

JSC/EC5 Spacesuit Knowledge Capture (KC) Series Synopsis

All KC events will be approved for public using NASA Form 1676.

This synopsis provides information about the Knowledge Capture event below.

Topic: Apollo Spacesuit Modifications for the Apollo-Soyuz Project

Date: June 24, 2015 **Time:** 11:30 a.m. – 1 p.m. **Location:** JSC/B5S/R3102

DAA 1676 Form #: 33701

This is a link to all lecture material and video <\\js-ea-fs-01\pd01\EC\Knowledge-Capture\FY15 Knowledge Capture\20150624 McBarron Apollo SS Mods for ASTP\For 1676 Review & Public Release>

*A copy of the video will be provided to the NASA Technical Library and STI Program's YouTube via the Agency's Large File Transfer (LFT), or by DVD using the USPS when the DAA 1676 review is complete.

Assessment of Export Control Applicability:

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* This file is also attached to this 1676 and will be used for distribution.

For 1676 review use Synopsis McBarron Apollo-Soyuz Project 6-24-2015.docx

Presenter: Jim McBarron

Synopsis: With over 50 years of experience with NASA spacesuit development and operations, as well as for early U.S. Air Force pressure suits, Jim McBarron shared his significant knowledge about modifications to the Apollo spacesuit for use in the Apollo-Soyuz Test Project (ASTP). This included requirements and design changes implemented to establish the ASTP spacesuit design baseline. Additionally, he identified Apollo spacesuit contact details including quantity of spacesuits delivered to support the Apollo and Skylab Programs, and the ASTP. He concluded by identifying a summary of noteworthy lessons learned with recommendations for future spacesuit development.

Biography: In 1960, James (Jim) William McBarron II earned a bachelor of science in geology at the University of Dayton in Dayton, Ohio, and in 1983, he received a master of business administration from the University of Houston – Clear Lake in Houston, Texas. During his time in college, from 1958 to 1961, he worked part time on a University of Dayton contract with the Wright Patterson Air Force Base Aeromedical Laboratory that provided student test subjects to determine human endurance characteristics during and after exposure to extreme environmental conditions. His work as a student assistant also involved pressure suit design testing including suit hardware evaluation for the NASA Project Mercury. His career at NASA began in 1961 as an aerospace technologist with the Crew Equipment Branch, Life Sciences Division, Space Task Group, at Langley Field, Virginia. During his time with NASA, McBarron supported the Manned Spacecraft Center at JSC and worked with spacesuits for

all NASA flight programs including Mercury, Gemini, Apollo, Apollo-Soyuz Test Project (ASTP), Skylab, Shuttle, and the ISS. Throughout his career, he was given several prestigious awards including the American Astronautical Society Victor A. Prather Award for outstanding contribution in the field of EV protection in space in 1979. He is the author and co-author of many spacesuit-related publications. Before he retired in 1999, McBarron was the CTSD chief engineer for EVA projects. In 1999, McBarron took a position with ILC Dover, Inc. as spacesuit systems manager where he reviewed advanced spacesuit technology requirements and design concepts for future manned space flight programs. In 2002, McBarron started his own consulting service to support development of advanced spacesuit technology and inflatable products for current and future manned-space missions.

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U.S. SPACESUIT KNOWLEDGE CAPTURE SESSION

TODAY:

Apollo Spacesuit Modifications for the Apollo-Soyuz Test Project (ASTP) Spacesuit

SESSION BRIEFINGS IN-WORK:

- “Space Shuttle Extravehicular Mobility Unit (EMU) Spacesuit Development for Initial Space Shuttle Program Flights”
- “Space Shuttle EMU Spacesuit Development for the International Space Station Program”

James W McBarron II
Retired NASA JSC
June 24, 2015

TODAY'S AGENDA

- **ASTP MISSION BACKGROUND**
- **ASTP SPACESUIT DEVELOPMENT:**
 - Requirements
 - Apollo Spacesuit Modifications
 - Components Design
 - Certification
 - Mission Details
- **APOLLO-SKYLAB-ASTP SUMMARY:**
 - Lessons Learned
 - Spacesuits Delivered
 - Cost and Labor Data

APOLLO-SOYUZ TEST PROJECT

BACKGROUND

- May 1972 - A joint project agreement between the United States and the Soviet Union was made to establish a common (universal) docking system for future joint spacecraft operations.
- July 15, 1975 - Two manned spacecraft were launched into earth orbit:
 - Apollo Command and Service Module (CSM) with an attached docking module from Merritt Island, Florida.
 - Soyuz from the Soviet Cosmodrome at Baykonur.

