N85-16922

D33

CHALLENGES IN THE DEVELOPMENT OF THE SHUTTLE EXTRAVEHICULAR MOBILITY UNIT

Harold J. McMann and James W. McBarron II
NASA Lyndon B. Johnson Space Center
Houston, Texas 77058

ABSTRACT

The development of the Shuttle extravehicular mobility unit (EMU) has required significant technology advances in the design of the astronaut life support system and space-suit assembly. For the first time in U.S. manned space flight, the life support system and space-suit assemblies are integrated into a single system and optimized for the primary function of supporting astronaut extravehicular operations. Rather than accommodating a limited, male-only astronaut population, the EMU must satisfy size requirements for both males and females with a minimum of sized parts. In addition, the Shuttle EMU has been designed to implement Space Shuttle Program philosophy of long operating life and mission reuse capability to minimize program lifetime cost.

INTRODUCTION

The advancement in life support system and space-suit technology achieved by the development of the Shuttle extravehicular mobility unit (EMU) shown in figure 1 is best illustrated by comparison with the requirements for and the design features of the Apollo EMU shown in figures 2 and 3. This comparison is relevant because of the excellent performance of the Apollo EMU demonstrated during 162 man-hours of astronaut lunar surface exploration and scientific task accomplishments. The same basic Apollo EMU space-suit design was again successfully demonstrated during the Skylab Program, when an additional 81 man-hours of astronaut extravehicular activity (EVA) tasks were performed.

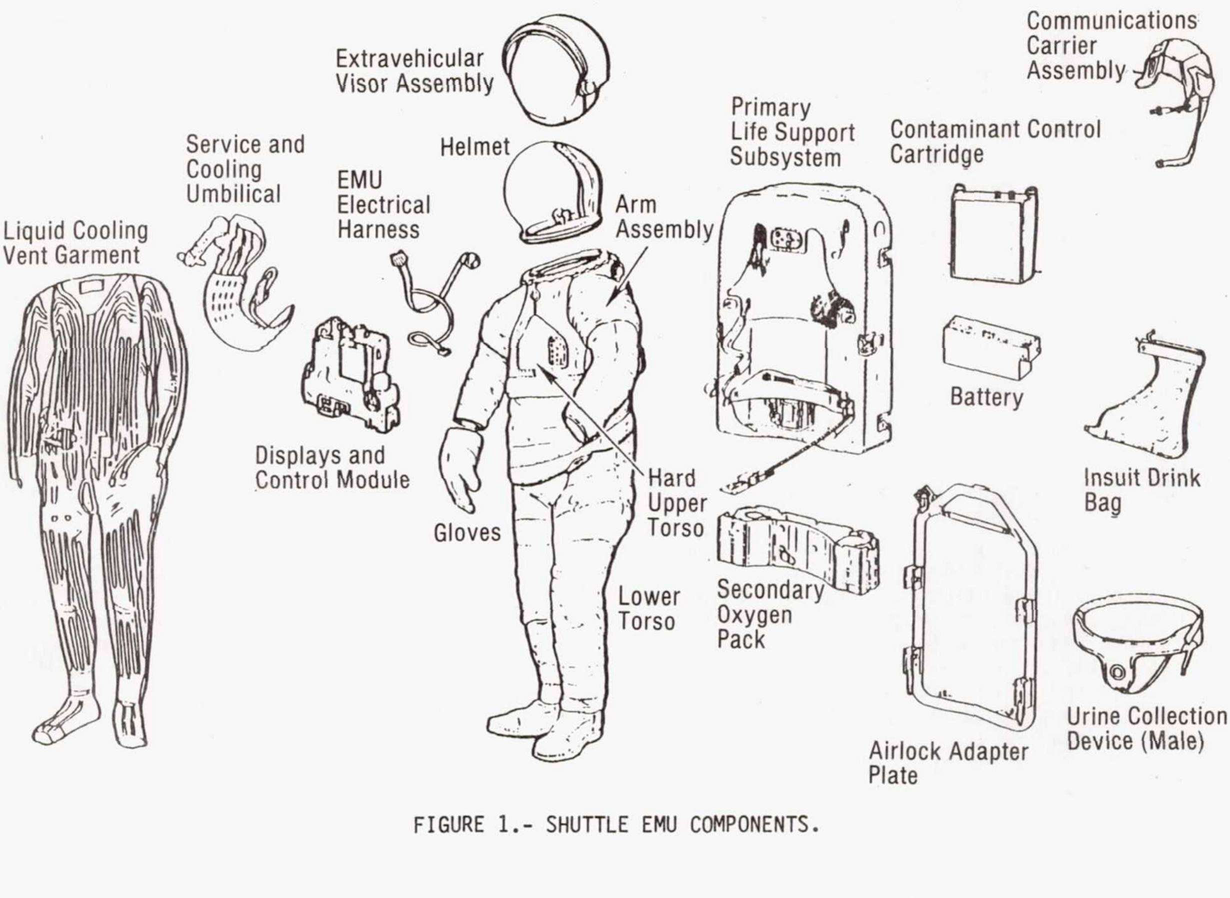

FIGURE 1.- SHUTTLE EMU COMPONENTS.

SHUTTLE	APOLLO
• NO SUIT REQUIREMENT FOR ORBITER LIFE SUPPORT SYSTEM COMPATIBILITY FOR LOSS OF SPACECRAFT CABIN PRESSURE	• COMMAND MODULE AND LUNAR MODULE LIFE SUPPORT SYSTEM COMPATIBILITY FOR LOSS OF SPACECRAFT CABIN PRESSURE
• LIFE SUPPORT SYSTEM INCLUDING DISPLAYS AND CONTROLS MODULE INTEGRATED WITH SUIT PRIOR TO LAUNCH	• PORTABLE LIFE SUPPORT SYSTEM AND REMOTE CONTROLS UNIT ATTACHED INFLIGHT AFTER SUIT WAS DONNED
• INCREASED UPPER TORSO MOBILITY	• BASELINE FOR SHUTTLE COMPARISON
• CONSTRAINED FRONT-TO-BACK DIMENSION FOR ORBITER INTERDECK HATCH PASSTHROUGH	• NO SPECIFIC CONSTRAINT ON SIZE
• NO REQUIREMENT FOR ONE-SIXTH-G LOWER TORSO WALKING MOBILITY	• ONE-SIXTH-G LUNAR SURFACE LOWER TORSO WALKING MOBILITY
• OPERATION FROM 14.7 PSIA TO VACUUM	• OPERATION FROM 5 PSIA TO VACUUM
• ZERO-G ENVIRONMENT USE AND RECHARGE COMPATIBILITY	• BOTH ONE-SIXTH AND ZERO-G ENVIRONMENT USE COMPATIBILITY AND ONLY ONE-SIXTH-G RECHARGE CAPABILITY
• MULTIPLE MISSION AND ASTRONAUT REUSE	• SINGLE MISSION AND INDIVIDUAL ASTRONAUT USE ONLY
• 5TH TO 95TH PERCENTILE FEMALE AND MALE STANDARD SIZES	• MALE CUSTOM SIZES ONLY
• ZERO-G BODY GROWTH SIZING PROVISION	• NO REQUIREMENT - ZERO-G BODY GROWTH IDENTIFIED DURING SKYLAB PROGRAM
• ENHANCEMENT OF MAINTAINABILITY	• BASELINE FOR COMPARISON
• OPERATING LIFETIME OF 6 YEARS FOR SOFT GOODS AND 15 YEARS FOR HARDWARE	• OPERATING LIFETIME OF 4 YEARS

FIGURE 2.- SIGNIFICANT REQUIREMENT DIFFERENCES BETWEEN SHUTTLE AND APOLLO EMU'S.

