N72-27117

11

SKYLAB ASTRONAUT LIFE SUPPORT ASSEMBLY

J. Travis Brown
NASA Manned Spacecraft Center

INTRODUCTION

In its early conceptual stages, the Skylab Program (originally the Apollo Applications Program) was concerned with maximum utilization of available flight-qualified equipment. A comparative study was performed to define an optimum portable life support system for suited operations inside and outside the Skylab cluster. Emphasis was placed on utilization of qualified equipment, modified versions of qualified equipment, and new systems made up to state-of-the-art components. This report outlines the mission constraints, operational modes, and evaluation ground rules by which the Skylab portable life support system was selected; this report also describes the resulting design now being developed.

MISSION MODES

The Skylab cluster is depicted in figures 11.1 and 11.2, and the mission profile is shown in figure 11.3. The associated extravehicular activity (EVA) is concerned primarily with retrieval of film from the Apollo telescope mount. The EVA is distributed among the missions as follows: Skylab 1 and 2 (SL 1/2), one EVA; SL 1/3, three EVAs; and SL 1/4, two EVAs. An EVA is initiated from and supported by the airlock module (AM), which is equipped with an EVA hatch and support panels providing oxygen, cooling water, communications, and electrical power. Hatches isolate the AM from the multiple docking adapter (MDA) and the orbital workshop so that only the AM volume of atmosphere is lost during EVA cabin decompression. During Skylab missions, there are two types of intravehicular activity (IVA) planned with the crewmen wearing a suit in a pressurized cabin: (1) suit vented, operations carried out by a crewman with the suit pressure equal to local ambient, and (2) suit pressurized, operations carried out by a crewman with the suit pressurized to approximately 3.9 psi above local ambient pressure.

In addition to the nominal EVA and IVA mission modes, certain contingency modes must be accommodated inside the Skylab cluster, in a vacuum (or near vacuum) environment. The

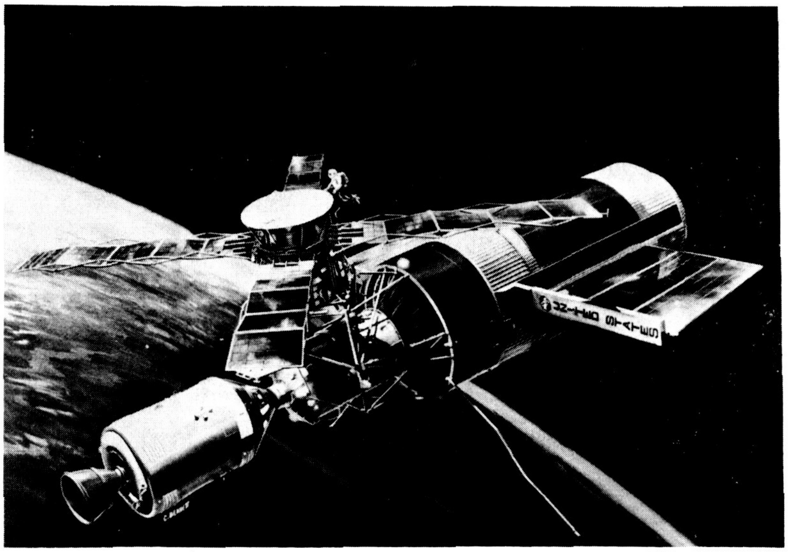
Figure 11.1 *Skylab I.*

contingency modes involve (1) suited entrance through the command module tunnel into the MDA in the event the MDA remote pressurization system malfunctions and (2) suited transfer across the AM-MDA hatch, isolation of the AM, and subsequent repressurization of the MDA due to inability of AM repressurization following EVA. A portable life support system must be capable of properly cooling and ventilating a suited crewman for the EVA, IVA, and contingency modes of operation. The system must also have the capability of automatic compensation for a change from either of the IVA modes of operation to the EVA mode (i.e., protection against loss of cabin pressure).

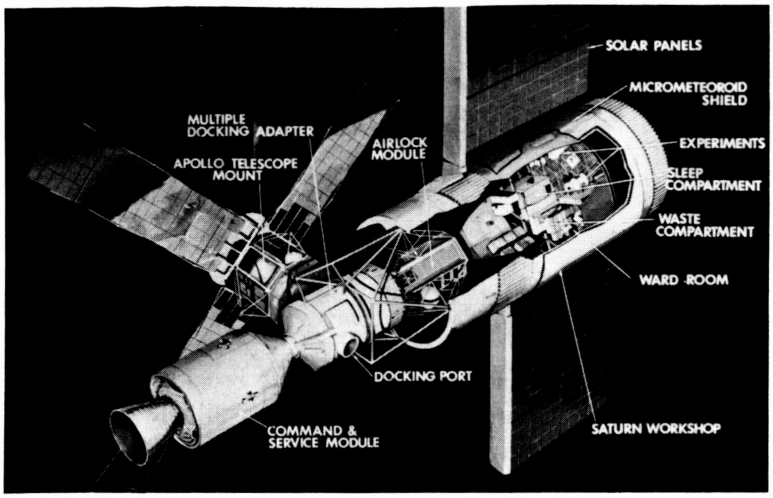

Figure 11.2 *Orbital workshop.*

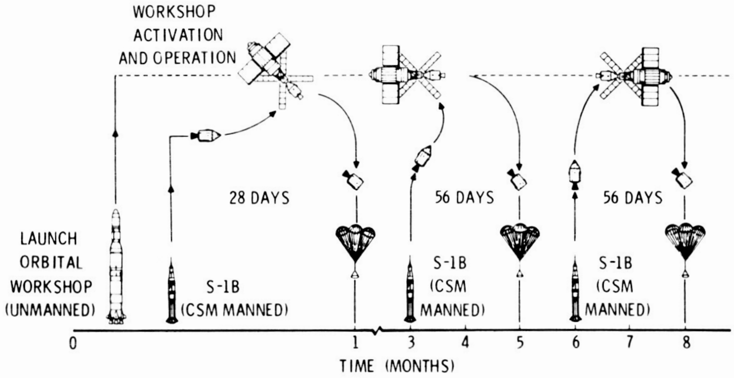

Figure 11.3 *Skylab mission profile.*

CONSTRAINTS

The following technical constraints were adhered to in the comparative study effort:

1. Two men in EVA simultaneously or 1-man IVA
2. An EVA duration of 3 hr nominal
3. Prebreathing time (45 min)
4. No low-pressure umbilical (i.e., suit hose) connections or disconnections in a vacuum environment
5. Provision of hardline communications and biomedical data to spacecraft
6. Provision for the following contingencies with allowable degradation as shown:
    a. Loss of primary cooling mode
        (1) 30 min
        (2) 300 Btu maximum body heat storage
        (3) 2000 Btu/hr metabolic rate
    b. Loss of primary ventilation mode
        (1) 30 min
        (2) 15 torr maximum inspired carbon dioxide partial pressure
    c. Loss of primary oxygen supply
        (1) 30 min
        (2) Audible and visible warnings if secondary oxygen supply is automatically activated

   d. Fail open of any ventilation loop relief valve
      (1) 30 min
      (2) Suit pressure maintained
      (3) Relief valve override or sufficient makeup oxygen

7. Must have minimum volume, high reliability, and uncomplicated checkout and service requirements

Evaluation Ground Rules

The comparative study results were dependent on the evaluation ground rules and their order of preference. The following ground rules, listed in order of priority, were used for the optimization study.

1. Probability of accomplishing all tasks
2. Cost
3. Spacecraft system impact
4. Total launch weight

CANDIDATE SYSTEMS

From approximately 40 combinations of portable life support systems investigated, the following were candidates for the final, complete tradeoff analysis.

1. Astronaut life support assembly (ALSA). Nonexisting system with design based on the use of state-of-the-art components. The system will be composed of the following:
   a. Pressure control unit (PCU)
   b. Life support umbilical (LSU)
   c. Secondary oxygen pack (SOP)
2. Apollo portable life support system (PLSS). Developed by Hamilton Standard Division of United Aircraft Corporation; now used for lunar exploration.
3. Modified PLSS. Apollo PLSS modified to utilize oxygen/electrical/spacecraft umbilical. Augmented by a suit ventilation unit (SVU) – (simplified open-loop oxygen system) to satisfy the IVA mission modes.
4. Portable environmental control system (PECS). Advanced backpack being developed by AiResearch Manufacturing Company, Garrett Corporation, at the time of the study (was later canceled).
5. New system (hybrid backpack, oxygen/electrical/spacecraft umbilical). Designed specifically for Skylab mission requirements.
6. New system (hybrid backpack, oxygen/electrical/cooling-water umbilical). Designed specifically for Skylab mission requirements.

