

Delivery of Servicing & Performance Checkout Equipment to the International Space Station Joint Airlock to Support Extravehicular Activity

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ABSTRACT

In July 2001, during Space Shuttle Flight 7A, the Joint Airlock was added to the International Space Station (ISS) and utilized in performing the first extravehicular activity (EVA) from the ISS. Unlike previous airlock designs built by the United States or Russia, the Joint Airlock provides the ISS with the unique capability for performing EVAs utilizing either U.S. or Russian spacesuits. This EVA capability is made possible by the use of U.S.- and Russian-manufactured hardware items referred to as Servicing and Performance Checkout Equipment (SPCE) located in both the Joint Airlock's Equipment and Crew Locks.

This paper provides a description for each SPCE item along with a summary of the requirements and capabilities provided in support of EVA events from the ISS Joint Airlock.

INTRODUCTION

Extravehicular activities (EVAs) performed from the International Space Station (ISS) utilize either the Russian Orlan-M spacesuit or the United States Space Shuttle extravehicular mobility unit (EMU). In order to allow the unique EVA capability for utilizing either the EMU or Orlan spacesuit from the ISS Joint Airlock, several key hardware assemblies referred to as Servicing and Performance Checkout Equipment (SPCE) were incorporated into the airlock's design. These SPCE items provide the necessary ISS interfaces in order to service and checkout the EMUs and Orlans before and after each EVA. The SPCE also provides an interface for the transfer of critical life support resources to both the EMUs and Orlans, via their respective spacesuit umbilicals, during pre-breathe, depressurization,

vacuum, and repressurization umbilical operations. In addition, the SPCE also provides a recharge capability

for EMU and EVA tool batteries, controls for activation of the Airlock depressurization pump, and instrumentation for monitoring atmospheric pressure during egress and ingress activities. The SPCE project not only involved the design and development of several assemblies, but also the integration and checkout of this hardware into the Joint Airlock.

ISS JOINT AIRLOCK FUNCTIONS

The ISS Joint Airlock, as shown in Figure 1 being attached to the ISS, consists of an Equipment Lock chamber and a Crew Lock chamber attached to ISS Node 1. Together, the Equipment Lock, Crew Lock, and Node 1 provide the isolation and pressure sealing functions required between space vacuum and the Crew Lock, between the Crew Lock and the Equipment Lock, and between the Equipment Lock and Node 1 for supporting egress and ingress activities associated with the EVA event. Equalization valves located on the Node hatch, intravehicular (IV) hatch, and extravehicular (EV) hatch provide the means for pressure equalization.

In addition to supporting EVA egress and ingress activities, the Joint Airlock also provides accommodations for EMU and Orlan-M spacesuit donning and doffing; stowage of suit support equipment and consumables; and checkout, servicing, and maintenance support for EMUs and Orlan-M spacesuits and other key EVA equipment. The larger chamber, or Equipment Lock, contains nearly all of the Airlock and EVA equipment needed for checkout, recharge, servicing, repair, and stowage operations for the EMUs and Orlan-M spacesuits. In addition, the Equipment

Lock contains donning stand interfaces on the two rack faces to facilitate spacesuit donning and doffing activities using U.S. or Russian donning stands. The smaller chamber, or Crew Lock, is used for routine egress and ingress, including the transfer of equipment to and from space. The Crew Lock provides the physical interfaces between the ISS and the EMU or Orlan spacesuits for supporting all umbilical operations during sea level, depressurization, EVA, and repressurization events. When not in use, the EMUs are stowed within the Joint Airlock, while the Orlan spacesuits and support equipment are returned to the Russian docking compartment.



Figure 1 – Joint Airlock being attached to the International Space Station

GOVERNMENT-FURNISHED HARDWARE

The ISS Joint Airlock contains several key Airlock and EVA items provided by NASA and the Russian Space Agency (RSA), as government-furnished hardware, which allow EVAs to be performed utilizing the U.S. EMUs or Russian Orlan-M spacesuits. These internally-located items include the spacesuit Servicing and Performance Checkout Equipment (SPCE); EMUs and

support hardware; Orlan spacesuits and support hardware; and the Russian Airlock Depressurization Pump Assembly (including pump and pump control electronics).

SPCE

Located within the ISS Joint Airlock is a distributed set of hardware assemblies, referred to as Servicing and Performance Checkout Equipment (SPCE), which permit the servicing and checkout of EMUs and Orlans prior to and after each EVA, including the recharge of EMU and EVA tool batteries. During pre-breathe, EVA, and post-EVA umbilical operations, the SPCE provides an interface for the transfer of critical life-support resources to both the EMUs and to the Orlan-M spacesuits via their respective umbilicals. In addition, the SPCE includes controls for the activation of the Airlock depressurization pump and instrumentation for monitoring Crewlock pressure during egress and ingress activities.

EMUs and Support Hardware

Three U.S.-provided Shuttle EMUs (including 1 spare) and various pieces of support hardware, including umbilicals and consumables, provide the capability to perform autonomous EMU-based EVAs from the ISS (i.e., when the Shuttle is not present).

Orlan-M Spacesuits and Support Hardware

Three Russian-provided Orlan-M suits (including 1 spare) and various pieces of support hardware, including umbilicals and consumables, provide the capability to perform Orlan-based EVAs from the ISS. An Orlan-based EVA capability already exists in the Russian segment of the ISS, via Docking Compartment #1; however, there is a long-term desire to perform Russian EVAs from the Joint Airlock in order to conserve air by utilizing the depressurization pump assembly. To date, 6 Orlan-based EVAs have been performed from the Russian segment of the ISS. Negotiations with the Russian Space Agency to plan and conduct Orlan-based EVAs from the Joint Airlock are in work.

Russian Airlock Depressurization Pump Assembly

The Russian-provided Airlock depressurization pump, used to recover approximately 70% of the gas which is, typically, vented, is comprised of 2 major components: the depressurization pump and the pump control electronics. The depressurization pump is a two-stage vacuum pump used to transfer gas between the Crew Lock and Node element. The pump control electronics contain a power converter, pump control circuitry, and electronics used to measure and provide pump performance to the ISS Crew and to ground personnel.

This paper will concentrate on the unique design and functions of the SPCE and how these items provide the capability for supporting both U.S.- and Russian-based EVAs from the ISS Joint Airlock.

SPCE PROJECT

At the NASA/Johnson Space Center (NASA/JSC) in Houston, Texas, the SPCE hardware described above was designed, developed, tested, and certified to support EVAs utilizing either the EMU or Orlan-M spacesuit. Note that this required NASA to work very closely with RSA and RSA contractors, namely RSC-Energia and Zvezda (the Orlan spacesuit manufacturer), in order to meet the unique requirements for the Russian Orlan-M spacesuit. The completed SPCE hardware was, then, provided to the ISS Program as government-furnished equipment (GFE) and integrated into the Joint Airlock at the NASA/Marshall Space Flight Center (NASA/MSFC) in Huntsville, Alabama, by Boeing. System-level tests of the SPCE hardware were subsequently performed both at NASA/JSC and at NASA/MSFC utilizing both EMU and Orlan spacesuits and other support hardware.

Hardware Description

Implementing the ISS Program requirements levied on the SPCE Project, as summarized in Table 1, resulted in the development of several SPCE hardware assemblies. These items include the Battery Charger Assembly (BCA), Battery Stowage Assembly (BSA), EMU Don/Doff Assembly (EDDA), Fluid Pumping Unit (FPU), Power Supply Assembly (PSA), Umbilical Interface Assembly (UIA), and various SPCE maintenance fixtures. Figure 3 shows the relative locations of the SPCE hardware within the Airlock.