SHUTTLE	APOLLO
• HARD FIBERGLASS UPPER TORSO STRUCTURE WITH INTEGRAL LSS/DCM BOLT-ON ATTACHMENT, COOLING WATER AND VENT GAS DUCTING, AND ELECTRICAL HARNESS ROUTING	• SOFT FABRIC TORSO WITH BRACKETS FOR PLSS/RCU HARNESS STRAP ATTACHMENT; SEPARATE INTERNAL COOLING WATER AND VENT GAS DUCTING; AND MULTIPLE GAS, WATER, AND ELECTRICAL CONNECTORS
• GIMBALED SHOULDER JOINT WITH SCYE BEARING TO INCREASE UPPER ARM MOBILITY; WAIST BEARING TO PROVIDE UPPER TORSO ROTATION CAPABILITY WITH ASTRONAUT IN EV FOOT RESTRAINTS	• CABLE RESTRAINED SHOULDER CONVOLUTE JOINT FOR UPPER ARM MOBILITY, CABLE/PULLEY RESTRAINED WAIST AND HIP CONVOLUTES FOR WALKING CAPABILITY
• DENSE LSS PACKAGING - 80% DENSITY	• RELAXED LSS PACKAGING - 40% DENSITY
• FLANGE MOUNTING OF LSS TO SUIT	• STRAPS, HOSES, AND ELECTRICAL LINES USED TO CONNECT LSS TO SUIT
• LSS OPTIMIZED TO LIMIT EMU FRONT-TO-BACK DIMENSION TO 19-3/4 IN.	• EMU FRONT-TO-BACK DIMENSION OF 30 IN.
• AUTOMATIC ACTIVATION OF EMERGENCY OXYGEN SYSTEM	• ASTRONAUT MANUAL ACTIVATION OF EMERGENCY OXYGEN SYSTEM
• SINGLE UMBILICAL CONNECTION FOR LSS RESERVICE	• MULTIPLE UMBILICAL CONNECTIONS FOR LSS RESERVICE
• INTERGRAL MOTOR-DRIVEN LSS WATER PUMP, FAN, AND WATER SEPARATOR ASSEMBLY	• INDIVIDUALLY POWERED LSS FAN AND WATER PUMP, WITH WATER SEPARATOR AS SEPARATE COMPONENT
• SUBLIMATOR PROVIDES FOR UMBILICAL IVA OR EVA OPERATION BY USING CHILLED WATER FOR COOLING VENTILATING GAS AS WELL AS HEAT TRANSPORT WATER LOOP	• NO PLSS-TO-SPACECRAFT UMBILICAL CAPABILITY
• ASTRONAUT PROVIDED WITH SYSTEM PERFORMANCE STATUS, INCLUDING EXPENDABLES, WARNINGS, AND CORRECTIVE ACTION PROCEDURES	• ASTRONAUT PROVIDED WARNINGS, OXYGEN QUANTITY, AND SUIT PRESSURE ONLY
• SUIT REDUNDANT AXIAL LOAD RESTRAINTS FOR ALL FABRIC PRESSURE RESTRAINT ELEMENTS	• REDUNDANT SUIT AXIAL LOAD RESTRAINT FOR KNEE CONVOLUTE JOINT ONLY
• SUIT SIZING COMPONENTS MODULARITY WITH FLANGE-MOUNTED FABRIC PRESSURE RESTRAINT AND BLADDER HARDWARE ATTACHMENT. SEPARABLE SIZED COMPONENTS INCLUDE UPPER ARMS, LOWER ARMS, GLOVES, WAIST, LEG SECTION, AND BOOTS	• LIMITED SIZE COMPONENT MODULARITY (GLOVES) WITH SEWN AND ADHESIVE OVERTAPED PRESSURE RESTRAINT AND BLADDER TO CONVOLUTE JOINT INTEGRATION. CORD-WRAPED AND ADHESIVE-BONDED FABRIC PRESSURE RESTRAINT AND BLADDER HARDWARE ATTACHMENT
• LOW ENDURANCE AND AGE LIFE APOLLO COMPONENTS ELIMINATED:	
• METAL DISCONNECT ENTRY CLOSURE	• PRESSURE-SEALING SLIDE FASTENER ENTRY CLOSURE
• FABRIC WEBBING WITH METAL ATTACHMENT BRACKETS FOR AXIAL RESTRAINT LOADS	• METAL CABLES AND SWAGES FOR AXIAL RESTRAINT LOADS
• POLYURETHANE-COATED NYLON BLADDER FABRICS	• NEOPRENE-COATED NYLON BLADDER FABRIC
• REDUCED COST SUIT MANUFACTURING PROCESSES:	
• HEAT-SEALED BLADDER SEAMS	• SEWN AND ADHESIVE BONDED AND TAPED BLADDER SEAMS
• FLAT PATTERNED FABRIC JOINT ELEMENTS	• DIPPED CONVOLUTE JOINT ELEMENTS
• MULTIPLE LAYER SEWN-THROUGH SEAMS FOR THERMAL MICROMETEOROID GARMENT INSULATION	• INDIVIDUAL LAYER TAPED SEAMS FOR THERMAL MICROMETEOROID GARMENT INSULATION

FIGURE 3.- DESIGN DIFFERENCES BETWEEN SHUTTLE AND APOLLO EMU'S.

The two major challenges met in the development of the Shuttle EMU are

1. Enhancement of astronaut EVA operations

2. Capability for multiple mission reuse by male and female astronauts

The design approaches and problems experienced in meeting these challenges are presented in this paper.

ENHANCEMENT OF ASTRONAUT EVA OPERATIONS

LIFE SUPPORT SYSTEM AND SPACE-SUIT INTEGRATION

Elimination of the requirement that the space suit be compatible with the Orbiter life support system for astronaut protection in the event of loss of cabin pressure provided the first opportunity in U.S. manned-space-flight history to optimize the EMU design solely for EVA operation. Deleted were design-compromising interface requirements between the space suit and the crew station, the couches, and the vehicle life support system. Operating with these requirements necessitated assembly and disassembly of the Apollo EMU in flight, and attachment and removal of the portable life support system while the space suit was worn. This approach required separate portable life support system attachment straps and mounting brackets, with multiple hoses and connections for ventilation oxygen, emergency pressurization, and cooling water. Electrical cables had to be connected and checked out before EVA. The optimization of the Shuttle EMU for EVA operations shown in figure 4 was accomplished by completely integrating the life support system and its controls and displays into the upper torso portion of the space suit.

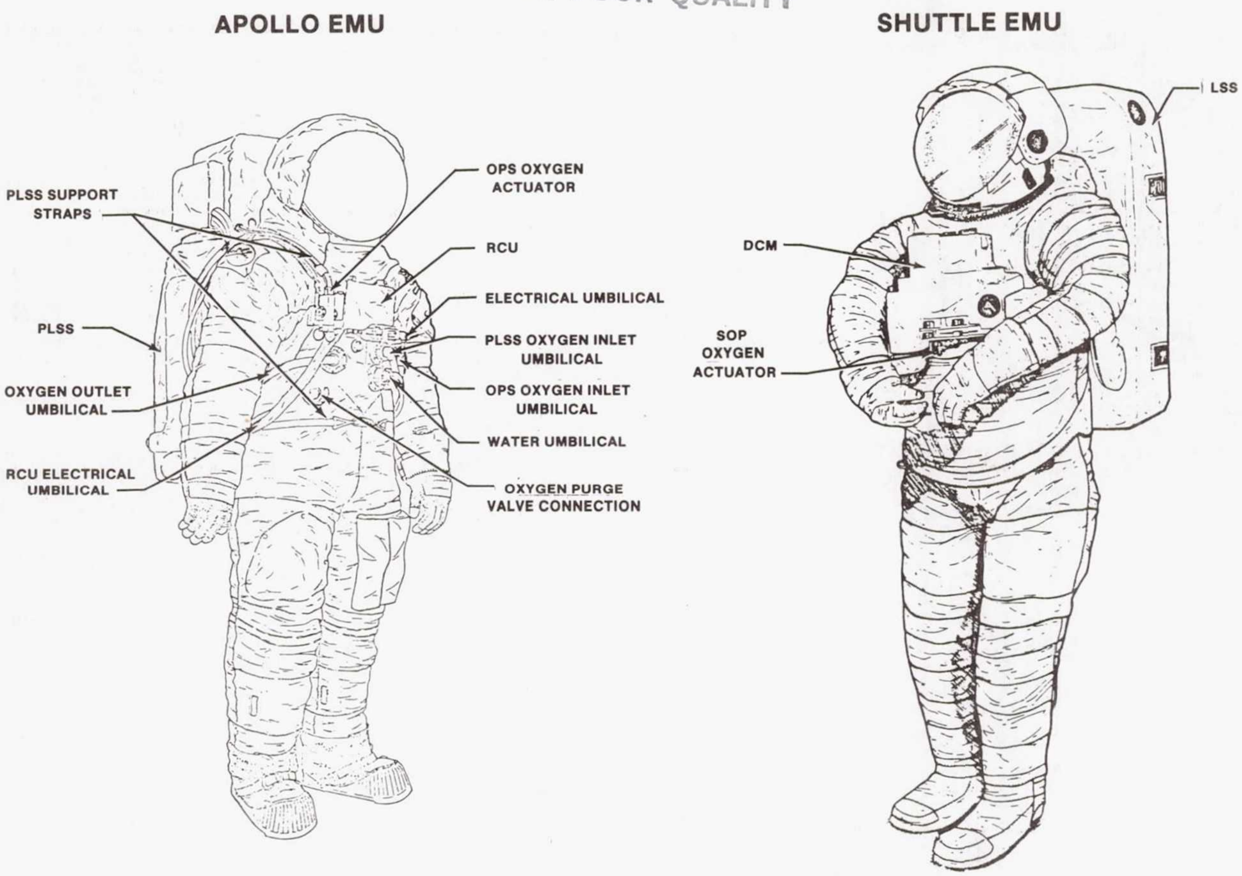

FIGURE 4.- PLSS/DCM TO SPACE SUIT ATTACHMENT METHODS.

HARD UPPER TORSO CONFIGURATION

A rigid aluminum, formed upper torso that conformed to the shape of the body was initially selected to provide a dimensionally fixed life support system mounting structure. This hard upper torso (HUT) design provided the capability to incorporate shoulder bearings, which significantly increased astronaut arm mobility. This configuration was changed, however, after excessive difficulty in donning and doffing satisfactorily was revealed during development testing.

The donning and doffing problem caused by the aluminum HUT and shoulder bearing configuration was solved by incorporating gimbaled shoulder bearings which pivoted at the hard upper torso, with a laminated fabric bellows interface for pressure integrity. This design increased upward movement of the upper arms during donning. The complex geometry of the shoulders and neck area resulting from this design change made aluminum forming of the HUT undesirable. Fiberglass material was then selected. This material permitted molding of the shell and the integral layup and bonding of the gas ventilation and cooling water ducting into the upper torso structure and, thus, provided a smooth and more comfortable internal profile.

