Portable Life Support Systems

- PLSS designs from past programs (all from 2008 ICES conference)
  - Panel Overview (James McBarron)
  - Gemini EVA Life Support Systems (Harold McMann)
  - Apollo Portable Life Support Systems (Maurice Carson)
  - Skylab Astronaut Life Support Assembly (Joseph Gillerman)
  - Shuttle EMU Life Support System (Richard Wilde)
- EVA Suit Technology Development (Liana Rodriggs - 2016)

38th International Conference On Environmental Systems

History Panel On EVA Portable Life Support Systems

JULY 1, 2008

JAMES MCBARRON II
Panel Organizer
McBarron Consulting

ICES HISTORY PANEL

EVA PORTABLE LIFE SUPPORT SYSTEMS

- PANEL MEMBERS
  - Gemini EVA LSS Projects - Harold J.McMann
  - Apollo EMU PLSS Program - Maurice Carson
  - Skylab ALSA Program - Joseph B. Gillerman
  - Shuttle EMU LSS Program - Richard C. Wilde

ICES HISTORY PANEL

EVA PORTABLE LIFE SUPPORT SYSTEMS

- PRESENTATION GROUNDRULES
  - System Description: Short and Concise
  - Challenges or Issues Encountered, and How Resolved
  - Lessons Learned
  - 20 Minutes Time Limit

- QUESTIONS AND RESPONSES PERIOD
  - After all Panel Members Presentations

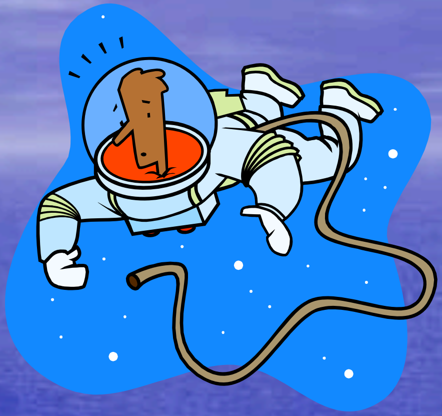
38th ICES Conference EVA Life Support System History Panel

Gemini EVA Life Support Systems

Harold J. McMann

July 1, 2008

Gemini EVA Life Support Systems
AGENDA

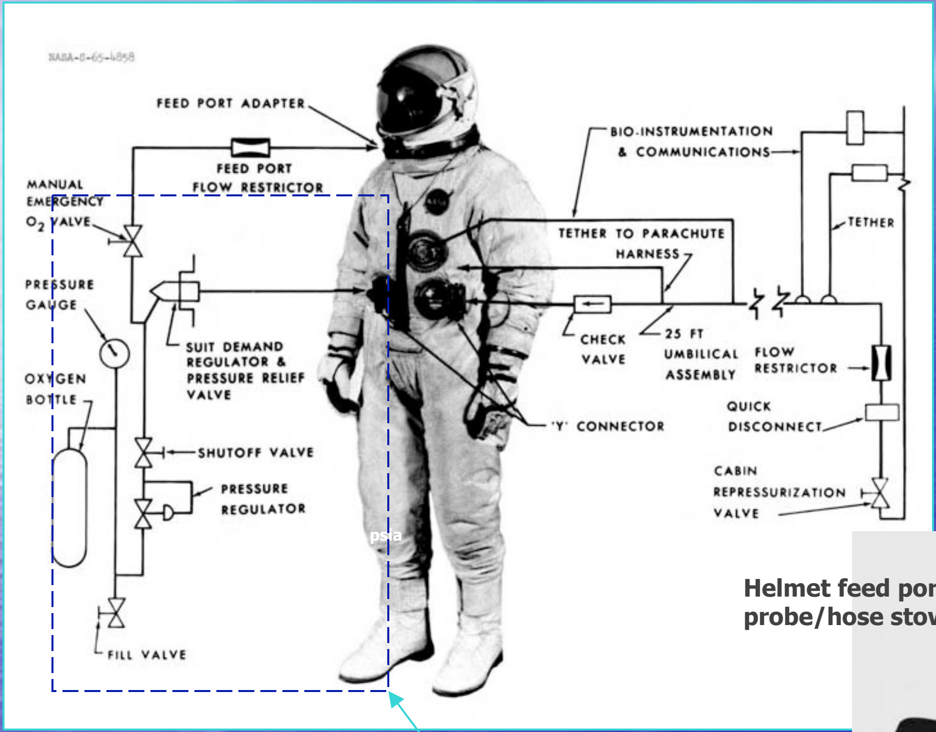


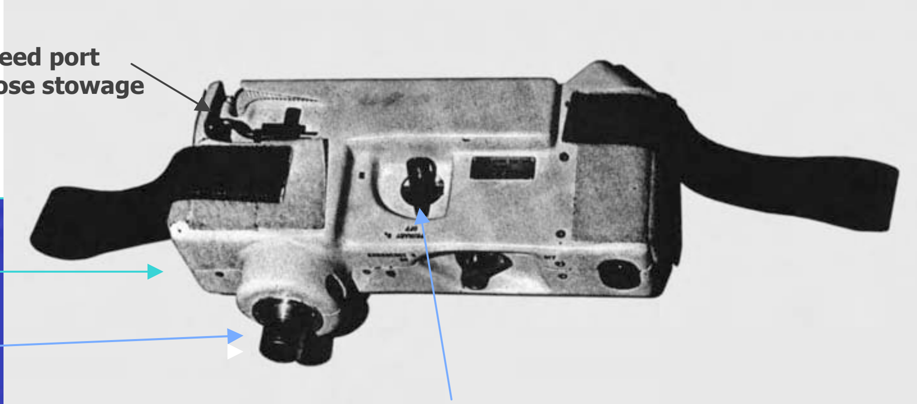
- *Introduction*
- *Systems Descriptions*
- *Major Challenges Met*
- *Issues Experienced and Resolution*
- *Lessons Learned*
- *Final Thoughts*

Gemini EVA Life Support Systems Descriptions

- *1963 – First Concept: Oxygen flowing from two Project Mercury 7500 psi oxygen bottles through a regulator and orifice into the suit and out a relief valve to provide 15 minutes of EVA*
- *March 18, 1965 – Cosmonaut Aleksei Leonov performed world's first EVA*
- *March 26, 1965 – At JSC, Branch Chief Jim Correale established Gemini IV tiger team under Larry E. Bell to:*
  - *Design, build, test and provide a suit and life support system to enable Ed White to perform EVA on June 3, 1965*
    - ***Open-loop system***
    - ***Use oxygen via umbilical***
- *Remaining Gemini flights – ejector system*
- *Air Force Maneuvering unit to be flown*
  - *Flights IX and XII*

Gemini IV EVA Life Support System Description





Helmet feed port probe/hose stowage

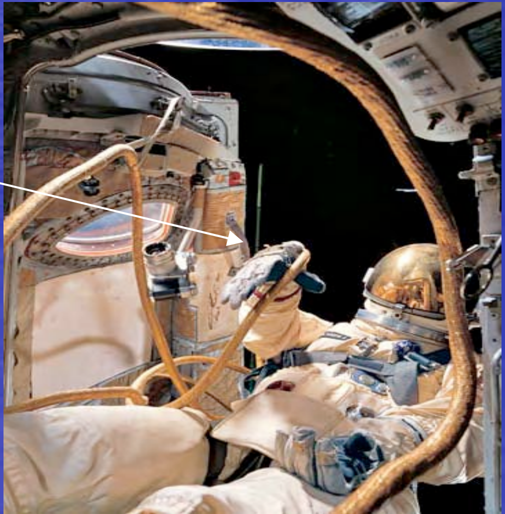
Ventilation Control Module (VCM)

Inlet from suit

Emergency Oxygen shutoff valve

Gemini IV EVA Life Support System Challenges and Issues

- *Challenges…*
  - ***69 days from inception to orbit***
  - ***Need for secrecy***
  - ***Management approval***
- *Issues*
  - ***Serious overheating during manipulation of faulty hatch-locking mechanism***
    - ***Profuse sweating***
    - ***Visor fogging***



Hatch closure handle

- *Challenges met by…*
  - ***Dedicated tiger team; handwritten documentation: end-to-end tests in vacuum chamber with flight EVA hardware and flight crew***
  - ***Calling system "Chamber Vent System"***
  - ***"Do or Die" presentation to top Center management***
- *Issues Resolved by…*
  - ***Fixing hatch mechanism***
  - ***Paying more attention to training for tasks – pace workload***

Gemini IV EVA Life Support System Lessons Learned

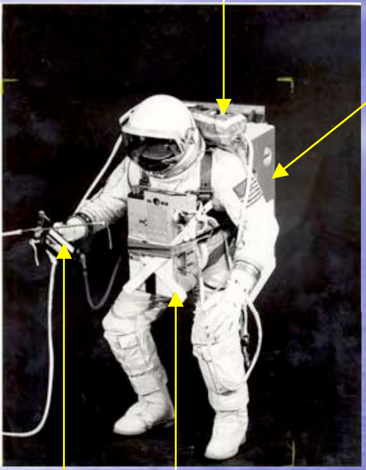
- *Adequate cooling from the 8.2lb/hr oxygen flow was experienced by Ed White during the 36 minute EVA except when mounting the camera and during ingress*
- *<u>Conclusion:</u> Gas cooling (i.e., cooling primarily by evaporation of perspiration into dry gas stream) provided by the Gemini IV EVA Life Support System was satisfactory only for low to moderate work loads.*

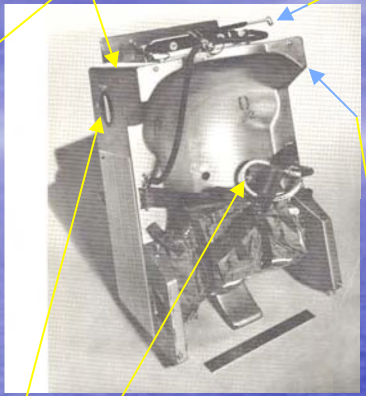
Gemini VIII EVA Life Support System Description

75 foot electrical cable/load-bearing tether stowage bag

Extravehicular Support Package (ESP)

HHMU Stowage





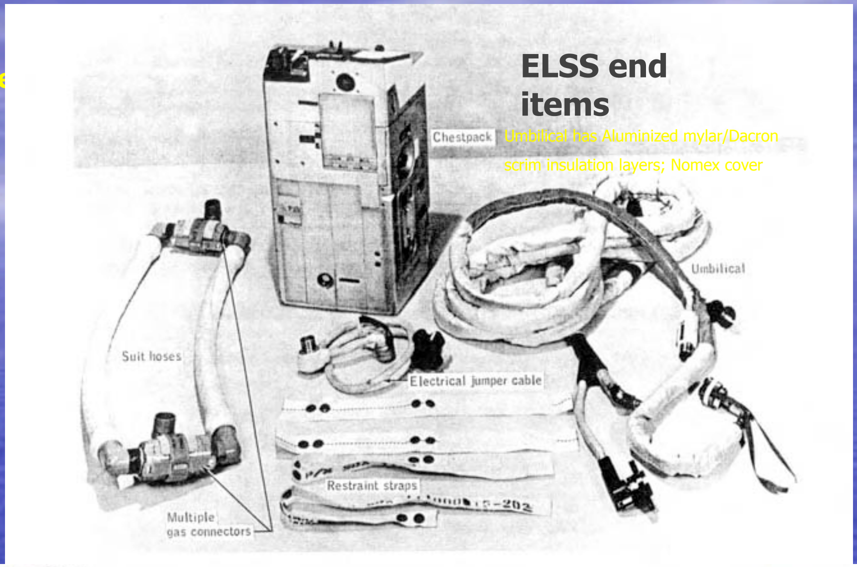
Propellant shutoff valve

Oxygen shutoff valve (like propellant shutoff valve)

HHMU

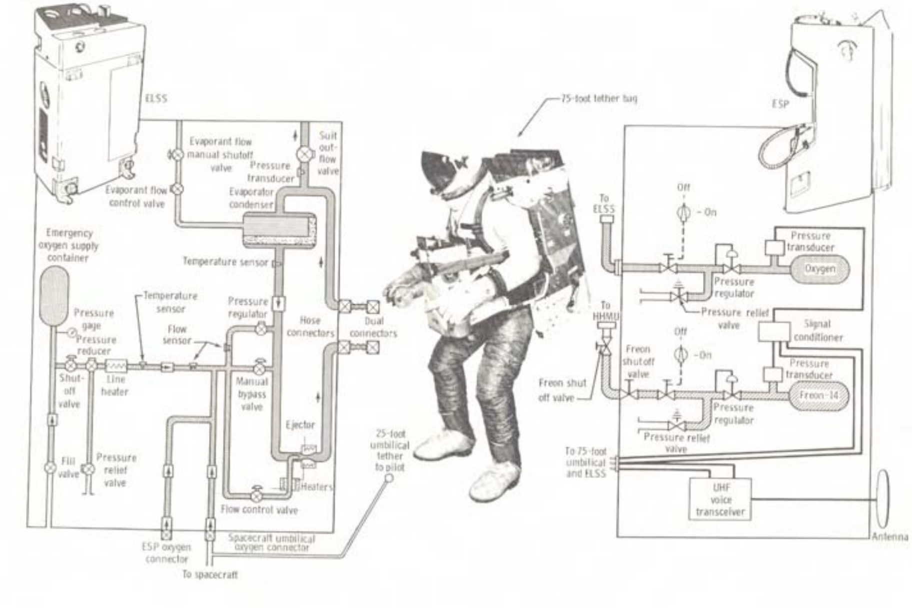
ELSS chestpack

Oxygen hose to ELSS



ELSS end items

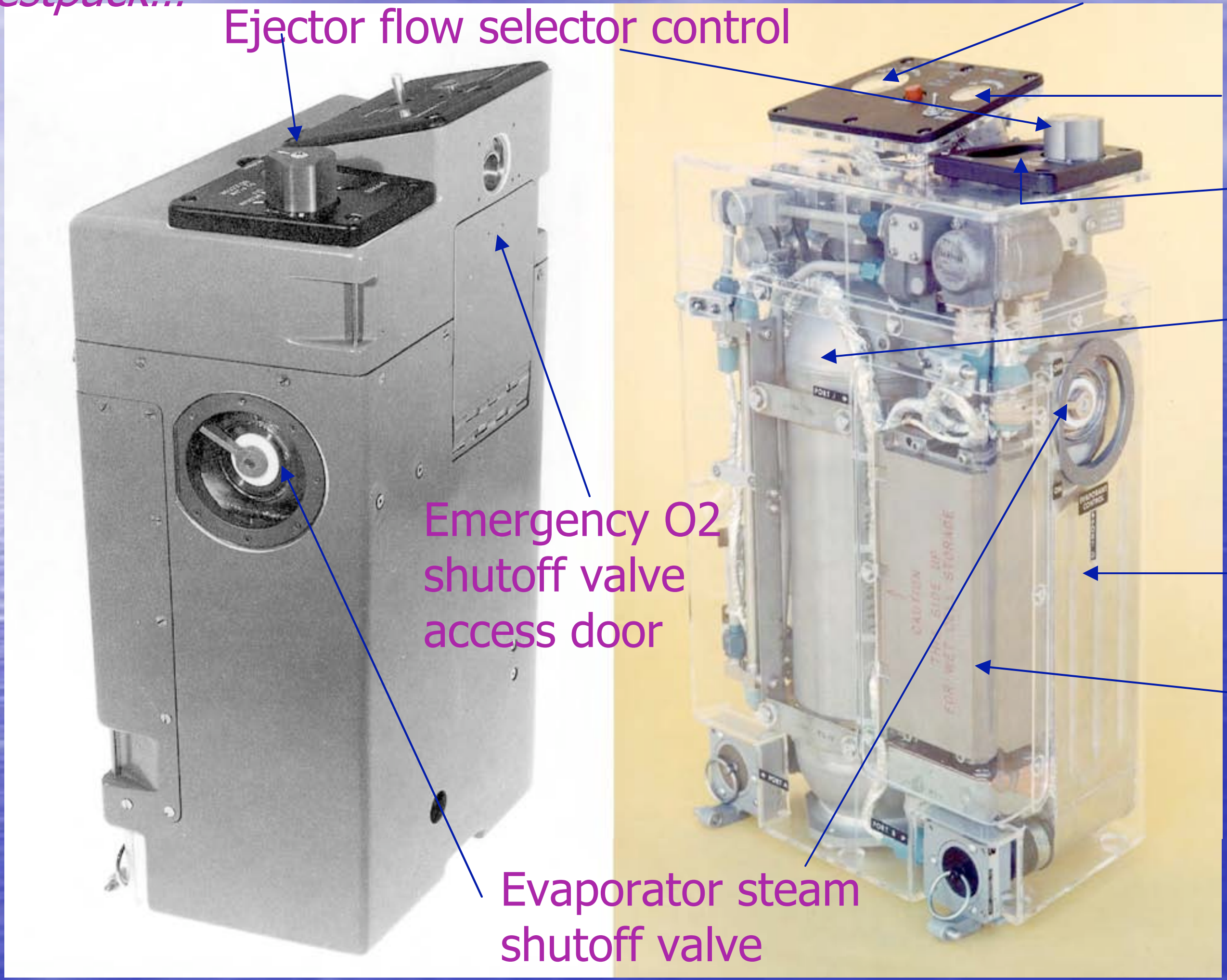
Umbilical has Aluminized mylar/Dacron scrim insulation layers; Nomex cover



- •ESP provides oxygen, electrical power, comm (hardline and RF)
- •AMU planned for IX-A would provide similar services (except no hardline comm)

Gemini VIII EVA Life Support System Description

ELSS chestpack…


Ejector flow selector control

H2O2 or ESP O2 quantity

Emer O2 tank pressure

Recessed rocker-type bypass valve control

7500 psi Oxygen tank

Emergency O2 shutoff valve access door

Evaporator

AgO-Zn battery

Evaporator steam shutoff valve

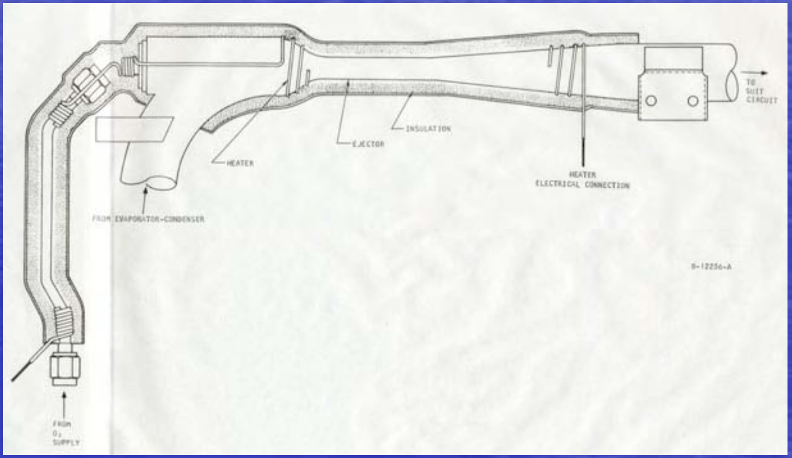
Gemini VIII EVA Life Support System Challenges and Issues

- *Challenges…*
  - ***Designing and building umbilical with sufficient thermal insulation***

- *Issues*
  - ***Ice blockage of ejector***
    - ***During extended ELSS manned test run with off-nominal procedures, ice built up around ejector primary tube and eventually blocked all flow***
    - ***Bypass flow introduced upstream of ejector – failed to provide flow***
  - ***Landing with charged emergency oxygen tank***

- *Challenges met by…*
  - ***MSC applied several layers of aluminized mylar/dacron scrim; added tether & sheath; potted and performed tests***

- *Issues Resolved by…*
  - ***Adding heater to ejector***



  - ***Real time development of tank discharge procedures and relay by phone to on-site technicians in Okinawa***

Gemini EVA Life Support
Gemini VIII System Lessons Learned

- *Deviate from approved procedures at your peril*
- *Do a comprehensive failure modes and effects analysis during design*
  - *Probably would have shown the design flaw of having bypass flow routed upstream of ejector (fixed for Gemini IX-A)*
  - *Also might have pointed out possibility of ejector icing (need for heating)*
- *Always ask "Not <u>how</u>…but <u>what if?</u>"*
  - *We should have been ready for a landing with a charged oxygen tank*

Gemini IX-A EVA Life Support System Description

Astronaut Maneuvering Unit (AMU)…

ELSS chestpack

Antenna

Batteries

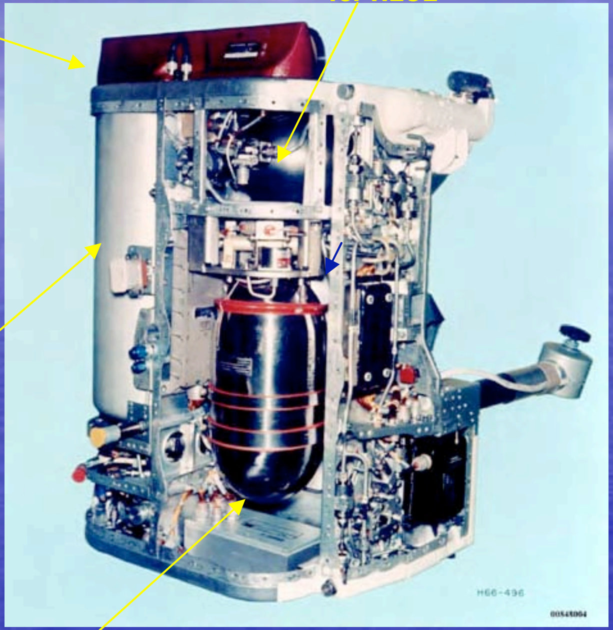
H2O2 Thrusters (16 places)