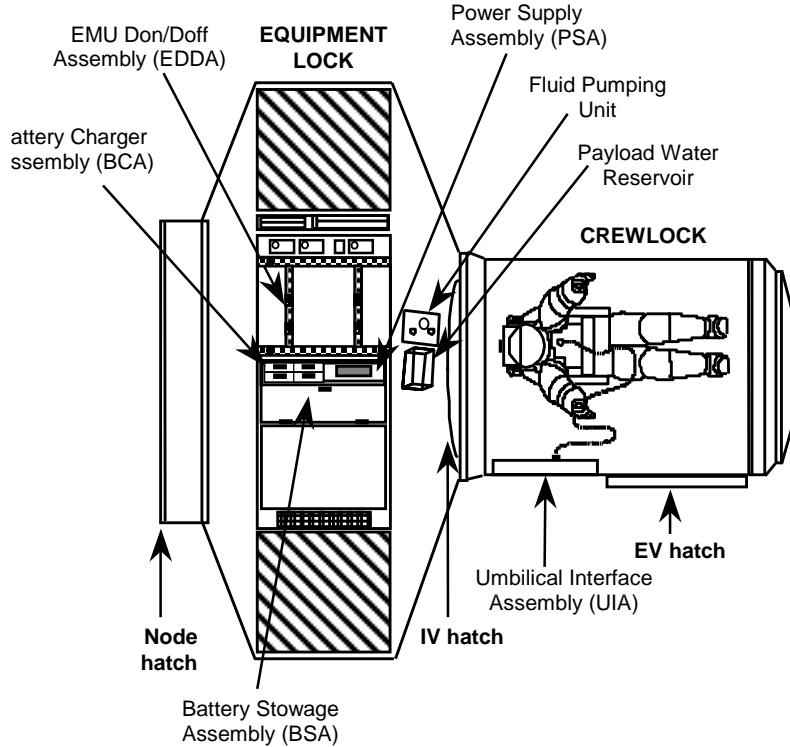


Figure 3 – Relative Locations of the SPCE Hardware in the Joint Airlock (view of Avionics Rack side)

Table 1 – SPCE Performance Requirements

Battery Recharge & Discharge	Physical Requirements
- Provide in-suit EMU battery recharge (2)	- SPCE major assemblies designed as Orbital Replacement Units (ORUs)
- Provide spare EMU battery recharge (2)	- Weight, data, power, structural, and mechanical interfaces per individual SPCE Assembly-to-Airlock Interface Control Documents (ICDs):
- Provide EVA tool battery recharge (18)	
- Provide EMU battery discharge	
Communications & Data	Oxygen Supply
- Provide interface and conditioning electronics between EMUs & Orlans and Airlock for hard-line communications	- Receive 900 psi oxygen from Airlock
- Provide analog and serial data to Airlock to allow ground monitoring of system operations	- Provide oxygen to EMU for tank recharge
- Provide pressure sensor to allow monitoring of Crewlock absolute pressure	- Provide oxygen to EMU for pre-breathe and umbilical operations
	- Provide oxygen to Orlan-M for pre-breathe and umbilical operations (70 psig)
Displays and Controls	Power
- Provide displays and controls necessary to operate SPCE and conduct EMU / Orlan-M servicing and checkout operations	- Convert 120 Vdc Airlock power
- Provide switch and indicators for activation of Airlock depressurization pump	- Supply power to two EMUs
	- Supply power to two Orlan-M spacesuits
	- Supply SPCE internal power
Maintenance Support	Suit Don / Doff
- Provide equipment to conduct cooling line flushing operations	- Provide structure for restraint of EMU during don and doff activities via Airlock-provided seat track anchors
- Provide data interface for EMU diagnostics	
- Provide data interface for battery charger reprogramming	
- Provide data interface to allow EMU battery discharge	
- Provide routine SPCE maintenance provisions	
Umbilical Cooling	
	- Provide interface for EMU cooling water
	- Provide interface for Orlan-M cooling water
Water Fill & Drain	
	- Provide EMU water fill
	- Provide EMU condensate drain

The SPCE assemblies and maintenance fixtures do not comprise a system by themselves; but rather, they are part of the overall, integrated Airlock system, providing key functions in support of EVA. The SPCE assemblies interface with the Airlock structure, electrical system, data system, and fluid systems. The SPCE also interfaces to the EMU and to the Orlan-M spacesuit via their umbilicals (which are also not considered part of the SPCE).

Below is a summary of each of the SPCE items along with a listing of primary requirements and a more specific description for their function and operation.

Battery Charger Assembly (BCA)

The primary function of the BCA, located in the Avionics Rack, is to recharge EMU and U.S. EVA tool batteries.

Top-level requirements for the BCA are shown in Table 2.

Table 2- Battery Charger Assembly Top-level Requirements

- Operate from 120 Vdc Airlock power
- Provide recharge power and control for up to 4 EMU batteries, two of which are located in the EMUs, two in the BSA
- Provide recharge power and control for helmet light, power tool, rechargeable EMU battery assembly (REBA) batteries via the BSA (18 total)
- Provide analog data to Airlock MDM for performance monitoring
- Provide serial data port (RS-485) to allow:
 - monitoring of recharge performance
- Provide serial data port (RS-232) to allow:
 - reprogramming of charge parameters
 - discharge capability for EMU batteries
- Provide display for monitoring charge status
- Be designed for installation into Airlock Avionics Rack
- Be designed for cooling via Airlock Avionics Rack cold plate
- Be designed for simple crew operation
- Be capable of survival in a vacuum
- Be designed as an ORU
- Weight not to exceed 30 kg (66 lbm)

Layout: The BCA is comprised of four, independent, battery charger modules (BCMs) mounted into a single structure, as shown in Figure 4. Each BCM has six output channels, providing the BCA with the capability to charge up to 24 batteries or battery packs. Two of these channels are dedicated to charging batteries in the EMU spacesuits. The remaining 22 channels are for charging batteries via the BSA. Each BCM is identical and interchangeable as an orbital replacement unit (ORU) to permit on-orbit replacement for a failed unit. This allows the crew to maintain a charge capability of critical batteries in the event one of the subassemblies fails.

Commercial Design: The BCMs are modified versions of the Commercial-Off-The-Shelf (COTS) Christie Electric Corporation (CEC)TM CASP2000 programmable charger. The CASP is a Charger, Analyzer, Sequencer and Power supply. The BCM only utilizes the Charger and Sequencer portions of the CASP2000 charger. The CASP2000 was selected for its capabilities to charge batteries of different chemistry, capacity, charge rate, charge voltage and charge method through the use of charge "Parameter Tables" which define the charge profile. It also has the flexibility to modify the Parameter Tables to add or delete batteries as required. This proved to be very beneficial during the development of the BCMs. For example, before the BCMs were completed, the Helmet Light and Pistol Grip Tool (PGT) battery technology was changed from Nickel Cadmium (NiCad) to Nickel Metal Hydrid (NiMH). In addition, the Rechargeable EVA Battery Assembly (REBA) battery



Figure 4 – Battery Charger Assembly (BCA) (top) and Battery Charger Module (BCM) (bottom)

was a late addition to the manifest of EVA batteries. These changes were accommodated by, simply, updating the charge Profile Tables in the BCMs.

Modifications to Commercial Design: While the functional capabilities of the CASP2000 met the requirements for charging EVA batteries, it did not meet many of the other ISS requirements for GFE hardware. Modifications made to the basic design include a simplified crew interface utilizing toggle switches in lieu of a keypad; design for conductive, rather than convective cooling; solid-state switches to replace mechanical relays; higher reliability parts where possible; upgraded display; design for operation from 120 Vdc rather than 120 Vac; addition of analog data outputs; and addition of an RS-485 serial data interface.

Operation: Charge is initiated when the crewmember toggles the mode switch to the charge position. The BCM, then, charges the batteries, sequentially, from Channel 1 through Channel 6. The charger identifies the battery connected to a particular channel by means of an identification (ID) resistor and uses the Parameter Table to determine the correct charge profile for charging the battery (charge current, charge method, termination

method). For the CASP2000, the resistor is located within the connecting cables. For the BCMs, the resistors are located in the BSA (since each slot in the BSA is dedicated to a particular battery type). Each channel also includes a thermocouple for monitoring battery temperature. Charge status can be monitored on-orbit from the front panel of the BCM and by the crew or ground personnel through the RS-485 serial data interface. This data provides real-time monitoring of batteries being charged, as well as the history of the batteries that have completed charge. Status messages provide feedback on whether the charge was completed successfully or terminated due to an error.

Charge Profiles and Time Duration: The zinc-silver oxide EMU batteries utilize a constant current charge algorithm with a voltage cut-off termination. An EMU battery typically will take 18-20 hours to charge. As mentioned earlier, the Helmet, PGT and REBA batteries are NiMH and utilize the ReFlex charge algorithm with negative slope termination. The ReFlex charge is a charge algorithm developed by CEC. It uses a constant current charge for 970 milliseconds, discharges the battery at 2.5 times the charge current for 5 milliseconds, and, then, lets the battery rest for 25 milliseconds. This algorithm allows charging at a higher charge current without the battery over heating or forming gas bubbles around the electrodes. The negative slope termination does not use a set voltage cut-off, but continues charging until the battery voltage reaches its peak voltage and then decreases for 3 consecutive sample periods. All of the NiMH batteries typically charge in 3-1/2 to 4 hours.