LIFE SUPPORT SYSTEM DESIGN APPROACH

A closed-loop life support system similar to the configuration developed for the Apollo Program was selected for Shuttle use, as shown schematically in figure 5, rather than the umbilical-type systems used during the Gemini and Skylab Programs. The closed-loop concept is superior for the Shuttle application since vehicle dependency is minimized and astronauts are freed from managing bulky umbilicals.

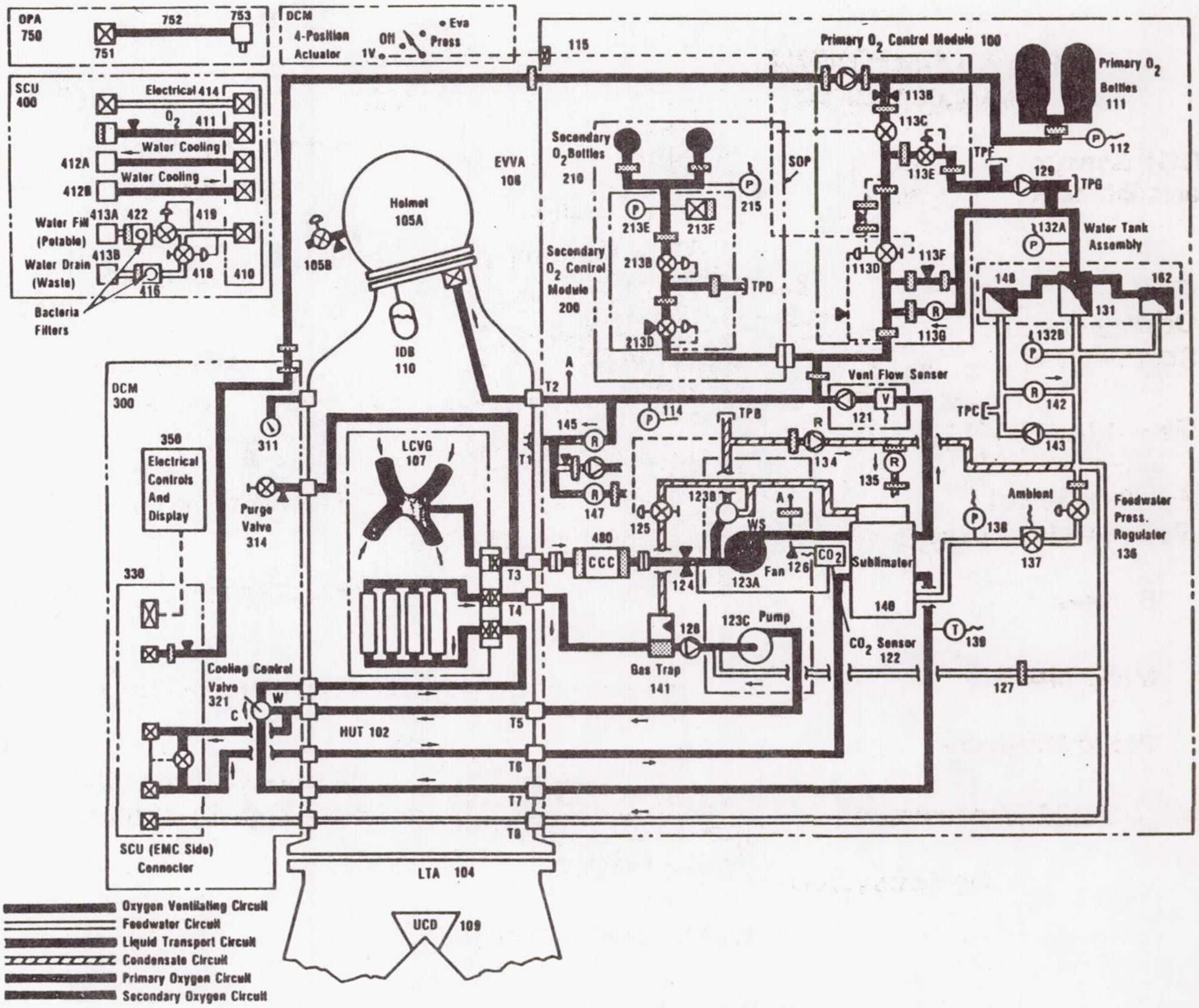

FIGURE 5.- SPACE SHUTTLE EMU SCHEMATIC.

The primary life support system (PLSS) of the Shuttle EMU provides cooling of the astronauts by the circulation of cool water through small-diameter tubes contained in the liquid cooling and ventilation garment. A water sublimator and heat exchanger, similar in concept to that of the Apollo unit, is used to cool the water and also to cool and dehumidify the oxygen in the recirculating ventilation loop. As in the Apollo EMU, lithium hydroxide and charcoal are used to remove carbon dioxide (CO_2) and odors from the oxygen gas stream of the Shuttle EMU.

Makeup oxygen is regulated to 4.3 psi from twin 1000-psi PLSS storage tanks shown in figure 6. A secondary oxygen package (SOP) located below the PLSS provides 30 minutes of emergency purge flow from two 6000-psi spheres. The SOP is brought on standby just before EVA, using the valve actuator shown in figure 7, and provides flow automatically any time suit pressure drops below 4.0 psi. Controls and displays are located on the displays and control module (DCM) (fig. 8), which is mounted on the front of the HUT. A silver oxide/zinc battery provides power for the radio, the caution and warning system, and the fluid circulation equipment.

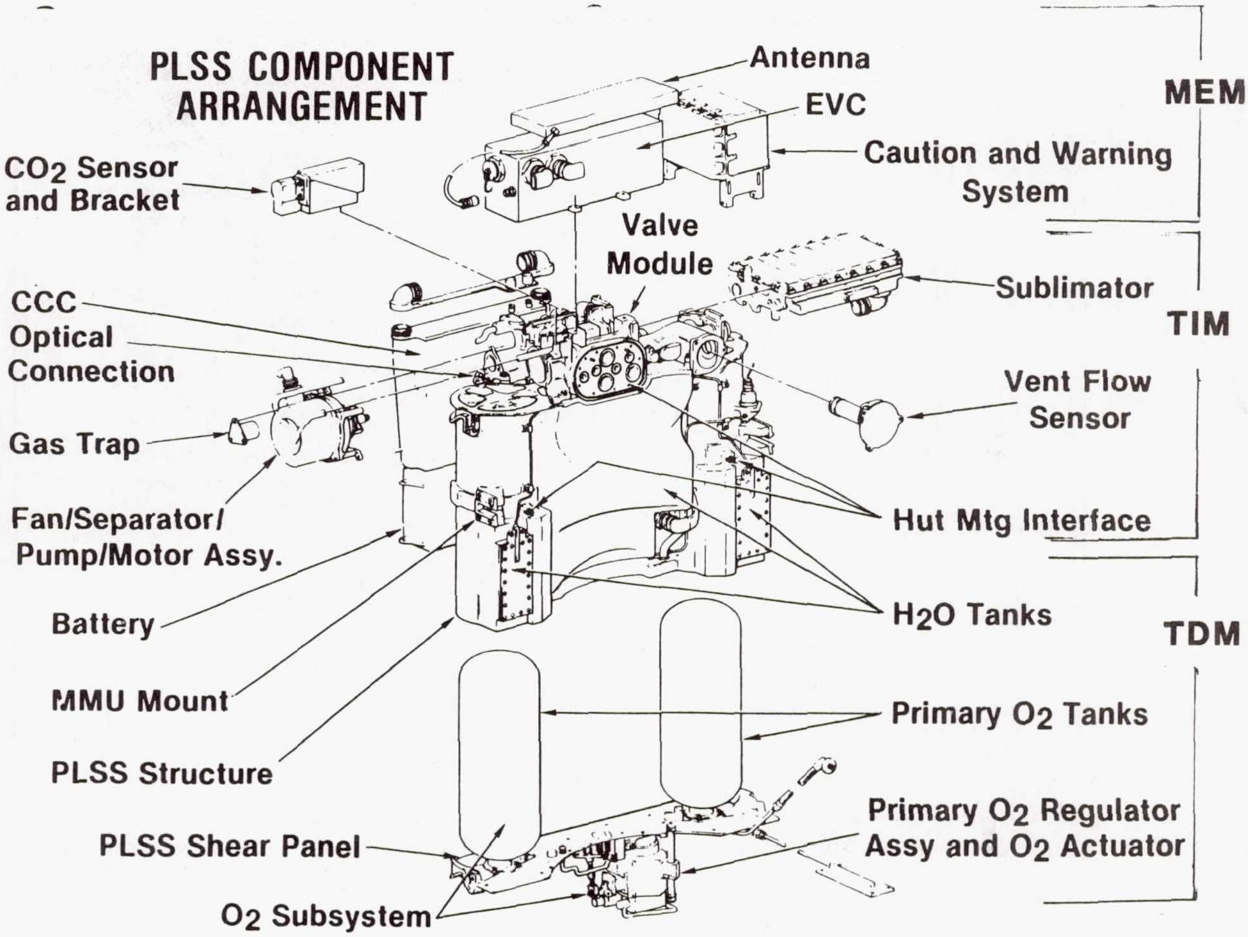

FIGURE 6.- SHUTTLE EMU PLSS.