Shutoff valve (propellant on one side; oxygen on the other)

Chromel-R metal cloth covering for suit legs

125 foot electical cable/tether

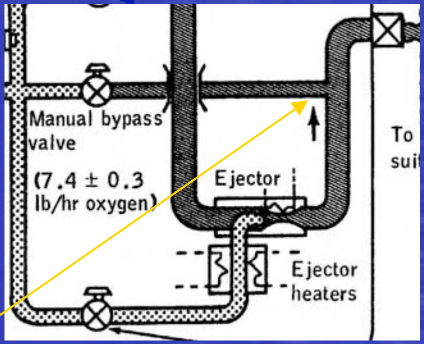
AMU Hand controllers



Helium pressurization tank for H2O2

H2O2 storage tank

Oxygen storage tank



- *For flight IX-A, the ELSS configuration was the same as for Gemini VIII, except a change was made to re-route bypass flow downstream of the ejector*

Gemini IX-A EVA Life Support System Issues and Resolution

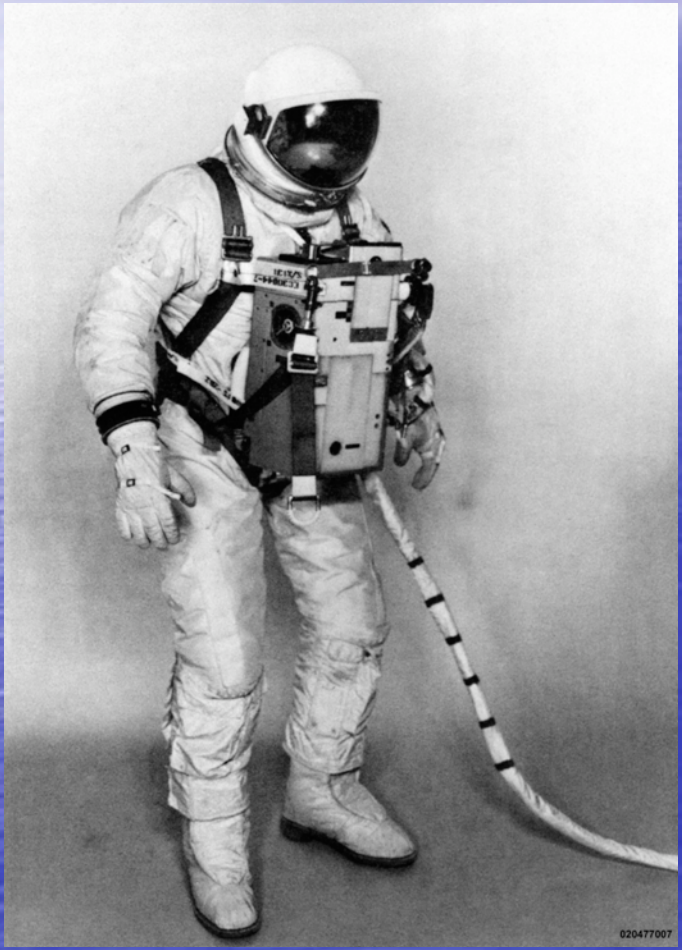
- *Issues…*
  - **"Contained explosions" experienced preflight on two chestpacks during 7500psi oxygen fill procedures**
    - **Cause was combination of poor materials selection and poor fill check valve design**
  - **Crewman overheating and visor fogging during Gemini IX-A EVA**
    - **Inadequate foot restraints for AMU donning**

- *Resolved by…*
  - **For Gemini IX-A, system was cleaned and checked; new valve installed and reduced fill rate utilized. New valve design introduced for Gemini X and subs.**
  - **Neutral buoyancy as a 0-g simulation technique was emphasized**

Gemini IX-A EVA Life Support System Lessons Learned

- *Gas-type cooling was inadequate for the magnitude of workloads being encountered in flight*
  - *The ELSS met its spec, but the spec was being routinely exceeded*
- *Lessening of the workload through better preflight 0-g simulation and better means of body positioning and restraint were required*
- *Antifog needed to be carried and applied to the visor before EVA*
- *Greater attention needed to be paid to materials selection, design, and contamination control for high-pressure oxygen systems (THIS WAS A LESSON <u>NOT</u> LEARNED UNTIL 1980!)*

Gemini X through XII EVA Life Support System Description



<u>For Gemini X</u>: Basic ELSS[1], but 50 foot O2/N2/elec/tether umbilical used

- ***Oxygen, electrical and tether connections made in cabin pre-EVA***
- ***Nitrogen gas connection made EVA at adapter for HHMU evaluation***

<u>For Gemini XI</u>: Basic ELSS[1] but 30 foot O2/N2/elec/tether umbilical used

<u>For Gemini XII</u>: Basic ELSS[1] with "standard "25 foot umbilical (O2/elec/tether) used – tether shortened; more user-friendly hooks used

[1] with modified oxygen fill check valve and Bypass flow change

Gemini X-XII Challenges and Issues

- *Gemini XI*
  - ***Challenges***
    - ***Assure adequacy of EVA system during orbital conditions***
  - ***Issues***
    - ***EVA Crewmember became overheated; experienced heavy breathing; sweat in eyes***

- *Gemini XI*
  - ***Challenges Met by…***
    - ***Conducting manned test in thermal/vacuum facility with flight hardware and EVA crewmember***
  - ***Issues Resolved by…***
    - ***EVA tasks for Gemini XII scaled back***
    - ***More use made of neutral buoyancy simulation – use flight crew***
    - ***Plan to evaluate better body restraints on Gemini XII***

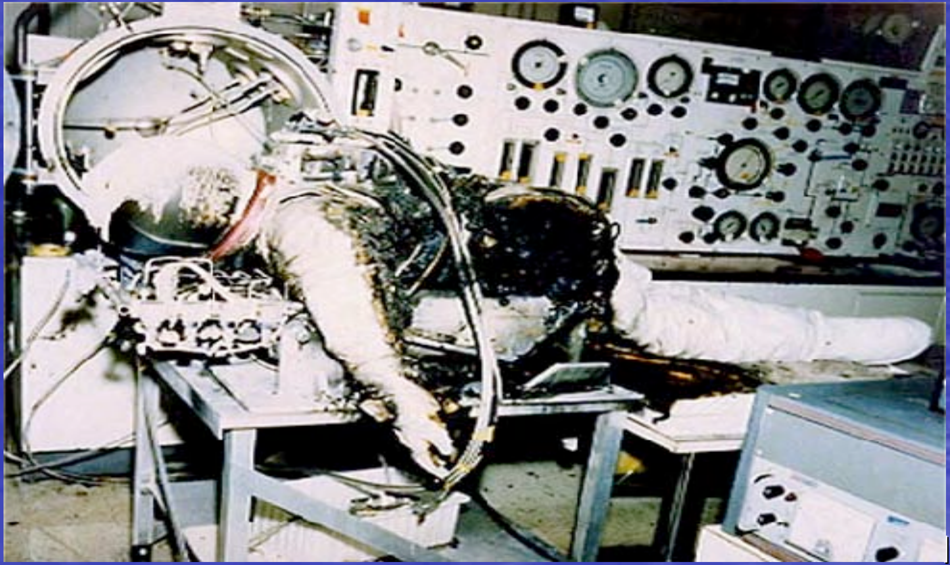
Gemini X-XII Challenges and Issues

- *Gemini XII*
  - *Challenges*
    - ***Provide extra dry oxygen by allowing CM to use bypass flow along with umbilical flow***
    - ***Provide adequate cooling for task timeline***
  - *Issues*
    - ***No issues identified***
      - ***CM did mention that his feet were cold, but not uncomfortably so***
      - ***This was in contrast to previous CM comments to the effect that their feet were neither not nor cold***

- *Gemini XII*
  - *Challenges Met by…*
    - ***Carefully budgeting oxygen vs time***
    - ***Conducting underwater training with flight crew and monitoring heart rate to get indications of workloads experienced – five sessions with flight crew conducted***
  - *Issues Resolved by…*
    - ***No further action required***

Gemini X-XII Lessons Learned

- *EVA workload could be controlled within desired limits by proper procedures and indoctrination*
- *High-fidelity underwater simulation was a good predictor of success on orbit*
- *Life support systems with more margin and less dependence on evaporation of perspiration were required*
  - *When workloads were moderate, ELSS kept astronaut comfortable; however, gas-type cooling was ineffective for anything other than moderate workloads, and did not allow for "catching up" thermally*
- *Bulk of umbilical in cabin caused more problems than had been experienced in training – 50 feet was too long*
- *Underwater simulations needed to include the flight crews, rather than just test subjects*
- *Our experience with the 7500 psi oxygen fill check valve failure didn't sink in at the time (Lesson NOT learned!)*
  - *We finally learned our lesson at great cost (fiscal and human) in April of 1980*



Gemini EVA Life Support System Final Thoughts

- *We went from a requirement first articulated on March 26, 1965, to successfully carrying out the first US EVA on June 3, 1965 – 69 days from dream to reality*
- *The question was not "Can we do it?" – it was "How are we going to do it?"*
- *That's the thought I want to leave with you*

PORTABLE LIFE SUPPORT SYSTEM HISTORY PANEL

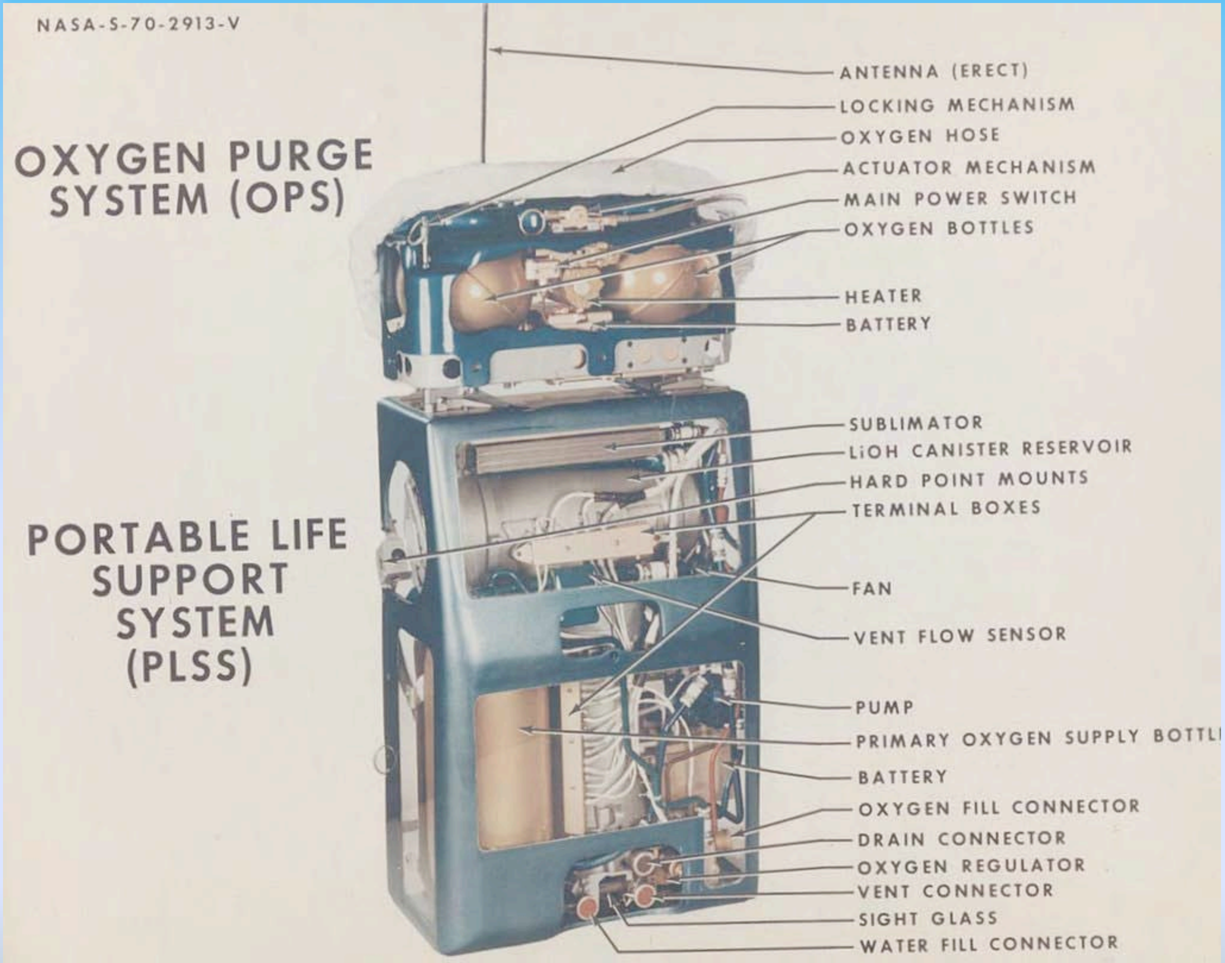
38TH INTERNATIONAL CONFERENCE ON ENVIRONMENTAL SYSTEMS

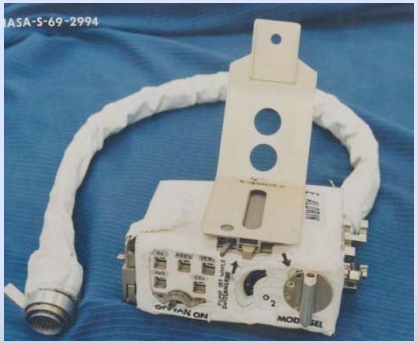
APOLLO PORTABLE LIFE SUPPORT SYSTEM

MAURICE CARSON

JULY 1, 2008

PLSS/OPS/RCU DESCRIPTION





CRITICAL SPECIFICATIONS

CREW SERVICES PROVIDED:

- PRESSURIZATION
- VENTILATION
- CONTAMINANTS AND HUMIDITY CONTROL
- COOLING
- POWER, DATA, COMMUNICATION, AND COMFORT CONTROLS

SUIT OPERATING PRESSURE – 3.5 - 3.9 PSIA

VENTILATION FLOW RATE – 5.5 CFM (MIN)

EMERGENCY (PURGE) CAPABILITY – 30 MIN @ 8 LB/HR

COOLING WATER (LCG) FLOWRATE – 240 LB/HR W/TEMP CONTROL

RECHARGEABLE FROM LUNAR MODULE

CRITICAL SPECIFICATIONS

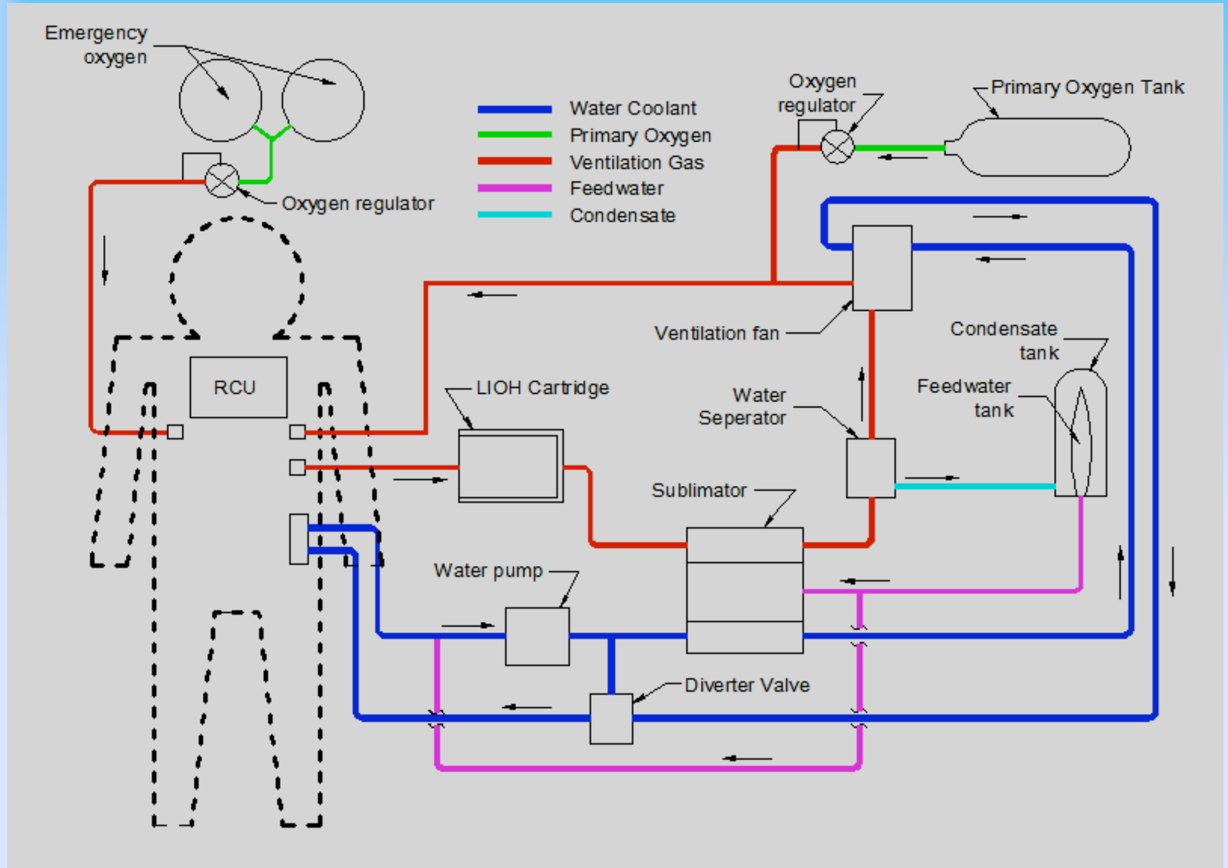
MISSION SPECIFIC DESIGN PARAMETERS:

	APOLLO 9-14	APOLLO 15-17
AVERAGE/PEAK METABOLIC LOAD	1600/2000 BTU/HR	1600/2000 BTU/HR
MAX HEAT LEAK IN/OUT	250/250 BTU/HR	300/350 BTU/HR
MISSION TIME @ AVG/PEAK WORKLOAD	4/3 HRS	5/6 HRS
OXYGEN RECHARGE PRESSURE	1020 PSIA	1410 PSIA
BATTERY CAPACITY	279 W/HR	360 W/HR
EMERGENGY OXYGEN PURGE TIME	30 MIN	30 MIN

MAJOR DESIGN GOALS

- PROVIDE ULTIMATE RELIABILITY
  - DURING LUNAR EXCURSIONS, NO RESCUE IS POSSIBLE
  - DESIGN FOR TWO FAULT TOLERANCE WHERE POSSIBLE
  - USE EEE (BURNED IN) ELECTRICAL PARTS THROUGHOUT
  - TEST AND RETEST EVERYTHING
    - COMPONENT PERFORMANCE AND ENDURANCE TESTS
    - PARTS/SUBASSEMBLY/ASSEMBLY PERFORMANCE, ENDURANCE AND ENVIRONMENTS TESTS
    - SYSTEM PERFORMANCE LIMITS WITH CANNED MAN RIG
    - EXTENSIVE MANNED TESTING WITH SUIT (VACUUM PERFORMANCE, MISSION USE (IV AND EV), THERMAL VACUUM
- PROVIDE UTMOST SIMPLICITY
- PROVIDE GENEROUS PERFORMANCE MARGINS

SIMPLIFIED SCHEMATIC



NOTE: ELECTRICAL NETWORK, SWITCHES, CONTROLS, COMMUNICATIONS, INSTRUMENTATION, TEST AND SERVICE PORTS NOT SHOWN.

