PREFACE

This document is submitted by the Vought Systems Division, LTV Aerospace Corporation, P.O. Box 6267, Dallas, Texas 75222, to the National Aeronautics and Space Administration, Manned Spacecraft Center (MSC), Houston, Texas, in accordance with Contract No. NAS9-12507, dated 28 March, 1972. It is the Final Report for Work Breakdown Structure Subtask 1.2 Pressure Suit Requirements. Work reported in this document was conducted by ILC Industries, Inc., 350 Pear Street, Dover, Delaware 19901, for Vought Systems Division under Purchase Order No. 826814-UZ. The study was conducted over the time period 19 June 1972 through 19 December 1972. An informal oral briefing was given at NASA-MSC on 20 December 1972, and review copies of this document were submitted at that time.

DECEMBER 19, 1972

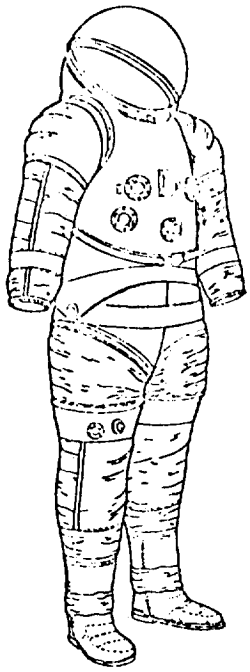
ER-051-01

REQUIREMENTS STUDY

FOR

SPACE SHUTTLE PRESSURE SUIT

AN EARTH ORBITAL SPACE STUDY OF MAN AND HIS ENVIRONMENTS



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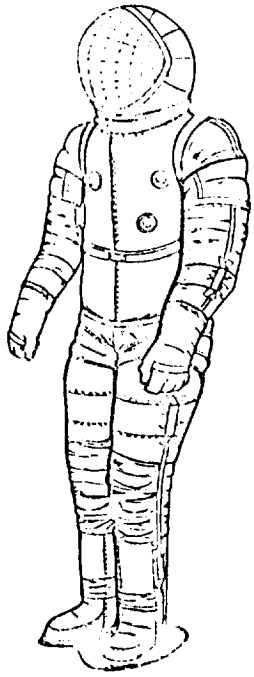

Conducted by ILC INDUSTRIES, INC. for
VOUGHT MISSILES AND SPACE COMPANY
P.O. No. 826814-UZ

ILC Report
No. ER-051-01
December 19, 1972

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SPACE SHUTTLE PRESSURE SUIT

AN EARTH ORBITAL SPACE STUDY OF MAN AND HIS ENVIRONMENTS

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1.1 INTRODUCTION

This report, prepared by ILC Industries, Inc. Dover, Delaware, provides the results of a pressure suit requirements study for the space shuttle program, and is in response to Purchase Order Number 826814-UZ issued by LTV Aerospace Corporation, Vought Missiles and Space Company (VMSC) of Dallas, Texas. The program was conducted during the calendar period of June 19, 1972 through December 19, 1972. This study included the research and analysis of data acquired from the documents listed in the bibliography, consultant reports submitted by members of the ILC engineering staff, and test data gathered during the implementation of the following contracts:

a. NASA 9-6100, "The Apollo and Skylab Suit Program".
b. NASA 9-12995, "The 8.0 psi Emergency Intravehicular Suit Programs".
c. IR&D Program, "Study of EVA Suit Concepts".

The report contains the results of the study analysis as conducted by ILC Industries and includes a discussion of three (3) major topics, which include:

a. Mission Considerations - Section II. This section discusses the general Shuttle program requirements, and a brief description of internal and external spacecraft environments. In addition, information concerning the personnel participating in the missions, their tasks and responsibilities, and their basic individual needs for pressure suits is discussed.

b. Suit Requirements - Section III. This section contains the bulk of the report and describes the overall recommendations relative to Space Shuttle Pressure Suit requirements.

c. Conclusions - Section IV. This section of the report discusses the utilization of contemporary suit designs for the Shuttle program as well as offering new configurations and recommendations. Lastly, schedule and cost considerations have been provided for support of a Shuttle suit program utilizing the recommended suit configurations.

1.2 OBJECTIVE

The objective of this study was to establish performance and design requirements for the space Shuttle EVA and IVA Pressure Suits. These requirements have been established to support the overall nominal, contingency, and emergency EVA/IVA Space Shuttle System requirements defined in Purchase Order Number 826814-UZ from VMSC.

1.3 SCOPE

Utilizing the tasks defined by Vought Missiles and Space Company (VMSC) of LTV aerospace, a systems analysis to determine the performance requirements, and to establish human factors design considerations for the Space Shuttle Pressure Suit(s) has been performed. The analysis encompassed investigation of the following areas.

a. The suit operating pressure, and its impact on pressure suit design and performance.

b. Environmental protection requirements to include thermal insulation, impact protection and heat removal requirements of the suit ventilation system in view of projected crewman work loads.

c. Human factors associated with pressure-suit operations, with emphasis on the man-machine interfaces.

d. Mobility and visibility required by the crewman to complete the movements or tasks defined for the Shuttle craft. This will include all phases from cock-pit operations to the performance of EVA tasks. Recommendations will indicate the relative movement needs for arm, neck, waist, leg, ankle, etc., to perform various EV and IV tasks.

e. Pressure suit sizing requirements.

f. Recommended materials for Shuttle Pressure Suit usage.

g. Stowage or access requirements as dictated by spacecraft or emergency procedure guidelines.

h. Pressure suit weight restrictions and donning and doffing criteria.

i. Flight maintenance in terms of usage, frequency of use and level of care to be exercised during use.

j. Crew necessities such as communications, waste management, comfort, emergency and monitoring provisions.

k. Special suit requirements such as load carrying capabilities, tethers, belts and activity restraints.

l. Useful life requirements including shelf life and cycle life as required by task and timeline profiles, or as indicated by program schedules.

m. Reliability and maintainability resulting from mission requirements.

n. The hazards or dangers associated with the requirements as part of the task study, as set forth in the EVA and IVA task definitions. The requirements for pressure suits contained herein has considered anticipated safety problem areas.

o. Consideration of the utilization of contemporary suit designs for the Shuttle program.

p. Schedule and cost considerations including crew suit quantities required to support the program.

This report not only includes a definition of the pressure-suit performance requirements, but also takes into consideration the possible, distinct and separate needs of all crew members, passengers and/or EVA crewman as defined by the baseline EVA and IVA task guidelines provided by the VMSC Shuttle study.

2.1 MISSION PROFILE

The space shuttle vehicle and shuttle program is the first step toward future operational space programs that will have major government, commercial and domestic values. This, the shuttle program, has been assigned the task of placing satellites into orbit, maintaining orbiting satellites and returning satellites from space that might require modification, rework or that must be replaced due to obsolescence. The spacecraft can also be used as a space rescue vehicle, weather observation post or an aerial mapping platform. In addition, as this vehicle becomes operational, specialized physical science studies can be performed that could improve the knowledge, culture and environment of the people.

The shuttle vehicle is composed of two (2) modules consisting of a reusable orbiter spacecraft which performs the spaceflight missions and an expendable booster module which provides the power to launch the orbiter vertically into the required orbit.

The orbiter vehicle will be a reusable spacecraft which provides a pressurized cabin for a crew of four (4) people and six (6) passengers. In addition, it will include a cargo bay 60 feet in length and 15 feet in diameter that will carry a payload of up to 65,000 pounds. The Shuttle program includes plans for 477 mission flights for a total of five (5) vehicles over the eleven (11) year period that extends from 1978 through 1988. Development, qualification and flight test of the vehicle and its support equipment is scheduled for a calendar period between 1972 and 1978. Design, maintenance and ground support goals for the vehicle have considered a 14 calendar day ground turnaround time which will include initial landing, sub-orbital flight to the launch facility and the completion of launch readiness preparations.

Shuttle is a manned program, which means that the crewmen with specialized equipment will observe, experience and describe new

findings as explorers of space. To accomplish this, man will need to venture from the spacecraft and prove his ability to do constructive work in space. This study provides the goals, design objectives and specific requirements and recommendations for the suits that will be used as part of the Shuttle program. As a basic thought the suits will be required to protect man from:

a. a low ambient pressure,
b. extreme thermal characteristics of space, and
c. the lack of a breathable gas.

Also, during EVA, the crewman must be protected against an anticipated impact from micrometeroids.

In addition, the pressure suit must provide the EVA crewmen with sufficient mobility, dexterity and visibility to perform their assigned duties during scheduled, unscheduled and contingency modes of mission operations.

Of the 477 missions planned, approximately 65% of these (310 missions) will include scheduled extravehicular activity by one or two suited crewmen. These activities might include, as a minimum, the following tasks:

a. maintenance on satellites
b. maintenance and servicing of large astronomical observatories
c. assist in payload deployment and retrieval activities
d. free flying operations with a maneuvering unit
e. scientific experiments

During these activities, there may be as many as seven (7) EVA's per mission and each EVA could last as long as eight (8) hours in duration.

2.2 SPACECRAFT ENVIRONMENT

The environmental control or life support system for the orbiter vehicle will provide a habitable environment for the crew and passengers who will be dressed in a shirtsleeve configuration and be within a thermally insulated and pressurized cabin. During their shirtsleeve activities it will be necessary for the crew to monitor the spacecraft gas composition, pressure, temperature, relative humidity, ventilation flow rate and the rate at which the breathable gas is being consumed.

The space shuttle orbiter RFP No. 9-BC421-67-2-40P provided the following cabin environmental requirements which will exist during normal operation of the orbiter vehicle:

a. Pressure - The cabin will be pressurized to 14.7 psia with a two (2) gas system composed of approximately 80% Nitrogen and 20% oxygen. (Partial pressure of oxygen will be maintained at 3.0 to 3.2 psi.)

b. Temperature - The cabin temperature will be selectable (± 2°F) by the crewman within the range of 65° - 80°F. In addition, the crewman shall not be exposed to a direct contact temperature of greater than 113°F.

   Temperature requirements for an unpressurized cabin during a contingency earth reentry have not been documented to date. However, preliminary data from North American Rockwell, Space Division and Vought Missiles and Space Company have indicated that the cabin effective environment could reach a maximum of 120°F (sink temperature) during earth reentry or a minimum of -190°F during a 96 hour waiting period for a rescue vehicle.

c. Humidity - The relative humidity within the cabin is expected to be maintained between 36% and 60%, based upon a dew point range of 40° to 60°F with the cabin dry bulb temperature at 70°F.

d. Lighting - A lighting system will be provided within the vehicle to provide general illumination during the mission and allow the crew members to

locate, operate, and read all displays and controls. In addition, the lighting will allow the crewman visual access to interior visual surfaces, and permit stowage and retrieval of all crew equipment located within the cabin volume.

Exterior lighting must also be provided as a visual aid for rendezvous, docking and vehicle altitude.

e. Vibration - Requirements for all phases of the mission should technically be considered. However, since information is not available at this time detailing the vibration levels for all mission phases, the shuttle launch and boost vibration will be considered as the requirement. This has been based on past experience from the Apollo and Skylab programs which have shown that these levels far exceed all other mission vibration levels. Figure 2-1 illustrates the shuttle orbiter launch and boost vibration requirements.

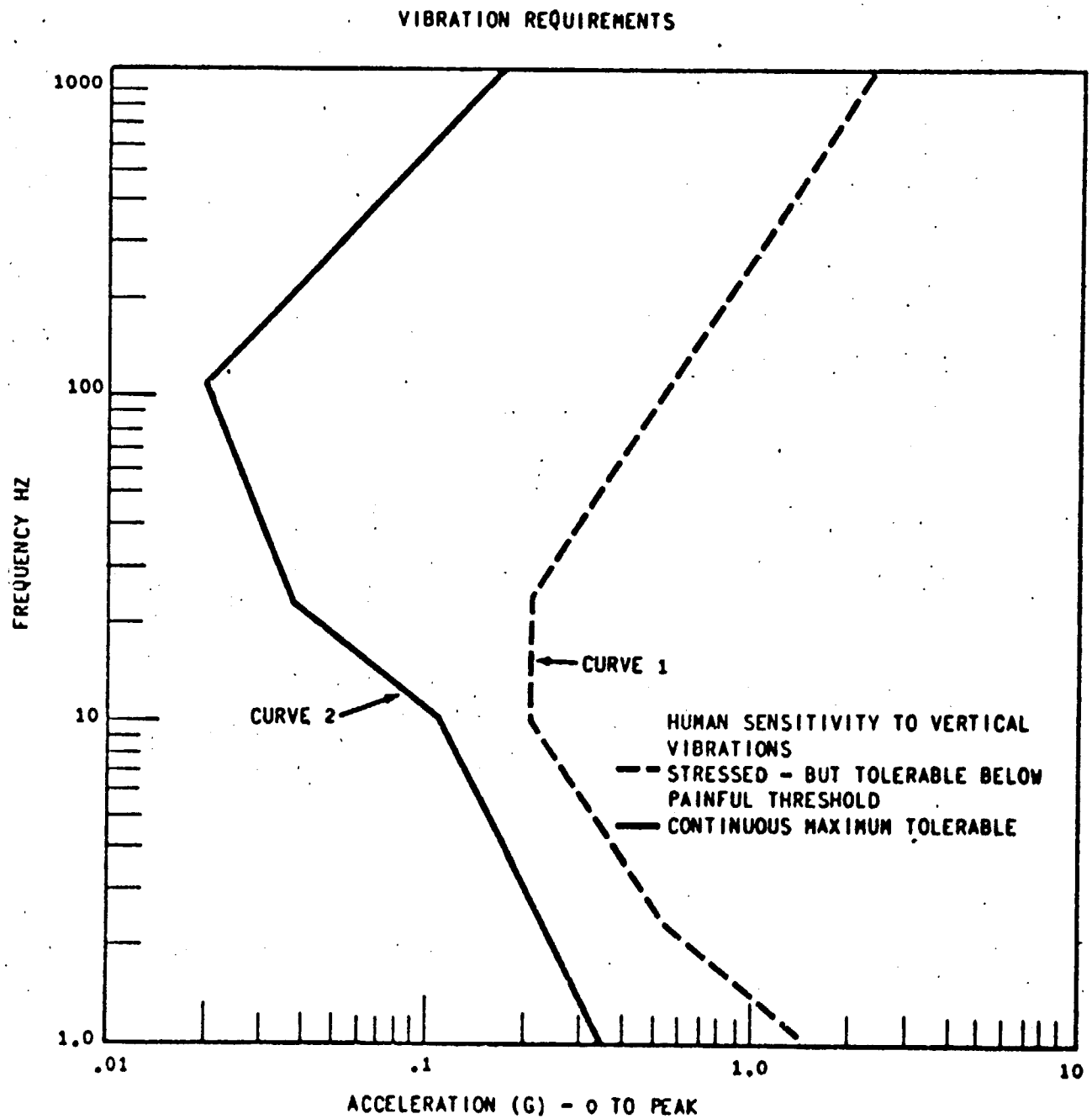

VIBRATION REQUIREMENTS
1000
100
10
1.0
FREQUENCY HZ
.01
.1
1.0
10
ACCELERATION (G) - 0 TO PEAK
CURVE 1
CURVE 2
HUMAN SENSITIVITY TO VERTICAL VIBRATIONS
STRESSED - BUT TOLERABLE BELOW PAINFUL THRESHOLD
CONTINUOUS MAXIMUM TOLERABLE

FIGURE 2-1

2.3 SPACE ENVIRONMENT

The environment in space will confront man with many hazards which will require consideration. Among these hazards are atmospheric pressures, gravity levels, thermal conditions, meteoroid environments and visual problems. The crew and passengers may also require protection from these dangers during a contingency transfer. Special attention however should be given to the EVA crewman. The space environments discussed in this paragraph are based on NASA Technical Memorandum, Document Number NASA TMX-64622, and the report prepared by J. R. Goodman and M. I. Radnofsky titled Lunar Surface and Free Space Hazards Relating to Space Suit Design dated 21 April 1965.

2.3.1 ATMOSPHERIC PRESSURE. The atmospheric pressure within the earth orbit planned for the Shuttle spacecraft is 10^{-14} torr, or less. This atmospheric condition dictates that man must be provided with an artificial pressure environment of breathable gas. This gas environment will prevent exposure of his body to a vacuum pressure and will permit normal respiration. Pressure suits should be utilized to enclose the astronaut in a 100% oxygen environment pressurized at 8.0 psia. A portable environmental control system should also be used to circulate the oxygen through the suit under pressure.

2.3.2 GRAVITY. In orbit around the earth a zero gravity environment will exist and will dictate the use of special tethering, foot restraints and tooling. Torque, compression and tension forces exerted by and through the body might cause the body to move position in lieu of the object intended to be moved. Restraint, tether and restraint aids will provide the astronaut with sufficient support to do work in the zero gravity environment.

2.3.3 THERMAL ENVIRONMENT. Vehicle surface temperatures of -263°F to +285°F can be expected. A thermal garment should be worn over the pressure vessel that will afford ample insulation from these temperatures.

2.3.4 MICROMETEOROID. Micrometeoroids that could penetrate the pressure suit are a part of the hazards in space. These micrometeoroids are predicted to travel at speeds within a range of 11 to 72 Km/Sec. Protection against micrometeoroids having a size of 0.0316 inch in diameter and a weight of up to 1 gram should be considered in the pressure suit design.

2.3.5 VISUAL PROBLEMS. Protection from UV, IR and visible light energy must also be provided as part of the pressure suit program for Shuttle. The energy levels expected can be harmful to the skin and particularly the human eye.

2.3.6 SPACE RADIATION. The radiation environment that should be considered in the design for the EVA Pressure Suit is defined in the LTV midterm briefing dated November 1972 and is titled "Study of Space Shuttle EVA/IVA Support Requirements."

2.4 PERSONNEL

A basic crew of two (2) consisting of a Commander and pilot is required to operate or "fly" the orbiter vehicle during each shuttle mission. In addition, the basic crew of two (2) may also be augmented by a mission specialist and a payload specialist as well as a maximum of six (6) passengers or observers. The specific complement for a flight is dependent upon the objectives of the individual mission. The responsibilities and basic duties for these on-board personnel are as follows:

a. Commander - In command of the flight and responsible for the overall space vehicle, payload, flight operations and vehicle safety. Proficient in all phases of vehicle flight, payload manipulation, docking, and subsystem command, control, and monitoring operations. Knowledgeable of payload and payload systems as they relate to flight operations, communication requirements, data handling, and vehicle safety.

b. Pilot - Duties essentially equivalent to that of the commander. Second in command.

c. Mission Specialist - Responsible for interfacing of payload and orbiter operations and management of payload operations. Proficient in vehicle and payload subsystems, flight operations and payload communications data management. Crew may include more than one mission specialist.

d. Payload Specialist - Responsible for the applications, technology, and science payload and instrument operations. Detailed knowledge of instruments, operations, requirements, objectives, and supporting equipment. Crew may include more than one payload specialist.

e. Passenger or Observer - Anyone on board who has no direct part in the space shuttle or payload operation. These could be either male or female passengers or observers who are:

   (1) Scientists from the U.S. and other nations who will be monitoring experiments being performed in space by EV Crewmen.

(2) Leaders from the U.S. and other countries receiving a U.S. public relations tour of space.

(3) Personnel being transported (shuttled) to a modular space station.

2.5 SUIT UTILIZATION

Space Shuttle missions will require a variety of onboard equipment to support planned, unscheduled and contingency operations during IV, EV and shirtsleeve modes of activity. The equipment needed is a function of the tasks defined for the Shuttle missions.

The various configurations of suits required to support Shuttle missions are directly related to the job categories, responsibilities and the tasks to be performed by the crew and passengers. As a result, this paragraph shall focus on the basic tasks for the crew and passengers requiring protection by a pressure suit.

A requirement presently exists to provide a pressure suit that will afford the crewman protection during planned and unscheduled EVA or IVA mission tasks. Supplemental pressure protection must also be provided to the crew and passengers due to the possibility of a potential loss in cabin pressure which could be induced by any of the following conditions:

a. Failure of:
   (1) Environmental Control System
   (2) Cabin Pressure Seals
   (3) Mechanical Latching System for hatches
   (4) Spacecraft Guidance, propulsion, etc., requiring an in-space rescue of crew and passengers.
   (5) Structural members of spacecraft induced by crash with other space vehicles or satellites.

b. Micrometeoroid penetration

c. In-flight trouble shooting analysis of malfunctioning systems requiring a low cabin pressure.

The following subparagraphs discuss the basic suited crew and passenger tasks utilized to prepare the requirements discussed in Section III of this report.

2.5.1 EVA AND IVA TASKS. As a primary function, the EVA Pressure suit will permit the EVA crewman to venture from the spacecraft cabin to remote unpressurized areas either external to the spacecraft or within various types of payloads. During this time, the EVA crewman will perform such activities as:

a. maintenance of satellites

b. exterior maintenance of orbiter

c. offer assistance during payload deployment and retrieval

d. rescue operations

e. scientific experiments

Specifically, ILC Industries utilized seven (7) task scenarios or categories which were selected by Vought Missiles and Space Company to be representative of the planned or unscheduled tasks which a crewman could perform by EVA and unpressurized IVA during orbiter operations. These seven (7) representative tasks scenarios are presented in Table 2-1.

Appendix "A" provides a detailed summary of both the general tasks and a descriptive procedure required to perform each of the seven (7) scenarios previously discussed.

2.5.2 FLIGHT CREW SUITED TASKS. During the majority of the Space Shuttle missions it is expected that the flight crew will perform all assigned tasks in shirtsleeve attire with the

REPRESENTATIVE TASK SCENARIOS

NO.	DESCRIPTION OF TASK
1.	EVA maintenance of a large space telescope (LST)
2.	EVA and IVA support of an earth observation sortie
3.	Satellite and tug retrieval and deployment readiness
4.	EVA inspection and repair of the orbiter vehicle exterior
5.	Deployment and retraction of plasma wake experiments
6.	Maintenance of an x-ray astronomy observatory
7.	Maintenance and servicing of astronomy explorer

EVA AND IVA ORBITER OPERATIONS

TABLE 2-1

exception of the planned or unscheduled EVA or IVA operations described in the previous subparagraph. However, in the event of a cabin or satellite module decompression, emergency IV pressure suit protection will be required. In this case, a pressurized suit will be needed to permit the following tasks:

a. allow the commander and pilot to control the orbiter vehicle and perform earth re-entry and landing operations.

b. allow the crew to assist the EVA or IVA crewmen into the orbiter vehicle by opening a malfunctioned airlock hatch.

c. allow the crew to assist passengers to ingress their couches and don their couch restraint harnesses and Life Support systems.

d. allow the crew to assist the passengers in performing a contingency EVA to a rescue vehicle if the shuttle orbiter is unable to reenter the earth's atmosphere.

e. allow the crew to perform a contingency EVA to a docked or undocked rescue vehicle.

f. allow the crew (mission and/or payload specialist) to perform a contingency EVA transfer from a docked payload module to the orbiter cabin.

The above tasks are based on present shuttle mission information. Additional tasks may be added as further mission definition becomes available.

2.5.3 PASSENGER TASKS. Paragraph 2.4 noted that the passenger or observer would have no direct part in the space shuttle or payload operations. Therefore, it is expected that the passenger will always be in a shirtsleeve attire unless a cabin decompression occurs as might be induced by the conditions discussed in paragraph 2.5. In the event of such a decompression, the passengers or observers may be required to perform the following tasks in a pressurized suit:

a. Perform an emergency transfer through the airlock and into a docked or undocked rescue shuttle spacecraft with the assistance of an EVA or flight crewman.

b. Return to the passenger couch in a pressurized suit after a malfunction of the Shuttle vehicle and attach the harness restraint system with assistance and prepare for earth reentry.

2.6 SUIT CONCEPTS

By reviewing the mission considerations previously discussed in this section, it was concluded that the following basic suit concepts are required to satisfy the space shuttle program.

These consist of:

a. EV and IV Suit to perform planned, unscheduled and contingency tasks.

b. IV Suit to provide the pilot, commander, mission specialist, and payload specialist with a pressure garment for emergency pressurization.

c. IV Suit to provide the Shuttle passengers with a pressure garment for emergency pressurization.

The afore listed Shuttle Suit support modes may be satisfied by numerous suit concepts, some of which could include the present A7LB-CMP (modified A7L type) and A7LB-EV Apollo configured suits, as well as the ISSA suits, AES suits and hybrid configurations of each of these.

In addition, these three (3) basic suit support areas could be satisfied by one common suit or by as many as three.

The subsequent sections of this report shall investigate these areas by providing the requirements for each of these concepts and utilizing the requirements in conjunction with cost considerations to provide a final concept recommendation in Section IV.

Various concepts of pressure suit subsystems were also considered in order to determine the best combination of subsystems and suits which will satisfy the three (3) basic suit support areas. Each of these subsystems will be further discussed in the suit requirements section of this report (Section III).

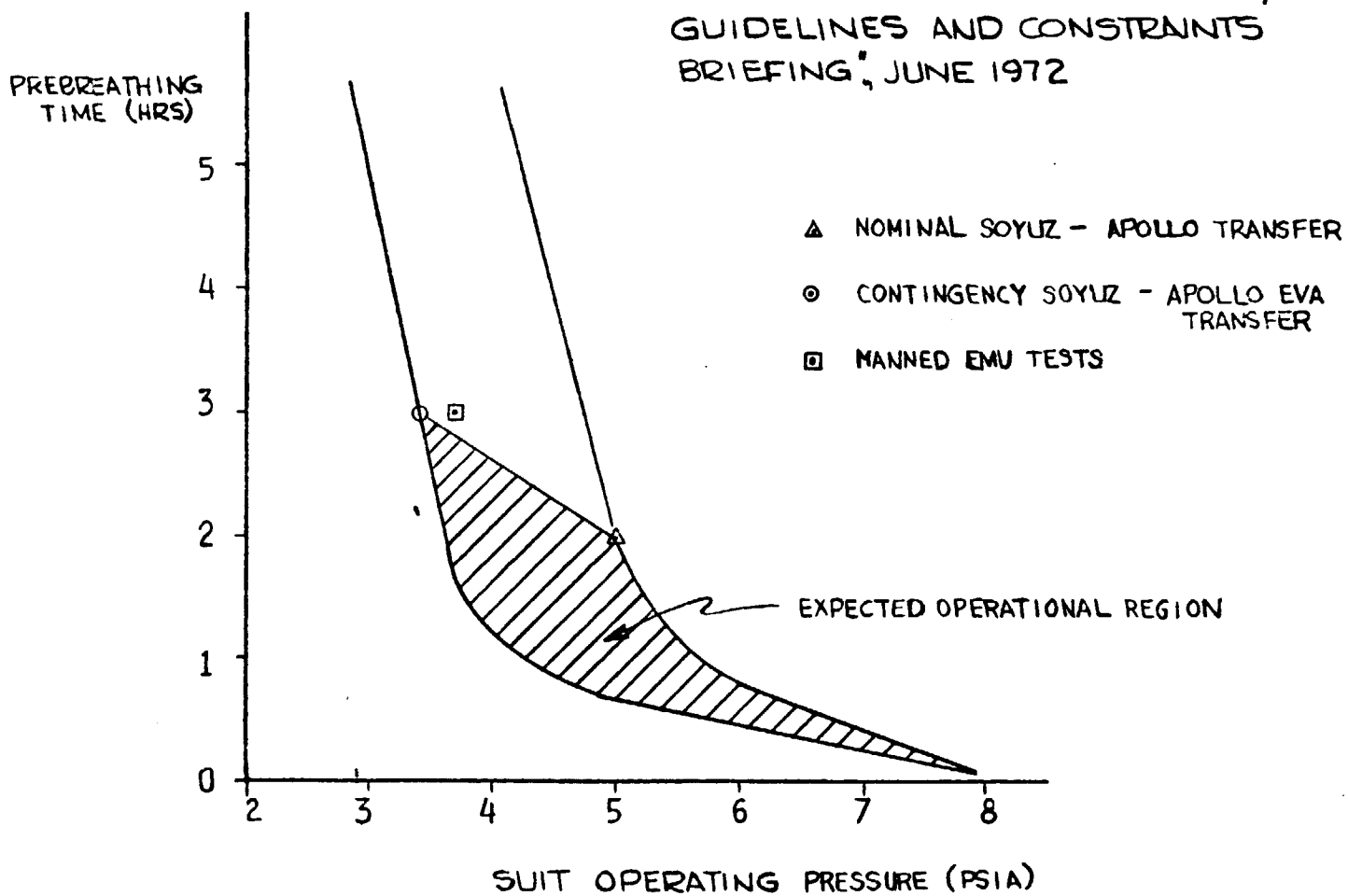
3.1 PRESSURIZATION

At ambient earth pressures, the human body is saturated with nitrogen. 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 decompression sickness and can be prevented by breathing 100% oxygen for extended periods of time prior to exposure to a lower ambient pressure. This oxygen breathing process is known as pre-breathing.

Based on studies by Vought Missiles and Space Company (VMSC) a suit operating pressure of 8.0 psi has been selected to be used as the requirement for both the EVA Suit and IV Emergency Pressure Suits. This selection was primarily chosen since no pre-breathing of 100% oxygen would be required when decreasing the ambient spacecraft pressure of 14.7 psia down to an 8.0 psia spacesuit pressure. This operating pressure would therefore provide the IV and EV crewmen with the greatest amount of safety during an IV Emergency condition where time would not permit pre-breathing. In addition, such a suit operating pressure would also permit the EVA crewman to perform his tasks in the minimum amount of time without requiring any pre-breathing. Figure 3-1 illustrates a typical curve which may be used to describe the pre-breathing time as a function of suit pressure. This curve however, varies for different subjects depending upon the subjects weight, age and general physical condition, and therefore should not be considered a baseline for all subjects.

As a result of the above, the following pressures should be utilized as the design goals for each pressure suit concept:

a. Operating Pressure = 8.0 psid (X)
b. Structural Pressure = 12.0 psid (1.5X)
c. Proof Pressure = 16.0 psid (2X)
d. Burst Pressure = 20.0 psid (2.5X)



PREBREATHING REQUIREMENTS
FIGURE 3-1

In order to assist VMSC in the selection of the EVA suit operating pressure, the impact of an 8.0 psi operating pressure on suit design was investigated. Those areas considered are discussed in the following paragraphs.

3.1.1 PRESSURE VERSUS MOBILITY. An evaluation of mobility in various joints of the A7LB Pressure Suit was conducted. The evaluation of these joints was performed at operating pressures of 4.0, 5.5, 6.0, 6.5, 7.0 and 7.5 psig. The objective was to determine the pressure at which each joint would lose acceptable mobility. The results of the test are provided in Table 3-1 of this study. This table illustrates that the shoulder, hip and waist joints of the A7LB Suit became operationally impractical at pressures above 6.0 psig.

A study of suit mobility was also conducted using the A7LB, AES and ISSA suit designs. The suits were operated at staged pressures of from 1.0 psig to 8.0 psig. Joint ranges and corresponding torques were measured at 4.0 and 8.0 psig.*

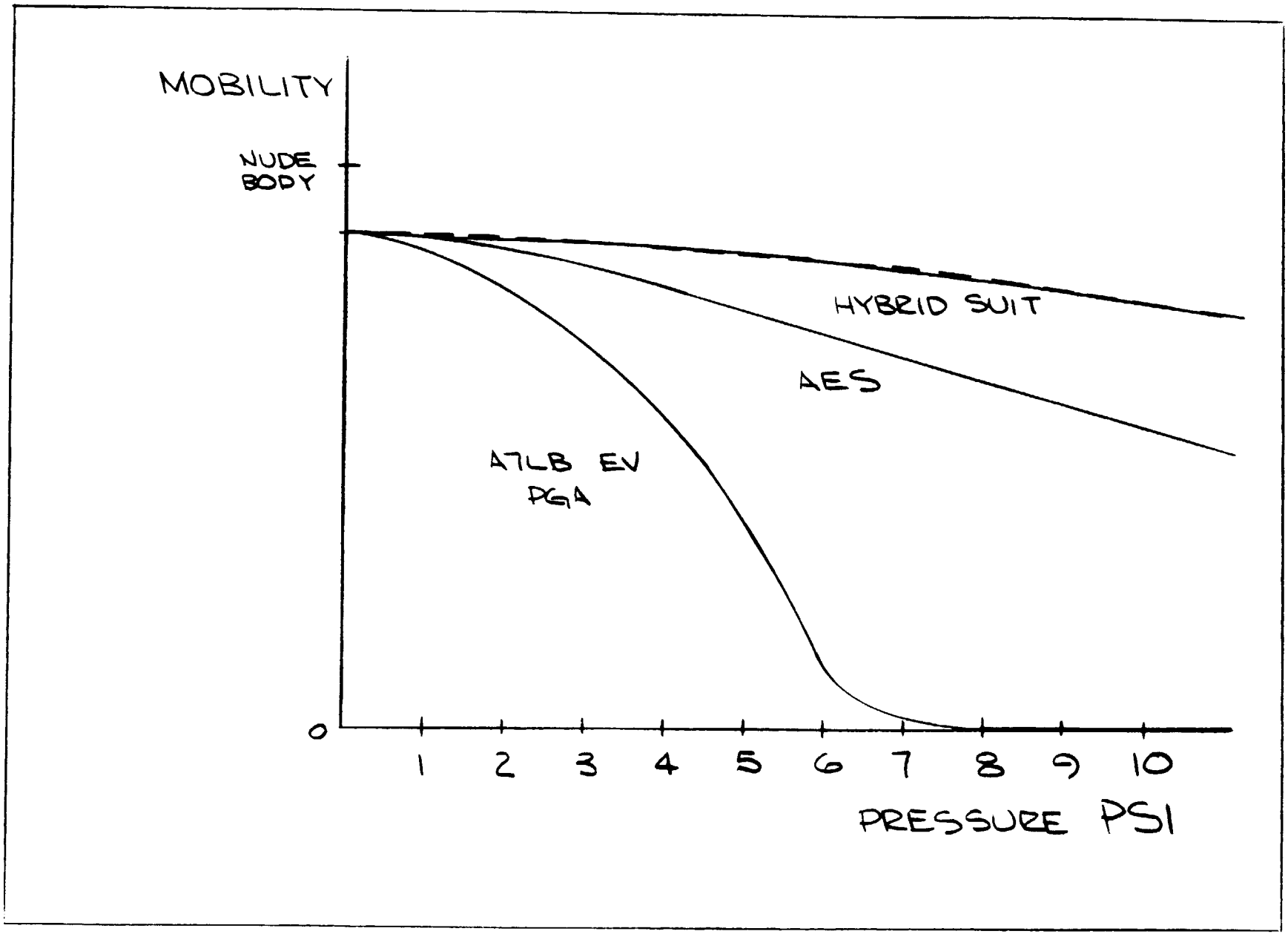
An increase in suit operating-pressure had varying effects on the mobility of each joint; some existing designs worked as well at 8 psig as they did at 4 psig; others became totally unacceptable at 8 psig. A new hybrid joint which includes the best features in each of the existing designs would be feasible for use in an 8 psig suit and should be relatively insensitive to variations in operating pressure. Design judgement was used to predict the relationship between pressure and mobility for some typical EV pressure suit designs. Figure 3-2 illustrates this relationship.

Examples of some feasible joint designs include the AES type shoulder, waist, and thigh joints, and the modified A7LB type

*ILC Industries "Advanced Suit Program Project 01-502 Status Report" dated 15 June 1972.

	ELBOW	KNEE	SHOULDER UP/DOWN	SHOULDER FORWARD/BACKWARD	ANKLE	HIP/THIGH FLEXURE MOVEMENT
5.5 PSI	Slightly harder to move but no noticeable difference in range from 4 psig	Slightly harder to move but no noticeable difference in range from 4 psig	Slightly Harder than at 4.0 PSI	Noticeably Harder to move than at 4.0 PSI	Slightly Harder to move than at 4.0 PSI	Slightly harder to move than at 4.0 psi
6.0 PSI	Same as at 5.5 PSI	Same as at 5.5 PSI	Stiffer and cannot hold joint in intermediate position - becoming unstable	Extremely Stiff and difficult to move	Same as at 5.5 PSI	Range decreased considerably. Waist beginning to become unstable.
6.5 PSI	Same force as 5.5 PSI but range is restricted	Approximately the same as at 5.5 PSI	Too stiff to move	Too stiff to move	Becoming harder to move than at 6.0 PSI	Range approximately the same as at 6.0 PSI. Became more difficult to move
7.0 PSI	Slightly more force required than at 5.5 PSI Same as 6.5 PSI	Approximately the same as at 5.5 PSI	Too stiff to move	Too stiff to move	Difficult to move. Movement decreased in range.	Range approximately the same as at 6.0 PSI. More difficult to move than at 6.5 PSI (high torque).
7.5 PSI	Same as at 7.0 PSI except slightly less range	Approximately the same as at 5.5 PSI but less range	Too stiff to move	Too stiff to move	Same as at 7.0 PSI	Almost impossible to move

A7LB MOBILITY EVALUATION
Table 3-1



PRESSURE VERSUS MOBILITY

FIGURE 3-2

elbow and knee joints. These joints have been examined during unmanned tests at 8 psig with torque versus range recorded. With minor design modifications, these hybrid joints should operate effectively at 8.0 psid.

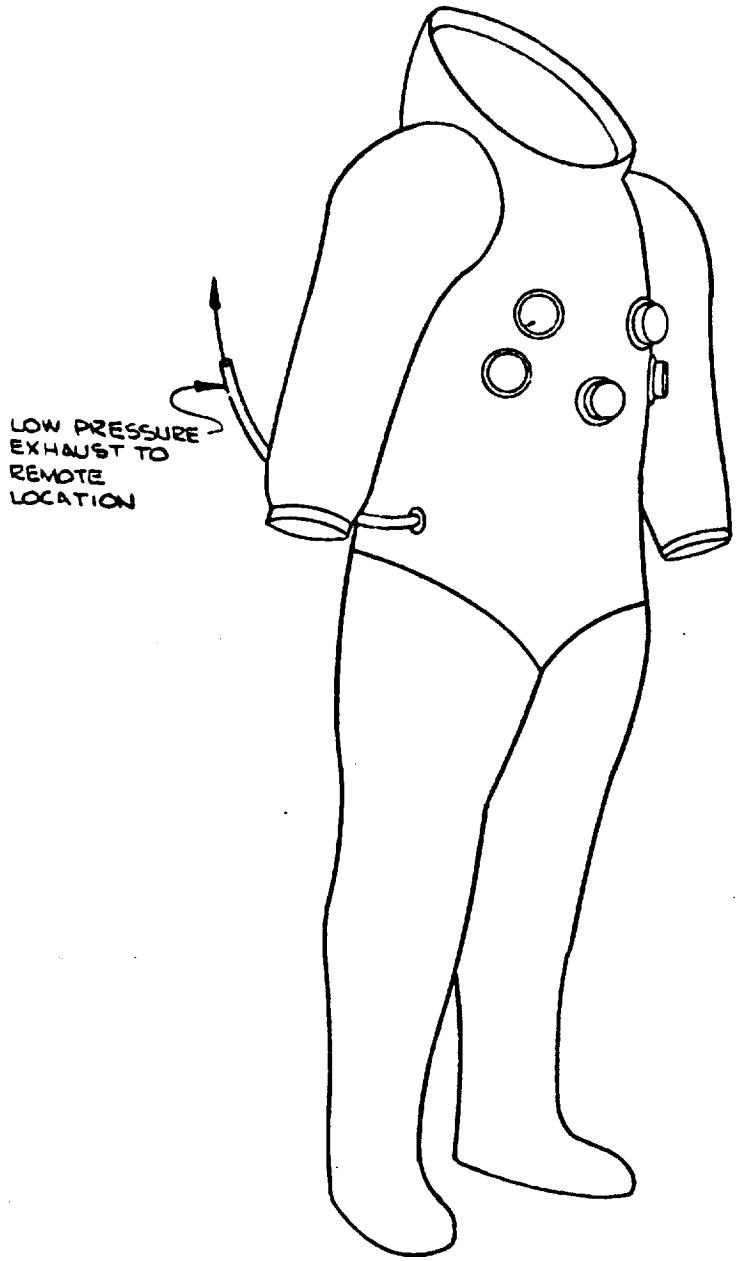
The only area of mobility found to be significantly affected by a higher operating pressure is in gloves. Existing EV glove designs are marginal at 4 psid, partly due to the encumbrance of the thermal cover layer. Currently, NASA-Ames Research Center has contractors developing gloves for operating pressures of 8 psig. Assuming these efforts are successful, and a satisfactory 8 psig pressure glove is produced, then the problem of thermal layer encumbrance will require attention.

It should also be noted that the NASA/MSC Lunar Receiving Laboratory uses a glove (and arm) that operates at one atmosphere (14.7 psia) of pressure. This glove provides good pressurized finger and metacarpal dexterity and wrist mobility, but it is marginial in thumb dexterity. Unfortunately this glove is high in weight due to the use of numerous hard elements of steel and aluminum. However, it does demonstrate the feasibility of good glove dexterity at high pressures, and considerable weight reduction could be achieved by use of lighter materials in similar glove designs for operating at 8.0 psig.

3.1.2 PRESSURE VERSUS LEAKAGE AND CONTAMINATION. An increase in the suit operating pressure has varying effects on suit leakage and depends upon the system design characteristics. The current Apollo-Skylab pressure suit or EV A7LB Suit has an allowable leakage of 180 scc/min prior to flight and a maximum leakage of 360 scc/min after 115 hours of contingency operation. In actual flight, a majority of these leakage values have been within a 30 to 100 scc/min range. By utilizing hybrid suit design techniques, it is feasible that suit system leakage at pressures

of 8.0 psia can be reduced to approximately 50 - 80 scc/min. These hybrid design techniques include the usage of hard ring closures or couplings in lieu of zipper closures, and the use of bearing seals to provide rotation at critical suit joints. This leakage value may also be maintained throughout the suit life by utilizing a modular suit concept which will enable easy replacement of bearing and coupling components.

Contaminants can also be generated from an EV pressure suit by off-gassing or by lint production, particularly from the TMG. Neither of these conditions is a function of the operating pressure. This is the case since the volumetric flow remains fairly constant over the pressure range of 4 - 8 psig when venting to a vacuum. As a result, aerosols of body products such as skin, oil and perspiration will remain the same per unit volume since they are also being produced by the occupant at a rate which is independent of pressure. Other types of contaminants such as off-gassing or lint generation of fabrics, or general overall suit materials, including off-gassing of lubricants, can be reduced through careful selection of materials. Since this material selection may result in a compromise on overall suit design, it is recommended that a Contaminant Barrier Garment (CBG) similar to that shown in Figure 3-3 be utilized. This concept would permit the crewman to don this thin elastomer garment whenever he is required to operate in a contaminant or leakage sensitive area. Such a garment could be fabricated from an unsupported elastomeric film approximately 10 mils in thickness. The garment could be one piece in construction with a simple gas sealing closure (zipper, roll seal, etc.) routed and located similar to the rear entry design of the Apollo A7L suit. This will permit quick donning if it later becomes a requirement. The CBG should be donned with the helmet and gloves removed from the suit. Low pressure elastomer seals, similar in concept to the Skylab wrist dams, would be provided at the torso



FEATURES

- LOW PRESSURE GAS SEALS AT HELMET, WRIST, UMBILICAL CONNECTORS.
- THIN, DURABLE. PLIABLE ELASTOMER, POSSIBLY SILICONE
- DETACHABLE WHEN NOT REQUIRED

CONTAMINANT BARRIER GARMENT

FIGURE 3-3

neck ring, wrist disconnects, ankles and suit umbilical connectors. In order to prevent pressurization of the CBG by suit leakage, one or several vent tubes would be coupled to one main tube which would exhaust all leakage and contaminants away from the working area. As a result the CBG will be simple in design (no mobility joints, etc.), light in weight (approximately 0.25 pounds) and will not impede the crewman's mobility.

3.1.3 OPERATING PRESSURE VERSUS WEIGHT AND STRUCTURAL INTEGRITY. In theory, the weight of any structure or pressure vessel should be directly proportional to the loads it must support for the same material, shape, etc. In practice, however, many other considerations affect the configuration (and thus the weight) of the structure. Rigidity, corrosion resistance, attachment to other components, flammability, wear resistance and workability are some of these considerations.

This is true in space suit design. One example is the attachment of fabric to hardware, such as bearing and disconnect couplings. A certain minimum width of fabric must be anchored mechanically to the hardware, thus dictating one dimension of the bearing; this dimension may be larger than that required to support loads imposed by the suit operating pressure. Another example is the suit wall. In many areas, such as the arms, the fabric is much stronger than is required purely for plug loads and hoop stresses due to the pressure. This is because the fabric must also be durable enough to accept general wear and tear, and have adequate puncture resistance.

A major consideration in structural analysis of a space suit is the loading generated by the suit occupant, i.e. "man-induced loads". Apollo and Skylab suit experience shows that, in the A7LB legs, these loads can be 2 to 3 times higher than plug loads induced by operating pressure. Obviously the man-induced loads are not a function of suit operating pressure, yet they definitely affect the structural design and thus the weight of the suit.

The end result of these and other considerations is that suit weight is not a direct function of operating pressure. Partly for this reason, the 8 psi hybrid suit development should emphasize the use of light weight materials for suit hardware. For example, the use of fiber epoxy composites in place of metals should be evaluated for bearing capture rings. The rings would be approximately the same size and shape in most materials, and a composite ring would weigh up to 50% less than an aluminum ring.

3.1.4 OPERATING PRESSURE VERSUS STOWAGE VOLUMES. Due to the increased use of hard goods, the stowage volume for a high pressure (8 psia) suit will probably be slightly larger than that for a 4 psia suit. However, incorporation of a high pressure suit (8 psia) which has a detachable waist disconnect as well as helmet and glove disconnects will provide more stowage flexibility by allowing the choice of separate stowage of each suit section or stowage of the entire assembly. The Advanced Extravehicular Suits (AES) exhibited the ability to stow a hard goods type suit in the present Apollo Command Module Stowage container. Based upon design information to date, it is expected that an 8.0 psia hybrid EV pressure suit will have a smaller stowage volume than the AES suit.

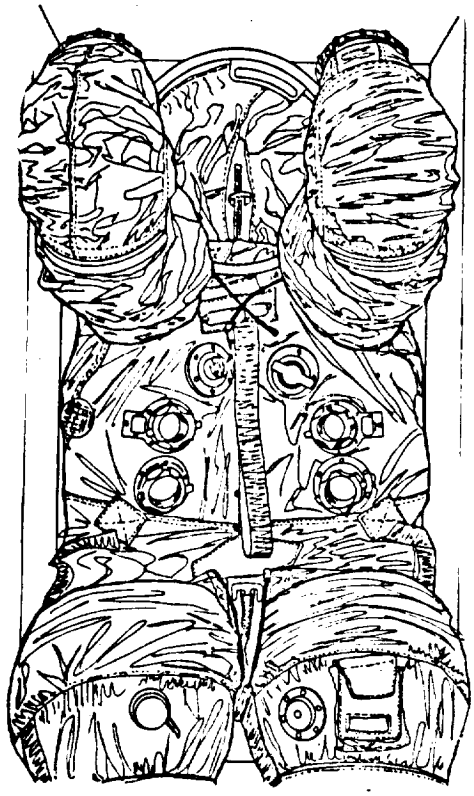
It has therefore been concluded that the operating pressure has little affect upon the stowage volume of the suit. Figure 3-4 illustrates typical stowage volume requirements for the A7LB and AES Suits.