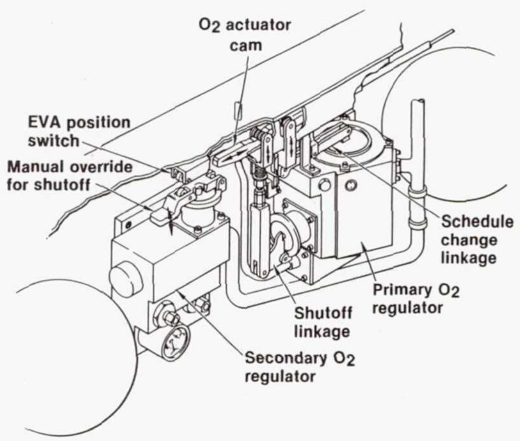

FIGURE 7.- SOP WITH FOUR-POSITION ACTUATOR VALVES AND LINKAGE.

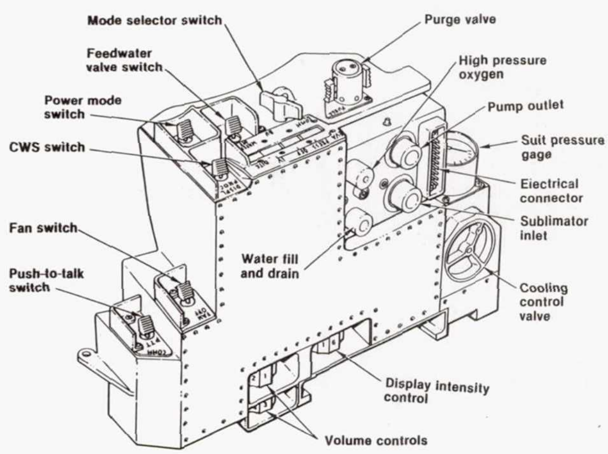

FIGURE 8.- DCM FRONT VIEW.

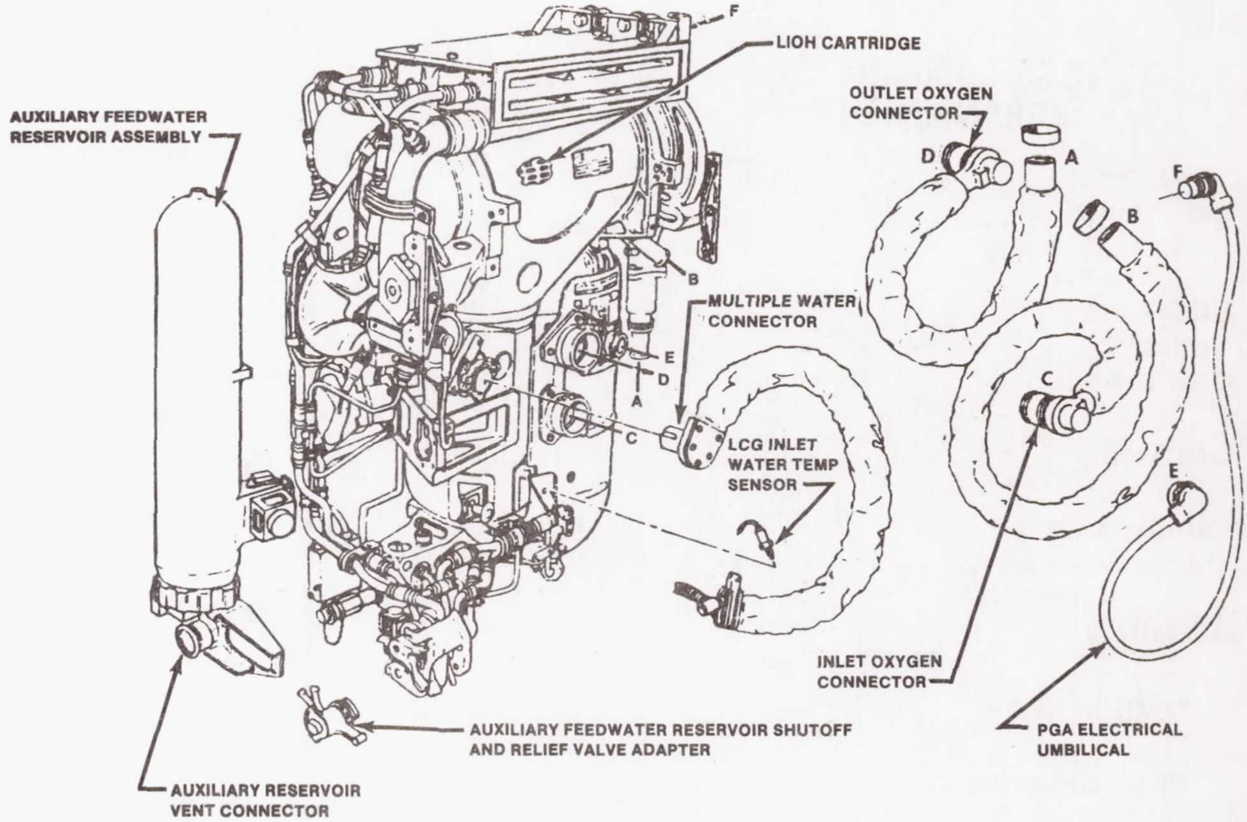

FIGURE 9.- APOLLO EMU PLSS FLUID HOSES.

EMU FRONT-TO-BACK DIMENSION

Shuttle EMU designers found that the Orbiter interdeck hatch passthrough requirement imposed a front-to-back dimensional constraint which ruled out conventional plumbing methods for coupling the components and subsystems of the EMU. Figures 9 and 10 show the various runs of tubing and hoses required for the Apollo life support system. Selection of this approach for Shuttle would have increased the envelope size to unacceptable dimensions, because of not only the physical size of the hoses and fittings involved but also the space required for tool insertion in assembly and disassembly.

The approach selected to solve this problem was modularization of the entire life support system. The Shuttle PLSS is divided into the following three modules (fig. 6).

1. Time dependent module (TDM)

2. Time independent module (TIM)

3. Major electronics module (MEM)

The TDM consists of components the physical size of which is a function of mission time or total metabolic load or both. These components are the water tanks, the battery, the contaminant control cartridge (CCC), and the oxygen subsystem. The water tanks are shaped to conform to the contour of the back of the HUT and, in combination with protective shrouds around the oxygen tanks, form an integrated structure for the PLSS. This structure provides attachment points for the airlock adapter plate (AAP), used for flight stowage and as a holding fixture for donning and doffing, and for the manned maneuvering unit (MMU). The CCC and the battery are nested together in a rear cavity of the PLSS; this configuration provides easy access for recharge and maintains a dense package.

The TIM consists of a valve module, which provides internal connecting water and gas lines, plus provisions for mounting cartridge-type valves, transducers, a sublimator, and rotating machinery.

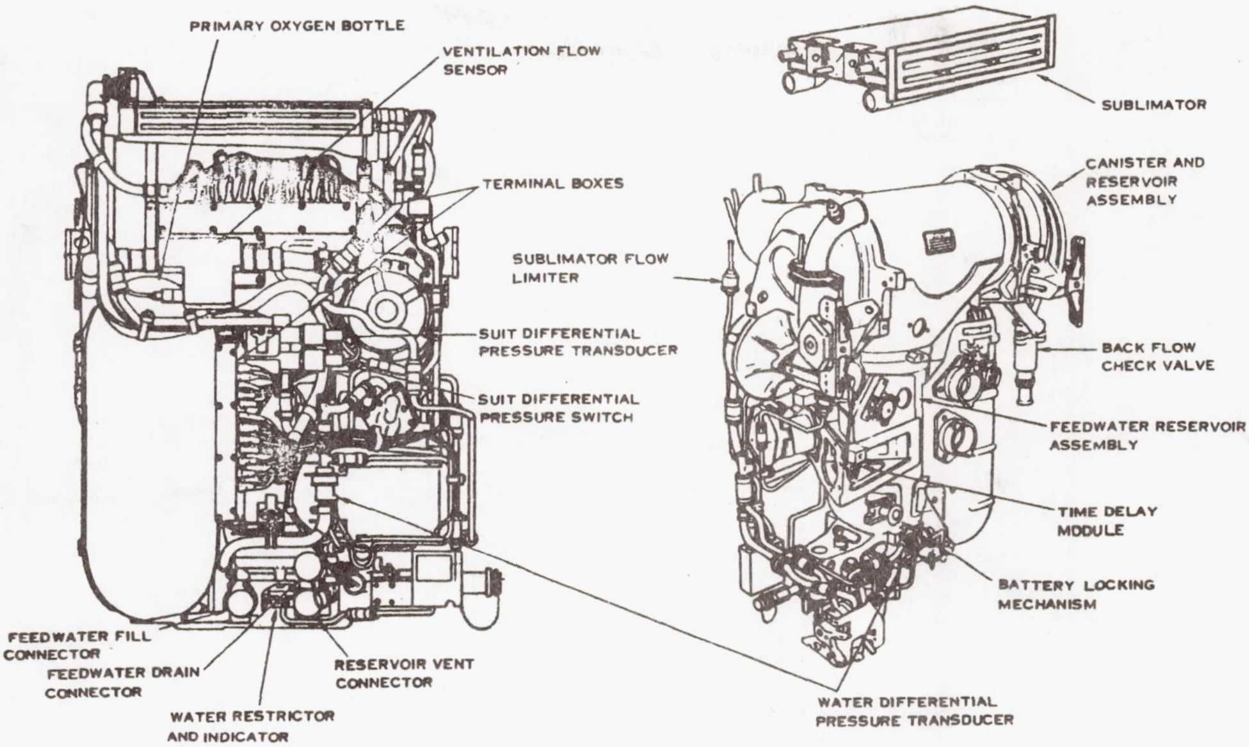

FIGURE 10.- APOLLO EMU PLSS COMPONENT LAYOUT.

