements
- Physiological Monitoring Requirements
- Performance Monitoring Requirements
- Man's Physiological Requirements/Limitations
- Man's Psychological Considerations
- Mobility Restrictions Due to EC/LSS Hardware
- Man's Task Performance Capabilities in EVA
- Time Required to Perform Task
- Prebreathing Requirements

SUBSYSTEM HARDWARE/EQUIPMENT

- EVA Qualified EC/LSS Hardware
- State of EC/LSS Equipment Development
- EC/LSS Equipment Operational Characteristics
- EC/LSS Equipment Performance Characteristics
- EC/LS System Status Monitoring Requirements
- Hardware Operational Lifetime
- Equipment Operational Time in EVA
- Hardware Shelf Life
- Recharge Capabilities (Portable)
- Recharge Time Required
- Space Suit - EC/LSS Interface Requirements
- Equipment Maintainability
- Equipment Reliability
- Equipment Transportability
- Preparation/Checkout Time
- EC/LSS Replacement Spares Requirements
- Spares Shelf Life
- Contamination Data/Limits
- Umbilical/Tether Characteristics
- System Volume/Size/Mass/Center of Gravity
- Total System Weight
- Replacement Spares Weight
- Special Equipment Design Requirements
- Special Equipment Qualification Requirements
- Cost of Existing Qualified Units
- New Hardware Development/Technology Costs
- Suit Cooling System (Suit H_2O Loop) Hardware
- Communications Requirements
- Space Suit External Configuration

FAMILIARIZATION/SIMULATION/TRAINING

- Equipment Testing/Qualification Requirements
- Simulation Requirements
- Simulation Equipment/Mockup Requirements
- Simulation Facilities Available
- Crewman Task Familiarization/Training
- Operational Procedures Development
- Maintenance Manual Development
- Equipment Maintenance/Repair Training

SPECIAL

- Crew Safety
- Backup/Emergency Systems Available

TABLE A-1: EVA Systems Design/Selection Considerations (Cont'd.)

SYSTEM NOMENCLATURE: SPACE SUIT AND SUPPORT HARDWARE

EVA MISSION/FUNCTION

- EVA Mission Definition
- Frequency of EVA Operations
- Tool Requirements (Manual/Powered)
- Qualified EVA Controls and Displays
- Time Required to Perform Task
- Number of Times Task is Performed
- Restraint Requirements to Perform Task
- Required Degree of Manual Dexterity
- Crew Translation Distance
- Mobility Aid Requirements (Handrails/Handholds)
- Cargo Quantity to be Handled
- Total Number of Crewmen Required for EVA

SPACECRAFT HARDWARE/SYSTEMS INTEGRATION

- Vehicle Time on Orbit
- Translation Path to EVA Worksite
- Equipment Along Translation Route
- Power Requirements
- Umbilical/Tether Entanglement Characteristics
- Vehicle Manpower Support Requirements
- External Lighting Requirements
- Workstation Orientation/Location
- Workstation Ingress/Egress Volume Requirements
- Working Volume Required at Worksite
- Tool Interface Requirements
- Volume Required for Support Equipment Stowage
- Suit Stowage Volume
- Suit Donning/Doffing Station Requirements
- Medical Support Capabilities
- Suit Drying System Requirements
- Stowage Environment

SUBSYSTEM HARDWARE/EQUIPMENT

- Space Suit Development/Equipment Costs
- EVA Qualified Suit Hardware
- EVA Equipment Operational Characteristics
- Suit System Weight
- Suit Replacement Spares Requirements
- Suit Hardware Operational Life
- Special Equipment Design Requirements
- Special Equipment Qualification Requirements
- Suit Maintainability/Reliability
- Suit Transportability
- Suit Shelf Life
- Waste Management Requirements
- Biomedical Support Hardware
- Communications Requirements
- Total Suit Anthropometrics
- Umbilical/Tether Characteristics
- Crewman Life Support Expendables
- Life Support System Performance Characteristics
- Life Support System Expendables Requirements
- Life Support System (Volume/Size/Mass)
- State of EVA Support Equipment Development
- Existing EVA Qualified Cargo Transfer Systems (Manual/Powered)
- Existing EVA Qualified Crew Translation Systems (Manual/Powered)
- Qualified Crewman/Cargo Restraint Systems
- Umbilical/Tether Management
- Suit Operating Pressure
- Suit's Ventilation Capability
- Suit Drying Time