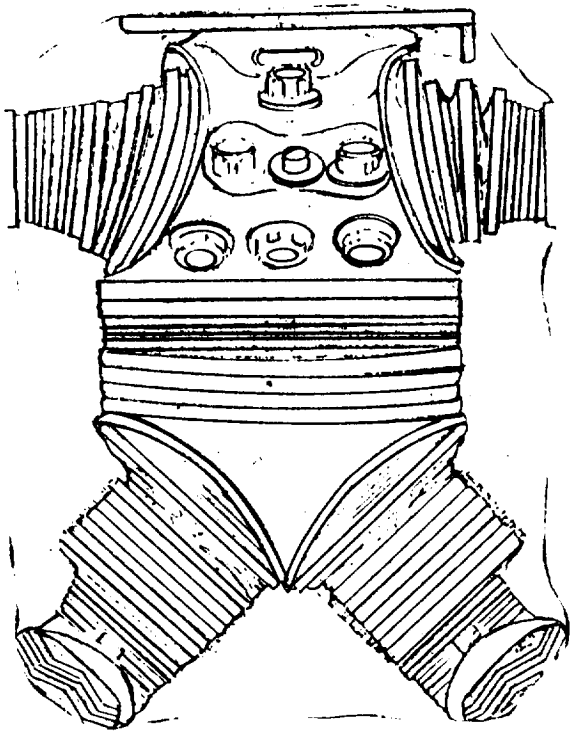
3.1.5 OPERATING PRESSURE VERSUS CYCLE LIFE. Increased suit operating pressure affects the cycle life of a pressure suit joint in the same manner as it affects the mobility of a joint. If the mobility of an existing suit joint becomes unacceptable at 8 psid, cycle life of that joint will most probably be drastically reduced at some lower pressure due to increased loads and abrasion as well as increased stiffness in the joint itself.

A7LB PGA

Envelope 32 x 20 x 9 Inches

Volume 3.33 ft^3





AiResearch AES

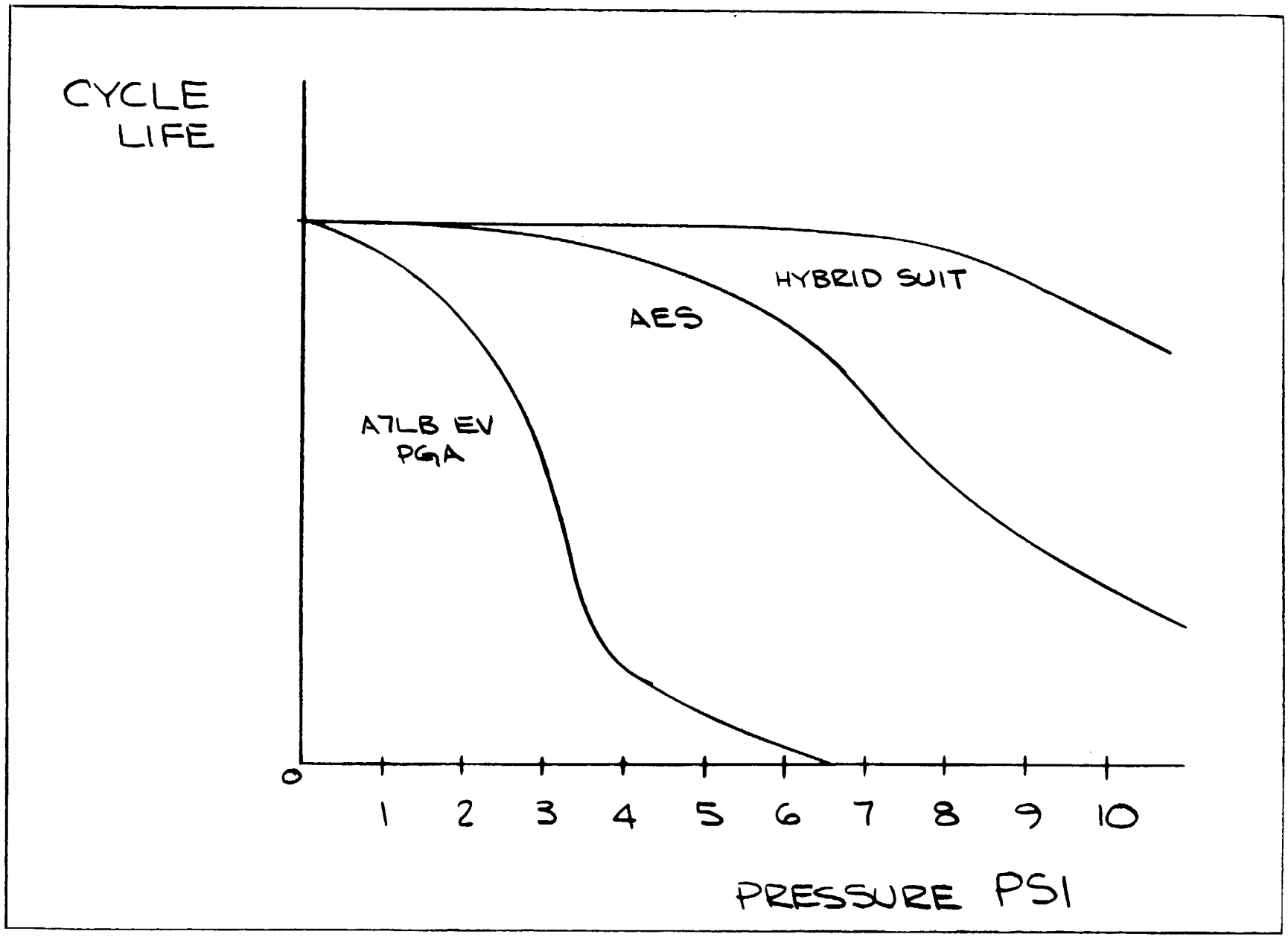
Envelope 28½ x 23 x 15 Inches

Volume 5.69 ft^3

PRESSURE VERSUS STOWAGE

FIGURE 3-4

This problem can be overcome by utilizing available joint designs which have demonstrated acceptable mobility and cycle life at 8.0 psi. Figure 3-5 illustrates the relationship between cycle life and pressure. This curve closely corresponds to that which represents mobility versus pressure.



PRESSURE VERSUS CYCLE LIFE

FIGURE 3-5

3.2 VENTILATION

The Pressure Suit Ventilation System provides three major functions:

a. Circulation of Cooling Gas
b. CO_2 Washout
c. Visor Defogging (Humidity Control)

In order to accomplish these, the suit ventilation system must provide the proper routing of ducting to the helmet area, arms, legs and torso to insure the maximum in crewman comfort. In addition the ventilation flow over the pressure suit helmet must be such that the partial pressure of CO_2 does not exceed 7.5 m.m. Hg. at the crewman's oral-nasal area with adequate life support system vent flow.*

Experience gained from the Apollo program has demonstrated that the design of the suit ventilation system is an important consideration in the overall suit system design. A design feature which should be considered in the space shuttle ventilation system is the provision for manual balancing of the inlet pressure and flow for each suit vent system to account for different arm and leg lengths or pressure drops in the different suits. Without such a provision, system mismatches in suit flow rates such as those which have been experienced in the Apollo Command Module (CM) could occur. These mismatches occurred because the CM provides one primary flow of oxygen which is divided among each of the three pressure suits. If a pressure drop difference exists among each of the three suits, a different flow rate also exists in each suit. Such functional interface deficiencies can be eliminated in the shuttle program by:

a. utilizing new light weight ducting materials.
b. improving the crush resistance and flexural endurance of the ducting.

*Vent flow rates to be defined by VMSC.

c. determining the best vent duct routing configuration and attachment to the suit walls.

d. evaluating better methods for joining, branching, and terminating the ducting.

e. providing a means to adjust the suit system pressure drop to obtain a balanced flow to each suit when more than one is being supplied ventilation from a common Environmental Control System (ECS).

The ventilation system will interface with either the space shuttle vehicle environmental control system (ECS) or an emergency or primary portable life support system through the oxygen connectors. Two basic types of connector design were considered for shuttle pressure suit use:

(1) Individual oxygen connectors (Apollo or Skylab Concept) or;

(2) A unitized connector assembly

Table 3-2 depicts the advantages and disadvantages of each of these designs. The preliminary recommendation, as described by this table is that the individual connectors are the most desirable for use on the shuttle program. Finalization of the recommendation for individual connectors is dependent on the detailed portable life support system configuration. If a chest mounted ice pack and control box is selected, space and accessability considerations may favor integration of two (2) of the oxygen connectors and the inlet and outlet water connectors into a unitized connector assembly.

Based on individual connectors, Table 3-3 was prepared to illustrate the recommended number of oxygen connectors required to support each pressure suit concept with reasons why these quantities are required.

PRESENT APOLLO CONNECTOR ORIENTATION	
ADVANTAGES	**DISADVANTAGES**
A. Easy to manufacture hardware.	A. Long donning time due to numerous hoses and umbilicals.
B. Separate umbilicals are flexible and easy to position on the suit.	B. Hoses and umbilicals interfere with crewman's mobility and can become lodged on spacecraft hardware.
C. More reliable since redundant connectors exist on suit and can be used during an emergency or ECS transfer.	C. Weight penalty.
D. Presently qualified for Apollo/Skylab use.	
E. Allows for reverse air flow for efficient suit drying.	
F. Adaptable to all qualified GSE equipment including ventilators, test stands, portable test rigs, etc.	

UNITIZED CONNECTORS	
ADVANTAGES	**DISADVANTAGES**
A. One main umbilical should provide greater EVA mobility and less interference possibilities.	A. Stiffness of umbilical may present donning difficulties (impact of stiffness is unknown).
B. Can be mounted on chest area of EV suit torso.	B. Difficult to manufacture due to close tolerances to guarantee electrical continuity as well as O_2 and water connections.
C. Weight savings.	C. Less reliable due to difficulty in manufacturing and no redundancy of connectors.
	D. New hardware design required (similar to ALSA connector).
	E. Suit redesign to vent duct routing, etc. required.
	F. Crosstalk inefficiencies i.e., warm water, cold air, in close proximity.
	G. Higher load on suit wall than separate connectors.
	H. More difficult to maintain since problem with one will affect all connectors.
	I. When changing ECS systems. Could be disastrous if connector would not engage in this situation.
	J. Modifications such as special adapters or hardware redesign would be required to present Apollo/Skylab GSE equipment.

CONNECTOR CONCEPT COMPARISON

TABLE 3-2

IV EMERGENCY CREW SUIT	IV EMERGENCY PASSENGER SUIT
2 Inlet; 2 Outlet	2 Inlet; 2 Outlet

Reasons:

(1) Will permit transfer from or to vehicle ECS when using portable emergency LSS during:

a. Contingency EV transfer from the disabled spacecraft to a rescue vehicle.

b. Contingency IV Passenger transfer from a remote location within the orbiter to the passenger couch. Transfer of a crewman from within a satellite to the crew station couch.

EVA/IVA PRESSURE SUIT
2 Inlet; 2 Outlet

Reasons:

(1) Most reliable-provides a backup set of connectors in case prime connectors fail to operate.

(2) Will permit transfer from vehicle ECS to portable LSS rather than leaving the suit without life support during a transfer (contingency-abort EVA and ingress depressurized cabin).

(3) Will permit attachment of the backup or Emergency Life Support System directly to the suit, rather than using the prime LSS as the flow path to the suit.

OXYGEN CONNECTOR REQUIREMENTS

TABLE 3-3

3.3 LEAKAGE

Pressure suit leakage is primarily a function of suit design, with the suit entry or closure having been (historically) the highest leakage source.

The present Apollo and Skylab Pressure Suits are required not to exceed a leakage of 180 scc/minute at 3.75 + 0.25 psia for any normal operational mode. The leakage is permitted to increase to 360 scc/minute during a contingency pressurized return in a depressurized spacecraft (115 HR-Apollo and 13 HR-Skylab).

Several requirements also exist for EV and IV advanced pressure suits based on Requests for Proposals (RFP) recently distributed by NASA. These requirements are:

EV Suit (OES) RFP No. 9-BC-73-36-2-263P	400 scc/minute at 8.0 psi (when new - at PDA) 1000 scc/minute at 8.0 psi (during service life - 50 - 6 hr EVA's or 1 year)
IV Emergency Crew Suit RFP No. 9-BC-76-80-2-108P	400 scc/minute at 8.0 psi (at PDA) 1000 scc/minute at 8.0 psi during service life of 1 year

Table 3-4 provides a summary of pre- and post-flight leakages for the A7L (Apollo 7 through 14) and A7LB (Apollo 15 and 16) pressure suit configurations. It should be noted that the majority of these suits had a leakage rate of 90 scc/minute or less, both in pre- and post-flight testing.

To prevent contamination of payload sensors and sensitive optical and thermal control surfaces, as well as minimize the quantity of oxygen which is supplied by the EVA life support system, it is imperative that the EVA pressure suit leakage be kept to a minimum. Therefore, it is recommended that the following areas be further investigated:

FLIGHT NUMBER	CREWMEN	SERIAL NO.	PRE-FLIGHT PGA LEAKAGE (PTA) CC/MIN	POST-FLIGHT PGA LEAKAGE CC/MIN
Apollo 7	CDR	A7L-004	60	90
	CMP	A7L-005	90	100
	LMP	A7L-006	125	265
Apollo 8	CDR	A7L-030	60	50
	CMP	A7L-037	87	35
	LMP	A7L-031	55	65
Apollo 9	CDR	A7L-020	90	54
	CMP	A7L-019	200	225
	LMP	A7L-015	55	53
Apollo 10	CDR	A7L-047	60	75
	CMP	A7L-043	108	75
	LMP	A7L-044	60	75
Apollo 11	CDR	A7L-056	33	117
	CMP	A7L-033	60	85
	LMP	A7L-077	95	115
Apollo 12	CDR	A7L-065	105	400
	CMP	A7L-056	55	18
	LMP	A7L-067	51	45
Apollo 13	CDR	A7L-078	80	90
	CMP	A7L-088	130	145
	LMP	A7L-061	58	60
Apollo 14	CDR	A7L-090	93	130
	CMP	A7L-085	125	135
	LMP	A7L-073	90	100
Apollo 15	CDR	A7LB-315	80	40
	CMP	A7LB-094	80	45
	LMP	A7LB-320	110	110
Apollo 16	CDR	A7LB-322	55	155
	CMP	A7LB-082	90	120
	LMP	A7LB-327	108	220

NOTE: All data taken at sea level ambient conditions using O_2 with PGA pressurized to 3.75 psig. Data from ILC Memo ILC-M-61292 dated 6/6/72.

LEAKAGE RATES FOR APOLLO SUITS
Table 3-4

(1) Use of a hard ring waist disconnect for suit entry in all suit concepts (EVA and IV emergency suits).

(2) Use of new attachment methods for the suit bladder and restraint materials.

(3) Eliminate friction dependent devices such as cable systems.

(4) Incorporation of easily replaceable seals at the waist, helmet and wrist closures as well as at all bearing interfaces and modular joint interfaces. This will permit easy and inexpensive maintenance on the ground during the suit life.

It is estimated that the shuttle pressure suit leakage can be reduced to approximately 80 scc/minute at 8 psia in all suit configurations by utilizing the above mentioned design features.

3.4 VENT SYSTEM PRESSURE DROP

Maximum allowable pressure drops for the Apollo, Skylab and 8.0 psi development suits are shown in Table 3-5.

Pressure drop across the suit is basically a function of the ventilation ducting, its length and construction, and routing. The design and construction of oxygen connectors as well as the pressure suit fit also affect suit pressure drop.

The internal design of the pressure suit oxygen connectors should be studied to establish methods of reducing the pressure drop of these connectors. In addition, the suit ducting design including material, shape and routing changes from the present A7LB ducting, is presently being studied by NASA and ILC Industries to improve the state-of-the-art.

Firm data concerning these new designs are not available at this time; as a result, a reasonable estimate of suit pressure drop cannot be made. However, since the pressure drop requirements in the NASA RFP's are less than the present pressure suit design requirements (which can be improved upon), it is recommended that these values (see Table 3-5) be used as the design goal for all pressure suit concepts until system test data becomes available.

APOLLO A7LB SUIT	SKYLAB A7LB SUIT
1.8 Inches of H_2O Maximum Excluding Male Inlet & Outlet O_2 Connectors at Conditions of: 6.0 ACFM of O_2 77°F 3.9 psia (Approximately 5.0 Inches H_2O @ 8.0 psia and 7 ACFM)	1.2 Inches of H_2O Minimum 2.5 Inches of H_2O Maximum Excluding Male Inlet & Outlet O_2 Connector at Conditions of: 6.0 ACFM of O_2 77°F 3.9 psia (Approximately 7.0 Inches of H_2O @ 8.0 psia and 7 ACFM)

SHUTTLE EV SUIT (8.0 PSI-OES) (RFP. No. 9-BC73-36-2-263P)	SHUTTLE IV SUIT (8.0 PSI-EIS)
3.6 Inches of H_2O Maximum Excluding Male Inlet and Outlet O_2 Connectors at Conditions of: 7.0 ACFM of O_2 77°F 8.0 psia	3.6 Inches of H_2O Maximum Excluding Male Inlet and Outlet O_2 Connector at Conditions of: 7.0 ACFM of O_2 77°F 8.0 psia

SUIT PRESSURE DROP REQUIREMENTS

TABLE 3-5

3.5 THERMAL AND METEOROID PROTECTION

3.5.1 THERMAL GARMENTS. The crewman will require protection from the thermal radiation and meteoroid flux anticipated during orbital EVA. Protection is also required for the IV crew and passengers during an EV contingency transfer to a rescue vehicle. Thermal protection is required to prevent heat build up due to solar radiation and heat loss to deep space while in shadows. The surface of the EVA suit will have to withstand contact with hardware surfaces ranging from approximately -263°F to +285°F.

3.5.1.1 Construction. The current Apollo and Skylab life support systems have demonstrated the capability of maintaining crewman comfort when the heat flux into the suit is limited to 250 btu/hr and heat flux out of the suit is limited to 350 btu/hr. It is recommended that these heat transfer requirements continue to be utilized in the shuttle EVA suit program. Thermal-vacuum tests have demonstrated that these requirements can be easily met with three layers of metalized film separated by a light weight spacer fabric.

Teflon fabric has also been demonstrated to be a very durable cover fabric. In addition to being durable, it's also resistant to temperature extremes, is flame resistant, and has good reflective properties.

Although the aforesaid materials have served well, new synthetic fabrics, such as Halar, which hold promise of providing equal or better properties with lighter weight are being developed. Any new programs should consider the latest proven developments in this area.

3.5.1.2 Configuration. To provide minimum encumberance to a crewman working in an enclosed area not subject to thermal extremes, it is recommended that thermal protection be provided

in the form of easily donned trousers and a jacket. This is the recommended aporoach since it offers many advantages as illustrated in Table 3-6. It should be noted, that the jacket and trousers approach was originally used in the Apollo program, and was abandoned primarily because the PGA required an intravehicular fire protective cover. Due to the shuttle atmospheric requirements protection of this magnitude should no longer be necessary.

The basic boots should provide permanently integrated thermal protection since the presence of thermal insulation during IV or EV operations with the boots should not provide any significant encumberance. Thermally insulated covers for the gloves could be utilized or special EV gloves provided. This will depend on the direction of current glove development programs.

For emergency EVA transfer in an IV emergency crew suit, thermal protection will be required. A thermal garment of one piece construction with a simple rear entry closure (utilizing velcro, snaps or zippers) permitting quick donning by a pressurized IV crewman, should be sufficient. Separate thermally insulated covers could be provided for the gloves to permit acceptable hand dexterity. In addition, a soft visored hood providing adequate EVA eye protection could be integrated to the garment. Such a one piece garment would require sufficient bulk to permit the emergency life support system (ELSS) to be completely covered, providing a venting hole if a purging ELSS is utilized. In addition, if it is undesirable to cover the ELSS, a two piece garment, separating at the waist could provide slots to allow donning without removal of the ELSS or vehicle ECS.

A similar but less sophisticated contingency thermal garment design would also be required for the passengers with the

REMOVABLE THERMAL GARMENT	
ADVANTAGES	DISADVANTAGES
A. Easier to maintain pressure suit. B. Manufacture of separate thermal garment is easier and less costly. C. Will easily adapt to a uniform sizing system. D. Can be exchanged between crewmen, thereby decreasing quantities. E. Gain mobility in pressure suit if garment is removed when suit is used IV.	A. Will not be asthetically clean looking due to loose fit.

INTEGRATED THERMAL GARMENT	
ADVANTAGES	DISADVANTAGES
A. Will provide tight fitting "asthetically clean" looking garment.	A. Difficult to maintain pressure suit since de-integration is required for repair operations. B. More costly to manufacture, since many separate sections are required to permit sizing changes to be performed. C. Thermal garment cannot be removed from pressure suit if IV requirement exists and additional mobility cannot be obtained if needed.

THERMAL GARMENT TO SUIT INTERFACE COMPARISON

TABLE 3-6

possible use of thermal mittens attached to the garment arms. Contingency thermal garments of this general design would provide adequate transfer capability and require the minimum in stowage weight and volume.

3.5.2 Meteroid Garment. Apollo and Skylab experience has demonstrated that thermal garment constructions adequate to meet the thermal requirements of the mission will provide adequate meteoroid impact protection. (I.E., an acceptable probability of no penetration of the gas retention layer.) Additional protection may be incorporated within the thermal cover garment by the use of layers of neoprene coated nylon.

The multiple layers of material progressively dissipate the impact energy of the meteoroid particles. Finally, the pressure garment itself can absorb a considerable amount of this energy without significantly affecting its pressure integrity.

3.6 IMPACT PROTECTION

Impact Protection should be considered in the shuttle pressure suit design. The various types of impact protection investigated include:

a. Micrometeroid impact protection.
b. Ground packaging and handling impact protection.
c. Flight stowage protection and EVA/IVA impact protection during the performance of tasks.

Micrometeroid impact protection has been discussed in paragraph 3.5.2 of this section. The remaining types of impact protection shall be discussed herein.

The pressure suits should be packaged in appropriate shipping containers which will provide protection from impact shock and vibration during normal air and ground vehicle transportation and handling. Test requirements, such as those discussed in MIL-STD-810, methods 516 and 514 procedure II and X respectively, should be used as guidelines to verify the ability of the shipping container to protect the pressure suits from these impact environments.

In addition, the pressure suits must also be durable enough to permit active handling both on the ground and in space after numerous reuses.

The pressure suit flight stowage configuration must also provide adequate restraint to protect the suit from impacting the vehicle or itself during the various mission phases. Examples of various stowage concepts which can accomplish this are discussed in paragraph 3.10.1 of this report.

In addition to flight stowage, the EVA pressure suits must also provide the crewman with protection from impacts within the

shuttle orbiter airlock, sortie can, large space telescope and other experiments which offer the crewman little room to maneuver. These close working conditions could cause impacts with the pressure helmet, gloves, arms and legs. The impact loads on the suit from a tether-waist belt system or similar tether-suit interface must also be considered (i.e., a crewman becoming dislodged from his restraint system and relying on his tether and suit to stop his free movement.)

The IV emergency pressure suits must also provide impact protection for the crewman and passengers as they perform contingency or survival tasks within the orbiter vehicle.

3.7 HUMAN FACTORS

The Pressure Suit is designed to accommodate man and protect him from the hazardous environments of space travel. To accomplish this, certain design constraints must be considered in the development of the shuttle suits. Some of these constraints are discussed herein.

The pressure suit is part of the man's environmental control system. Therefore, it must provide an adequate pressure vessel as well as protection from the external environments of temperature and impact.

The suits must also provide suitable visibility, dexterity, mobility and comfort, as well as durability and serviceability.

Other human factors to be investigated could be determined through a survey of the best judgement responses from astronauts and other qualified NASA and contractor personnel. Factors such as those concerned with hardware location and the need for certain support hardware, such as a pressure gage or feedport, should be considered in this survey. Appendix "B" is a typical questionnaire which could be used in accomplishing this.

The following paragraphs discuss those major areas which should be considered when designing for human factors in the shuttle pressure suits.

3.7.1 PRESSURE SUIT MOBILITY REQUIREMENTS. This subparagraph shall define the recommended mobility requirements for the following pressure suit concepts:

a. EVA/IVA Pressure Suit for planned, unscheduled and contingency operations.

b. IV Emergency Pilot, Commander, Mission Specialist and Payload Specialist suit.

c. IV Emergency Passenger Suit.

The mobility requirements for each pressure suit concept were selected through the use of the following guidelines:

a. The EVA/IVA Pressure Suit will be used to perform all planned Shuttle suited tasks. As a result it must clearly possess the maximum available range in all joints with the lowest possible torque. Therefore, the mobility requirements herein attempt to represent the "nude body" ranges in as many joints as possible.

b. The IV Emergency Crew Suit shall be used pressurized to operate the spacecraft during a contingency earth return. In addition, this suit will also be required to permit:

   (1) Contingency IV repairs

   (2) Contingency IV transfer through the airlock and into the crew couches.

   (3) The assistance of suited (pressurized) passengers through the airlock during a contingency transfer to a rescue spacecraft.

   (4) Contingency EVA transfer from a docked payload module to the orbiter cabin.

c. The IV Emergency Passenger Pressure Suit shall only be used for passenger survival. As a result, minimum mobility will be required to allow the passenger to:

   (1) Perform an emergency transfer through the airlock and into a second docked shuttle spacecraft with the assistance of an EVA crewman or the suited pilot or commander.

   (2) Perform an emergency EV transfer from one spacecraft to a second undocked spacecraft with assistance.

   (3) Return to the passenger couch in a pressurized suit after a malfunction of the shuttle vehicle and attach the restraint system with assistance.

Figure 3-6* illustrates a typical passenger couch configuration in the sitting, sleeping, zero-g, and zero-g with clerical tray positions. The design of the IV passenger emergency suit and passenger couch should be compatible to insure proper interfaces exist. Further definition of the couch restraint system and available foot restraints and hand holds will be needed to determine the final mobility requirements in future studies.

Utilizing these guidelines, Figures 3-9 through 3-16, have been prepared to describe the mobility ranges required for each suit concept. In addition, the current A7LB pressure suit mobility and advanced EVA suit RFP** requirements have also been added to each figure to illustrate the Apollo and Skylab state-of-the-art as well as advanced EV suit requirements. Figure 3-7 illustrates the body orientation references used for the mobility charts.

No attempt has been made to recommend maximum allowable torque values since the minimum torque available is the most desirable for all suit concepts. As test data becomes available for eight (8) psia mobility joints, realistic torque requirements can be established.

The mobility requirements described on the attached pages are the result of an analysis of body movements necessary to:

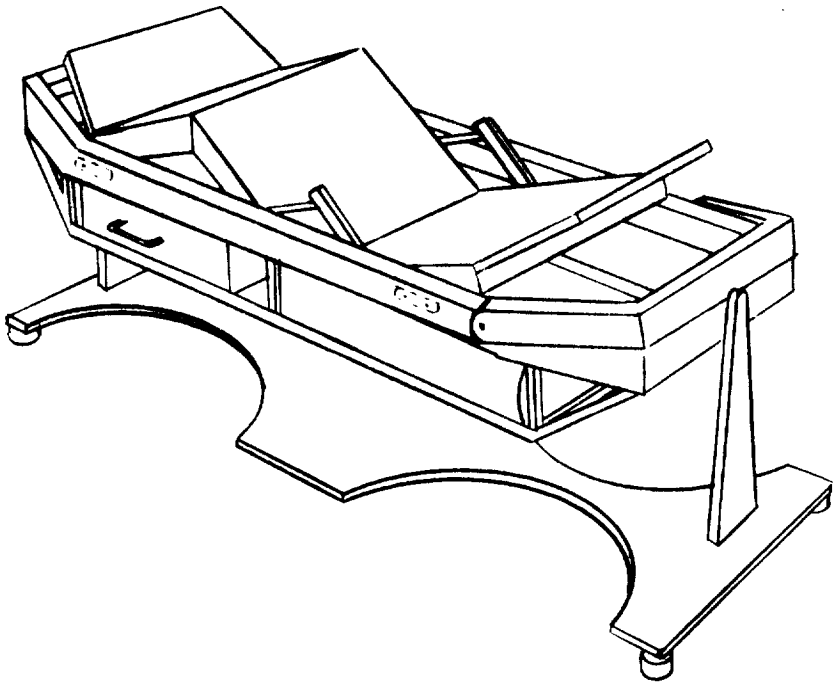
a. Perform the EVA tasks as defined by Vought Missiles and Space Company and outlined in Appendix "A" of this study.

b. Perform the IV emergency pilot and commander tasks based upon studies of the North American Rockwell and NASA, MSC shuttle orbiter cockpits. A sketch of the cockpit design studied is illustrated in Figure 3-8.

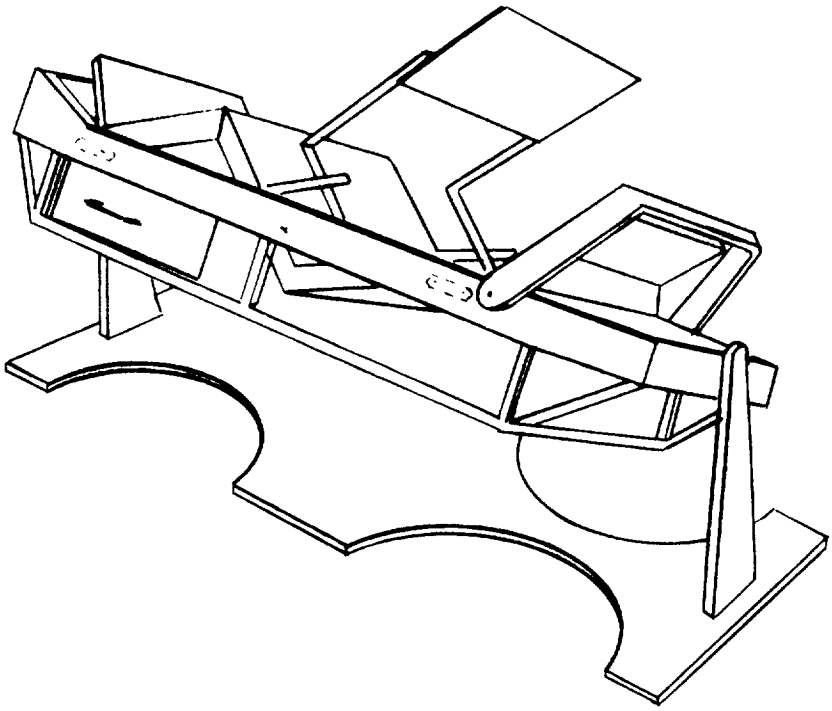
c. Perform the IV passenger survival tasks previously discussed.

d. Perform additional crew tasks as discussed in paragraph 2.5.2.

*Compliments of the Martin Marietta Corp., Denver Division.
**NASA RFP Number 9-BC-73-36-2-263P.



COUCH, ZERO-G POSITION

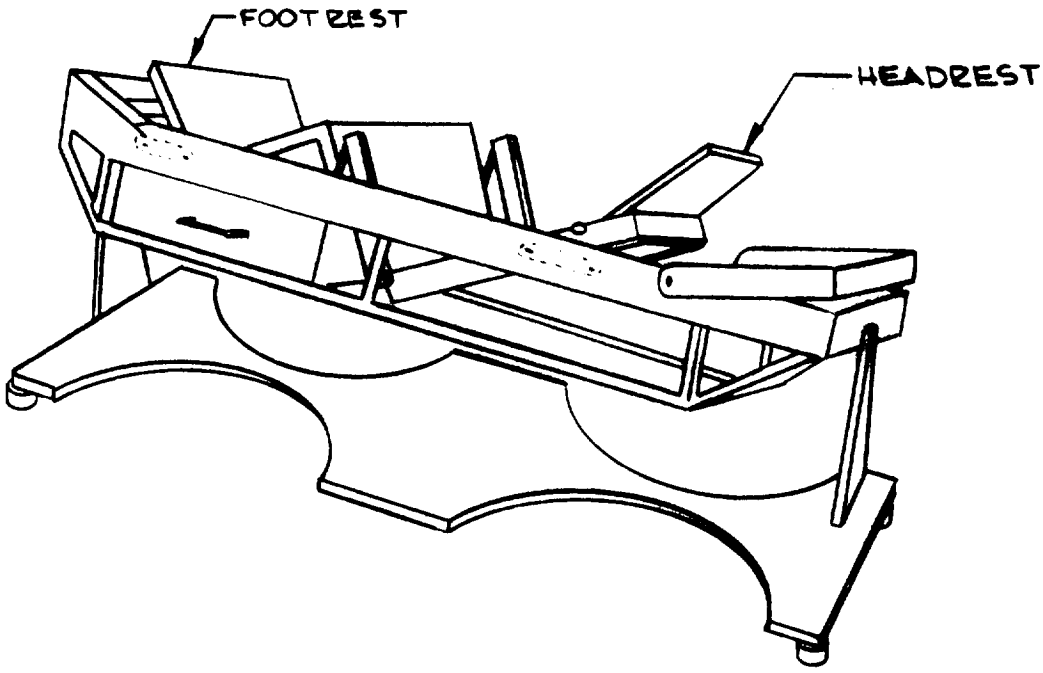


COUCH WITH CLERICAL TRAY,
ZERO-G POSITION

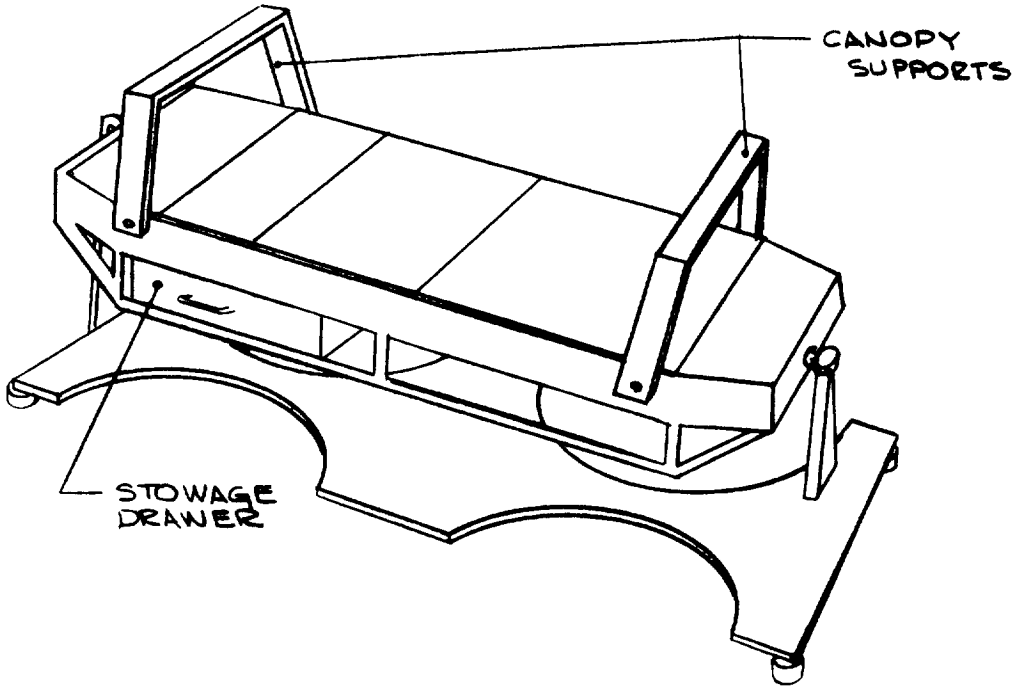
PASSENGER COUCH CONFIGURATION

FIGURE 3-6

(SHEET 1 OF 2)



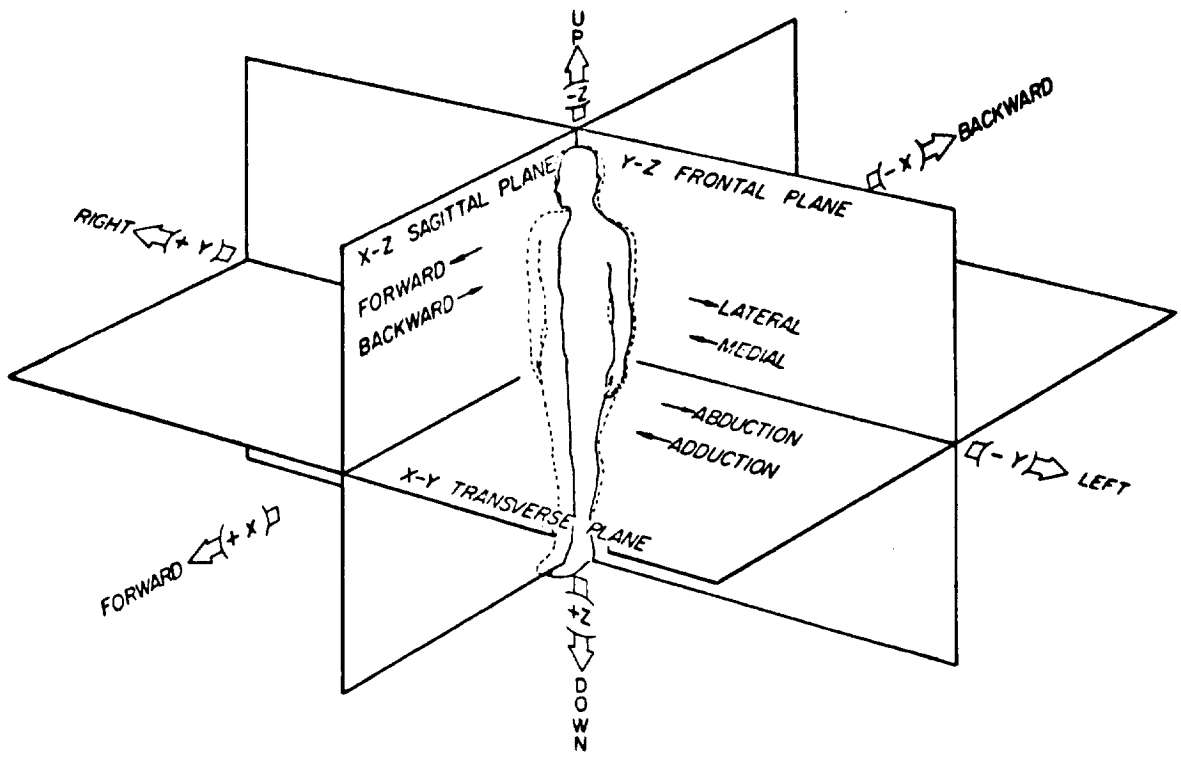
COUCH, SITTING POSITION



COUCH, SLEEP POSITION

PASSENGER COUCH CONFIGURATION

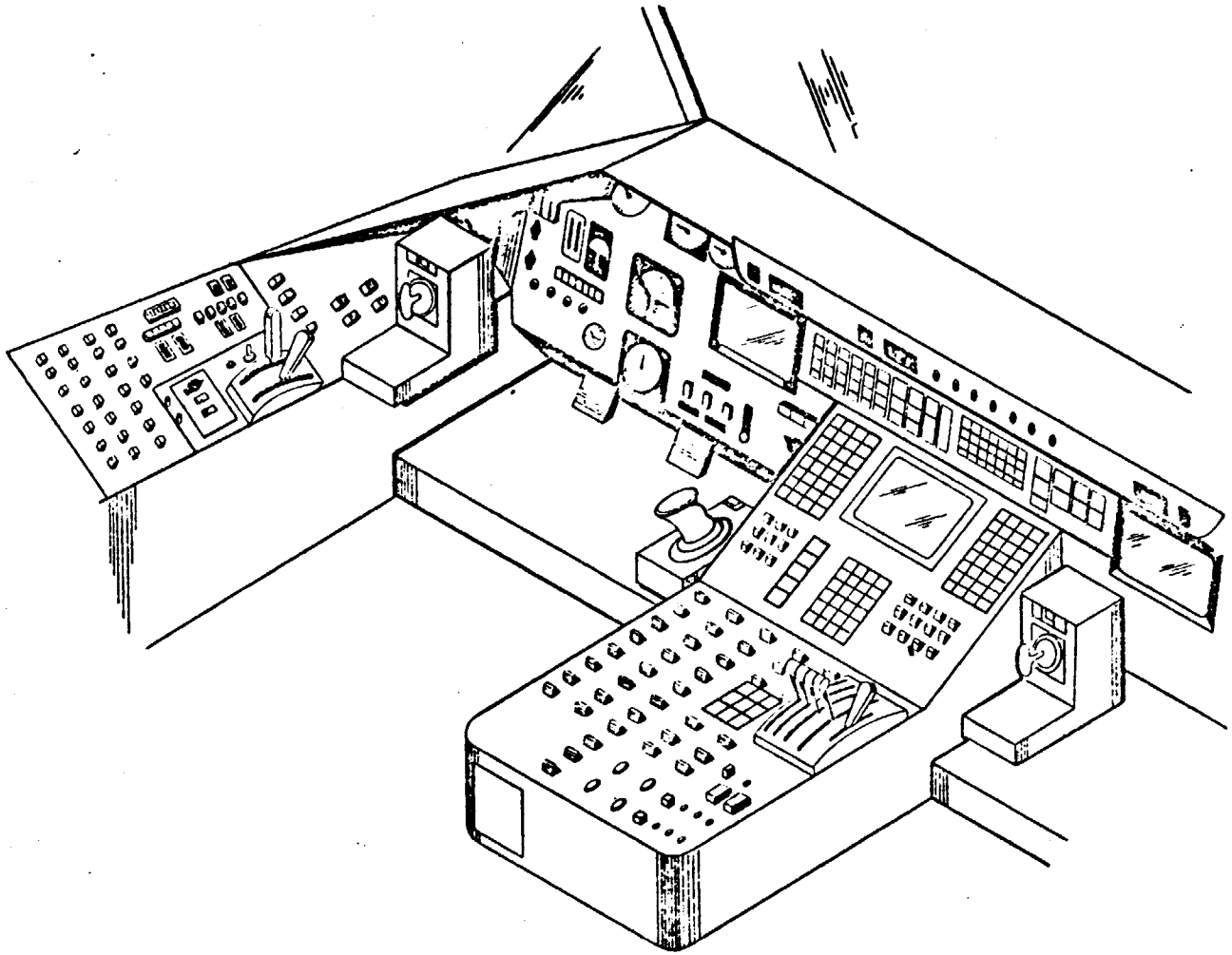
FIGURE 3-6
(SHEET 2 OF 2)



DEFINITIONS

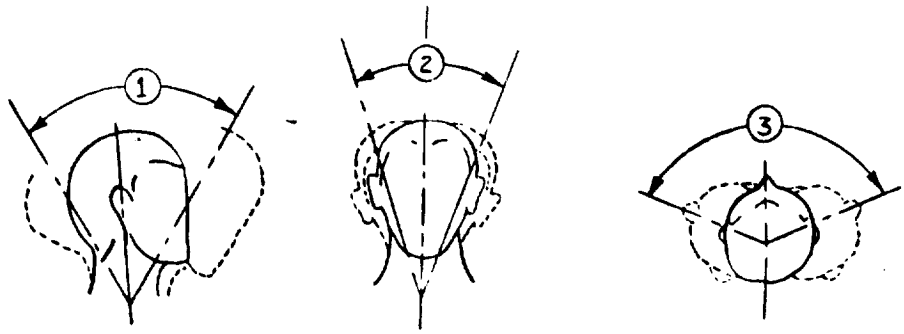
ABDUCTION	AWAY FROM X-Z PLANE IN X-Y PLANE
ADDUCTION	TOWARD X-Z PLANE IN X-Y PLANE
EXTENSION	STRAIGHTENING OR INCREASING ANGLE BETWEEN BODY PARTS
FLEXION	BENDING OR DECREASING ANGLE BETWEEN BODY PARTS
LATERAL	AWAY FROM X-Z PLANE IN Y-Z PLANE
MEDIAL	TOWARD X-Z PLANE IN Y-Z PLANE
PRONATION	FACE DOWN
SUPINATION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

Figure 3-7 Body Orientation References



FLIGHT CREW STATION

FIGURE 3-8



RECOMMENDED SUIT MOBILITY

NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Forward-Backward	**	**	**
2	Left-Right	**	**	**
3	Rotation Left-Right	**	**	**

REFERENCES

NO.	MOVEMENT	A7LB-EV	ADVANCED EVA SUIT RFP
1	Forward-Backward	45°	--*
2	Left-Right	55°	--*
3	Rotation Left-Right	165°	--*

* No neck joint is recommended; but the RFP recommends the use of a bubble helmet. (RFP No. 9-BC-73-36-2-263P)

** The man's head movement within the helmet shall be adequate to meet the VISIBILITY requirements in Paragraph 3.7.3.

EVA & IV Emergency Suits - None of the three (3) shuttle suit configurations require a neck joint. However it is important that the pressure suit helmet permit the crewman to move his neck within the helmet in order to provide the visibility required to complete the mission tasks (planned, unscheduled, and contingency tasks). Paragraph 3.7.3 discusses the visibility requirements and recommends the helmet design for each suit concept. The table below illustrates a summary of the helmet recommendations.