The MEM components, which are mounted on top of the TIM, consist of the caution and warning system, the extravehicular communications radio, and a CO_2 sensor. The SOP fits snugly at the bottom of the PLSS.

The packaging density achieved in the Shuttle life support system is 80 percent, compared to 40 percent for the Apollo life support system.

ELIMINATION OF EXPOSED OXYGEN VENTILATION HOSES

By flange mounting the PLSS and the DCM to the HUT as shown in figure 1, designers not only enhanced Shuttle EMU packaging and met the 19-3/4-inch front-to-back dimensional requirement, they also solved one of the most worrisome problems of the Apollo EMU design - exposed ventilation hoses. Rupture or severe damage to the Apollo PLSS hoses could have had catastrophic results, since severe loss of pressure integrity could easily have exceeded emergency oxygen system capability.

ASTRONAUT MOBILITY

One of the more important requirements for efficient performance of EVA tasks in the zero-g environment is astronaut upper body mobility. Shuttle EMU upper body mobility is superior to that of the Apollo EMU as a result of incorporating gimbaled bearing shoulder joints, a gimbaled wrist joint in each glove, and a waist bearing. This configuration resulted in the increased mobility ranges shown in figure 11.

The objective to increase lower torso mobility for the Shuttle EMU was initially considered but was not implemented because of the lack of a walking requirement in zero g and the disadvantages of additional design complexity, weight, and increased development and manufacturing costs. As a result, the lower body mobility of the Shuttle EMU is less than that of the Apollo EMU.

The flat patterned fabric joints shown in figure 12 were selected for the Shuttle EMU because of their increased flexure cycle life and reduced manufacturing cost.

UPPER BODY MOBILITY JOINTS	MOTION	SHUTTLE EMU	APOLLO EMU
● SHOULDER	LATERAL-MEDIAL	205°	135°
	FLEXION	196°	158°
	ADDUCTION-ABDUCTION	123°	101°
● ELBOW	FLEXION	133°	137°
● WRIST	ADDUCTION-ABDUCTION	148°	128°
	FLEXION-EXTENSION	111°	92°
● WAIST	ROTATION	212°	49°
LOWER BODY MOBILITY JOINTS			
● WAIST	FLEXION	102°	112°
● HIP	FLEXION	63°	90°
● KNEE	FLEXION	82°	106°
● ANKLE	FLEXION-EXTENSION	102°	103°

FIGURE 11.- SPACE-SUIT MOBILITY-JOINT RANGE COMPARISON.

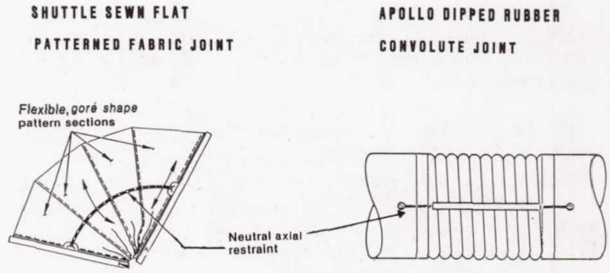

FIGURE 12.- SPACE-SUIT MOBILITY-JOINT DESIGN APPROACHES.

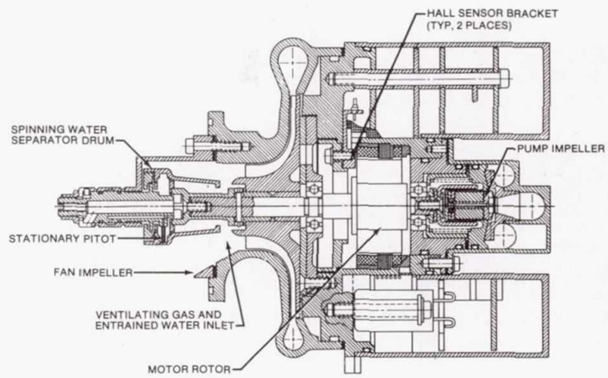

FIGURE 13.- FAN/PUMP/SEPARATOR ASSEMBLY.

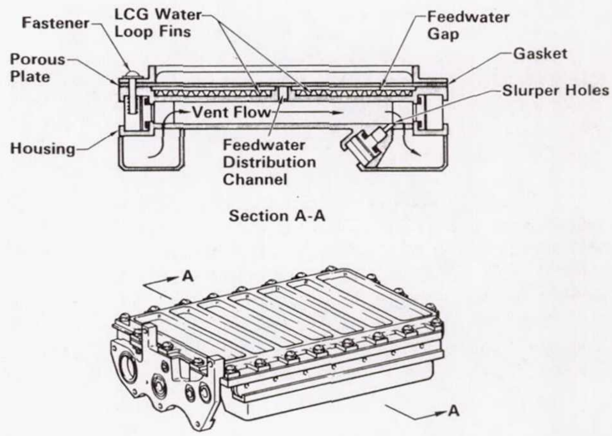

FIGURE 14.- SUBLIMATOR.

FAN OPERATION AT SEA-LEVEL ATMOSPHERE

The Shuttle EMU provides astronaut ventilation during a 3-1/2-hour oxygen prebreathe period at sea-level pressure followed by airlock depressurization to vacuum and suit pressure control at 4.3 psia. In Apollo missions, the 5-psia, 100-percent oxygen lunar module cabin atmosphere eliminated the need for prebreathing and reduced the fan design-load requirements. The requirement for Shuttle EMU fan operation over a wide range of pressures was solved by the development of a motor with speed limiting circuitry so that virtually all operating conditions are met within speed variations of less than 15 percent. To sense rotor position, two Hall-effect electromagnetic sensors shown in figure 13 are used for commutation, and power input is "chopped" at the lower pressure during EVA to control speed and decrease power consumption. The Apollo EMU fan was limited to momentary operation at sea-level pressure to prevent overheating of its motor winding.

PLSS OPERATION IN ZERO g

Separation and removal of humidity in the PLSS ventilation loop occurs in two stages. First, the gas stream is cooled in the sublimator and the resulting condensate spreads over fins coated with a hydrophilic substance. It is then transported by pressure differential through holes into a collection manifold, called the "slurper" (fig. 14), where the mixture of ventilation oxygen and water enters a rotating drum and stationary pitot assembly. The drum is mounted to the motor shaft at the fan inlet shown in figure 13, and the driving force for the slurper is the fan pressure rise. When spinning at about 19 000 rpm, the tapered drum slings the water droplets to the periphery of the housing, where the water stream contacts a stationary pitot tube. As much as 25 psid pressure can be developed in this manner, and the water is pumped either into the EMU water storage tanks or directly to the sublimator for immediate heat-rejection use. The water-free oxygen stream is returned to the fan inlet. Thus, unlike the Apollo EMU wherein condensate was stored and dumped at the end of an EVA, the Shuttle EMU makes use of metabolically generated water and thereby allows a reduction in stored water requirements. This approach aided in the attainment of the compact PLSS packaging.

The tasks of ventilation at various system pressures, water circulation, and moisture removal from the ventilation loop are accomplished by the integrated fan/pump/separator assembly shown in figure 13. The high efficiency of this assembly is illustrated by noting that the Shuttle water pump consumes only 2 watts, compared to 10 watts for the Apollo pump.

In addition to water in the gas stream, the opposite problem also exists - the presence of as much as 30 cubic inches of unwanted gas bubbles in the cooling water loop. These bubbles are produced by (1) attachment of a liquid cooling garment partly filled with water or (2) evolution due to the system pressure reduction during depressurization. In Apollo missions, lunar 1/6-g force provided the means of separation and the loop was periodically "burped" to remove gas. In the Shuttle EMU, a fine mesh (18 micrometer) cylindrical screen shown in figure 15 receives the full 240-lb/hr cooling loop waterflow, delivered by a centrifugal pump magnetically coupled to the motor shaft. The screen has a very low flow resistance to water and a very high (comparative) resistance to gas flow so that water flows radially outward, and gas bubbles and a small flow of water are carried out through the exit orifice and into the water separator described previously.

IN-FLIGHT CHECKOUT AND STATUS MONITORING

During Apollo missions, the EMU was donned and checked following a written checklist, and EMU performance during EVA was monitored by ground controllers using telemetry, which required an extensive real-time EVA support team. In addition to an oxygen pressure tank "gas gage," the Apollo EVA astronaut had a suit pressure gage and five electromechanical warning flags to alert him of EMU system malfunctions.