Design Description: A block diagram for the BCM is shown in [Figure 5](#). Each BCM has six (6) charge channels. The batteries (or battery packs) are charged in series beginning with channel one through channel six. The Input Board provides the electromagnetic interference (EMI) filtering of the 120 Vdc input power, provides the auxiliary power required for all of the electronics, and provides the drive power for the battery charging. The Power Board provides the output power stage and control for charging the batteries. Additional control circuitry was added for redundant safety of the charge process. A power transistor provides the battery discharge capability. The Central Processing Unit (CPU) Board is the main processing unit of the charger. It contains the charge profile tables used to recognize and setup the proper charge, the various charge algorithms used to control the charge (constant current, constant potential, reflex, etc.), and the history and data used to monitor the charge. The Micro-controller and Micro-controller Daughter boards were added to simplify the crew interface. Two switches replaced the original front panel and a new Liquid Crystal Display (LCD) was added to provide additional monitoring and status information. Each BCM provides both analog and serial data to the Airlock Multiplexer/Demultiplexer (MDM), which serves as the Airlock's data acquisition and control device. The

analog data provides voltage and current information for each BCM. The serial data includes channel identification, battery type, charge status, charge time, and other information. Since the MDM has only one available serial data port for the BCA, the four serial data outputs from the 4 BCMs are "daisy-chained" together and connected to the single MDM port using the EIA RS-485 standard.

Problems Encountered with the BCM: While adding a micro-controller to the BCM design seemed straightforward, interfacing it to the CPU board proved to be much more challenging than initially anticipated. The main issue was trying to capture the asynchronous data being sent from the CASP2000 microprocessor to what it thinks is the original LCD display. This was done with the new micro-controller by simulating "pushing" buttons on the original keypad to request the battery type and history data and, then, capturing the data. Unfortunately, this caused garbled messages on the new display, which could be corrected (as an on-orbit work-around) by scrolling through the data again. This issue was addressed in the latest upgrades to the BCMs by parsing the data more accurately and requesting the data several times if it appeared there was a problem with the data. Another significant problem, still under investigation at the time of this writing, is an apparent undercharge condition when charging EMU batteries. Since an

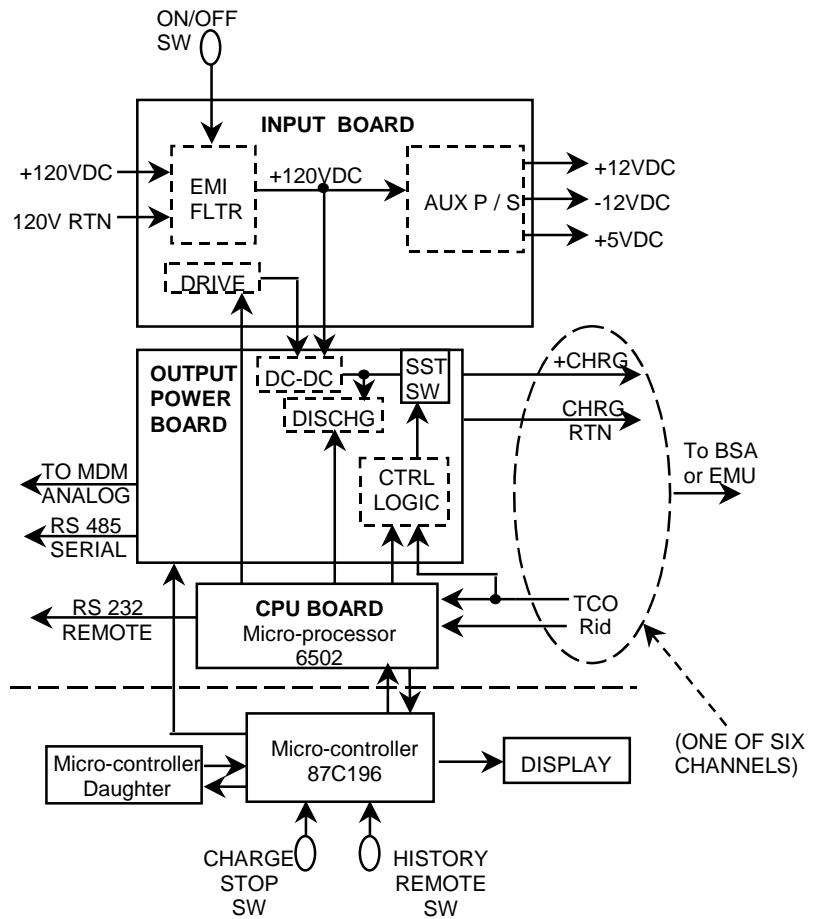


Figure 5 – Block Diagram of Battery Charger Module (BCM)

upgraded ISS version of the EMU battery was not available when delivery of the BCA was made for Joint Airlock integration, an older, Shuttle, version of the EMU battery was utilized for the certification of the BCA. Although the batteries, on paper, should have behaved exactly the same, subtle differences have prevented the BCA on-orbit from performing a "full" EMU battery recharge. It is believed that electrical noise, as a result of insufficient filtering, being generated from the "as delivered" BCM is responsible for the undercharge condition. Ground testing with an upgraded BCM has successfully demonstrated a full charge of the EMU battery. In April 2002, 2 upgraded BCMS were installed in the Joint Airlock, replacing 2 older configuration BCMS. An in-flight experiment is scheduled for late May 2002 to determine if the upgrades made to the BCMS will solve this undercharge condition.

Battery Stowage Assembly (BSA)

The function of the BSA is to provide the physical containment and electrical interfaces for recharge of EMU and U.S. EVA tool batteries. The BSA mounts in the Airlock Avionics Rack, just below the PSA and BCA. BSA top-level requirements are shown in [Table 3](#).

**Table 3 - Battery Stowage Assembly (BSA)
Top-level Requirements**

- Power and charge control provided by BCA
- Provides the capability to charge up to 22 batteries
- Provide indicator for on-going charge
- Charge automatically terminates when BSA door is open (charge resumes automatically when closed and BCM switches turned ON)
- Provides both analog & discrete interfaces to BCA for control & ground telemetry
- Be designed for installation into the Airlock Avionics Rack
- Be designed for cooling via Airlock Avionics Rack cold plate
- Be designed as an ORU
- Designed to survive vacuum exposure
- Weight not to exceed 34 kg (75 lbm)

Layout: The BSA contains mounting provisions for 2 EMU, 9 helmet light, and 5 power tool batteries as shown in [Figure 6](#). Via a front-mounted external port, an electrical harness can be attached which allows for the recharge of 2 REBA batteries. During recharge, the BSA provides a visual cue to the crew for the on-going charging process by means of a light emitting diode (LED). As a safety precaution, the charging process is stopped if the BSA door is opened, but reinitiated when the BSA door is closed. As mentioned previously, BSA power and battery charging power is obtained from the BCMS.

Design Description: A block diagram of the BSA is shown in [Figure 7](#). The BSA is the interface between the 4 BCMS and the EVA batteries. The BSA receives +12

Vdc from each BCM to power the electronics. One BCM is adequate to fully power the BSA. Hardwire connections for the charge power, ID resistor, and Thermal Cut-off (TCO) signals are routed from each battery to a particular BCM. The ID resistor identifies a particular battery to the BCM. A light-emitting diode (LED) indicates that charging is occurring in one or more BCMS. Thermocouples in the batteries are monitored and activate the BCM TCO signal if the battery becomes too hot during charge. Opening the BSA door during charge activates all of the TCO signals and stops charging on all 4 BCMS. Charging is automatically resumed when the door is closed. A fan provides airflow to prevent the build-up of any gasses, should a battery vent during charge. Redundant fans and door switches are provided in the case of a failure.