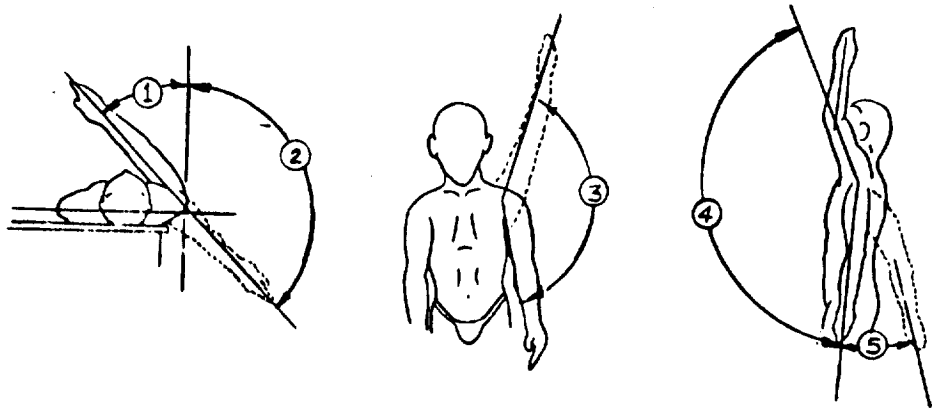
SUMMARY OF HELMET RECOMMENDATIONS

Suit Concepts

	EV	IV PILOT/COMMANDER	IV PASSENGER
Design Helmet Similiar To:	Hemispherical Helmet (AES Type)	ILC ISSA "Soft" Helmet	SAC ISSA "Soft" Helmet

NECK MOBILITY

FIGURE 3-9



RECOMMENDED SUIT MOBILITY

NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Adduction	105°	10°	Not Required
2	Abduction	Combined	90°	Not Required
3	Lateral-Medial	180°	100°	100°
4	Flexion	180°	140°	Not Required
5	Extension	30°	30°	Not Required

REFERENCES

NO.	MOVEMENT	A7LB/EV	ADVANCED EVA SUIT RFP
1	Adduction	10°	105°
2	Abduction	90°	Combined
3	Lateral-Medial	130°	180°
4	Flexion	160°	180°
5	Extension	10°	0°

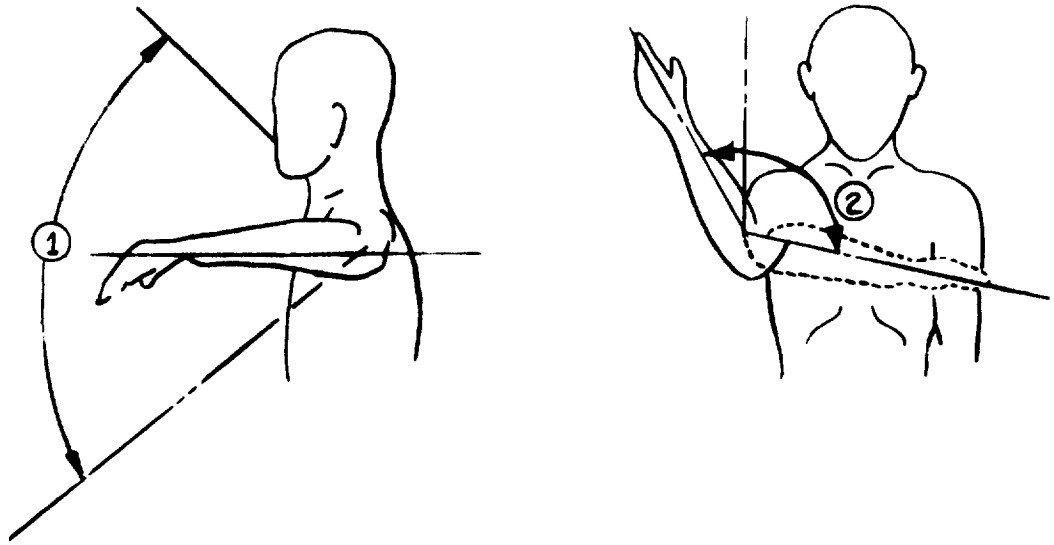
EVA - Maximum shoulder mobility is a definite requirement for the EV pressure suit to perform the necessary planned maintenance and repair tasks.

The IV Emergency Pilot/Commander Suit - will require upward, downward, and cross reach not achievable in the sagital plane alone. This is due to the great number of switches which are located on control panels overhead, front, and to the left and right of the two crewmen. The neutral point for the IV shoulder joint should be toward the couch arm rest spread since the hand controller will be operated a majority of the time during emergency vehicle return and is located in line with the arm rest. This will require the shoulder neutral point to be approximately 10° up from the arm to side position.

IV Emergency Passenger - Shoulder mobility will be required in the passenger suit to perform tasks such as traversing handholds and ingress or egress from the passenger couch.

SHOULDER MOBILITY

FIGURE 3-10 (Sheet 1 of 2)



RECOMMENDED SUIT MOBILITY

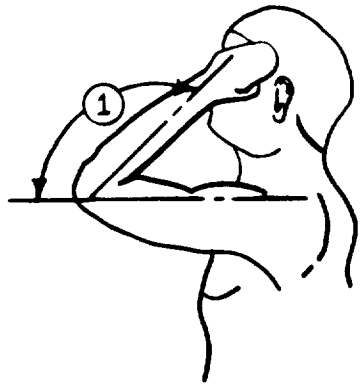
NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Rotation (Up-Down)	90° Up 60° Dwn.	90° Up 60° Dwn.	Not Required
2	Rotation Lateral Medial	130°	115°	Not Required

REFERENCES

NO.	MOVEMENT	A7LB-EV	ADVANCED EVA SUIT RFP
1	Rotation (Up-Down)	125°	90° Up 60° Dwn.
2	Rotation Lateral Medial	140°	130°

SHOULDER MOBILITY

FIGURE 3-10 (Sheet 2 of 2)



RECOMMENDED SUIT MOBILITY

NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Flexion-Extension	135°	100°	100°

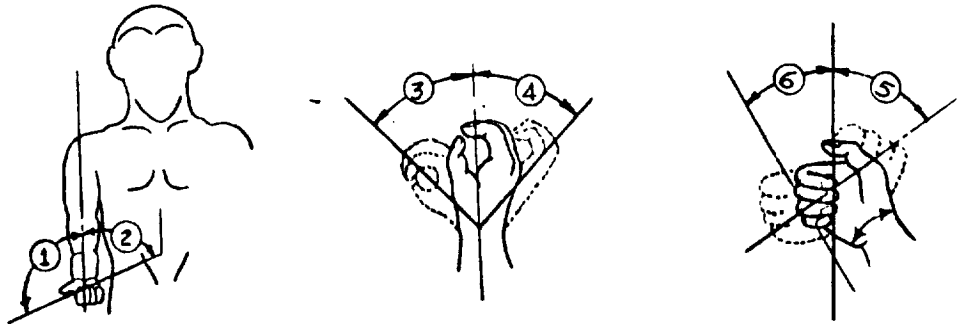
REFERENCES

NO.	MOVEMENT	A7LB-EV	ADVANCED EVA SUIT RFP
1	Flexion-Extension	130°	150°

Since all suit concepts are required to perform reaching or cross reaching tasks an elbow joint is required in each suit configuration.

ELBOW MOBILITY

FIGURE 3-11



RECOMMENDED SUIT MOBILITY

NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Supination	90°	90°	None Required
2	Pronation	90°	90°	None Required
3	Adduction	70°	30°	None Required
4	Abduction	45°	15°	None Required
5	Backward	35°	25°	None Required
6	Forward	40°	25°	None Required

REFERENCES

NO.	MOVEMENT	A7LB/EV	ADVANCED EVA SUIT RFP
1	Supination	90°	90°
2	Pronation	90°	90°
3	Adduction	70°	--
4	Abduction	45°	--
5	Backward	35°	--
6	Forward	40°	--

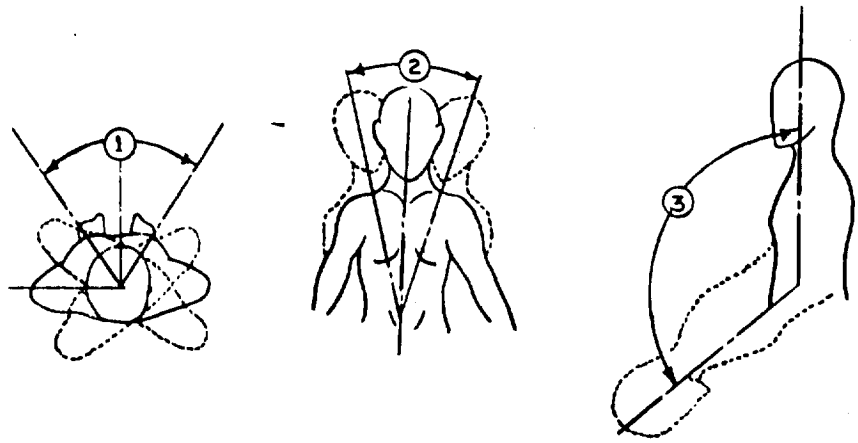
EVA Suit - High Wrist Mobility with low torque is especially required for EVA tasks such as traversing handholds and handrails as well as performing all maintenance and repair operations. This has been demonstrated during the Apollo CM EVA's where crewman have discovered that low torque wrist mobility is extremely important during zero "G" movements.

IV Emergency Pilot/Commander Suit - Wrist mobility is also important in the IV emergency pilot/commander's suit. In this case the wrist will be used to operate the hand controller and "T" handle controller. In addition, mobility will also be required for traversing handholds, operating Airlock hatches and ingress or egress of the crew couches in zero "G".

IV Emergency Passenger Suit - No wrist mobility is required at this time in the IV emergency passenger suit.

WRIST MOBILITY

FIGURE 3-12



RECOMMENDED SUIT MOBILITY

NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Rotation, Left-Right	90°	None Required *	None Required
2	Flexion, Left-Right	15°	None Required	None Required
3	Flexion Forward	45°	25°	None Required

REFERENCES

NO.	MOVEMENT	A7LB/EV	ADVANCED EVA SUIT RFP
1	Rotation Left	5°	0°
2	Flexion, Left-Right	60°	±15°
3	Flexion, Forward	110° **	45°

* A waist bearing would be beneficial in reaching controls and during contingency operations. Due its excessive weight, it is not recommended at this time.

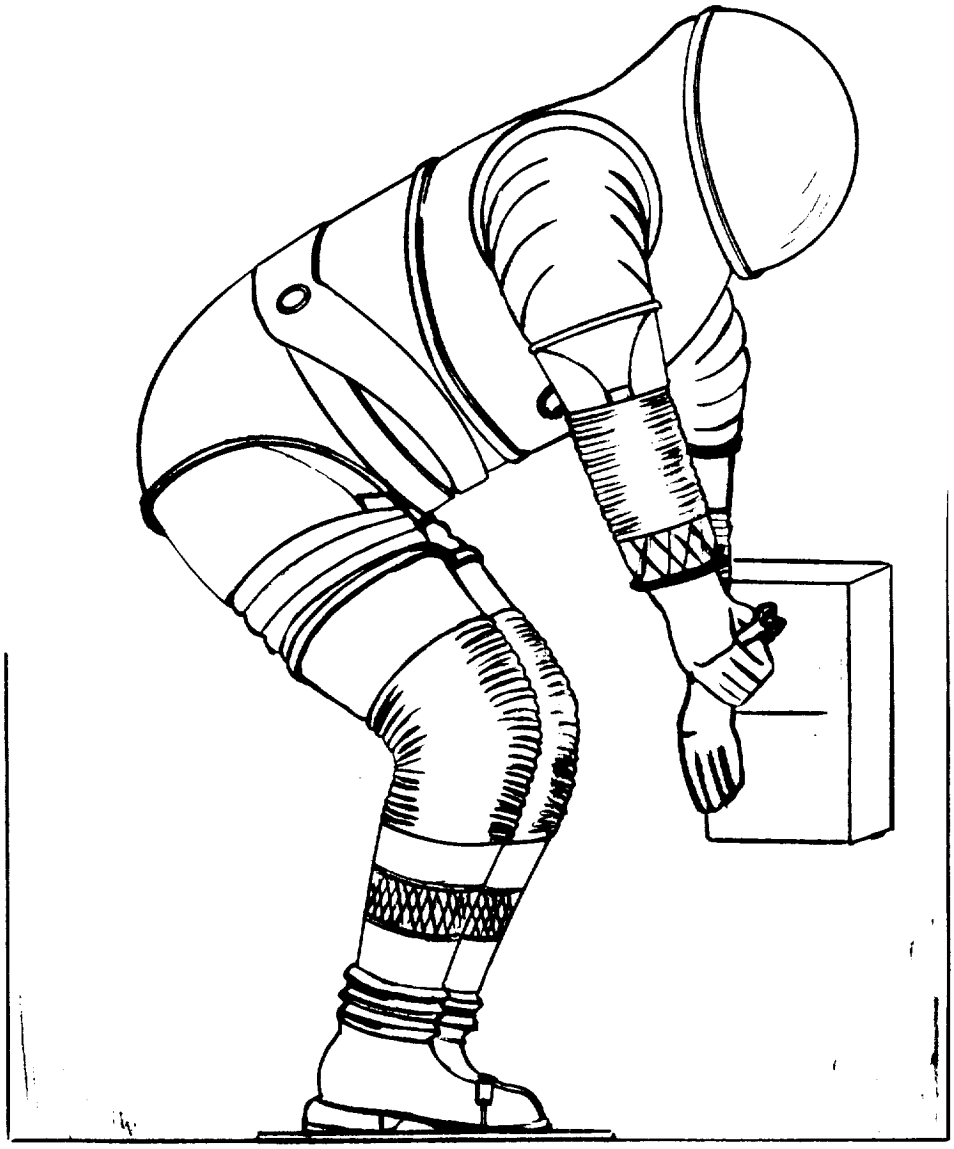
** Includes thigh flexion.

EVA Suit - It is difficult at this time to define the exact amount of waist mobility required during the shuttle EVA. Investigation of the seven (7) EVA scenarios has revealed that the "large space telescope" and "austere earth observatory" scenarios possess tasks requiring the need for waist mobility. Tasks such as bending down to:

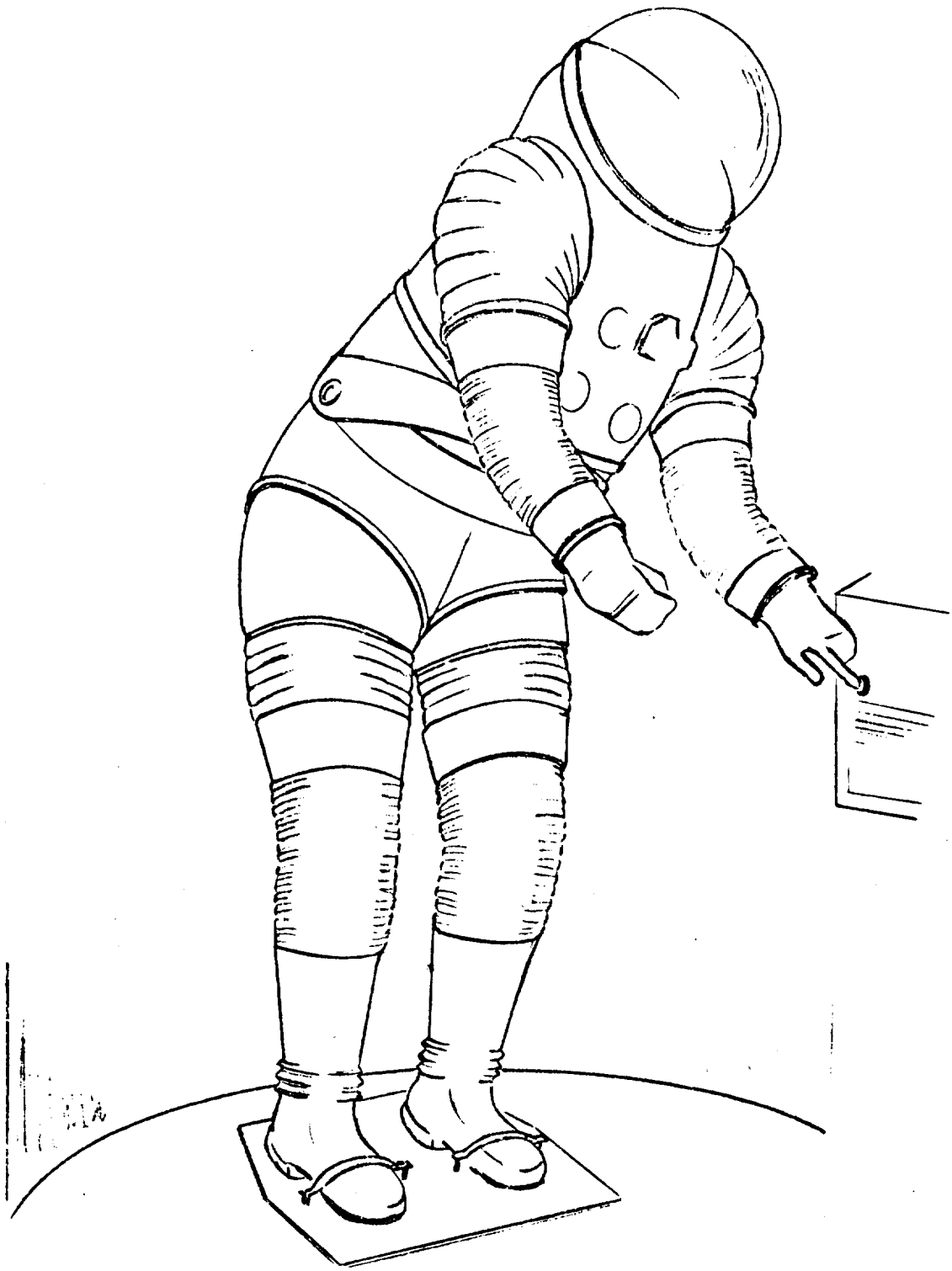
(1) Clean the lower portion of the LST mirror while in a foot restraint.
(2) Reach special tools from suit pockets on the legs.
(3) Reach down to operate special equipment during maintenance (tape recorders, electrical controls, etc.)
(4) Retreive a loose tool or satellite component without leaving the foot restraint. Figure 3-13 illustrates some of these tasks.
(5) Rotate in manipulator platform to look to each side and back to spacecraft.

IV Emergency Crew and Passenger Suits - Waist flexion is recommended for the IV crew suit to allow the crewman to reach all cockpit controls as well as ease his contingency tasks such as bending down to assist passengers and assist with IV Emergency Repairs. In addition, it will also permit the IV crewmen to maintain his seated position with the least amount of effort. Only a soft waist joint is recommended to insure the suit weight is a minimum. No waist mobility is recommended for the passenger suit.

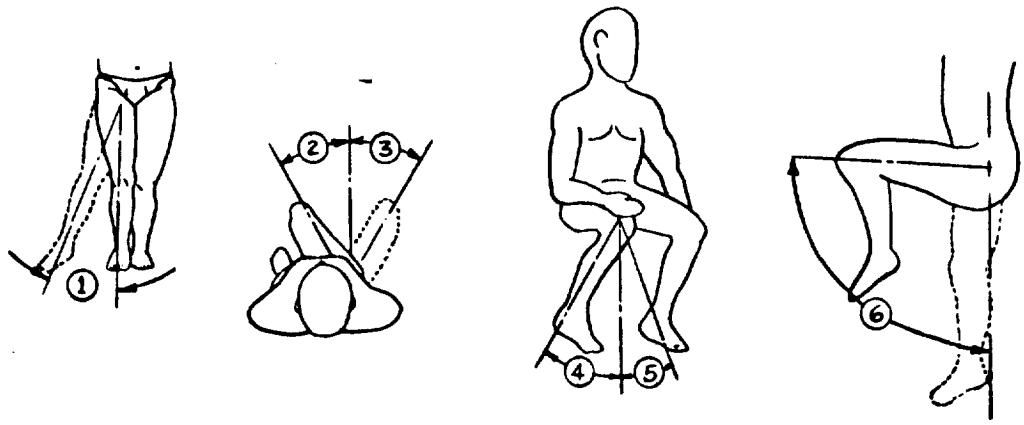
WAIST MOBILITY
FIGURE 3-13 (Sheet 1 of 3)



WAIST MOBILITY
FIGURE 3-13 (SHEET 2 OF 3)



WAIST MOBILITY
FIGURE 3-13 (SHEET 3 OF 3)



RECOMMENDED SUIT MOBILITY

NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Abduction (Leg Straight)	30°	None Required	None Required
2	Adduction (Leg Bent)	30°	None Required	None Required
3	Abduction (Leg Bent)	55°	None Required	None Required
4	Rotation Lateral	30°	None Required	None Required
5	Rotation Medial	30°	None Required	None Required
6	Flexion	100°	85°	85°

REFERENCES

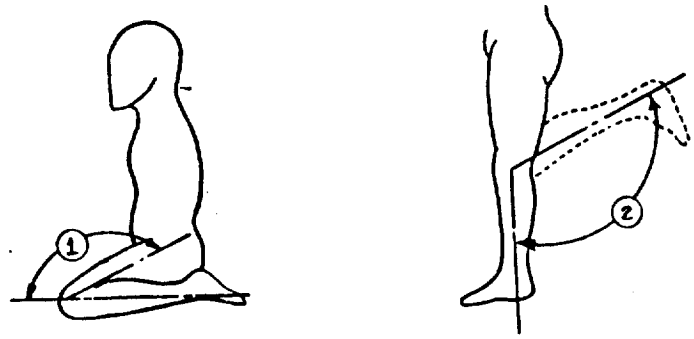
NO.	MOVEMENT	A7LB/EV	ADVANCED EVA SUIT RFP
1	Abduction (Leg Straight)	20°	20°
2	Adduction (Leg Bent)	5°	--
3	Abduction (Leg Bent)	15°	--
4	Rotation Lateral	20°	--
5	Rotation Medial	20°	--
6	Flexion	70°	100°

EVA Suit - Maximum hip mobility is required in the EVA pressure suit to insure the crewman's motion is not impeded when operating in the EVA or IVA foot restraints in close areas. Tasks requiring rotation, side to side, or bending motions will require hip mobility.

IV Emergency Crew and Passenger Suits - The only hip mobility required for either of the IV emergency suits is the hip flexion. This is required to permit proper interface with the crew or passenger couch for a seated position.

HIP MOBILITY

FIGURE 3-14



RECOMMENDED SUIT MOBILITY

NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Flexion (Kneeling)	150°	105°	105°
2	Flexion (Standing)	110°	90°	90°

REFERENCES

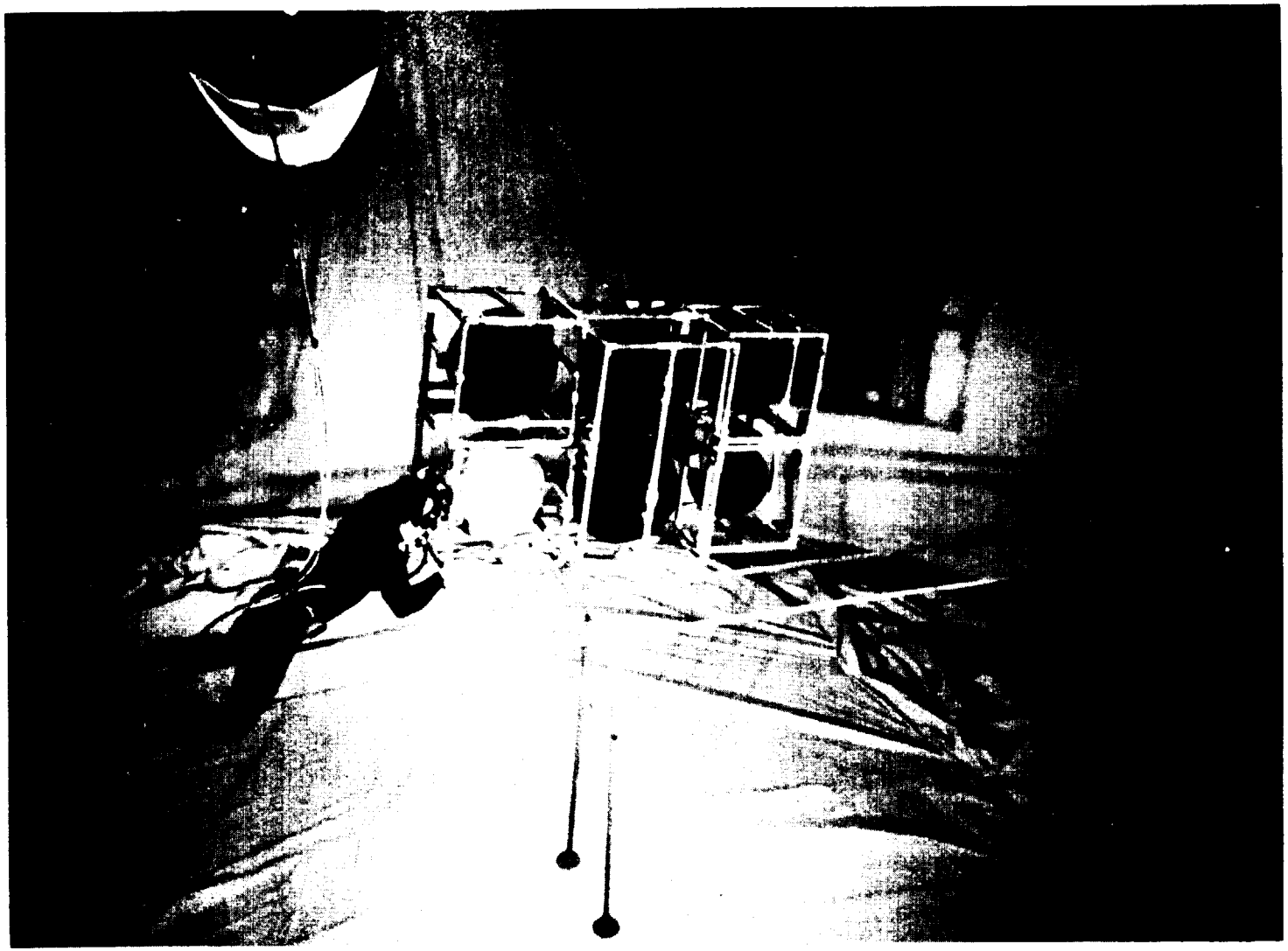
NO.	MOVEMENT	A7LB/EV	ADVANCED EVA SUIT RFP
1	Flexion (Kneeling)	150°	170°
2	Flexion (Standing)	105°	120°

EVA Suit - A high degree of knee mobility will be required in the EVA/IVA pressure suit to allow maximum EV/IV capability while the crewman is in the foot restraint. The knees may also be required to perform shimmying of single or dual rail systems for cargo transfer or movement of the suited man in close quarters. Figure 3-15 illustrates some cargo transfer techniques studied by NASA Langley Research Center.

IV Emergency Crew and Passenger Suits - Knee flexion is required in the IV emergency pressure suits to allow the crewman to conform to the shuttle couch seated position. In addition the knee will also permit the crew to operate the vehicle foot pedal controls.

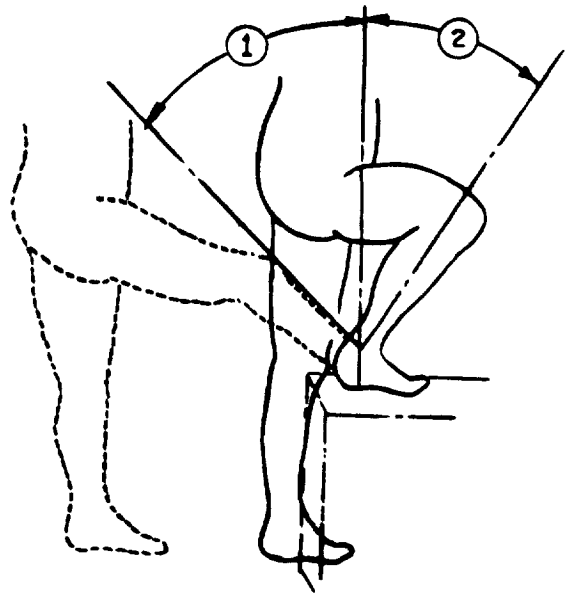
KNEE MOBILITY

FIGURE 3-15 (Sheet 1 of 2)



PROPOSED MANNED TRANSFER OF CARGO

Figure 3 - 15 (Sheet 2 of 2)



RECOMMENDED SUIT MOBILITY

NO.	MOVEMENT	EVA/IVA	IV EMERGENCY CREW	IV EMERGENCY PASSENGER
1	Extension	45°	45°	None Required
2	Flexion	45°	20°	None Required

REFERENCES

NO.	MOVEMENT	A7LB/EV	ADVANCED EVA SUIT RFP
1	Extension	50°	45°
2	Flexion	30°	45°

EVA Suit - Ankle mobility is required while the crewman performs tasks within the foot restraints.

IV Emergency Crew Suit - Ankle mobility is required to operate the spacecraft foot controls during re-entry and descent.

IV Emergency Passenger Suit - No ankle mobility is required at this time in the IV emergency passenger suit.

ANKLE MOBILITY

FIGURE 3-16

3.7.2 DEXTERITY. Gloved hand dexterity continues to be extremely important as it has been during the Apollo missions. Ballooning of a pressurized glove palm should be less than that experienced in Apollo gloves.

Subparagraphs 3.7.2.1 through 3.7.2.3 will consider the hand and finger dexterity required for each shuttle pressure suit configuration (i.e., EV/IV; Emergency Crew; Emergency Passenger Suit). This study will not attempt to recommend maximum torque values to perform each task since such values would be meaningless if the state-of-the-art cannot manufacture to them. There are presently three (3) contractors studying the design of an 8.0 psig pressure glove for the NASA Ames Research Center. These studies will determine the degree of ease with which a pressurized crewman can perform the tasks which are discussed in the following subparagraphs.

3.7.2.1 EVA and IVA Pressure Suit Glove. The greatest amount of dexterity combined with low torque is required in the pressure gloves for the EVA and IVA Suit operating modes. The need for thermal insulation on the exterior of the EV glove will sacrifice some dexterity in order to gain thermal comfort. It is therefore recommended that the EVA gloves include a removable thermal cover or that a second pair of IVA gloves be provided (in lieu of integrated gloves). Figure 3-17 illustrates the dexterity required in the EVA and IVA pressure suit gloves. It should be noted that this glove dexterity closely resembles that required for the IV emergency crewman's suit and as a result it is recommended that the same glove design be used in both suit configurations.

3.7.2.2 IV Emergency Crewman's Suit. Figure 3-18 illustrates some typical controls which must be operated by the crewman in a pressurized suit during an emergency IV return to earth. It can be seen that considerable dexterity with corresponding low torque

TYPES OF HAND AND/OR FINGER PREHENSION

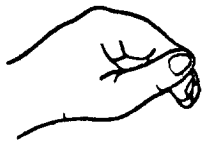
PALMAR

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

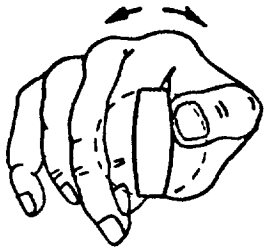


RELATED TASKS
1. USING ROTARY
2. USING TOGGLE SWITCH

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 OF 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

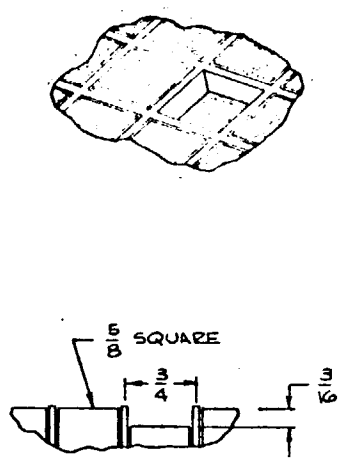
FINGER-PULLING OPERATIONS
RELATED TASKS
1. REMOVAL AND INSTALLATION OF EXPERIMENT MODULES DURING MAINTENANCE
2. REMOVAL AND INSTALLATION OF QUICK RELEASE PINS

EVA DEXTERITY REQUIREMENTS

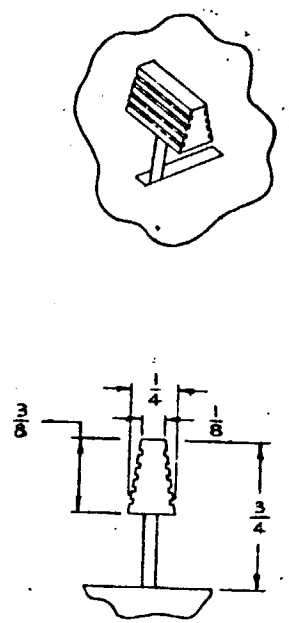
FIGURE 3-17

is needed to meet these requirements. In addition, Figure 3-19 illustrates hand operations such as grasping, hand rotation, and finger operations to demonstrate typical operations which the crewman will be required to perform in the Pressurized IV Emergency Suit. Figures 3-18 and 3-19 represent the dexterity requirements for the IV Emergency Crewman's Suit.

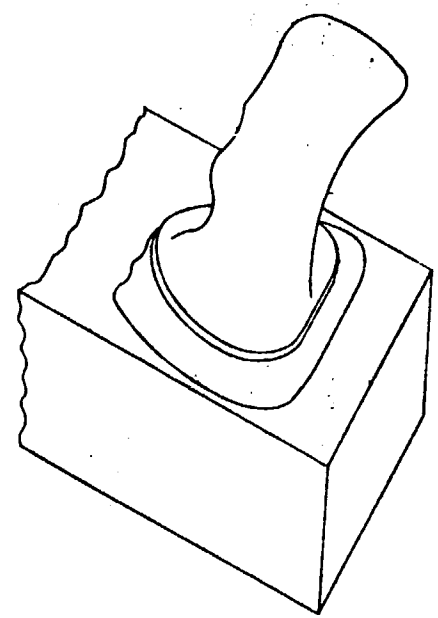
A primary activity defining requirements for glove dexterity is manipulation of the Shuttle Craft control stick and related switches. Smooth actuation and hand comfort are essential. Normal supination with pronation movements will require a wrist bearing. Each and every glove finger should be equally comfortable and stable in flexion. The thumb must extend and rotate toward the first digit to permit it to depress a 1/8" diameter button mounted on top of the control stick, while the metacarpal remains in place around the control stick grip handle. Other push-button switches (3/8" x 3/8" squares) are recessed on control panels, and require actuation by extended fingers. The index and middle fingers must spread 1/2" at the second metacarpal to fit over a TEE handle control. Though first and third metacarpal dexterity is not definitely required, some bias (20°) movement is desirable.



PUSHBUTTON-FOR CHANGING COUNT
ON COMPUTER DISPLAYS

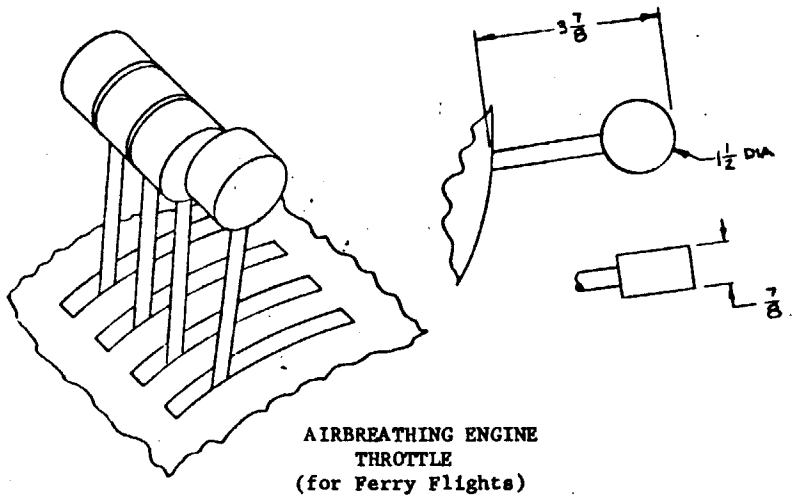


TYPICAL TOGGLE
SWITCH

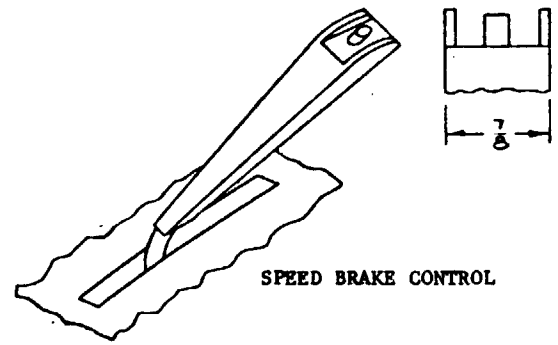


VEHICLE RATIONAL
CONTROLLER

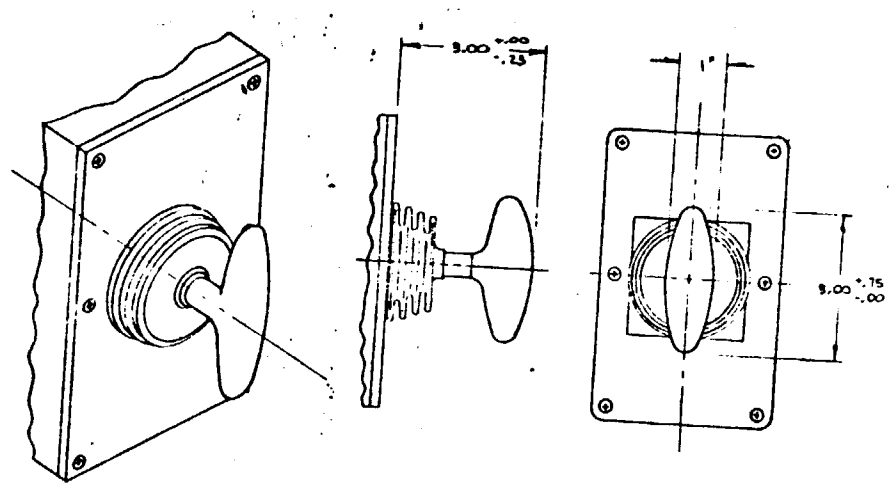
TYPICAL FLIGHT CREW STATION CONTROLS
FIGURE 3-18 (Sheet 1 of 2)



AIRBREATHING ENGINE
THROTTLE
(for Ferry Flights)



SPEED BRAKE CONTROL



TRANSLATIONAL CONTROLLER

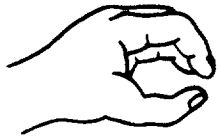
TYPICAL FLIGHT CREW STATION CONTROLS
FIGURE 3-18 (Sheet 2 of 2)

I. TYPES OF HAND AND/OR FINGER PREHENSION

PALMAR

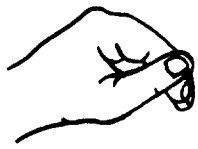
RELATED TASKS
1. WRITING
2. USING ROTARY

TIP



RELATED TASKS
PICKING UP SMALL OBJECTS

LATERAL

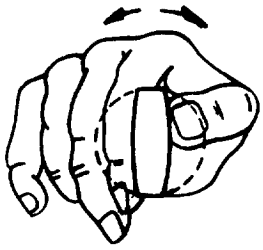


RELATED TASKS
1. USING ROTARY
2. USING TOGGLE SWITCH

GRASP

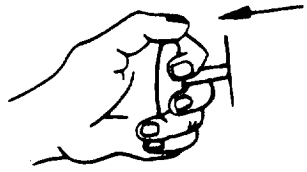
RELATED TASKS
1. USING HAND CONTROLLER AND LEVERS
2. USING HANDHOLD AND HANDRAILS
3. LOCKING AND UNLOCKING AIRLOCK HATCHES
4. INGRESS AND EGRESS FROM COUCHES

II. OTHER TYPES OF REQUIRED HAND-FINGER OPERATIONS

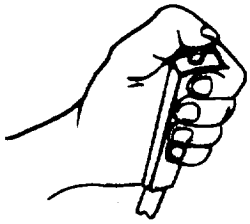


HAND ROTATION
(WITH LATERAL PREHENSION)

FINGER
(PUSHBUTTON OPERATIONS)



FINGER
1. PULLING OPERATIONS
2. ROTATING OPERATIONS



THUMB
(BUTTON OR THUMBWHEEL OPERATIONS)

HAND AND FINGER TASKS

IV FLIGHT CREW DEXTERITY REQUIREMENTS

FIGURE 3-19

3.7.2.3 IV Emergency Passenger Suit. The tasks to be performed by the passenger and the survival task requirements in case of an emergency have been discussed in Section II. In addition to determining the mobility joints required as a result of these survival requirements, the amount of finger and hand dexterity can also be defined. Since the shuttle passenger is only concerned with survival and has no flight tasks, it has been concluded that grasping, finger pulling, and rotating will be the only types of operations required. Figure 3-20 describes these hand and finger tasks. Since the amount of dexterity required in the passenger pressure suit gloves is far less than that required for the EVA and IVA and IV Emergency Crew Gloves, a separate design should be considered if a cost savings results due to glove manufacture, standard sizing, etc. However, if a cost savings is not obtainable, then the same glove design used for the EVA and IV crew should be utilized for the passenger.

3.7.3 VISIBILITY. Each space shuttle pressure suit must provide a means of visibility for the suited subject. In addition, when performing EVA tasks, eye protection must also be provided to the crewman. The following subparagraphs discuss the different types of visibility required for each shuttle pressure suit configuration.

3.7.3.1 EVA Pressure Suit Visibility. Numerous tasks will be performed by the EVA crewman during planned, unscheduled and contingency portions of the mission, requiring high degrees of visibility. Visibility such as that offered by the AES hemispherical or A7LB configured helmets will satisfy this requirement.

The visual range of the Apollo-Skylab helmet has been proven to be acceptable for all Apollo operations including lunar as well as intravehicular tasks.

GRASP

RELATED TASKS:

1. USING HANDHOLD AND HANDRAILS
2. INGRESS AND EGRESS PASSENGER COUCH

HAND-FINGER OPERATIONS

RELATED TASKS:

1. PULLING OPERATIONS
2. ROTATING OPERATIONS

} LATCHES; PIP PINS ETC.

PASSENGER DEXTERITY REQUIREMENTS

FIGURE 3-20

Therefore, the field of vision and optical clarity requirements for the shuttle EVA pressure helmet should be similar to the Apollo and Skylab requirements defined to be approximately:

a. Temporal 90°
b. Superior - Temporal 62°
c. Superior 85°
d. Inferior - Temporal 85°
e. Inferior 70°

This field of vision for each eye assumes that the head is fixed and in a neutral and natural posture within the helmet.

The field of vision is then projected onto the surface of the helmet from the reference eye. The resulting area should be transparent and of good optical quality. This area should be as free as possible of visible striae, cloudiness, and imperfections such as pits, bubbles, scratches, foreign particles, and other inclusions but no more than 4 imperfections shall be visible, nor shall there be more than 1 imperfection per square inch of the critical area. Imperfections shall not exceed 30/100 inch diameter.

The shuttle helmet design should also provide the crewman with protection during intravehicular operations within the large space telescope (LST) or similar confined areas where impact with controls or instrumentation is likely to occur. It should also permit good upward as well as downward visibility for operations within or external to the LST or other experimental packages. This will enable the crewman to best perform his tasks without repositioning his body to visually check the alignment of modules or to read the display of checkout equipment.

Due to the need for eye protection from solar radiation, infrared and ultraviolet rays, the shuttle EVA pressure suit helmet should be designed to permit attachment of a supplemental visor assembly. Visor assemblies similar to those used on the Apollo and Skylab programs should prove adequate for space shuttle use.

Using the aforementioned requirements, two configurations of existing EVA pressure suit helmets were investigated to formulate a recommendation for shuttle helmet design. Table 3-7 describes the advantages and disadvantages of the A7LB and AES configured helmets. Using this information, it is recommended that the AES hemispherical configured helmet be utilized for shuttle EVA suits since it is most desirable from the structural, visibility, and comfort aspects as well as being the least costly to manufacture.

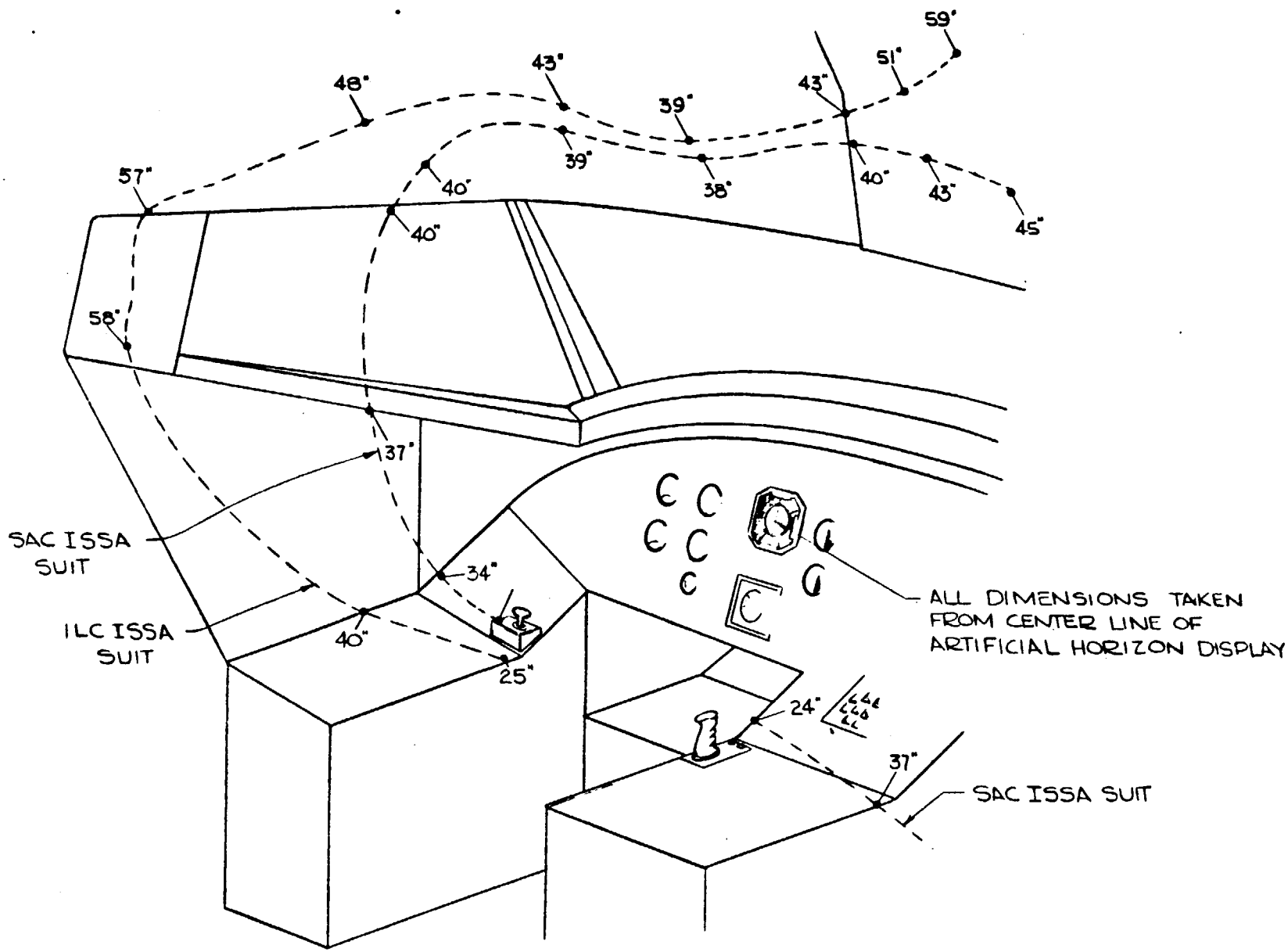
3.7.3.2 IV Visibility. Suited evaluations were conducted in the Space Shuttle Orbiter Simulator at NASA-MSC to determine the amount of visibility required by the emergency IV crewman's suit. The evaluation was conducted with an A7LB-EV PGA, ILC and SAC ISSA Suits and Litton AES Suit with Mr. Jack Mays as the subject. Each suit was pressurized to 4 psig during the evaluations. Mr. Mays was asked to reach controls and to describe his visual range while he assumed the suit to be restrained to the Shuttle Orbiter Couch (no straps available). The couch was located so that the distance from the main display panel (artificial horizon) to the crewman's eye was 28-1/2 inches. The crewman's visibility in the ILC and SAC ISSA Suits was mapped within the cabin using masking tape and the results are illustrated in Figure 3-21. The following results were noted based on the above evaluations:

AES TYPE HEMISPHERICAL HELMET	
ADVANTAGES	**DISADVANTAGES**
A. Excellent visibility - (no need for suit neck mobility).	A. Large bulky neck ring due to large diameter.
B. Can better withstand pressures above 8 psid	B. Not certification tested for any mission.
C. Easy to manufacture (Lower Cost).	C. Heavier.
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.	