Descriptions of Systems

The ALSA. (See "System Advantages and Disadvantages.")

Apollo PLSS (fig. 11.4). This system contains closed-loop ventilation, a cooling-water circulation loop, a sublimator heat-rejection source, a primary oxygen supply, a battery power supply, and a space suit communications system. There is no umbilical associated with employment of this system. An oxygen purge system (OPS) and separate high-pressure oxygen bottles and regulator are employed as a backup oxygen supply and backup to the primary cooling subsystem.

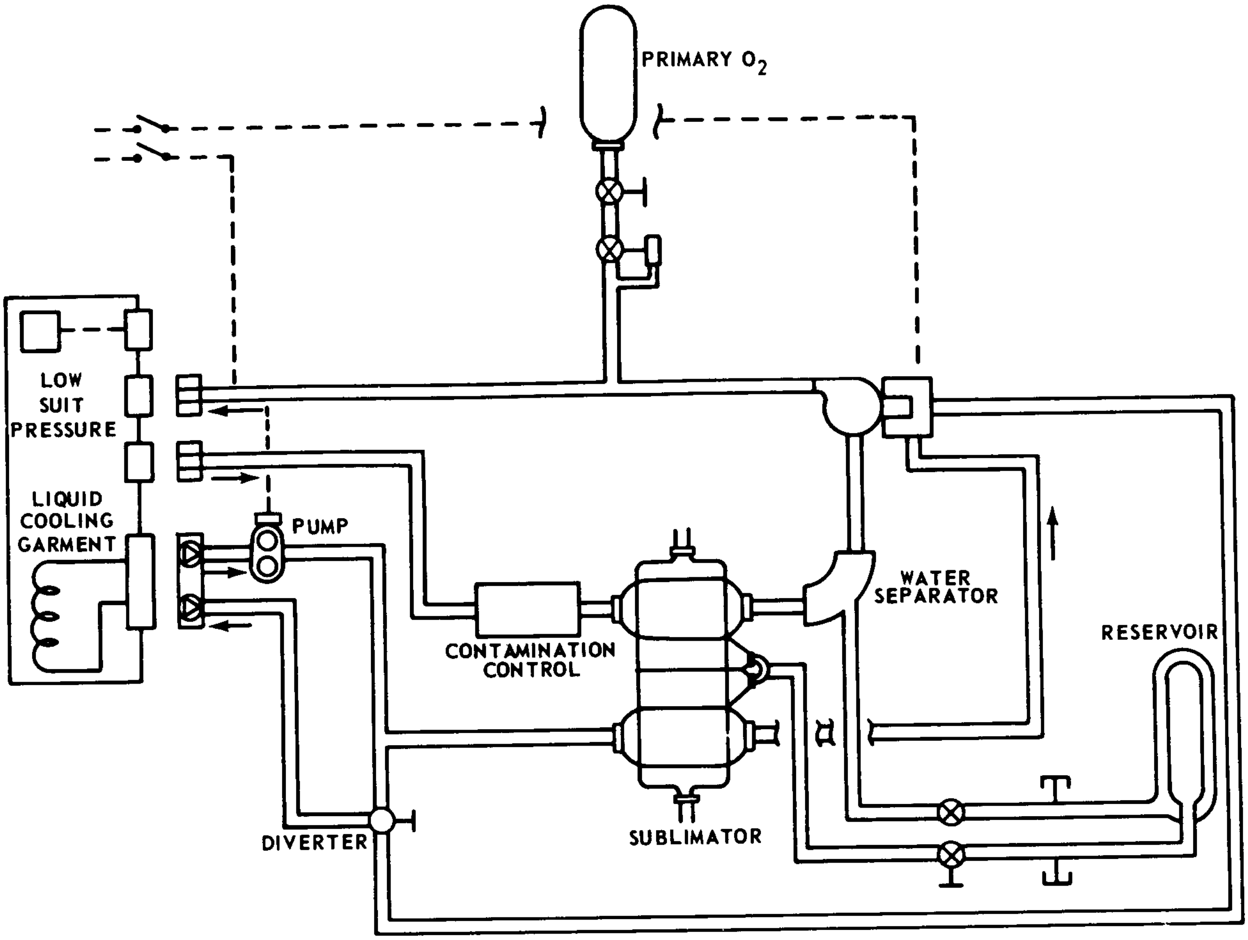

Figure 11.4 *Apollo portable life support system.*

The ventilation loop provides carbon dioxide removal, humidity control, and oxygen makeup from the primary oxygen supply. Suit pressure is controlled to approximately 3.9 psia. The cooling-water circulation loop provides heat transport from the liquid cooling garment (LCG) to the sublimator, which rejects heat by sublimation of stored water to a vacuum environment. The space suit communications system provides two-way voice communications between the crewman inside the spacecraft and the EVA crewmen; processing of physiological, environmental, and expendable status outputs for telemetry transmission to the spacecraft; and generation of signals for audible alarm to indicate critical environmental conditions. Two Apollo PLSS versions are available, providing up to 8 hr of use. To provide pressurized-suit operations capability inside the spacecraft (i.e., IVA pressurized), an SVU and umbilical are required. The SVU is a suit pressure regulator that plugs into the suit-outlet port and maintains suit pressure above local ambient pressure. Oxygen must be supplied to the suit inlet by a spacecraft umbilical. The associated umbilical uses supply and return cooling-water lines for metabolic cooling via an LCG.

Modified PLSS (oxygen/electrical spacecraft umbilical). The battery and primary oxygen bottle are used as backup, with electrical/communications and oxygen being supplied through an umbilical for normal operation. Figure 11.5 is a schematic of the modified PLSS and shows how the umbilical/PLSS interface is configured. In the event the umbilical or spacecraft oxygen supply is lost, the emergency oxygen supply automatically actuates because of the oxygen regulator configuration, and visible and audible warnings will be triggered. An oxygen valve allows a high oxygen flow to bypass the 3.9-psi regulator, thus providing a means of backup cooling from the umbilical supply. The higher flow rate vents at the suit relief valve, which is an added component to the PLSS. This unit can be used with or without an umbilical; but without an umbilical, it will not provide backup electrical power, instrumentation, and communications. The IVA suit-pressurized operations must be accommodated by use of an SVU and oxygen/electrical/water umbilical.