The Shuttle EMU caution and warning system shown in figure 16 uses a microprocessor and slightly more than 5 kilobits of memory to provide the user with procedures to be used during checkout, to allow tracking of limiting consumables during EVA, and to provide notification of out-of-limit conditions with appropriate corrective actions. This approach puts the information directly at the point where action can be taken - with the user. Continuing the effort to make the EMU "user friendly," all controls and displays are located on the DCM shown in figure 8. By contrast, the Apollo PLSS had the suit cooling water control valve, the sublimator on/off valve, and the primary oxygen supply valve located on a remote lower corner of the backpack, which was difficult to reach.

IN-FLIGHT RECHARGE

In-flight recharge of water, oxygen, and electrical power is accomplished through a common connector located on the DCM shown in figure 8. One connection accomplishes the same task as several connections made separately on the Apollo backpack. The service and cooling umbilical (SCU), which mates to the common connector, also allows the recirculation of water for cooling the astronaut during suited operations before airlock depressurization using the PLSS pump and an Orbiter heat exchanger. The Apollo EMU had no such PLSS capability. Removal of the CCC involves unzipping a flap on the PLSS thermal cover, releasing two latches, and pulling out the expended can, with a reversal of steps to install a new one. The battery can also be replaced instead of being recharged in place to expedite reuse. Total recharge time is about 1 hour if the battery is replaced rather than being recharged. Battery recharge takes approximately 19 hours.

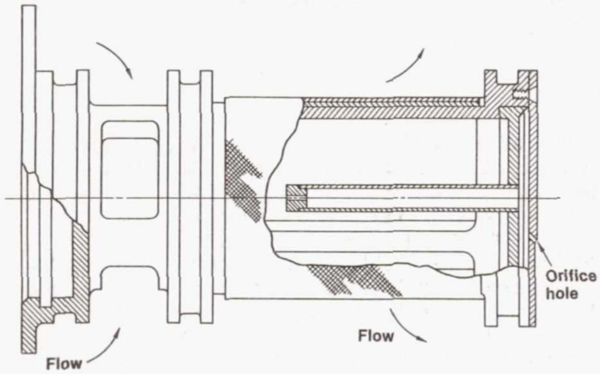

FIGURE 15.- GAS TRAP.

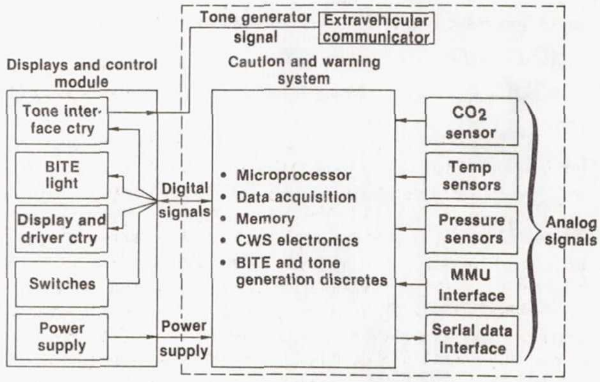

FIGURE 16.- CAUTION AND WARNING SYSTEM BLOCK DIAGRAM.

SPACECRAFT UMBILICAL OPERATION

Although umbilicals have appreciable drawbacks from the crew handling aspect, there are cases in which umbilical EVA capability might be useful. For example, consider a payload benefiting from EVA but with a sensitivity to water vapor contamination. Use of the standard Shuttle EMU would not be appropriate because of the EMU sublimator exhaust, but water vapor emission could be avoided by using suit cooling water chilled by the vehicle's radiator-based heat-rejection system and circulated by the PLSS pump. Another instance might require that an astronaut plan to extend an EVA past the expendables limits. By using an extended length SCU with its water circulation, power, and oxygen lines, the Shuttle EMU will provide this capability.

CAPABILITY FOR MULTIPLE MISSION REUSE BY MALE AND FEMALE ASTRONAUTS

SPACE-SUIT SIZING TO ACCOMMODATE FEMALES AND A LARGE SIZE POPULATION OF ASTRONAUTS

The large number of planned Shuttle missions results in a large astronaut size population to be accommodated with correctly sized and fitted space suits. The scope of the requirement to satisfactorily fit both female and male Shuttle astronauts whose body dimensions vary from 5th percentile female to the 95th percentile male is shown in figure 17. The design approach to meet this large variation in body dimensions was to use a modular system of interchangeable, standard-sized components shown in figure 18. Unlike the Apollo approach to manufacture custom-sized suits using individual astronaut's measurements, the Shuttle suit design approach provides the capability to "custom-assemble" previously manufactured and "on the shelf" standard size components. After mission use, the Shuttle suit is disassembled and components are made available for subsequent mission use by another astronaut. The critical design feature necessary to allow for the modularity of the standard size components was the flange mounting of fabric restraint and bladder components to joint bearings and disconnects shown in figure 19. By removing a series of circumferentially spaced screws and a mounting ring, different standard-sized fabric components can be interchanged easily. Pressure integrity between the fabric bladder material and the bearing or disconnect is assured by use of an O-ring seal. The Apollo suit design approach used adhesive bonding of the fabric bladder to hardware with a cord overwrap to provide adequate structural integrity. Removal of either side of this interface was difficult and required considerable time and effort since adhesive removal, surface cleaning, and long adhesive cure times were necessary.

Figure 20 shows the different standard-sized suit components required for the pressure retention portion of the Shuttle EMU space suit. Standard sizes of thermal micrometeoroid garment components,

CRITICAL BODY DIMENSIONS	5TH PERCENTILE FEMALE, IN. -TO-	95TH PERCENTILE MALE, IN.	MAX. SIZE VARIATION, IN.
CHEST BREADTH	9.9	14.5	4.6
CHEST DEPTH	8.2	10.9	2.7
CHEST CIRCUMFERENCE	32.4	43.2	10.8
SHOULDER CIRCUMFERENCE	36.7	50.6	13.9
SHOULDER BREADTH	15.2	18.4	3.2
SHOULDER HEIGHT	48.4	61.7	13.3
FINGERTIP SPAN	60.0	77.0	17.0
TORSO LENGTH	22.1	27.7	5.6
HIP BREADTH	12.4	15.3	2.9
CROTCH HEIGHT	26.8	36.8	10.0
KNEE HEIGHT	15.0	21.3	6.3
STANDING HEIGHT	59.9	74.3	14.4

FIGURE 17.- SHUTTLE EMU SPACE SUIT ASTRONAUT SIZE REQUIREMENTS AND VARIATION.

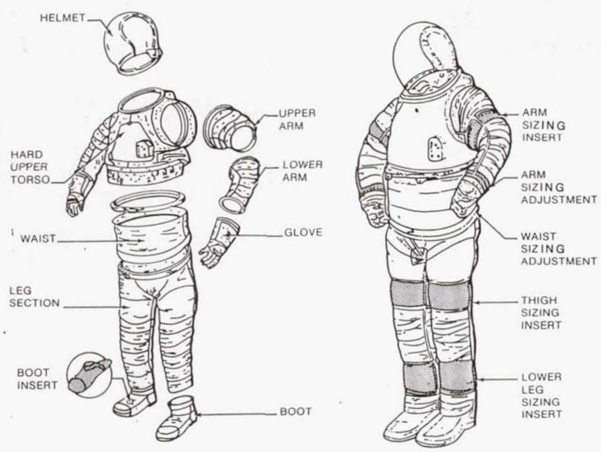

FIGURE 18.- SHUTTLE EMU SPACE-SUIT COMPONENT MODULARITY AND LENGTH SIZING ADJUSTMENTS.

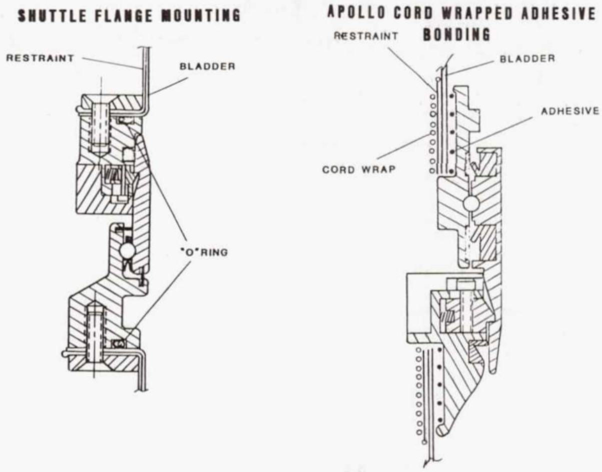

FIGURE 19.- SPACE-SUIT PRESSURE RESTRAINT AND BLADDER TO HARDWARE ATTACHMENT METHODS.

liquid cooling ventilation garment, and communication carrier are also necessary. The quantity of possible size combinations of each major component of the space suit is also identified.

AGE AND OPERATING LIFE

The Shuttle EMU is designed for multiple mission reuse, as compared to the single mission use required for the Apollo EMU. This design resulted in increased age and operating life requirements for the Shuttle EMU space-suit assembly and life support system.

Space-Suit Assembly

To accomplish multiyear, multimission capability for the suit, a requirement for 6 years age life for nonmetallic materials and 15 years for metallic hardware was implemented. This compares with the 4-year age life capability of the Apollo EMU suit design. The 6-year age life requirement resulted in the selection of polyurethane-coated nylon fabric for the Shuttle suit pressure bladder in lieu of the neoprene-coated nylon fabric and the combination neoprene and natural rubber convolute compound used in the Apollo suit. The 6-year life requirement resulted in a 462-hour manned pressurized operating lifetime requirement as compared with the 105-hour capability of the Apollo EMU suit design.