APOLLO/SKYLAB CONFIGURED HELMET	
ADVANTAGES	**DISADVANTAGES**
A. Qualified for Apollo/Skylab Missions.	A. Difficult to manufacture.
B. Small neck ring will provide least amount of interference in close areas.	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.

HELMET CONCEPT COMPARISON

TABLE 3-7



IV VISIBILITY FIELD
FIGURE 3-21

a. The A7LB and AES type "hard" shell helmets provided more visibility than is needed for the IV Emergency Crew Suit. This was the case since both of these helmet configurations allowed the subject to see displays and controls far beyond his nude body reach envelope for a restrained or unrestrained crewman.

b. The SAC ISSA Suit visibility was marginal and could be considered the minimum acceptable for Shuttle Orbiter use.

c. The ILC ISSA Suit visibility was greater than the minimum allowable and was slightly better than the crewman's nude body reach envelope.

As a result, it was concluded that the Shuttle IV Crewman's Suit should use the ILC ISSA Suit visibility envelope as a design goal and should not provide a visibility envelope smaller than the SAC ISSA Suit. It was also concluded that due to the large stowage volume and high weight and cost associated with the hard shell type helmet (AES and A7LB), that a "soft" helmet configuration, such as those used in the ISSA Suits is most desirable for constant wear or in a stowed configuration.

The advantages of the soft helmet configuration include:

a. low weight value
b. significant comfort unpressurized for constant wear
c. small stowage volume
d. low manufacturing costs

3.7.3.3 Passenger Suit Visibility Requirements. During emergency conditions, the shuttle passengers are basically interested in survival. Visibility will assist them during a pressurized transfer to a Rescue Shuttle Vehicle or during a pressurized return to the passenger couch after a malfunction of the orbiter vehicle and prepare for earth reentry. Since the passengers require mobility only for survival and have no

mission tasks to perform, it is concluded that a "soft" helmet configuration such as those utilized in the ISSA Suits will be adequate. Therefore, the visual range provided by the SAC ISSA helmet is recommended as the design goal for the passenger suit.

3.7.4 COMFORT. Every effort should be made to maximize comfort for the crew and passengers. Comfort distractions will reduce personnel performance or concentration. The psychological condition of the crew and passengers will affect the rate at which the onboard consumables are used. Some factors requiring consideration relative to comfort include:

a. ambient temperature, pressure and gas composition
b. skin abrasion, pinching and pressure points
c. perspiration, dehydration and fatigue.

These comfort conditions will be discussed relative to suit design. Because crew and passenger comfort is of great importance, each subject within this study gives considerable attention to human factors.

The suit in itself can not directly control ambient temperature, pressure and gas composition within it. The spacecraft and portable environmental control systems have direct control over these factors of human comfort. However, indirectly the suit designs have considerable effect on these factors through suit leakage rates, thermal insulation layers and the distribution of ventilating gasses within the suit. A second garment, called the Liquid Cooling Garment (LCG), will provide body cooling in the EV Suit as discussed in paragraph 3.7.5 of this study.

Paragraph 3.2 discussed recommendations relative to gas distribution within the suit and the suit design considerations for thermal control are discussed in paragraph 3.5 of this study.

Suit fit has a direct effect on the conditions which might cause skin abrasion, pinching and pressure points. Cushion or comfort pads, special fabric liners and suit sizing adjustments have been considered as design features that would enhance comfort in these areas of concern. However, there should be special attention given to these comfort problems during suit concept and development phases of design. The center of the suit joint should match the center of the body joint. The joint design should minimize gathering of material in order to eliminate any pinching of the skin. Suit joint geometry should compensate for suit foreshortening conditions which might cause the suit to move against the body and create a pressure point. Paragraph 3.8 will discuss various suit sizing approaches and will provide recommendations for suit sizing systems.

The range of mobility is of great importance in that the suited man must have adequate freedom of movement to accomplish assigned tasks. At the same time much thought and concern should be given to the maximum allowable torque required to achieve the specified range of movement.

Paragraph 3.7.1 discussed sample work cycle and mobility needs to accomplish typical shuttle missions. The energy expenditures required by a nude man to perform these tasks could prove to be quite strenuous. In a pressure suit, those energy levels needed to operate the suit must be added to those required by the nude man. During EVA work conditions the body is expected to generate some 1000 to 2000 btu's per hour. This heat load generated within a thermally insulated suit can create a high perspiration rate, eventual dehydration of the body and, finally, critical fatigue. To avoid this, the Liquid Cooling Garment and Ventilation System are recommended as described in paragraph 3.7.5.

To optimize the complete suit system, designs that control perspiration, dehydration and fatigue, and low torque suit joints are of extreme importance and will require further study and development.

3.7.5 TEMPERATURE. The environmental temperature to which the suited crewman is exposed is of vital importance to his health as well as his ability to efficiently perform mission tasks for extended EVA periods of 1 to 8 hours. The crewman must be adequately protected to prevent skin damage due to exposure to contact temperatures of 39°F to 113°F.* The thermal insulation layers of the shuttle EVA suit should limit the maximum heat transfer into the suit to 250 btu/hr and transfer out to 350 btu/hr.

In addition to controlling the heat flux of the thermal environment, a temperature control system will be required to remove heat from within the pressure suit. The projected work loads are as follows:

400 btu/hr	minimum rate
800 btu/hr	mission average - all EVA's
1,000 btu/hr	maximum average - greater than 4 hour EVA
1,200 btu/hr	maximum average - less than 4 hour EVA
2,000 btu/hr	maximum average - 1/2 hour EVA

From Apollo experience, a suit ventilation flow of 12 acfm is sufficient to remove approxmately 800 btu an hour and maintain an in-suit temperature of 62° to 106°F. During EVA operation, a more efficient method of removing metabolic heat from within the space suit is required. The normal EVA heat loads generated by the body range from 1000 to 2000 btu. To remove this heat load, a liquid cooling garment similar to that used for the

*Per Shuttle Orbiter RFP (113°F) and The Bioastronautics Data Book, NASA SP-3006 (39°F).

Apollo and Skylab programs is recommended. However, in an effort to reduce weight and cost, new designs for removing body heat should be investigated. An objective in using a liquid cooling garment is to maintain the body temperature below the perspiration threshold. This reduces the body fatigue factors induced by dehydration.

There are three major considerations associated with the Liquid Cooling Garment system.

a. The coolant ducting must be in close and direct contact with the body to be effective.

b. The temperature of the coolant must be easily adjusted.

c. Sizing and the cost associated with good sizing is a consideration. The cooling garment must fit many crewmen with considerable accuracy and comfort, and yet not restrict mobility.

If the present Apollo LCG weight and cost are considered excessive for the shuttle program, it is recommended that a separate study be conducted relative to body cooling systems. The following factors should be considered:

a. spacing of tubing (total heat transfer area)
b. zone control of temperature
c. areas of the body not requiring cooling versus those areas that require concentrated cooling.
d. sizing adjustment problems
e. weight
f. cost (by simplified construction)

Concepts such as a liquid cooled vest in lieu of a full suit concept, as well as strategically located liquid cooled pads should also be considered in this study.

3.8 SUIT SIZING

The baseline for the sizing study for the shuttle pressure suits consisted of a detailed review of the present Apollo pressure suit sizing system. In the Apollo system, the torso was custom patterned to the subject, with limbs selected from standard sizes. Adjustable cables on the torso and adjustment capabilities built into the limbs provided areas for "fine-tuning" the fit. Lastly gloves were fabricated from hand casts to insure a conformal fit.

The impact of the sizing system upon the manufacturing process was first investigated. In a "one size fits all" system the problems of documentation, identification, and in-process tracking are minimized. The efficiency of the cutting, stitching and assembly operations is maximized. In the other extreme, where a size is generated for each and every crewman encountered (which is really a custom size system) the above problems are maximized and the efficiencies are low.

Another aspect of the sizing system is the interchangeability of suit parts and suit assemblies among crewmen. Ability to directly fit, or fit with minimum rework, a multiple of crewmen in a given suit is a desirable feature.

In an effort to tie together the above criteria, Table 3-8 was generated. Values from one to four were assigned to illustrate the relative importance; a value of one would be poor, four would be good.

SIZING SYSTEM	FIT	MOBILITY	MANUFACTURING COST	INTERCHANGEABILITY
One size fits all	1	1	4	4
8 size	2	2	3 - 4	3 - 4
12 size	2	2 - 3	2 - 3	3
Custom	4	4	1	1

TABLE 3-8

In order to determine the best sizing system to be used for the shuttle program, a size summary was made of the Apollo crewmen as illustrated in Table 3-9. The fit check problems encountered during the Apollo program were then reviewed. Several minor additions had been made to the original sizing system due to unusual postures, unexpected high foot instep, exaggerated muscular development, etc. However, there were no significant fit problems in some 190 suits constructed.

3.8.1 PRESSURE SUIT TORSO SIZING. A review of sizing systems for the pressure suit torso was made based on experience obtained during the Apollo program. The ranges of the four major torso dimensions (vertical trunk diameter, chest, waist and butt circumference) were determined for the 5th to 95th percentile. These ranges were then divided into increments required to maintain an acceptable torso fit.

A "one-size-fits-all" torso system is impossible since there are too many increments required. The mathematical sum of these increments results in a 96 size system, which would cover all combinations. In a population of 100 men, this is equivalent to a custom sized system.

Elimination of extreme combinations which occur infrequently and/or by rearrangement of the increments could result in a more manageable system. The following systems were developed and tested against the Apollo crew history with these results:

SIZE SYSTEM	PERCENT OF CREWMEN WITH NOMINAL FIT	PERCENT OF CREWMEN WITH SLIGHT DEVIATION IN FIT (1/4")
24	45.9	13.0
18 to 20	44.2	10.2
12	45.9	22.1
9	44.2	15.3

BY RECOMMENDED VTD NOMINAL +0 - 1/2

	VTD	CHEST AT SCYE	CHEST	WAIST	BUTTOCKS	CROTCH HEIGHT	FLOOR TO KNEE	KNEE TO CROTCH	SLEEVE INSEAM	SHOULDER ELBOW	ELBOW TO WRIST	HEIGHT	WEIGHT
ALLEN	24 3/4	36 1/4	33 1/2	28	34	30 7/8	18 5/8	12 1/4	17 7/8	12	10	65 1/4	126
TRULY	24 3/4	38	36 3/4	33	38	32	19 3/8	12 5/8	18 3/4	13 1/4	11	67	153
CONRAD	24 3/4	38 1/2	37	32	37 1/2	31	18 1/2	12 1/2	18 1/4	12 5/8	10 1/8	66 1/2	145
GIBSON	24 3/4	38 7/8	37	33	37 3/4	32 1/2	18 3/4	13 3/4	19	13 1/4	10 1/8	68	156
MCCANDLESS	25	38	36 3/4	31	36	33 1/4	19 1/4	14	18 3/4	12 5/8	10 6/8	69 1/4	150
MUSGRAVE	25	39 1/4	38	32	37	34	19 1/2	14 1/2	19 1/8	14	11	69 3/4	160
ANDERS	25	39 1/2	38 1/4	31	36	31 1/2	18 3/4	12 3/4	19 1/8	13	10 1/4	67 1/4	148
KERWIN	25	39 1/2	37 7/8	32 1/4	39 1/4	35 3/4	20	15 /34	20 1/2		11	72	175
HENIZE	25	39 3/4	38 1/2	33	38	31	17 3/4	13 1/4	19 1/4	13 1/2	10 1/4	66 1/2	170
EISELE	25	40	38 1/2	32	37	32	19	13	19 1/4	13	11 1/4	67 3/4	160
BRAND	25	41 1/2	39 1/2	36	39 1/4							70	183
HOLMQUIST	25 1/4	38 1/4	37	30 3/4	37	33 3/4	19 3/8	14 3/8	19 3/4	13 1/2	11	69 3/4	145
GORDON	25 1/4	39 1/4	37 3/4	31 1/2	37 1/4	30 1/2	17 3/4	12 3/4	17 5/8	13	10 1/4	68 1/2	155
SHEPARD	25 1/4	40 1/2	39 1/4	32 1/4	39	33 1/4	19 1/4	14	19 3/4	14 3/8	11 1/4	69	170
IRWIN	25 1/4	41	39 5/8	32 1/4	38 1/2	31 1/2	18 3/4	12 3/4	18 3/4	12 3/4	10 1/2	66 3/4	165
GARRIOTT	25 1/2	37 1/2	35 3/4	31	35 3/4	33	18 3/4	14 1/4	18 7/8	13	10 3/8	69	146
CARR	25 1/2	39 1/2	38	30 1/2	35	31 3/4	19 1/4	12 1/2	19 3/4	12 7/8	11	67 3/4	150
COOPER	25 1/2	39 1/2	37 3/4	32	36 1/2	32 1/8	19 3/4	12 3/8		14 3/8	11 5/8	68 3/4	154
ROOSA	25 1/2	39 1/2	38 1/4	34 1/4	39	33 1/2	19 3/4	13 3/4	19 1/2	13 1/2	10 7/8	69 1/2	163
WORDEN	25 1/2	39 3/4	38	30 1/2	37	34 1/4	20	14 1/4	19 5/8	13 3/8	11 1/8	70	153
SCHMITT	25 1/2	40	39 5/8	34	40 1/4	32	18 3/4	13 1/4	18 3/4	13 1/8	10 1/2	67 1/4	170
WEITZ	25 1/2	40 3/4	39 1/2	35 1/4	39 1/2	32 3/4	18 5/8	14 1/8	19 1/4	14	10 1/2	69 3/4	183
CHAPMAN	25 1/2	43	42 1/2	36	40							69 3/4	191
MATTINGLY	25 3/4	37 1/4	35 1/2	28 1/2	35	32 5/8	19 1/2	13 1/8	18 3/8	12 3/8	10 1/2	69	140
CUNNINGHAM	25 3/4	37 3/4	36 1/4	30 1/2	36 3/4	32 1/4	19 1/4	13	19 1/4	13 1/8	10 3/4	69 3/4	156
BULL	25 3/4	38	35 3/4	31	35 5/8	33 1/4	20	13 1/4	19 3/8	12 3/8	10 3/4	69 7/8	148
PARKER	25 3/4	38	37 3/8	32	38 1/2	33	20	13	18 1/4	13 1/2	11 1/4	69 1/4	168
HAISE	25 3/4	39	38	32	37 1/4	33	19 1/8	13 7/8	18 7/8	12 3/8	10 3/8	69	153
CRIPPIN	25 3/4	39 1/4	38	34 1/4	39	32 3/4	19 5/8	13 1/8	18 7/8	13	11	69 1/2	162
EVANS	26	37 3/4	36 3/4	30 1/2	36 3/4	33 3/4	20	13 3/4	19 1/4	14 1/8	11 1/8	69 3/4	164
ALDRIN	26	39	38 1/2	32	37 1/2	32 3/4	18 5/8	14 1/8	18 7/8	12 1/2	10 3/4	69 1/2	167
PERKOWSKI	26	39 1/2	37 7/8	33 1/2	38	30 3/8	19	11 3/8	18 1/4	13	10 3/4	67	175
SLAYTON	26	39 1/2	38 3/4	32	38 1/2	33 1/2						69 3/4	169
BORMAN	26	40	38 3/4	33	39	33	20	13	18 1/4			69 1/4	168
ARMSTRONG	26	40	38 3/4	35	39 3/4	33 3/4	20	13 3/4	19	12 7/8	11 3/8	70 3/8	173
SHERRA	26	41	39 3/4	36	40	32 3/4	20	12 3/4	18 5/8	13 1/4	10	69 3/4	197
FULLERTON	26 1/4	37 3/4	36 1/2	32	38	33 3/4	20	13 3/4	20 7/8	13 1/2	11 1/2	70 3/4	163
BEAN	26 1/4	38 3/4	36 3/4	31 1/2	36 1/2	32	18 7/8	13 1/8	19 1/4	13 1/8	11	68 1/2	156
POGUE	26 1/4	38 3/4	37 1/2	32 1/2	37 1/2	32 1/4	19 5/8	12 5/8	18 7/8	13	10 5/8	68 1/4	164
OVERMYER	26 1/4	39 1/2	37 1/2	32	38	34 1/4	20 1/4	14	20 1/4	13 1/2	11 1/2	71 1/4	169
YOUNG	26 1/4	40 1/2	39 1/4	32	37 1/4	31 1/2	19 1/4	12 1/4	19	13	10 3/4	69 1/4	168
SCOTT	26 1/4	42 1/2	38 1/2	31 3/4	39 1/4	33 1/2	20 1/2	13	19 3/4	14 1/2	10 5/8		
COLLINS	26 1/2	37 1/2	36 3/4	31 1/4	38 1/2	34	20	14	19 1/4	12 1/4	11 3/4	70 1/2	167
DUKE	26 1/2	37 3/4	35 3/4	31	36 1/2	34	20 3/8	13 5/8	19 3/4	13 3/8	10 7/8	71 1/8	156
ENGLE	26 1/2	39	37	31 1/2	37 1/2	34 1/2	19 3/4	14 3/4	20 1/4	13 5/8	10 1/2	71 3/4	157
SCHWEICKART	26 1/2	39	37 1/2	32 3/4	37	34 3/8	20	14 3/8	19 3/8	12 3/4	11	71 3/4	165
LENOIR	26 3/4	37 1/4	36	32	38 1/2	32		12 7/8	19 3/4	12 3/4	11	70 1/4	165
ENGLAND	26 3/4	37 1/2	35 1/2	30	37	31 3/4	18 1/4	13 1/2	18 1/2	13	10 1/4	69 1/2	155
MICHEL	27	38 1/2	37 1/2	32 1/2	38	33 1/4	20	13 1/4	19 3/4	13 1/4	10 3/8	70 1/2	181
MITCHELL	27	40 1/4	39	34	38 1/2	32 1/4	19 5/8	12 5/8	19	13	11 1/8	70	181
SWIGERT	27	40 1/2	39	34	40 1/2	33	19 3/8	13 5/8	19 1/4	13 5/8	11	71	187
LIND	27	41 1/4	40 3/8	34 1/4	39	32 3/4	19 7/8	12 7/8	19 1/2	12 1/2	11	70 3/4	174
THORNTON	27	41 1/2	39 1/2	36 1/2	40 1/2	34 1/2	20	14 /12	19 1/2	14 1/4	11 1/2	72 3/8	210
LOVELL	27 1/4	38 3/4	37 1/4	35 1/2	38 1/2	33	20	13	18 1/4	12 1/2	10 3/8	70 1/2	173
MCDIVITT	27 1/2	37 1/4	35 3/4	32 3/4	37 1/4	32 1/2	19 3/8	13 1/8	19 5/8	12 3/4	10 1/8	70 3/4	159
CERNAN	27 1/2	39 1/2	38 1/8	33 3/4	39	33 1/2	19 3/4	13 3/4	19	13 1/4	10 5/8	71 1/4	175
STAFFORD	27 1/2	42 1/2	41 1/4	36 1/4	38	32 3/4	19 3/4	13	19 1/2	13 1/2	10 1/2	71 1/2	172
LOUSMA	27 1/2	42 3/4	41	35 3/4	39 3/4	33 1/2	20 3/4	12 3/4	20	14	11 1/2	72 1/2	199

APOLLO CREW SIZING HISTORY

TABLE 3-9

The conclusions to be gained from the testing of these sizing systems is that there is little or no advantage to large numbers of sizes. The success rate is low due to the distribution of most of the crewmen into a few central groups. Unusual combinations are also a problem.

Elimination of some of the variables was then investigated. In a suit with a waist entry, the waist would have to be oversized to clear the shoulders and butt in donning. Eliminating the waist as a critical dimension (leaving VTD, chest and butt circumference) would seem to increase the possibilities of a more useful sizing system. The following systems were developed and tested against the Apollo crew history with these results:

SIZE SYSTEM	PERCENT OF CREWMEN WITH NOMINAL FIT	PERCENT OF CREWMEN WITH SLIGHT DEVIATION IN FIT (1/4")
12 with one common waist entry	61.2	15.3
9 with one common waist entry	56.1	10.2

This illustrates that a major improvement occurs in the percent of crewmen which can be fit with the elimination of only one of the variables (waist circumference). It should be further noted that with a waist disconnect entry additional versatility could be obtained by interchanging upper and lower torso sections. Such a system was not tested against the Apollo crew but could be expected to increase the percentage of successful fit by approximately 7 percent.

To further explore the possibilities of eliminating torso dimensional variables, the chest and butt circumferences were investigated. The chest area was found difficult to adjust without changing the arm orientation. In addition, studies have shown that the butt circumference is the easier variable to manipulate. By providing a one inch adjustment or allowing the butt circumference easement to be approximately one inch greater than the 1-3/4 inches (maximum) easement presently used in the Apollo program, a significant improvement in the usefulness of the 9 and 12 size systems results. Thus, a torso which has no waist adjustment and an easement of 2-3/4 inches maximum in the butt circumference was evaluated against the Apollo crew history with these results:

SIZE SYSTEM (Common Waist and one inch butt cir. change)	PERCENT OF CREWMEN WITH NOMINAL FIT	PERCENT OF CREWMEN WITH SLIGHT DEVIATION IN FIT (1/4")
12	78.2	6.8
9	76.5	6.8

Again it should be noted that the addition of a waist disconnect entry allowing interchangeability of the upper and lower torso sections was not examined in this study. However, the addition of such an entry system could be expected to increase the percentage of successful crewman fit by approximately 7 percent.

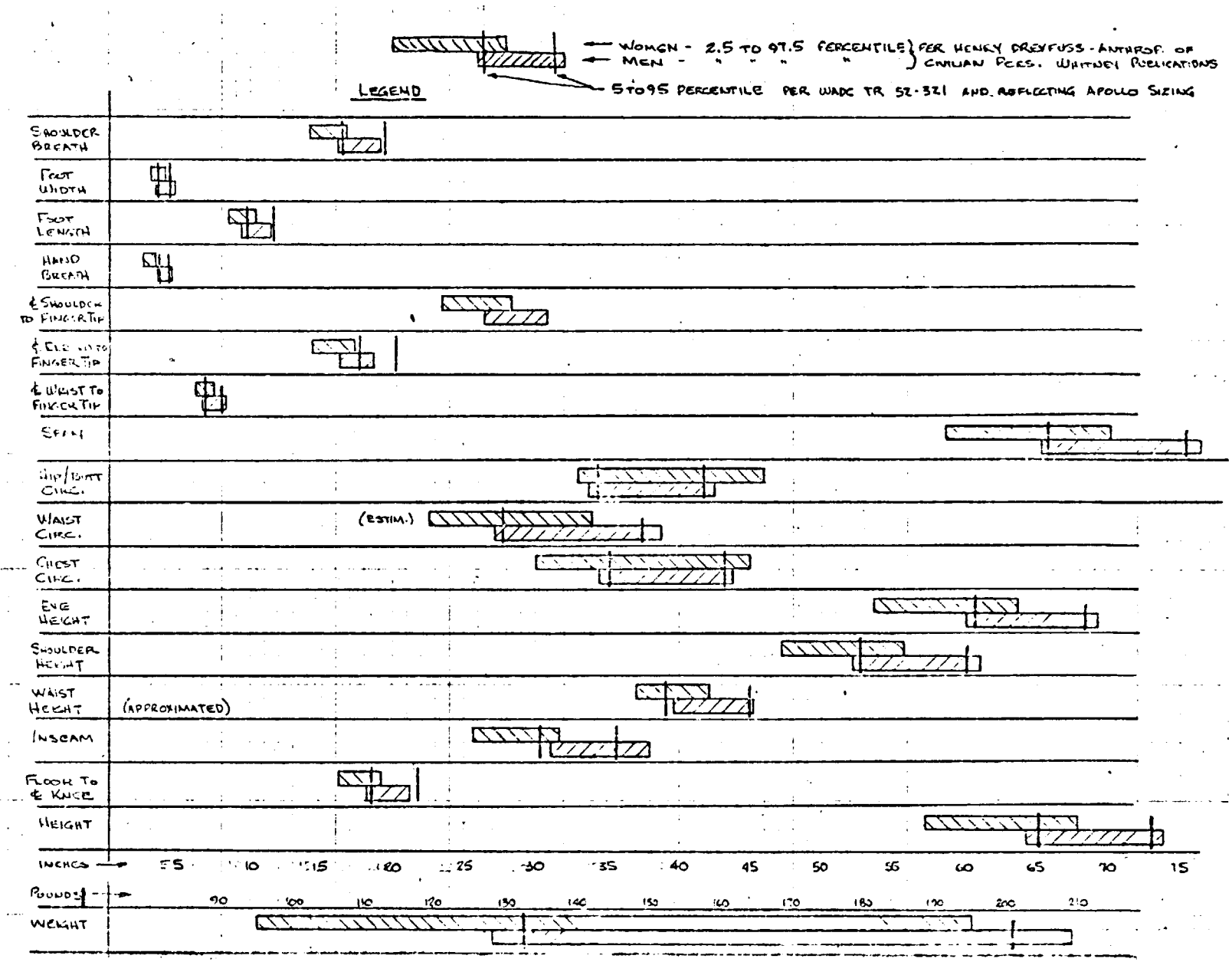
In conclusion, it is recommended that a nine or twelve torso sizing system be utilized for both the EVA and IV emergency crew suits with a common sized hard waist disconnect entry and a one inch adjustment or easement in the butt circumference. This will permit a nominal fit to approximately 85 percent of the Apollo crewmen population with an additional slight deviation in fit to approximately 7% of the crewmen. This results in a total of a 92% acceptable fitting capability. The remaining

8% of the Apollo crewmen population would require a custom fitted suit or would have to accept a fit that was less than desirable by Apollo standards.

It should be noted that all sizing systems shown might probably be further improved by increasing the tolerance on the fit.

The torso sizing system for the shuttle passenger suits was not investigated in detail. However, based on the previous discussion it can be concluded that variations in the ease-ment of the passenger suit torso are acceptable since the passenger has no suited flight tasks and will have assistance for those tasks he must perform. Thus a torso sizing system smaller than the 9 size system is entirely feasible which will satisfy the population in the 5th and 95th percentile. However, since both male and female passengers are expected to be participating on the space shuttle missions it is important that passenger suit sizing system also account for the dimensional variations between the sexes. Table 3-10 illustrates some of the anthropometric dimensional differences between males and females.

3.8.2 SUIT LEG LENGTHS. Leg length variations from the Apollo crew (per Table 3-11) were investigated to determine the various leg sizes based on the vertical trunk diameter. Table 3-11 illustrates the Apollo crew leg lengths for the recommended 9 and 12 size torso systems based on the vertical trunk diameter. The table illustrates that the crotch height may vary as much as 5-1/4 inches. In addition the floor to knee dimensions have also been provided in this table since the knee joint on the suit must be centered at the crewman's knee to obtain the maximum mobility. As a result adjustment capability should be provided above and below the suit knee joint to permit proper centering.



MALE AND FEMALE ANTHROPOMETRIC

DIMENSIONAL DIFFERENCES

TABLE 3-10

SIZE NO.	VTD 5th To 95th PERCENTILE	APOLLO HISTORY CROTCH HEIGHT (30 1/2 - 35 3/4) 5th to 95th	INCREMENT	APOLLO HISTORY FLOOR TO KNEE (17 1/2 - 21) 5th to 95th	INCREMENT
1	24 5/8 - 25 1/8	30 7/8 - 35 3/4	4 7/8	17 3/4 - 20	2 1/4
2	24 3/4 - 25 1/4	30 1/2 - 35 3/4	5 1/4	17 3/4 - 20	2 1/4
3	25 1/4 - 25 3/4	30 1/2 - 34 1/4	3 3/4	17 3/4 - 20	2 1/4
4	25 1/2 - 26	30 3/8 - 34 1/2	4 1/8	18 5/8 - 20	1 3/8
5	25 3/4 - 26 1/4	30 3/8 - 34 1/4	3 7/8	18 5/8 - 20 1/2	1 7/8
6	26 - 26 1/2	30 3/8 - 34 3/8	4	18 5/8 - 20 1/2	1 7/8
7	26 1/4 - 26 3/4	31 1/2 - 34 1/2	3	18 1/4 - 20 1/2	2 1/4
8	26 1/2 - 27 1/8	32 1/4 - 34 1/2	3 1/4	19 3/8 - 20 3/4	1 3/8
9	27 - 27 1/2	32 1/4 - 34 1/2	3 1/4	19 3/8 - 20 3/4	1 3/8

1	24 5/8 - 25 1/8	30 7/8 - 35 3/4	4 7/8	17 3/4 - 20	2 1/4
2	24 3/4 - 25 1/4	30 1/2 - 35 3/4	5 1/4	17 3/4 - 20	2 1/4
3	25 - 25 1/4	30 1/2 - 35 3/4	5 1/4	17 3/4 - 20	2 1/4
4	25 1/4 - 25 3/4	30 1/2 - 34 1/4	3 3/4	17 3/4 - 20	2 1/4
5	25 1/2 - 26	30 3/8 - 34 1/2	4 1/8	18 5/8 - 20	1 3/8
6	25 3/4 - 26 1/4	30 3/8 - 34 1/4	3 7/8	18 5/8 - 20 1/2	1 7/8
7	25 7/8 - 26 3/8	30 3/8 - 34 1/4	3 7/8	18 5/8 - 20 1/2	1 7/8
8	26 1/8 - 26 5/8	31 1/2 - 34 1/2	3	18 7/8 - 20 1/2	1 5/8
9	26 3/8 - 26 7/8	31 3/4 - 34 1/2	2 3/4	18 1/4 - 20 3/8	2 1/8
10	26 1/2 - 27	31 3/4 - 34 1/2	2 3/4	18 1/4 - 20 3/8	2 1/8
11	26 3/4 - 27 1/4	31 3/4 - 34 1/2	2 3/4	18 1/4 - 20	1 3/4
12	27 - 27 1/2	32 1/4 - 34 1/2	3 1/4	19 3/8 - 20 3/4	1 3/8

LEG LENGTH VARIATIONS
TABLE 3-11

Standard size legs with no adjustment capabilities seem quite reasonable. These would result in a nine (9) size leg system with increments of 0.58 inch $(\frac{5.25}{9})$ or a twelve (12) size leg system with increments of 0.44 inch $(\frac{5.25}{12})$.

It can also be seen that only one (1) adjustable sized leg could be used on all suits if it could be designed with an adjustable capability of 0 to 2-1/4 inches between the boot and the knee and an adjustment of 0 to 3-1/2 inches between the knee and the thigh for the Apollo crew.

As a result, the pressure suit legs will easily adapt to a sizing system for all suit concepts. Since the amount of adjustment capability for the advanced suits is a function of the basic suit design it is difficult to recommend an exact number of leg sizes. However, judgement indicates that a 4 size adjustable leg system should be possible.

3.8.3 SUIT ARM LENGTHS. The same general philosophy as discussed in paragraph 3.8.2 for suit leg lengths was applied to the suit arm lengths. Table 3-12 illustrates the arm length sizes for the recommended 9 and 12 size torso ranges based on the vertical trunk diameter.

In this case standard size arms with no adjustment capabilities would result in a nine (9) size arm system with increments of 0.41 inch or a twelve (12) size arm system with increments of 0.31 inch.

One adjustable length arm could also be used if it could be designed with the necessary adjustment length. Since the adjustment capability in the advanced pressure suits is unknown at this time, a final conclusion of the recommended number of arm sizes is difficult to provide. However, judgement indicates

SIZE NO.	VTD 5th to 95th PERCENTILE	APOLLO HISTORY SLEEVE INSEAM (18 - 21 3/4) 5th to 95th	INCREMENT	APOLLO HISTORY ELBOW TO WRIST (9 3/4-11 1/4) 5th to 95th	INCREMENT
1	24 5/8 - 25 1/8	17 7/8 - 20 5/8	2 3/4	10 - 11 1/2	1 1/2
2	24 3/4 - 25 1/4	17 5/8 - 20 5/8	3	10 - 11 1/2	1 1/2
3	25 1/4 - 25 3/4	17 5/8 - 19 3/4	2 1/3	10 1/4 - 11 5/8	1 3/8
4	25 1/2 - 26	18 1/4 - 19 3/4	1 1/2	10 - 11 5/8	1 5/8
5	25 3/4 - 26 1/4	18 1/4 - 20 7/3	2 5/8	10 - 11 1/2	1 1/2
6	26 - 26 1/2	18 1/4 - 20 7/8	2 5/8	10 - 11 3/4	1 3/4
7	26 1/4 - 26 3/4	18 1/2 - 20 7/8	2 3/8	10 1/4 - 11 3/4	1 1/2
8	26 1/2 - 27 1/8	18 1/4 - 20	1 3/4	10 1/8 - 11 1/2	1 3/8
9	27 - 27 1/2	18 1/4 - 20	1 3/4	10 1/8 - 11 1/2	1 3/8

1	24 5/8 - 25 1/8	17 7/8 - 20 5/8	2 3/4	10 - 11 1/2	1 1/2
2	24 3/4 - 25 1/4	17 5/8 - 20 5/8	3	10 - 11 1/2	1 1/2
3	25 - 25 1/4	17 5/8 - 20 5/8	3	10 1/4 - 11 1/2	1 1/4
4	25 1/4 - 25 3/4	17 5/8 - 19 3/4	2 1/8	10 1/4 - 11 5/8	1 3/8
5	25 1/2 - 26	18 1/4 - 19 3/4	1 1/2	10 - 11 3/8	1 3/8
6	25 3/4 - 26 1/4	18 1/4 - 20 7/8	2 5/8	10 - 11 1/2	1 1/2
7	25 7/8 - 26 3/8	18 1/4 - 20 7/8	2 5/8	10 - 11 1/2	1 1/2
8	26 1/8 - 26 5/8	18 7/8 - 20 7/8	2	10 1/2 - 11 3/4	1 1/4
9	26 3/8 - 26 7/8	18 1/2 - 20 1/4	1 3/4	10 1/4 - 11 3/4	1 1/2
10	26 1/2 - 27	15 1/2 - 20 1/4	1 3/4	10 1/4 - 11 3/4	1 1/2
11	26 3/4 - 27 1/4	18 1/4 - 19 3/4	1 1/2	10 1/4 - 11 1/2	1 1/4
12	27 - 27 1/2	18 1/4 - 20	1 3/4	10 1/8 - 11 1/2	1 3/8

ARM LENGTH VARIATIONS
TABLE 3-12

approximately a 6-size adjustable arm system should be possible. Arm sizing, like leg sizing, should be incorporated into all three pressure suit concepts.

3.8.4 GLOVES. Due to the need for maximum mobility in the EVA and IV emergency crew gloves, these could be custom fitted for each crewman.

It should be noted however, that current information from ILC studies of the 8.0 psi pressure gloves indicates that a standard glove sizing system of twelve (12) to eighteen (18) sizes is feasible to support all subjects within the required percentile ranges. However, further development is required in this area to prove this theory.

A standard size glove system is definitely recommended for the passengers since their dexterity requirments are are far less than the shuttle crew as discussed in paragraph 3.7.2 of this report. Further cost savings may be acquired in the passenger suit gloves by providing a mitten type glove which encloses the thumb and first finger (index finger), individually and separately and one common bladder encloses the remaining three fingers (2nd, 3rd, and 4th fingers).

3.8.5 BOOTS. Basic data on boot sizing for pressure suits was difficult to locate in any references. As a result the Apollo boot sizes were utilized. Investigation revealed that the five (5) size boot systems utilized on the Apollo and Skylab programs was adequate for all Astronaut foot sizes. Therefore, it is recommended that a five size system be utilized for the EVA and IV emergency crew suits.

In addition, the shuttle passenger when pressurized in his IV suit is not expected to utilize foot restraints or for that

matter use his feet at all. As a result, it is recommended that the design and sizing system for the passenger boot be at a much lower level of detail with possibly one or two sizes to satisfy all passenger foot requirements.

3.9 MATERIALS

Materials for intravehicular and extravehicular shuttle suit applications should have characteristics that do not present potential hazards to personnel or equipment.

Selection of the optimum materials for each application requires trade-off studies based on the analysis of the most critical parameters.

Materials with a previous history of reliable performance should be utilized where applicable. New state-of-the-art materials should also be considered if previously used materials cannot fulfill the shuttle requirements or if the new materials offer a distinct advantage in performance.

The following subparagraphs discuss the material as well as flammability and off gassing recommendations for consideration in the shuttle pressure suit design.

3.9.1 PRESSURE RESTRAINT MATERIALS. As a minimum, the following characteristics should be considered in the selection of materials for the pressure restraint layer:

a. Strength/Weight and modulus
b. Durability (wear and abrasion resistance)
c. Tear resistance
d. Resistance to temperature and pressure extremes
e. Chemical resistance
f. Flammability
g. Shelf life and service life
h. Ease of fabrication

New high strength and modulus organic fibers are recommended for restraint fabric, webbing, and cable applications. These materials should provide structural integrity and minimal growth

at the recommended higher suit operating pressures. One such material is DuPont's PRD-49 high performance fiber.

Preliminary evaluations* indicate that this fiber, when woven into fabric, provides the required structural integrity and minimal growth at high operating pressures (8 psi). Similar results were found during evaluations of PRD-49 tapes, webbing and thread.

However, suitable sizings and coatings should be investigated to improve the abrasion and wear resistance of these PRD-49 yarns.

3.9.2 PRESSURE BLADDER MATERIALS. When investigating those materials most suitable for use as the pressure suit bladder, several characteristics are of prime importance. These consist of:

a. Tensile and elongation properties
b. Tensile set resistance
c. Tear and puncture resistance
d. Low permeability
e. Age resistance (shelf and service life)
f. Ease of fabrication (bonding, sealing, etc.)
g. Resistance to temperature extremes

Neoprene coated nylon fabric has performed reliably as a bladder material in the Apollo and Skylab programs. This material has a low permeability and good resistance to tearing and aging. The disadvantage of this material is that it requires the use of stitched, bonded and/or taped seams which are costly to manufacture due to the manhours involved in performing such manufacturing processes.

*NASA Contract 9-21995, "The 8.0 psi Emergency Intravehicular Suit Programs"

Heat sealable urethane coated fabric may prove to be a more advantageous bladder material since it should provide more reliable seams and offer a fabrication advantage by the use of heat sealing techniques.

The neoprene/natural rubber latex convolutes and boot bladders presently used on the Apollo and Skylab programs have exhibited limited shelf and service life due to poor temperature and oxygen aging resistance. Neoprene and urethane materials should be considered for use in bladders for the shuttle suit mobility joints. Solvent dipped neoprene has exhibited superior resistance to aging and has a lower permeability than similar latex dipped parts. While seamless dipped parts may be preferred for comfort, the heat sealing approach, utilizing urethane films, offers greater sizing flexibility and ease of fabrication.

3.9.3 HELMET AND VISORS. This subparagraph shall discuss those materials which should be considered for use in the various pressure suit helmet designs. When considering the materials to be used, the following factors should be of concern:

a. Optical clarity
b. Structural integrity
c. Shelf life and service life
d. Abrasion resistance
e. Folding and flex endurance (flexible IV visor)
f. Resistance to cracking and crazing (rigid EV visor)

A soft visor has been recommended for the IV emergency pressure suit since it will satisfy the visibility requirements discussed in paragraph 3.7.3, and it can be easily stowed within the vehicle if it is not worn as a constant wear garment.

A transparent, flexible, polyvinyl chloride may be used for the visor material. This material exhibits good optical characteristics after forming and can readily be heat-sealed or bonded

to the bladder materials.

Transparent urethane films may also be considered, but these exhibit poorer optical, forming and flammability characteristics.

For extravehicular helmets and visors, polycarbonate (lexan) is the recommended material based on past experience in the Apollo and Skylab programs. Polycarbonate exhibits superior resistance to impact, temperature extremes, radiation and chemical attack.

Other rigid transparent materials such as polyterepthalate (Tenite 7 DRO) and amorphous polyamide (Trogamid T) should also be considered. These materials have excellent mechanical properties and chemical resistance and do not exhibit the stress crazing problems associated with polycarbonate. However, further evaluation of their UV resistance, impact properties and service temperatures should be performed in order to determine the acceptability of these materials for EVA applications.

3.9.4 BOOT SOLE. When investigating materials to be considered for use on the pressure suit boot sole, the following characteristics are important:

a. Light in weight
b. Durable
c. Chemical and age resistant
d. Flame resistant
e. Easy to manufacture
f. Resistant to flex cracking

The fluorocarbon (fluorel) material used on the Apollo and Skylab boot sole is difficult to process due to its poor molding and knitting characteristics and in addition has relatively poor flex cracking resistance. Fluorel was originally selected for the Apollo and Skylab programs based on its flame resistance

cnaracteristics in a 100% oxygen environment. However, the less stringent flammability requirements (Ref. Para. 3.9.7) of 14.7 psia oxygen-nitrogen cabin atmosphere should allow the selection of a more reliable material for the boot sole.

Neoprene Rubber is a candidate material which could be used in place of the fluorocarbon materials for intravehicular suit applications with a reinforced inner sole stiffener.

In addition, a fluorocarbon compound such as Viton should also be considered for IV use. The Viton material can provide an acceptable boot sole with a greater degree of flame and high temperature resistance than neoprene.

For extravehicular boot sole applications, Fluorocarbon and Silicone elastomers are the recommended candidates. Viton, a fluorocarbon elastomer, exhibits excellent flex cracking resistance at temperatures down to -180°F and demonstrates good retention of physical properties up to approximately 300°F.

Silicone elastomers, also prime candidates for the EV sole material, have excellent high and low temperature properties and durability.

If a completely rigid EV boot sole design is selected for EV applications, flex cracking will not be a problem. Durability and high and low temperature stability (-263°F to +285°F) will then be of primary concern.

3.9.5 HARDWARE. Composites reinforced with high strength and modulus fibers should be evaluated for use in pressure suit structural hardware applications. Although aluminum and stainless steel hardware have performed reliably in previous programs, the high strength composites should offer a significant weight advantage. However, the relatively low interlaminar shear strength of a composite must be considered in each hardware application.

Lightweight glass filled thermoplastics, such as Noryl or Lexan, should be considered as candidates for connector type hardware. These materials offer reduced weight with excellent mechanical properties and chemical resistance. Aluminum and corrosion resistant steels should also be utilized for hardware where particular properties of composites render them inadequate for the application.

3.9.6 LUBRICANTS. Self lubricating materials are recommended for use, where feasible. Materials such as filled and unfilled fluorocarbon plastics (TFE, CTFE, etc.) provide excellent bearing surfaces with low vapor pressures and temperature stability in hard vacuums.

Molyebdenun Disulfide (MoS_2) and teflon particles may be impregnated in a variety of plastics and incorporated into metals to provide self lubrication.

Special conditions such as high vacuum, temperature extremes, radiation and zero gravity affect the selection of suitable lubricating materials for the extravehicular space environment.

A lubricant in space environments should exhibit the following characteristics:

a. Provide lubricating qualities in vacuum
b. Low volability (vapor pressure)
c. Resist temperature extremes
d. Provide chemical inertness
e. Low in toxicity and non-deposit forming
f. Retain lubricating qualities

Where self lubricating materials cannot be utilized, resin bonded film lubricants of laminar solids (MoS_2) or teflon are recommended (i.e., silicone, alhyds, silicates, etc.).

These bonded systems offer thermal stability and low volatibility over a wide temperature range, and afford excellent radiation resistance and wear life.

Where the application does not lend itself to the use of solid film lubricants, oils and greases such as Krytox fluorinated oils may be used. However, the higher volatility of these materials, as compared with solid film lubricants, may result in evaporation and off-gassing in high temperature and hard vacuum space environments. Oils and greases decompose at lower temperatures than solid films, exhibit viscosity changes with temperature and are less stable to radiation. The evaporation of lubricating oils in a vacuum and their subsequent condensation on nearby optical surfaces should be an important consideration in the lubricant selection. The fluorinated oils may be utilized in intravehicular applications where hard space vacuum will not be encountered. However, bonded film lubricants are also recommended for IV applications.

3.9.7 FLAMMABILITY AND OFF-GASSING. Due to the reduction of cabin atmospheres from 70% oxygen in the Skylab program to an oxygen/nitrogen mixture (20% O_2 - 80% N_2), material flammability requirements should be less stringent. It is recommended that materials which are self extinguishing in air be considered in place of the standard Apollo or Skylab non-flammable materials if such materials offer superior performance characteristics. Tradeoff studies of flammability versus other critical parameters will be required to insure a best-effort program with respect to flammability of shuttle materials.

Many of the non-flammable materials presently utilized in the Apollo and Skylab programs are expensive, difficult to process and are marginally acceptable based on other critical parameters.

Reduction of the flammability requirements will permit the use of materials which offer a distinct advantage in performance over present Apollo or Skylab materials.

The off-gassing characteristics of materials must be evaluated in all expected exposure environmental combination.

The combination of pressure, temperature and atmosphere affect the degree and rate of materials off-gassing.

Materials exposed to hard vacuum and high temperatures should have a low vapor pressure and high decompositon temperature. Vapor pressures must be low enough to prevent any significant off-gassing at the predicted worst-case pressure and temperature conditions.

3.10 INTERFACE

The general interface requirements between the spacecraft and space suits have been studied. Such items as space requirements, weights, and suit maintenance provisions and work station interfaces have been considered in this paragraph. Design goals, concepts and recommendations have been provided that may have some affect on the spacecraft design.

3.10.1 PRESSURE SUIT STOWAGE. Paragraph 3.10.3 of this report discusses the EVA donning and doffing envelope requirements and recommends that donning and doffing be accomplished within the space shuttle orbiter Airlock. In addition, it is recommended that two EVA pressure suits be stowed within the Airlock at earth launch and reentry as well as during the spaceflight. This will provide a minimum space impact on the orbiter crew compartments. EVA pressure suit stowage can be accomplished in several ways. Some of these include:

a. Container or locker stowage

(1) Stowage of two (2) suits in a padded container or locker which is fixed to the spacecraft.