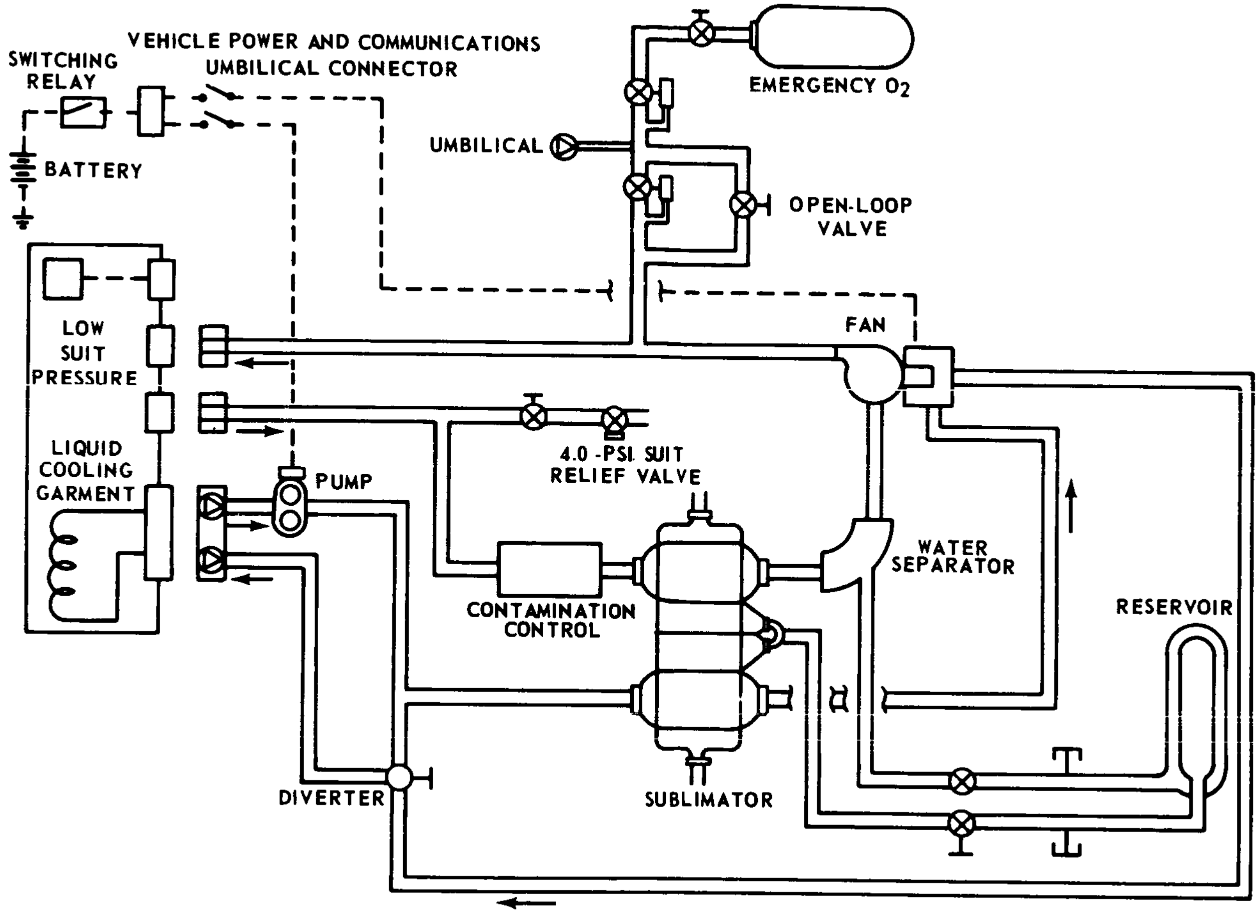

Figure 11.5 *Modified Apollo portable life support system.*

The PECS. Figure 11.6 schematically illustrates the PECS, which contains closed-loop oxygen ventilation, a cooling-water circulation loop, an evaporator heat-rejection source, an oxygen supply, a battery, and a liquid-to-liquid heat exchanger. The system expendables are sized such that EVA may be performed with or without an umbilical, and IVA can be accomplished by using a special umbilical that provides circulating cooling water to the liquid-to-liquid heat exchanger. When operating EVA on an oxygen/electrical umbilical, the evaporator serves as the prime heat-rejection source with umbilical high-flow gas as a backup. If an oxygen/electrical/water umbilical is used, the PECS liquid-to-liquid heat exchanger serves as the prime cooling mode, with the evaporator utilized as a backup. Electrical power and communications can be provided by the umbilical; electrical power can be obtained from the PECS battery; and a transceiver unit can be installed for biomedical/communications.

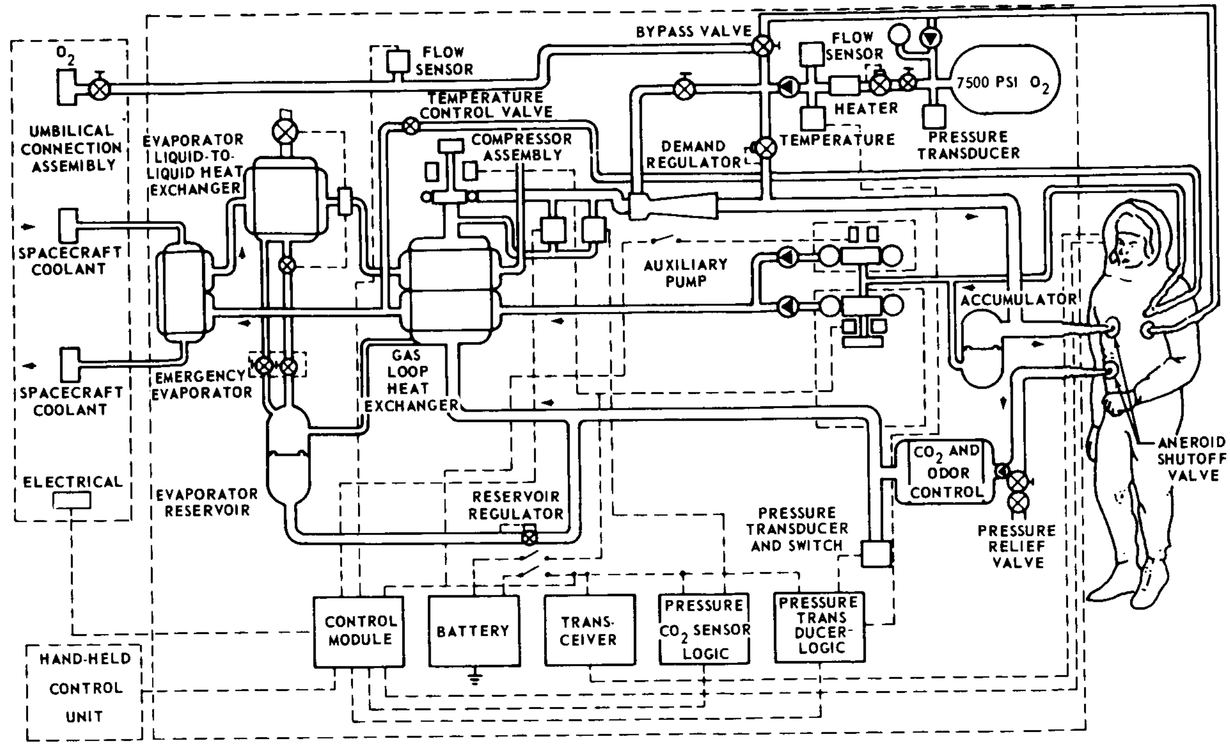

Figure 11.6 *Portable environmental control system.*

New System (hybrid backpack, oxygen/electrical/spacecraft umbilical). Figure 11.7 is a schematic of the new system that is designed specifically for Skylab mission requirements. The system contains closed-loop oxygen ventilation, a cooling-water circulation loop, an evaporator heat-rejection source, an emergency oxygen supply, an emergency power supply, and an evaporative water reservoir. The system is dependent on an umbilical for primary oxygen supply, high-flow oxygen backup cooling, electrical power, and biomedical/communications. The evaporator is the prime mode of cooling, while both the battery and the oxygen bottle serve as backups. This system has self-contained capability for emergency cases where umbilical independence is necessary, but, in this event, would be time limited (i.e., the oxygen bottle and battery sized for 30 min).

New System (hybrid backpack, oxygen/electrical/cooling-water umbilical). This system, figure 11.8, is designed specifically for Skylab mission requirements. This system is similar to the new system explained in the previous paragraph except that it employs a liquid-to-liquid heat exchanger for water umbilical use. The evaporator serves as a backup but unlike the PECS, the evaporator water supply, oxygen supply, and battery are sized for a 30-min emergency situation. The system can be used for IVA with a water umbilical since it employs a liquid-to-liquid heat exchanger. It has self-contained capability for EVA, but only for the 30-min emergency time.