PLSS MOUNTED CONTROLS

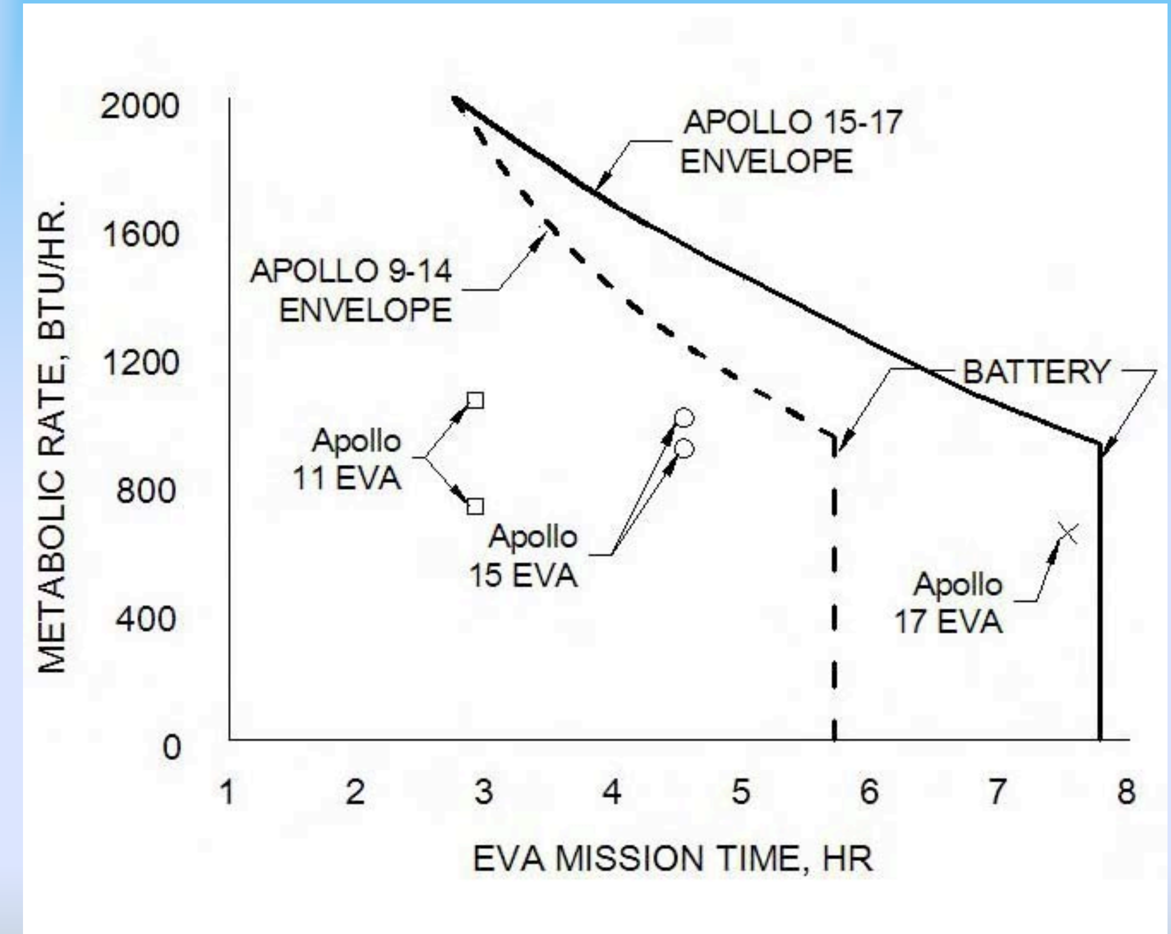
- OXYGEN ON/OFF
- FEEDWATER ON/OFF
- DIVERTER VALVE

RCU MOUNTED CONTROLS

- FAN ON/OFF
- PUMP ON/OFF
- OPS ON/OFF
- COMMUNICATION
  - PTT
  - MODE SELECTION
  - VOLUME CONTROL

10 CHANNELS OF TM DATA

EXPENDABLES DURATION



MAJOR DESIGN/DEVELOPMENT CHALLENGE

MAXIMIZE MISSION & CREWPERSON CAPABILITY

- MATCH PLSS/MAN CAPABILITIES
  - WORK TIME
  - WORK LOAD CAPBILITY
- EASE CREWPERSON OPERATION AND INTERFACE
- REDUCE OVERHEAD TASKS

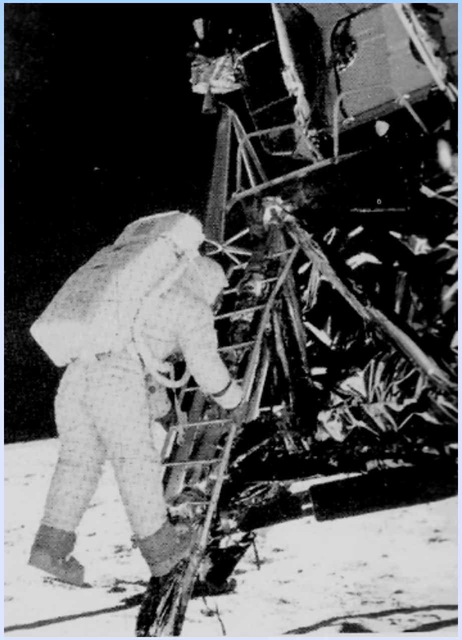
MINIMIZE MISSION HAZARDS

- RUGGEDIZE DESIGNS AGAINST FALLS AND ROUGH HANDLING
- PROTECT CONTROLS AGAINST INADVERTANT OR WRONG ACTUATION
- PROTECT AGAINST ELECTRICAL HAZARDS
  - BATTERY REPLACEMENTS DURING RECHARGING
  - ELECTRICAL CONNECTS/DISCONNECTS BETWEEN PLSS AND PGA

MAJOR DESIGN CHALLENGE

MINIMIZE IMPACTS ON THE APOLLO MISSION OVERALL OBJECTIVES:

- REDUCE WEIGHT TO BARE MINIMUM
- PACKAGE FOR MINIMUM VOLUME
- REDUCE EXPENDABLES USAGE
  - CLOSED LOOP VENTILATION & COOLING
  - MINIMIZE POWER USAGE (45 WATTS FOR FAN, PUMP, COMM, DATA COMBINED)
- MINIMIZE PLSS OVERHEAD TASKS
- MAXIMIZE LUNAR EVA TIME



MAJOR CHALLENGE

PURE OXYGEN SAFETY CONSIDERATIONS:

- FIRE SAFETY CONCERNS
  - 1400 PSI PRIMARY OXYGEN
  - 5800 PSI SECONDARY OXYGEN (SOP)
  - PURE OXYGEN IN VENTILATION CIRCUIT
  - STOWAGE IN LM IN AN OXYGEN ENRICHED ENVIRONMENT

LEAKAGE AND SEALS

CLEANLINESS VERIFICATION

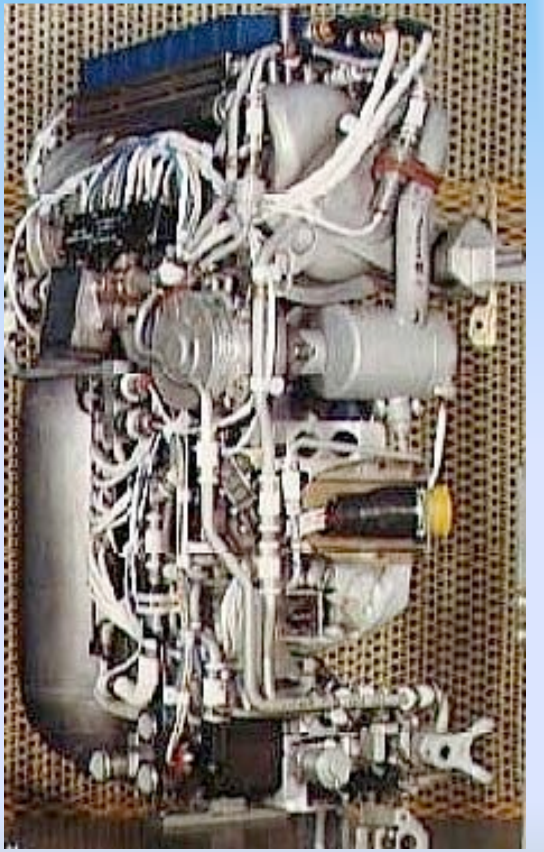
POSSIBLE FREEZING IN 5800 PSI REGULATOR DUE TO ADIABATIC COOLING

CONDUCT FIRE SAFETY TESTING OF ALL MATERIALS

LESSON LEARNED

NEED FOR IMPROVED INTEGRATION

- BETTER INTEGRATION OF COMPONENTS INSIDE THE PLSS TO REMOVE CLUTTER
- BETTER INTEGRATION OF PLSS WITH PGA COMPONENTS
- ADVANTAGES OF IMPROVED INTEGRATION
  - INCREASES SAFETY
  - REDUCES DONNING/DOFFING OVERHEAD
  - REDUCES CHECKOUT TIMELINE
  - RESULTS IN MORE EFFICIENT USE OF EVA TIME
  - INCREASES RELIABILITY /MAINTAINABILITY
  - RESULTS IN COST, WEIGHT, AND VOLUME REDUCTION



LESSON LEARNED

DESIGN FOR IMPROVED MAINTAINABILITY

- PROVIDE BETTER ACCESS FOR MAINTENANCE

  NO HARD POTTING OF ELECTRONICS

  ELIMINATE LINES/FITTINGS BY INTEGRATING COMPONENTS INTO MODULES (MANIFOLDING)

  PROVIDE MORE AUTOMONOUS CHECKOUT CAPABILITY

  PROVIDE MORE BUILT-IN TROUBLE SHOOTING CAPABILITY

LESSON LEARNED

HIGH PRESSURE OXYGEN CAN BE HAZARDOUS TO YOUR HEALTH

DURING LARORATORY TEST OPERATIONS A CHARGED (5800 PSI) OXYGEN PURGE SYSTEM EXPLODED SPREADING SHRAPNEL AND CAUSING INJURY TO A TECHNICIAN.

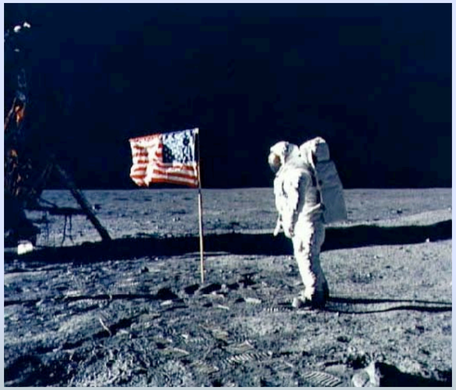
SUBSEQUENT INVESTIGATION DETERMINED THAT EITHER INADEQUATE CLEANING OF REGULATOR ORIFICES AFTER MACHINING, OR SHARP EDGES LEFT AFTER MACHINING CAUSED HEATING AND PROVIDED A FUEL AND IGNITION DURING BLOWDOWN TESTS.

LESSON LEARNED

DESIGN FOR MAXIMUM CREWPERSON FRIENDLINESS

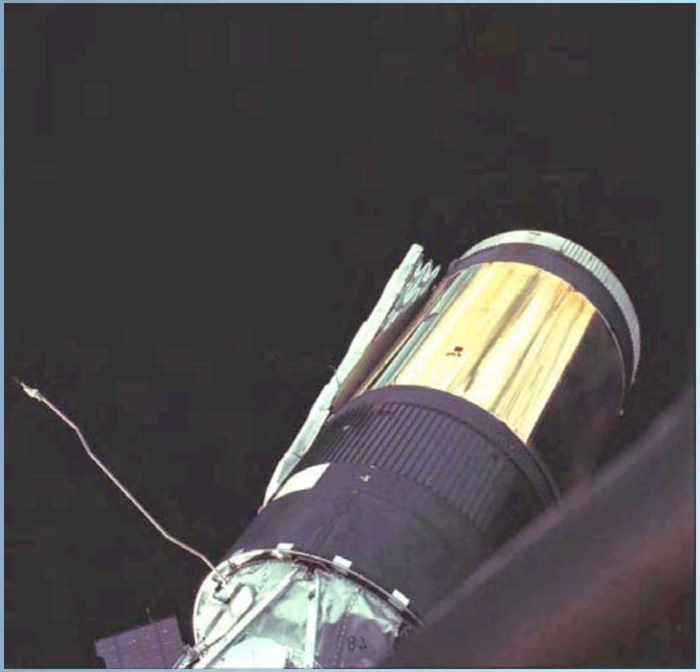
GIVE THE CREWPERSON AS MUCH HELP AS POSSIBLE

- PROVIDE ALL CONTROLS UPFRONT AND VISABLE
- KEEP DONNING/DOFFING CHECKOUT SIMPLE
- PROVIDE MORE SELF-DIAGNOSIS INSTRUMENTATION AND WARNING ALERTS
- REDUCE BULK



38th ICES Conference

EVA Life Support System History Panel



Launch Problems

After EVA Repair

Skylab Astronaut Life Support Assembly

Joseph B. Gillerman

July 1, 2008

ASTRONAUT LIFE SUPPORT ASSEMBLY (ALSA)

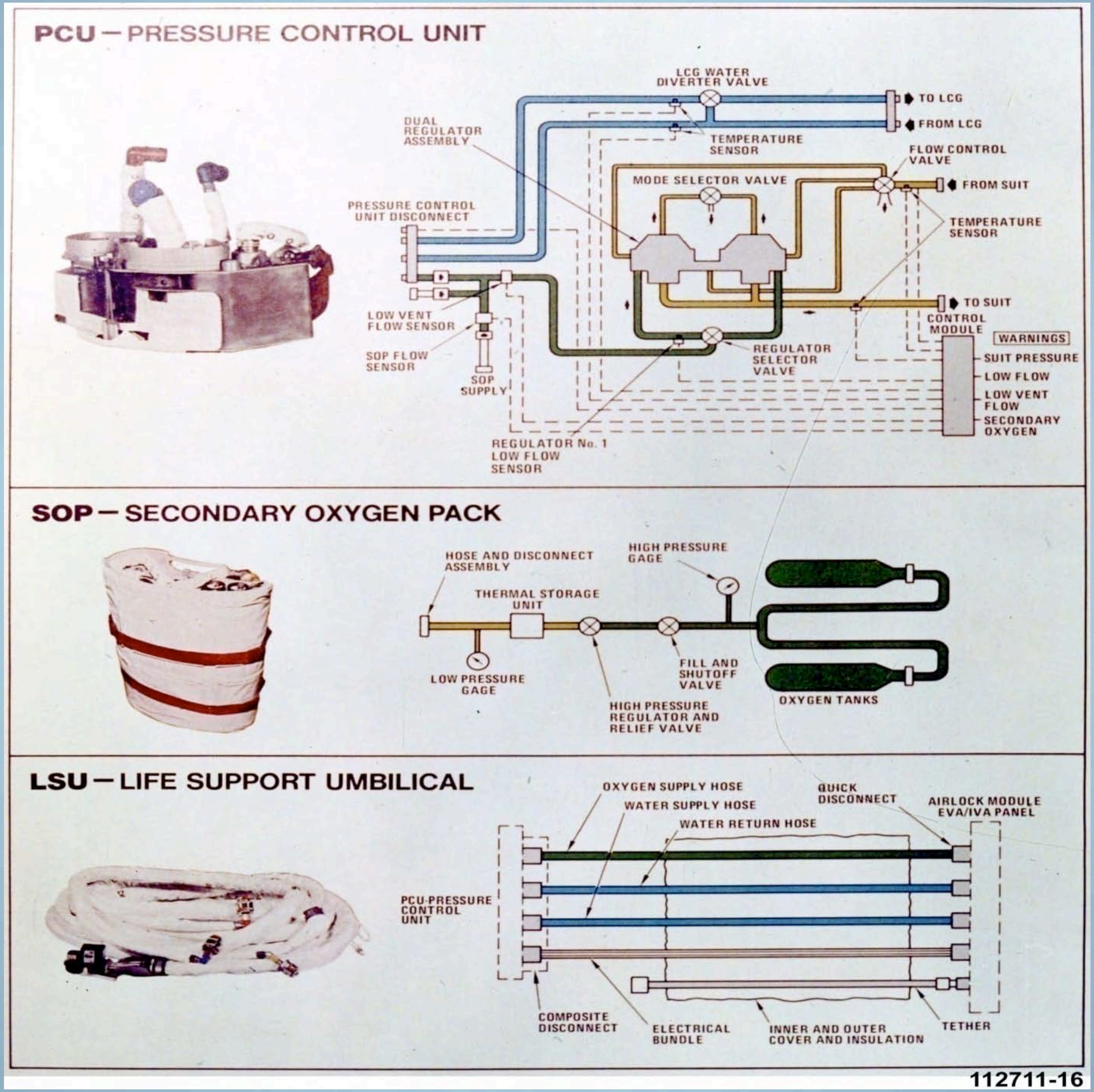
- An Umbilical supplied open-loop system, different than prior Mercury, Gemini and Apollo Systems:

  \- Pressure Control Unit (PCU) provided Thermal Control, Oxygen, Suit Pressurization and Purification by washout

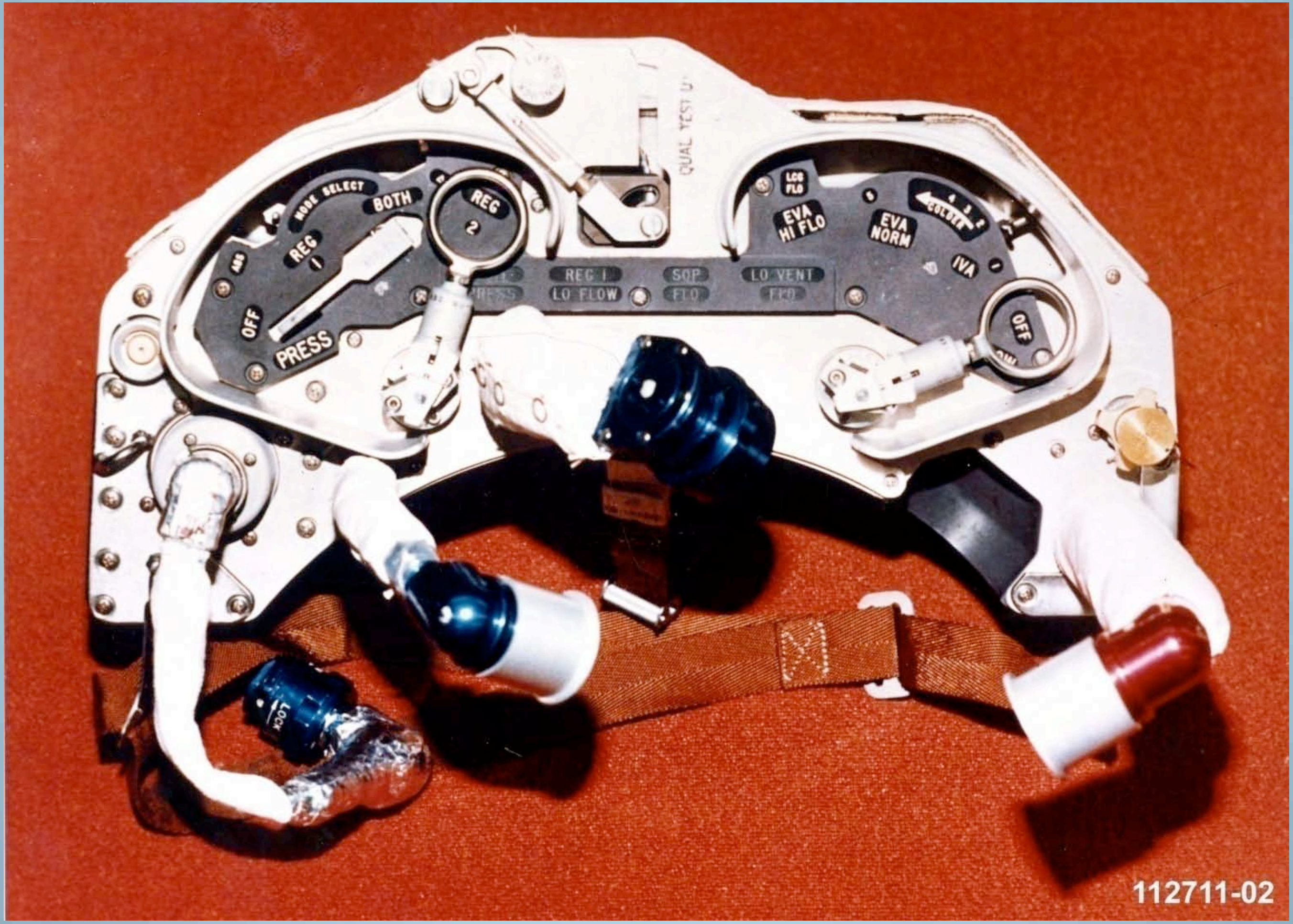
  \- Life Support Umbilical (LSU) provided Skylab supplied cooling water to the Liquid cooled Garment; Oxygen; Electrical power; Communications, and Biomed data to the PCU