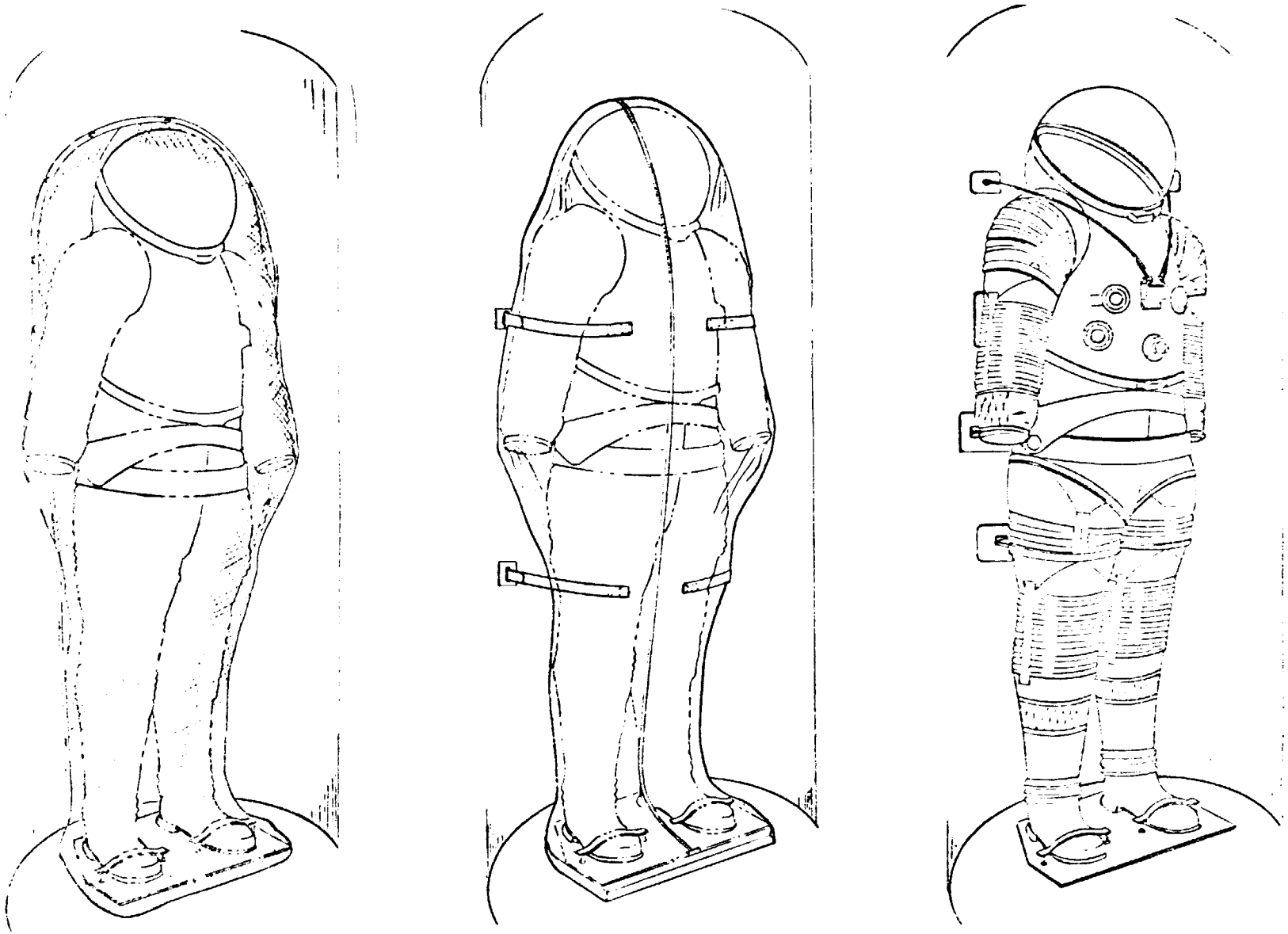
(2) Stowage of each suit in a duffle bag with a draw string. These are then stowed within a container or locker assembly.

The folded volume of the shuttle EVA suit is expected to be smaller than the AES volume discussed in paragraph 3.1.4.

b. Suspended in Airlock

Mechanical attachments should be used to secure the boots (foot restraint) while

(1) The legs, torso, arms and neck areas are secured with bungee cords which attach to the Airlock wall or,



EV SUIT STOWAGE CONCEPTS
FIGURE 3-22

a. The shuttle orbiter to carry heavier payloads.

b. A broader selection of vehicle suit stowage locations due to the lesser affect on vehicle center of gravity.

c. A greater selection in the method of suit stowage due to less stringent structural requirements on the vehicle at launch and reentry.

d. Easier and more realistic one (1) "g" crewman training due to ease in donning, doffing, and miscellaneous training tasks.

e. Less costly and easier ground packaging, shipping and storage of pressure suits.

f. Probable reduction in bulk permitting more efficient manned operations and utilization of spacecraft stowage volume.

3.10.2.1 The hybrid 8 psi EVA shuttle pressure suit should have a target weight of 50 pounds maximum. This includes the torso and limb assemblies, the helmet, gloves, bio-instrumentation and electrical harnesses, and removeable thermal insulation. The table below illustrates a weight comparison of the A7LB PGA, Litton AES, Garrett AiResearch AES and a target weight for the Hybrid EVA suits.

Hybrid EVA Suit	A7LB	Litton AES	AiResearch AES
Target 50 Lbs.	56.15 Lbs.	61.69 Lbs.	59.52 Lbs.

Areas where significant weight reduction could be attained on the 8 psi suit are:

a. Use of higher strength to weight ratio restraint fabrics.

b. The use of fabric in lieu of rubber joints.

c. Use of lighter weight bladder material.

d. Use of composite materials such as reinforced plastics in place of metal parts.

e. Reduction in thermal insulation material by using newly developed materials. (i.e., use of Nomex in lieu of beta cloth.)

f. Thorough evaluation of environmental requirements to preclude over-designing the system, resulting in unnecessary weight.

The weight of the EVA suit will be greater than that of the IV Emergency Suits due to the extra protection needed for:

a. Thermal control

b. Attachment of Life Support equipment

c. The severe man-induced loads caused by strenuous EVA and IVA tasks.

d. The interface with restraint devices such as foot restraints, tethers and handholds.

e. High suit cycle life requirements.

f. A high degree of visibility.

g. Visors for EVA eye protection.

h. Greater mobility requirements.

3.10.2.2 The IV emergency crew suit, if worn as a constant wear garment should have a target weight of 17 pounds. This weight includes the torso and limbs, soft helmet with a hard ring disconnect, gloves, and a hard ring waist entry design. This target weight could be reduced to approximately 14 pounds if the suit were only donned during an emergency. This is the case since the suit helmet and gloves could be integrated to the upper torso (could be detachable with roll seals) and eliminate the need for disconnect hardware at the helmet and glove interfaces.

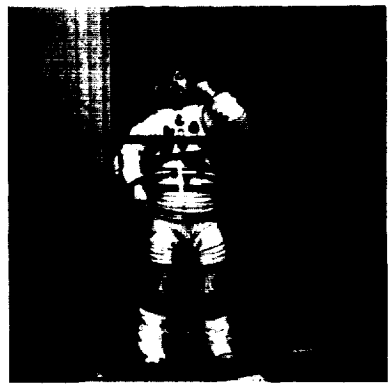
The weight of these suits is expected to be considerably less than the EV Pressure Suit since they are not required to provide the protection previously described and since support equipment such as a liquid cooling garment and bio-instrumentation will not be required.

3.10.2.3 The weight of the IV emergency passenger suit should be less than the IV emergency crew suit if worn either as a constant wear suit or stowed and donned only when the need for survival arises. This suit should be limited to 14 pounds for a constant wear configuration and 11 pounds if used only for survival purposes.

3.10.3 DONNING AND DOFFING. The envelope or minimum volume required in order to don two (2) suits should be available within the shuttle spacecraft. This will permit suit donning by two men simultaneously if an unplanned or contingency condition occurs requiring immediate attention by more than one man. A donning exercise was conducted to demonstrate the ability to stow and don two (2) EV pressure suits within an envelope which closely represents that of the space shuttle airlock. The volume used was a square parallelepiped with dimensions of 49.5 x 49.5 x 92 inches. As illustrated in Figure 3-23, two Advanced Extravehicular Suit (AES) Assemblies and two Portable Life Support Systems (PLSS) were successfully donned within this envelope. Since this represented the minimum allowable volume for the donning and doffing of two Extravehicular suits, the procedure in performing the donning became important. The following donning procedure was successful within the aforementioned volume.

a. Prepare Pressure Suits for Donning. The pressure suits should be prepared for donning by placing the lower suit torsos in foot restraints located opposite each other and close to the airlock wall. The foot restraints should be oriented in order to allow the two crewmen to "face" each other,

Envelope for Donning Two AES Suits



Envelope for Donning of One AES Suit

Envelope for Donning one ISSA Suit

SUIT DONNING AND DOFFING ENVELOPE

Figure 3-23

thereby permitting each to assist the other during the donning if desired. The upper torsos with helmet and gloves should be stowed in the airlock within easy reach. It is suggested that an interim stowage attachment utilizing quick release pins, snaps, stowage bags or netting restraints be provided for the upper suit torso to simplify the donning procedure.

b. Donning Procedure. After one (1) man prepares the pressure suits, the following donning procedure is suggested:

(1) The first (1st) crewman ingresses the airlock and dons the lower suit torso. This crewman remains in position while the second crewman ingresses.

(2) The second (2nd) crewman ingresses the airlock and dons the second lower suit torso. He then remains in position or assists the first (1st) crewman during the next sequence.

(3) The first (1st) crewman dons the upper suit torso either by himself or with the assistance of the second (2nd) crewman.

(4) The second (2nd) crewman performs step 3 with or without assistance of the first (1st) crewman.

This essentially completes the suit donning sequence since the donning of the suit helmet, visor, and gloves is considered to be a minor task which will be the final portion of the donning prior to EVA egress.

It should be noted that the height dimension of 92 inches can be reduced to approximately 80 inches since the upper suit torso may be donned by bending at the waist and then straightening up. Therefore, for a minimum envelope, only adequate head room (for helmet/visor) is required which is a function of the man's height plus increases due to the suit torso, boots, and the helmet/-visor assemblies.

The previously discussed exercise utilized two Advanced Extravehicular Suits (AES) since these suits closely represent the configuration of the recommended hybrid EV/IV pressure suit entry design (Hard ring entry).

In addition to the two (2) man donning sequence, the minimum envelope for the donning of one (1) AES was also investigated and found to be 40 x 40 x 80 inches. This one man donning sequence is illustrated in Figure 3-23.

The IV Pressure Suit donning envelope was also investigated by performing a donning exercise utilizing an ISSA prototype. It was concluded that this suit, which is representative of the IV Emergency Suits, can be donned in a minimum volume of 29 x 29 x 76 inches.

3.10.4 IN-FLIGHT MAINTENANCE. In order to ascertain the needs for in-flight maintenance, both Apollo and Skylab requirements were reviewed based on anticipated requirements during Shuttle missions. Differences in maintenance and repair requirements between these three types of missions relate to mission duration, wear times, suits used, and general tasks to be performed with attendant risks of suit wear or damage probability. The contents of Apollo and Skylab Flight Maintenance Kits support the suit maintenance for those specific situations. Therefore, the nature of Shuttle tasks, duration of wear, and damage risk must be analyzed to develop the most suitable maintenance needs for the space Shuttle suits.

The several suit types being considered for Shuttle mission usage include:

a. EVA and IVA dual purpose maintenance suit
b. IV emergency protective crew suit
c. IV emergency protective suit for passenger.

It is anticipated that all of these special suits will possess similar types of materials and construction. These similarities will lend themselves to the development of a universally applicable in-flight maintenance program which would support any suit type appropriate for Shuttle missions. This approach has the benefit of reducing development costs, payload weight and cabin space requirements.

3.10.4.1 In-Flight Maintenance Kit. The onboard items to support in-flight maintenance needs will be based upon an assessment of the specific requirements of the Shuttle Suit design and a detailed analysis of Shuttle suit activity. A significant factor for maintenance and repair considerations is that the distances to be traversed while wearing Shuttle Suits in "Zero G" are much more extensive than in either Apollo or Skylab missions. This increases the hazard of suit damage because of the increased opportunity for abrasion or snagging against vehicle hardware.

The recommended content and rationale for Shuttle Flight Maintenance Kits is as follows:

a. A container for on-board stowage of the complete assembly. The container materials will be affected by allowable weight, containment capacity required, flammability and outgassing restrictions, and cabin location for satisfactory accessibility. For example, an aluminum container would be larger and non-flammable, but could weigh considerably more than a container composed of Telfon-coated Beta fabric over a formed polycarbonate stiffener.

b. Instruction pouch assembly...this should be easily accessible from the kit container exterior or upon first opening of the container itself. This would be a printed instruction sheet protected by a sealed transparent plastic envelope.

c. Lacing Kit...this would include a suitable quantity of cord and a lacing needle for use in relacing suit components after removal of the thermal protective layer.

d. Seal removal tool...this should be a nylon rod with a preformed tip to facilitate removal of o-ring seals. A lanyard with a pile fastener strip would be attached to tools to accommodate temporary stowage by engaging the pile strip with any convenient hook strip.

e. Lubricant pouch assembly...this would contain a number of fluorinated oil-saturated pads used to lubricate seals and o-rings prior to pressurized suit usage, either IVA or EVA, if required.

f. Bladder repair kit...this would contain a number of patches, tape, and adhesive appropriate for repairing the suit bladder. The bladder material, whether of neoprene, polyurethane or some other material, will dictate the nature of the repair items.

g. Fabrics repair kit...this would include a number of fabric patches, thread and needles for stitching. Fabric patches of both thermal cover and restraint material would be included, since abrasion or damage to either will need to be repaired to prevent further damage to other exposed layers. Only one thread type is recommended for all fabric repairs.

h. Visor or helmet cleaning kit...this would include cleaning solution applicator pads and drying tissues. These would be used to clean fingerprints, smudges, dust or lint that can be expected to occur on transparent surfaces during handling. The cleaning solution may be stored in ampules requiring a syringe for its removal and use, or the applicator pads may be pre-impregnated with the cleaning solution. The latter approach offers considerable convenience and weight reduction by eliminating the syringe assembly.

i. Spare parts...suitable pouches in the container would provide protected stowage for such parts as lip seals for neck rings or disconnects, and for o-rings for water or gas connectors.

Examination of the recommended flight maintenance kit contents led to a determination of its expected weight and volume.

The stowage envelope and weight (with contents) for the Apollo and Skylab in-flight maintenance kits are as follows:

	APOLLO	SKYLAB
Weight	0.6 lbs.	5.0 lbs.
Envelope	5 x 7 x 1.5 inches	9 x 9 x 4 inches
Container Design	Soft Cloth	Aluminum
Useage Time	One Apollo Mission	3 Skylab Mission (140 days)

It is recommended that the soft container design successfully used in the Apollo missions be used in the shuttle program. Due to the larger quantity of suits required on the shuttle program it is estimated that the weight would be approximately 1.5 pounds with an approximate envelope of 7 x 7 x 2.5 inches.

Recommendations for Shuttle Suit maintenance, especially cleaning and drying, are based primarily upon experience with Apollo Suits, modified by factors peculiar to the Shuttle missions. Generally, it is believed that the most effective design engineering trade-off between performance and cost can be made by correlating the requirements for the Shuttle Suits throughout the major phases of a suit life cycle, i.e., flight preparation, stowage, use, cleaning, drying, repair, etc. It is of primary importance to reduce or eliminate in-flight suit maintenance. As much maintenance as possible should be accomplished during ground activity between flights.

3.10.4.2 Suit Drying. Previous experience using Apollo Suits has shown that little perspiration dampness is deposited upon suit materials. This is because of body cooling provided by the combination of the LCG and the ventilation flow within the PGA. In early Apollo flights, the suits were never removed. Later, in Apollo 16, the suits were donned and doffed many times

between usages, i.e., three 7 hour EVA's on the lunar surface, during lunar ascent, CM EVA and earth reentry. Apollo suits were not reused after completion of a flight. Therefore, special in-flight cleaning and drying procedures and equipment were not used during Apollo missions. However, on two separate Apollo missions, a cellulolytic species of fungus (chatomiun globosum) was isolated and identified as a flight contaminant. This fungal species is one found in nature having the ability to decompose cellulose or high molecular weight compounds. The potential for fungus causing deterioration of suit materials merits concern relative to Shuttle Suit cleaning and drying.

In contrast to Apollo usage, Shuttle Suits will be worn more total hours because of their reuse over many flights. Most of the EVA tasks will be of shorter duration than Apollo tasks, but will be similar in work loads.

Shuttle IV Suits would be worn for emergency purposes and the predicted work loads are estimated to be approximately 400-1000 Btu/hr. Actual emergency usage of an IV Suit would not logically require, or permit, drying after use. However, IV Suit usage in a standby status or for "shirt-sleeve" working conditions would probably result in a need for suit drying after such use either on the ground or in flight.

Excessive suit dampness and accompanying odors are the main factors to be controlled during flight by drying after use. A single 7 day Shuttle mission is not considered long enough, nor are conditions conducive, for the promotion of significant fungus or bacterial growth. Such growths require more humidity, time, and higher temperatures to develop to an extent that would cause suit materials to deteriorate or present a health hazard to persons exposed. Repeated use of suits over a number of missions, however, could provide opportunity for fungal and

bacterial growth to reach hazardous levels, unless appropriate preventive procedures are applied.

Based upon Apollo experience, most aerobic and anaerobic bacteria fail to multiply in a spacesuit environment. Few bacteria can adapt and servive. Suit fabric test swatches that had been sanitized showed little effect on bacterial growth. Use of desiccants tends to preserve bacteria up to 12 days, but longer desiccant drying will eliminate some species. Generally, bacterial growth conditions are about the same as fungus growth.

The following paragraphs discuss the various in-flight suit drying methods that have been considered to prevent excessive suit dampness and its accompanying odors from occurring during flights.

a. Cabin Drying

(1) It is believed that Shuttle Suits will not be dried adequately by open exposure to the cabin atmosphere. Currently, the ECS is expected to maintain a relative humidity between 36% and 60%*, based upon a dew point range of 40° to 60°F with cabin atmosphere temperatures between 70° and 75°F. However, telcons with NASA, MSC indicates the Shuttle cabin relative humidity may be maintained at much higher levels. Therefore, the amount of time required for open suit drying may be extremely long and impractical.

(2) Drying can be done more quickly and efficiently by connecting hoses to a closed suit to effect a forced reverse ventilation flow through the suit. This would insure even, interior drying at suit extremities. Also, this simple method could accommodate the practice of placing the LCG, Communications Headgear, socks, etc., inside the suit for drying. Equipment and space required would be minimized, even if it becomes necessary to provide extremely

*Relative Humidity and Dew Point Table WSTAB-0-6G
U.S. Department of Commerce
National Weather Service

dry (5 to 10% R.H.) cabin atmospheric flow through a suit. This second method is recommended for Shuttle Orbiter use if significant dampness has been accumulated in the suit components.

(3) The third drying method would require an auxiliary blower or drier source added to Method 2 above. After doffing the suit and its support equipment, all damp undergarments and interior components (LCG, etc.) would be placed inside the suit, and the suit closed. Hoses would then be connected to the suit so that a reverse flow through the suit ventilation system would be effected. The supply hose from an auxiliary blower would provide a high flow rate and operate for a time duration to be determined relative to the amount of moisture involved. The exhaust hose should lead to a condenser and filter for removal of excess moisture and contaminants to permit recycling directly to the suit. If this were not feasible the exhaust could dump directly into the cabin atmosphere for subsequent processing through its Life Support system. After drying, the suit would then be stowed in its appropriate location.

(4) Desiccants are recommended for use in Shuttle Suits after any in-flight drying procedure and at all times while stowed. Desiccant rejuvenation could take place between flights during the ground maintenance.

b. Locker Drying

(1) This method would require a drying locker suitable for on-board drying and stowage of the suit and its components. The damp, open suit(s) would be placed in the locker and dried cabin atmosphere would then be purged through the locker for a prescribed period of time. Recent testing by NASA indicates that fungus growth, rather than bacteria, is the biggest problem resulting from perspiration dampened suits. Fungus growth is eliminated by drying the suit for 10 hours at a relative humidity of less than 6%. Bacterial growth is coincidentally eliminated, by the fungus, by drying, or because of both

factors. After drying, suitable valving would stop the dry flow and in turn, connect the locker to a chamber containing suitable desiccants. Whether or not a forced circulation flow would be necessary through the desiccant chamber will have to be determined by further testing.

(2) An alternate drying method which has also been considered is use of a vacuum chamber. Damp suit components would be placed (open) in the chamber, and valving would be opened to space to evacuate the contained moisture. This method is not recommended because of the high loss of cabin atmosphere volume with each drying cycle. Also, there would be a high risk of damage to the suit bladder layer because of "pinching" or blowing caused by sudden pressure inequalities during chamber evacuation. Further, there is also concern about materials deterioration potential when interior suit portions are exposed to a vacuum.

Since control of fungal growth is relatively more important that that of bacterial growth, it is expected that periodic cleaning during ground maintenance will concentrate on elimination of fungus, which will in turn eliminate harmful bacteria. Use of a USDA approved, non-ionic, cleaning and sanitizing agent is recommended during ground maintenance of Shuttle Suits. Current candidates for consideration include AFCO SLASH from Alex. C. Fergusson Company and Sanitized DPN-10 from Sanitized Incorporated. Residual fungistats and bacteriostats resulting from ground maintenance cleaning procedures should be considered for extended suit life.

References

1. 7LB Suit Evaluations with the Ascomycetous species Chaetomium globosum by Paul A. Volz and Douglas E. Jerger, January 19, 1972.

2. Interpretation of C globosum 7LB Study by P. A. Volz and D. E. Jerger, January 22, 1972.

3.10.5 SUIT COMMUNICATIONS. A radio communications system is required for each suit configuration that is recommended for use in support of Shuttle missions. During depressurized modes of cabin or spacecraft operations, voice communication is essential. Communications stations strategically located in the spacecraft are also recommended for use during pressurized modes of operation. A headset communications system similar to the Apollo program is recommended for suited personnel; a microphone and speaker concept is recommended for personnel in a shirt-sleeve configuration. Table 3-13 discusses the advantages and disadvantages of utilizing a separate communications system versus a helmet integrated system in the EVA shuttle pressure suit. The inability to communicate by voice through the vacuum environment of space dictates the need for a communications system. As a result, it is recommended that the IV Emergency Suits also be provided with simplified voice communications systems to permit communication between the passengers and the crew, and between the crew and the ground. Suited personnel require a microphone and earphone system which will interface with the suit and suit systems. During shirt-sleeve operations within a cabin, specialized communications systems are not required, however, communications between pressurized cabins will be required.

Another communications requirement is biomedical monitoring. Vital life systems of each crewman require periodic analysis during each mission. These data will contribute to a safe and successful EVA mission, and provide the physiological information needed in the development of future spacecraft systems, working tools, etc. Continuous monitoring should not be necessary except for those crewmen performing EVA missions. To assure control of the consumables used during each EVA mission, the condition of the crewman, and a safe, successful mission, monitoring of vital life systems is essential. One station located in the spacecraft for bio-medical monitoring is suggested for periodic reports on the health of unsuited crewmen. It is also recommended that each crewman suited for EVA

COMMUNICATIONS SYSTEM INTEGRATED INTO PRESSURE SUIT TORSO	
ADVANTAGES	DISADVANTAGES
A. Easy donning - short donning time since there is no need to don a "headset" and mate the electrical harness.	A. New concept requiring development, thereby impacting program cost.
B. More comfortable to crewman since electrical wiring is integrated in suit and the man's head is free of all hardware.	B. Second communications carrier required when crewman is not wearing suit.
	C. Methods of attachment of the communications system to Helmet may impact the structural characteristics of the helmet.
	D. Electrical connection would be made via the helmet neck ring. Therefore helmet could not be rotated if scratches occurred in the visual area.
	E. A malfunction of the communications system would affect the helmet usage. A Modular design could avoid this but may increase unit costs.
	F. Vent ducting may be required in the Helmet depending upon communications design for proper CO_2 washout.

COMMUNICATIONS SYSTEM - WORN SEPARATELY AS IN APOLLO/SKYLAB	
ADVANTAGES	DISADVANTAGES
A. "Comm. Carrier" is qualified for Apollo/Skylab missions.	A. Longer donning time due to electrical connection and the donning of the Communications Carrier (10 seconds approx).
B. Easy to change communications carrier in case unit fails and requires replacement.	B. Separate item to stow on spacecraft.
C. Attenuates ambient noise.	C. May be uncomfortable to crewmen since equipment is donned on head.
	D. Restricts head mobility within helmet in some cases.
	E. Requires different sizes for different crewman.

COMMUNICATIONS SYSTEM COMPARISON

TABLE 3- 13

tasks be outfitted with bio-sensing devices similar to those on the Apollo and Skylab programs.

3.10.6 WASTE MANAGEMENT. In addition to standard spacecraft waste facilities typical of the Skylab program, a portable waste management system is recommended as an optional provision. Accommodations for solid and liquid waste collection during contingency modes of operation in the spacecraft are required to satisfy minimum hygiene needs. To provide for these needs, either a disposable brief or disposable brief liner is recommended. For EVA, the waste management system now employed for the Apollo and Skylab programs is suggested.

An all mode environmental waste management system is essential to ensure that total attention can be given to the planned mission tasks. All bothersome or annoying problems of waste management must be eliminated. The lack of adequate waste management systems can adversely affect the cabin or suit Environmental Control System. This could cause the mission to be aborted or cause a valuable phase of a mission to be bypassed.

3.10.7 RESTRAINT. There is a need for restraint systems to secure the crewman or passenger in the couch, at each work station, and to provide containment of tools that will be needed. Foot, hand, and body restraint systems have been considered. The following subparagraphs provide rationale relative to the needs for different types of restraint systems and their applications.

3.10.7.1 Couch Restraint System. The couch harness system employed in the Apollo spacecraft as a restraint provision is recommended for Shuttle. The head rests should be contoured to accommodate launch and powered flight G-loads. The couch restraint system should also be designed to accommodate a suited

or unsuited crewman. The design of the couch and its restraint system should provide the man with adequate mobility to perform the tasks required during the various mission phases, and should accommodate personnel having anthropometric dimensions that fall within the 5th and 95th percentile range for male USAF flying personnel.

3.10.7.2 Work Station Foot Restraint Systems. Restraint systems are required at each work station to assist the crewman in maintaining his posture while he is performing work tasks. The torque, compression and tension exerted through the body while performing work tasks are prime considerations in determining the type of restraint system selected for use in each work station. Various concepts of EVA and IVA work station foot restraints were investigated for use on the shuttle program. These consisted of:

a. The present Skylab configurated foot restraints for EVA.

b. Use of the open floor grid concept (Skylab OWS) inside the Shuttle cabin for IV Restraint.

c. Use of velcro on the cabin floor and boot soles and heels for IV Restraint.

d. Use of a dutch shoe (Apollo) or heel clip (Skylab type) for restraining the IV crewman at a work station.

e. Use of toe and ankle straps for restraining the IV crewman.

f. Use of hard attachments on EVA or IVA boots which interface with hooks, clips, etc. on the vehicle.

g. Use of a magnetic boot for IV foot restraint on the vehicle floor.

After consideration of the work station foot restraints discussed earlier, the following recommendations were prepared:

a. EVA Foot Restraint

The present Skylab foot restraint (See Figure 3-24) is the best configuration available for extra-vehicular use. Reasons for this are:

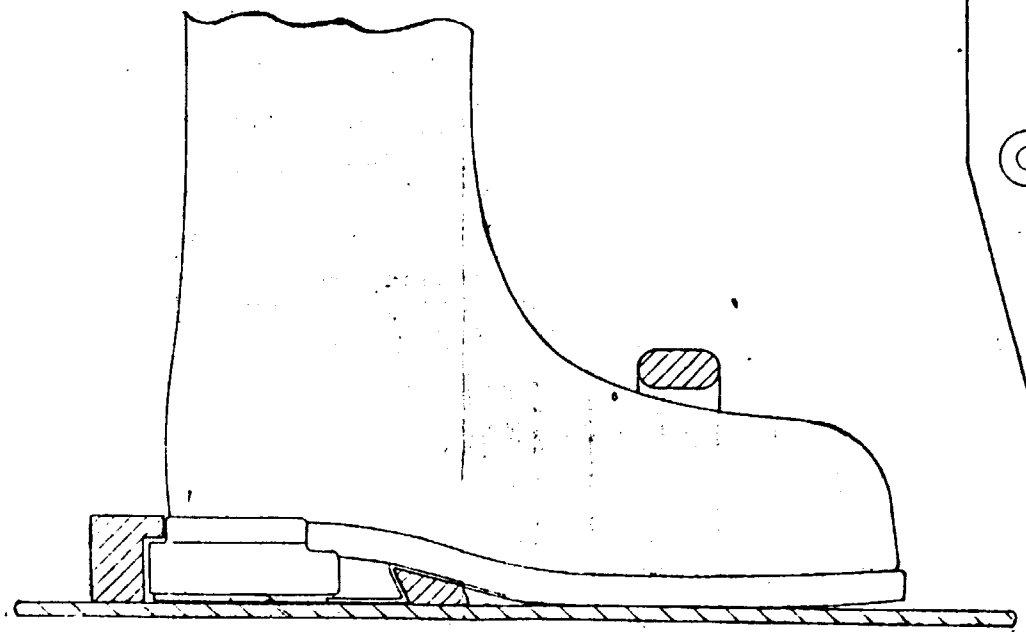
(1) Sizing. No boot or foot restraint sizing problem exists with the Skylab restraints; sizing does present a problem with other designs.

(2) Safety. The foot restraint provides the only positive retention system which requires minimal effort on the part of the crewman to remain within the restraint.

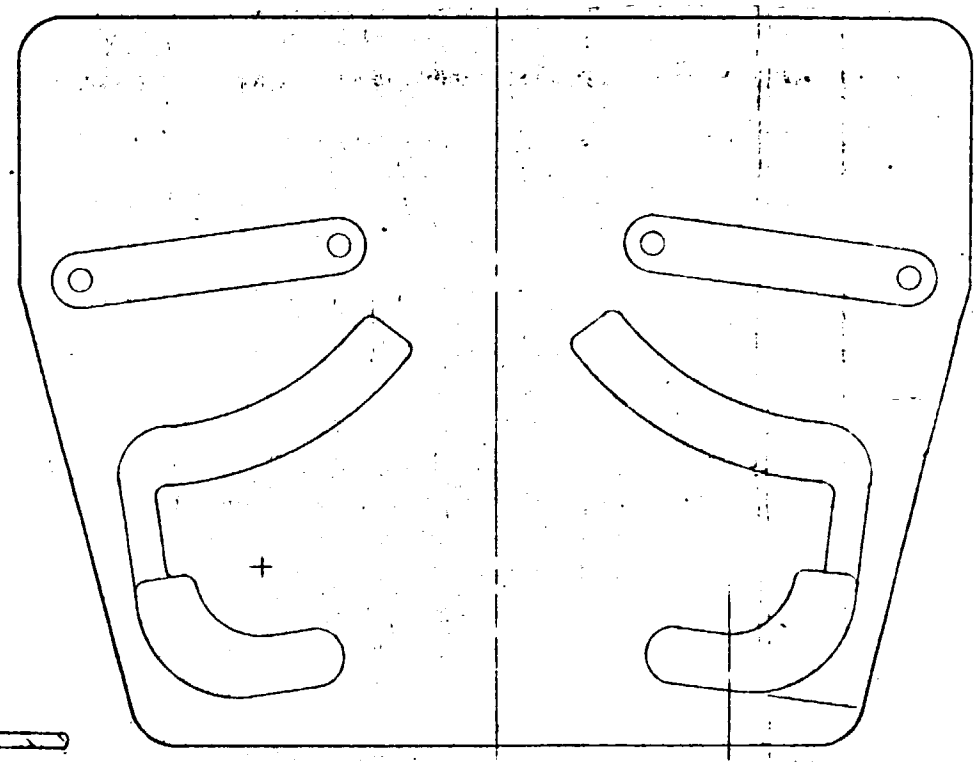
By providing a Skylab, or similar design of foot restraint, all boots will be interchangeable with all foot restraints thereby eliminating the need for adjustment either in size or orientation. The nominal center to center heel distance for the foot restraint should be approximately eleven (11) to fourteen (14) inches depending on the tasks to be performed and the most comfortable position for the crewman while performing the task. The use of hard point attachment hooks, clips or rings is considered unacceptable for EVA since these require the crewman to perform clipping or locking of tethers or hooks directly to the boot unassisted. In addition, the crewman may be required to remove the boots from the restraints quickly during an emergency, which would be difficult with this type of restraint.

b. IV Foot Restraints

(1) The Skylab foot restraint is also recommended for IV usage and can also serve as a donning station for the EV suits. Figure 3-24 illustrates the Skylab configured foot restraint. Besides utilizing it for the reasons previously stated in the EV foot restraint section above, it will also provide standardization and permit interfaces of EV or IV suit boots with all foot restraints. This would allow emergency operations by an IV suited crewman if the need presents itself either IV and pressurized (cargo bay), or EV for short periods of time.



BOOT - RESTRAINT ASSEMBLY



FOOT RESTRAINTS FOR SUN END, TRANSFER, FAS
& OWS WORK STATIONS

SKYLAB FOOT RESTRAINT
FIGURE 3-24

(2) The use of toe or ankle straps or hard point attachments of hooks, clips or rings is feasible for IV use due to weight savings, but restrictions due to adjustments required and quick doffing problems during an emergency make them undesirable. Likewise, the use of magnetic boots which interface with the vehicle floor is considered to require further development (possible during a Skylab mission) prior to recommending their use. Tests have been conducted by NASA Langley Research Center* demonstrating the feasibility of this concept, but the weight effects on the suit boots or strap on boots, as well as on the vehicle, are unknown. In addition, the electromagnetic effect on the vehicle controls and communications is also unknown.

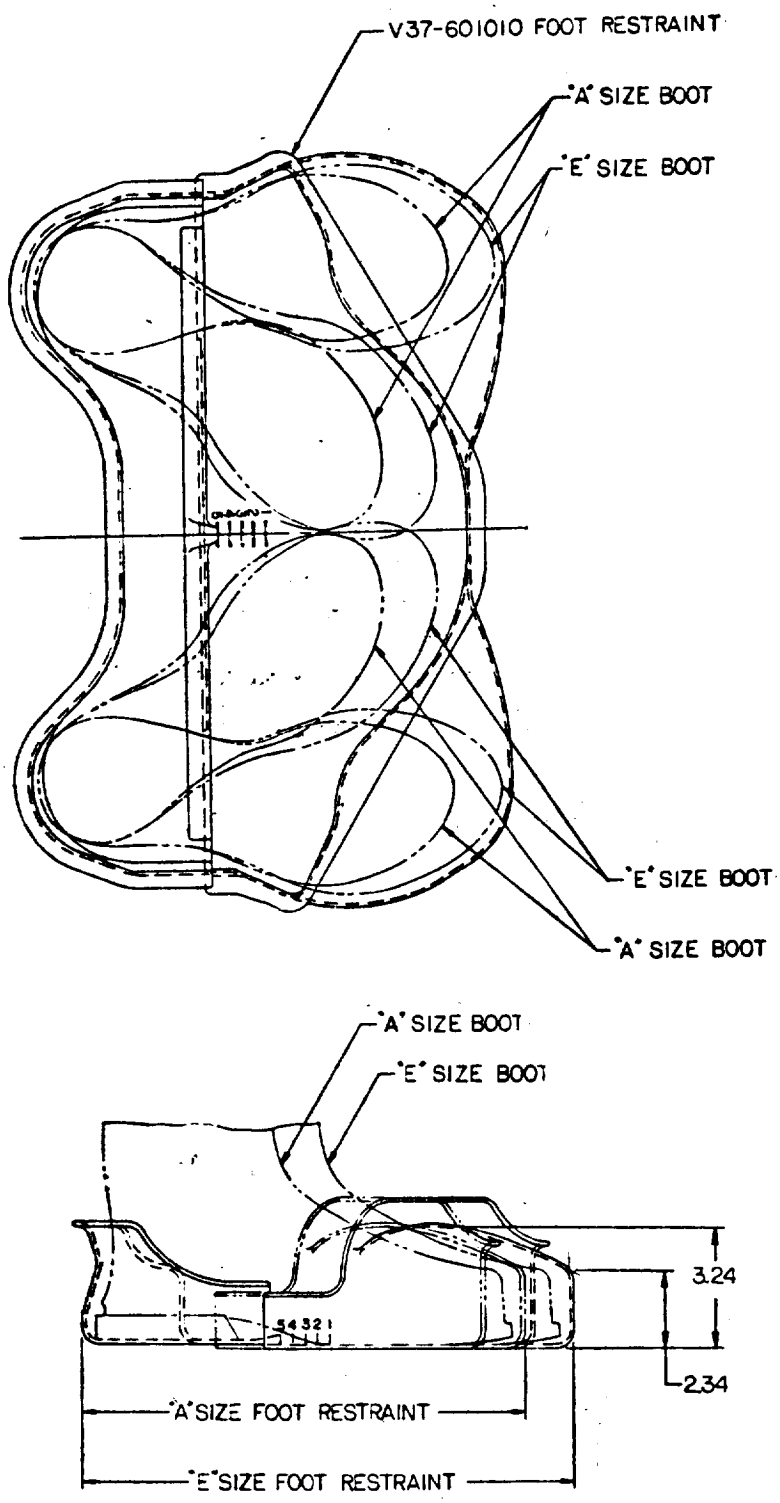
(3) The use of an open floor grid concept (Skylab type) for the Shuttle cabin floor may be useful in the zero "g" environment, but it will tend to generate small metallic chips during the insertion and removal of the mating boot section. This problem may be overcome by other methods of attaching the boot to the floor grid.

(4) Velcro used as the boot to floor interface has been found helpful on the Apollo program to prevent slippage, but should not be utilized if the crewman is expected to exert high forces pushing or pulling at a work station or anywhere else within the vehicle.

(5) Lastly, the Apollo "dutch shoe" type foot restraint for either EV or IV use is considered unacceptable, since it requires adjustment to interface with all size boots and does not provide a method of positive retention or gripping such as the Skylab configuration. Figure 3-25 illustrates this foot restraint.

(6) In general it should be noted that the pressure suit can be designed to interface with any of these foot restraints. This may require the usage of a special slip on boot such as the Apollo "lunar type" boot to accommodate IV interfaces such as open floor grid, use of hard attachment points on boots, magnetic boot, etc.

*NASA technical note D-6774, April 1972 results of Intravehicular Manned Cargo-Transfer Studies in simulated weightlessness.



APOLLO CSM FOOT RESTRAINT

FIGURE 3-25

3.10.7.3 Traversing Aids. Traversing through space between vehicles, along the outside of a spacecraft and inside a spacecraft in a zero-gravity environment has been studied. Handrails or handholds, foot rails and portable propulsion systems are applicable to Shuttle Missions.

3.10.7.3.1 Handholds and Handrails. The use of handhold or handrail systems will be required to support both EVA and IVA activities. These systems will enable the crewman to move quickly while outside as well as inside the vehicle in the performance of his tasks. Figure 3-26 illustrates typical handholds and handrails used on the Apollo program. Handrail or handhold concepts considered are:

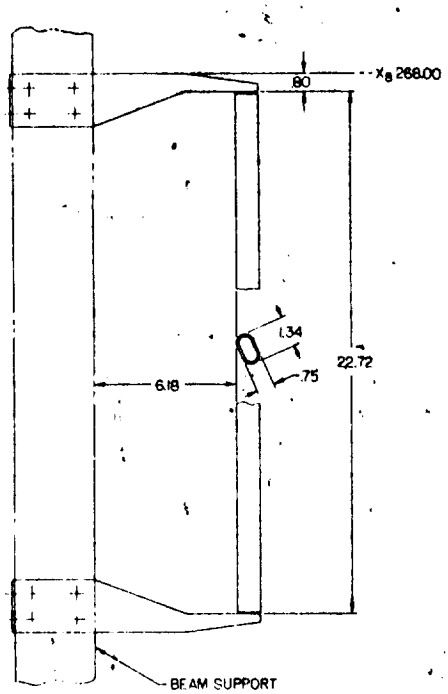
a. Permanent handholds or rails similar in cross-section and length to the Apollo-Skylab configuration. These rails or handholds can be strategically located along the spacecraft and at predetermined work stations.

b. Portable handholds might be employed. These handholds would interface with strategically located attachment points along a predetermined path between work stations.

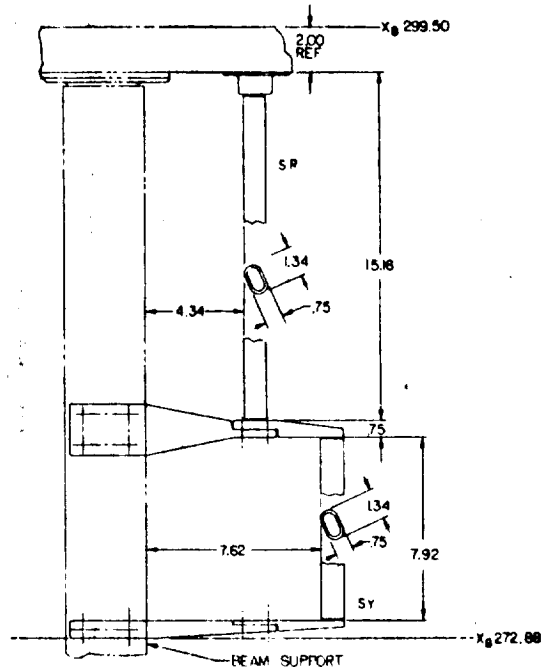
c. Single or dual railing has been considered for use in conveying cargo, tool containers, and equipment from one work station to another.

From the above concepts, one feasible method for reducing the quantity of handrails required by any one mission would be to provide detachable handrails strategically located for a particular set of mission tasks, but removed and/or relocated while the shuttle vehicle is being readied for a subsequent mission. Methods similar to this may permit vehicle weight savings and still provide the required EVA path for all possible mission tasks.

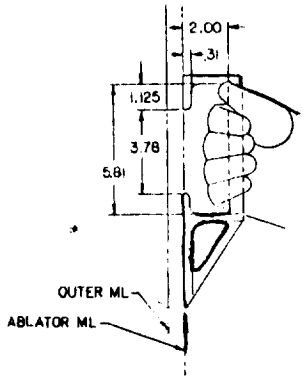
In addition to the above, a single or dual rail system similar to those studied by the NASA Langley Research Center could be considered for the extravehicular manned transfer of cargo from the

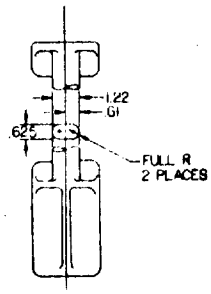


HANDHOLD



HANDHOLD





TYPICAL APOLLO HANDHOLDS AND HANDRAILS

FIGURE 3-26

vehicle if a manipulator malfunction occurs.* Figure 3-15 illustrates the cargo transfer techniques studied. All the above types of handhold or handrail systems are compatible with all types of suit concepts.

3.10.7.3.2 Maneuvering Units. Figures 3-27 and 3-28 illustrate the various maneuvering units which will be utilized on the Skylab program and may be considered for the Shuttle program. Experience on the Skylab program has shown the major areas of controversy to be:

a. The type of harness configuration to be used to attach the maneuvering unit to the suit and

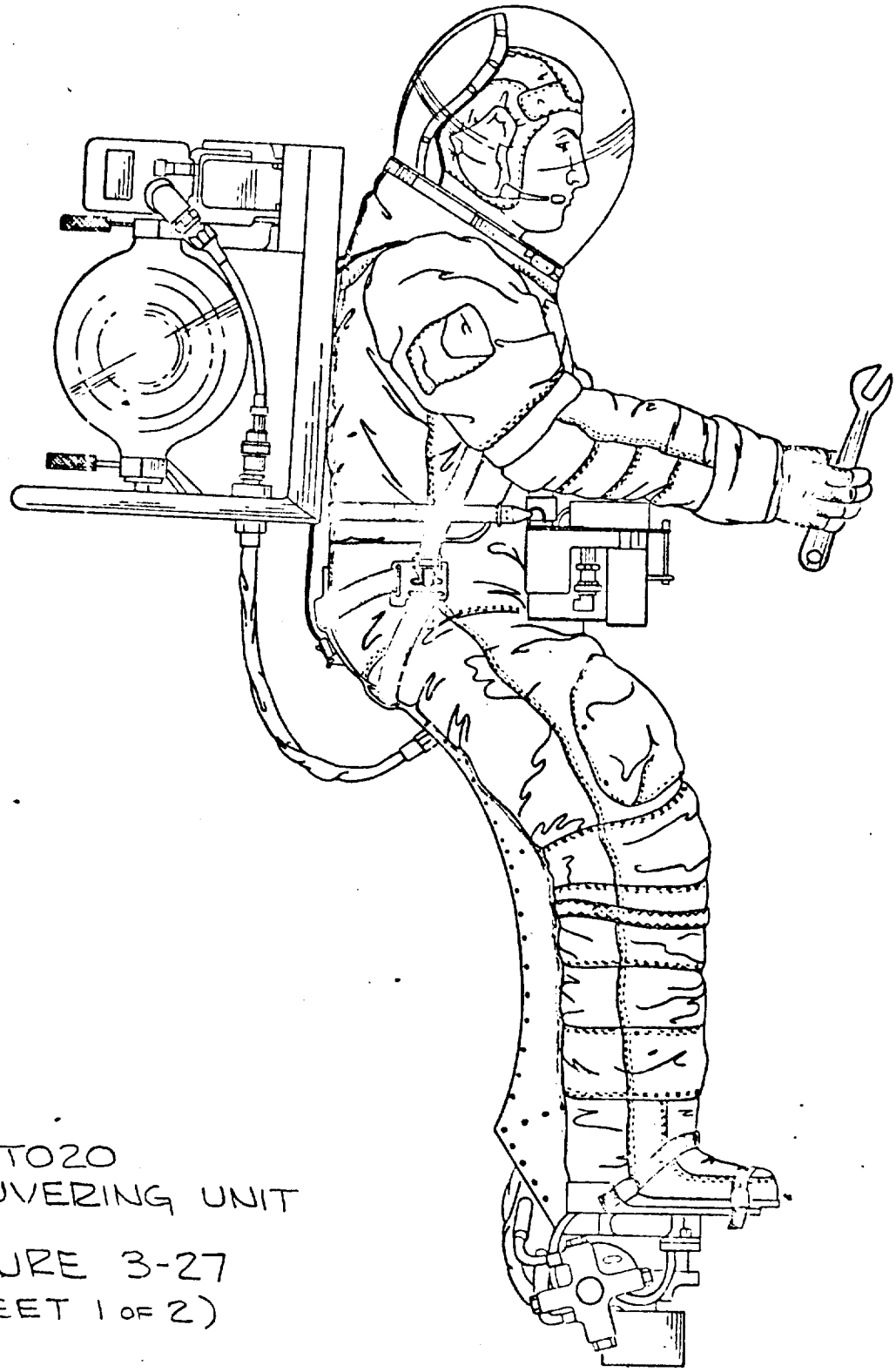
b. the foot restraint to boot interface required.

These areas are easily resolved by providing the suit with hard point attachments and a boot design which easily adapts to all foot restraints to be used. Therefore, the EVA suit should easily interface with any of the above maneuvering units.

3.10.7.3.3 Manipulators. As part of the normal mission tasks, or during unscheduled or contingency conditions, the suited EV crewman will be required to support manipulators or teleoperators by connecting umbilicals, securing payloads outside the spacecraft, adding a protective cover to a payload, restraining a payload in the shuttle cargo bay, securing latches, etc. These are basic EVA tasks and must be performed by the Shuttle EVA Pressure Suit.