CREW PHYSIOLOGY/PERFORMANCE

- Vehicle Cabin Pressure
- Vehicle Atmosphere (One or Two Gas System)
- Number of Support Personnel Required for Don/Doff
- Illumination Levels
- Suit Preparation/Checkout Time
- Force Requirements to Perform Task
- Crew Sizing
- Food and Water Requirements
- Duration of EVA
- Man's Physiological Limitations
- Man's Psychological Considerations
- Man's Task Performance Capabilities in EVA
- Force Capabilities of Suited Crewman
- Mobility Capabilities of Suited Crewman
- Reach Capabilities of Suited Crewman
- Crewman Time Limits in EVA
- Crewman/Suit External Volume
- Cargo Handling Capabilities
- Cargo Mass Handling Limits
- Status Self Monitoring
- Comfort Requirements
- In-Suit Time Limits
- Don/Doff Time Requirements
- Prebreathing Time Requirements
- Anticipated Metabolic Rates
- Anticipated Total Energy Expenditure

FAMILIARIZATION/SIMULATION/TRAINING

- Total Simulation Requirements
- Simulation Equipment/Mockup Requirements
- Simulation Facilities Available
- Crewman Familiarization/Training
- Operational Procedures Development
- Launch Operations Integration

SPECIAL

- Crewman Safety
- Crewman Rescue
- Backup/Emergency Systems
- Radiation Protection

TABLE A-1: EVA Systems Design/Selection Considerations (Cont'd.)

SYSTEM NOMENCLATURE: AIRLOCKS AND EQUIPMENT

EVA MISSION/FUNCTION

- EVA Mission Definition
- Frequency of EVA
- Mobility Aid Requirements
- Number of Hatches
- EVA Cargo Mass/Size/Volume

SPACECRAFT HARDWARE/SYSTEMS INTEGRATION

- Vehicle Description/Characteristics/Orientation in Orbit
- Vehicle Time on Orbit
- Translation Path to Worksite
- Vehicle/System Interface Requirements
- Vehicle Integration
- Vehicle Manpower Support Requirements
- Lighting Requirements
- Airlock Orientation/Location
- Airlock Egress/Ingress Volume Requirements
- Working Volume Required in Airlock
- Umbilical Stowage Requirements
- Life Support System Interface Requirements
- Crewman/Suit External Volume

SUBSYSTEM HARDWARE/EQUIPMENT

- Power Requirements (Lights, etc.)
- System Expendable Requirement
- Airlock Development Costs (to Orbit)
- Airlock Equipment Costs
- EVA Qualified Airlock Hardware
- Airlock Operational Characteristics
- Airlock Preparation/Checkout Time
- Airlock System Weight
- Airlock Replacement Parts Requirement
- Airlock Hardware Operational Life
- Replacement Parts Shelf Life
- Total Pressure Suit Anthropometrics
- Life Support System (Volume/Size Limits)
- State of Airlock Support Equipment Development
- Communications Requirements
- Required Hatch Size
- Qualified Crewman Restraint Systems
- Qualified Cargo Restraint System

CREW PHYSIOLOGY/PERFORMANCE

- Man's Physiological Limitations
- Man's Psychological Considerations
- Man's "Weightless" Task Performance Capabilities
- Force Capabilities of Suited Crewman
- Mobility Capabilities of Suited Crewman
- Reach Capabilities of Suited Crewman
- Visibility Capabilities of Suited Crewman
- Decompression/Recompression Time
- Decompression/Recompression Rate

FAMILIARIZATION/SIMULATION/TRAINING

- Total Simulation Requirements
- Simulation Equipment/Mockup Requirements
- Simulation Facilities Available
- Crewman Familiarization/Training
- Operational Procedures Development

SPECIAL

- Crewman Safety
- Crewman Rescue
- Backup/Emergency System

TABLE A-1: EVA Systems Design/Selection Considerations (Cont'd.)

SYSTEM NOMENCLATURE: CREW AND CARGO TRANSFER

EVA MISSION/FUNCTION

- EVA Mission Definition
- Frequency of EVA Operations
- Tool Support Requirements
- Support Hardware Requirements
- Hardware Design Requirements
- Hardware Qualification Requirements
- Qualified EVA Controls and Displays
- Space Suit/Translation System Interface
- Cargo/Space Suit Interface
- Transfer/Translation Distance
- Cargo Quantity to be Handled
- Number of Times Task is Performed

SPACECRAFT HARDWARE/SYSTEMS INTEGRATION

- Vehicle Description/Characteristics/Orientation in Orbit
- Vehicle Time on Orbit
- Vehicle/System Interface Requirements
- System Power Requirements
- System Expendable Requirements
- External Lighting Requirements
- Worksite Orientation/Location
- Working Volume Required at Workstation
- Tool Interface Requirements
- Support Hardware Interface Requirements
- Total System Weight
- Volume Required for Support Hardware Stowage
- Cargo Packaging Requirements
- Airlock and Hatch Size/Shape
- Vehicle/System Integration
- Umbilical Management
- Crewman/Suit External Volume
- Vehicle Manpower Support Requirements