  \- Secondary Oxygen Pack (SOP) provided an emergency oxygen supply

SYSTEM DESCRIPTION



PCU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ABS
REG 1
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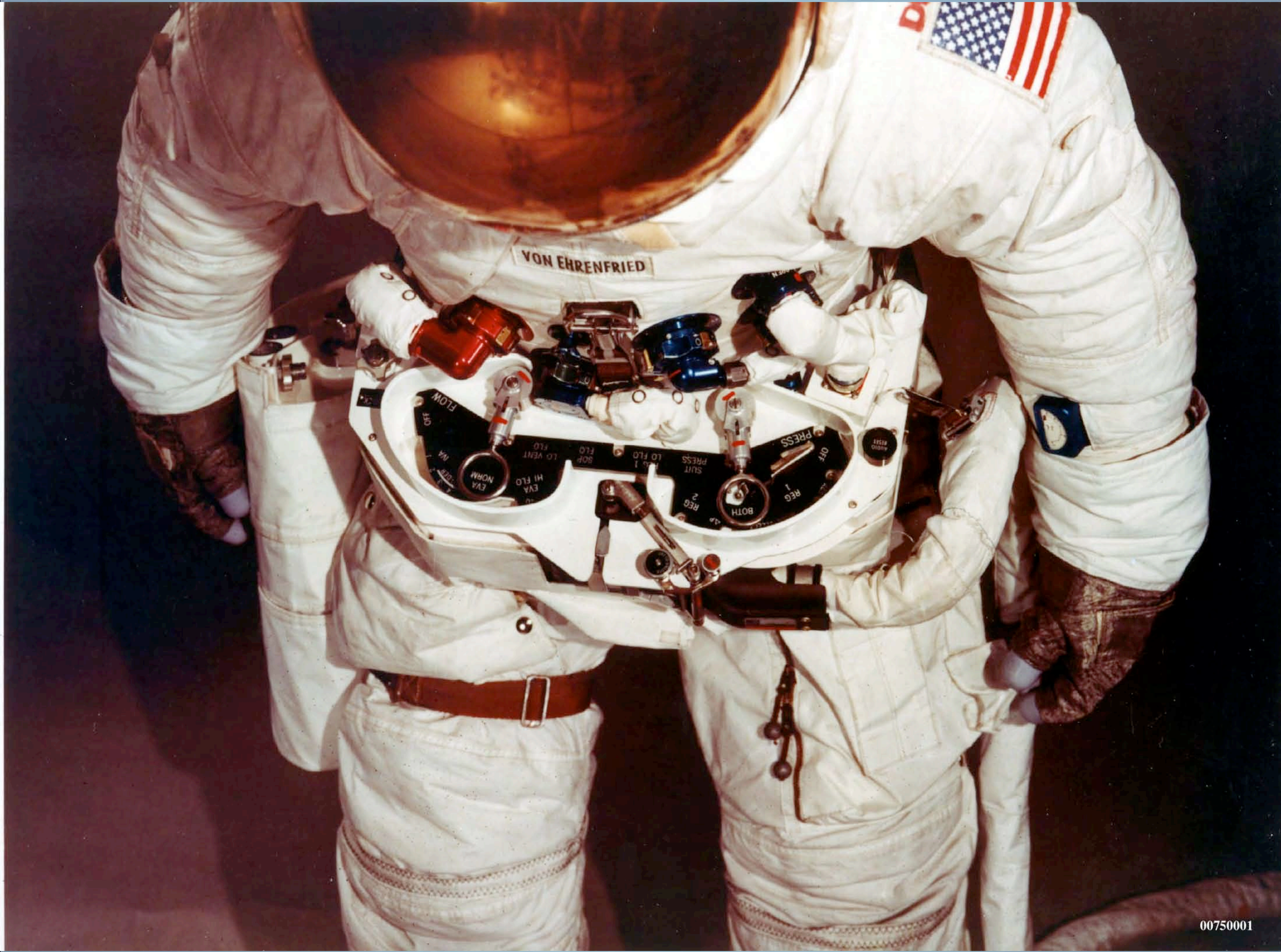
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FLOW
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EVA
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OFF
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AUDIO
RESET

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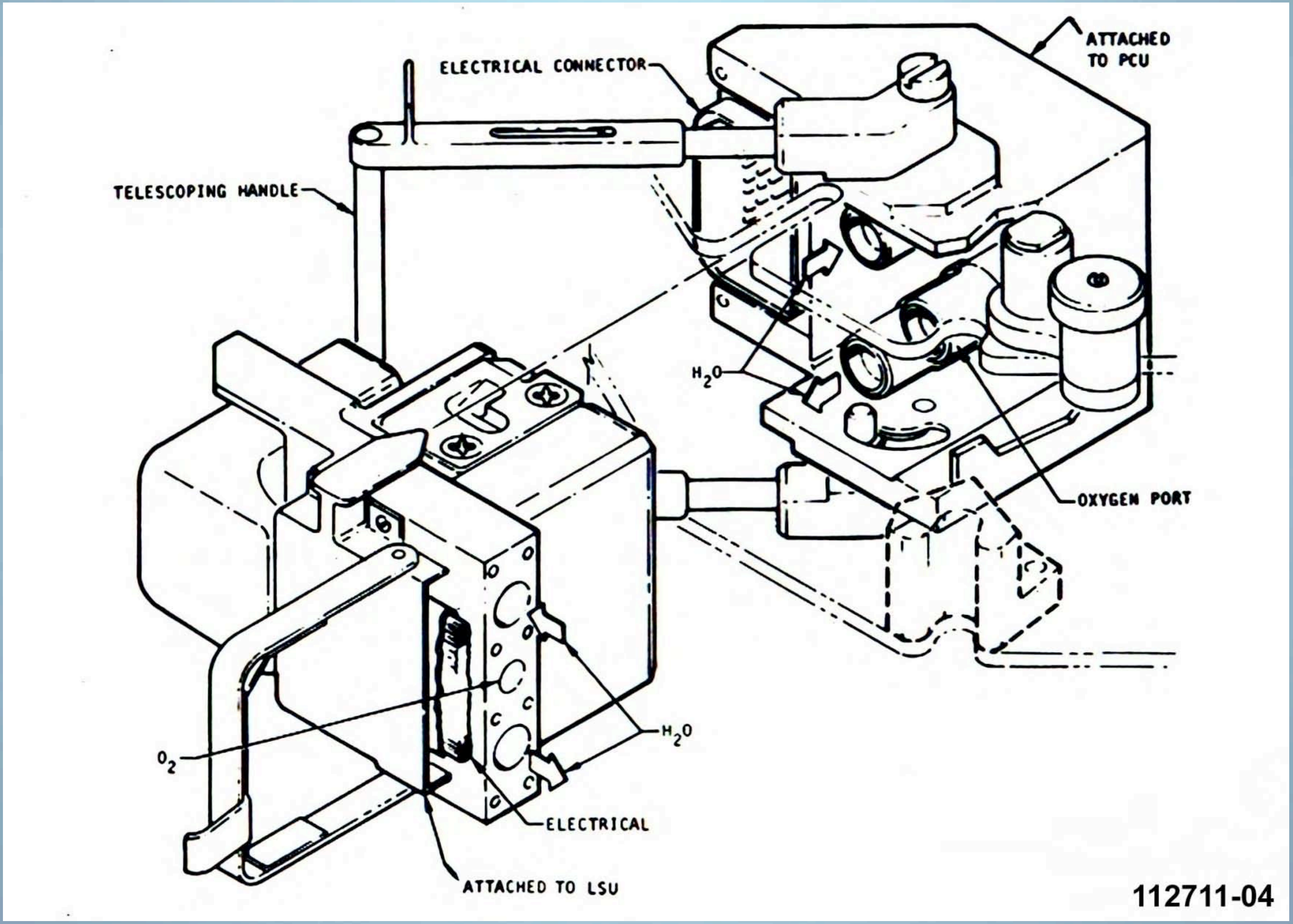
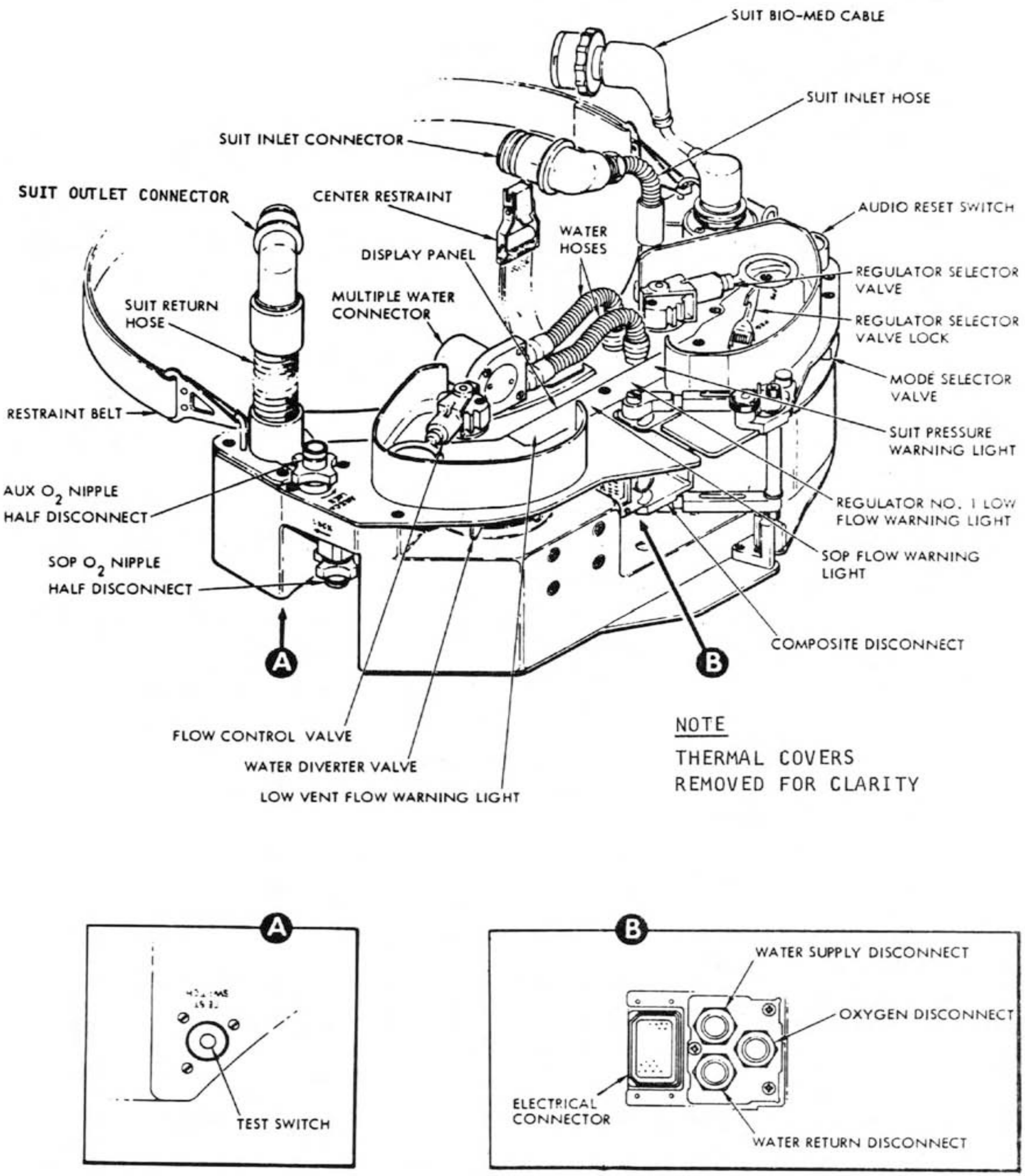
Composite Disconnect



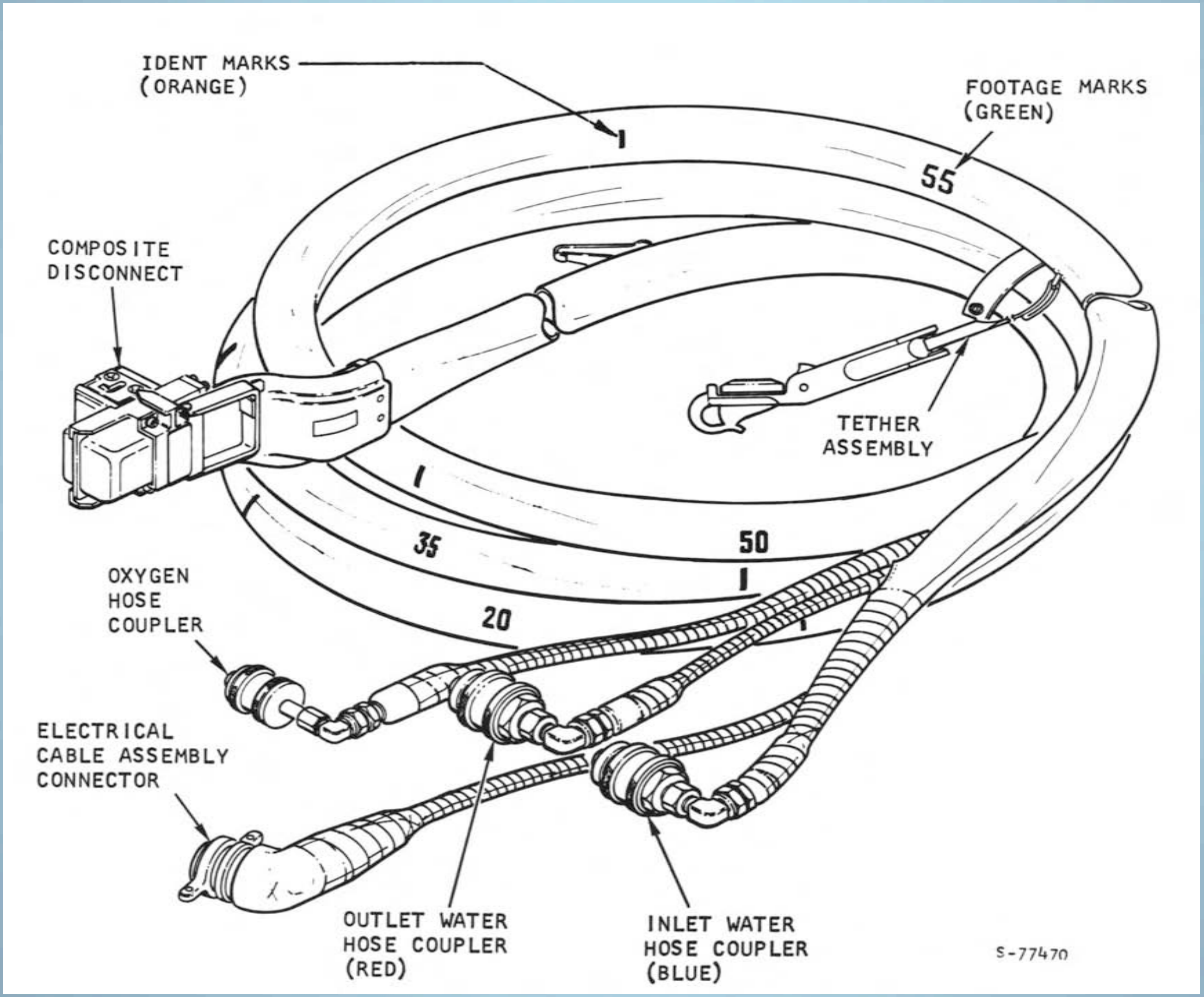


NOTE

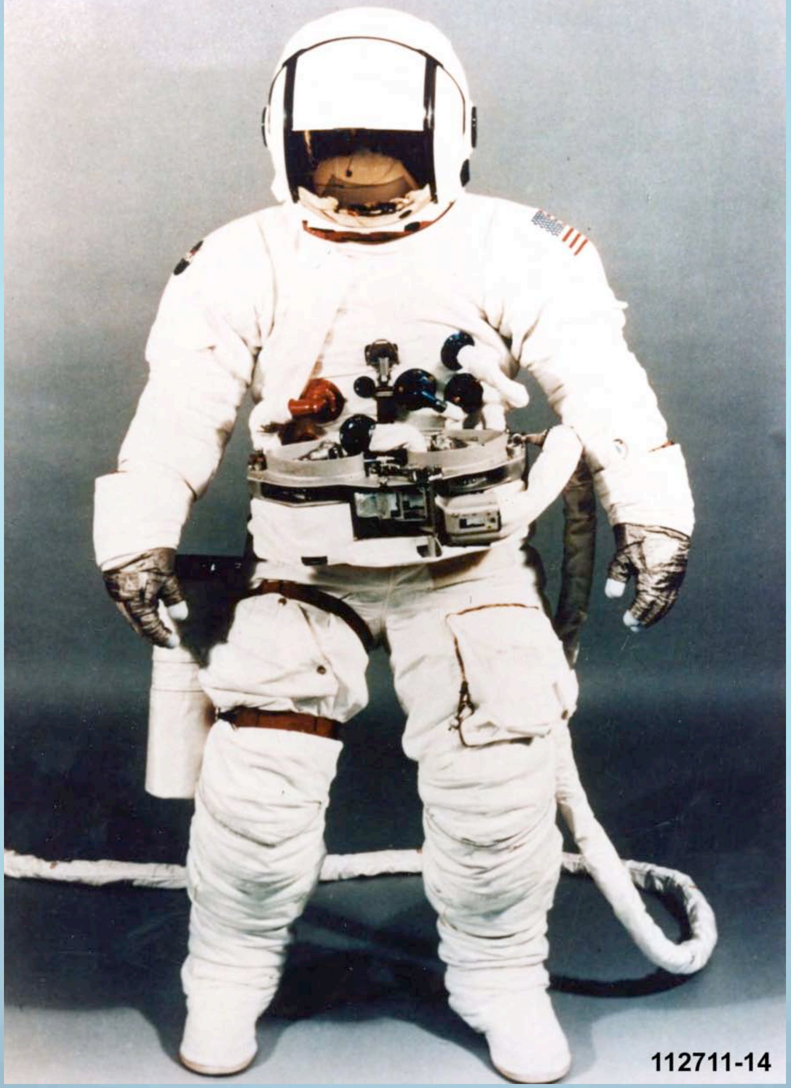
THERMAL COVERS
REMOVED FOR CLARITY

SECONDARY OXYGEN PACK

Life Support Umbilical



ALSA Ready To Go



SOP Design and Test for Fracture Mechanics

Redesign to change to A7LB suit

Umbilical Management

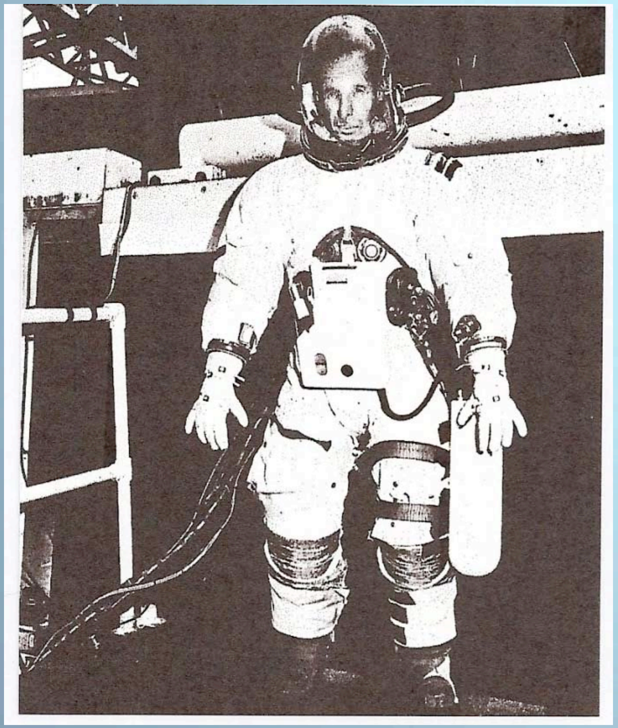
EVA and IVA

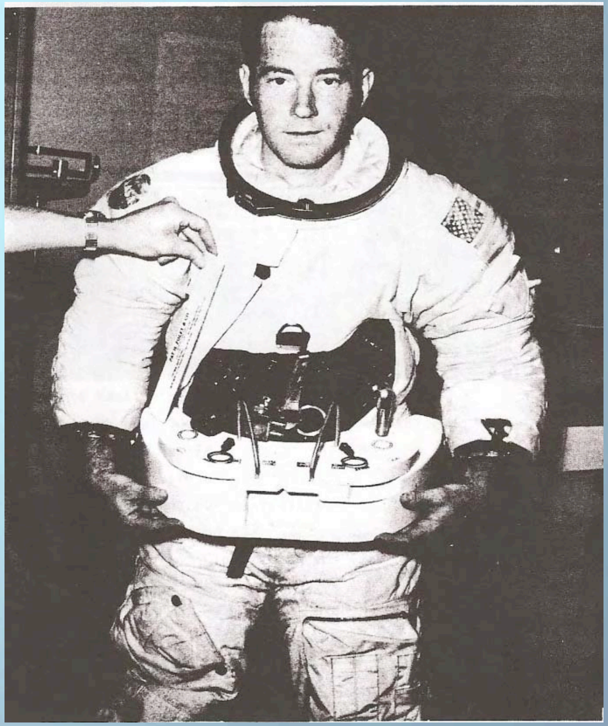
Program Challenges

CHALLENGE: CHANGE FROM A7L TO A7LB SUIT

A7LB Suit was designed to mate with the Apollo Backpack LSS.