Low endurance life components used for the Apollo suit had to be replaced as a result of this longer life requirement. These included the Apollo suit pressure-sealing slide fastener used for donning and doffing. This component was found to be life limited to approximately 50 opening and closing cycles, with an average of 3 replacements required in each Apollo flight suit before launch. The Shuttle suit design uses an oval-shaped metal disconnect to attach the hard upper torso to the lower torso assembly, and the device is not cycle life limited.

To increase the reliability of the suit for multiple mission use, a redundant axial load restraint design shown in figure 21 was incorporated into all fabric pressure restraint elements. This design consists of independent webbings, sewn together to maintain joint stability, which have separate hardware attachment brackets. In the event of a primary restraint webbing failure, the redundant restraint webbing and brackets are capable of maintaining suit pressure integrity to enable completion of three 7-hour EVA's on a mission with minimum effect on astronaut mobility.

Figure 22 shows the different bladder seam design approaches used for the Shuttle and Apollo EMU suits. The heat-sealed bladder seam design was selected for the Shuttle suit to reduce seam leakage, which was a recurring problem with the Apollo suits, and also to reduce manufacturing time and cost.

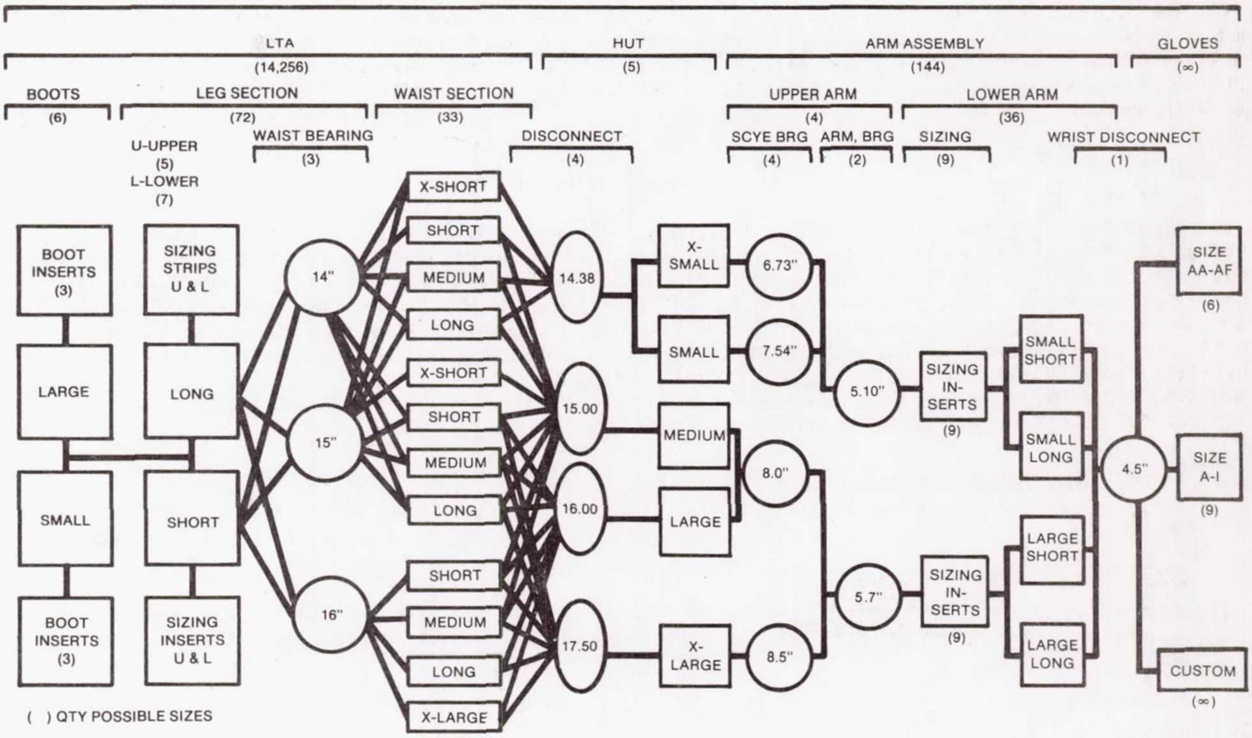

FIGURE 20.- SHUTTLE EMU SPACE-SUIT SIZING SYSTEM - PRESSURE RETENTION ASSEMBLY.

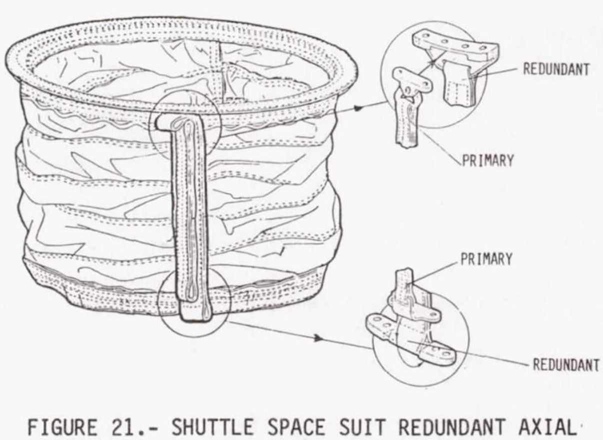

FIGURE 21.- SHUTTLE SPACE SUIT REDUNDANT AXIAL LOAD RESTRAINT DESIGN.

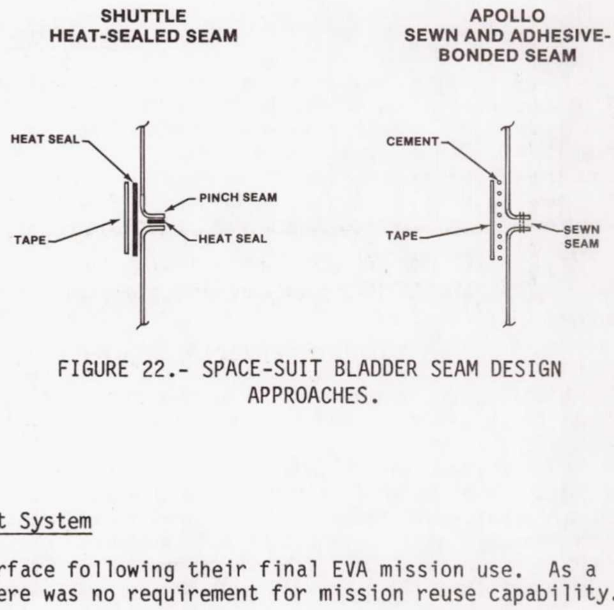

FIGURE 22.- SPACE-SUIT BLADDER SEAM DESIGN APPROACHES.

Life Support System

The Apollo backpacks were left on the lunar surface following their final EVA mission use. As a result, required operating lifetime was low, and there was no requirement for mission reuse capability.

The goal of 15-year service life for the Shuttle life support system with mission to mission reuse was approached by determining from the mission model and required hardware turnaround time the number of units required and, then, certifying for the required number of operating hours and cycles. For example, a typical EMU fan motor can be expected to operate for slightly more than 1500 hours from STS-11 through fiscal year 1995, and the DCM status switch can be expected to undergo about 145 000 cycles.

Naturally, a considerable amount of ground maintenance will be necessary over this long time period. The modular accessible design shown in figure 6 enhances rapid replacement of components. For example, 13 components plug, cartridge fashion, into the valve module.

The Shuttle EMU aluminum porous plate sublimator is much smaller (one-sixth the plate area) and much lighter (3.2 pounds compared to 7.7 pounds) than the Apollo EMU unit. Its small size helped in achieving the reduced Shuttle EMU envelope. Significantly less plate area is required, and a single porous plate, which is bolted to one side of the unit, is used. Since it is removable, it may be cleaned and/or replaced.

CONCLUDING REMARKS

The majority of the operational EVA experience planned for the Space Shuttle lies ahead. However, the success of the EVA demonstration conducted during the STS-6 mission is significant. Also, although the actual Shuttle EVA mission time to date is relatively small (fig. 23), the Shuttle EMU has already exceeded EMU time at vacuum (fig. 24) for the total Apollo Program, principally because of the 15-year-life certification and chamber training of astronauts conducted for each Shuttle mission. Figure 25 shows the accumulated manned operating pressure time of the EMU space suit, including operating time in which only life support system mockups are used, such as for underwater neutral-buoyancy training. Based on this impressive accumulation of EMU system operational time, the current indications are that the EMU development challenges are being met.