APOLLO-SOYUZ TEST PROJECT

BACKGROUND

- July 17, 1975 - The two spacecraft rendezvoused, docked, and conducted two days of docked operations:
 - Crews transferred through the docking module four times conducting joint scientific investigations.
- July 19, 1975 - The Soyuz spacecraft returned crew safely to Earth.
- July 24, 1975 - The Apollo Command Module (CM) returned crew safely to Earth.



ASTP SPACESUIT DEVELOPMENT

MISSION REQUIREMENTS

- Conduct suited oxygen pre-breathe before launch.
- Crew wear spacesuit's at CM Environmental Control System (ECS) ventilation pressure (0.2 psi) during critical mission phases:
 - Launch
 - Soyuz Docking
 - Common Module Undocking
- Provide short-term emergency pressure protection in event of CM depressurization:
 - Operate CM controls during CM cabin pressure loss.
- No extravehicular activity to be performed.

ASTP SPACESUIT DEVELOPMENT

INTERFACE REQUIREMENTS

- CM:
 - Atmosphere ~100% oxygen gas at 5.0 psi pressure.
 - Couch launch and water landing restraint system.
 - Navigation and control optical systems.
 - Controls visibility and operation.
- Pressure Garment Assembly (PGA) self-connect and disconnect capability for all CM connectors:
 - ECS gas inlet and outlet, and electrical.
- Medical self injector application.
- Post-landing water survival life vest.

ASTP SPACESUIT DEVELOPMENT

ENVIRONMENTAL REQUIREMENTS

- Cabin Atmosphere Compatibility:
 - Odor and Toxicity
 - 100% Oxygen and Humidity
- Pre-launch:
 - Salt Fog
 - Sand and Dust
- Launch:
 - Vibration
 - Acceleration
 - Acoustic Noise
- Landing Water Impact

ASTP SPACESUIT DEVELOPMENT

CONTRACT DELIVERY REQUIREMENTS

- Custom-sized suits for each mission-assigned astronaut.
- Provide training, flight, and flight backup spacesuits for each prime crewmember.
- Provide training and flight spacesuits for each backup crewmember.
- Deliver training spacesuits 12 months before flight.
- Deliver flight spacesuits 6 months before flight.
- Deliver prime crew flight backup spacesuits 3 months before flight.

ASTP SPACESUIT DEVELOPMENT

CONTRACT SUPPORT REQUIREMENTS

- Provide 4-year shelf age life from completion of pre-delivery acceptance testing.
- Provide spacesuit maintenance and checkout support for interface tests and crew training at NASA JSC.
- Provide preflight suit maintenance and pre-installation checkout support for suited CM vacuum, interface tests, Count Down Demonstration Test (CDDT), and launch at NASA KSC.
- Provide test support and in-flight mission analysis at contractors plant and at NASA JSC.

ASTP SPACESUIT DEVELOPMENT

DESIGN REQUIREMENTS

PRESSURE GARMENT ASSEMBLY:

- 0.2 and 3.75 psig operating pressures.
- 6.0 psig proof, 8.0 psig structural, and 10.0 psig burst pressures.
- 4.7 inches water pressure maximum from inlet to outlet gas connectors at CM 12 cfm oxygen gas flow rate (diverter valve open).
- Leakage rate less than 180 scc/minute at either 0.2 or 3.7 psig.
- Helmet CO₂ level less than 16 mm/Hg at 1600 BTU/Hour rate.
- Helmet-mounted feed port for in-suit nourishment.
- Hands dexterity and fingers tactility to operate CM controls.
- Adequate crewman helmet vision for CM displays and mission interfaces.
- Post-landing ocean water immersion.