SUBSYSTEM HARDWARE/EQUIPMENT

- Support Hardware Power Requirements
- System Development Costs (to Orbit)
- System Equipment Costs
- EVA Qualified Transfer/Translation Hardware
- EVA System Operational Characteristics
- Hardware Spares Requirements
- Systems Operational Life
- Spare Shelf Life
- Hardware Maintainability
- Hardware Reliability
- System Flexibility
- Cargo/Transfer System Interface
- System Maintenance Requirements
- Systems Checkout Time
- Transfer System Stop Distance/Automatic Shutdown
- System(s) Manual Override
- Existing EVA Qualified Transfer/Translation System
- Qualified Cargo Restraint Systems
- Qualified Crewman Restraint Systems
- Communication Requirements
- Total Pressure Suit Anthropometrics
- Umbilical/Tether Characteristics
- Transfer System Cargo Limits
- Life Support System Performance Characteristics
- Life Support System (Volume/Size/Mass)
- State of EVA Support Equipment Development
- AMU

CREW PHYSIOLOGY/PERFORMANCE

- Number of Crewmen Required for System Operation
- Illumination Levels
- Total Energy Expenditure
- Estimated Metabolic Workloads Anticipated
- Transfer/Translation Rate
- Transfer/Translation System Loading/Unloading Time
- Transfer/Translation Attitude Control
- Man's Physiological Limitations
- Man's Psychological Considerations
- Man's Task Performance Capabilities in EVA
- Force Capabilities of Suited Crewman
- Mobility Capabilities of Suited Crewman
- Reach Capabilities of Suited Crewman
- Visibility Capabilities of Suited Crewman
- Time Required to Translate/Perform Transfer
- Restraint Requirements to Perform Transfer
- Cargo Mass Handling Limits
- Crewman Life Support Expendables
- Life Support System Expendable Requirements
- Crewman Time Limits in EVA

FAMILIARIZATION/SIMULATION/TRAINING

- Total Simulation Requirements
- Simulation Equipment/Mockup Requirements
- Simulation Facilities Available
- Crewman Familiarization/Training
- Operational Procedures Development

SPECIAL

- Crewman Safety
- Crewman Rescue
- Backup/Emergency Systems

TABLE A-1: EVA Systems Design/Selection Considerations (Cont'd.)

SYSTEM NOMENCLATURE: EVA WORKSITES

EVA MISSION/FUNCTION

- EVA Mission Definition
- Classification of Task
- Frequency of EVA Operations
- Number of Crewmen Required at Worksite
- Working Volume Required at Worksite
- Worksite Preparation/Checkout Time
- Tool Requirements (Manual and Powered)
- Force Required to Perform Task
- Pressure Suit Anthropometrics
- Restraint Requirements to Perform Task
- Mobility Aids Required to Perform Task
- Umbilical/Tether Management

SPACECRAFT HARDWARE/SYSTEMS INTEGRATION

- Vehicle Description/Characteristics
- Vehicle Orientation in Orbit
- Vehicle Time on Orbit
- Worksite Hardware/Vehicle Interface Requirements
- Translation Path to EVA Worksite
- Equipment Along Translation Path
- Power Requirements (Lights, Equipment)
- Number of Worksites Required
- Spacecraft EVA Manpower Support Requirements
- Worksite Orientation/Location
- Prepared Worksite Requirements
- Workstation Ingress/Egress Volume Requirements
- Crewman Life Support Expendables
- Volume Required for Support Equipment and Spares Stowage
- Weight of Replacement Spares
- Life Support System Physical Characteristics
- Space Suit and Hardware Physical Characteristics

SUBSYSTEM HARDWARE/EQUIPMENT

- EVA Qualified Worksite Hardware
- EVA Equipment Operational Characteristics
- Worksite System and Subsystem Weight Penalty
- External Lighting Requirements
- Replacement Spares Requirements
- Spares Shelf Life
- Equipment Operational Life
- Type of Life Support System Required
- Umbilical/Tether Characteristics
- Life Support System Performance Characteristics
- Life Support System Physical Characteristics
- Life Support System Expendable Requirements
- Qualified EVA Controls and Displays
- Approved Mobility Aids (Handrails, Handholds)
- Equipment Reliability
- Equipment Maintainability
- Status of EVA Support Equipment Development
- Type of Restraints Required
- Type of Crew and Cargo Transfer System(s) Required
- EVA Qualified Restraint Systems
- EVA Qualified Crew/Cargo Transfer Systems
- Special Equipment Handling Requirements
- Systems and Equipment Flight Qualification
- Communication Systems
- Existing Qualified Equipment Cost
- New Hardware Development/Technology Cost