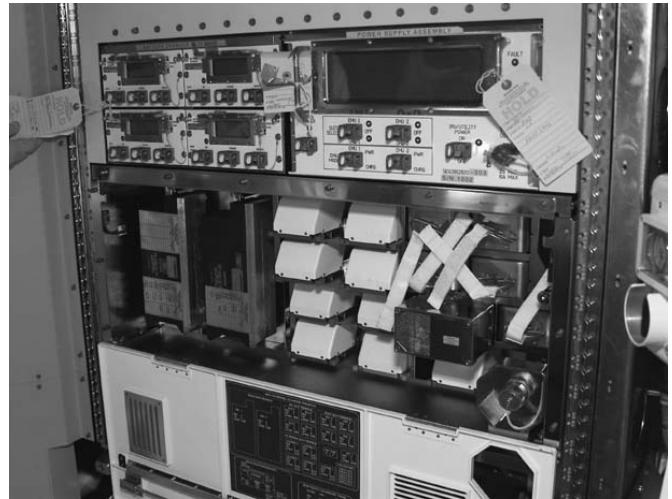
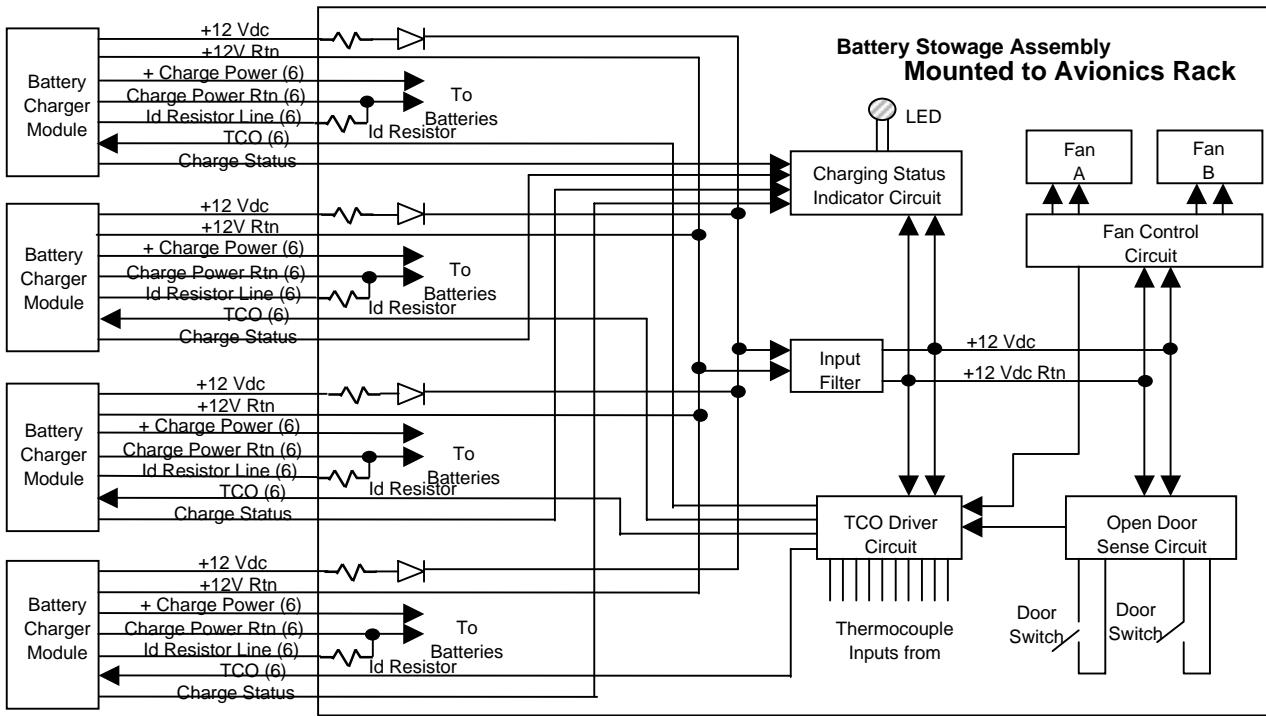


Figure 6- Open Battery Stowage Assembly (BSA) Showing Full Complement of EVA Batteries

EMU Don/Doff Assembly (EDDA)

The EDDA is an aluminum structure which provides the physical restraint of the EMU during donning and doffing activities. There are two EDDAs in the Joint Airlock. One EDDA is attached to the Avionics Rack; the other EDDA is attached to the Cabin Air Rack. The EDDA is shown in [Figure 8](#) attached to the Avionics Rack. A summary of the top-level requirements for the EDDA is provided in [Table 4](#).

Design Description: Each EDDA attaches to the rack face via four hex stud interfaces using ISS standard seat track anchors. In order to maintain commonality with Shuttle operations (since the same EMU is utilized), the EDDA employs the same backpack attachment method used on the Shuttle Orbiter. However, since the EDDA is not required to fit onto the curved wall of the Shuttle Airlock nor withstand Shuttle launch loads, it is a much simpler structure than the existing Shuttle donning stand from both a design and manufacturing standpoint.



**Figure 7 - Battery Stowage Assembly (BSA)
Block Diagram**



Figure 8 – EMU Don / Doff Assembly (EDDA)

The EDDA has been designed to “swing away” from the rack face to permit access to the rack face and to the back of the EMU (for carbon dioxide scrubber cartridge and battery replacement, for example). Use of the standard set track anchor and seat track allows height of the EDDA from the floor to be adjusted in one-inch increments to accommodate various crew sizes and preferences.

**Table 4 - EMU Don / Doff Assembly
Top-level Requirements**

- Provide structure for restraint of EMUs during donning and doffing activities
- Provide EMU restraint to facilitate donning & doffing via standard Shuttle latches & handles
- Provide additional features to facilitate EMU servicing and maintenance
- Be designed for mounting onto Airlock racks via standard seat track anchors
- Be designed for simple crew operation
- Be designed as an ORU
- Weight not to exceed 11.3 kg (25 lbm)

Fluid Pumping Unit (FPU)

The function of the FPU is to provide the capability to refill the EMU water tanks after each EVA. A summary of the top-level requirements for the FPU is provided in [Table 5](#).

Layout: Since the Joint Airlock does not provide a source of potable water, it must be retrieved from either

Table 5 - Fluid Pumping Unit (FPU) Top-level Requirements

- Provide the capability to refill two EMUs, one at-a-time or simultaneously
- FPU power provided by PSA
- Provide regulation of the water pressure to the EMU (55.1 - 103.4 kPa) (12 +3/-4 psig)
- Provide capability to monitor the amount of water pumped into the EMUs
- Provide auxiliary water outlet port
- Provide fault indication for over-pressure and over-temperature
- Provide automatic shutdown for over-pressure
- Water flow rate to EMU 27.2 kg/hr (60 lbm/hr)
- Be compatible with EMU water purity and iodine requirements
- Be designed for installation into the Airlock end cone area (FPU)
- Be designed as an ORU
- Be designed to survive vacuum exposure
- Weight not to exceed 13.6 (30 lbm)

the Shuttle or ISS galley. This is presently performed utilizing a payload water reservoir (PWR), as shown in [Figure 9](#), which is not considered part of the SPCE Project. The FPU developed for the ISS, as shown in [Figure 10](#), is a variation of a design originally developed by NASA's Ames Research Center and previously flown aboard the Space Shuttle's Spacelab. For the ISS application, the FPU is used to pump the water from the PWR to the EMUs via the Airlock plumbing, the UIA, and the EMU umbilicals. It is located within the end cone area of the Joint Airlock and mounted to the secondary structure. The FPU also includes a digital counter, for monitoring the amount of water pumped into the EMU. An auxiliary water output is located on the front of the FPU and is selected via a manual valve on the front panel. The interface to the Joint Airlock plumbing is accomplished using a Gamah® fitting on the underside of the FPU.