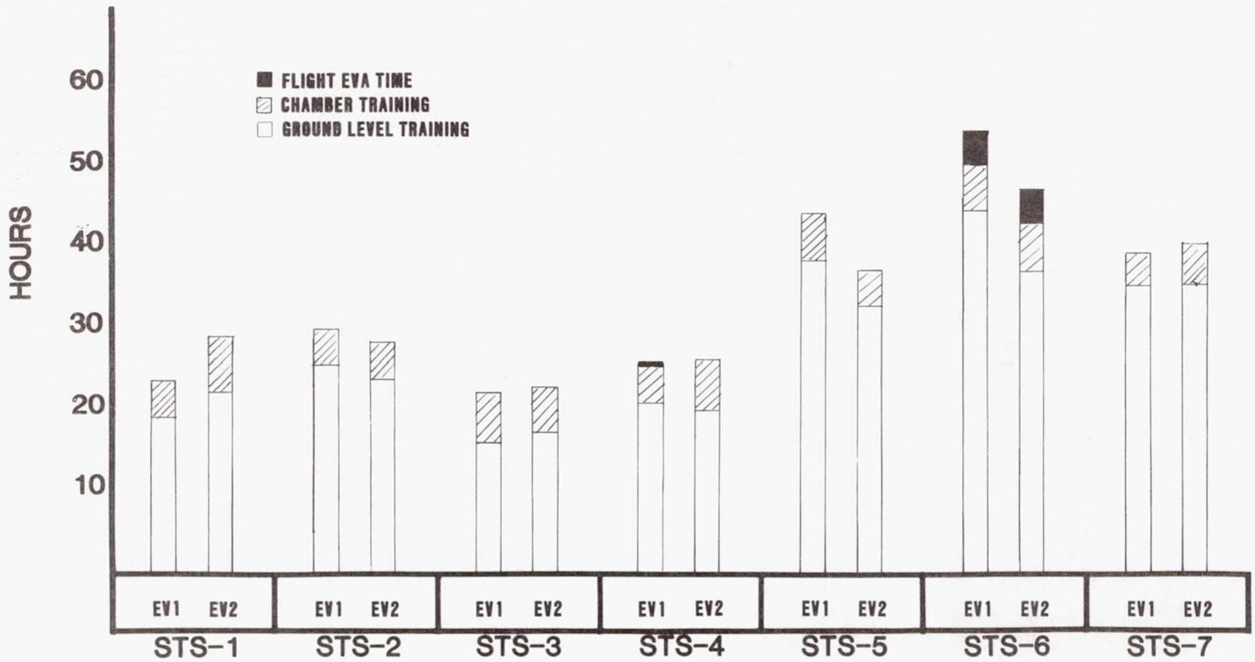

FIGURE 23.- SHUTTLE EMU SUITED HOURS OF USE.

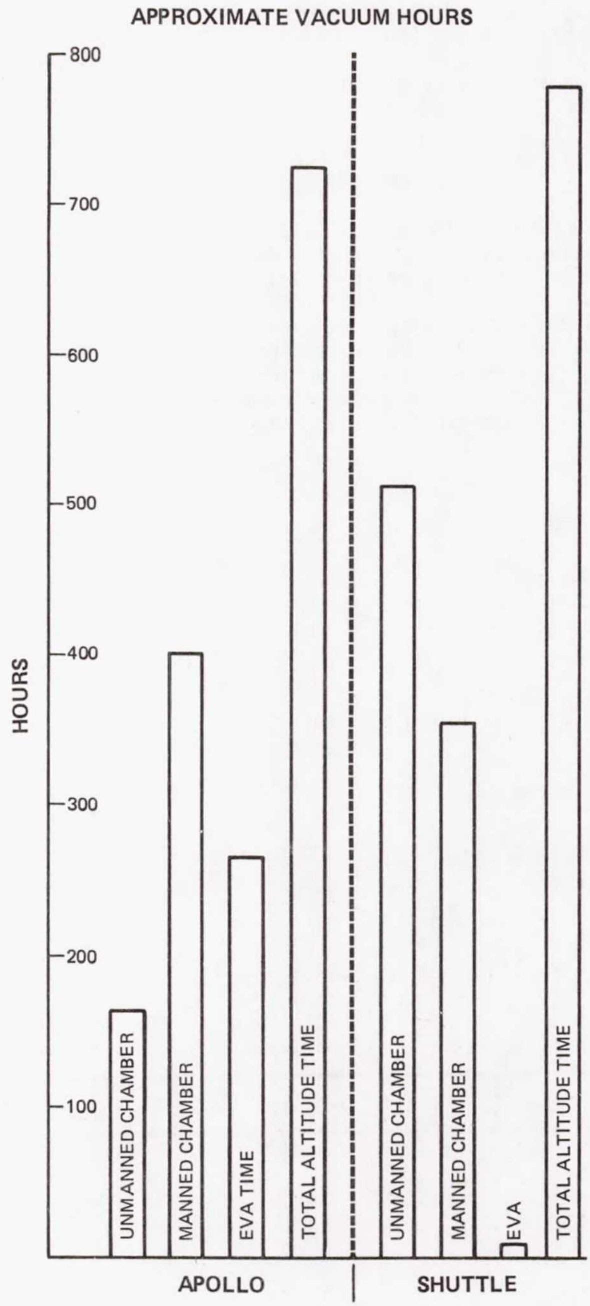

FIGURE 24.- COMPARISON OF APOLLO AND SHUTTLE EMU HOURS AT VACUUM.

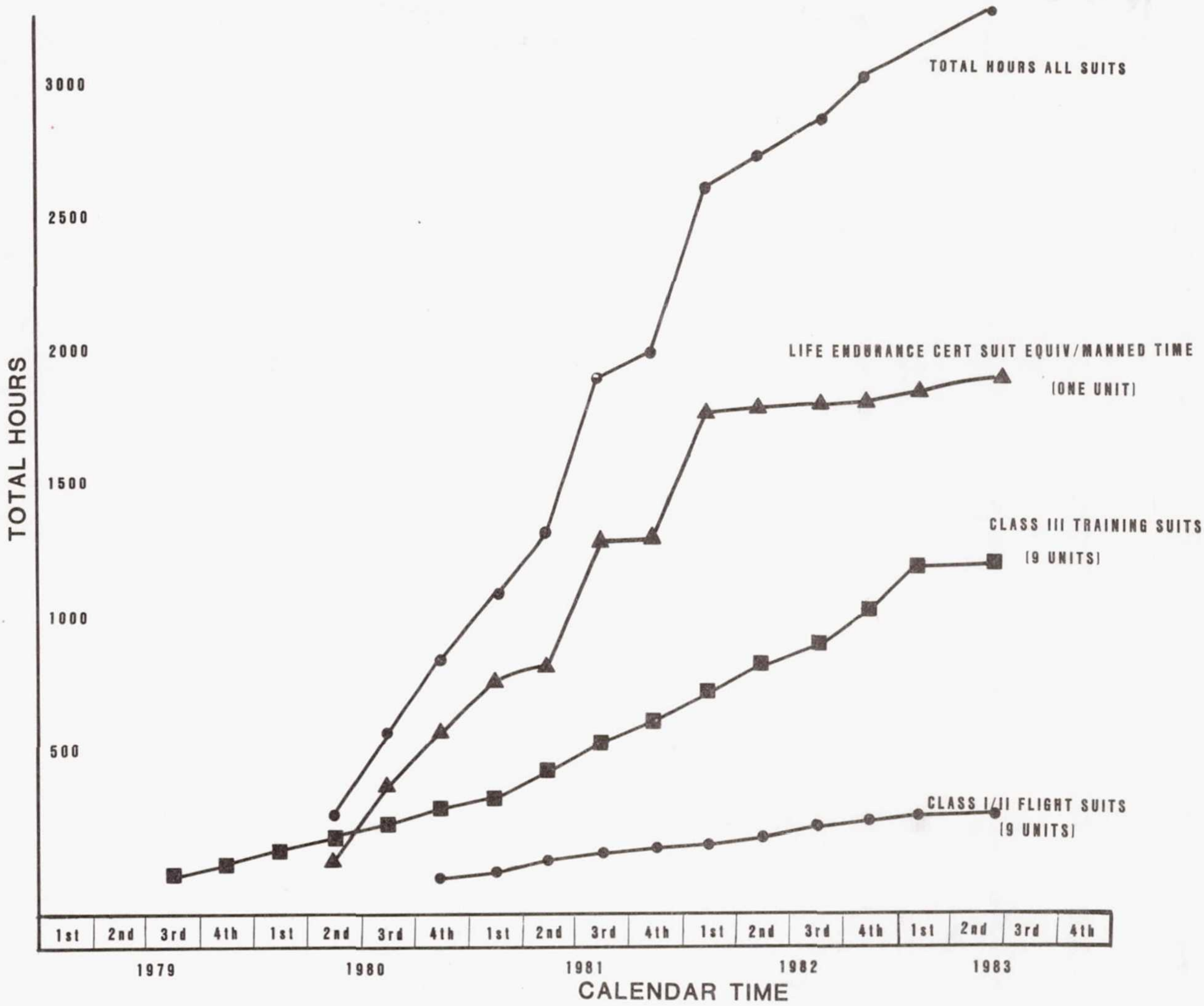

FIGURE 25.- SHUTTLE EMU SPACE SUIT ACCUMULATED MANNED OPERATING PRESSURE TIME (AS OF JUNE 1, 1983).

ACKNOWLEDGMENTS

The authors acknowledge the contributions of the following Shuttle EMU program personnel who provided technical suggestions and data for this paper: James Clougherty, Bill Maas, and Joe Whitman of ILC Dover, and Steve Krasinski, Fred Goodwin, and Phillip Heimlich of the Hamilton Standard Division of United Technologies Corporation. In addition, appreciation is extended to Cathy Kramer, Ann Marie Hoffman, and Deborah Poinsett of the Hamilton Standard JSC Field Support Office, who assisted in the preparation of the numerous draft revisions of this paper.