CREW PHYSIOLOGY/PERFORMANCE

- Man's Physiological Requirements/Limitations
- Man's Psychological Considerations
- Man's Task Performance Capabilities in EVA
- Force Emission Capabilities of Suited Crewman
- Reach Capabilities of Suited Crewman
- Visibility of Suited Crewman
- Illumination Levels Required
- Time Required to Perform Task
- Number of Times Task is Performed
- Approved Mass Handling Limits
- Life Support System Performance Characteristics
- Crewman Time Limits in EVA
- Translation Distance to Worksite
- Cargo Quantity to be Handled

FAMILIARIZATION/SIMULATION/TRAINING

- Design/Development Reviews Required
- Total and Part Task Simulation
- Simulation Techniques/Modes
- Simulation Equipment/Mockup Requirements
- Simulation Facilities Available
- Simulation Facilities Capabilities
- Simulation/Training Costs
- Crewman/Monitor Familiarization and Training
- Operational Procedures Development

SPECIAL

- Crewman Safety Requirements
- Crewman Rescue Capability
- Backup/Emergency Systems

TABLE A-1: EVA Systems Design/Selection Considerations (Cont'd.)

SYSTEM NOMENCLATURE: EXTERNAL LIGHTING

EVA MISSION/FUNCTION

- EVA Mission Definition
- Sun Angle
- Shadow Patterns
- Tool Support Requirements (Manual/Powered)
- Focus Configuration (Wide vs. Deep Field of Illumination)
- Type of Task to Perform
- Darkside/Lightside EVA
- Frequency of Use
- Duration of Each Use
- Crew Translation Distance

SPACECRAFT HARDWARE/SYSTEMS INTEGRATION

- Vehicle Description/Characteristics/Orientation in Orbit
- Translation Path to EVA Worksite
- Equipment Along Translation Route
- Vehicle/Light Interface Requirements
- Power Requirements
- Worksite Orientation/Location
- Workstation Ingress/Egress Lighting Requirements
- Tool Interface Requirements
- Obstruction
- Pre-Launch Checkout
- Volume Required for Support Equipment Stowage
- Stowage Environment for Spares
- Mobility Aids Requirements Location
- Crewman Restraint Systems Location
- Cargo Restraint Systems Location
- Cargo Volume Requirements at the Worksites
- Vehicle Time on Orbit

CREW PHYSIOLOGY/PERFORMANCE

- Lighting Requirements for Controls and Displays
- Illumination Levels
- Man's Physiological Limitations
- Man's Psychological Considerations
- Visibility Capabilities of Suited Astronaut
- Suited Crewman Reach Envelopes

SUBSYSTEM HARDWARE/EQUIPMENT

- Lighting Development Costs
- Lighting Equipment Costs
- EVA Qualified Lighting Hardware
- EVA Lighting Equipment Operational Characteristics
- Lighting System Total Weight
- Crewman/Light Protection
- Lighting Replacement Spares Requirements
- Lighting Equipment Operational Life
- Spares Shelf Life
- Special Support Equipment Design Requirements
- Special Equipment Qualification Requirements
- Lighting Equipment Maintainability
- Lighting Equipment Reliability
- New Hardware/Technology Costs
- Lighting Equipment Portability
- Type of Switch Control
- Recharge Time for Applicable Equipment
- Focus Adjustment
- Unit Envelope Configuration
- Cycles of Use (Number of Times Lights Can Cycle)
- Number of Lights Required
- Spectral Characteristics of Helmet/Visor
- Suit/Life Support System Volume

FAMILIARIZATION/SIMULATION/TRAINING

- Total Simulation Requirements
- Simulation Equipment/Mockup Requirements
- Simulation Facilities Available
- Crewman Familiarization/Training
- Operational Procedures Development

SPECIAL

- Crewman Safety
- Crewman Rescue
- Backup/Emergency Systems

TABLE A-1: EVA Systems Design/Selection Considerations (Cont'd.)