- Fittings interfered with the original chest location.
- Redesign to the waist location provided easy access to controls and allows CM to view feet for entering EVA restraints





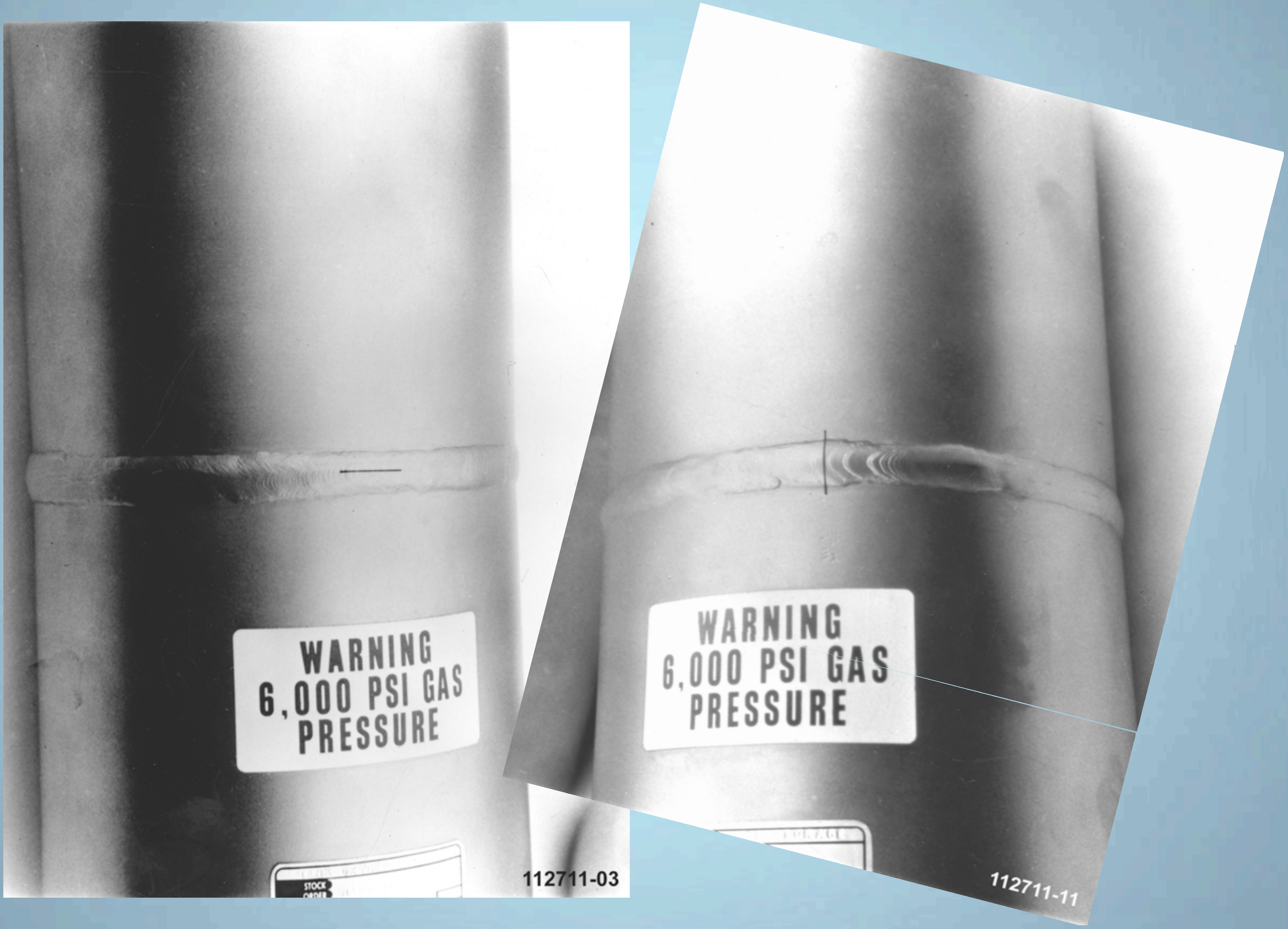
CHALLENGE: SOP FRACTURE MECHANICS

- Testing to confirm fracture mechanics design-to leak before burst
- 45 Inconel 718 test specimens tested for both parent material and also welds
- MDOP=6850 psig; proof=10275 psig; minimum burst=13700 psig min
- Six production configuration tanks were tested

  001 flawed - leaked 76612 cycles 0-6850 annular

  002 flawed - leaked 2259 cycles 0-6850 longitudinal
- Remaining tanks burst between 17900-18700 psig

SOP TANK FLAW



SOP TEST BURST TANKS

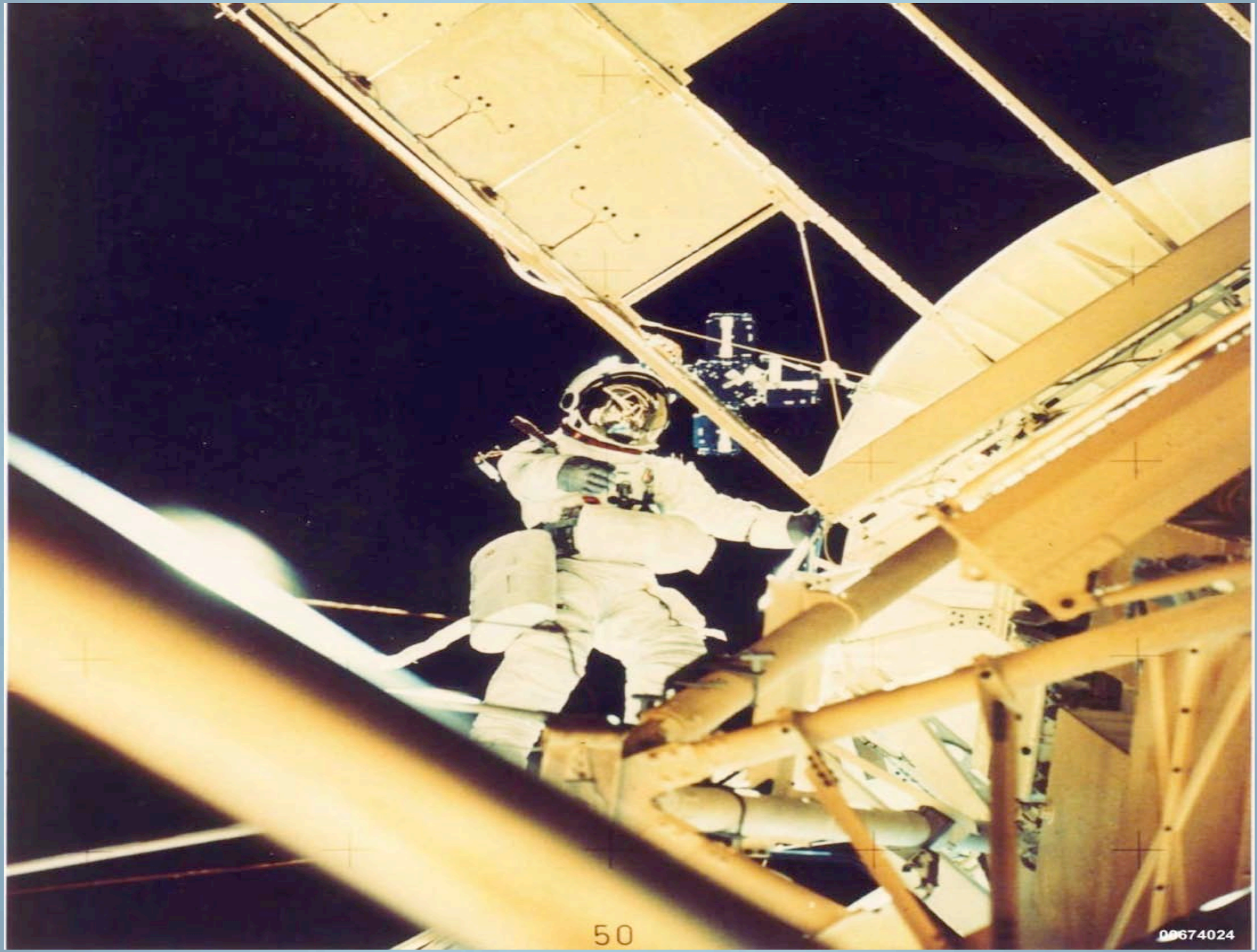
CHALLENGE: UMBILICAL MANAGEMENT

- Gemini experienced tangling of the Umbilical
- ALSA LSU being larger and longer required safe, reliable stowage/re-stowage of two 60 foot long LSU’s
- Two 40 inch diameter spherical cavities external to the Airlock Module were a part of the AM structure to more easily stow the LSU’s
- Additionally, the third crewman aided handling the LSU’s during egress and ingress

SIGNIFICANT LESSONS LEARNED

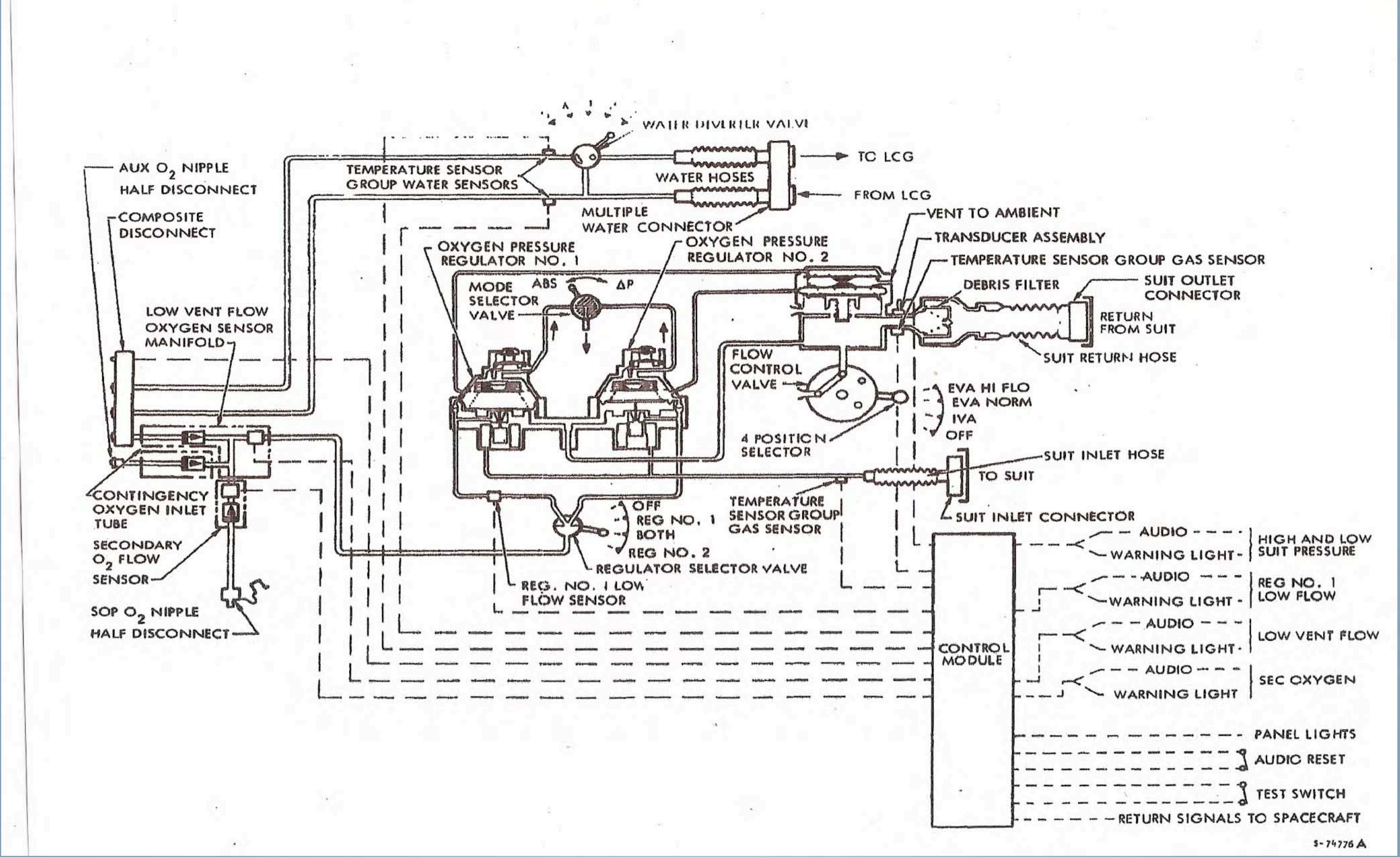
- Establish an Organization with experienced personnel with the required disciplines
- Maintain continual coordination with the customer/user
- Work continually with the flight crews to enable them to know and “feel” the system and procedures which they will be using
- There is never too much training and understanding for both the suppliers and the users
- Expect the Unexpected

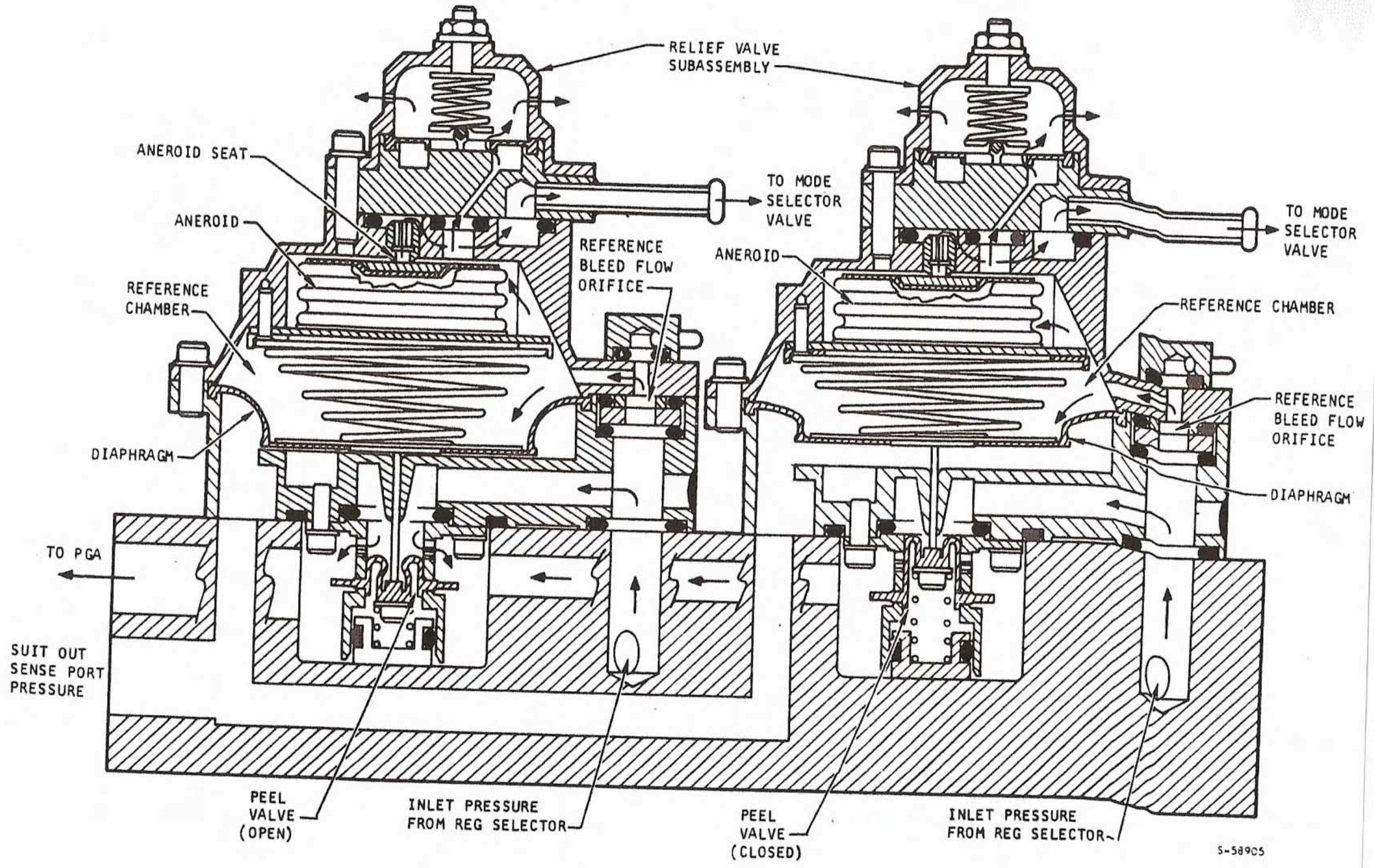
Owen Garriot - Skylab 3



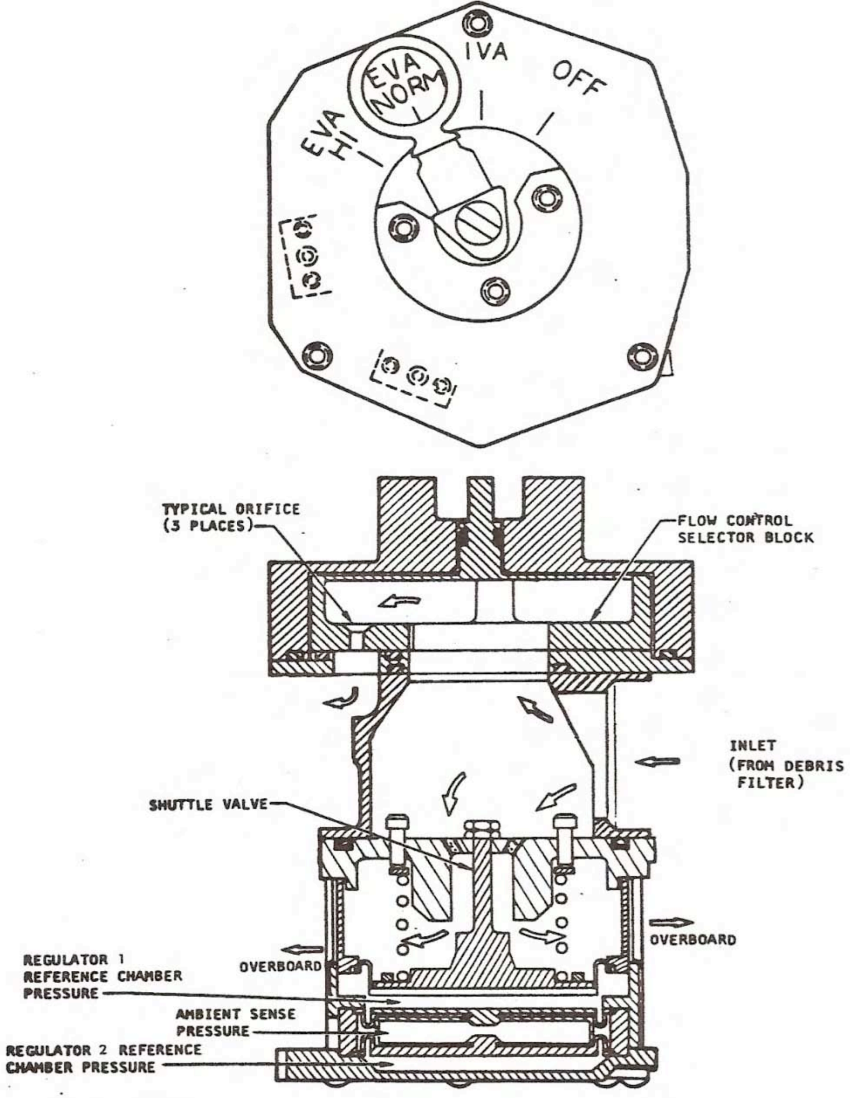
BACKUP INFORMATION

PCU SCHEMATIC




RELIEF VALVE SUBASSEMBLY
ANEROID SEAT
TO MODE SELECTOR VALVE
ANEROID
REFERENCE BLEED FLOW ORIFICE
ANEROID
TO MODE SELECTOR VALVE
REFERENCE CHAMBER
REFERENCE CHAMBER
REFERENCE BLEED FLOW ORIFICE
DIAPHRAGM
DIAPHRAGM
TO PGA
SUIT OUT SENSE PORT PRESSURE
PEEL VALVE (OPEN)
INLET PRESSURE FROM REG SELECTOR
PEEL VALVE (CLOSED)
INLET PRESSURE FROM REG SELECTOR
S-58905

FLOW CONTROL VALVE



Secondary Oxygen Pack

SHUTTLE EMU LIFE SUPPORT SYSTEM

38th International Conference on Environmental Systems

Richard C. Wilde
July 1, 2008

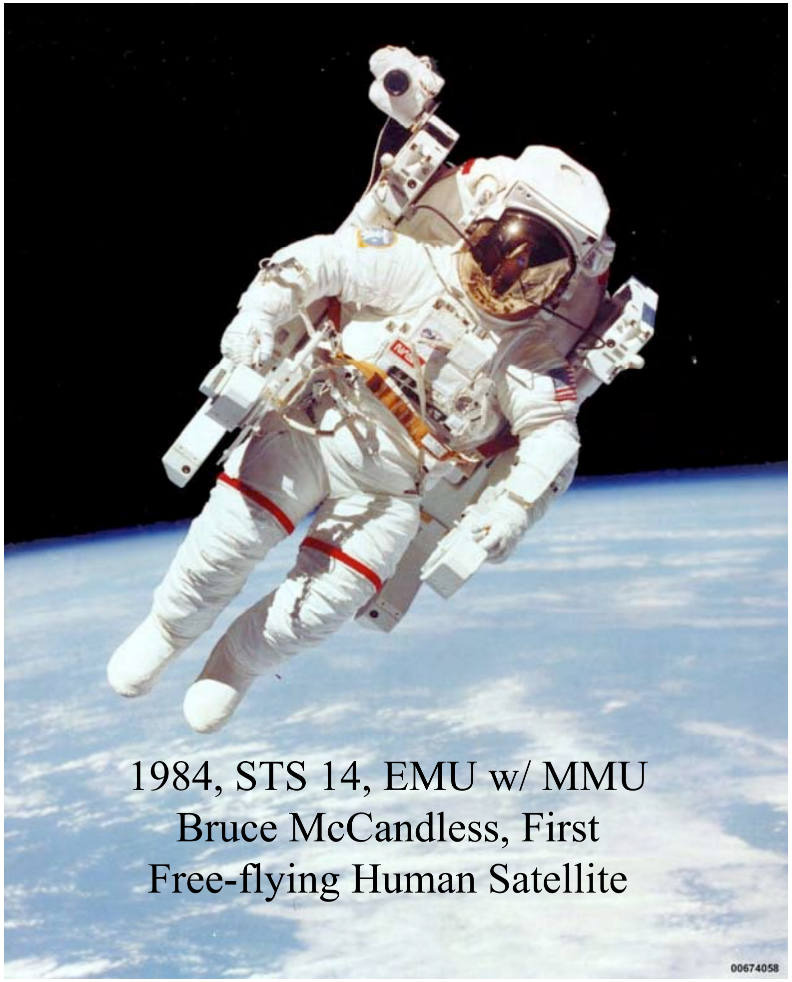
Hamilton Sundstrand
A United Technologies Company