Design Description: A diagram of the FPU is shown in [Figure 11](#). The FPU operates from 28 Vdc at less than 12 watts supplied by power from the PSA. The FPU includes two hermetically sealed switches: one for control of the main power to the FPU and the other for operation of the pump itself. The FPU uses a gear pump which is magnetically coupled to a brushless DC motor. The output of the pump is manually variable up to 109 kg/hr (240 lbm/hr), but is fixed at 27.2 kg/hr (60 lbm/hr) for this application. A thermocouple is mounted to the body of the pump to monitor pump temperature. The FPU includes four status LEDs: main power ON, pump ON, over-temperature fault, and over-pressure fault. After filling the PWR, it is connected to the water inlet quick disconnect connector on the front of the FPU. The pump is turned on and draws the water from the PWR through the inlet check valve (CV1) and a 7-micron particulate filter. The water is then pumped out of the

FPU and into the Airlock plumbing where it is transferred into the EMUs. As the water bladders in the EMU fill and the system pressure subsequently begins to increase, regulator PR1 begins to close down to keep the pressure from exceeding 15 psi. The flow rate decreases to zero when the regulator fully closes. Relief valve RV2, which opens at approximately 15 psi, prevents over-pressurization of the EMUs in the event that PR1 fails open. If RV2 also fails (closed), the pump is automatically shut down when the pressure, as sensed by pressure transducer P1, reaches 16 psi. RV1 provides additional protection by opening a circulation loop for the pump in the event that PR1 is closed and RV2 fails to open. Flowmeter F1 measures the amount of water that has been pumped and sends a pulsed output to a counter where the data is displayed. The LED display shows the number of pounds of water pumped. The display is re-set by cycling the FPU main power. Pressure gauge G1 provides the crew with a visual indication of system pressure. V1 is a manual valve that allows the crew to select whether the water is



Figure 9 – Payload Water Reservoir (PWR)

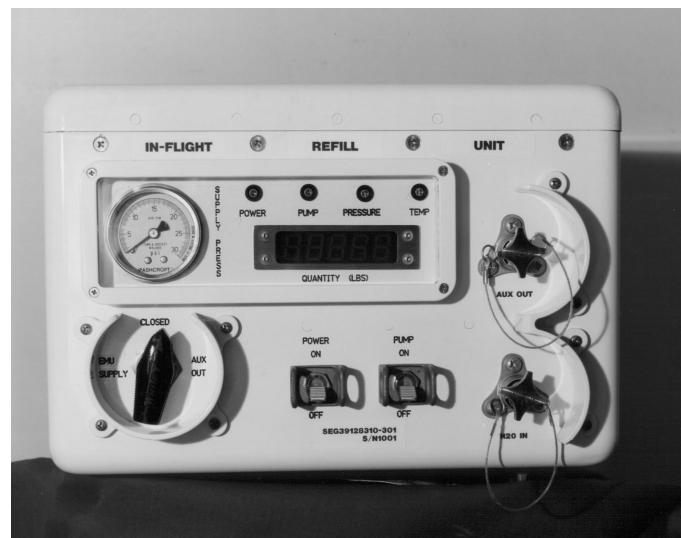


Figure 10 – Fluid Pumping Unit (FPU)

pumped into the Airlock (nominal) or out through an auxiliary port on the front of the FPU (off-nominal).

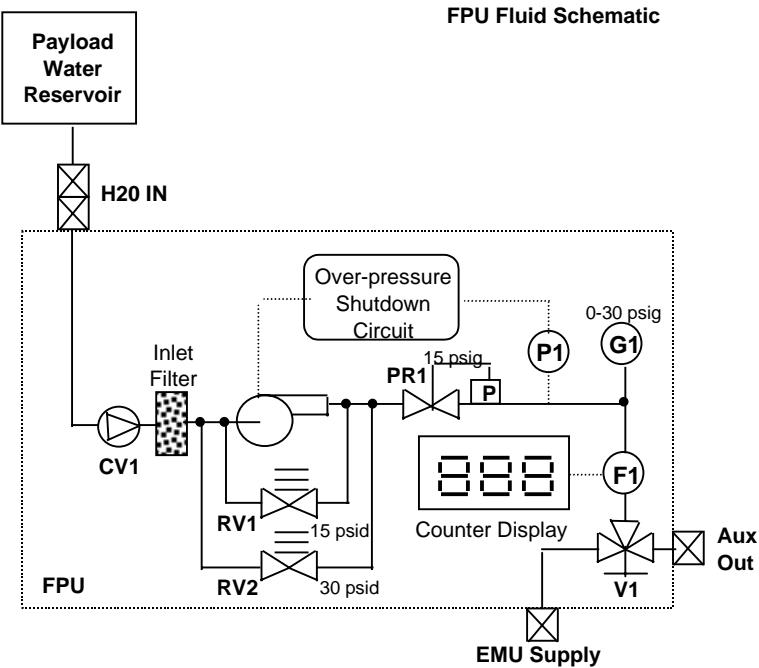
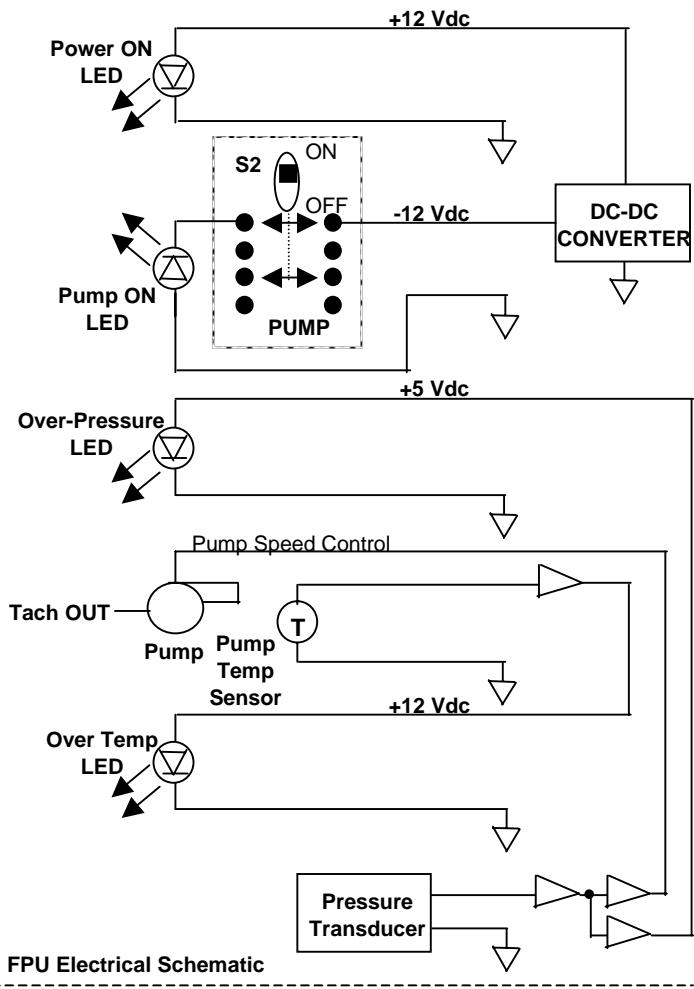


Figure 11 – Fluid Pumping Unit (FPU) Simplified Electrical and Fluid Schematics

Power Supply Assembly (PSA)

The PSA, as shown in [Figure 12](#), provides the capability to power two EMUs, two Orlan-M spacesuits, or one of each. The PSA also supplies power to the FPU and UIA, which are not designed to operate from the Airlock's 120 Vdc bus. The PSA includes a general purpose 28 Vdc utility electrical port on the front panel for powering portable equipment such as the Russian degassing pump. A large LCD provides status and loads information to the crew. Analog data, which includes the voltage and current for each PSA output, is continuously provided to the Airlock MDM to be accessed by either on-orbit or ground personnel. The PSA is mounted onto a cold-plate in the Airlock Avionics Rack. A summary of top-level requirements is provided in [Table 6](#). Specific PSA power outputs are shown in [Table 7](#).



Figure 12 - Power Supply Assembly (PSA)

Table 6 - Power Supply Assembly (PSA)
Top-level Requirements

- Operate from 120 Vdc Airlock-supplied power
- Provide power for two Shuttle EMUs, two Russian Orlan-M space suits, or one of each
- Provide power to FPU/Auxiliary port (28 Vdc)
- Provide power UIA electronics (26.5 Vdc)
- Provide over-voltage and over-current protection for EMUs, Orlan-M spacesuits, and FPU/auxiliary port
- Provide analog data to Airlock MDM for performance monitoring
- Provide display for monitoring status and loads information
- Be designed for installation into Airlock Avionics Rack
- Be designed for cooling via Airlock Avionics Rack cold plate
- Be capable of operation in a vacuum
- Be designed as an ORU
- Weight not to exceed 11.3 kg (25 lbm)

Design Description: The PSA consists of a set of DC-DC converter modules which convert the 120 Vdc input to

the following outputs: 18.5 Vdc (for the EMUs), 28.0 Vdc (for the Orlans), 28.0 Vdc (for the FPU), and 26.5 Vdc (for the UIA electronics). These converters are essentially Vicor™ catalog items with only minor design modifications. Each set of converters is capable of supplying up to 300 watts. This power level is needed, especially, to handle the startup loads from the Orlan-M spacesuits.