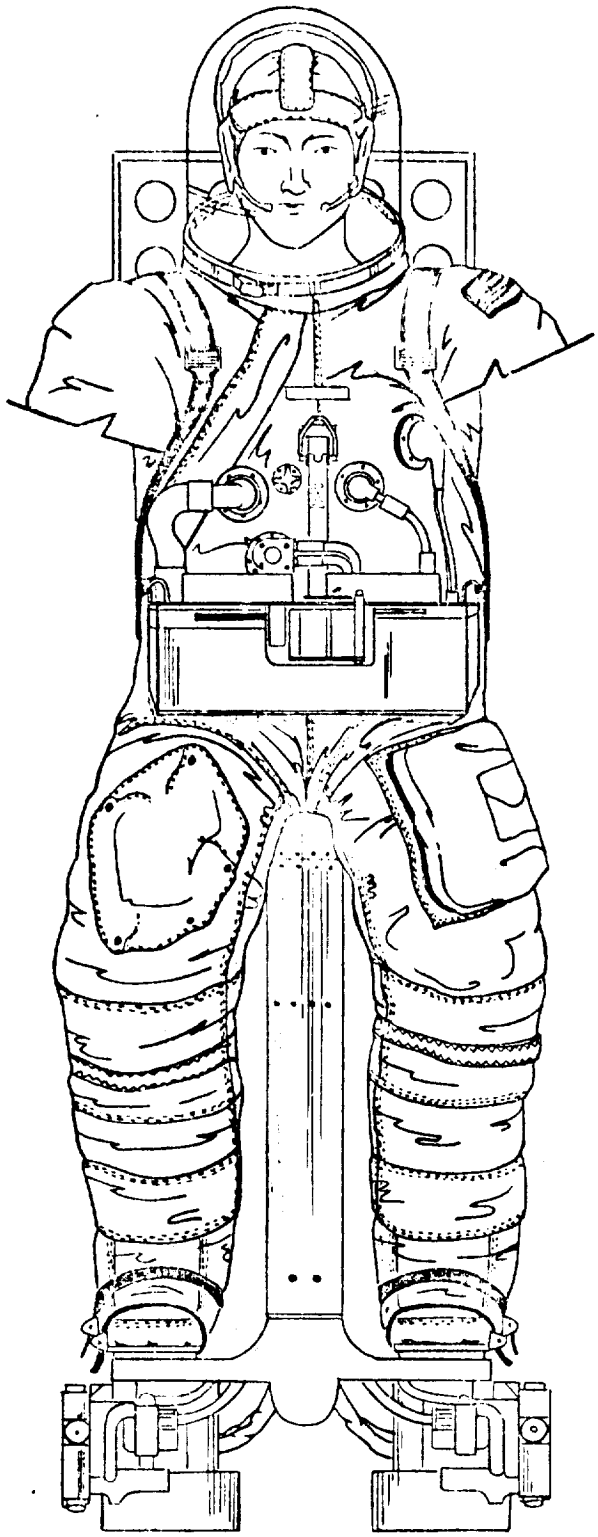
3.10.7.4 Tool Containment. The use of pockets and pouches on both EV and IV suits has been found to have great value on the Apollo program for the containment of tools. In addition, the

*NASA technical note D-6774, April 1972 Results of Intravehicular Manned Cargo-Transfer Studies in simulated weightlessness.



SKYLAB T020
MANEUVERING UNIT

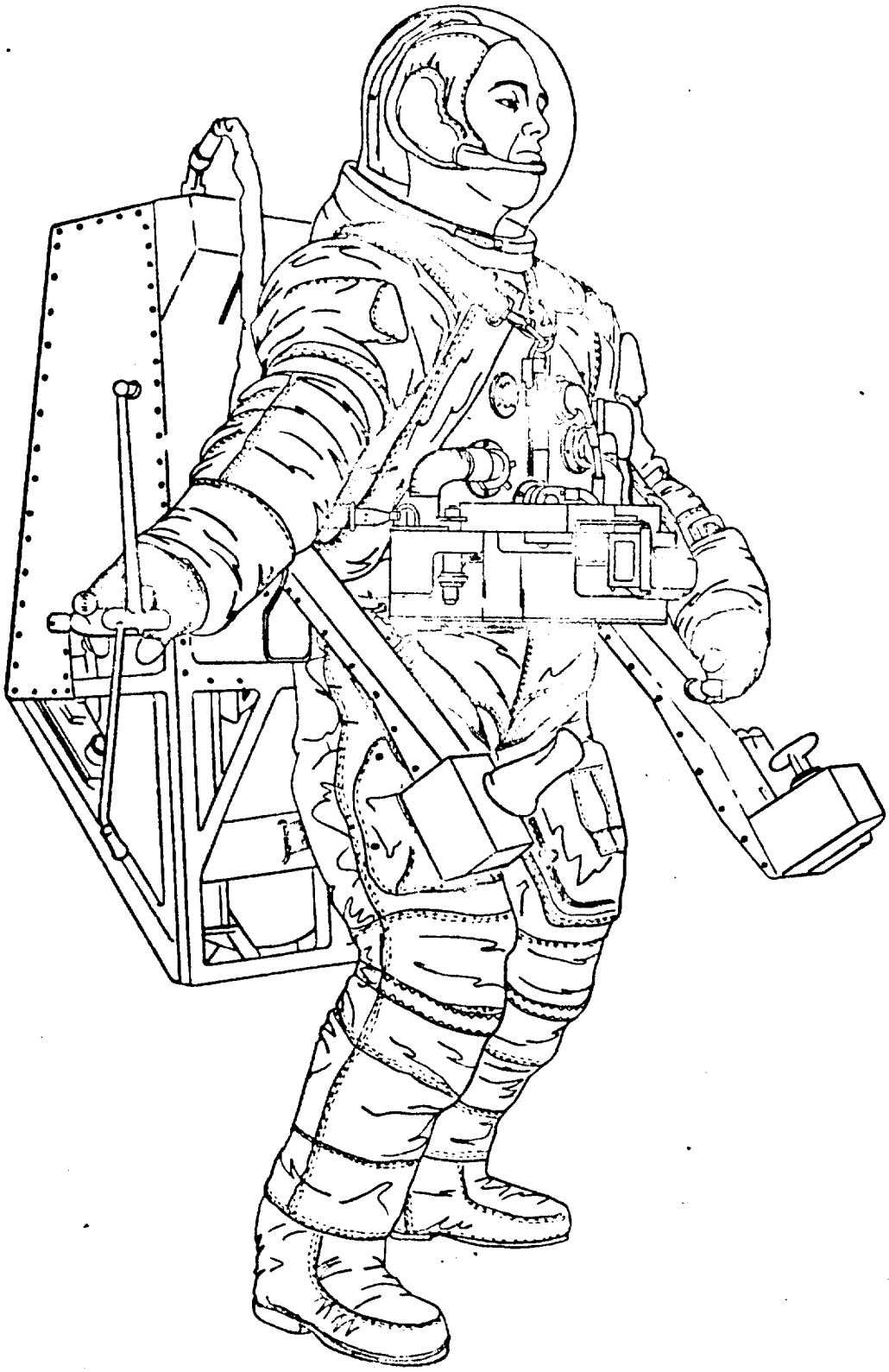
FIGURE 3-27
(SHEET 1 OF 2)



SKYLAB TO20 MANEUVERING UNIT

FIGURE 3-27

(SHEET 2 OF 2)



SKYLAB M509 MANEUVERING UNIT

FIGURE 3-28

same pocket configurations will be used on the Skylab program. As a result, it is recommended that pockets on the suit continue to be utilized for the carrying of items such as scissors, pens, pencils, flashlights, emergency procedures, etc. Past Apollo experiences should be used, however, to insure the pockets are accessible, easily opened and closed, and include stiffeners (where required) to allow easy access during insertion or removal of items.

3.10.8 TETHER SYSTEMS. Three tether modes have been considered for use in support of the Shuttle Program. These modes are:

a. Free space tether system.
b. Work space tether system.
c. Tether system for special equipment.

Space walks external to the spacecraft consisting of transfers and movements of the crewman from one work station to another require the use of safety tether systems between the space vehicle and the crewman. There is a variety of tether concepts to be considered. In addition, the use of tether hardware for free space excursions, work station activities and special equipment have also been considered. The compatibility of these three tether requirements with standard multi-purpose tether attachment hardware was investigated.

Some tether concepts considered are:

a. A tether line which attaches to a waist belt at the front, back or sides of the suit. The waist belt will distribute the load over the circumference of the suit. This system can be used for holding the man to handrails while doing a particular task if the foot restraints are not accessible of if they become damaged. It also may be used as the primary tether mode while the crewman is EVA.

b. Use of hardpoint attachments to the sides or front of suit for tether attachment.

c. The combination of items a. and b. above.

d. A wrist tether for EV transfer and to prevent films, tools or other hardware from being lost while performing maintenance, servicing or other EVA operations.

e. Tethers for the suit legs or boots if an EVA foot restraint is not available or it becomes damaged.

f. Utilization of a harness configuration (shoulder and crotch) to distribute loads over the suit torso.

g. Utilization of a waist tether for an IV crewman to secure him while operating the teleoperator system within the Shuttle Orbiter Cockpit. This can be accomplished by using side mounted suit hardware similar to the LM waist restraint brackets.

h. Usage of improved retractable type tethers for securing tools and preventing their loss in space.

The types of work required and the vehicle configuration surroundings at specific work stations somewhat dictate the type of tether system required. Foot, or waist tether systems or a combination of the two, have been considered. The type of tethering concept employed will depend upon the type of work required at a specific station.

Tether Systems for special equipment that is compatible with the spacecraft and the suit is a prime consideration for the shuttle program. Some equipment will be carried by the crewman to a work station, then tethered to specially configured attachments at the work station. This special equipment must not be loosely tethered and permit interference with the work station or cause possible injury to the crewman, or tethered equipment due to accidental impact. The best tether concepts were those most compatible with the man, suit, and tasks to be performed.

In considering the above, the following recommendations concerning the tether concepts are:

a. For emergency EVA tethering to the Shuttle vehicle, the waist belt tether is considered best. In addition, the use of hardpoint attachments on the suit is also required to provide the man with a means of attachment to the vehicle or an experiment. This will permit the man to perform the EVA tasks with a minimum of energy needed to maintain his position.

b. A wrist tether, either detachable or permanently fixed to the suit on either or both wrists, is desirable when retrieving items too large to be placed in a suit pocket on the leg, chest, etc. This will also reduce mobility interference. In most cases, the tether will be used as a secondary or backup system and prevent the carried package from becoming lost if the crewman loses his grip of the package during the transfer.

c. Tethers at the suit legs or boots are considered unacceptable due to the inability of the unassisted crewman to attach tethers to his legs or boots easily.

d. A harness configuration (shoulder and crotch) to distribute high loads over the suit torso is also considered unacceptable. This is because of the donning time required and the possibility of interference with oxygen, water and electrical umbilicals as well as tether and life support system attachment points.

e. A retractable type of tether for securing tools and preventing their loss in space is recommended. The present Apollo configured tethers should be improved to prevent overly quick retraction and provide better gripping characteristics to insure a more reliable system. Such a retractable tether type system could be attached to the suit or Life Support System and be used to provide easy access to small tools (screwdriver, pliers, etc.).

f. The utilization of a waist tether or suit hardpoint mounts for an IV Suit is considered unacceptable for the following reasons:

(1) A foot restraint such as velcro is required to prevent rotation. This will negate the necessity for waist tether during IV operations.

(2) Harness adjustment and donning time involved is lengthy.

(3) The donning of the tethering equipment would probably require the assistance of a second crewman.

It is therefore recommended that the tether system for IV not be considered since foot restraints and handrails can provide a quicker and a more positive means of restraint.

3.10.9 CONTROLS AND MONITORING PROVISIONS. The types of controls and monitoring provisions recommended for the space Shuttle pressure suits were investigated through examination of those utilized on the Apollo and Skylab programs. The recommendations for these are discussed in the following subparagraphs:

3.10.9.1 Pressure Relief Valve. A pressure relief valve should be installed on each of the Shuttle pressure suits to automatically prevent over-pressurization in the event of a failure in the spacecraft or EVA environmental control system or due to human error. A valve design similar to the poppet valve used on the Apollo program is not recommended due to its tendency to "stick" or shift in operating pressure range after long term non-use and storage.

Valves of the diaphragm actuated type are recommended for the Shuttle Program due to the reliability of this design in providing repeatable operating parameters after long term non-use.

3.10.9.2 Pressure Gage. A pressure gage with color codes to indicate safe operating zones and danger zones should be mounted on the pressure garment assembly for crewman monitoring of the suit pressure.

EVA - The EVA crewman should have the capability of monitoring his suit pressure during EVA when the suit and oxygen supply lines are prone to damage. In addition, the gage can also be utilized during the suit and EVA life support system combined leakage checkout, as well as providing a means of verifying the proper operation of the EVA Life Support System.

IV - Use of a pressure gage on the IV crewman or passenger suit should be considered primarily for the monitoring of suit leakage prior to performing a hatch opening or similar operation which could result in a cabin depressurization.

3.10.9.3 Ventilation Diverter Valve. A two-position ventilation gas diverter valve should be provided to allow crewman selection of ventilation gas flow to the helmet alone or the helmet and torso regions of the suit. The gas flow to the torso and helmet regions combined provide greater body area cooling than the full gas flow to the helmet which will provide for greater CO_2 washout in oral-nasal area.

3.10.9.4 Active Radiation Dosimeter. An active Dosimeter should be provided on the EV pressure suit for crewman monitoring of radiation exposure during the EVA activities.

A radiation dosimeter should also be provided for the IV crewmen such as the Mission Specialist or Payload Specialist who may be exposed to radiation during IV shirtsleeve operations within pressurized payloads. In addition a dosimeter pocket should be provided on the IV emregency crew suit to allow crewman monitoring of radiation exposure during a contingency EV transfer from a depressurized payload to the airlock.

There is no requirement to provide a suit mounted dosimeter for the passenger suit.

3.11 EMERGENCY PROVISIONS

It is considered necessary to provide emergency procedures, equipment and systems as backup protection for the crew and passengers in the event of a malfunction in any component, equipment and/or system provided for normal mission support operations. Seven categories of emergency conditions have been considered for analysis:

a. Fire
b. Toxic gas released into the environment
c. Explosion
d. Decompression of cabin due to a component and/or system malfunction, or a rupture caused by an impact with another object or structural failure of the cabin.
e. Inability to dock or undock.
f. Rescue of a disabled crewman.
g. In-flight rescue of crew and passengers.

Fire in a confined cabin is of great concern and requires protective measures over and above normal design considerations. Such items as fire resistant fabrics, portable breathing systems and fire extinguishing system methods are recommended. Fires are normally caused by failure combinations, however, every effort should be made to afford the crew and passengers maximum protection from the dangers of fire.

The selection of materials used in the construction of the vehicle and its associated components and assemblies is important in the prevention of releasing a toxic gas into the cabin environment. The gas or gasses released from the materials used resulting from fire or explosion could be toxic. The degree of toxicity and the volume and rate of toxic gas released under expected thermal and vacuum conditions should be evaluated. A limit as to the type and quantity of such characteristic materials should be specified and should receive special approval before they are used. Paragraph 3-9 discusses the suit materials recommended for the Space Shuttle Program.

An evaluation of protective devices should be made. This evaluation should consider such factors as location, function, and safety results after an explosion and the possibilities of igniting a secondary explosion. Explosive devices in or near a pressurized cabin should include designs necessary to prevent or preclude the release of shrapnel.

There are many factors which might induce a decompressive failure of the cabin. During docking maneuvers, the closing rate between vehicles could be suddenly increased to a rate that could result in a puncture of the cabin or injury to unrestrained personnel. Meteoroid impact is another potential hazard that could cause a puncture in the cabin wall. Seal leaks, stress cracks or seam separations caused by induced stresses could create significant leakage through the cabin structure.

The rate of leakage or decompression is of importance. It is assumed that explosive decompression would cause a catastrophic failure. However, a maximum safe decompression rate should be studied and protective measures provided that could afford significant safety to the crew and passengers.

It might be necessary to accommodate contingency docking and undocking. Although such problems might be remote, plans should be made for such failures. Should a spacecraft not be able to dock with another, a mission might unnecessarily be aborted. Inability to undock would prevent a successful re-entry and landing. Therefore, the undocking maneuver will also require some backup provision.

For reasons of health, accident or component failure, an EVA crewman might require assistance or rescue. These provisions have been somewhat provided for in that a minimum of two EVA spacesuits have been recommended for each Shuttle Mission. A backup oxygen supply system should also be provided as a part of the portable life support system.

Results of this study relative to emergency decompressive conditions have indicated that a short duration (20 minutes) portable oxygen supply system is recommended to provide unseated IV crewmen and passengers with sufficient oxygen to return to their respective couches and await instructions from the commander. In addition, the use of a breathing mask to support these suited personnel has also been investigated and is not recommended for the reasons stated in Table 3-14. The EV crewmen should be able to ingress through the airlock into the Shuttle cabin couches by using their EV life support systems (assuming a portable design). If the spacecraft cabin is unpressurized, and the leakage cannot be repaired by the crew, then a life support system will be required in the vehicle for the passengers and crew during earth re-entry, or while awaiting arrival of a rescue vehicle. The portable oxygen supply system may also be used to provide IV or EV emergency airlock transfer to a rescue vehicle.

The need to provide for an in-space rescue of the crew confined in a disabled spacecraft requires consideration. A spacecraft could be disabled with its cabin depressurized. Per the shuttle orbiter RFP, the vehicle is required to provide for a 96 hour in orbit contingency prior to rescue for the four (4) man crew.

During this 96 hour period, the crew will require such emergency provisions as:

a. food
b. water
c. waste management
d. supplementary protection from a low ambient pressure, and extreme temperatures
e. mobility
f. visibility
g. communications

BREATHING MASK INCORPORATED IN EMERGENCY IV SUIT	
ADVANTAGES	DISADVANTAGES
(1) Permit the usage of small quantity of O_2 to be supplied from emergency life support system.	(1) Configuration would be uncomfortable to the crewman.
(2) CO_2 washout is easily accomplished. Higher flow is required for CO_2 washout on present configuration.	(2) More complex design within the suit probably resulting in higher cost per pressure suit.
	(3) No voice communications would be available while breathing mask was donned unless communications was integrated into breathing mask requiring it to be donned during all mission phases. A second communications system could eliminate this.
	(4) Increased weight to pressure suit may exceed life support system and O_2 weight savings.

TABLE 3-14

A feed port on the all crew suits adjacent to the mouth similar to that employed in the Apollo and Skylab suit configuration could be used. A liquid waste transfer or containment system with transfer capabilities is also practical for Shuttle missions. Management of solid waste is a more complex problem. A waste management system could be used as recommended in paragraph 3.10.6 of this report. Pressure protection and thermal protection will be afforded by the pressure suits described in this report. Mobility, visability and communications systems have also been considered in the body of this report.

3.12 LOGISTICS

The logistics factors considered in this study include maintenance, parts provisioning and support personnel. It is recommended that a maintenance task analysis be conducted during the prototype phase of Shuttle suit development. This analysis should define those maintenance tasks required to keep the suit operational within specific performance limits. The specific tasks, frequencies of recurring tasks and personnel skills needed should be evaluated to determine facility, tool and personnel requirements.

The modular suit concept lends itself well to the maintenance concept recommended in paragraph 3.13. The logistics or parts provisioning requirements for this program will preclude the need of mass distribution of all parts to all suit facilities. Each site, based on the maintenance that it is authorized to perform, need only be provisioned with those parts required to support that maintenance. This method of operation will reduce the inventory of parts at operational and field sites. Only a depot facility will require complete provisioning of spare parts.

With some modification, the existing ground support equipment used to support the Apollo and Skylab programs could be used for Shuttle suits. Consideration should, however, be given to the pressure regulating and flow monitoring systems in the ground support equipment. The recommended pressure proposed for the Shuttle suit concepts should not have an adverse effect on tubing cross section and valve flow characteristics of the existing Apollo and Skylab GSE units.

It has been assumed that little change will be required in tool provisioning requirements from the needs of the Apollo and Skylab programs to the Shuttle program. However, until the suit designs for Shuttle have been finalized, detailed tool requirements cannot be provided.

Assuming a modular system, the maintenance tasks required of operational units will be limited to cleaning, testing, replacing seals and modules. The parts needed to support these tasks will be based on the quantity of suits in stock at a particular site. Specific parts provisioning should be determined after suit designs have been finalized.

Ground personnel requirements for Shuttle should be less than those needed to support the Apollo and Skylab programs. Because of design differences, personnel training will be required. The full scope of training needed will be dependent upon the changes in product design, test equipment and maintenance tasks. There are three categories of training anticipated. The first category prepares support personnel for design test operations. The second category relates to system qualification testing. The third category is that training needed to prepare personnel assigned to field and operational sites for testing, maintenance, and operation of the tools, equipment and suits assigned to those sites.

3.13 MAINTAINABILITY

It is essential that a maintainability program be established for the Shuttle suits that will accommodate mission requirements. Suit maintainability should be based on the following mission profile:

a. 7 day mission
b. A maximum of 7 EVA's per mission
c. An EVA or IVA duration ranging from 1 to 8 hours
d. 14 day ground turn-around time between missions

To establish an effective maintenance program having a minimum cost impact, the establishment of specific levels of maintenance is required. The suggested levels of maintenance considered include In-Flight, Organizational, Field, and Depot Maintenance.

3.13.1 IN-FLIGHT MAINTENANCE. This level of maintenance should be performed on the pressure suit during the mission to ensure confidence in suit performance. The maintenance required should be minimal, and limited to a general examination of the suits, lubrication of exposed seals, and the replacement of seals at component interface locations. Paragraph 3.10.4 discusses this subject in detail.

3.13.2 ORGANIZATIONAL MAINTENANCE. Maintenance at this level should encompass modular replacement of major components. This however, shall not be construed to mean replacement of components that are secured by adhesives, stitches, or welds. Examples of replaceable modules are those components which are attached with screws, clamps, zippers, and similar devices. Only standard hand tools and shop equipment will be necessary to accomplish the maintenance authorized at this level. Operational tests, cleaning and examination of the components are also suggested as tasks to be performed at this maintenance level.

3.13.3 FIELD MAINTENANCE. Maintenance at this level should encompass the disassembly, cleaning, inspection, and repair of non-structural components, and also includes the organizational level of maintenance. Special tools, equipment, and qualified personnel essential to the performance of this maintenance are prime considerations relative to cost and need.

3.13.4 DEPOT MAINTENANCE. Depot level maintenance can encompass field level maintenance and will also include maintenance of those components which are more structural in nature. Repair or replacement of the various pressure suit modules, thermal garments and other similar repairs are examples of depot level maintenance.

The tools, equipment, facilities, personnel, number of sites and level of training for personnel are prime considerations in the establishment of an effective maintenance program. It is suggested that a definitized plan be prepared that will direct the most economical maintenance program. Design and qualification test data and in service malfunction and descrepancy report data should be accumulated for study. These data should be used to predict maintenance requirements as a part of the maintainability program.

3.14 USEFUL LIFE

Definition of life requirements has been a recurring problem on both the Apollo and Skylab programs. Typically, life requirements on pressure suits have been defined in terms of cycle life, operational life and useful life. Cycle life, referring to the requirement of the suit to withstand a predetermined number of mobility actuations without failure, has been used primarily to define qualification requirements. Tracking of cycles throughout the life of the suit is impractical since it would require constant surveillance of suit use. Defining life in terms of "hours of use" has also proven to be impractical since the type of activity and the end affect on the suit can vary significantly between uses. As an example; 4 hours of prebreathing use prior to an Apollo Altitude Chamber Test is mild and is given the same weight as 4 hours of flight simulation, which is severe. Situations have occurred where suits used primarily for light testing have exceeded their useful life hours but are still in excellent condition.

Experience has shown that the most practical means of tracking suit life is by defining the "useful-life" of the suit. This is defined as that period of time commencing with pre-delivery acceptance and terminating upon completion of its operational life or until eight years have expired. Useful life thus consists of any combination of shelf life, or storage (unused time), and operational life, or mission utilization, for an eight year period. Operational life is further defined to consist of a pre-determined number of actual missions. For the IV suit, this has been determined to be 24 six day missions.* For the EV suit, operational life will be defined as 16 six day missions* for the planned EVA tasks. Therefore:

Useful Life = 8 years = Shelf Life + Operational Life

Useful Life = 8 years = Shelf Life + 24 six day missions (IV)

*"Minutes of crew complement meeting of 24 October 1972."

Useful Life = 8 years = Shelf Life + 16 six day planned EV missions (EV) (65% of total missions)

An eight (8) year useful life is presently recommended for synthetic rubber in MSFC STD 105 "Standards, Synthetic Rubber, Age Control Of." The period of eight (8) years has been chosen as the useful life based on the material and flammability recommendations discussed in paragraph 3.9 of this study and the useful life recommendation of MSFC STD 105.

By utilizing the recommended flammability requirements, newer materials with a significantly longer life can be used. As discussed in paragraph 3.9.2, the use of heat sealable urethane coated fabrics in lieu of the neoprene/natural rubber latex convolutes and boot bladder presently used on the Apollo program will also permit a significantly longer useful life for the suits.

3.14.1 The operational life of the EVA pressure suit was investigated by utilizing the seven (7) representative task scenarios which were prepared by Vought Missiles and Space Company. Since no mockups, preliminary flight plans, or other props were available to aid the calculation, experience and information obtained from the Apollo and Skylab programs were used. Also, numerous NASA films of the Apollo CM and Skylab (WIF Tests) EVA's were reviewed to determine the types of movements man can perform in a zero (0) "g" environment.

Several assumptions were made in order to achieve a level of confidence concerning the cycle calculations. These assumptions were:

a. When a manipulator is not used to transport the astronaut to a work area, Skylab type foot

restraints (Positive Heel Restraint) will be provided as a work station restraint system.

b. The crewman will be tethered at the waist at all work stations. This will stabilize the crewman's position requiring little or no effort to remain in the work station.

c. Rails or ladder assemblies will be used to transport cargo when the manipulator is inaccessible (NASA Langley concept).

d. The crewman will travel about 18" at a time using a hand over hand or foot propulsion method.

e. The crewman will only be required to replace modules which are the plug-in, or quick disconnect type. All modules were considered to have four (4) structural connections and one (1) electrical connection.

f. All EVA's will be performed using only one astronaut. The cycle data presented does not consider a second man managing a tether.

g. All cycle numbers are considered as design limit cycles. This means that the cycle considers use of the joint beyond the nominal angle position. (Nominal cycle equals 50% of the design angle shown in the mobility views of paragraph 3.7.1).

h. The total number of cycles includes both sides of bi-dimensional joints or joints that operate in more than one plane (i.e., five (5) elbows can be equal to five (5) cycles in either elbow or one shoulder could be one lateral-medial or one abduction-adduction or one extension-flexion).

i. The shuttle EVA's will require a greater amount of dexterity than the Skylab EVA's.

j. None of the cycle data identified in Table 3-16 include a safety factor. (Apollo and Skylab safety factor was two (2) times the actual).

k. Waist or thigh joint cycles are only possible when the astronaut is secured in some manner, i.e., the Skylab foot restraint. While the astronaut is free floating from an umbilical or using handholds it is difficult to move at the waist or thigh.

l. The ankles and boots are cycled each time the astronaut enters or leaves a positive foot restraint.

m. Knee cycles during translation or other unrestrained activities are calculated on the basis that the astronaut performs a "swimming" motion while he is trying to orientate himself or maneuver into a predetermined work station.

n. All calculations were based on the seven (7) representative task scenarios transmitted to ILC by VMSC.

o. Airlock maneuvers have been included in these calculations.

p. Training cycling for the flight suit has not been considered. As discussed in paragraph 4.2 of this report the use of a modular EVA suit is recommended. Therefore only one flight suit and training suit will be required for each crewman. The training cycling on the flight suit has been considered negligible since its primary function is to support the flights and will only be exposed to a short period of training to insure proper functioning prior to flight.

The seven (7) task scenarios considered are listed in Table 3-15 with their term of usage.

A description of the tasks performed in each of these scenarios is provided in Section II and Appendix "A" of this report.

Table 3-16 describes the number of cycles to which each joint of the EVA Crewman is exposed when he performs each scenario once.

Further information illustrating a detailed breakdown of the cycles required to perform each of the separate tasks for each of the seven EVA scenarios is presented in Appendix "C". Table 3-16 summarizes the information contained in this appendix.

SCENARIO NO.	TASK DESCRIPTION	USAGE IN 12 YEARS	AVERAGE USAGE IN 12 YEARS PER SUIT	AVERAGE USAGE IN 1 YEAR PER SUIT
1	Large Space Telescope	30	1.83	.153
2	Austere Earth observation sortie	72	4.39	.366
3	De-orbit Readiness of Tug and Satellite	530	32.28	2.688
4	Inspection and Repair of Orbiter Exterior	30	1.83	.153
5	Plasma Wake Experiment	25	1.52	.127
6	X-Ray Astronomy	26	1.58	.132
7	Free Flying Operations	75	4.57	.381
	TOTAL IN 12 YEARS	788	48	4

SEVEN TASK SCENARIOS
Table 3-15

SCENARIO	JOINTS									
	N *	S	E	G	WR	T	W	K	A	B
1. LARGE SPACE TELESCOPE	427	1,967	1,351	1,371	1,297	463	285	1,064	1,056	1,334
2. EARTH OBSERVATION SORTIE	71	484	424	480	376	0	2	156	30	24
3. DE-ORBIT READINESS OF SATELLITE & TUG	17	132	124	196	138	0	0	16	4	4
4. INSPECTION/REPAIR OF ORBITER	26	230	206	254	231	0	0	76	12	12
5. PLASMA WAKE EXPERIMENT	108	6,652	6,628	3,330	6,712	50	0	150	116	48
6. X-RAY ASTRONOMY OBSERVATORY	112	332	328	352	282	18	18	546	504	504
7. ASTRONOMY EXPLORER SATELLITE	21	125	124	211	153	0	14	14	2	2

MOVEMENT CODE LETTERS

N - NECK
S - SHOULDER
E - ELBOW
G - GLOVE
WR - WRIST
T - THIGH (Hip)
W - WAIST
K - KNEE
A - ANKLE
B - BOOT

* NOTE: No Neck joint is recommended. Reference Figure 3-9 for details.

SUIT JOINT CYCLES TO PERFORM EACH SCENARIO ONCE

TABLE 3-16

Since the distribution of the seven task scenarios over the twelve year period is unknown at this time, two methods were utilized to determine the total number of cycles one EVA suit would be exposed to during its useful life:

a. Determine suit cycles assuming it is exposed to an even distribution or average of all the scenarios in the suit's useful life.

b. Determine the worst case suit cycles assuming the suit was exposed to the two most difficult scenarios during each year of its useful life.

The number of scenarios which would occur in one year was determined as follows:

a. The total number of scenarios in twelve years was first divided by the total number of flights in that twelve years. This result then represents the number of scenarios performed per flight.

   Therefore $\frac{788 \text{ scenarios}}{597 \text{ flights}} = \frac{1.3 \text{ scenarios}}{\text{flight}}$

b. Utilizing the "minutes of the crew complement meeting of 24 October 1972", the pilot or commander can fly a maximum of three (3) flights per year. Of these flights, 65% are planned EVA's and 100% could include unscheduled or contingency EVA's. Therefore, multiplying the total number of scenarios performed per flight by the maximum number of planned, unscheduled and contingency EVA's one crewman can perform in a year, will result in the total scenarios one suit will be exposed to in one year.

   Therefore $1.3 \frac{\text{scenarios}}{\text{flight}} \times 3 \frac{\text{flights}}{\text{year-suit}} = 3.9 \text{ or } 4 \frac{\text{scenario}}{\text{year-suit}}$

c. From this it can be seen that one suit will be exposed to 48 scenarios in twelve years.

Utilizing the above, the first method was developed to determine the number of cycles exposed to one EV Shuttle suit if it experienced an even distribution or average of all the scenarios. This was accomplished by taking the total number of scenarios supported by

one suit in twelve years and dividing it by the total number of scenarios to be performed in twelve years. Therefore:

$$\frac{\frac{48 \text{ scenarios}}{12 \text{ years}}}{\frac{788 \text{ scenarios}}{12 \text{ years}}} = .061$$

As a result 6.1% of each of the seven task scenarios is performed by one suit in twelve years. The preceding Table 3-15 illustrated the scenario usage which one EVA suit would experience in one year and in twelve years if the suit was exposed to an even distribution or average of all the scenarios during its useful life.

The one year usage was then multiplied by each of the joint cycles illustrated in Table 3-16 to determine the total joint cycles exposed to one EVA suit in one year and in eight years. Table 3-17 illustrated the results of these calculations. (i.e. neck joint in scenario #1 for one (1) year equals (427) (.153) or 65 cycles).

As illustrated by Table 3-17, the total cycles accumulated on one EVA suit in eight years was extremely low. As a result, the second method previously described was used to determine the maximum or worst case number of cycles exposed to one suit. This was accomplished by assuming the four scenarios that one EVA suit will support in a year will be equally divided for the two worst case scenarios (No. 1 and No. 5). Using the joint cycles illustrated in Table 3-16, each of these were multiplied by two (2) for the first and fifth scenarios and the cycles summarized for a period of one and eight years. The results are illustrated in

SCENARIO NUMBER	N	S	E	G	WR	T	W	K	A	B
1	65	301	207	210	198	71	44	163	162	204
2	26	177	155	176	138	0	1	57	11	9
3	46	355	333	527	371	0	0	43	11	11
4	4	35	32	39	35	0	0	12	2	2
5	14	845	842	423	852	6	0	19	15	6
6	15	44	43	46	37	2	2	72	67	67
7	8	48	47	80	58	0	5	5	1	1
TOTAL CYCLES IN 1 YEAR (For all 7 Scenarios)	178	1,805	1,659	1,501	1,689	79	52	371	269	300
TOTAL CYCLES IN 8 YEARS (For all 7 Scenarios)	1,424	14,440	13,272	12,008	13,512	632	416	2,968	2,152	2,400

TOTAL CYCLES FOR EACH JOINT FOR A ONE AND
EIGHT YEAR PERIOD USING AN EVEN DISTRIBUTION OF SCENARIOS

TABLE 3-17

Table 3-18.

From this last table it can be seen that the shoulder, elbow, and wrist joints, and gloves or upper torso will experience the greatest amount of cycling and the remaining joints will experience a considerably lesser amount. Also the information contained in this table reveals that during worst case conditions the EVA pressure suit will have a cycle life in the upper torso, arms, and gloves of approximately 100,000 cycles in 8 years. This cycle quantity has been noted since it has been selected by NASA as the design goal for the 8.0 psi EVA orbital pressure suit.

In order to determine the EVA Suit design cycle goals, Tables 3-17 and 3-18 were examined to determine which requirements were most credible. It was concluded that neither table represented the realistic requirements. This is the case since the worst case Number 5 includes several unscheduled EVA's which will not be performed every time the suit is exposed to this scenario. As a result, the average of the cycles using the eight (8) year totals from both of these tables for each joint was calculated with the results shown on the following page.

SCENARIO NO.	N	S	E	G	WR	T	W	K	A	B
1	854	3,934	2,702	2,742	2,594	926	570	2,128	2,112	2,668
5	216	13,304	13,256	6,660	13,424	100	0	300	232	96
TOTAL CYCLES IN 1 YEAR-WORSE CASE	1,070	17,238	15,958	9,402	16,018	1,026	570	2,428	2,344	2,764
TOTAL CYCLES IN 8 YEARS-WORSE CASE	8,560	137,904	127,664	75,216	128,144	8,208	4,560	19,424	18,752	22,112

TOTAL CYCLES FOR EACH JOINT FOR A ONE AND EIGHT YEAR PERIOD USING WORSE CASE CONDITION

TABLE 3-18

Joint	8 Year Average Cycles	Design Goal - 8 year Safety Factor (2X)*
Shoulder	76,172	152,344
Elbow	70,468	140,936
Gloves	43,612	87,224
Wrist	70,828	141,656
Thigh	4,420	8,840
Waist	2,488	4,976
Knee	11,196	22,392
Ankle	10,452	20,904
Boot	12,256	24,512

Applying a safety factor of two (2) to all the above cycling numbers is recommended for use in the EVA suit development as design goals. This safety factor will account for the non-availability of detailed EVA task definition as discussed in the beginning of paragraph 3.14.1 and the small amount of ground cycling not accounted for in these calculations.

It can be seen that by the use of a modular pressure suit design which will be discussed in Section IV of this study, that those joints which exceed their cycle life could be removed and replaced without affecting the lower torso or major portion of the upper suit torso. In this manner, smaller quantities of complete suit systems will be required to support the overall space shuttle program which should result in a major cost savings.

*Safety Factor is 2.0 for Apollo and Skylab Suit Cycle Programs.

3.14.2 The operational life of the IV emergency pressure suits was difficult to calculate since the number of operations the crewmen or passengers perform during an emergency return is unavailable at this time.

3.14.2.1 As a result, information which was available from the Apollo and Skylab programs for intravehicular pressurized cycling was utilized to estimate the number of cycles the crew suit would experience in one five (5) hour* contingency mission. These cycles are illustrated in Table 3-19.

The guideline was used that the Commander or Pilot can only support a maximum of three (3) prime crews in any given year (plus three (3) backup crews for a total support of six (6) flights per year)**. Therefore, the maximum number of prime flights supported in a period of eight (8) years by one crewman would be twenty-four (24) flights.

As a result, the quantity of cycles for one 5-hour IV contingency return was multiplied by twenty-four flights to acquire the total IV emergency Pilot or Commander suit cycle life requirements in eight years. This is considered to be an extremely conservative approach since these suits are not expected to experience a contingency mission on every flight. However, this approach illustrates that designing to these cycles also can account for a possible 96 hour contingency in orbit requirement.

3.14.2.2 When considering the operational life of the emergency passenger suit, it was assumed that the passenger will have no flight tasks as discussed in Section II and that he will only

*"Statement of Work for Emergency IV Suit Assembly, (8.0 psi feasibility prototype)"
**"Minutes of shuttle crew complement meeting on 10/24/72."

5 HR. IV CONTINGENCY RETURN*		
Joints	Cycles*	Total Cycles In 24 Missions
Elbow (E)	370	8880
Wrist (WR)	210	5040
Glove (G)	410	9840
Shoulder (S)	200	4800
Knee (K)	36	864
Ankle (A)	16	384
Thigh (T)	16	384

*Derived from ILC Document No. 8821700902, "Test Plan for Qualification Design Limit Cycling of ILC Compounded Rubber Dipped Components for Apollo 16" - 74 hour contingency. Includes safety factor.

TABLE 3-19

CYCLE REQUIREMENTS FOR IV EMERGENCY PILOT/COMMANDER SUIT

be concerned with survival. Therefore, the total pressurized cycles imposed on these suits will be minimal. As a result, it was concluded that cycle life for the joints in the IV emergency passenger suit will not be a constraint in the life of this suit. Table 3-20 illustrates the total estimated cycles for a typical passenger suit to transfer from within the orbiter vehicle and ingress the passenger couch. In addition, the estimated cycles for the passenger to egress the passenger couch and perform a contingency EVA to a rescue vehicle is also included. The cycles for these passenger survival tasks were estimated assuming the passenger receives assistance from the IV pilot or commander or an EVA suited crewman. Information from NASA/MSC indicates the passengers will fly a maximum of one (1) flight per year, therefore the total cycles illustrated have been multiplied by eight (8) to represent the most conservative eight (8) year cycle requirement assuming a contingency occurs on each flight.

JOINTS	TASKS/CYCLES: TRANSFER FROM WITHIN THE ORBITER AND INGRESS COUCH		TRANSFER FROM COUCH THROUGH AIRLOCK AND PERFORM EVA TO RESCUE VEHICLE		TOTAL 8 YEARS
	1 YEAR	8 YEARS	1 YEAR	8 YEARS	
SHOULDER (S)	13	104	58	464	568
ELBOW (E)	13	104	76	608	712
GLOVE (G)	18	144	22	176	320
KNEE (K)	4	32	18	144	176
THIGH (T)	2	16	2	16	32

CYCLE REQUIREMENTS FOR IV EMERGENCY PASSENGER SUIT

TABLE 3-20

3.15 RELIABILITY

The reliability goals established to date for Shuttle Pressure Suits include an 8 year component life for soft goods, a high (greater than 100,000) EVA suit cycle life for suit joints, and design features that permit the crew and passengers to perform their assigned tasks during scheduled, unscheduled and contingency modes of operation. The useful life goals and mobility requirements are provided in Paragraphs 3.14 and 3.7.1 of this study. An additional constraint is that operating suit pressure has been increased from 4.0 PSID to 8.0 PSID. Efforts should be made to minimize the magnitude of the qualification program needed to acquire the needed reliability figures essential to the shuttle program. These suit design requirements will require a concentrated effort by Reliability early in the design to incorporate extended durability and ease of maintenance. A mathematical model, initially required for Apollo, should not be prepared; to reduce costs, emphasis should be placed on thorough in-line failure mode analysis of each subsystem and component as the design progresses. Realistic safety factors such as a safety factor of 2 for all suit cycling requirements, should be employed in each design, and extensive component testing should be used to verify the designs. Wherever possible, standard parts should be used and Apollo and Skylab components which have a history of high reliability should be modified as required to meet the new shuttle requirements.

The best design features of the A7LB, ISSA and AES suits are recommended for use in the Shuttle Pressure Suits. Based on the experiences of the Apollo and Skylab programs, suit designs such as pressure sealing zippers, sliding cables and integrated dipped convolutes have high failure rates and/or are not readily adaptable to shuttle suit design requirements. The most reliable pressure suit concepts, i.e., couplings, bearings and specially constructed convolutes as featured in the ISSA and AES suits are recommended.

To acquire low torque mobility with a reliable cycle life, combinations of bearings are recommended to replace the sliding cable concepts for the EVA suits. This design, although somewhat bulky and heavy, provides excellent mobility and superior cycle life.

A hard disconnect for suit entrance or closure is also recommended for all Shuttle suits as opposed to zipper or roll seal entrance systems for the reasons discussed in Table 3-21.

The natural rubber used in the Apollo and Skylab suits limit the component life to 3 years as opposed to the recommended 8 years for the shuttle program. Other materials are recommended for consideration and selective use in the shuttle suit that will meet the useful life recommendations of Section 3.14.

Table 3-22 displays the quantities of malfunctions experienced in The Apollo and Skylab Suits. The malfunction reports of the Apollo and Skylab suits were reviewed with the requirements of shuttle in mind. Reports against certain items were discarded as inappropriate, i.e., LEVA, Purge Valve, etc. The remainder were categorized according to the type of failure as related to the particular suits affected. Malfunction Reports requiring no corrective action, and those resulting from off-design testing were excluded from this analysis. Table 3-22 shows the quantity of valid malfunctions experienced for each PGA series and the total number of failures in each component category.

Where relevent, each suit assembly category is further subdivided to show significant localized malfunction activity. The approximate time frames for each PGA series are:

CONFIGURATION	USAGE	NO. OF SUITS
A5L/A6L	1966 - 1968	38
A7L	1968 - 1971	96
A7LB (EV and CMP) Apollo/Skylab	1970 - 1972	82

HARD WAIST DISCONNECT ENTRY	
ADVANTAGE	**DISADVANTAGE**
A. Easy to don.	A. Heavier in weight.
B. Low leakage.	B. Bulky and uncomfortable when unpressurized or in the seated position.
C. Reliable seal at all pressures discussed within this report.	C. Costly.
D. More adaptable to changes.	D. Increases stowage volume.
E. Sizing capabilities.	
F. Easy maintenance and replacement.	
G. High cycle life.	

ZIPPER ENTRY	
ADVANTAGE	**DISADVANTAGE**
A. Light weight.	A. Leakage is much higher than hard ring entry.
B. Comfortable when in seated position due to flexibility and no protrusions.	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	
ADVANTAGE	**DISADVANTAGE**
A. Soft, comfortable interface with crewman.	A. Difficult to don without assistance.
B. Inexpensive.	B. Higher leakage than hard waist disconnect.
C. Very adaptable to sizing changes.	C. Less reliable than hard waist disconnect.
	D. Lower cycle life than hard waist entry.

SUIT ENTRY COMPARISONS

TABLE 3-21

Suit Component	Total	A5L/A6L	A7L	A7LB/S/L
Cables				
Crotch	19	17	1	1
Glove	4	1	1	2
Knee Convolute	7	3	1	3
Shoulder	10	10	0	0
Boot	2	2	0	0
Convolutes				
Shoulder	4	1	2	1
Knee	4	2	2	0
Thigh	2	1	1	0
Pressure Sealing Zipper Closure	24	13	2	9
Restraint Zipper	10	7	1	2
Vent System				
Torso	5	2	0	3
Boot	1	1	0	0
Boot				
Sole	17	9	8	0
Bladder	2	0	2	0
Restraint Fabric	4	3	0	1
Velcro Pad	1	1	0	0
Vent Attachment	1	1	0	0
Wrist Disconnect	14	10	4	0
Gas Connector	13	10	3	0
Pressure Relief Valve	30	13	6	11
Neck Disconnect	14	13	1	0
Helmet				
Shell	19	1	18	0
Ring Bonding	10	0	4	6
Feed Port	7	3	4	0
Vent Pad	3	2	1	0
Pressure Gauge	11	6	5	0
Glove				
Bladder	9	4	2	3
Gauntlets	2	2	0	0
Vent Attachment	6	6	0	0
Dust Seal	5	4	0	1
Capstan Adjustment	1	0	1	0
Slider Flap	5	N/A	N/A	5
Thermal-Meteoroid Layers*				
Abrasion Layer	5	3	1	1
Cover Layer	17	2	15	0
Hardware	5	1	4	0

*Includes Glove MR's.

APOLLO MALFUNCTION REPORT SUMMARY
Table 3-22

The most significant reliability factor shown is the reduction in frequency of malfunctions. This benefit should be carried over into the Shuttle Suit reliability.

3.16 SAFETY PROVISIONS

Personnel safety is a prime consideration in the performance of each Shuttle mission. It is recommended that a safety program be established to monitor program activities and establish procedures which will satisfy the following requirements:

a. Preclude injury to or loss of personnel, or damage to equipment or property as a result of unsafe procedures, designs and/or practices associated with the manufacture, transport, operation, maintenance, test and/or overhaul of that being proposed.

b. Review all designs, specifications and standards, and through analyses of these data ensure that the systems, industrial and flight or operational safety requirements specified by the requirements document submitted by the prospective customer are satisfied.

c. Itemize potential hazards into the following four categories and establish designs, procedures and/or equipments necessary to assure personnel safety, and preclude damage to equipment and property:

   (1) Safety catastrophic. Condition(s) such that environment, personnel error, design characteristic, procedural deficiency, or subsystem or component malfunction will cause death or injury to personnel.

   (2) Safety Critical. Condition(s) such that environment, personnel error, design characteristic, procedural deficiency, or subsystem or component malfunction will cause a hazard which required immediate corrective action to avoid loss of or injury to personnel.

   (3) Safety Marginal. Condition(s) such that environment, personnel error, design characteristic, procedural deficiency, or subsystem failure or component malfunction will degrade system performance but which can be counteracted or controlled without causing damage to equipment or injury to personnel.

(4) Safety Negligible. Condition(s) such that personnel error, design characteristic, procedural deficiency, or subsystem failure or component malfunction will not result in major systems degradation, and will not produce system functional damage to equipment or injury to personnel.