ASTP PRESSURE GARMENT ASSEMBLY

APOLLO SPACESUIT MODIFICATIONS

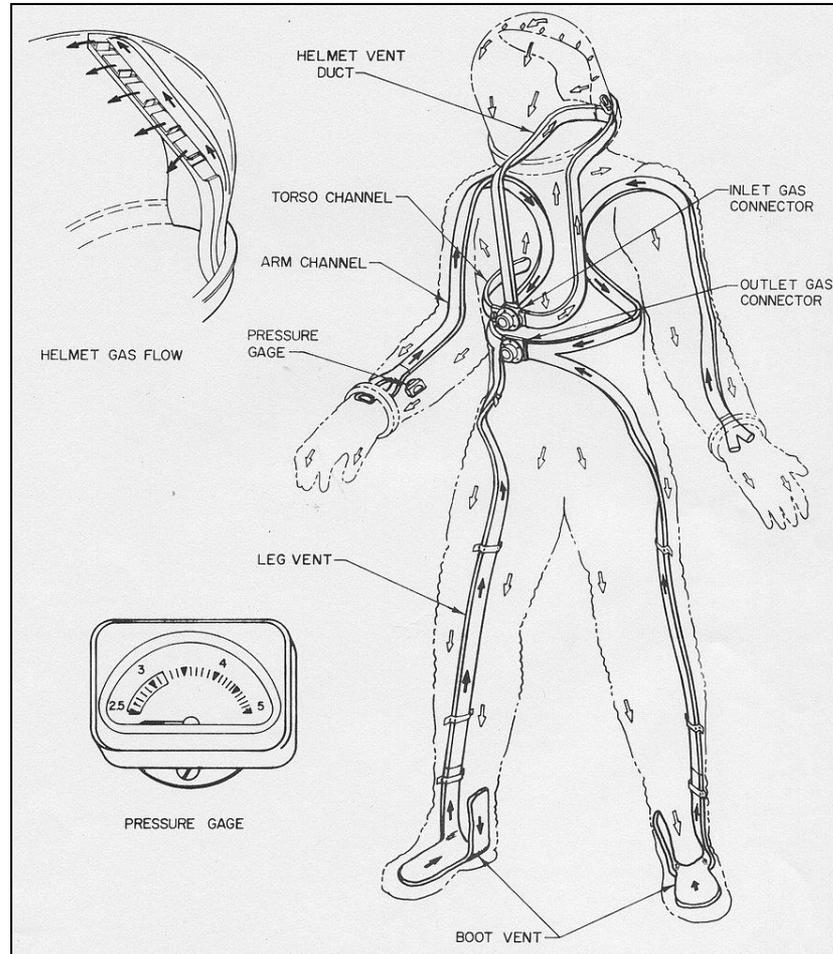
Baseline Design: Apollo 17 CMP A-7LB PGA:

- Deleted one set of ECS gas connectors.
- Redesigned internal ventilation gas routing.
- Deleted Liquid Cooling Garment (LCG) water connector.
- Deleted Portable Life Support System attachment brackets and pressure relief valve.
- Deleted Lunar Module tether brackets.
- Incorporated Skylab A-7LB EVA PGA boots.
- Added shoulders strap for under arms life vest attachment.
- Replaced extravehicular thermal-micrometeorite garment (TMG) with intravehicular Teflon Beta and PBI fabric's cover layer (IVCL).
- No Extravehicular LCG, Gloves, or Visor Assembly.