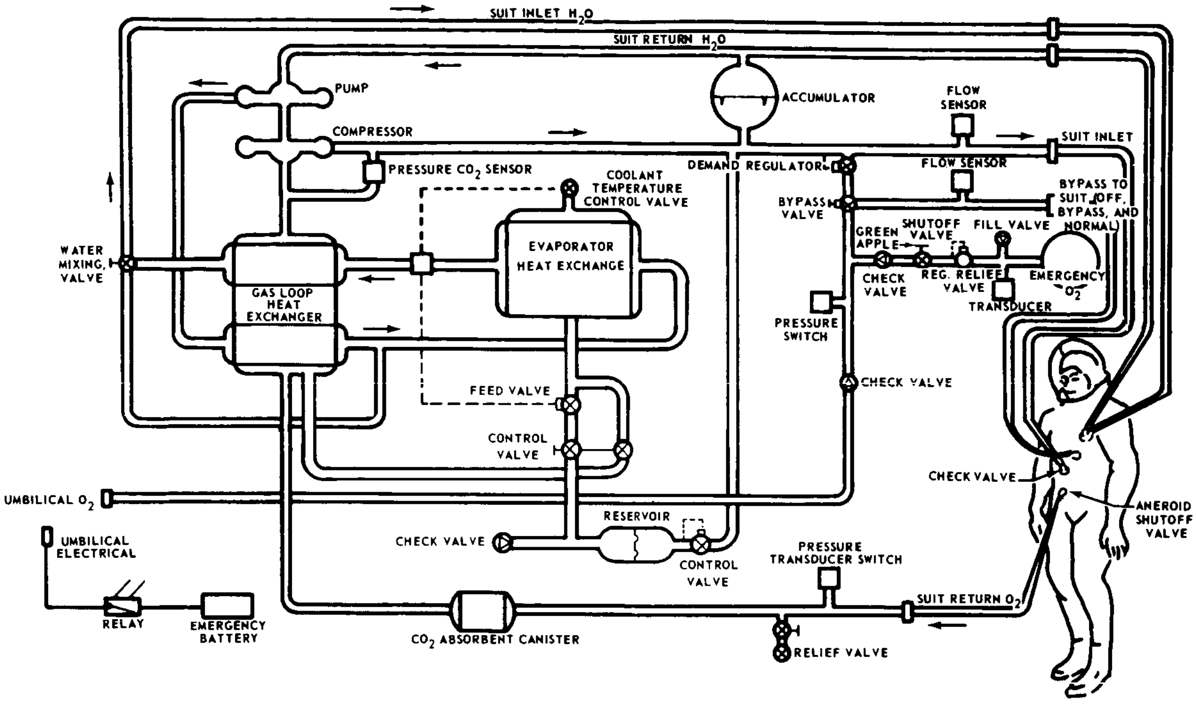

Figure 11.7 *Electrical/oxygen umbilical, new system (hybrid backpack).*

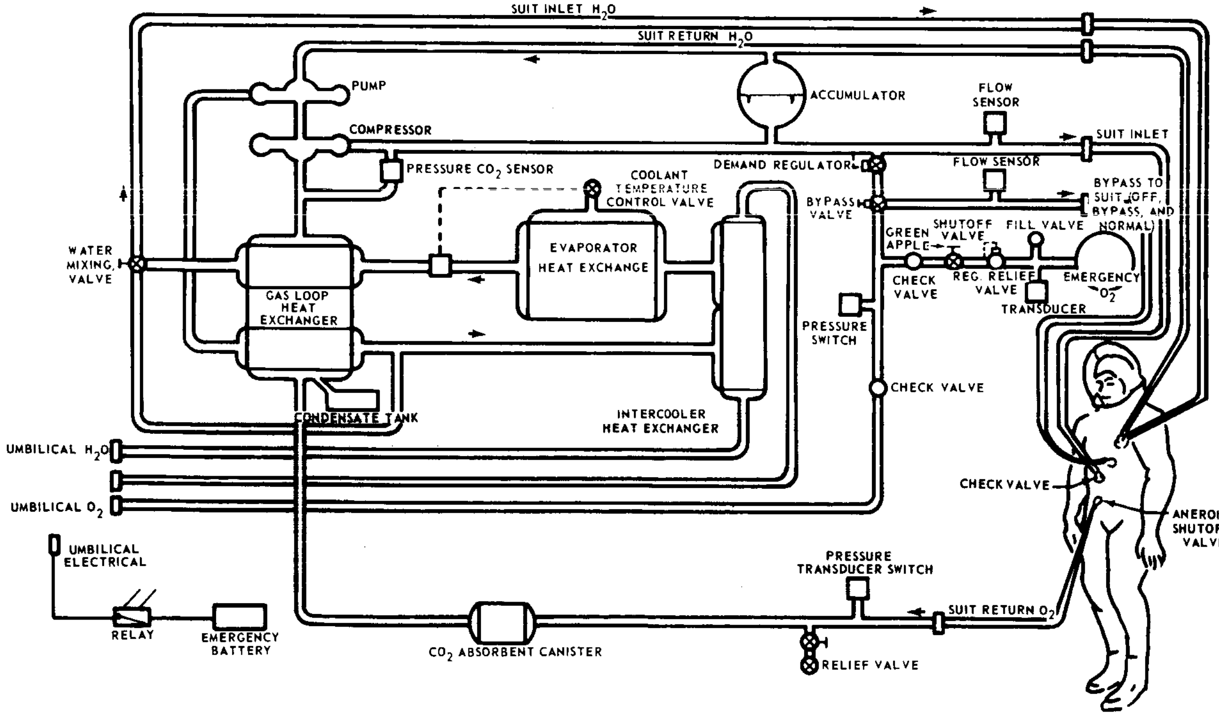

Figure 11.8 *Electrical/oxygen/water umbilical, new system (hybrid backpack).*

SYSTEM ADVANTAGES AND DISADVANTAGES

All of the portable life support systems chosen as candidates for the trade-off are capable of meeting the Skylab mission requirements, but each has definite advantages and disadvantages. Each candidate system is listed with its relative basic advantages and disadvantages (excluding cost and weight, which are discussed later).

1. The ALSA
   a. Advantages
      (1) Small volume
      (2) No recharge requirements
      (3) Minimum checkout requirements
      (4) The EVA and IVA accommodated with the same equipment
      (5) No time-dependent PCU expendables except for emergency
   b. Disadvantages
      (1) The ALSA is not self-contained (i.e., insufficient emergency oxygen for gas cooling for nonumbilical operation).
      (2) The continuous oxygen flow requirement from spacecraft makes the system time-weight critical.
2. The Apollo PLSS
   a. Advantages
      (1) Qualified, available with EVA usage history
      (2) Self-contained
   b. Disadvantages
      (1) Large volume (i.e., has been demonstrated that it is difficult to maneuver in truss area)
      (2) Less backup cooling than other systems (OPS used for backup cooling)
      (3) Complex recharge requirements (water and oxygen recharge systems must be added to either the command module or the AM)
      (4) No cooling capability in pressurized cabin (requires a cooling-water umbilical and SVU for IVA)
      (5) No provision for hardline communications or bioinstrumentation
3. The modified PLSS
   a. Advantages
      (1) Adequate backup modes
      (2) No oxygen recharge or battery replacement requirements
      (3) No OPS required
   b. Disadvantages
      (1) Large volume (has been demonstrated that it is difficult to maneuver in truss area)
      (2) No cooling capability in pressurized cabin (requires a cooling-water umbilical and SVU for IVA)
      (3) Complex recharge requirements (same as for Apollo PLSS)
      (4) Oversized backup expendables for Skylab EVA

4. The PECS
    a. Advantages
        (1) Good backup modes
        (2) Minimum recharge
        (3) Cooling capability in pressurized cabin
        (4) Smaller than PLSS
        (5) Only system with 4-hr self-contained capability that can also be used with an umbilical
        (6) Not as stringent on AM heat-rejection system design as other water umbilicals (i.e., has water boiler topoff capability or capability of using oxygen/electrical umbilical with water boiler as prime heat rejection)
    b. Disadvantages
        (1) More new development involved than PLSS or ALSA
        (2) Larger than ALSA
        (3) For nonumbilical operation, a water recharge system and an oxygen recharge system required in the spacecraft
5. The new system (hybrid backpack, oxygen/electrical umbilical)
    a. Advantages
        (1) Good backup mode designs
        (2) Optimum-sized backup expandables
        (3) Minimum size for closed-loop portable system
        (4) Smaller than PLSS and PECS
        (5) The AM heat-rejection system design not impacted as with water umbilical systems
        (6) Very little service and deservice required
        (7) Self-contained capability (for 30-min period)
    b. Disadvantages
        (1) More new development involved than with PLSS or ALSA
        (2) A water recharge system required in the spacecraft
        (3) No cooling capability in pressurized cabin (requires a cooling-water umbilical and SVU for IVA)
        (4) Larger than ALSA
6. The new system (hybrid backpack, oxygen/electrical/cooling-water umbilical):
    a. Advantages
        (1) Good backup mode designs
        (2) Optimum-sized backup expandables
        (3) Minimum size for closed-loop portable system
        (4) Smaller than PLSS and PECS
        (5) Minimum service and deservice required
        (6) Provides cooling capability in pressurized cabin
        (7) Self-contained capability (for 30-min period)
    b. Disadvantages
        (1) More new development involved than PLSS or ALSA
        (2) Cannot be used for a great length of time as a self-contained system
        (3) Larger than ALSA

OPTIMIZATION STUDY RESULTS

The study included a weight and volume analysis, mission accomplishment assessment, spacecraft impact investigation, and cost analysis. In considering each system with respect to the rating factors, it was found that no set of candidate equipment qualifies as optimum for all rating factors. "Probability of accomplishing all tasks" is best supported by the ALSA, because of its small volume and minimum checkout, service, and deservice requirements. Outstanding advantages are the relative ease of suit-pressurized transfer through the command module tunnel as compared to other candidate systems, accommodation of EVA and IVA requirements with one system (thus minimizing extra hardware for IVA as compared to other systems), and minimum volume carried on the suited astronaut (eases crowded AM interior problem and truss area EVA operations).