Table 7 - Power Supply Assembly Outputs

<u>Load</u>	<u>Supply</u>	<u>Current</u>
EMU (2)	18.5 ± 0.5 Vdc	5.5 Amps nominal (each)
Orlan-M (2)	28.0 ± 0.6 Vdc	3 amps nominal (each)
FPU / Utility Port	28.0 ± 1 Vdc	0.3 amps nominal, 6 amps max. from utility port
UIA	26.5 ± 1 Vdc	0.5 amps nominal

A block diagram of the PSA is shown in [Figure 13](#). The EMI Filter and Capacitor Block provide EMI Filtering of the 120 Vdc input power. The main power switch controls a “soft-start” circuit in the EMI Filter which controls the input of the 120 Vdc to the rest of the PSA. DC-DC Converter Modules provide the required output power. The EMU, Orlan, and FPU switches control the output enable lines of the DC-DC Converter Modules. The Signal Conditioning Board provides the monitoring and over-voltage / over-current protection circuits for the output power. Power transistors are located on the Transistor Board for the Orlan and FPU channels and are used in a crowbar circuit for over-voltage protection. When activated, the crowbar circuit clamps the output voltage and causes the over-current protection circuit to trip, which turns off the output of the DC-DC Converter Module. The crowbar circuit is designed such that it can remain clamped indefinitely without damage to the hardware. The EMU channel uses a power transistor as part of a linear regulator due to the electronics inside the EMU suit. The Logic Board and an LCD display provide on-orbit monitoring and status of the channels. Analog current and voltage data from each channel is provided to the MDM for ground monitoring.

Umbilical Interface Assembly (UIA)

The UIA, as shown in [Figure 14](#), is the sole interface for the transfer of power and fluids between the Airlock and the EMU and Orlan-M spacesuits via their respective umbilicals. The UIA is located in the Crew Lock, as shown in [Figure 3](#), and is mounted to the Crew Lock wall via a Boeing-provided mounting structure. The UIA contains controls and displays necessary to support pre-breathe, egress, EVA, and ingress umbilical operations for both the EMU and Orlan-M spacesuits. The UIA can

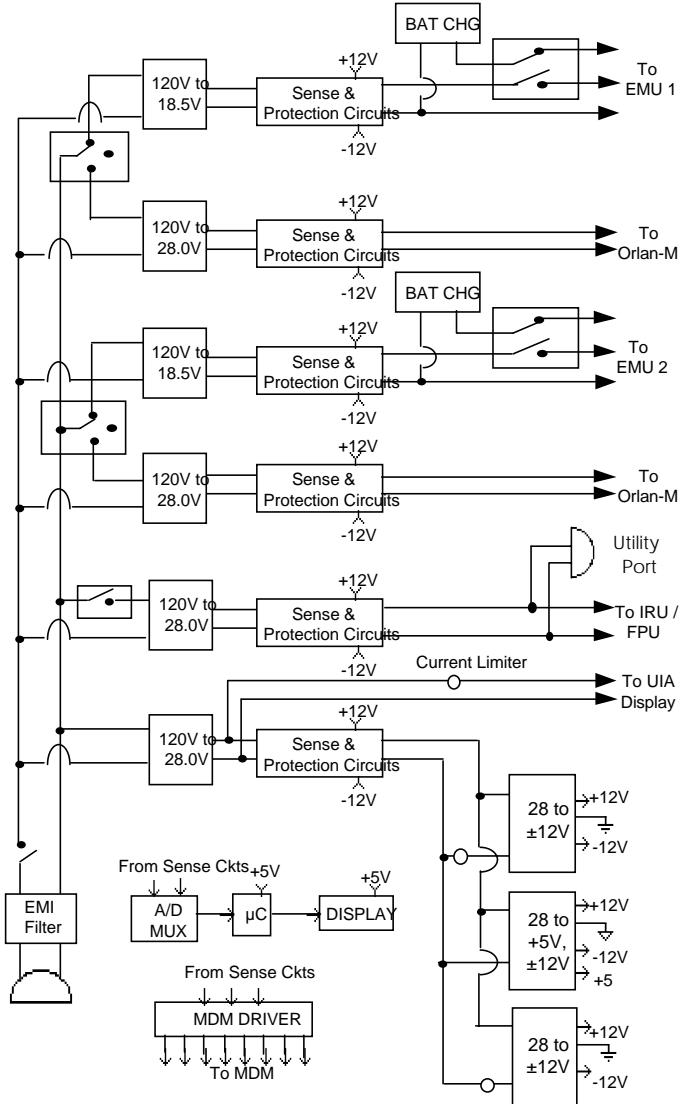


Figure 13 – Block Diagram of Power Supply Assembly (PSA)

support the operation of two EMUs, two Orlan-M spacesuits, or one of each. The UIA also houses the activation switch and status indicators for operation of the Russian-provided Airlock depressurization pump and a pressure sensor for monitoring Crew Lock absolute pressure. The UIA includes provisions for permanently mounting the Russian-provided On-board Spacesuit Control Assembly (OSCA). The OSCA is a manually-operated valve which provides control of the oxygen flow to the Orlan-M space suits. The OSCA is an ORU. The rest of the UIA is also an ORU. No lower level breakdowns are needed for on-orbit maintenance, except for routine replacement of biocide cartridges. A summary of top-level requirements for the UIA is provided in [Table 8](#). UIA functional interfaces are listed in [Table 9](#).

Design Description: The following resources are provided to the EMU and Orlan-M spacesuits. Refer to the schematic of the UIA as shown in [Figure 15](#).