SHUTTLE EMU: a 30 + YEAR PROGRAM

- 1975 - Program start
- 1983 - First shuttle EVA
- 1990s - Added EMU to Space Station
- Supported >200 EVA sorties to date

EMU provides:

- 7 hr independent life support (no umbilical) @ 1000 Btu/hr
- 4.3 ± 0.1 psi suit pressure
- Modular, resizable spacesuit
- Fail-safe redundancy
- Communications, data, lights, TV, mounts for tools & tethers
- Worksite restraint interfaces


1984, STS 14, EMU w/ MMU
Bruce McCandless, First
Free-flying Human Satellite

CHALLENGES DISCUSSED

Oxygen Regulator Fire

Motor Electronics Corrosion

Valve Module Corrosion

Water Tank Problems

CO_2 Scrubber Canister Evolution

EMU Health Monitoring Improvement

Challenge: Oxygen Regulator Fire

Item-

Secondary O_2 Pack Regulator Assembly:

Complex design includes 2-stage regulator, Shut-off valve, Pressure gages, Fill connector

Occurrence-

Tank refill to 6000 psi, burned lab tech

Causes-

- Compression ignition of flammable materials
- Contamination suspected, never proved

Solutions-

Worked w/NASA to develop safe design:

- Replaced Alum housing w/Monel
- Added tfe/metal barrier seals in front of static seals
- Redesigned item to eliminate compression ignition, i.e.:
  - Relocated SOV downstream of 1st regulator stage- LIMITS PRESS RISE RATE
  - Kept internal passage L/D < 10- LIMITS STAGNATION TEMP RISE
  - Eliminated sharp internal edges- NO CHIPS W/ HIGH SURFACE/VOLUME
- **CONTROLLED CLEANLINESS!!**

LESSONS LEARNED

- TREAT O_2 SYSTEMS W/RESPECT!
- USE NASA DESIGN DOCUMENTS:
  - NASA Pub 1113, Design for High Pressure O_2 Systems
  - NHB 8060.1B, O_2 Impact Tests

Challenge: Motor Electronics Corrosion

Item-

Prime mover for vent & coolant flow

Occurrence-

Failed on 1st use in flight, STS 5

Cause- Corrosion of Hall effect rotor-position sensors shifted duty cycle, motor failed to achieve normal operating RPM

2-step Solutions-

"Interim" to support near-in flight ops:

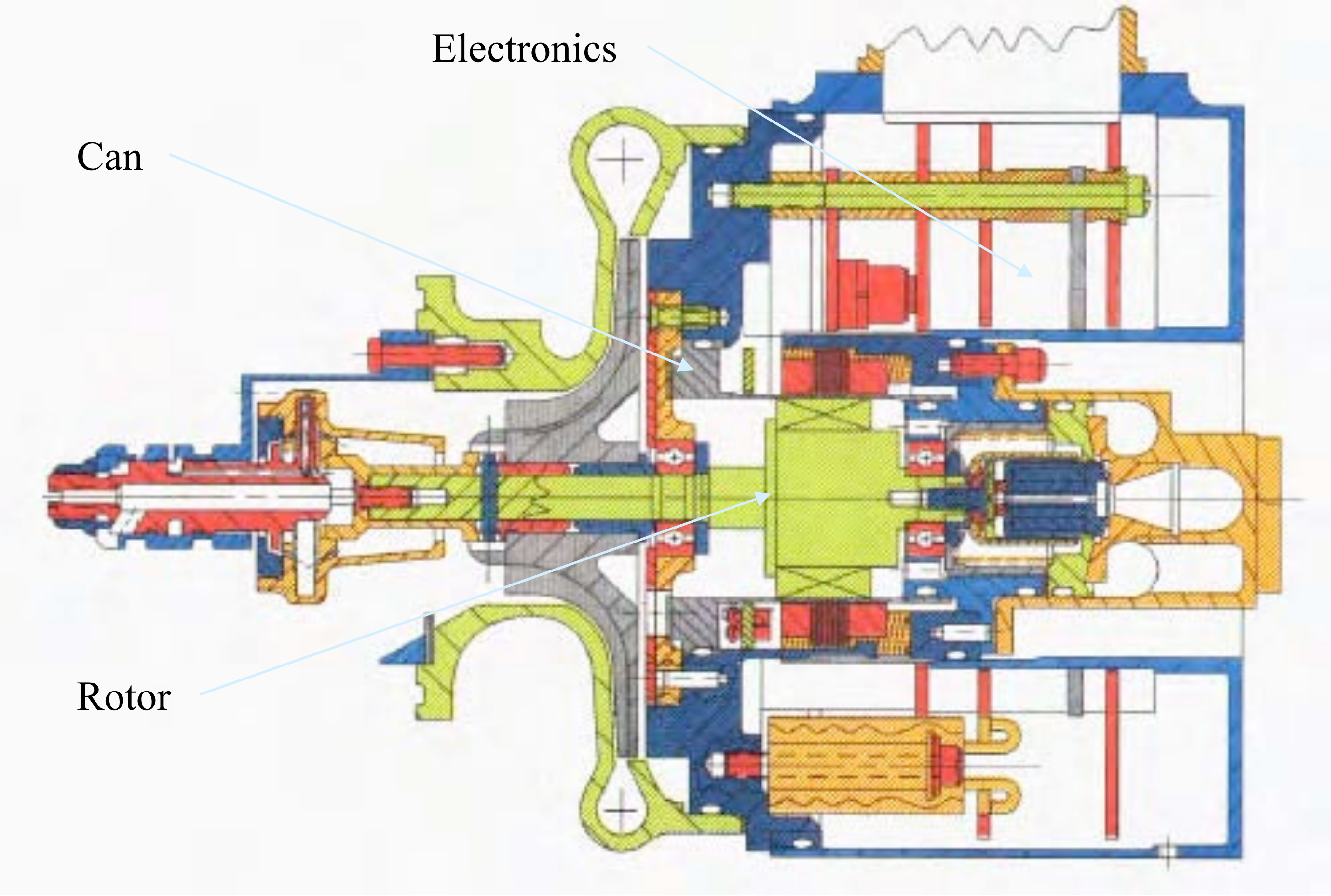
- Desensitized electronics to duty cycle
- Reduced operating voltage
- Improved speed control

"Canned Motor" permanent solution

- Developed hermetically sealed Hall effect sensors
- Rotor in-a-can isolated all electronics from vent loop moisture
- Improved venting of electronics cavity to overboard

- **LESSONS LEARNED**
- Isolate electronics from moisture
- Effective solution: No in-flight motor failures in 23+ years

EMU "Canned Motor"



Electronics

Can

Rotor

Challenge: Valve Module Corrosion

Item-

- Plumbs together many water valves and O_2 vent loop items
- Originally, a complex assembly of Alum casting and Alum tubing

Occurrence-

Extensive corrosion during flight cert

Causes-

- Difficult manufacturing process
- Presence of dissimilar metals in wet environment
- Developmental status of coatings

2-step Solution-

1st Step: Replaced Alum tubing w/SS

Problems:

- Couldn't control tubing location or inspect interior after coating
- 1st coating mfg backed out
- 2nd coating chipped at assembly

2nd Step: Machined module from SS

- Added significant weight, but solved corrosion problems

LESSONS LEARNED

- Design for manufacture and maintainability
- Ultra-pure water can promote corrosion over time
- Inadequate understanding of selected materials

Challenge: H_2O Tank Problems

Item-

Aluminum water tank walls, complex-shapes of elastomer bladders

Problems-

Bladder mat'ls leachates degraded sublimator perf

Wall corrosion noted at maintenance disassembly,

Required tank coating repair in the field

Causes-

1st mat'l (silicone) not easily formed

2nd & 3rd mat'ls (neoprene & urethane) Too H_2O-permeable, extracts degraded sublimator perf

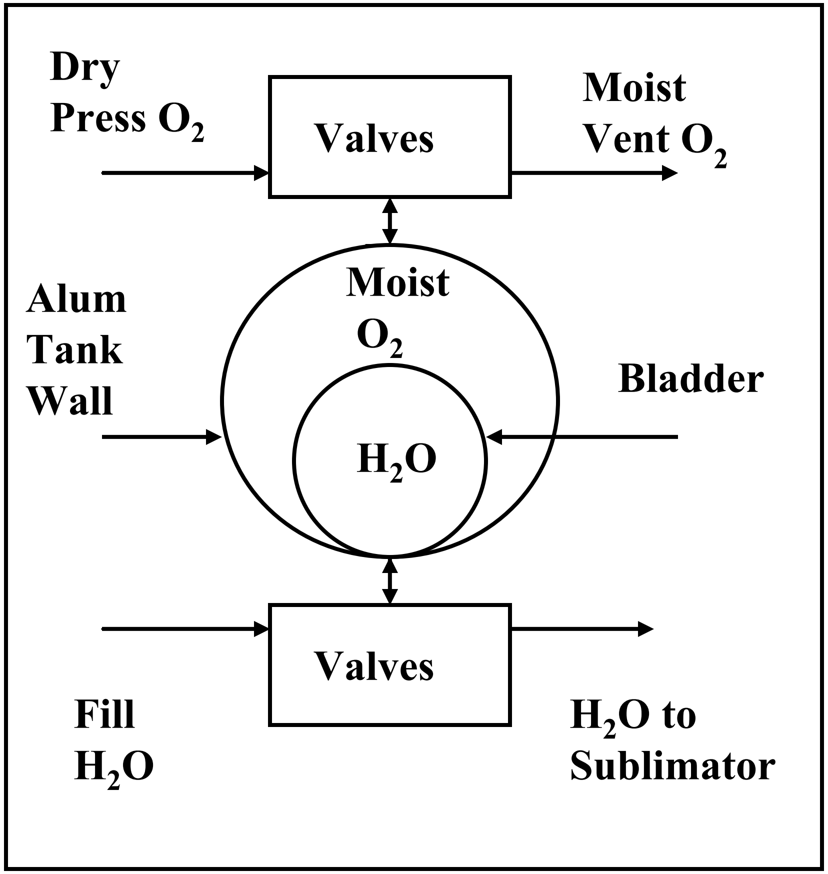
Overestimated gas purge effectiveness to keep tank wall dry

Solutions-

- 4th mat'l (fluorocarbon) good manufacturability
- Developed field repairable tank wall coating

LESSONS LEARNED

- Moist environment is VERY CORROSIVE
- Design for manufacture & maintainability
- Fluorocarbon bladders greatly reduced H_2O contamination. PROBABLY THE MOST COST-EFFECTIVE CHANGE MADE TO THE EMU!



Challenge: Evolve CO_2 Scrubber Canister

Shuttle EVA- 1-use LiOH, ground refill, 1000 Btu/hr for 7.5 hrs (Apollo profile)

1st Version: Brazed assy, H_2O cooled

- Problems w/H_2O disconnects & HX corrosion
- Can vendor lost $, no-bid follow on
- Good human test results w/o H_2O cooling

2nd Version: Welded assy, gas cooled

- LiOH supplier developed high perf, storable sorbent for Shuttle conditions
- Drop-in replacement, met perf reqts
- Minor later changes extended shelf life, replaced unavailable materials

Station EVA- Orbit-regenerable METOX 850 Btu/hr for 8 hrs

- Worked w/NASA to define ISS metabolic profile
- METOX eliminates LiOH transport weight penalty to/from ISS
- Drop-in replacement for LiOH can

LESSONS LEARNED

- Inadequate understanding of differences between Apollo & Shuttle requirements led to initial over design
- Close cooperation w/ LiOH supplier yielded good sorbent for shuttle EVA
- Close cooperation w/ NASA yielded good sorbent system for ISS EVA

Challenge: Improve EMU Health Monitoring

Item- Caution & Warning System

- Electronics in PLSS backpack
- Display in DCM chest pack
- Function- Detects critical EMU failures, sounds alarm to shorten EVA (Caution) or abort EVA (Warning)

Problems-

- "Fussy" suit don & checkout steps
- Lacked eng data to resolve anomalies or predict future problems (trending)
- Electronics became obsolescent
- Difficult field maintenance

Multi-step Evolution-

- Added easy-to-use donning cue cards
- Added separate real-time data system & transducers to provide engineering data
- Near end of 22-25 yr life, redesigned CWS w/ 16-bit µ and current, rad-hard electronics. This allowed:
  - Integration of RTDS w/ CWS
  - Improved donning & status checks
  - More info/better use of display
  - Ease of software upgrade

LESSONS LEARNED

- Make user interface easy to use
- Include engineering data to support diagnostics, trending & future mission planning
- Design for field maintainability and periodic electronics upgrade

Summary Thoughts on Lessons Learned

Study and understand the problems from previous programs, eg:

- High pressure O_2 requires special attention. USE THE NASA DESIGN DOCUMENTS!
- Wet or moist environments can be very corrosive and contaminating. Choose metals, elastomers and coatings very carefully.
- Design for manufacturability, maintenance ease and periodic upgrade of fast-evolving technologies.

Understand the differences between past and current programs, especially in requirements, materials and technologies.

Remember, "Those who cannot remember the past are condemned to repeat it." George Santayana, 1863-1952

EVA Suit Technology Development

Liana Rodriggs, JSC/EC5
Project Manager, Advanced EVA Development

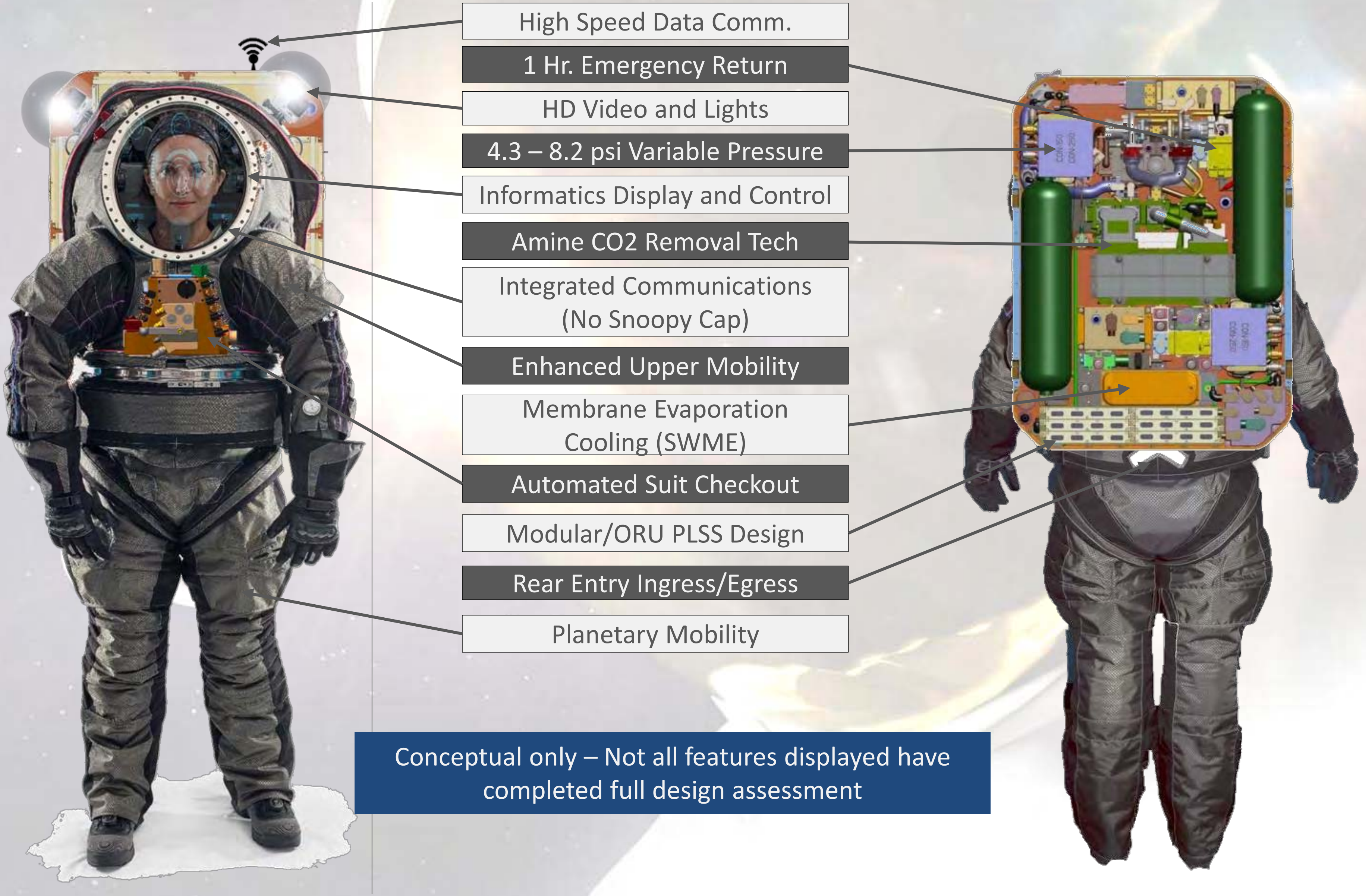
EVA Suit Technology Development Overview

- Development Objectives
- Portable Life Support System Development
- Power, Avionics, and Software System Development
- Pressure Garment System Development
- Upcoming Integrated Testing
- Technology Gap Closure Plan

Development Objectives

- To mature technologies and capabilities that will enable future EVA exploration systems for any of the proposed design reference missions
  - Incorporating lessons learned from 30+ years of EMU operations
  - Designing for the different environments of the potential destinations
  - Developing hardware that enables scientific exploration and supports the operational concepts of the potential destinations
- To produce real cost, performance, and reliability data through building and testing high-fidelity systems
- To systematically develop EVA technologies and systems to assist in closing gaps for an integrated humans to Mars mission in the 2030s

NASA Exploration EMU Reference Architecture



- High Speed Data Comm.
- 1 Hr. Emergency Return
- HD Video and Lights
- 4.3 – 8.2 psi Variable Pressure
- Informatics Display and Control
- Amine CO2 Removal Tech
- Integrated Communications (No Snoopy Cap)
- Enhanced Upper Mobility
- Membrane Evaporation Cooling (SWME)
- Automated Suit Checkout
- Modular/ORU PLSS Design
- Rear Entry Ingress/Egress
- Planetary Mobility

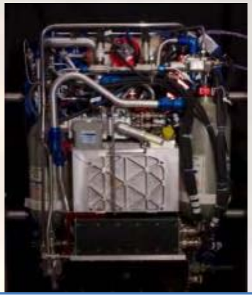
Conceptual only – Not all features displayed have completed full design assessment

PORTABLE LIFE SUPPORT SYSTEM (PLSS) TECHNOLOGY DEVELOPMENT

Portable Life Support System Technology Development

- A schematic trade study was undertaken in the early days of the Constellation Program to compare technology options for an exploration PLSS
  - Included NASA and Industry participation
- The selected schematic included key technology areas – 3000 psi O_2, rapid cycle amine CO_2 removal, and evaporative heat removal
- PLSS tech dev efforts have since focused on developing and testing the components and system per that schematic
  - Has resulted in some changes to the schematic
- Lessons learned from the 30+ years of EMU operations have also influenced the NASA reference PLSS design
  - Corporate knowledge from team experience
  - EMU Requirements Evolutions
  - Assured EMU Availability (AEA) Reports
  - PRACA FIAR summaries

Portable Life Support System Technology Development

	COMPLETE ✓	COMPLETE ✓	FY16/17/18
	PLSS 1.0 (Breadboard)	**PLSS 2.0 (Packaged GN2)**	**PLSS 2.5 (xPLSS) (Flight prototype)**
			
Purpose:	• Schematic validation with models • Component pneumo-hydraulic integration	• Packaged lab unit • System level performance	• Flight design without paperwork (GN2/Air only) • Integrated system performance
Hardware:	• Prototype: RCA, Fan, SWME, POR, SOR • Balance COTS/Instruments	• 2nd gen prototypes: RCA, SWME, POR, SOR • 1st gen prototypes: remainder	• 3rd gen prototypes; RCA, SWME, POR, SOR • 2nd gen prototypes: remainder
Testing:	• 8 simulated EVA transient profiles • 397 hrs of full PLSS operation • 595 hrs of SWME/thermal loop operation	• Pre-Installation Acceptance (PIA) test against system spec • 19 psia air human-in-the-loop testing with the Mark III spacesuit (2hr EVAs) • 25 EVAs, failure simulations, integration tests at vacuum	• PIA test against system spec • 100 unmanned EVAs in vacuum • Unmanned thermal vacuum testing • Pressurized launch vibe testing • EMI Testing • Static Magnetics Testing