The trade off analysis indicates that the ALSA is optimum from a cost standpoint, because of its simplicity and its ability to accommodate both EVA and IVA with the same system, thus minimizing hardware. The other candidate systems are either very complex and undeveloped or developed but more complex than required for Skylab requirements, either of which involves added costs. Several of the other candidate systems also require different sets of hardware for EVA and IVA.

All combinations of PLSS are similar with respect to "spacecraft system impact" because each requires either umbilical spacecraft support or water and oxygen recharge capability.

The weight tradeoff shows that the ALSA has the greatest total launch weight and that the two closed-loop systems with pressurized cabin cooling capability (PECS and new system–oxygen/electrical/water umbilical) offer the lowest weight penalties. It is concluded, however, that the degree of weight difference between the ALSA and other systems is outweighed by the operational and cost advantages of the ALSA. Therefore, based on the guidelines of the study, the ALSA is the optimum PLSS for supporting the Skylab missions.

ALSA CONTRACT

After review of the study and assessment of Skylab requirements by various Manned Spacecraft Center organizations, it was decided to develop the ALSA for Skylab mission EVA and IVA life support.

A request for proposal was distributed, and a Source Evaluation Board was used in selecting the contractor for PCU and SOP development. Contractual effort was initiated with the AiResearch Manufacturing Company, Garrett Corporation, in January 1970. A separate request for proposal was released for the LSU, and effort was initiated in June 1970 with AiResearch. The three subassemblies (PCU, SOP, and LSU) were combined into one contract and renamed the ALSA. The Critical Design Review was held in December 1970, and the First Article Configuration Inspection is scheduled for July 1971. Unmanned qualification testing will begin in July 1971, and manned qualification testing is scheduled for January 1972.

ALSA DESCRIPTION

General Description of the ALSA

The ALSA consists of three major subassemblies: the PCU, LSU, and SOP. Figure 11.9 depicts the ALSA as worn by a suited astronaut, while figure 11.10 illustrates the ALSA schematically.

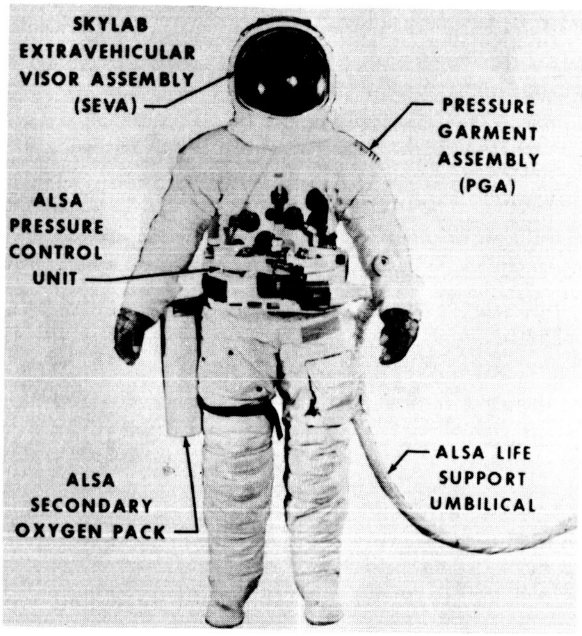

Figure 11.9 *Skylab extravehicular mobility unit.*

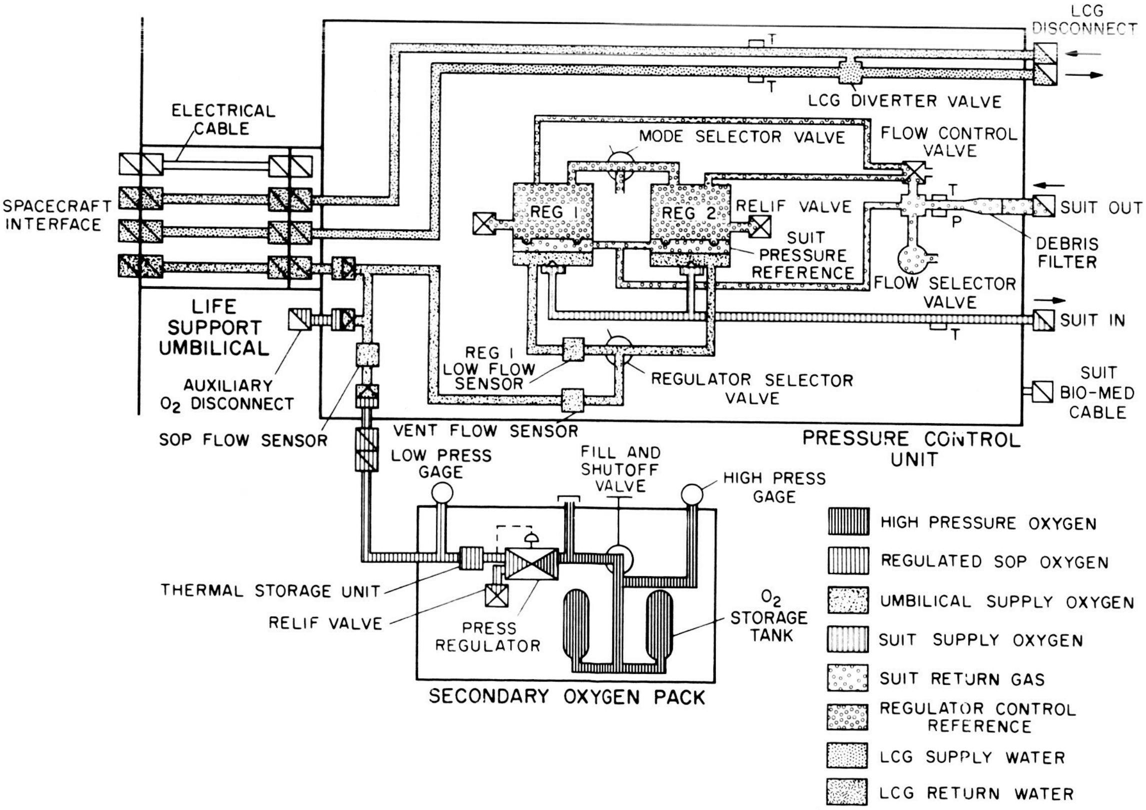

Figure 11.10 *Astronaut life support assembly schematic.*

The PCU. The PCU (fig. 11.11) provides oxygen ventilation, pressure control, cooling-water flow control, communications, instrumentation biomedical transmission, and an audiovisual warning system for a suited astronaut. The PCU provides the capability for maintaining a proper ventilation/pressurization balance for suited modes (see "Mission Modes") by receiving oxygen via a spacecraft-supplied umbilical or the SOP. Cooling water is provided to the LCG and returned to the spacecraft via the LSU; then it is routed into or around the LCG for astronaut comfort by a manually controlled water-diverter valve contained within the PCU.