It is recommended that a hazard analysis be performed on the suit as a part of the suit design and definition effort. The anlysis should include but not be limited to the following failures or malfunctions:

a. Cabin pressurization
b. Propulsion Systems
c. Electrical power
d. Environmental Control System
e. Spacecraft fuselage structure
f. Portable Life Support System.
g. Forced landing sites
h. Suit pressure and structural integrity

This analysis should be done based on mission phases, mission task schedules and spacecraft modes of operation.

4.1 UTILIZATION OF CONTEMPORARY SUIT DESIGN FOR THE SHUTTLE PROGRAM

After completing an examination of the mission considerations discussed in Section II and the pressure suit requirements discussed in Section III, the contemporary pressure suit designs were then reviewed to determine their acceptability for use in the shuttle program.

The A7LB-EV and CMP PGA's were the first to be examined since they represent the present Apollo and Skylab qualified state-of-the-art pressure suits. Table 4-1 was prepared to illustrate the advantages and disadvantages of utilizing these pressure suits for the shuttle program. As illustrated by this table major constraints such as low operational life, inadequate and costly maintenance, custom sizing requiring large suit quantities, and non-operational joints at 8.0 psi (requiring pre-breathing at lower operating pressures) make the A7LB Pressure Garment Assembly inadequate for space shuttle program use.

It should be understood that the Apollo and Skylab suits are, in many respects, obsolescent. This is largely due to the inertia of flight hardware configurations requiring design changes to be formally documented and in most cases subjected to certification testing, and phased into use without impacting mission milestones. As a result, there is a general reluctance to make any but the most crucial design changes to a set configuration, and new and better technology and materials are not used.

Advanced prototype pressure suits such as the Litton and AiResearch AES and ILC Industries and Space Age Controls ISSA, were also reviewed for utilization on the shuttle program. In general, these existing advanced suits (AES and ISSA) are also not acceptable as is for Shuttle applications. However, each of these suits has some outstanding feature which can be beneficial to Shuttle use, but none meet the shuttle suit

A7LB PRESSURE SUITS	
ADVANTAGES	DISADVANTAGES
A. Qualified for Apollo and Skylab Missions.	A. Life of dip goods is not adequate due to use of natural rubber in compound. (3 years shelf life)
B. A relatively small stowage volume required.	B. Leakage is high due to inherent design features such as zipper entry.
C. It has established reliability at 4 PSIA with good vent pressure comfort.	C. Demonstrated cycle life of many A7LB components are considerably lower than the expected cycle life of greater than 100,000 cycles for the upper torso.
	D. Apollo and Skylab suits were designed for a "one mission" capability with custom-sizing and minimum maintenance required. Shuttle guidelines suggest modularity for ease of maintenance and sizing, as well as maximum sizing adjustability.
	E. It is desirable to eliminate a number of marginal designs such as zippers, cables, cable guides, swage fittings, and slider flap assemblies.
	F. Unit production cost, based on actuals for AES and A7LB are comparable and the AES design has greater potential for lower unit cost through tooling.
	G. A7LB vent system pressure drop is not as low as redesigned system can attain.
	H. Re-qualification would be required to Shuttle requirements.
	I. Infield sizing capability would be restricted to arms/legs. Maintenance would be costly due to the inherent design.
	J. Structural Integrity of the A7LB suit is inadequate at an 8.0 PSID operating pressure; seam construction, restraint material, boots, cables, helmet, hardware can not survive a proof pressure of 16 PSID or burst pressure of 20 PSID.
	K. Waist and shoulder joints are totally unacceptable at 8.0 PSID (almost totally immobile).
	L. The cycle life of joints which do function at 8.0 PSID will be greatly reduced from their present capability.
	M. As a result of the above, prebreathing is definitely required.
	N. At pressures of 4.0-8.0 PSI, the mobility, cycle life, reliability, and structural integrity will progressively deteriorate as the operating pressure is increased from 4.0-8.0 PSI. (Reference paragraph 3.1)

UTILIZATION OF A7LB SUITS
FOR THE SHUTTLE PROGRAM

TABLE 4-1

requirements 100 percent. Therefore, the approach to be taken in the development of the Shuttle Suits is to mold the best features of all available advanced suits into one, two, or perhaps three, hybrid suit designs which meet the detailed Shuttle requirements. In addition, these designs should be refined to eliminate any minor deficiencies uncovered during the evaluation phases of each of the suits. Strong emphasis should also be placed on:

a. weight reduction by use of lighter materials
b. commonality of components between EV and IV suits
c. maintainability
d. usage of suit sizing systems in lieu of custom sizing
e. elimination of marginal reliability components discussed in Table 4-1
f. longer useful life
g. improved glove mobility

In general, utilize all the available technology to its best advantage.

4.2 CONFIGURATIONS AND RECOMMENDATIONS

By summarizing the results of the suit requirements section of this report, several conclusions concerning the recommended pressure suit configurations and basic recommendations for Shuttle Pressure Suit design can be made. Those requirements which have a major influence on pressure suit design are:

a. an operating pressure of 8.0 psia

b. maximum allowable leakage rate of approximately 80 scc/min at 8 psia

c. a standard sizing system for EV and IV crew pressure suits

d. the utilization of new materials which are higher in strength and those which are non-flammable in a one atmosphere air environment

e. light weight

f. quick donning capability

g. simple and quick ground maintenance dictating the need for suit modularization

h. an 8 year useful life with slightly more than 100,000 actual cycles exposed to most EVA suit Upper Torso Joints (does not include safety factor of 2X)

i. high reliability

j. use of hard ring closures.

The three basic suit concepts discussed in paragraph 2.6 and throughout the requirements section of this report were examined to determine the final recommendations for Shuttle Pressure Suit support.

Utilizing the mobility requirements and considering the weight, cost, and comfort penalities involved, it was concluded that one pressure suit configuration can not satisfy the EVA/IVA and the IV Emergency Crew Suit needs.

This conclusion was based on the fundamental requirements of each suit as presented in Table 4-2. However, as advanced 8.0 psi pressure suit programs progress in the future, and the mobility and cycle life requirements for the EVA Pressure Suit are firmly defined, it is possible that one light weight suit with unpressurized comfort can be used for both EVA and the IV Emergency Crew Members. This has been partially demonstrated by ILC Industries' light weight elbow and knee. These joints were tested beyond 100,000 cycles at 8.0 psig as a part of the IV Emergency Prototype Suit Program. However, sufficient data is not available for other joints such as the shoulder, hip and waist, to conclude that this suit could meet the EV mobility and cycle requirements.

In addition, as discussed in section 4.3 and 4.4 the program quantities for the IV Emergency Crew Suits will be approximately twice that for the EVA Suits, with the unit cost at one half (1/2) that of the EVA Suits. This notable cost difference is due to the large amount of hardware at the shoulder, hip, and waist to provide the mobility required for the EVA tasks. Also items such as a hard hemispherical helmet for maximum EVA and IVA visibility increase the unit cost.

The IV Emergency Passenger Suit concept was also examined to determine the feasibility of a third pressure suit. It can be seen through examination of the pressure suit requirement section of this report that the IV Emergency Crew Suit can definitely be used for passenger protection as well. However, if unit cost and production time could be significantly reduced by producing a less functional, simpler model of the IV Emergency Crew Suit, it would be advisable to use such a suit in the program. Based on the cost estimates for the IV Emergency Passenger Suit discussed in paragraph 4.4, the unit

EVA/IVA PRESSURE SUIT

a. High mobility with low torque when pressurized.

b. Long term useful life and cycle life.

c. Low leakage rate.

d. Minimum contamination.

e. Many EVA equipment and payload interfaces (foot restraints, tether systems, maneuvering units).

f. Structural integrity (vehicle and payload impact).

g. Long term environmental protection.

h. Maximum visibility.

IV EMERGENCY PRESSURE SUIT

a. Quick donning.

b. Small stowage volume.

c. Light in weight.

d. High degree of mobility and comfort while suit is unpressurized.

e. Mobility to operate the spacecraft when pressurized and perform contingency IV repairs and assist passengers perform EV contingency transfer.

COMPARISON OF BASIC EVA AND IV
EMERGENCY SUIT REQUIREMENTS

TABLE 4-2

cost of this low mobility suit would be approximately $13,500. This would not have a significant impact on the Shuttle Suit Program cost, discussed in paragraph 4.3, where only 24 passenger suits were recommended. However, as future modular space station and Shuttle frequencies increase, a significant program cost savings could be realized. Therefore, it is recommended that production of a third, low mobility IV Emergency Crew Suit be used for passengers, beginning in approximately 1984.

Figures 4-1, 4-2, and 4-3, illustrate each of the three pressure suit designs recommended.

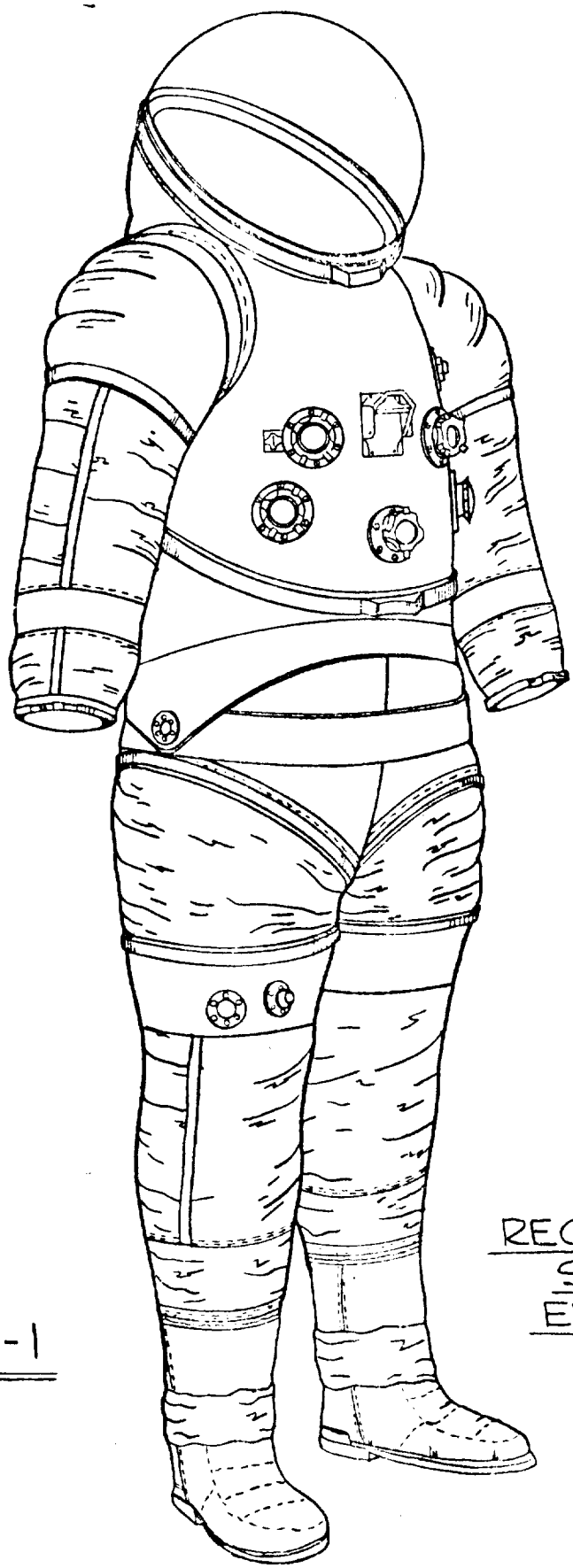
Throughout the requirements section of this report, suit modularization was recommended for the EVA and IV Emergency Crew Suits. This has been recommended due to the distinct advantages for the overall Shuttle program such as:

a. Maintenance turn around time would be greatly improved over the A7LB design, by allowing modules to be replaced in much less time and without risking damage to the suit.

b. The modules would be incrementally sized to accommodate the size range of crewmen, thereby allowing the procurement of a set of standard sized modules to provide a crewman with a pressure suit instead of procuring a complete custom sized suit, thus effecting a cost savings.

c. Spare modules would be stocked for replacement instead of requiring that a custom-sized component be provided on request, and a backup custom sized suit be used while awaiting delivery.

Figures 4-4 and 4-5 illustrate possible methods of modularizing the EVA and IV Emergency Crew Suit.



RECOMMENDED SHUTTLE EVA SUIT

FIGURE 4-1

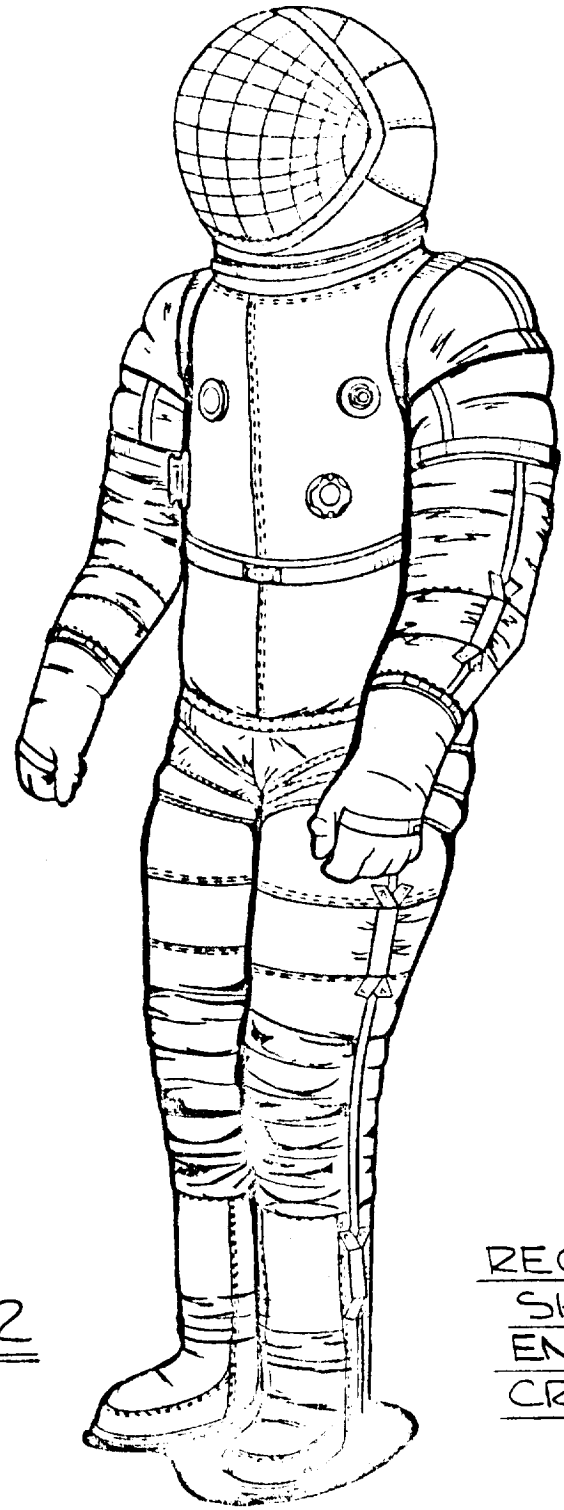


FIGURE 4-2

RECOMMENDED SHUTTLE IV EMERGENCY CREW SUIT

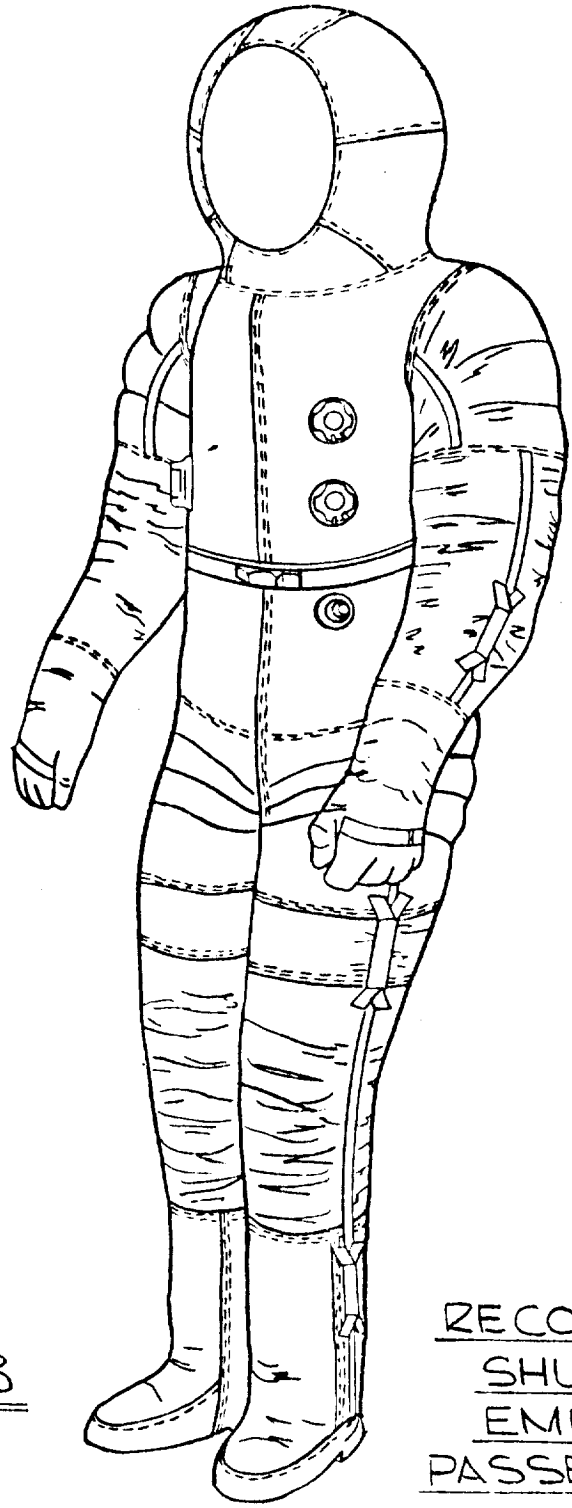


FIGURE 4-3

RECOMMENDED SHUTTLE IV EMERGENCY PASSENGER SUIT

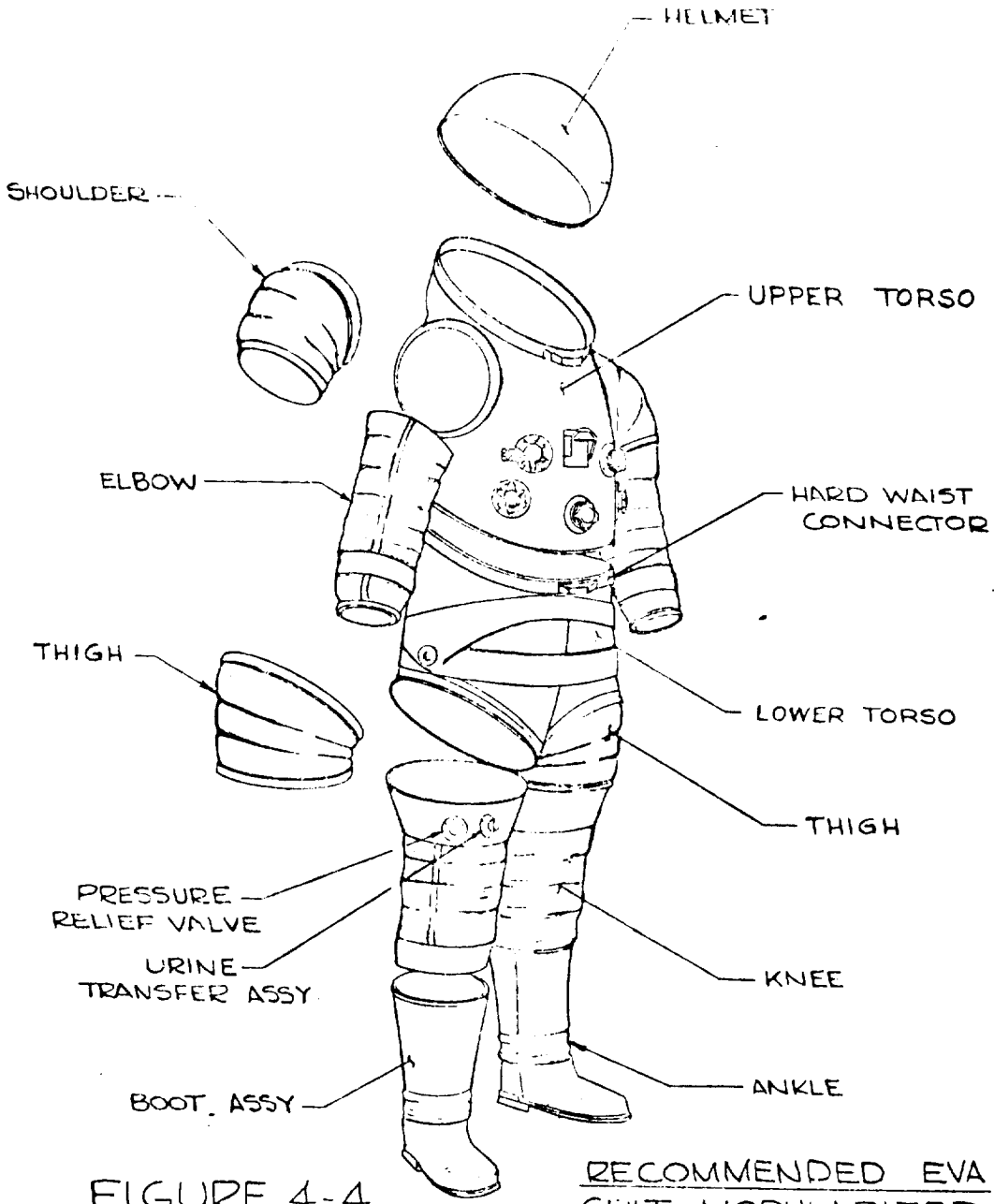


FIGURE 4-4

RECOMMENDED EVA SUIT MODULARIZED

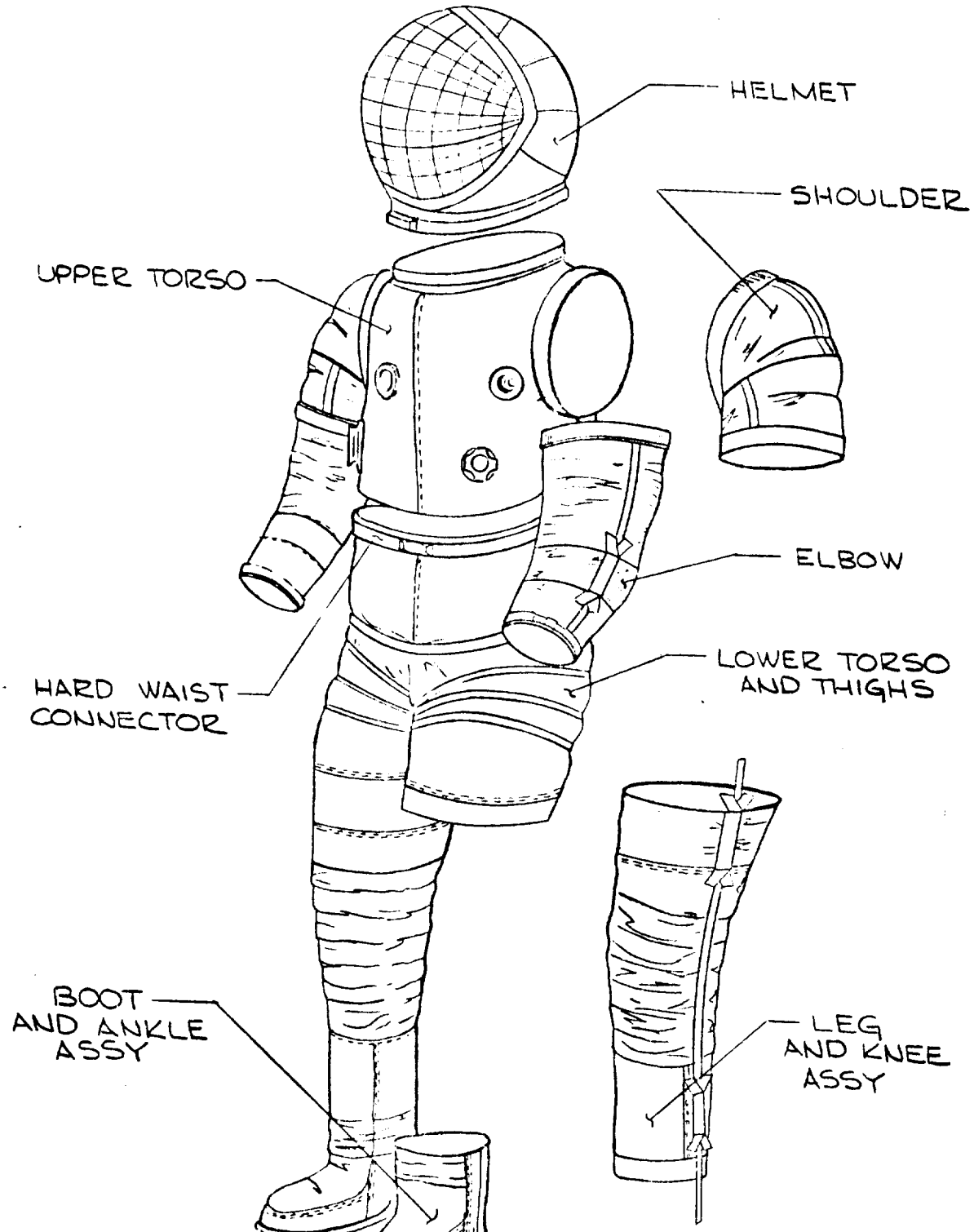


FIGURE 4-5

RECOMMENDED IV EMERGENCY CREW SUIT MODULARIZED

4.3 SCHEDULE CONSIDERATIONS

A study of the schedule considerations for the space shuttle pressure suits, involved a detailed investigation of each crew function and the establishment of a recommended approach for the pressure suit support of the shuttle program.

The quantities of torso limb suit assemblies (TLSA) and associated support components (gloves, helmets, SEVA, etc.) were established by utilizing the "NASA Traffic Model Build-Up Rate-Vehicle Launches" illustrated in Table 4-3 (rows 4, 5, and 6) and information as presented in the "Minutes of the Shuttle Crew Complement Meeting of 24 October 1972".

In general, the following guidelines were used to determine the pressure suit support quantities for the space shuttle program:

a. Frequency of Shuttle Flights - Starting in 1983, the "NASA Traffic Model Build-Up Rate-Vehicle launches," indicated a launch frequency of 60 flights a year. For the purpose of this study, this was interpolated as 5 per month.

b. Crew Training and Flight Frequency - The "Minutes of Shuttle Crew Complement Meeting of 24 October 1972" stipulates a breakdown of crew functions, training requirements, and frequency of flight for each function. Those selected for use in this study were as follows:

FUNCTION	TRAINING REQUIRED	FLT. FREQUENCY PER YEAR
Commander	*1 year first flt.	6 (prime and back-up)
Pilot	*1 year first flt.	6 (prime and back-up)
Mission Specialist	*1 year first flt.	3 (prime and back-up)
Payload Specialist	9 weeks	3 (prime and back-up)
Passengers	*1 week	1 (prime only)*

*Assumed - not specified

Each flight will have a prime and a back-up crew for Commander, Pilot, Mission and/or payload specialists.

c. Suits - Astronaut population distribution (tariff) across the sizing ranges (less boots and gloves) for a nine and twelve size suit system at 5 to 95 percentile have been developed based on WADC T/R #56-356, "A Height-Weight Sizing for Flight Clothing" as follows:

		Nine Size System			Twelve Size System		
	Size	No. of People per 1000	IV	EV	No. of People per 1000	IV	EV
Smallest	1	93	44	24	102	48	25
	2	264	123	65	102	48	25
	3	123	57	31	131	61	32
	4	69	32	17	131	61	32
	5	256	119	63	99	47	25
	6	92	43	23	99	46	25
	7	30	14	7	115	54	29
	8	54	25	13	115	54	29
	9	19	9	5	31	14	8
	10	1,000	466	248	31	14	8
	11				22	10	5
Largest	12				22	10	5
					1,000	466	248

d. Boots - Basic data inputs for standard boot sizing programs on pressure suits are not readily available. To facilitate a sizing approach, a search of Apollo actual boot size utilization for 75 subjects revealed the following: 11 subjects Size A, 22 subjects size B, 27 subjects size C, 9 subjects size D, and 6 subjects size E. The

following table converts this data for the recommended number of 714 pairs of boots required in this program.

	Size	No. per 75	No. per 714
Smallest	A	11	107
	B	22	207
	C	27	257
	D	9	86
Largest	E	6	57
		75	714

e. Gloves - Current program inputs indicate that a standard glove sizing system of 12 to 18 sizes may be developed to support all subjects within the required percentile ranges. This system has not been defined to an extent allowing incorporation in this study. However, its feasibility does permit the assumption that the gloves can be supplied on a one for one basis to the suits in the program. Therefore, this presentation includes glove pricing for 714 pairs of gloves.

f. Maintenance and Repair - Of the components removed and returned to Depot for maintenance and repair, it is estimated that 10% will not be repairable to a Class I level, and would be replaced in the inventory.

g. Useful Life - The suit useful life shall be eight years per paragraph 3.14 of this report.

h. Astronaut Attrition Rate - It is anticipated that there will be a minimum of a 100% astronaut attrition rate over the life of the program. However, any new subjects being introduced to the program should blend with the sizing range distribution previously established. Therefore, no impact is anticipated other than increased suit usage for familiarization.

i. Modularization of Suits - In order to realize the most return on the modular suit production concept, it is recommended that program logic be altered to reflect the following:

That each active astronaut be supplied with one (1) flight suit to be maintained as a Class I equivalent unit through its useful life. This is based on the presumption that the major training required would be handled in the training suit, and that flight suits would require minimal pre-flight usage.

That the Contractor manufacturing capability would be used to produce, maintain and PDA suits at the component level. That the suit assembly and fit checks would take place at Vandenberg AFB or KSC, or both, as determined by NASA.

The Torso limb assembly, TLSA, shall be subdivided and traced at the following module levels:

a. Upper Torso
b. Lower Torso
c. Arm Assembly (upper cone, elbow convolute, lower cone)
d. Leg Assembly (upper cone, knee convolute, lower cone)
e. Boots
f. Gloves
g. Helmet
h. Thermal Garment as associated with a. through g.

Spare Modules shall be supplied and the stock level maintained at an inverse percentage level.

(i.e.: One Module required on the size distribution chart - 100% spares, eight modules required 50% spares)

Through utilization of the previously listed guidelines, the requirements for the IV Emergency Pressure Suits and EVA/IVA pressure suits were established.

4.3.1 IV EMERGENCY PRESSURE SUIT REQUIREMENTS. The present NASA guidelines for the advanced IV Emergency Crew Pressure Suits do not include requirements for suit modularization. It is recommended that such a requirement be instituted. For purposes of costing the IV Emergency Pressure Suits, it has been assumed that suit modularization will be used, therefore eliminating the

need for a back-up pressure suit. The requirements for the various crewmen and passengers are discussed in the following subparagraphs with Tables 4-3 and 4-4 illustrating the program scheduling for each of these units over the eleven (11) year period extending from 1978 through the end of 1988.

4.3.1.1 Mission Commander and Mission Pilot. Starting in 1983, the traffic model build-up rate indicates a maximum rate of 5 flights per month, 60 flights per year. The crew flight support frequency is defined as 6 flights per year (one every 2 months), with support being defined as flight prime or flight back-up.

To support 60 flights a year, a total of 10 crews (each crew consisting of two (2) commanders and two (2) pilots will be required). The crews will be required to support the traffic model build-up rate as follows: (3) in 1977, (1) in 1978, (2) in 1980, (2) in 1981, and (2) in 1982 for a cumulative quantity of 10 crews.

The program presented consists of one (1) training suit (supplied due to extended first flight training), made available twelve (12) months prior to flight and one (1) flight suit made available six (6) months prior to flight for each of the 40 men required. The training suits are regarded as permanently available, and are not replaced due to service and/or useful life expiration. However, the flight suits are replaced at the expiration of eight (8) years from the time of delivery.

4.3.1.2 Mission Specialist (abbreviated MS). The flight support frequency of MS personnel is defined as three (3) flights a year, with support defined as either flight prime or flight back-up.

To support 60 flights (prime and back-up) a year, a total of 40 mission specialists will be needed. The crews (one (1) each, prime and back-up) will be required to support the traffic model build-up rate as follows: (6) in 1978, (2) in 1979, (4) in 1980, (4) in 1981, (4) in 1982, for a cumulative quantity of 20 crews.

The program presented consists of one (1) training suit (supplied due to extended first flight training) made available one (1) year prior to flight and one (1) flight suit made available six (6) months prior to flight for each of the 40 men required. The training suits are regarded as permanently available, and are not replaced due to service and/or useful life expiration. However, the flight suits are replaced at the expiration of eight (8) years from the time of delivery.

NASA telecon inputs have indicated that the first six (6) flights will be sub-orbital vehicle check-outs in nature, manned by a Commander and Pilot only. Therefore, the program presented assumes the first requirement for a mission specialist on the seventh (7) flight.

This study assumed one (1) MS per flight. However, by making use of the suits supplied for payload specialists, a flight can be structured to include more than one (1) Mission Specialist, without procuring additional suits.

4.3.1.3 Payload Specialist (abbreviated PS). The flight frequency support of a payload specialist has not been specified. For the purpose of this study, it has been assumed that a cadre of payload specialists will be developed capable of periodic flights, on a frequency equal to that of a mission specialist (see paragraph 2.2.1).

As suggested in the "Minutes of Shuttle Crew Complement Meeting of 24 October 1972", the complement of payload specialists on any one flight should be greater than one. This will allow "round-the-clock" operation. To this end, the program as presented includes one (1) PS through 1979, two (2) PS 1980 through 1982, and three (3) PS from 1983 and subsequent except as modified to allow "Modular Space Station Rotation Flights" starting in 1984.

To support 60 flights a year with a maximum of three (3) PS per flight, 20 crews of 6 men each will be required to support flight and flight back-up. It is felt that the mission training cycle of nine (9) weeks specified in the "Minutes of the Shuttle Crew Complement Meeting of 24 October 1972" warrants back-up to avoid mission abort. The men will be required to support the traffic model build-up rate as follows: (6) in 1978, (14) in 1979, (14) in 1980, (18) in 1981, (54) in 1982, and (14) in 1983.

The program as presented does not include a training suit for PS personnel due to the limited training time available. However, the flight suits are replaced at the expiration of eight (8) years from the time of delivery.

Telecon inputs have indicated that the first six (6) flights will be sub-orbital vehicle check-out in nature, manned by a Commander and Pilot only. Therefore, the program presented assumes the first requirement for a payload specialist on the seventh flight.

4.3.1.4 Passengers. Data supplied for the plotting of passenger requirements has not been sufficient to form any conclusions. However, telecon inputs have indicated that a crew of twelve (12) men will be maintained in the Modular Space Station starting in 1984. The following ground rules have been assumed in this study:

a. Duration of the stay for any one man in the space station will be six (6) months.

b. Time between flights for any crew will be six months.

c. Crews will fly repeat missions.

Utilizing the above ground rules it will be necessary to have four crews of six men each, or 24 men. These crews will be launched and retrieved as follows:

a. First crew of six men launched to man the space station.

b. Second crew launched three (3) months later to increase station complement to twelve (12) men.

   Third crew launched three (3) months later and the first crew retrieved.

c. Fourth crew launched three (3) months later and the second crew retrieved, etc.

No training suits would be supplied for passengers and due to the timing of the suits in the program as presented, no replacement suits are required. It should be noted that modularization of the IV passenger suits has not been accounted for since it would be impractical to provide such features in a suit which will experience little usage during its operational life. In addition, with the utilization of a small quantity sizing system, such as four (4) or five (5) sizes to cover the entire population, adequate suits should be available in the event some may require maintenance prior to the expiration of their useful life.

4.3.2 EVA/IVA PRESSURE SUIT REQUIREMENTS. Similar to the IV emergency crew pressure suit, modularization has also been considered in the costing of the Shuttle EVA pressure suits by eliminating the cost for a back-up EVA pressure suit. The requirements for the EVA pressure suits are discussed herein with Tables 4-4 and 4-5 illustrating the program scheduling for

the EVA suits over the eleven (11) year period extending from 1978 through the end of 1988.

Program data inputs have indicated that any EVA mission can be supported by either the Mission Commander, Pilot and/or Mission Specialist in any combination, or singly.

This study utilized the ground rule that one (1) EV suit would be supplied for each of the 20 Commanders, 20 Pilots, and 40 Mission Specialists required in the program.

The program presented consists of one (1) training suit (supplied due to extended first flight training), made available one (1) year prior to flight and one (1) flight suit made available six (6) months prior to flight for each of the 80 men required. The training suits are regarded as permanently available. However, the flight suits are replaced at the expiration of eight (8) years from the time of delivery.

DATE: 12/1/72

TITLE: SHUTTLE PROGRAM SUIT SUPPORT PLAN

AUTHORIZATION: PROJECT 05 - PURCH. ORDER 82681-U2

YEAR	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
QUARTER	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
① COMPLETE IV SUIT DEVELOPMENT PROGRAM	Δ10/73																		
② COMPLETE EV SUIT DEVELOPMENT PROGRAM		Δ6/74																	
③ SPACECRAFT CDR			Δ[illegible]/75																
④ TOTAL SHUTTLE FLTS — YEAR						6	15	24	32	40	60	60	60	60	60	60			
⑤ TOTAL SHUTTLE FLTS — QUARTER						2 1 3	3 4 4 4	6 6 6 6	6 8 9 9	9 9 10 12	15 15 15 15	15 15 15 15	15 15 15 15	15 15 15 15	15 15 15 15	15 15 15 15			
⑥ TOTAL SHUTTLE FLTS — CUMULATIVE						2 3 6	9 13 17 21	27 33 39 45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
⑦ IV SUIT PROGRAM																			
⑧ SUBMIT PRODUCTION IV SUIT QUOTE			Δ5/75																
⑨ CONTRACT AWARD			Δ7/75																
⑩ PDR			Δ9/75																
⑪ CDR			Δ12/75																
⑫ FACI				Δ4/76															
⑬ QUALIFICATION COMPLETION				Δ6/76															
⑭ TRAINING * (COMMANDER/PILOT SUIT DELIVERY REQMTS)					4 4 4	4		8	4 4	8									
⑮ FLIGHT (COMMANDER/PILOT SUIT DELIVERY REQMTS)					4	4 4 4		8		4 4 8									
⑯ CYCLE/SHELF LIFE REPLACEMENTS (COMMANDER/PILOT SUIT DELIVERY REQMTS)													4	4 4 4		8			
⑰ TRAINING * (MISSION SPECIALIST SUIT DELIVERY REQMTS)						6 4 2	4	4 4	2 6	6 2									
⑱ FLIGHT (MISSION SPECIALIST SUIT DELIVERY REQMTS)						6 4	2 4	6	2	2 4 6 4									
⑲ CYCLE/SHELF LIFE REPLACEMENTS (MISSION SPECIALIST SUIT DELIVERY REQMTS)														6 4	2 4	6			
⑳																			

* PENDING ADDITIONAL STUDIES, IT MAY BE POSSIBLE TO REDUCE THE NUMBER OF TRAINING SUITS BY USING THEM FOR OTHER SUBJECTS AFTER COMPLETION OF ONE YEAR OF TRAINING FOR THE INITIAL SUBJECT.

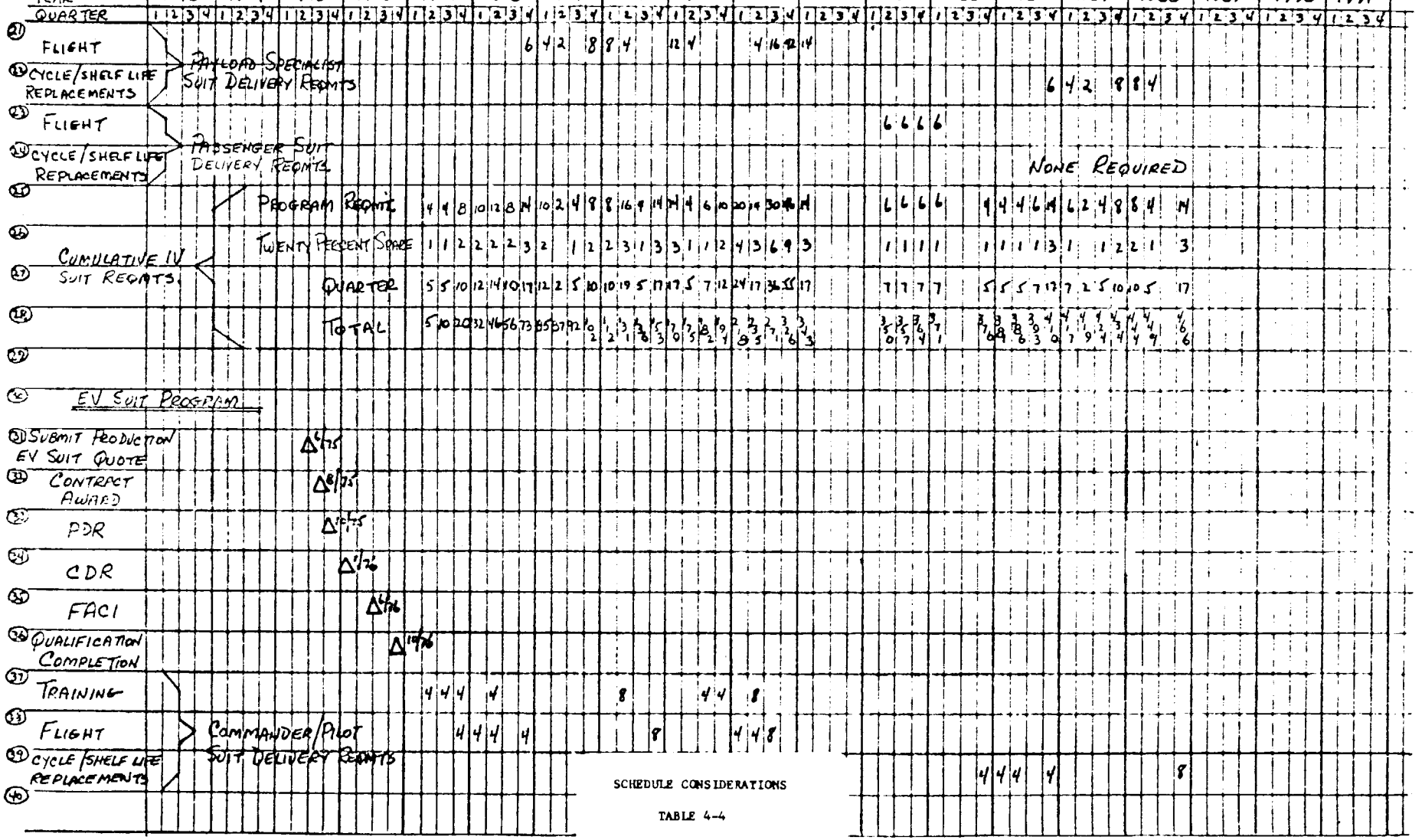
SCHEDULE CONSIDERATIONS

TABLE 4-3

TITLE: SHUTTLE PROGRAM SUIT SUPPORT PLAN

AUTHORIZATION: PROJECT 051 – PURCH. ORDER 82 68 14-UE

DATE: 12/1/72



SCHEDULE CONSIDERATIONS

TABLE 4-4

TITLE: SHUTTLE PROGRAM SUIT SUPPORT PLAN

AUTHORIZATION: PROJECT 051 - PURCH. ORDER 826814-UE

DATE: 12/1/72

Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Quarter	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
(41) Training						6 4 2	4	6 2	2 6	6 2									
(42) Flight	Mission Specialist					6 4 2	4	6 2		2 6 6 2									
(43) Cycle/Shelf Life Replacements	Suit Delivery Reqmts.													6 4 2	4	6			
(44)		Program Reqmt			4 4 8 10 12 8 8 6		4	14 2 4 2	6 10 12 20 14 2				4 4 4 6 8 2		4	14			
(45)		Twenty Percent Spare			1 1 2 2 2 2 2 1		1	3 3	1 2 2 4 3				1 1 1 1 2		1	3			
(46) Cumulative EV Suit Reqmts.			Quarter		5 5 10 12 14 10 10 7		5	17 2 17 2	7 12 14 24 17 2				5 5 5 7 10 2		5	17			
(47)			Total		5 10 20 32 46 56 66 73		78	95 97 114 116	123 135 149 173 190 192				197 202 207 214 224 226		231	248			
(48)																			
(49)																			
(50)																			
(51)																			
(52)																			
(53)																			
(54)																			
(55)																			
(56)																			
(57)																			
(58)																			
(59)																			
(60)																			

SCHEDULE CONSIDERATIONS

TABLE 4-5

4.4 COST CONSIDERATIONS

An examination of the schedule considerations discussed in paragraph 4.3 was conducted to determine the total program cost for the space shuttle pressure suit support during the thirteen (13) year period of 1975 through the end of 1988. The results of this cost study are illustrated in Table 4-6. The unit costs for the EVA TLSA were based on a combination of present A7LB costs and costs obtained for the AES pressure suit designs. In addition the IV emergency crew suit TLSA cost has been estimated based on the data presented in the requirements section of this report and preliminary information obtained from the 8.0 psi Emergency Intravehicular Suit program, Contract NAS 9-12995. All costs are based on "best guess" estimates made at this time and should be reconsidered upon the completion of the 8.0 psi Emergency IV and 8.0 psi EVA suit prototype programs.

It should also be noted that the costing illustrated in Table 4-6 accounts for the entire suit program cost including all suits for EVA and IV emergency (crew and passengers) as well as spares support, design, development, qualification, field, and depot support for the entire 13 year period commencing in 1975 and ending in 1988. In addition, all costing includes overhead, G&A, and fee.

TITLE: SHUTTLE PROGRAM SUIT SUPPORT PLAN - COST ESTIMATE

AUTHORIZATION: PROJECT 051 - PURCH. ORDER 820814-UE

DATE: 12/1/72

	UNIT COST - ONE EACH	PROGRAM QUAN. REQD	TOTAL PROGRAM COST	SUB-TOTAL EVA PROG.	SUB-TOTAL IV PROG.	PROGRAM SUPPT.	REMARKS
1 EVA TLSA	46,731.00	248	11,589,288.00	11,589,288.00			INCLUDES (42) SPARE SUIT SETS
2 IV TLSA	19,844.00	466	9,247,304.00		9,247,304.00		INCLUDES (79) SPARE SUIT SETS
3 EV GLOVES*	6,947.20	248	1,722,906.00	1,722,906.00			
4 IV GLOVES*	3,636.00	466	1,694,376.00		1,694,376.00		
5 TMG*	9,054.00	248	2,245,392.00	2,245,392.00			NOT SUPPLIED FOR IV SUIT.
6 SEVA*	8,000.00	80	640,000.00	640,000.00			SUPPLIED ONE EA. FOR 80 EV SUBJECTS ONLY.
7 IV COMPONENT REPLACEMENT			156,768.00		156,768.00		COMPUTED AT 10% OF COST OF (79) SPARE IV SUITS
8 EV COMPONENT REPLACEMENT			196,270.00	196,270.00			COMPUTED AT 10% OF COST OF (42) SPARE EV SUITS
9 EV DEVELOP COST			500,000.00	500,000.00			
10 IV DEVELOP COST			250,000.00		250,000.00		
11 EV QUAL. COST			500,000.00	500,000.00			
12 IV QUAL. COST			250,000.00		250,000.00		
13 FIELD SUPPORT			3,750,000.00			3,750,000.00	(13) YEAR TERM
14 DEPOT SUPPORT			1,500,000.00			1,500,000.00	(13) YEAR TERM
15			34,242,304.00	17,393,856.00	11,598,448.00	5,250,000.00	
16							
17							
18							
19							
20							

* BASED ON AZLB COSTING

COST CONSIDERATIONS

TABLE 4-6

This appendix lists the EVA and IVA tasks that might be performed to accomplish the seven scenarios identified in Table 2-1 of this report. In addition, a general outline of how the crewmen will accomplish these tasks is discussed.