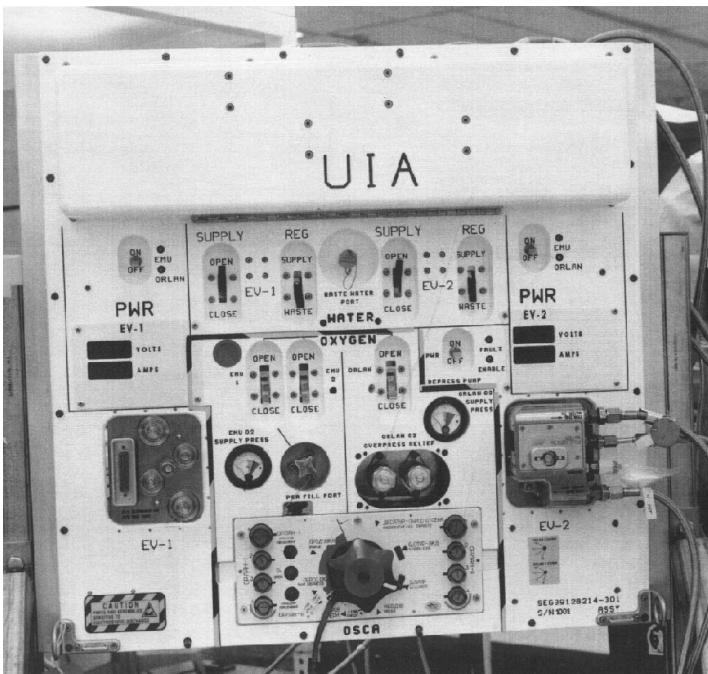


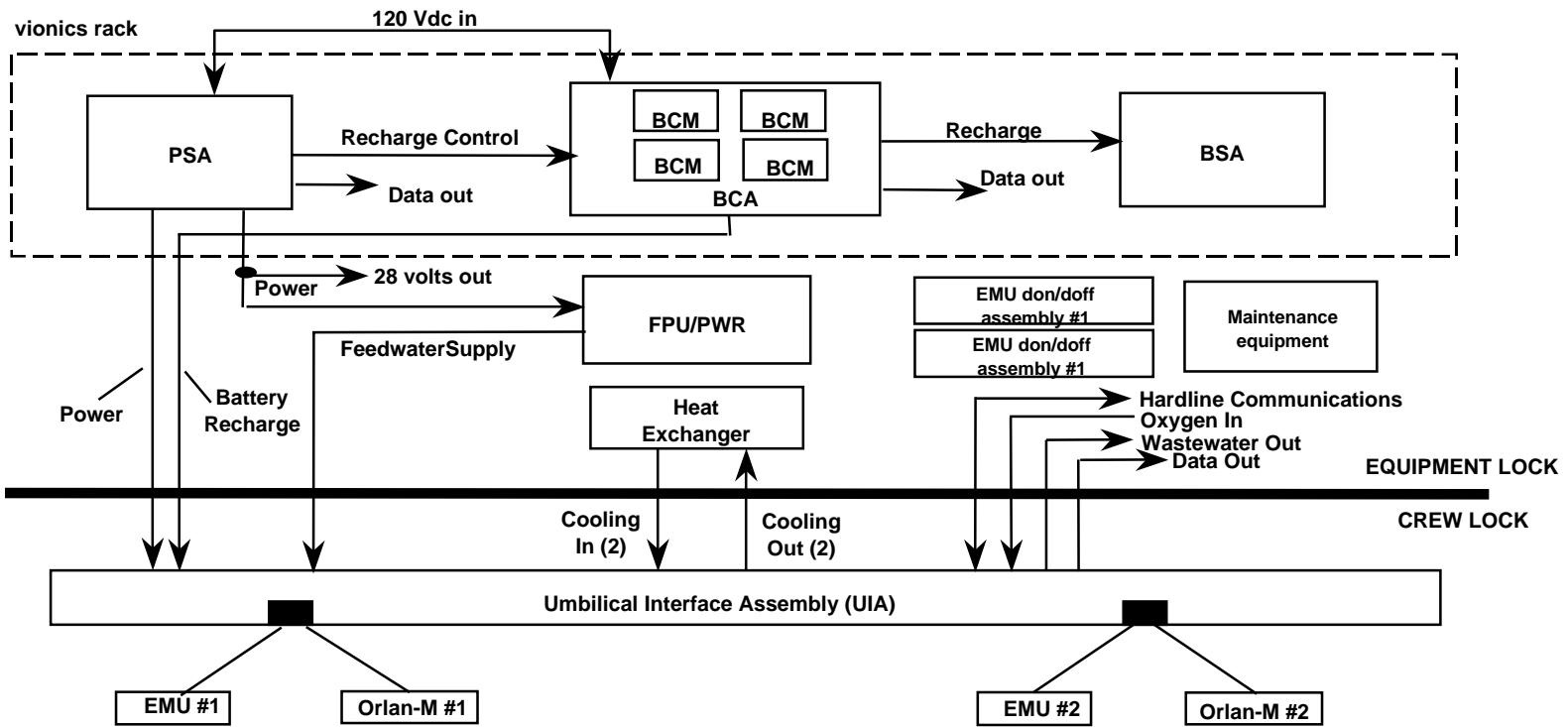
Figure 14 – Umbilical Interface Assembly (UIA)

Table 8 - Umbilical Interface Assembly Top-level Requirements

- Provide umbilical power to the EMUs and Orlan-Ms from the PSA
- Provide an interface to the FPU for refill of the EMU water tanks
- Provide bacterial control for EMU water tank refill and drain operations
- Provide a pressure sensor for ground monitoring of Crewlock atmospheric pressure
- Provide a location and oxygen interface for the OSCA including supply pressure readout, regulation, and over-pressure regulation
- Provide an ON/OFF switch and status indicators for depress pump operation
- Provide the interfaces, displays and controls necessary for accomplishing EMU oxygen tank refill; EMU water tank refill; EMU condensate drain and regulation; and EMU battery recharge for 2 EMUs
- Provide an interface between the EMUs and Orlans and the Joint Airlock for suit cooling
- Provide the conditioning interface circuitry to enable EMU & Orlan hardline communications to the Joint Airlock
- Provide analog data to the Airlock MDM to allow ground monitoring of voltage and current for each space suit
- Provide 900 psi oxygen recharge port
- Be designed for mounting a Boeing-provided mounting structure in the Crewlock
- Be designed for simple crew operation
- Be designed as an ORU
- Weight not to exceed 43 kg (95 lbm)

Table 9 - Umbilical Interface Assembly (UIA) Functional Interfaces

- Condensate and Feedwater Drain
 - See UIA-to-EMU below
- Communication
 - Provide conditioned hardline interface between EMUs and Orlans and EMU audio control panel (located in Equipment Lock)
- Feedwater
 - See UIA-to-EMU below
- Oxygen (to UIA):
 - Pressure: 6,205 kPa (900 psia)
 - Flowrate: 10.2 kg/hr (22.5 lbm/hr) minimum
- Power (from PSA)
 - Refer to Table 7 for suits and displays
- Suit Cooling
 - Provide cooling water interface to Airlock heat exchanger for each suit
 - Heat rejection rate:
 - EMU: 586 W (2,000 BTUs/hr) minimum per loop
 - Orlan-M: 400 W (1,365 BTUs/hr) minimum per loop
- UIA to EMU (via umbilical)
 - Oxygen
 - Pressure: 6,205 kPa (900 psia)
 - Flowrate: 3.4 kg/hr (7.49 lbm/hr) per EMU (worst case)
 - Power (from PSA)
 - Provide 18.5 +/- 0.5 Vdc at 6.5 amps average (from PSA), 8.0 amps peak per EMU
 - Provide EMU battery recharge line (one per EMU)
 - Feedwater tank recharge (from FPU)
 - Pressure: 55 kPa to 103.4 kPa (8.0 to 15.0 psig)
 - Flowrate: 27.2 kg/hr (60 lb/hr) (typical)
 - Feedwater Drain
 - Flowrate of 27.2 kg/hr at 55 kPa max (60 lbm/hr minimum at 8 psig max)
 - Condensate Drain
 - EMU-side wastewater pressure regulated to 114 kPa (16.5 psig) referenced to Crewlock ambient pressure
 - Pressure override regulation allows dumping of EMU tanks to waste water system at rated flow
 - Communication
 - Suit hardline interface to ISS communications network
 - Suit Cooling
 - Passive interface to Airlock cooling loop
- UIA to Orlan-M (via umbilical)
 - Oxygen
 - Pressure: 458.5 kPa to 506.8 kPa (70 +/- 3.5 psid) above Crewlock ambient pressure
 - Flowrate: 5.1 kg/hr (11.25 lbm/hr) minimum per Orlan (worst case)
 - Power (from PSA)
 - Provide 28.0 +/- 0.6 Vdc at 3.0 amps average, 12.0 amps peak per Orlan
 - Communication
 - Suit hardline interface to ISS communications network
 - Suit Cooling
 - Passive interface to Airlock cooling loop



**Figure 15 – Umbilical Interface Assembly (UIA)
Block Diagram For ISS Joint Airlock Resources**

Audio: The UIA provides a conditioned, electrical interface between the EMUs and/or Orlans and the Joint Airlock to support hard-line communications.

Data: The UIA provides analog data to the Airlock MDM for the voltage and current provided to each suit, similar to the analog data provided by the PSA. The interface is also used to transmit Crew Lock pressure data and to tie the depressurization pump control switch and indicators to the depressurization pump control electronics and MDM software.

Cooling Water: The UIA provides two passive interfaces between the Airlock heat exchanger and two attached spacesuits, either EMUs or Orlans. The spacesuit's pump is used to circulate water through the heat exchanger.

Feedwater: The UIA receives feedwater from the FPU and PWR, via the Airlock plumbing, and provides the interface to pass it through to the EMUs. The UIA includes a manual shut-off valve to control filling operations. There is no feedwater interface for the Orlan-M. The Russians provide Orlan-M feedwater separately.

Oxygen: The UIA receives oxygen directly from the Airlock oxygen system at 6,205 kPa (900 psi). The UIA then distributes the oxygen to the spacesuits. For the EMUs, this is a direct feed to the umbilicals through a manual shut-off valve. For the Orlan-M spacesuits, the pressure is first regulated down to 482.6 kPa (70 psig),

then supplied to the OSCA. The Russian umbilicals then carry the oxygen to the suit.

Power: The UIA provides the electrical interface between the PSA (via Airlock wiring) and the EMU and Orlan-M spacesuits via their respective umbilicals. The UIA has a switch to shut off power when needed and LED displays to allow the suited crewmembers to monitor system health.

Wastewater: The UIA accepts condensate and wastewater from the EMUs. During manned umbilical operations, a regulator in the UIA regulates the upstream (EMU side) pressure to 113.8 kPa (16.5 psig). A manual override allows the EMU tanks to be drained directly to the wastewater system during servicing. There is no wastewater interface for the Orlan-M. The UIA also includes a wastewater port on the front panel to support maintenance operations, such as flushing the cooling loops.