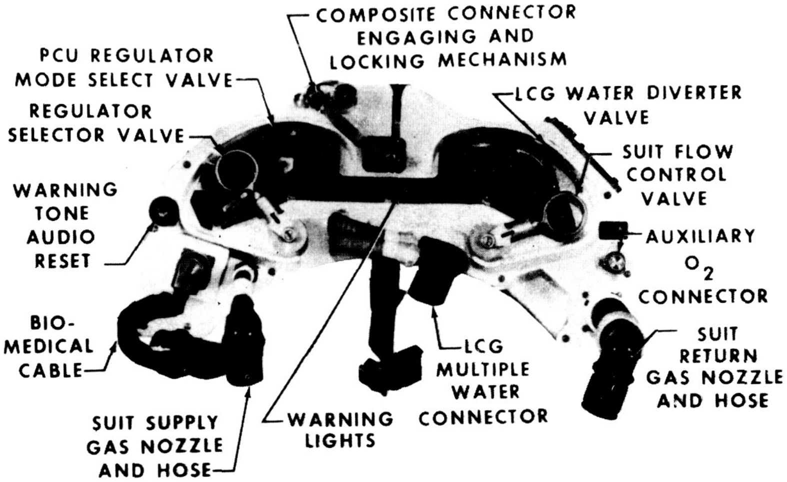

Figure 11.11 *Pressure control unit.*

The LSU. The LSU contains one oxygen hose, two water hoses, a structural restraint tether, thermal insulation and cover, and an electrical cable for providing power from the spacecraft to the PCU, voice communications, and biomedical and suit-loop instrumentation readouts to the spacecraft from the PCU. Figure 11.12 shows a coiled LSU. At the astronaut end of the LSU, each hose terminates at a disconnect, and the electrical cable terminates at the connector. The three disconnects and the electrical connector are contained in a single, composite housing, thus allowing one operation for LSU/PCU mating. The LSU spacecraft end contains quick disconnects for the oxygen and water hoses, an electrical connector for the electrical cable, and a tether hook to structurally link the astronaut to the spacecraft.

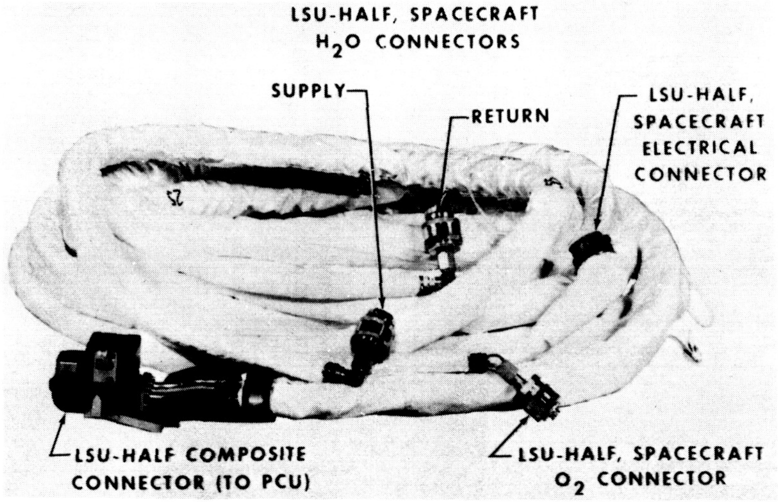

Figure 11.12 *Life support umbilical.*

The SOP. The SOP, (fig. 11.13) serves as a backup oxygen supply to the PCU in case of an insufficient supply from the LSU or an increased flow demand (beyond the capacity of the spacecraft supply) created at the pressure garment assembly (PGA) because of a tear or other off-nominal condition. The SOP provides 4.0 lb of usable gaseous oxygen, regulated to interface with the PCU pressure and temperature requirements. The SOP assembly, less gages and manual controls, is encased within a protective cover that limits the temperature extremes to which the gas

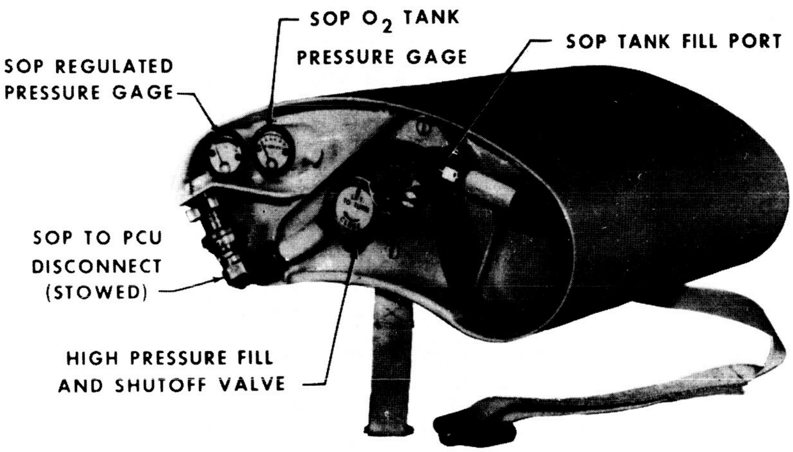

Figure 11.13 *Secondary oxygen pack.*

temperatures may vary during a 4-hr EVA mission. The thermal cover also serves as protection against impact or scratching of the tank outer shell and as a meteoroid protective cover for the SOP assembly.

The SOP has acquired two mission functions in addition to its basic function with the PCU. The SOP will be used in combination with an Apollo emergency oxygen mask assembly (fig. 11.14) to provide a ''walkaround'' emergency oxygen system for crewman protection during any atmosphere contamination occurrence. Also, the SOP will serve as the breathing oxygen supply for a suited, untethered portion of the M-509 experiment (astronaut maneuvering equipment experiment).

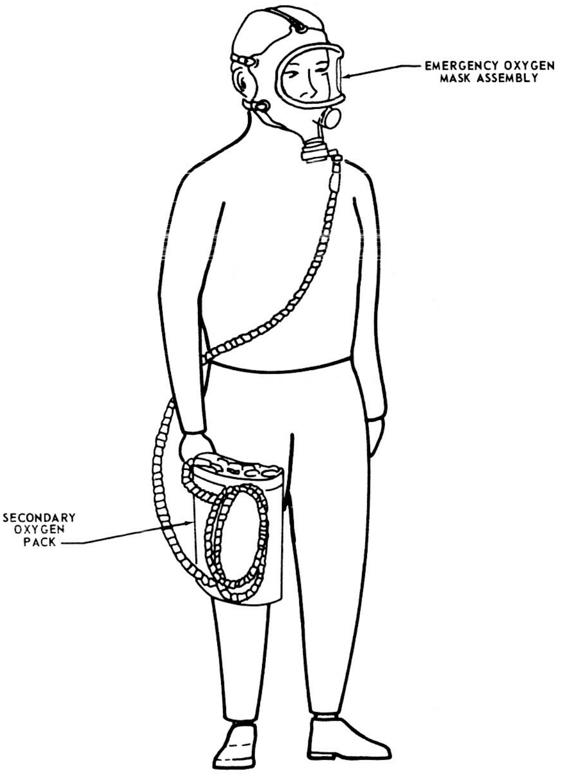

Figure 11.14 *Skylab walkaround emergency oxygen system.*

PCU Detailed Description

The PCU (fig. 11.10) contains the following functional subsystems:

- Oxygen circuit
  - Oxygen supply
  - Pressure regulation
  - Suit pressure circuit
  - Flow control
- Electrical circuit
  - Pressure control unit power
  - Communications
  - Biomedical
  - Suit loop instrumentation
  - Warning logic and display

Oxygen Circuit. The characteristics of the oxygen circuit follow:

Oxygen supply. Oxygen may be supplied to the PCU from any one of three sources, (1) normal LSU supply which connects to the PCU at the composite disconnect, (2) SOP supply which is connected to the PCU by a flex hose and disconnect on the bottom right side of the PCU, and (3) an auxiliary disconnect on the top right side of the PCU. This disconnect may be used to connect a second SOP to the PCU; however, it is normally not employed. The three separate connections are manifolded together, internal to the PCU. Separate filters and check valve assemblies for each oxygen supply are provided. The check valves permit isolation of the supplies in case one of the supply lines fails. Pressure at the manifold assembly interface determines which supply will furnish oxygen to the crewman. If the supply pressure from the umbilical should decrease below SOP regulation pressure (30 to 45 psig) because of high demand flow requirements or loss of supply pressure, SOP flow will automatically commence and make up the required demand flow until supply pressure again increases to above 30 to 45 psig. The nominal maximum flow to the suit, if demanded (e.g., for a suit tear), is 27 lb/hr with an approximately 30-psia supply pressure at the pressure-flow control valve. The two flow sensors that provide a caution and warning signal, visible and audible, to the crewman are located within the oxygen supply system, upstream of the pressure-flow control valve. The SOP flow sensor, located in the SOP supply line, provides a caution and warning signal when SOP flow commences at 0.05 to 0.20 lb/hr. The low-vent flow sensor, located downstream of where the three supplies are manifolded together, provides warning to the crewman when flow decreases to approximately 5.0 lb/hr, which is insufficient for proper carbon dioxide washout.