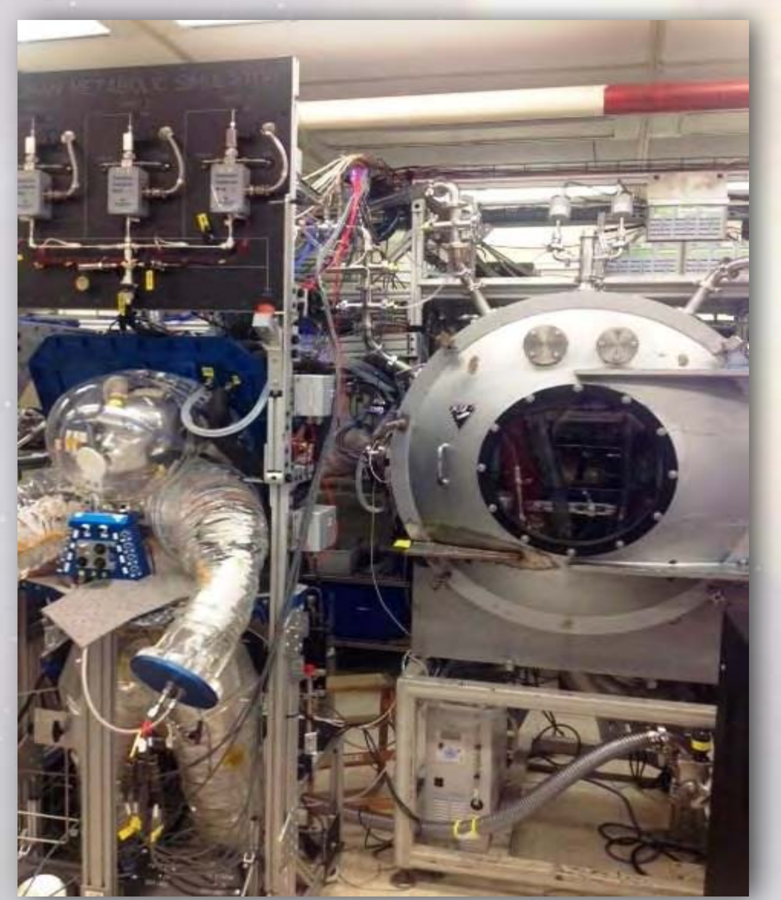
PLSS 2.0 Testing

PLSS 2.0 Testing: March 2013 – July 2015

- Pre-installation acceptance testing of all components and integrated system against draft PLSS specification
- Human In The Loop (HITL) Testing (10/27/15 – 12/18/15)
  - Nineteen 2-hr EVAs using 6 test subjects in the Mark III space suit
  - Quantitative and subjective evaluations of PLSS operation
  - 3 metabolic rate profiles (300-3000 Btu/hr)
  - Simulated nominal EVA using Primary Thermal Control Loop and contingency ops using Auxiliary Thermal Control Loop

PLSS 2.0 Testing

- Unmanned Vacuum Testing (1/9/15 – 7/9/15)
  - Completed 298 hrs of vacuum operation and 25 EVAs spanning various metabolic profiles (300-3000 BTU/hr)

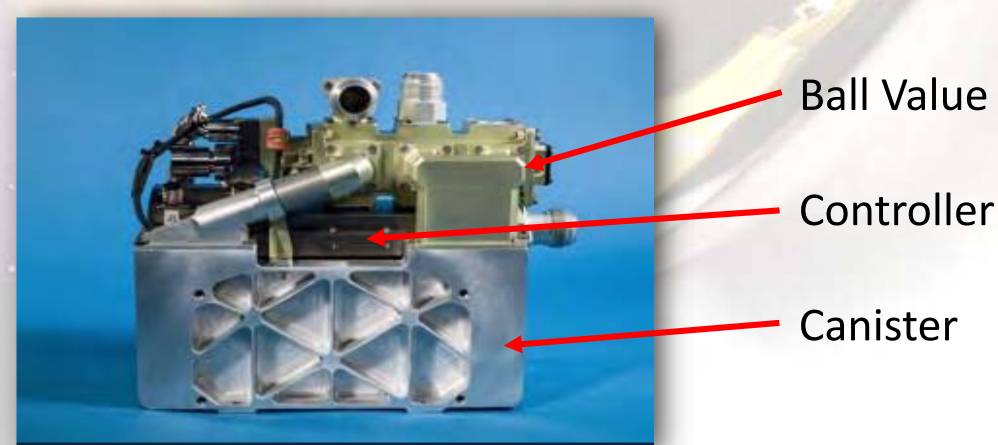


  - Evaluated performance of PLSS component and system-level designs
  - Validated and updated component specifications and PLSS requirements
  - Tested hardware to failure and simulated other failure conditions
  - Evaluated airlock, suitport, and EVA abort ops cons
  - Demonstrated vehicle interfaces and consumable recharge methods, flow rates, and times
  - Evaluated controller algorithms
  - Demonstrated consumables sizing and ran to depletion to observe telemetry signatures

Rapid Cycle Amine (RCA)

- RCA provides CO2 and humidity removal via a two bed chemical sorbent canister
  - RCA 1.0 and 2.0 were tested at a component level and within the PLSS 1.0 and PLSS 2.0 systems
  - Lessons learned and increased fidelity were incorporated into the RCA 3.0 design intended for use in PLSS 2.5 (ex. valve design, integrated controller, O2 compatibility)
    - Manufacturing, assembly, functional verifications, and air rig performance testing complete
- Advantages:
  - Real-time regenerative – CO2 removal system will not limit EVA duration and reduces consumables
  - Reduces mass as compared to the EMU MetOx
  - Eliminates most failure modes that introduce water into the helmet and space suit

RCA 3.0



RCA 3.0

Variable Oxygen Regulator (VOR)

- VOR provides dual stage pressure regulation for oxygen and pressure control for space suits
  - VOR 1.0 and 2.0 were tested at a component level and within the PLSS 1.0 and PLSS 2.0 systems
    - VOR 2.0 underwent Oxygen and contaminant compatibility testing at WSTF as well as thermal, vibration and orientation testing
  - Lessons learned and increased fidelity were incorporated into the VOR 3.0 design intended for use in PLSS 2.5 (ex Monel body, O2 compatibility, relevant environments)
    - Manufacturing, assembly and functional verifications complete
- Advantages:
  - Continuously adjustable pressure settings (~4000 set points) to control suit pressure between 0 and 8.4 psid
  - Robust design, tolerant of contamination & combustion events


VOR 2.0


VOR 2.0 in Primary O2 Assy


VOR 3.0

Suit Water Membrane Evaporator (SWME)

- SWME provides heat rejection and water degassing via hollow fiber membranes
  - Gen1 SWME were early developmental versions
  - Gen2 and Gen3 SWME included improvements such as reduced size, new fabrication methods, and more flight-like backpressure valve and were tested at the component level and within the PLSS 1.0 and PLSS 2.0 systems
  - Gen4 SWME is currently under development for use in PLSS 2.5
    - New square cross section to optimize PLSS packaging
    - New manufacturing techniques
    - New Multi-cartridge system: commonality between SWME+Mini-ME
    - New water-compatible epoxy
    - New backpressure valve technology: spool valve – allows for pressure equalization in case of off-nominal repress/depress
    - New mid-fiber temperature sensor to monitor system health
    - Planned biocide compatibility testing

Gen 1

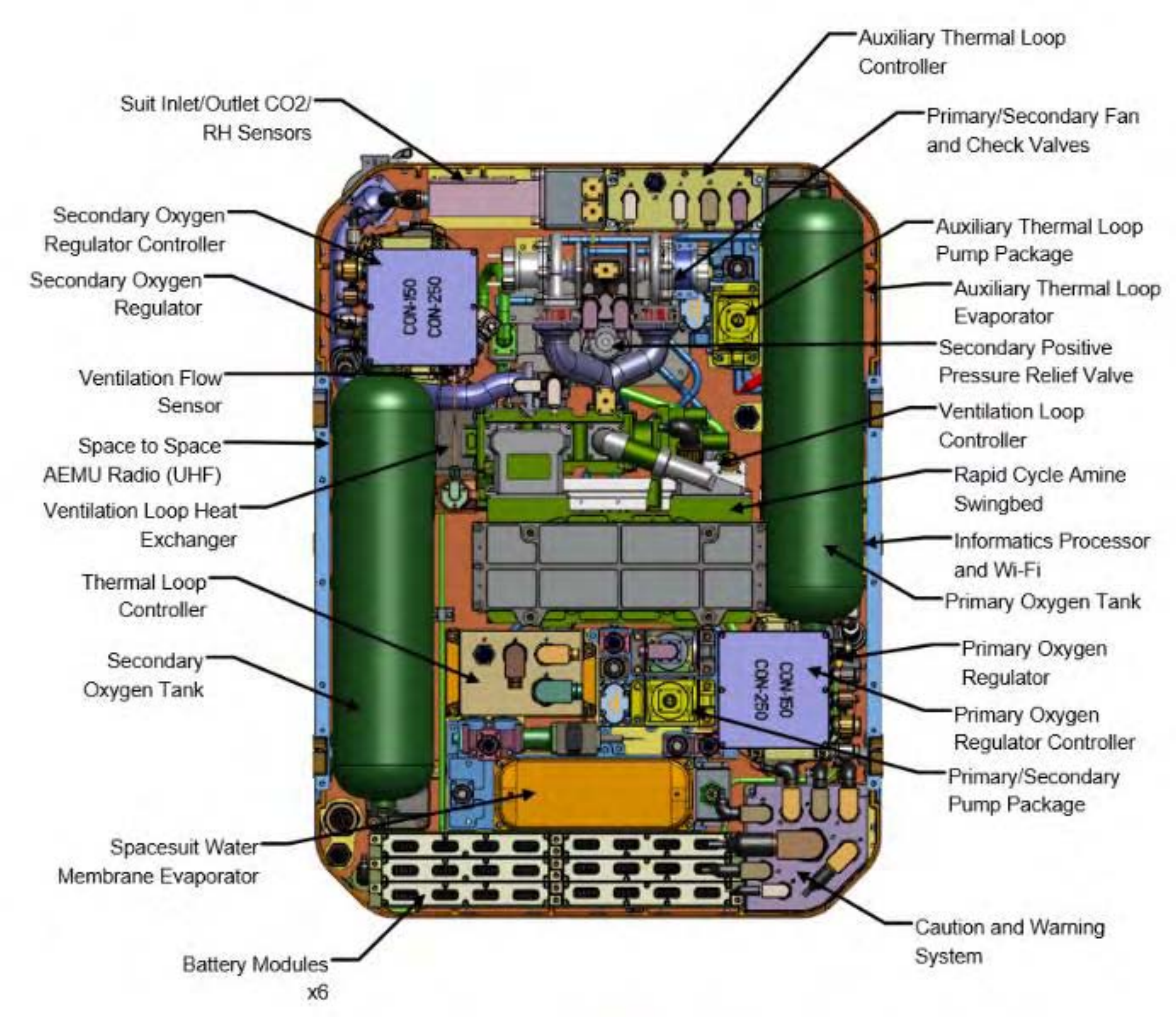
Gen 2

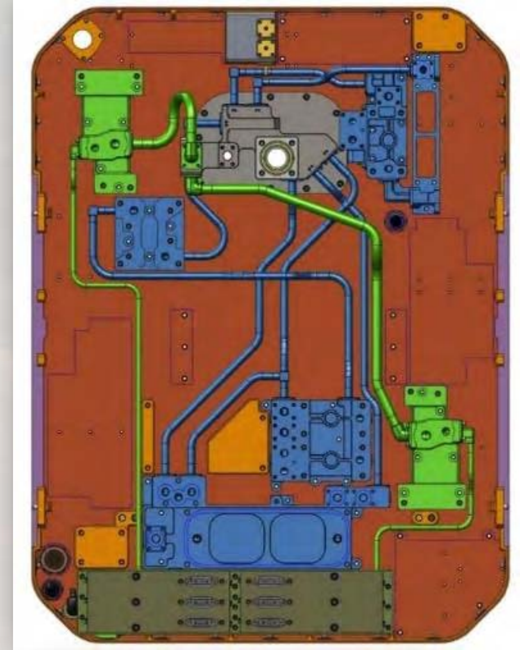
Gen 3

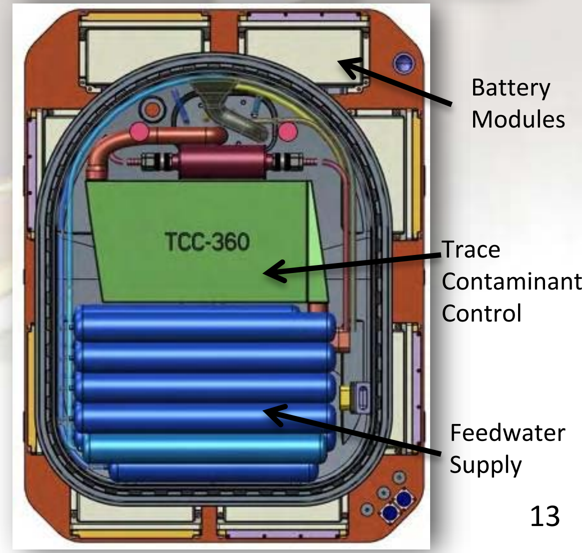
Gen 4

Cartridge

PLSS Packaging







POWER, AVIONICS, AND SOFTWARE (PAS) TECHNOLOGY DEVELOPMENT

PAS 2.0

- Completed assembly and integrated testing of PAS 2.0
  - Includes Caution and Warning System (CWS), Display and Control Unit (DCU) simulator, Communication Assembly, Informatics Assembly, Biomed simulator, Integrated Audio Mics and speakers
  - Implemented Core Flight Software for the CWS
  - Demonstrated PAS subsystem performance
    - Power distribution, fault protection, and data transfer
    - Power loading, processor throughput, inter-assembly functional operations, and inter-assembly messaging
    - Continuous operation of the CWS and Informatics processors while switching between the umbilical and battery power sources using the DCU


DCU Simulator


Power load boxes


Informatics/Crit 3 PMAD Assembly

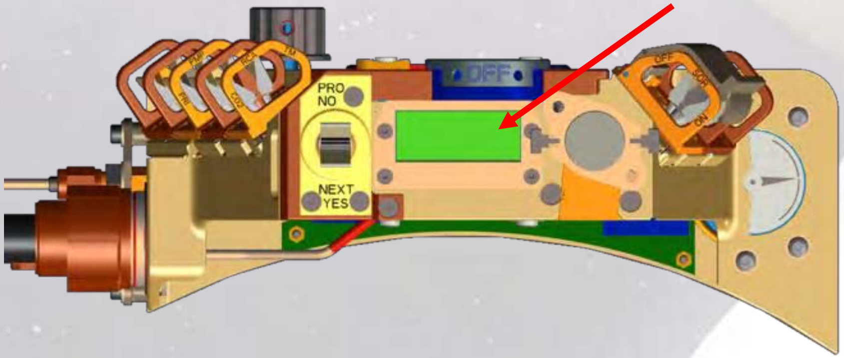

Comm/Radio Assembly


CWS/Crit 1 PMAD Assembly

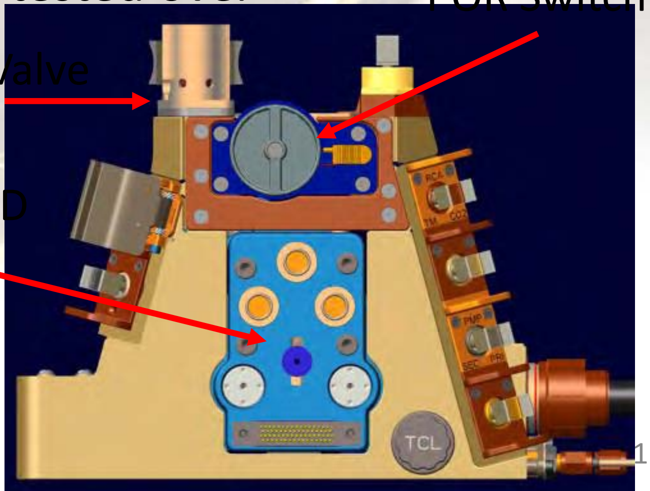

CWS/Informatics/ PMAD Integrated Testing

Display and Control Unit (DCU)

- The DCU enables control of the PLSS/Suit functions (pressure, cooling, fans, etc.)
- The DCU also provides text status and warning messages
- Initial concepts explored menu-driven and manual approaches
  - Prototypes were evaluated and a hybrid approach was selected with direct manual control of key functions
- Follow-on prototyping focused on packaging and input devices
  - Triangular design centered around the common connector quick disconnect
  - Space constrained to fit on Z-series upper torso (40% smaller than EMU DCM)
- DCU 2.0 is currently under development and will be tested over the next year



LCD Screen



Purge Valve

POR Switch

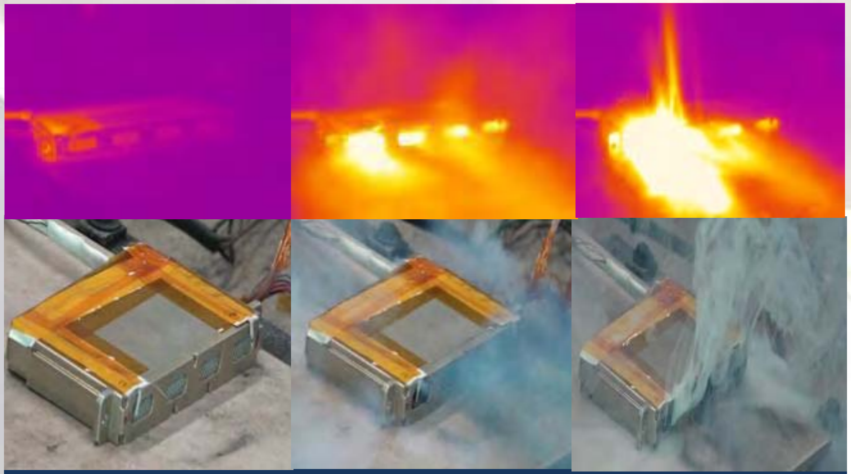
Common QD

Battery Development

- Power for the critical and non-critical space suit functions in the reference design will be provided by a distributed battery system
  - Battery modules (all the same) will be located inside the PLSS and on the front side of the PLSS plate
- 10 prototype battery packs and a charger have been completed and will be utilized during the PLSS Live Loads test
  - Incorporated NESC findings to limit thermal runaway propagation of 18650-type cells into the prototypes
- Performed initial Thermal Runaway Propagation (TRP) testing of battery module design using Moli 2.5 Ah cells
  - Design performed well except for managing cell ejecta
  - Additional testing is planned

Batteries in PLSS 2.5

Battery pack



TRP Battery Testing

Informatics

- Conducted interviews with EVA stakeholders, received specialized field-geology training, developed operational concepts and functional requirements
- Tested prototypes in analog exploration missions, such as Desert RATS
- Evaluated numerous technologies for graphical displays and space suit human-machine interfaces (HMIs).
  - Evaluated multiple COTS solutions via in-house lab testing
  - Evaluated multiple custom solutions via SBIR contracts
- Limited vocabulary speech recognition is a strong candidate for control of informatics with other methods (traditional switches, glove-finger sensors, etc.) used to supplement the system

PRESSURE GARMENT SYSTEM (PGS) TECHNOLOGY DEVELOPMENT

Pressure Garment Technology Development

2005 — 2010 — 2012 — 2016

CxP

ETDD/ETDP

AES/GCD

MK III 1992

WEI 1998

REI 2006

- Exploration mission tradestudy support via timeline analysis and end-to-end analog testing with pressurized suits, robotic assistants, and mid-fidelity vehicles/habitats
- Exploration pressure garment requirements development
  - Suit fit and strength analysis
  - Extensive multi-suit mobility studies
  - Suited joint torque
  - Dust/dirt protection and mitigation
  - Suit mass and center of gravity

Z -1 2011

- Mobility demonstrator
- First prototype compatible with delta pressure suitport don/doff evaluations
- Optimized for larger crew population

Z -2 2016

- Highest fidelity planetary prototype since Apollo
- Rated for 100% oxygen environments
- Certified for testing in the NBL
- Optimized for smaller crew population

Z-2 Design Features

Hybrid Composite Hatch (Carbon/S-Glass/AL)

Integrated Comm. Systems

Ti Waist Bearing w/1.75” Integral Sizing Ring

Composite Brief

2 Bearing Toroidal Convolute Soft Hip

Ankle Bearing

Gen 2 Adjustable Walking Boot

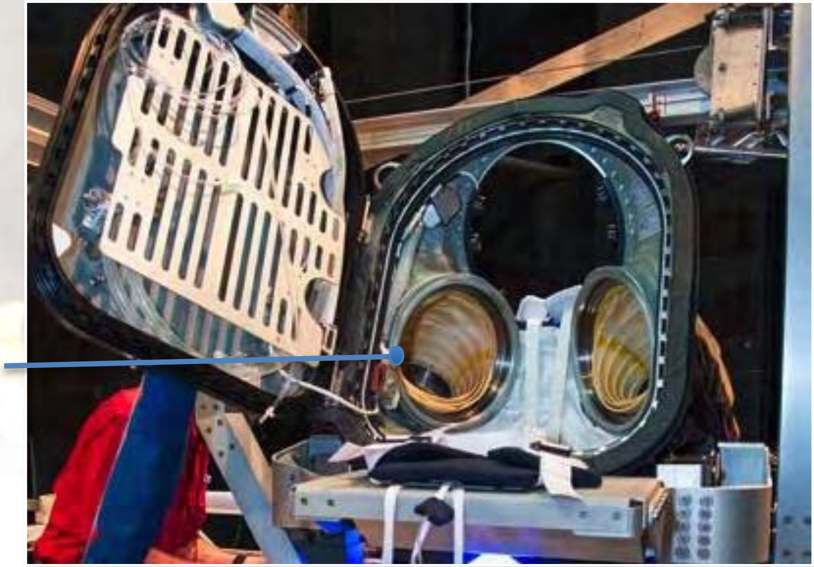
Removable SIP (not shown)