UIA Fluid Interfaces and Connectors: The fluid interfaces to the Airlock are made using Gamah® fittings. These fittings are accessible through an access panel on the front of the UIA (not shown in Figure 14). The electrical connectors are standard ISS connectors and are also accessible through this access panel interface. The UIA houses biocide filters (not shown in Figure 14) for the feedwater and wastewater circuits. These filters provide particulate filtration and also regulate the amount of iodine in the EMU feedwater and wastewater circuits. This level is maintained at 4 parts per million to inhibit

bacterial growth. The filters use the same internal cartridges and filter media as those currently used in the Space Shuttle. The outer housing has been redesigned for this specific mounting application.

In order to allow both the U.S. and Russian umbilicals to connect to the UIA, common mating connector interfaces were developed. The portion that is attached to the UIA (and treated as part of the UIA) is referred to as the Umbilical Connector Block (UCB). The mating connector to the UCB is referred to as the Umbilical Connector Manifold (UCM). The UCM is the half that is an integral part of the umbilicals. A UCB (open connector on the left of the UIA) and UCM (mounted to UIA in right portion of the UIA) can be seen in Figure 14. There are two versions of the UCM: the U.S. version which has the electrical connector, the feedwater fill/drain interface, and the cooling loop interfaces; and the Russian version which has only the electrical/hardline communications connector and the cooling loop interfaces. Various quantities of these mating halves were supplied to both Hamilton-Sundstrand, the manufacturer of the EMU and EMU umbilical, and Zvezda, the manufacturer of the Orlan-M and Orlan umbilical, for build-up and test of the certification and flight umbilicals.

SPCE Maintenance Fixtures – Several unique SPCE maintenance fixtures were developed to meet miscellaneous requirements to: 1) provide a direct computer interface to the SPCE battery chargers (e.g., upload new charge profiles or discharge EMU batteries), 2) “polish” the Joint Airlock’s spacesuit cooling water circuits, 3) route EMU diagnostic data to an ISS laptop computer, and to 4) provide general maintenance to the SPCE assemblies. To meet these requirements, the following maintenance fixtures were developed: BCM-to-Laptop Cable, Cooling Loop Flushing Fixture, EMU Serial Data Cable, and O-ring/Braycote Kits.

BCM-to-Laptop Cable: This cable attaches between the BCM and the laptop computer in order to load charge profiles into the BCMS or to initiate an EMU battery discharge.

Cooling Loop Flushing Fixture: There are a number of concerns regarding cross contamination of the water systems of both suits, particularly with respect to the EMU sublimator, which is sensitive to trace amounts of certain chemicals and contaminants in the water. There is also concern with mixing dissolved iodine, which is used to inhibit bacterial growth in the EMU, with silver ions, which is used to inhibit bacterial growth in the Orlan-M. The present operational baseline calls for flushing the spacesuit cooling loop (and Airlock heat exchanger) circuit following an Orlan EVA and prior to an EMU EVA. This operation is not needed following an EMU EVA in preparation of an Orlan EVA; since, the Orlan spacesuit is not susceptible to contamination to its feedwater circuit by the presence of iodine or iodine reactants. The Cooling Loop Flushing Fixture design is based on the UCM described earlier. For flushing the

lines to support EMU operations, it allows water to be pumped from the FPU, through the feedwater lines, through the cooling loop, and then into the wastewater port on the front of the UIA. The two loops are flushed serially. The amount of water required to satisfactorily clean the lines is on the order of 1 liter.

EMU Serial Data Cable: This cable attaches between the EMU and a standard ISS laptop computer in order to capture EMU diagnostic data. The EMU diagnostic data, available in a 4800 bit per second serial format, contains EMU information such as temperatures, pressures, currents, voltages and discrete data. This capability is made available in order to perform EMU trending or troubleshooting in the event of an on-orbit anomaly.

O-ring/Braycote Kits: The O-ring kit contains miscellaneous SPCE assembly item O-rings that may be needed at some point in the ISS Program. The Braycote kit provides the on-orbit crew with the capability for lubricating SPCE seals and other SPCE items (e.g., UCM 7/16" bolt threads).

Other SPCE Items: A number of other SPCE miscellaneous items were provided to the ISS Program. These include adjustable bungees, spare bacteriacide cartridges, spare umbilical restraint straps, spare umbilical pouch straps, and a UIA contingency cover.

Bungees: 4 adjustable bungees are provided for miscellaneous restraint of Airlock hardware items.

Spare Bacteriacide Cartridges: 2 spare bacteriacide cartridges are made available for routine servicing of the UIA. These cartridges are good for 26 EVAs (~ 63 gallons of water flowing through the cartridge) or 2 years.

Spare Umbilical Restraint Straps: These are straps are used to secure the EMU umbilical to the inside wall of the Crewlock.

Spare Umbilical Pouch Straps: These are straps are used to secure the EMU umbilical pouch to the inside wall of the Crewlock.

UIA Contingency Cover: This cover attaches to the back of the UIA for the exclusive case in which an EVA is to be conducted from within the Equipment Lock. No EVAs from the Equipment Lock are planned. However, the Joint Airlock contains the necessary interfaces for conducting such an EVA. The scenario for which this may occur is the case for an EV hatch failure in the Crew Lock. In this scenario, the Crewmembers would remove the EMU umbilicals from the UIA and perform an emergency ingress into the Equipment Lock (which requires the Equipment Lock to be depressurized). Using an on-orbit spare UIA and the EMU umbilicals (retrieved from the Crewlock), the ISS crew would then have an EVA capability from the Equipment Lock.

CURRENT STATUS

The SPCE assemblies and miscellaneous hardware items described above were developed by NASA/JSC and integrated in the ISS Joint Airlock. They were primarily delivered to the ISS aboard Space Shuttle Flight 7A in July 2001 and have successfully supported EMU EVAs conducted from the ISS Joint Airlock in July 2001, February 2002, April 2002, and June 2002.

Negotiations are currently underway with the Russian Space Agency and its primary contractor, Energia, to plan an Orlan-based EVA from the Joint Airlock in the near future. However, due to recent manpower support and budgetary constraints, Orlan-based EVAs from the ISS Joint Airlock may not occur for a year or more.

SUMMARY / CONCLUSION

Several SPCE hardware assemblies and miscellaneous items were designed and developed by NASA/JSC for the ISS Program and delivered aboard the ISS Joint Airlock in July 2001. A great deal of coordination, integration, and testing was required between NASA and RSA and their contractors, Boeing, Lockheed-Martin, RSC-Energia, and Zvezda to accomplish this project. The SPCE items provide the unique capability for allowing both U.S. and Russian EVAs to be conducted from ISS Joint Airlock. Thus far, 9 EMU EVAs have been successfully conducted from the ISS Joint Airlock with many other EVAs planned for the life of the ISS Program. Some on-orbit performance anomalies have been identified with the SPCE, but do not pose any threats to the continued support for EVA. Negotiations are currently underway with the Russian Space Agency to plan and conduct an Orlan-based EVA from the Joint Airlock; although budgetary and other constraints may delay this from happening in the near future.

Gamah® is a product line of the Stanley Aviation Co.

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ACRONYMS

BCA	Battery Charger Assembly
BSA	Battery Stowage Assembly
COTS	Commercial Off-The-Shelf
CPU	Central Processing Unit
EDDA	EMU Don / Doff Assembly
EMU	Extravehicular Mobility Unit
EV	Extravehicular
EVA	Extravehicular Activity
FPU	Fluid Pumping Unit
GFE	Government Furnished Equipment
ID	Identification
IV	Intravehicular
ISS	International Space Station
JSC	Johnson Space Center
LCD	Liquid Crystal Display
LED	Light-Emitting Diode
MDM	Multiplexer / Demultiplexer
MSFC	Marshall Space Flight Center
NASA	National Aeronautics & Space Administration
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride ORU
OSCA	On-board Spacesuit Control Assembly
PGT	Pistol Grip Tool
PSA	Power Supply Assembly
PWR	Payload Water Reservoir
RF	Radio Frequency
RITF	Receiving Inspection Test Facility (RITF)
RPCM	Remote Power Control Module
RSA	Russian Space Agency
SPCE	Servicing & Performance Checkout Equipment
SSATA	Space Station Airlock Test Article
TCO	Thermal Cut-Off
TTL	Transistor-Transistor Logic
UCB	Umbilical Connector Block
UCM	Umbilical Connector Manifold
UIA	Umbilical Interface Assembly