SYSTEM NOMENCLATURE: COMMUNICATION AND TELEMETRY

EVA MISSION/FUNCTION

- EVA Mission Definition
- Number of Channels Required
- Distance Traveled from Prime Spacecraft
- System Preparation/Checkout Time
- Support Tool Requirements
- Ground Support Equipment Requirements

SPACECRAFT HARDWARE/SYSTEMS INTEGRATION

- Vehicle Description/Characteristics/Orientation in Orbit
- Vehicle Time on Orbit
- Vehicle/Ground/Space Suit Interface Requirements
- Power Requirements
- Spacecraft/Ground Manpower Support Requirements
- System Compatibility
- Tool Interface Requirements
- Stowage Volume Required for Spare Equipment
- Equipment Storage/Storage Environment
- Labeling Support Requirements

SUBSYSTEM HARDWARE/EQUIPMENT

- EVA Equipment Performance Monitoring Requirements
- State of Data Management Systems Development
- System Development Costs
- System Equipment Costs
- Cost of Existing Qualified Units
- Existing EVA Qualified Equipment
- Equipment Operational Characteristics
- Equipment Performance Characteristics
- System Weight
- Replacement Spares Requirement
- Equipment Operational Life
- Equipment Shelf Life
- Spares Shelf Life
- Special Equipment Design Requirements
- New Equipment Qualification Requirements
- Equipment Transportability
- System Volume/Size/Mass
- Fault Isolation Ease
- System Maintainability
- System Reliability
- New Hardware Development/Technology Costs
- Backup System Requirements

CREW PHYSIOLOGY/PERFORMANCE

- Crewman Biomedical Monitoring Requirements
- Crewman Physiological Monitoring Requirements
- Crewman Performance Monitoring Requirements
- Crewman Behavioral Monitoring Requirements
- Total Number of Crewmen Required for EVA

FAMILIARIZATION/SIMULATION/TRAINING

- Equipment Testing/Qualification Requirements
- Crewman Equipment Operation Familiarization/Training
- Operational Procedures Development
- Maintenance Manual Development
- Equipment Maintenance and Repair Training
- Total Simulation Training Requirements

SPECIAL

- Crew Safety Requirements
- Backup Emergency Requirements
- Qualified Backup Emergency Systems
- Caution and Warning Requirements

TABLE A-1: EVA Systems Design/Selection Considerations (Cont'd.)

SYSTEM NOMENCLATURE: DATA/INFORMATION MANAGEMENT SYSTEMS

EVA MISSION/FUNCTION

- EVA Mission Definition
- Frequency of EVA Operations
- Duration of EVA
- Distance Traveled From Prime Spacecraft
- Destination of Data (Spacecraft, Earth)
- Quantity of Data Per Unit Time
- Number of Channels Required
- Tool Requirements
- Special Equipment Design Requirements

SPACECRAFT HARDWARE/SYSTEMS INTEGRATION

- Vehicle Description/Characteristics
- Spacecraft Manpower Support Requirements (Monitor, Control)
- Power Requirements
- Storage Volume Required for Spare Equipment
- Storage Environment/Atmosphere for Spares

CREW PHYSIOLOGY/PERFORMANCE

- Crewman Workload Allocation
- Crewman Physiological Monitoring Requirements
- Crewman Performance Monitoring Requirements
- Crewman Behavioral Monitoring Requirements
- Man's Performance Capabilities in EVA
- Total Number of Crewmen Required for EVA

SUBSYSTEM HARDWARE/EQUIPMENT

- EVA Equipment Performance Monitoring Requirements
- Spacecraft Manpower Support Requirements (Monitor, Control)
- Existing Qualified Systems in Use or Available
- State of Data Management Systems Development
  - Sensors
  - Signal Conditioners
  - Transmitters
  - Receivers
  - Recorders
  - Displays
  - Antennas
  - Audio
  - Visual
  - TV
- Type of System (Hardline, Telemetry etc.)
- Type of Data (Film, Magnetic Tapes, Display, etc.)
- Equipment Operational Characteristics
- Equipment Performance Characteristics
- Hardware Operational Lifetime
- Equipment Shelf Life
- Equipment Transportability
- Replacement Spares Requirements
- Spare Shelf Life
- System Volume/Size/Mass
- System Weight
- Replacement Spares Weight
- New Hardware Development/Technology Costs
- New Equipment Qualification Requirements
- Cost of Existing Qualified Units
- System(s) Reliability
- System(s) Maintainability
- Ground Support Equipment Requirements
- Ground Support Personnel

FAMILIARIZATION/SIMULATION/TRAINING

- Equipment Testing/Qualification Requirements
- Crewman Equipment Operation Familiarization/Training
- Maintenance Manual Development
- Equipment Maintenance/Repair Training

SPECIAL

- Backup System(s) Requirements
- Crewman Safety Requirements
- Backup/Emergency Requirements
- Qualified Backup/Emergency Systems