Pressure regulation and control. Flow from the oxygen manifold proceeds directly into the pressure-flow control valve inlet selector where either (or both) of two pressure regulators may be selected for automatic control of suit pressure. An OFF position is also provided. The regulators are identical in construction and may be individually selected by the regulator selector valve for checkout or for isolation to correct a regulator failure. Suit pressure control points within each regulator are set at different levels so that when the regulator selector valve is in the BOTH position, regulator 1 is normally used to control suit pressure. Regulator 2 is used as a backup in case regulator 1 fails. A flow sensor in the regulator 1 triggers a warning REG. 1 LOW FLOW when flow decreases to approximately 3.0 lb/hr, indicating a regulator 1 failure. Each regulator can flow up to 13.0 lb/hr, with an inlet pressure of 30 psia and 0° F at the inlet. The suit-pressure reference, common for both regulators, is downstream of the suit within the debris filter housing.

Low-pressure circuit. Flow from the pressure-flow regulator proceeds to the suit via the suit-inlet hose and nozzle assembly. From the suit, exhaust gas enters a 1-in.-inside-diam hose and disconnect assembly and proceeds through the debris filter. A bypass relief valve is provided in the debris filter so that if clogging occurs, full flow will bypass the filter through the relief valve. Downstream of the debris filter, suit exhaust gas temperature and pressure are measured. A warning indicator is provided at this point for either low or high suit pressure. Audio and visual indication is given when the suit-to-ambient pressure differential has decreased to 3.2 ± 0.1 psid or increased to 4.35 ± 0.15 psid.

Flow control. Suit exhaust gas proceeds to one of four orifices within the flow control valve, which provides the capability necessary to control flow at the various cabin and suit pressures. Three of the four orifices within the flow control valve are selectable by manual control, (1) the EVA NORM position, (2) the EVA HI FLO position, and (3) the IVA position. The fourth orifice is controlled by a shuttle valve that references ambient pressure on one side of a diaphragm within the valve and suit-pressure-regulator reference pressure on the other side of the diaphragm. The valve begins to shuttle closed when suit-to-ambient differential is approximately 1 psid, thus providing the proper oxygen flow rate when the suit is pressurized from a soft suit mode. Downstream of the flow control valve orifices, an annular exhaust section is provided that vents exhaust gas overboard through vent holes within the PCU. These vent hoses are placed such that venting is thrust canceling.

Water Circuit. The ALSA/spacecraft cooling-water circuit is a closed-loop system. Water cooled by the AM cooling system enters the PCU via the LSU, at the composite disconnect with a maximum pressure of 37.2 psig and a maximum flow rate of 250 lb/hr. The water system within the PCU has two functions, (1) to transport water from the umbilical to the LCG and (2) to provide supply-water diversion from the LCG via the water diverter valve. The diverter valve provides from 0 to 100 percent flow bypass capability of the LCG. The valve is manually controlled and is accessible to the suited crewman. The flow schematic for the water circuit is shown in figure 11.10. As shown, water supply and return to the LCG are accomplished through two hoses and a single disconnect assembly. Temperature sensors, located in the PCU, monitor LCG inlet temperature and diverter valve mixed-return-water temperature.

Electrical System. The characteristics of the electrical system follow:

PCU power. Spacecraft electrical power (25 to 30 V dc and maximum current of 2.0 A) is provided to the PCU via the LSU. A single electrical connector for all LSU electrical conductors is provided at the composite disconnect. The PCU will withstand over and under voltage variations of 3.0 V from the steady-state upper and lower limits, without damage, for a maximum period of 1 sec.

Communications. Voice communications between the spacecraft and the suited crewman are transmitted and received via the biomedical cable (PGA electrical interface to the PCU), PCU internal wiring, and the LSU electrical cable.

Biomedical. Biomedical data are transmitted to the spacecraft via the biomedical cable, PCU internal wiring, and the LSU electrical cable.

Suit loop instrumentation. The control module within the PCU continuously receives and conditions the signals from the following suit loop sensors:

The PGA inlet gas temperature
The PGA outlet gas temperature
The PGA pressure
The LCG water inlet temperature
The LCG water outlet temperature

Each suit loop parameter voltage analog is provided by the control module to the PCU internal wiring and is then transmitted to the spacecraft via the LSU electrical cable.

Warning logic and display. The control module continuously monitors and evaluates the ALSA performance, based upon signals from the following sensors:

Suit pressure
Regulator 1 flow
Secondary oxygen pack flow
Vent flow

The suit pressure transducer is in the debris-filter-assembly duct, downstream of the suit. The regulator 1 flow sensor is between the regulator selector and the regulator 1 inlet. The SOP sensor is in the oxygen manifold, downstream of the SOP check valve. The vent flow sensor is between the oxygen manifold and the regulator selector valve.

The control module signal conditioning and logic will provide a 1.7 kHz modulating warning tone to the suited crewman if any of the following events occur:

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

Coincident to the warning tone, the appropriate event warning message on the display panel (mounted on top of the PCU and visible to the suited crewman) will illuminate (fig. 11.11). The warning messages displayed from left to right are suit pressure, regulator 1 low flow, SOP flow, and low vent flow. The suited crewman may turn off the warning tone by depressing the RESET switch on the top left of the PCU. The illuminated warning message, however, will stay illuminated as long as the off-nominal conditions exist. All warning message lamps and their respective lamp drivers, the warning logic, and the warning tone generator may be tested by depressing the TEST switch on the bottom right of the PCU.

LSU Detailed Description

The LSU provides the following functions: (1) transports gaseous oxygen from the spacecraft to the PCU for ventilation and pressurization of the PGA, (2) serves as a cooling-water supply and return between the spacecraft and the PCU, (3) couples voice communications, biomedical, and other instrumentation readouts from the suited astronaut to the spacecraft, (4) provides structural linkage between the spacecraft and the astronaut, and (5) supplies spacecraft power to the PCU.

Figure 11.15 illustrates schematically how these functions are provided, while figure 11.12 is a photograph of the coiled LSU. The LSU is 60 ft long, with a diameter of approximately 1.75 in.

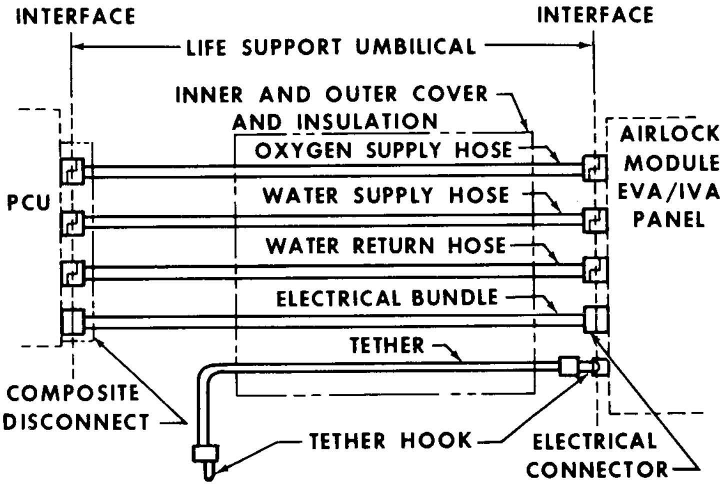

Figure 11.15 *Life support umbilical schematic.*

Oxygen Supply Hose. The oxygen supply hose is flexible, silicone rubber, and metal reinforced with an outer covering of Viton-coated Beta glass. The hose has a 0.25-in. internal diam and a 0.11-in. wall thickness. The B-nut fittings are molded into the hose ends for quick-disconnect attachment.