SCENARIO #1

EVA MAINTENANCE OF A LARGE SPACE TELESCOPE (LST)

GENERAL TASKS

a. Aperture End

(1) Replace the secondary mirror module.

(2) Replace the 6 contamination monitoring gages in the area of the secondary mirror.

(3) Replace the 2 mass spectrometer end instruments in the area of the secondary mirror.

b. Inside the Telescope Tube.

(1) Replace the 4 contamination monitoring gages.

(2) Clean primary and secondary mirror surfaces.

c. Replace 2 RCS modules on opposite sides of the LST.

d. Replace one assembly containing two dual rollout solar all panel.

PROCEDURE (NOT NECESSARILY IN SEQUENCE) FOR REPLACING THE LST COMPONENTS

a. Unstow EVA equipment.

b. Don and checkout EVA equipment and prepare for EVA.

c. Exit orbiter vehicle through airlock.

d. Translate across orbiter vehicle surface to sortie can.

e. Unstow spare component.

f. Translate across sortie can and LST to worksite.

g. Prepare worksite for removal of component.

h. Gain access to component.

i. Remove component.

j. Transport removed component to orbiter vehicle and stow

k. Transport spare component to worksite

l. Install spare component.

m. Replace parts removed to gain access.

n. Prepare to return to orbiter vehicle.

o. Repeat "e" through "n" for other components.

p. Translate across LST and sortie can to orbiter vehicle.

q. Translate across orbiter vehicle to airlock opening.

r. Re-enter orbiter vehicle through airlock

s. Doff EVA equipment and stow

SCENARIO # 2

EVA AND IVA SUPPORT OF AN EARTH OBSERVATION SORTIE

GENERAL TASKS

a. Preparation of Sortie EVA in Open Payload Bay

(1) Install 4 small film magazines

(2) Install 1 large film magazine

(3) Assemble and erect the large dish antenna

b. Support EVA in Open Payload Bay

(1) Replace 4 small film magazines

(2) Replace 1 large film magazine

c. Stowage of EVA Antenna in Open Payload Bay

(1) Disassemble and stow the large disc antenna

d. Stowage IVA in a Closed Unpressurized Payload Bay

(1) Remove 4 small film magazines

(2) Remove 1 large film magazine

e. Unscheduled EVA in Unpressurized Sortie Facility

(1) Operate the observation telescope and control data equipment:

Small film magazine, 6 in. X 9 in. X 6 in. - 5 lb.

Large film magazine, 15 in. X 50 in. X 20 in. - 45 lb.

Assemble dish antenna - 30 ft. dia. X 3 ft. thick - 276 lb.

It is assumed that the dish antenna is broken down into 10 pieces (9.5 ft. X 15 ft. X 1.5 ft. - 20 lb) which are stowed in the payload bay. These pieces are to be fitted together and attached to a drive mechanism mounted in the payload bay.

PROCEDURE (NOT NECESSARILY IN SEQUENCE) FOR PERFORMING THE TASKS, EVA OR IVA

a. Unstow EVA or IVA equipment and equipment to be carried to the worksite.

b. Don and checkout EVA or IVA equipment and prepare for exiting Orbiter vehicle cabin or sortie experiment facility.

c. Exit Orbiter vehicle through airlock.

d. Translate to payload bay worksite.

e. Prepare work site for tasks.

f. Accomplish assigned tasks.

g. Prepare for return to Orbiter vehicle.

h. Translate from worksite to airlock opening.

i. Re-enter Orbiter vehicle through airlock.

j. Doff EVA or IVA equipment and stow.

SCENARIO #3

SATELLITE AND TUG RETRIEVAL AND DEPLOYMENT READINESS

GENERAL TASKS

The following are general tasks which could be accomplished by EVA or IVA (with payload bay doors closed) to prepare a tug and satellite for deorbit and landing.

a. Connect umbilical connections to tug and satellite.

b. Install covers on delicate instruments and lenses.

c. Purge tug and satellite systems which contain harmful materials.

d. Perform safety and health checks on the Tug and satellite.

e. Aid in tying down the tug and satellite to the payload bay structure.

f. Fold or reposition antennas, solar cell arrays and sensors which have been deployed and erected.

PROCEDURE (NOT NECESSARILY IN SEQUENCE) FOR PERFORMING THE DE-ORBIT READINESS TASKS BY EVA OR IVA

a. Unstow EVA equipment and equipment to be carried to the work site.

b. Don and checkout EVA equipment and prepare to exit the orbiter vehicle cabin.

c. Exit orbiter vehicle thru airlock.

d. Translate to space tug work site area.

e. Prepare work site for tasks.

f. Accomplish tug tasks.

g. Prepare work site for departure.

h. Translate to satellite work site area.

i. Prepare work site for tasks.

j. Accomplish satellite tasks.

k. Prepare work site for departure.

l. Translate to safety site clear of payload bay.

m. Remain at safety site until space tug and satellite are lowered into payload bay.

n. Translate to payload bay space tug work site.

o. Prepare work site for tasks.

p. Accomplish tug tasks.

q. Prepare work site for departure.

r. Translate to satellite work site.

s. Prepare work site for tasks.

t. Accomplish satellite tasks.

u. Prepare work site for departure.

v. Translate from payload bay to airlock opening.

w. Re-enter orbiter vehicle through airlock.

x. Doff EVA equipment and stow.

SCENARIO #4

EVA INSPECTION AND REPAIR OF THE ORBITER VEHICLE EXTERIOR

GENERAL TASKS

The following are orbiter vehicle components to be inspected for proper condition and repaired if necessary, by EVA in preparation for de-orbit.

a. Thermal Protection System (TPS) over the exterior surface.

b. Structural supports, fluid connections and electrical connections for the External Tank Subsystem.

c. All doors and mechanisms operated after launch.

d. Payload bay equipment prior to closing payload bay doors.

e. Sensors and sensor ports such as pitot-static tubes, air data transducer ports, horizon sensors and star trackers.

f. Antennas.

g. Aerodynamic control surfaces.

h. Exhaust ports such as APU and evaporative heat sink.

i. Windows.

j. Emergency egress doors.

k. Abort rocket structural supports and electrical connections.

The orbiter vehicle is in any obtainable orbit (Ref. MSC-06746) preparing to deorbit and land.

PROCEDURE - (NOT NECESSARILY IN SEQUENCE) FOR PERFORMING THE INSPECTION TASKS

a. Unstow EVA equipment and equipment to be carried during the inspection.

b. Don and checkout EVA equipment and prepare to exit the orbiter vehicle cabin.

c. Exit orbiter vehicle through the airlock.

d. Translate to open payload bay.

e. Perform inspection task.

f. Translate to safety site clear of payload bay.

g. Remain at safety site until payload bay doors are closed.

h. Translate over the orbiter vehicle surface making a visual inspection.

i. Return to area of airlock opening.

j. Re-enter orbiter vehicle through airlock.

k. Doff EVA equipment and stow.

PROCEDURE - (NOT NECESSARILY IN SEQUENCE) FOR PERFORMING ANY REPAIR TASKS

a. Unstow EVA equipment and repair tools and equipment.

b. Don and checkout EVA equipment and prepare to exit the orbiter vehicle cabin.

c. Exit Orbiter vehicle through the airlock.

d. Translate to repair worksite.

e. Prepare worksite for tasks.

f. Perform repair

g. Prepare worksite for departure.

h. Translate to area of airlock opening.

i. Re-enter Orbiter vehicle through airlock.

j. Doff EVA equipment and stow.

SCENARIO #5

DEPLOYMENT AND RETRACTION OF PLASMA WAKE EXPERIMENTS

GENERAL TASKS

To be performed either EVA or IVA:

a. Replace 6 sensors on the end of a 160 ft. boom by EVA without retracting the boom.

Sensor Sizes and Weights:

(1) 8 in. X 10 in. X 11 in. - 15 lbs.

(2) 6 in. X 6 in. X 6 in. - 5 lbs.

(3) 2.5 cubic feet - 30 lbs.

(4) 9 in. X 9 in. X 12 in. - 20 lbs.

(5) 6 in. dia X 1 in. - 3 lbs.

(6) 5.6 in. dia. X 1 in. - 5.5 lbs.

b. Manually retract a boom by unpressurized IVA inside the experiment compartment.

c. Manually retract a boom by EVA outside the experiment compartment.

d. Manually rotate the sortie lab into position for conducting experiments.

e. Manually rotate the sortie lab into the stowed position following the completion of the experiments.

It is desirable to change the boom mounted equipment by EVA and complete the mission and then retract the boom manually before de-orbit.

PROCEDURE (NOT NECESSARILY IN SEQUENCE FOR CHANGING THE BOOM MOUNTED EQUIPMENT BY EVA

a. Unstow EVA equipment and equipment to be taken to the worksite.

b. Don and checkout EVA equipment and prepare to exit the orbiter through the airlock.

c. Exit orbiter vehicle through the airlock.

d. Translate to worksite at end of extended 160 ft. boom.

e. Prepare worksite for equipment change.

f. Accomplish equipment change.

g. Prepare worksite for departure.

h. Translate to area of airlock opening.

i. Re-enter orbiter vehicle through airlock.

j. Doff EVA equipment and stow.

PROCEDURE (NOT NECESSARILY IN SEQUENCE) FOR RETRACTING THE BOOM MANUALLY BY IVA WITHIN THE PRESSURIZED EXPERIMENT COMPARTMENT

a. Unstow IVA equipment.

b. Don and checkout IVA equipment.

c. Enter pressurized experiment compartment.

d. Depressurize pressurized compartment.

e. Open boom inner airlock door.

f. Install crank in retraction mechanism and crank in boom.

g. Close outer airlock door.

h. Pressurize the compartment.

i. Re-enter Orbiter vehicle cabin.

j. Doff IVA equipment and stow.

SCENARIO #5 (Cont'd)

PROCEDURE (NOT NECESSARILY IN SEQUENCE) FOR RETRACTING THE BOOM MANUALLY BY EVA

a. Unstow EVA equipment and equipment to be carried to the worksite.

b. Don and checkout EVA equipment and prepare to exit the orbiter vehicle cabin.

c. Exit orbiter vehicle through the airlock.

d. Translate to area of boom housing.

e. Prepare worksite for manual retraction task.

f. Retract boom by turning the boom forcing the links into the housing one by one.

g. Assist in closing airlock outer door.

h. Prepare worksite for departure.

i. Translate to area of airlock opening.

j. Re-enter orbiter vehicle through airlock.

k. Doff EVA equipment and stow.

PROCEDURE (NOT NECESSARILY IN SEQUENCE) FOR ROTATING THE SORTIE LAB TO CHANGE ITS POSITION

a. Unstow EVA equipment.

b. Don and checkout EVA equipment and prepare to exit the orbiter vehicle cabin.

c. Exit orbiter vehicle through the airlock.

d. Translate to area of sortie lab.

e. Prepare for rotation operation.

f. Manually rotate sortie lab into desired position.

g. Prepare for departure from work area.

h. Translate to area of airlock opening.

i. Re-enter orbiter vehicle through airlock.

j. Doff EVA equipment and stow.

SCENARIO # 6

MAINTENANCE OF AN X-RAY ASTRONOMY OBSERVATORY

GENERAL TASKS

a. Replace the proportional counter array (15 in. X 26 in. X 66 in. - 166 lb.)

b. Replace the scintillation counter (20 in. X 30 in. X 27 in. - 286 lb.)

c. Replace the crystal spectrograph (29 in. X 64 in. X 28 in. - 177 lb).

PROCEDURE (NOT NECESSARILY IN SEQUENCE) FOR REPLACING EACH COMPONENT BY UNPRESSURIZED IVA

a. Unstow IVA equipment, replacement component and other equipment to be carried to the work site.

b. Don and checkout IVA equipment.

c. Enter the X-Ray Observatory pressurizable compartment.

d. Depressurize X-Ray compartment.

e. Gain access into the telescope tube.

f. Translate through the telescope tube to the work site area with replacement component and required equipment.

g. Prepare the work site area.

h. Gain access to the component to be replaced.

i. Accomplish component replacement.

j. Replace any parts removed to gain access.

k. Prepare work site for departure.

l. Translate from work site to area of access opening between telescope tube and the pressurizable compartment with replaced component and other equipment.

m. Exit the telescope tube with component and other equipment.

n. Close access opening between the telescope tube and the pressurizable compartment.

o. Repressurize the compartment.

p. Doff IVA equipment and stow all equipment.

SCENARIO # 7

MAINTENANCE AND SERVICING OF ASTRONOMY EXPLORER

GENERAL TASKS

a. Repressurize gaseous nitrogen RCS tanks - 6 lbs.

b. Replace worn thruster - 0.02 lb. thruster.

c. Replace deteriorating TV camera.

d. Replace damaged or deteriorating Solar cell panel 10 in. X 40 in. X .10 in.

PROCEDURE (NOT NECESSARILY IN SEQUENCE) FOR ASTRONOMY EXPLORER SATELLITE MAINTENANCE AND SERVICING

a. Unstow EVA equipment and spare components.

b. Don and checkout EVA equipment and prepare for EVA.

c. Exit Orbiter vehicle through airlock.

d. Translate to area of free flying maneuvering unit in the payload bay.

e. Unstow, prepare for use and checkout the free flying maneuvering unit.

f. Translate from Orbiter to the Satellite.

g. Dock with Satellite at worksite.

h. Prepare worksite for maintenance and servicing.

i. Perform maintenance and servicing.

j. Prepare to return to Orbiter.

k. Translate from Satellite to Orbiter.

l. Dock with Orbiter to area of Payload bay.

m. Shut down and stow the free flying maneuvering unit.

n. Translate to airlock opening.

o. Re-enter Orbiter through airlock.

p. Doff EVA equipment and stow.

The objective of this survey is to establish performance and design requirements for the space Shuttle EVA and IVA Pressure Suits required to support the nominal, unscheduled, and emergency EVA/IVA Space Shuttle System requirements. This survey will serve to collect direct comments from astronauts and qualified suit subjects.

This survey of specific subjects relative to the human engineering of pressure suits should be compiled for consideration. These data should be used to influence the designs of future Shuttle Pressure Suits. In an effort to reduce the subjectivity of these factors, best judgement responses from astronauts and other qualified NASA personnel should be correlated. The results of all responses should be summarized and published as pressure suit requirements guidelines.

It is requested that each individual participating in the survey review and check (✓) their concurring response, and provide any additional recommendations or comments which they may have in the appropriate columns.

HUMAN FACTORS FOR SHUTTLE PROGRAM - PRESSURE SUIT				
COMMENT	RESPONSE			RECOMMENDATION
	YES	NO	SAME AS SKYLAB	
1. FEED PORT a. Desired b. Preferred location c. Operational concept				
2. PRESSURE GAUGE a. Desired b. Preferred location c. Gauge size sm. profile/sm. resolution lge. profile/lge. resolution (easier to read/better accuracy)				
3. EVA VISOR a. Integrated with helmet b. Separate assembly				
4. HEAD COOLING a. Desired b. Liquid Cooled Hood c. Air Cooled Hood d. Internal sweat band to wipe head				
5. PRE-BREATHE PREFERENCE Would you consider pre-breathing oxygen during EVA suit and ECS donning and system checkout if the prebreathing time lasted: a. 3-3½ hours				

HUMAN FACTORS FOR SHUTTLE PROGRAM - PRESSURE SUIT				
COMMENT	RESPONSE			RECOMMENDATION
	YES	NO	SAME AS SKYLAB	
b. 1-2 hours				
c. Approximately 0.5 hours				
d. No prebreathing				
6. POCKET LOCATIONS ON SUIT (EV) a. Pencil Pocket on left shoulder. b. Pen Light Pocket on right shoulder. c. Datalist Pocket, optional about the legs. d. Scissors Pocket, optional about the suit e. Passive Radiation Dosimeter, optional about the suit. f. Other pockets-(specify purpose) g. All pocket locations optional.				
7. POCKET LOCATIONS ON SUIT (IV) a. Pencil Pocket on left shoulder. b. Pen Light Pocket on right shoulder. c. Datalist Pocket, optional about the legs. d. Checklist Pocket, optional about the legs.				

HUMAN FACTORS FOR SHUTTLE PROGRAM - PRESSURE SUIT				
COMMENT	RESPONSE			RECOMMENDATION
	YES	NO	SAME AS SKYLAB	
e. Scissors Pocket, optional about the suit. f. Passive Radiation Dosimeter, optional about the suit. g. Other pockets-(specify purpose). h. All pocket locations optional.				
8. NOURISHMENT DURING EVA a. Water b. Vitamin enriched juice c. Food supplement d. Other				
9. BOOT SOLES (EV) a. Rigid (Skylab type) b. Flexible (Apollo type) c. Lightweight				
10. BOOT SOLES (IV) a. Rigid (Skylab type) b. Flexible (Apollo type) c. Lightweight				
11. GLOVE CAPABILITY OPTIONS (EV/IV) a. Number of Fingers 1. Five fingers; or 2. Three fingers (thumb; 1st; 2nd/3rd/4th fingers) b. Finger Stable Position 1. Fingers Straight				

HUMAN FACTORS FOR SHUTTLE PROGRAM - PRESSURE SUIT				
COMMENT	RESPONSE			RECOMMENDATION
	YES	NO	SAME AS SKYLAB	
11. 2. Fingers slightly curved 3. Fingers curved to extreme c. Thermal Insulation Removeable from glove Integrated with glove d. Cooling to Glove Water cooling Air cooling (A7LB-EV type) e. Integrated finger lights f. Finger nails				
12. GLOVE CAPABILITY OPTIONS (IV emergency) a. Number of fingers 1. Five fingers; or 2. Three fingers (thumb; 1st; 2nd/3rd/4th fingers) b. Finger Stable position 1. Fingers straight 2. Fingers slightly curved 3. Fingers curved to extreme c. Integrated Finger Lights d. Finger nails				
13. WAIST MOBILITY - EV It will be difficult at this time to define exactly what joints are needed since the exact Shuttle EV/IV tasks are an unknown. Cont'd. on next page.				

HUMAN FACTORS FOR SHUTTLE PROGRAM - PRESSURE SUIT				
COMMENT	RESPONSE			RECOMMENDATION
	YES	NO	SAME AS SKYLAB	
13. Cont'd. One major joint which is under question is the waist. In Zero "G" is a waist joint: a. Desirable b. Is a 90° waist flexure low torque desirable c. Is a 30° waist flexure low torque desirable				
14. WAIST MOBILITY - EMERGENCY IV Would you favor an IV Emergency ("Get Me Back") Suit which: a. Has a waist joint b. Has no waist joint but has a biased hip joint (For seated position) with good mobility for ingress/egress and long term seated comfort.				
15. SUIT CONNECTOR LOCATIONS a. Remain on chest (EV/IV) b. Relocate on chest (EV/IV) c. Locate on Back (EV only) Unitized or separate d. Locate on side (EV only). Unitized or separate e. Multiple locations - (specify where).				

HUMAN FACTORS FOR SHUTTLE PROGRAM - PRESSURE SUIT				
COMMENT	RESPONSE			RECOMMENDATION
	YES	NO	SAME AS SKYLAB	
16. NEED FOR SUPPORT HARDWARE FOR EVA a. FCS b. BioBelt c. Valsalva Device d. Comfort gloves e. Wristlets				
17. LOCATION OF PORTABLE ECS ON SUIT a. On front-Skylab type b. On back c. Back of Helmet/Visor d. Other				
18. TETHERS a. Waist Belt b. Tethers to maintain a crewman at a work station either EV or IV (LM type) c. Wrist tether d. Advanced retractable tethers e. What type of tether to suit attachment do you prefer.				
19. HANDRAILS/HANDHOLDS a. Would it be feasible to use some type of detachable hand hold to permit emergency relocation.				

HUMAN FACTORS FOR SHUTTLE PROGRAM - PRESSURE SUIT				
COMMENT	RESPONSE			RECOMMENDATION
	YES	NO	SAME AS SKYLAB	
19. b. Is a single or dual rail concept feasible for transferring large cargo packages (Re: NASA-Langley WIF Tests) c. Is a ladder more feasible for use d. Which type of hand hold/ hand rail do you favor.				
20. FOOT RESTRAINTS (EV/IV) a. Apollo "Dutch Shoe" configuration b. Skylab "Positive Heel Retention" configuration c. Use of toe or ankle straps d. Magnetic boot to vehicle floor e. Skylab open floor grid concept f. Use of hard attachments on the EVA/IVA Boots which interface with clips, hooks, tethers, etc. on the vehicle. g. Which type of foot restraint do you favor for EV or cabin IV use.				

HUMAN FACTORS FOR SHUTTLE PROGRAM - PRESSURE SUIT				
COMMENT	RESPONSE			RECOMMENDATION
	YES	NO	SAME AS SKYLAB	
RECOMMENDATIONS Please list any additional comments or recommendations you may have concerning Space Shuttle Pressure Suits.				

This appendix presents the detailed results of the ILC Industries EVA/IVA suit joint cycle analysis. Included are each of the seven representative task scenarios with a table summarizing the suit joint cycles required to complete that scenario once. Following the summary table, comprehensive tables detailing the joint cycles required to perform each individual portion of the task are also provided.

SCENARIO #1

TASK	LARGE SPACE TELESCOPE MAINTENANCE									
	MOVEMENTS									
	N	S	E	G	WR	T	W	K	A	B
A. REPLACE SECONDARY MIRROR MODULE	100	476	316	332	316	108	64	299	292	378
REPLACE CONTAMINATION GAUGES (6)										
REPLACE MASS SPEC. GAUGES (2)										
B. REPLACE CONTAMINATION GAUGES	87	471	339	315	309	119	59	235	220	300
CLEAN PRIMARY MIRROR										
C. REPLACE RCS MODULES (4)	160	584	416	432	392	128	100	335	366	390
D. REPLACE DUAL ROLL-OUT SOLAR PANELS (2)	80	436	280	292	280	108	62	195	178	266
TOTAL	427	1967	1351	1371	1297	463	285	1064	1056	1334

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #1A TASK: LARGE SPACE TELESCOPE

MOVEMENT:	Egress Orbiter	Trans. to S/C	Trans. to SMM	Service SMM	Trans to S/C	Exch. Equip.	Trans. to Work Site	Replace Gauges	Return to S/C	Store Equip.	Return to Orbiter	Ingress	Total
NECK	10	10	10	5	10	4	10	7	10	4	10	10	100
SHOULDER	288	30	10	12	10	14	10	36	10	14	30	12	476
ELBOW	144	30	10	10	10	8	10	34	10	8	30	12	316
GLOVE	134	30	10	18	10	12	10	34	10	12	30	22	332
WRIST	134	30	10	14	10	6	10	34	10	6	30	22	316
THIGH	50	20	2	-	2	2	2	-	2	2	20	6	108
WAIST	51	-	2	-	2	2	2	-	2	2	-	1	64
KNEE	48	-	56	-	56	4	56	4	56	4	-	15	299
ANKLE	10	10	56	4	56	8	56	18	56	8	10	-	292
BOOT	110	10	56	4	56	2	56	4	56	2	10	12	378

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #1B TASK: LARGE SPACE TELESCOPE MOVEMENT:	Egress Orbiter	Trans. S/C	Trans W/S	Replace Gauges	Trans. to S/C & CL. Mir.	Store Equip	Return to Orbiter	Ingress	Total
NECK	10	10	15	10	18	4	10	10	87
SHOULDER	288	30	15	52	30	14	30	12	471
ELBOW	144	30	15	50	50	8	30	12	339
GLOVE	134	30	15	50	22	12	30	22	315
WRIST	134	30	15	50	22	6	30	22	309
THIGH	50	20	3	-	18	2	20	6	119
WAIST	51	-	3	-	2	2	-	1	59
KNEE	48	-	84	8	76	4	-	15	235
ANKLE	10	10	84	22	76	8	10	-	220
BOOT	110	10	84	8	64	2	10	12	300

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #1C TASK: LARGE SPACE TELESCOPE

MOVEMENT:	Egress Orbiter	Trans. S/C	Trans. RCS (4)	Replace RCS (4)	Trans S/C (4)	Stow. Equip.	Return Orbiter	Ingress	Total
NECK	10	10	20	64	20	16	10	10	160
SHOULDER	288	30	20	128	20	56	30	12	584
ELBOW	144	30	20	128	20	32	30	12	416
GLOVE	134	30	20	128	20	48	30	22	432
WRIST	134	30	20	112	20	24	30	22	392
THIGH	50	20	4	16	4	8	20	6	128
WAIST	51	--	4	32	4	8	--	1	100
KNEE	48	--	112	16	112	32	--	15	335
ANKLE	10	10	112	80	112	32	10	--	366
BOOT	110	10	112	16	112	8	10	12	390

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #1D TASK: LARGE SPACE TELESCOPE

MOVEMENT:	Egress Orbiter	Trans S/C	Trans S/P (2)	Replace Solar Pan	Trans S/C	Stowage Equipment	Return Orbiter	Ingress	Total
NECK	10	10	10	12	10	8	10	10	80
SHOULDER	288	30	10	28	10	28	30	12	436
ELBOW	144	30	10	28	10	16	30	12	280
GLOVE	134	30	10	32	10	24	30	22	292
WRIST	134	30	10	32	10	12	30	22	280
THIGH	50	20	2	4	2	4	20	6	108
WAIST	51	--	2	2	2	4	--	1	62
KNEE	48	--	56	12	56	8	--	15	195
ANKLE	10	10	56	20	56	16	10	--	178
BOOT	110	10	56	8	56	4	10	12	266

SCENARIO #2

TASK	AUSTERE EARTH OBSERVATION SORTIE									
	MOVEMENT									
	N	S	E	G	Wr	T	W	K	A	B
A. SUPPORT SORTIE EVA IN OPEN PAYLOAD BAY	22	152	124	132	102	0	0	44	4	4
B. SUPPORT EVA IN OPEN PAYLOAD BAY	7	92	84	102	82	0	0	34	4	4
C. STOW ANTENNA IN OPEN PAYLOAD BAY	22	104	76	82	62	0	0	28	4	4
D. IVA IN CLOSED UNPRESSURIZED PAYLOAD BAY	7	92	84	102	82	0	0	34	4	4
E. UNSCHEDULED IVA IN UNPRESSURIZED SORTIE FACILITY.	13	44	56	62	48	0	2	16	14	8
TOTAL CYCLES	71	484	424	480	376	0	2	156	30	24

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #2A TASK: AUSTERE EARTH OBSERVATION SORTIE

MOVEMENT:	Egress	Mount Manip.	Trans. Pallet	Replace Film	Erect Antenna	Trans A/L	Exit Manip.	Ingress	Total
NECK	3	--	--	--	15	--	--	4	22
SHOULDER	12	10	--	48	60	--	10	12	152
ELBOW	12	6	--	48	40	--	6	12	124
GLOVE	16	10	2	52	30	2	8	12	132
WRIST	10	8	4	40	20	4	8	8	102
THIGH	--	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	--	--	--	--	--
KNEE	4	4	--	16	10	--	4	6	44
ANKLE	--	2	--	--	--	--	2	--	4
BOOT	--	2	--	--	--	--	2	--	4

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #2B TASK: AUSTERE EARTH OBSERVATION SORTIE

MOVEMENT:	Egress	Mount. Manip.	Trans. Pallet	Replace Film	Trans A/L	Exit Manip.	Ingress	Total
NECK	3	--	--	--	--	--	4	7
SHOULDER	12	10	--	48	--	10	12	92
ELBOW	12	6	--	48	--	6	12	84
GLOVE	16	10	2	52	2	8	12	102
WRIST	10	8	4	40	4	8	8	82
THIGH	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	--	--	--	--
KNEE	4	4	--	16	--	4	6	34
ANKLE	--	2	--	--	--	2	--	4
BOOT	--	2	--	--	--	2	--	4

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #2C TASK: STOWAGE OF ANTENNA EVA OPEN PAYLOAD BAY

MOVEMENT:	Egress	Mount Manip.	Trans. Ant.	Dis & Stow. Ant.	Trans. A/L	Exit. Manip.	Ingress	Total
NECK	3	-	-	15	-	-	4	22
SHOULDER	12	10	-	60	-	10	12	104
ELBOW	12	6	-	40	-	6	12	76
GLOVE	16	10	2	30	2	10	12	82
WRIST	10	8	4	20	4	8	8	62
THIGH	-	-	-	-	-	-	-	-
WAIST	-	-	-	-	-	-	-	-
KNEE	4	4	-	10	-	4	6	28
ANKLE	-	2	-	-	-	2	-	4
BOOT	-	2	-	-	-	2	-	4

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #2D TASK: STOWAGE IVA IN CLOSED UNPRESSURIZED PAYLOAD BAY

MOVEMENT:	Egress	Mount Manip.	Trans Pallet	Replace Film	Trans A/L	Exit Manip.	Ingress	Total
NECK	3	--	--	--	--	--	4	7
SHOULDER	12	10	--	48	--	10	12	92
ELBOW	12	6	--	48	--	6	12	84
GLOVE	16	10	2	52	2	8	12	102
WRIST	10	8	4	40	4	8	8	82
THIGH	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	--	--	--	--
KNEE	4	4	--	16	--	4	6	34
ANKLE	--	2	--	--	--	2	--	4
BOOT	--	2	--	--	--	2	--	4

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO 2E TASK: UNSCHEDULED IVA IN UNPRESSURIZED SORTIE FACILITY

MOVEMENT:	Trans. S/C	Operate Tele. Data Equip.	Return to Orbiter	Total
NECK	5	3	5	13
SHOULDER	16	12	16	44
ELBOW	22	12	22	56
GLOVE	22	18	22	62
WRIST	16	16	16	48
THIGH	--	--	--	--
WAIST	--	2	--	2
KNEE	8	--	8	16
ANKLE	4	6	4	14
BOOT	4	--	4	8

SCENARIO #3

TASK	DE-ORBIT READINESS OF SHUTTLE TUG & SATELLITE									
	MOVEMENT									
	N	S	E	G	Wr	T	W	K	A	B
CONNECT UMBILICALS	17	132	124	196	138	0	0	16	4	4
INSTALL PROTECTIVE COVERS										
SECURE PAYLOADS										
STOW SOLAR ARRAYS										
TOTAL CYCLES	17	132	124	196	138	0	0	16	4	4

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO #3 TASK: DE-ORBIT READINESS OF TUG AND SATELLITE

MOVEMENT:	Egress Orbiter	Mount Manip.	Connect Umbilicals	Install Covers	Secure Payload	Fold Solar Arrays	Exit Man	Ingress Orbiter	Total
NECK	3	--	2	3	6	--	--	3	17
SHOULDER	12	10	26	14	24	24	10	12	132
ELBOW	12	6	26	14	24	24	6	12	124
GLOVE	16	10	26	26	60	32	10	16	196
WRIST	10	8	24	10	48	20	8	10	138
THIGH	--	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	--	--	--	--	--
KNEE	4	4	--	--	--	--	4	4	16
ANKLE	--	2	--	--	--	--	2	--	4
BOOT	--	2	--	--	--	--	2	--	4

SCENARIO #4

TASK	INSPECTION/REPAIR OF SHUTTLE ORBITER									
	MOVEMENT									
	N	S	E	G	Wr	T	W	K	A	B
A. MALFUNCTION OF RCS DOORS/PORTS	6	50	42	64	59	0	0	16	4	4
B. MALFUNCTION OF RUDDER AND ELEVONS	20	180	164	190	172	0	0	60	8	8
TOTAL	26	230	206	254	231	0	0	76	12	12

CYCLING REQUIREMENTS FOR SHUTTLE

SCENARIO 4A TASK: INSPECTION REPAIR

MOVEMENT: INSPECT AND REPAIR MALFUNCTION OF RCS DOORS/PORTS

	EXIT ORBITER	MOUNT MANIPULATOR	INSPECT REPAIR RCS	EGRESS MANIPULATOR	EGRESS ORBITER	TOTAL
NECK	3	--	--	--	3	6
SHOULDER	12	10	6	10	12	50
ELBOW	12	6	6	6	12	42
GLOVE	16	10	12	10	16	64
WRIST	10	8	23	8	10	59
THIGH	--	--	--	--	--	--
WAIST	--	--	--	--	--	--
KNEE	4	4	--	4	4	16
ANKLE	--	2	--	2	--	4
BOOT	--	2	--	2	--	4

ASSUMPTIONS:

(1) Astronaut first trys to open RCS doors using his hands.

(2) Astronaut eventually opens RCS door by using hand crank.

CYCLING REQUIREMENTS FOR SHUTTLE

SCENARIO: 4B TASK: INSPECTION & REPAIR

MOVEMENT: INSPECT AND REPAIR MALFUNCTION OF RUDDER AND ELEVONS

	EGRESS ORBITER	MOUNT MANIPULATOR	MOUNT MANIPULATOR	INSPECT RUDDER	REPAIR RUDDER	INSPECT ELEVONS	MOUNT MANIPULATOR	MOUNT MANIPULATOR	INGRESS ORBITER	TOTAL
NECK	3	--	--	12	2	--	--	--	3	20
SHOULDER	12	10	10	38	9	69	10	10	12	180
ELBOW	12	6	6	38	8	70	6	6	12	164
GLOVE	16	10	10	38	10	70	10	10	16	190
WRIST	10	8	8	38	11	71	8	8	10	172
THIGH	--	--	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	--	--	--	--	--	--
KNEE	4	4	4	18	4	14	4	4	4	60
ANKLE	--	2	2	--	--	--	2	2	--	8
BOOT	--	2	2	--	--	--	2	2	--	8

SCENARIO #5

TASK	DEPLOYMENT/ RETRACTION OF PLASMA WAKE EXPERIMENTS									
	MOVEMENT									
	N	S	E	G	Wr	T	W	K	A	B
A. REPLACE SENSORS ON END OF 160' BOOM WITHOUT RETRACTING BOOM.	32	548	540	630	644	0	0	28	4	24
B. MANUALLY RETRACT 160' BOOM IV WITH SUIT PRESSURIZED	24	2046	2046	334	2032	25	0	20	52	4
C. MANUALLY RETRACT 160' BOOM EV OF THE BOOM COMPARTMENT.	22	1998	1982	290	1984	25	0	26	52	12
D. MANUALLY UNSTOW SORTIE CAN AND EXPERIMENT	15	1030	1030	1038	1026	0	0	38	4	4
E. MANUALLY STOW SORTIE CAN AND EXPERIMENT	15	1030	1030	1038	1026	0	0	38	4	4
TOTAL	108	6652	6628	3330	6712	50	0	150	116	48

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO 5A TASK: PLASMA WAKE

MOVEMENT: REPLACE SENSORS ON END OF 160' BOOM WITHOUT RETRACTING BOOM

	EGRESS ORBITER	MOUNT MANIPULATOR	TRANS BOOM	TRANS SENS.	REPLACE SENS.	TRANS. MANIP.	MOUNT MANIP.	TRANS A/L	INGRESS ORBITER	TOTAL
NECK	3	--	3	5	10	5	--	3	3	32
SHOULDER	12	10	--	200	104	200	10	--	12	548
ELBOW	12	6	--	200	104	200	6	--	12	540
GLOVE	16	10	2	200	174	200	10	2	16	630
WRIST	10	8	4	200	200	200	8	4	10	644
THIGH	--	--	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	--	--	--	--	--	--
KNEE	4	4	--	4	4	4	4	--	4	28
ANKLE	--	2	--	--	--	--	2	--	--	4
BOOT	--	2	--	10	--	10	2	--	--	24

ASSUMPTION

(1) When the astronaut is free floating or tethered, he is less likely to move his waist or thigh due to the zero G environment. This assumption does not hold true when he is in the foot restraint.

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO: 5B TASK: PLASMA WAKE

MOVEMENT: MANUALLY RETRACT 160' BOOM IV WITH SUIT PRESSURIZED

	TRANS S/C	TRANS BOOM	MOUNT REST.	RETRACT BOOM	EXIT REST.	TRANS. ORBITER	INGRESS ORBITER	TOTAL
NECK	3	2	2	10	2	2	3	24
SHOULDER	12	44	2	1930	2	44	12	2046
ELBOW	12	44	2	1930	2	44	12	2046
GLOVE	16	44	2	210	2	44	16	334
WRIST	10	44	2	1920	2	44	10	2032
THIGH	--	--	--	25	--	--	--	25
WAIST	--	--	--	--	--	--	--	--
KNEE	4	4	2	--	2	4	4	20
ANKLE	--	4	2	40	2	4	--	52
BOOT	--	--	2	--	2	--	--	4

CYCLING REQUIREMENTS
FOR
SHUTTLE

SCENARIO: 5C TASK: PLASMA WAKE

MOVEMENT: MANUALLY RETRACT THE 160' ROOM EV OF THE BOOM COMPARTMENT

	EGRESS ORBITER	MOUNT MANIP.	TRANS BOOM	EXIT MANIP.	MOUNT RESTRAINTS	RETRACT BOOM	MOUNT MANIP	TRANS ORBIT	EXIT MANIP	EGRESS ORBITER	TOTAL
NECK	3	--	3	--	2	10	1	--	--	3	22
SHOULDER	12	10	--	10	2	1930	12	--	10	12	1998
ELBOW	12	6	--	6	2	1930	8	--	6	12	1982
GLOVE	16	10	2	10	2	210	12	2	10	16	290
WRIST	10	8	4	8	2	1920	10	4	8	10	1984
THIGH	--	--	--	--	--	25	--	--	--	--	25
WAIST	--	--	--	--	--	--	--	--	--	--	--
KNEE	4	4	--	4	2	--	4	--	4	4	26
ANKLE	--	2	--	2	2	40	4	--	2	--	52
BOOT	--	2	--	2	2	--	4	--	2	--	12

CYCLING REQUIREMENTS FOR SHUTTLE

SCENARIO: 5D TASK: PLASMA WAKE

MOVEMENT: UNSTOW SORTIE CAN AND EXPERIMENT MANUALLY

	EGRESS ORBITER	TRANS P/B	INSTALL WINCH	ATTACH CABLE	TRANS WINCH	UNSTOW EXPERIMENT	INGRESS ORBITER	TOTAL
NECK	3	--	--	2	2	5	3	15
SHOULDER	12	28	34	46	42	856	12	1030
ELBOW	12	28	34	46	42	856	12	1030
GLOVE	16	28	34	46	42	856	16	1038
WRIST	10	28	34	46	42	856	10	1026
THIGH	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	--	--	--	--
KNEE	4	6	8	6	6	4	4	38
ANKLE	--	--	--	--	--	4	--	4
BOOT	--	--	--	--	--	4	--	4

SCENARIO 5E TASK: PLASMA WAKE

MOVEMENT: STOW SORTIE CAN AND EXPERIMENT MANUALLY

	EGRESS ORBITER	STOW EXPERIMENT	REMOVE CABLE	TRANS WINCH	STOW WINCH	TRANS ORBITER	INGRESS ORBITER	TOTAL
NECK	3	5	2	2	--	--	3	15
SHOULDER	12	856	46	42	34	28	12	1030
ELBOW	12	856	46	42	34	28	12	1030
GLOVE	16	856	46	42	34	28	16	1038
WRIST	10	856	46	42	34	28	10	1026
THIGH	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	--	--	--	--
KNEE	4	4	6	6	8	6	4	38
ANKLE	--	4	--	--	--	--	--	4
BOOT	--	4	--	--	--	--	--	4

SCENARIO #6

TASK	X-RAY ASTRONOMY OBSERVATORY									
	MOVEMENT									
	N	S	E	G	Wr	T	W	K	A	B
A. REPLACE THE PROPORTIONAL COUNTER ARRAY	36	105	107	115	91	6	6	182	168	168
B. REPLACE SCINTELLATION COUNTER	38	116	112	120	97	6	6	182	168	168
C. REPLACE THE CRYSTAL SPECTOGRAPH	38	111	109	117	94	6	6	182	168	168
TOTAL	112	332	328	352	282	18	18	546	504	504

CYCLING REQUIREMENTS FOR SHUTTLE

SCENARIO 6A TASK: X-RAY ASTRONOMY OBSERVATORY

MOVEMENT: REPLACE THE PROPORTIONAL COUNTER ARRAY

	EGRESS ORBITER	TRANS WORKSITE	REPLACE PGA	TRANS ORBITER	INGRESS ORBITER	TOTAL
NECK	3	15	--	15	3	36
SHOULDER	12	15	51	15	12	105
ELBOW	12	15	53	15	12	107
GLOVE	16	15	53	15	16	115
WRIST	10	15	41	15	10	91
THIGH	--	3	--	3	--	6
WAIST	--	3	--	3	--	6
KNEE	4	84	6	84	4	182
ANKLE	--	84	--	84	0	168
BOOT	--	84	--	84	0	168

CYCLING REQUIREMENTS FOR SHUTTLE

SCENARIO: 6 B TASK: X-RAY ASTRONOMY OBSERVATORY

MOVEMENT: REPLACE SCINTELLATION COUNTER

	EGRESS ORBITER	TRANS WORKSITE	REPLACE COUNTER	TRANS ORBITER	INGRESS ORBITER	TOTAL
NECK	3	15	2	15	3	38
SHOULDER	12	15	62	15	12	116
ELBOW	12	15	58	15	12	112
GLOVE	16	15	15	15	16	120
WRIST	10	15	47	15	10	97
THIGH	--	3	--	3	--	6
WAIST	--	3	--	3	--	6
KNEE	4	84	6	84	4	182
ANKLE	--	84	--	84	0	168
BOOT	--	84	--	84	0	168

CYCLING REQUIREMENTS FOR SHUTTLE

SCENARIO: 6C TASK: X-RAY ASTRONOMY OBSERVATORY

MOVEMENT: REPLACE THE CRYSTAL SPECTOGRAPH

	EGRESS ORBITER	TRANS WORKSITE	REPLACE SPECTOGRAPH	TRANS ORBITER	INGRESS ORBITER	TOTAL
NECK	3	15	2	15	3	38
SHOULDER	12	15	57	15	12	111
ELBOW	12	15	55	15	12	109
GLOVE	16	15	55	15	16	117
WRIST	10	15	44	15	10	94
THIGH	--	3	--	3	--	6
WAIST	--	3	--	3	--	6
KNEE	4	84	6	84	4	182
ANKLE	--	84	--	84	0	168
BOOT	--	84	--	84	0	168

SCENARIO #7

	FREE FLYING OPERATIONS									
TASK	MOVEMENT									
	N	S	E	G	Wr	T	W	K	A	B
PERFORM MAINTENANCE ON ASTRONOMY EXPLORER SATELLITE	21	125	124	211	153	0	14	14	2	2
TOTAL	21	125	124	211	153	0	14	14	2	2

CYCLING REQUIREMENTS FOR SHUTTLE

SCENARIO: 7 TASK: FREE FLYING OPERATIONS

MOVEMENT: PERFORM MAINTENANCE ON ASTRONOMY EXPLORER SATELLITE

	EGRESS ORBITER	TRANS P/B	MOUNT FFM	REPRESS N_2	REPLACE THURSTER	REPLACE CAMERA	REPLACE SOLAR PANEL	TOTAL
NECK	3	--	--	--	7	5	6	21
SHOULDER	12	25	9	11	22	20	26	125
ELBOW	12	25	7	12	22	20	26	124
GLOVE	16	25	16	14	46	42	52	211
WRIST	10	25	15	21	26	22	34	153
THIGH	--	--	--	--	--	--	--	--
WAIST	--	--	--	--	4	4	6	14
KNEE	4	6	4	--	--	--	--	14
ANKLE	--	--	2	--	--	--	--	2
BOOT	--	--	2	--	--	--	--	2

BIBLIOGRAPHY

LUNAR SURFACE AND FREE SPACE HAZARDS RELATING TO SPACE SUIT DESIGN by J. R. Goodman and M. I. Radnofsky dated April 21, 1965.

STUDY OF SPACE SHUTTLE EVA/IVA SUPPORT REQUIREMENTS by LTV, VMSC dated October, 1972.

STUDY OF SPACE SHUTTLE EVA/IVA SUPPORT REQUIREMENTS by LTV, VMSC dated November 1972.

TASK GUIDELINES CONSTRAINTS BRIEFING by LTV, VMSC dated June, 1972.

BIOASTRONAUTICS DATA BOOK published by NASA dated 1964.

SPACE AND PLANETARY ENVIRONMENT CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT published by NASA George C. Marshall Space Flight Center. Marshall Space Center, Alabama dated November 1971. - NASA TM X-64627.

ORBITER WINDOW DESIGN TEMPERATURES by NASA MSC DB CHIEF, Biomedical Research Division dated October 1972. - Memo DB6-72-199

GENERAL SPECIFICATION, MANNED SPACE FLIGHT FOOT RESTRAINTS, FUNCTIONAL DESIGN REQUIREMENTS FOR published by NASA MSC, document number SC-R-0008 dated November 11, 1971.

PREBREATHING DATA SUMMARY FOR USE IN THE VMSC SPACE SHUTTLE EVA/IVA EQUIPMENT STUDY by LTV VMSC dated July 26, 1972.

RESULTS OF INTRAVEHICULAR MANNED CARGO-TRANSFER STUDIES IN SIMULATED WEIGHTLESSNESS document number NASA NTN D-6774 dated April 1972.

MINUTES OF SHUTTLE CREW COMPLEMENT MEETING by LTV VMSC dated October 24, 1972.

COMMENTS TO QUESTIONSTIONS PRESENTED TO ASTRONAUT MATTINGLY prepared by LTV VMSC and ILC Industries dated September 15, 1972.

STATEMENT OF WORK FOR ORBITAL EVA SPACE SUIT ASSEMBLY (OES), 8.0 PSI submitted by NASA MSC RFP Number 9 BC-73-36-2-263P.

EMERGENCY IV PRESSURE SUIT ASSEMBLY WORK STATEMENT prepared by NASA MSC, RFP Number 9-BC-76-80-2-108P.

MIL-STD-810, MILITARY STANDARD, ENVIRONMENTAL TEST METHODS.

RELATIVE HUMIDITY AND DEW POINT TABLE, WASTAB-0-6G, U. S. Department of Commerce, National Weather Service.

CEI SPECIFICATION FOR A7LB PRESSURE GARMENT ASSEMBLY WITH THERMAL METEOROID GARMENT FOR APOLLO EMU prepared by ILC Industries dated January 30, 1970 - CP 3001.

TERRESTRIAL ENVIRONMENT (CLIMATIC) CRITERIA GUIDELINES FOR USE IN SPACE VEHICLE DEVELOPMENT, published by George C. Marshall Space Flight Center, MSFC, Alabama, May, 1971, NASA TM X-64589.