13x11 Elliptical Hemispherical Helmet

2 Bearing Rolling Convolute Shoulder

RC Waist Joint

EMU Style Acme Thread FAR



Composite HUT (Carbon/S-Glass) (1” Vernier Sizing)

Z-2 Verification Testing

- Suit Mobility/Sizing Verification
  - Completed fit-checks for 7 subjects in the design sizing range
  - Verified mobility and fit via task completion
    - Isolated joint mobility
    - Object relocation tasks
    - Unassisted kneel/recover
    - Walking
    - Unassisted boot reach and adjustment
- CO2 Washout Verification - Z-2 provided adequate washout at all tested conditions
  - Conducted in Chamber B at ambient external conditions
  - 6 test subjects representing range of suit sizing
  - Suit pressure at 4.3 and 8.3 psid
  - CO2 monitored at the nose with nasal cannula
  - Metabolic rates 1000– 3000 BTU/hr achieved with treadmill or walking in place
  - Airflow rates 2 – 6 acfm

Titanium Bearings

- Titanium is a highly desirable material for use in space suits because of the high strength to density ratio
  - Anticipate a 24 lb mass saving on a single EVA space suit
- Titanium is more prone to wear than steel and future exploration space suit bearings must have a cycle life ~100x that of current EMU bearings
  - Phase II SBIR in work has shown substantially increased cycle life and weight benefits through the use of bearing coatings, and new bearing ball materials
- Titanium is flammable in reduced pressure, 100% O2 environments
  - Performed bearing ignitability testing of realistic space suit bearings, while cycling to failure without any signs of ignition
- Future Work
  - Conduct cycle testing of full spacesuit system with bearings to verify cycle life and component bearing test results
  - Down select to new bearing architecture
  - Repeat ignitability testing of the newly developed bearing architecture and materials

Scye bearing post-test

Hip bearing test set-up in WSTF chamber

Energy Mobility Testing

- Goal: Evaluate suited mobility at the system level by measuring metabolic cost of functional tasks in different space suits
  - Alternative to traditional approach to defining mobility
- Approach: Performed testing with 6 subjects and 3 suits (Mark III, REI, Demonstrator) and measured rate of CO2 production
- Results: Statistically relevant differences between similar suit architectures performing functional tasks exist
  - Method shows great promise to be robust and reliable, but needs continued refinement

Walking

Side Step

Stair Climbing

Upper body Object Relocation

Full body Object Relocation

High Performance EVA Glove (HPEG)

- Gas Pressurized EVA Gloves
  - Link-net bladder/restraint test article
    - Completed fabrication
    - Received one pair in Jun 2016
  - Gas pressurized glove prototypes
    - Completed fabrication
    - Held Pre-Test Review
    - Completed verification testing
    - Received two pairs in Aug 2016
  - Testing of prototypes planned for Fall 2016
- Mechanical Counter Pressure Gloves
  - Held Pre-Test Review
  - Completed manned glovebox testing
  - Received prototype hardware in Jul 2016

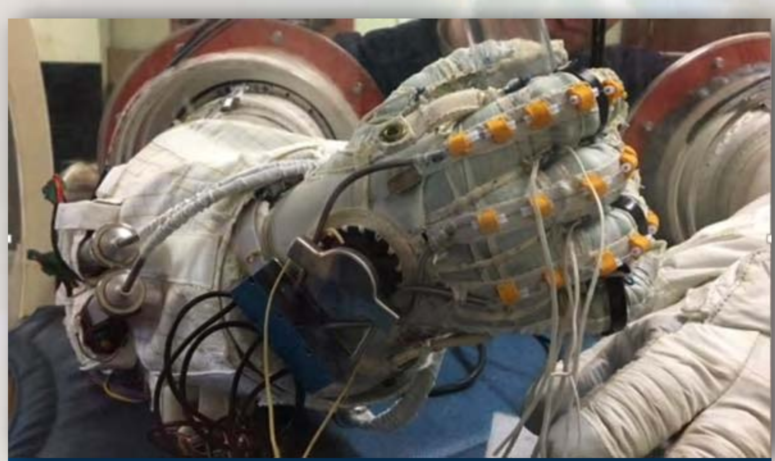
Link-Net Bladder/Restraint and Cover Layer

Gas Pressurized Glove Prototypes

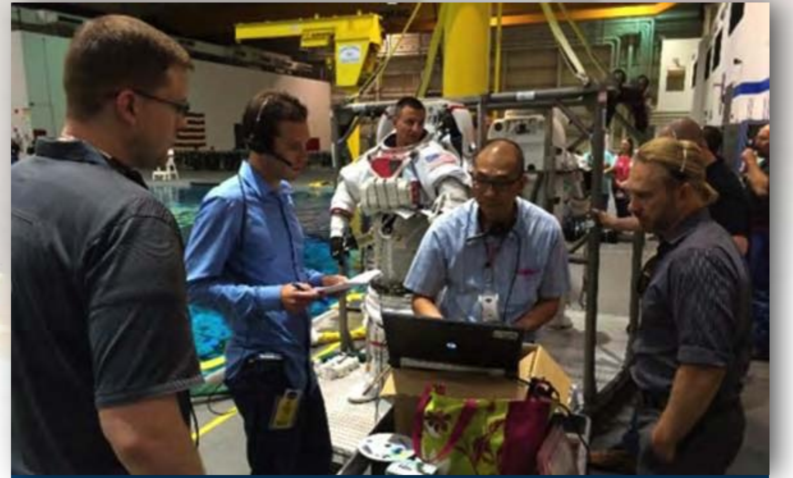
Glovebox Testing of Mechanical Counter Pressure Prototypes

High Performance EVA Glove (HPEG)

- Robotically Assisted EVA Gloves
  - Completed hardware upgrades to the 2nd Space Suit RoboGlove (SSRG) prototype
  - New system includes sensors that determine finger position to enable more precise control and "power steering" to ease the effort required to execute grasps
  - Evaluations planned for Sep 2016
- Sensor Suite
  - Completed successful NBL test on July 11, 2016
    - Over 4 hours of data collected
    - Approximately 30 sensors measuring fingernail strain, force, temperature and humidity
    - Test report expected in Fall of 2016
  - Future work will assess the sensor suite's ability to evaluate various prototype gloves



New enhancements on SSRG prototype 2

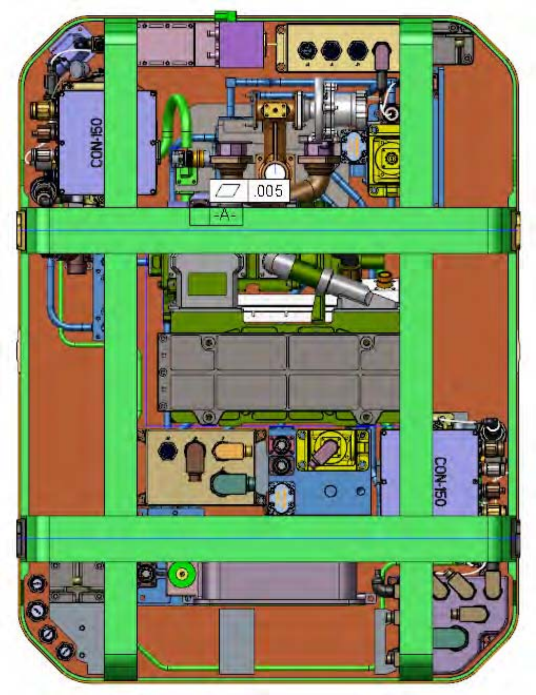


Sensor Suite NBL Test

UPCOMING INTEGRATED TESTING

PLSS Electrical Live Loads Testing

- A partial assembly of the xPLSS prototype will be tested this fall
  - Assembly of the test configuration has begun
- Test Objectives:
  - Power Switch, Routing, and Current Limiting
    - Demonstrate power switching from SCU power to battery power and vice verse
    - Demonstrate power routing of input power to the attached loads (controllers and radio)
    - Demonstrate current limiting to the attached loads under simulated failed conditions
    - Demonstrate current limit reset with power cycle
    - Demonstrate current monitoring for each attached load
  - Communications
    - Validate the latest PLSS Data and Control Communications Specification
    - Evaluate controller digital command I/O approaches
  - Evaluate grounding differences and the impact on noise seen on the signal lines during quiescent and complex loading
  - Evaluate DCU display and controls



Z-2 NBL Test Series

- Z-2 Suit will be tested in the NBL to evaluate its performance in micro-gravity compared to EMU
  - Performance is relative to performing ISS tasks
  - Performance metrics are ratings of mobility and worksite ergonomics
  - Approximately 16 runs beginning late September through winter 2017
- Two Z-2 suit configurations will be evaluated during Z-2 NBL test series:
  - Z-2 suit with Z-2 Lower Torso Assembly (referred to as ZLTA)
  - Z-2 suit with EMU Lower Torso Assembly (referred to as ELTA)
- Detailed Objectives:
  1. Evaluate ability of Z-2 with ELTA to perform ISS critical contingency EVA (CCE) tasks
  2. Evaluate EMU tools with Z-2 upper torso architecture
  3. Evaluate Z-2 with advanced PLSS package volume (PLSS 2.5) for use on ISS
  4. Evaluate suit usability with subjects who span size range of Z-2
  5. Evaluate added performance from highly mobile LTA (ZLTA)
  6. Evaluate capabilities of highly mobile LTA (ZLTA) at 8.0 psid (zero pre-breathe pressure)

EVA SUIT TECHNOLOGY GAP CLOSURE PLAN

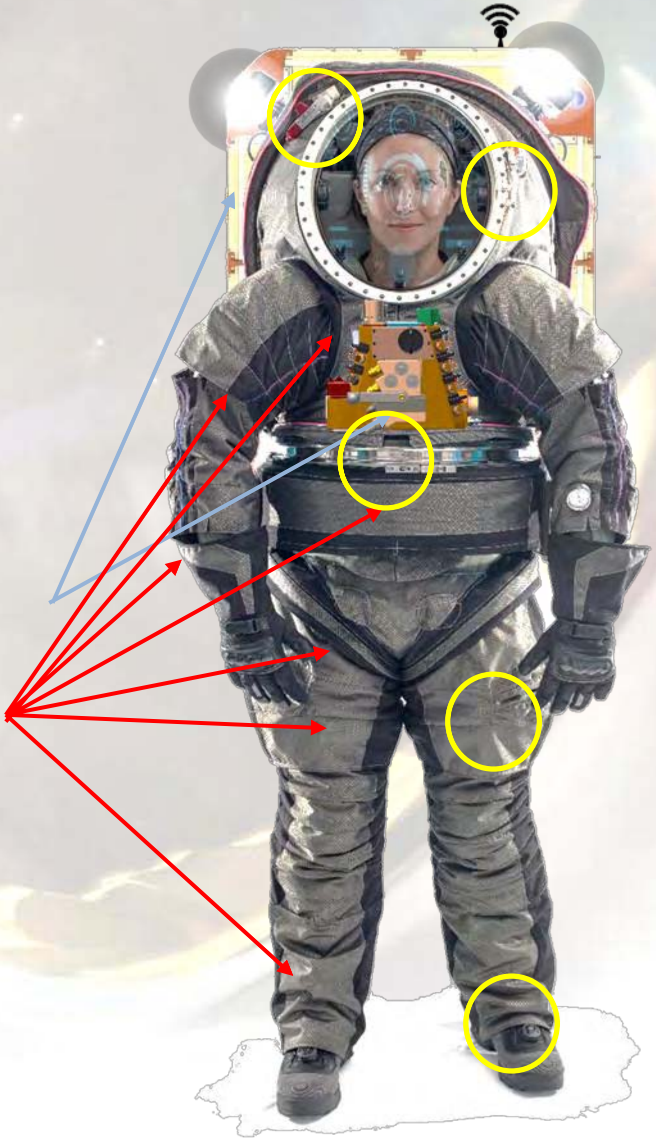
EVA Suit Technology Gap Closure Plan

- System Maturation Team (SMT) Gaps assessed annually to update progress on existing gaps and identify any new gaps based on changes to reference missions or new information from technology development efforts
- Gaps generally divided as either a technology/hardware or knowledge gap
- Key focus areas for technology gaps in near-term:
  - Dust Tolerant Mechanisms
  - Textiles for High Abrasion Environments
  - Thermal Insulation for Non-vacuum Environments
  - Dust Mitigation Strategy for Remote Habitats
  - Mass Reduction Strategies
  - Closed Loop Life Support Systems

EVA Suit SMT Technology Gaps

Dust Tolerant Mechanisms

- Space suits for planetary exploration will be required to operate nominally in a coarse dirt and fine dust environment for up to 600 hrs with minimal maintenance required
- Nominal operation is considered less than 10% increase in running torque for bearings, less than 10% increase in actuation torque for disconnects, and less than 2 sccm increase in leakage
- Key mechanisms in space suits include:
  - Quick disconnects for oxygen, water, and power/data lines; gas exhaust ports, relief and purge valves
  - Bearings in the pressure garment arms, legs, and waist
  - Component hard disconnects at the pressure garment wrist, arm, waist thigh, and ankle; and hinges at the pressure garment rear hatch



- Desired Technology Capabilities:
  - Mechanisms with quick change-out dust seals
  - Mechanisms with active dust repellant properties

EVA Suit SMT Technology Gaps

Textiles for High Abrasion Environments

- NASA needs suit material(s) and systems of layers of materials that are capable of long duration exposure to dust and abrasive activities that are also flexible so as not to compromise mobility (walking, kneeling, etc.)

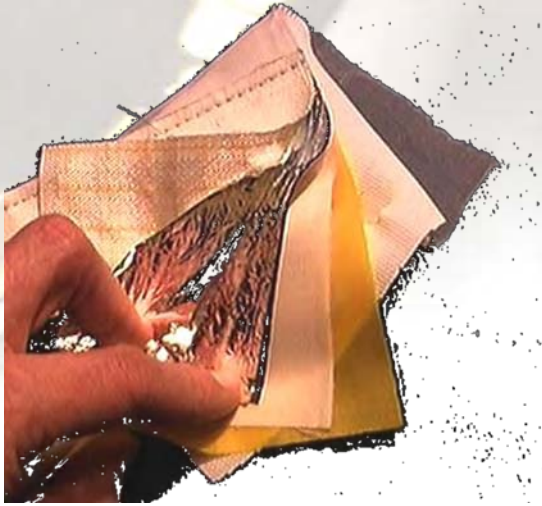
- Desired Technology Capabilities:
  - Self-healing textiles
  - Damage sensing textiles
  - Manufacturing techniques to minimize dust migration between textile layers
  - Textiles or coatings with active dust repellant features
  - Textiles or coatings with passive dust repellant features

EVA Suit SMT Technology Gaps

Thermal Insulation for Non-Vacuum Environments

- Current space suit insulation technologies rely heavily on the vacuum of the low-earth orbit environment to minimize heat transfer by separation of layers in the space suit material lay-up
- However, various exploration destinations, and specifically Mars, exhibit low pressure atmosphere which allows convection to occur

- Desired Technology Capabilities:
  - Lightweight, flexible, durable, and thin to minimize interference with mobility features of suits (Note: If one or more of the above characteristics is an issue, but could be resolved for space suit application through development, the technology is of interest)
  - Adaptable for seasonal variations in temperature

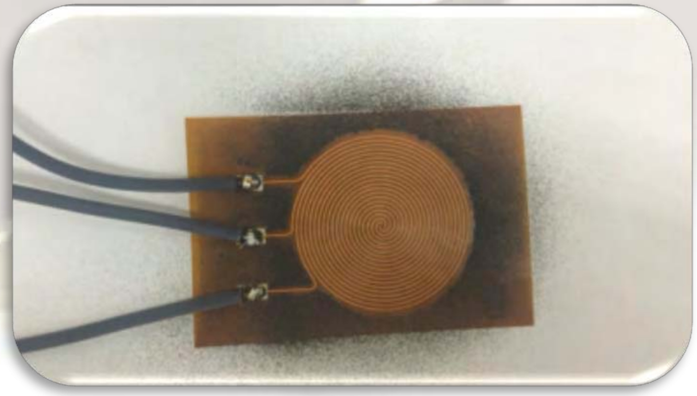


EVA Suit SMT Technology Gaps

Dust Mitigation Strategy for Remote Habitats

- Exclusion of dust from habitable environments is a system level challenge
- Space suited crewmembers will bring some amount of dust into the habitat following each EVA. In reduced gravity environments fine dust does not quickly settle out of the habitat atmosphere.

- Desired Technology Capabilities:
  - System to remove/repel dust from space suits
  - System to remove and collect dust from the habitat atmosphere
  - System to remove and collect dust from habitat surfaces
  - System of locks that employ the above to mitigate dust in the habitable volumes



EVA Suit SMT Technology Gaps

Mass Reduction Strategies

- Launch mass from Earth’s surface has always been a challenge but introduction of gravity environment for EVA will create greater need for reduced on-back mass.
- Gravity environments will increase the need for finer alignment of EVA suit system CG to optimize mobility and efficiency.

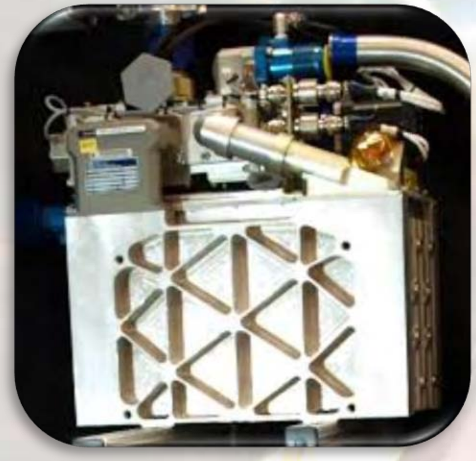
- Desired Technology Capabilities:
  - Composite lay-ups that meet load requirements (pressure and impact) with minimal mass
  - High reliability methods for fabricating complex composite geometries
  - In-situ printing of replacement suit components
  - Lightweight bearings

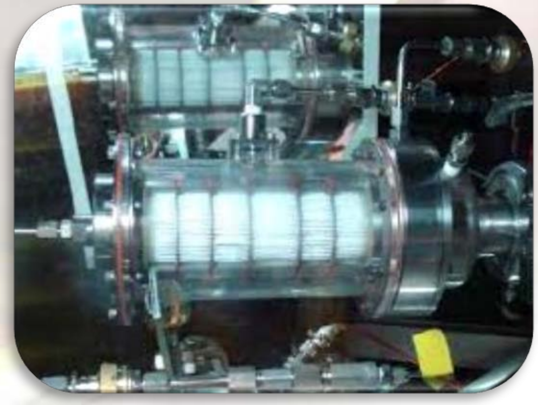
EVA Suit SMT Technology Gaps

Closed Loop Life Support Systems

- NASA needs EVA CO2 and H2O removal system that is low mass, low power, low consumable at the mission architecture level, minimizes exhaust pollutions (for planetary protection considerations), and functions within the Mars CO2 atmosphere and convective thermal environment.

- Desired Technology Capabilities:
  - Small package that enables the overall Portable Life Support System (PLSS) volume to be minimized.
  - Remove CO2 at rates up to 190 g/hr with concentrations <2mmHg
  - Accommodate these removal rates for up to 12hrs with 8 hrs of autonomous EVA time and potentially 4 hrs of pre-breathe time.
  - Remove H2O vapor at rates up to 150 g/hr with <75% RH in oxygen carrier gas with trace CO2





EVA Suit SMT Technology Gaps

Displays and Controls for Crew Autonomy

- NASA needs a radiation tolerant graphical display that is compatible with the suit that can be operated via a hands-free user input device to control the informatics system. This could consist of a speech recognition system

- Desired Technology Capabilities:
  - Non-intrusive to both mobility and field of view (no interference with primary task completion when not in use)
  - Either 100% O2 compatible and inside the PGS -OR- compatible with the helmet & visors and external dust environment
  - Low power
  - Functions in extreme lighting conditions
  - Wide and/or infinite eye-box

Closing EVA Suit SMT Technology Gaps

- The EVA Community is actively working to collaborate with scientists and engineers across spaceflight
  - Participate in intra-agency technical interchange meetings
    - Human Research Program Investigators Workshop
    - EVA Technology Workshop
  - Maintain high-level list of technology and knowledge gaps with associated closure plans
    - EVA System Maturation Team
    - NASA Technology Roadmap
  - Partner across Government, Industry, and Academia to strategically target gap areas by priority with emphasis on cross-cutting areas
    - Small Business Innovative Research Program
    - Space Act Agreements
    - Research grants (NSTRF, NAIC, NSBRI, etc.)
  - Publish latest technical developments and research results in relevant publicly accessible forums
    - Conference papers (AIAA, ICES, SAFE, IFAI, SAMPE, etc.)
    - Trade publications
    - NASA Tech Briefs

Summary

- A significant amount of space suit hardware development at the component and integrated system has occurred in recent years
  - Many other components and technologies have been matured than were covered in this presentation
- However, there are areas that still require a lot of investment, particularly to enable EVA's on Mars
- Through sharing of knowledge, it is our hope that we are closing the gaps to EVA's at exploration destinations