Water Supply and Return Hoses. The water supply and return hoses are identical to the oxygen supply hose described previously except that the internal diameter is 0.375 in. rather than 0.25 in. Quick disconnects are attached to the B-nut fittings molded into the hose ends in the same manner as on the oxygen supply hose.

Electrical Cable Assembly. The electrical cable assembly provides the interface between the PCU and the spacecraft for electrical power, communications, and instrumentation. The electrical cable consists of two connectors, wires, and two layers of Beta glass covering to isolate the cable from the other parts of the LSU.

Tether Assembly. The tether assembly serves as a structural connection between the suited crewman and the spacecraft. This assembly is shorter than the LSU assembly to prevent undue loads from being applied to the hoses or electrical wires. The tether is made from Nomex webbing. Quick-release hook assemblies are fastened to each end, allowing attachment of the tether to the PCU/PGA and to the spacecraft.

Cover Assembly. The cover assembly provides thermal and micrometeoroid protection to the enclosed hoses, electrical cable, and tether. The cover is loosely fitted around the assembly to allow relative action between hoses, electrical bundle, and tether to prevent wear at local stress points during use and to provide flexibility. The protective cover (from inner to outer) consists of an inner cover, two layers of gold-coated Kapton separated by one layer of Beta marquisette, six layers of aluminized Kapton separated by layers of Beta marquisette, two more layers of gold-coated Kapton separated by Beta marquisette, and an outer cover. The inner and outer covers are fabricated with Teflon-coated Beta glass. This assembly is fabricated in a flat pattern and then hand stitched around the umbilical assembly.

Composite Disconnect. The LSU half of the composite disconnect provides a single operation for PCU attachment and detachment. This single operation connects the water lines, oxygen line, and electrical cable to the PCU corresponding subassemblies. An isometric drawing of the composite disconnect is shown in figure 11.16. Connection to the PCU is made by inserting the LSU half of the composite disconnect into the PCU half and operating the handle extension on the PCU. This single manual operation cams the two halves together and locks them in place, completing the connection.

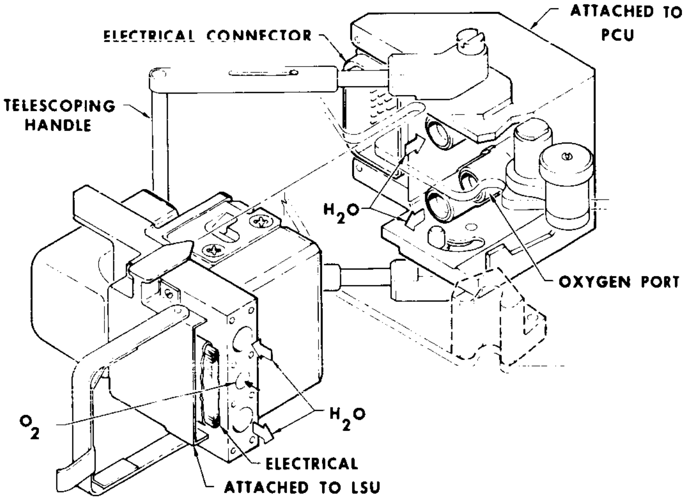

Figure 11.16 *Composite disconnect.*

SOP Detailed Description

The SOP is used as a backup oxygen supply for the PCU in case of an insufficient supply from the spacecraft/LSU or in the event of an increased flow demand beyond the capacity of the LSU due to a PGA tear or other off-nominal occurrence. The SOP provides 4.0 lb of usable gaseous oxygen, regulated to interface with the PCU pressure and temperature requirements. Figure 11.17 is a schematic illustration of the SOP, and figure 11.13 shows the external design of the SOP.

High-Pressure Circuit. The SOP high-pressure circuit consists of two oxygen tanks, a 0- to 10,000-psig pressure gage, a fill and shutoff valve, a pressure regulator, and interconnecting plumbing.

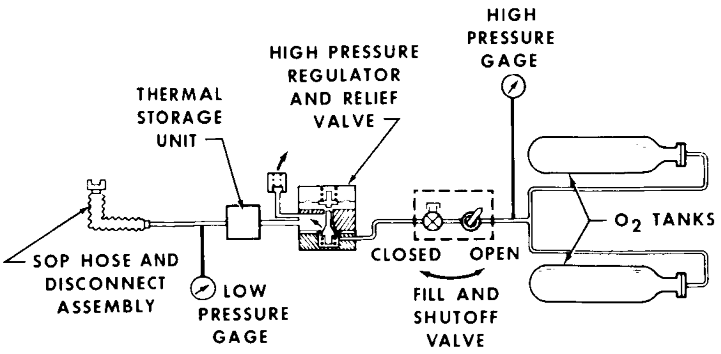

Figure 11.17 *Secondary oxygen pack schematic.*

Oxygen tanks. Each tank is fabricated of Inconel 718 and incorporates internal copper fins that are brazed to the internal wall of the tanks. The copper fins are required to provide sufficient heat transfer from the tank wall to the fluid during tank blowdown from 6000 to 200 psig such that gas discharge temperature is maintained above -20° F throughout this period. The tank is designed to fracture mechanics criteria; that is, a leakage failure mode will occur rather than a rupture or fragmentation failure at maximum operating pressure.

High-pressure gage. The high-pressure gage is used to monitor the oxygen pressure in the high-pressure oxygen tanks before and during use.

Fill and shutoff valve. The fill and shutoff valve is used to fill the high-pressure oxygen tanks with 6000 psig of gaseous oxygen and also provides a means of isolating the tanks after filling and during storage.

High-pressure regulator. The high-pressure regulator controls downstream pressure to 30 to 45 psig during flow (up to 13 lb/hr), while inlet pressure to the regulator may vary from 200 to 6850 psig. The unit contains a metal diaphragm-operated poppet metering valve. Regulated pressure is a result of force balance or unbalance on the metal diaphragm.

Low-Pressure Circuit. The low-pressure circuit of the SOP consists of the regulating and relief section of the high-pressure regulator, the thermal storage unit, the low-pressure gage, and the SOP hose and disconnect assembly. Normal operating pressure of the circuit is 30 to 45 psig maximum.

Pressure regulation. The high-pressure regulator (see previous section "High-pressure regulator") is capable of supplying from 0 to 13 lb/hr to the PCU at a regulated pressure of 30 to 45 psig; the inlet pressure to the regulator is 200 to 6850 psig. Within the regulator assembly, on the low-pressure side, is a relief valve that limits the regulated pressure with a failed-open regulator condition.

Thermal storage unit. The thermal storage unit is a 3-lb aluminum block with manifolds at each end and 21 flow-through passages each 0.25-in. diam. The oxygen from the high-pressure regulator valve enters the unit, makes one pass through the unit, and flows out the other side. The gas is warmed approximately 15° F during blowdown, and the aluminum block is cooled down to the exit gas temperature. The unit is also utilized as part of the support structure for the SOP assembly. It is centrally located between the two oxygen tanks.

Low-pressure gage. The low-pressure gage is used to monitor the regulated oxygen pressure or lockup pressure from the high-pressure regulator before and during use of the SOP. It is a 0- to 150-psig bourdon-tube-type gage.

Hose and disconnect. The SOP hose and disconnect assembly mates to the PCU disconnect and enables easy disengagement of the SOP from the PCU. The disconnect is self-sealing to prevent loss of oxygen and to prevent contamination of the SOP when disconnected from the PCU. When mated, the disconnects form a zero-leakage minimal-inclusion flow-through fitting assembly. The SOP hose is 18 in. long and similar to the LSU oxygen supply hose. It is covered with a fire protection cover consisting of two layers of Beta glass.

CONCLUSIONS

Based on evaluation thus far, it appears that the astronaut life support assembly accommodates all Skylab mission requirements and that the optimization study conclusions are valid. For example, evaluation of high-fidelity mockups indicates the astronaut life support assembly is favorable from a crewman's usefulness standpoint and that minimizing the expendables carried by the crewman for near-spacecraft-type extravehicular activity is the most desirable approach.

Also, it is concluded that the comparative study approach as described herein is a reasonable method for choosing an optimum portable life support system for any particular space program.