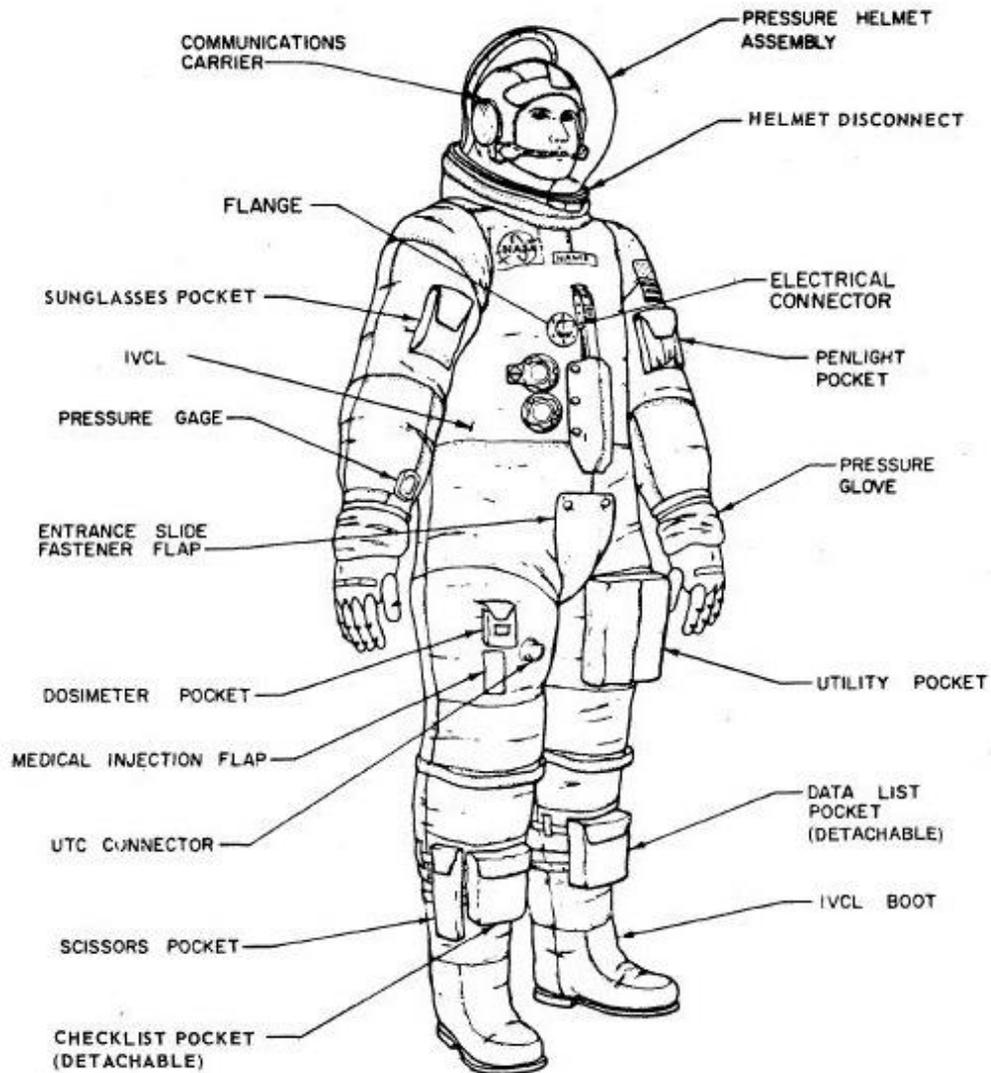


ASTP PRESSURE GARMENT ASSEMBLY

INTERNAL ECS GAS VENTILATION DUCT ROUTING



ASTP SPACESUIT



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ASTP SPACESUIT DEVELOPMENT

COMPONENTS DESIGN REQUIREMENTS

URINE COLLECTION DEVICE (UCD):

- Accommodate crewman.
- Provide in-suit storage of urine with 950 scc fluid capacity.
- Capability to transfer fluid from inside suit to CM stowage container.
- One standard size with four sizes roll-on cuffs.
- 0.5 psi maximum air pressure decay leakage after 5 minutes at 1 psi.
- 2.0 psi maximum proof pressure.
- Disposable - one mission use only.

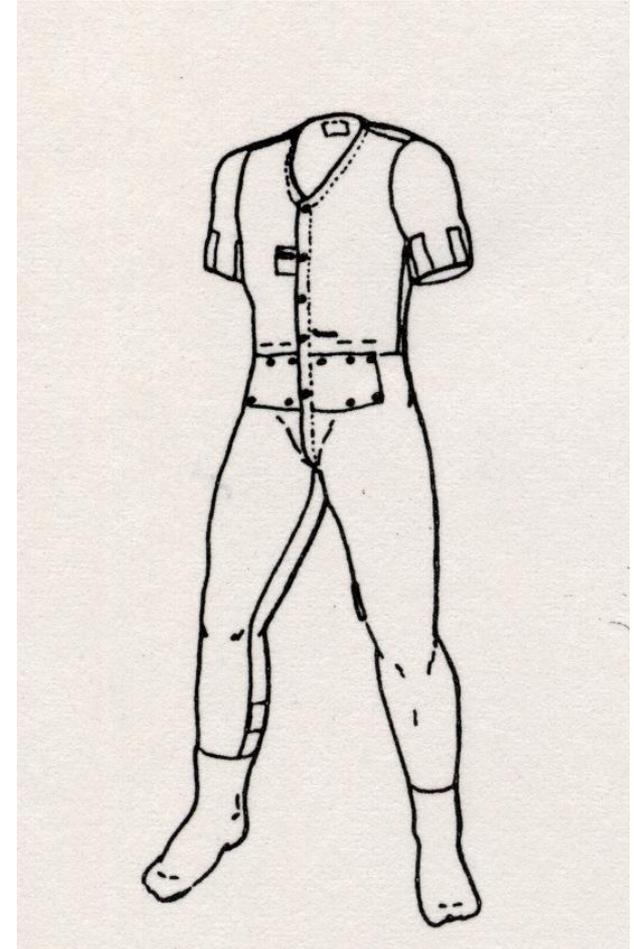


ASTP SPACESUIT DEVELOPMENT

COMPONENTS DESIGN REQUIREMENTS

CONSTANT WEAR GARMENT:

- Provide worn comfort during launch and CM-suited mission phases.
- Cotton undergarment covering over arms, torso, and legs.
- Separate donned/doffed socks.
- Pocket for radiation dosimeter.
- Attachment provision for biomedical instrumentation.



ASTP SPACESUIT DEVELOPMENT

COMPONENTS DESIGN REQUIREMENTS

GOVERNMENT-FURNISHED EQUIPMENT (GFE) COMMUNICATIONS CARRIER ASSEMBLY (CCA):

- Self-donning and doffing and attachment to PGA Electrical Harness (EEH).
- Redundant microphones and earphones.
- Six standard sizes.
- Optional use chin or neck strap.
- Connector for PGA EEH attachment.

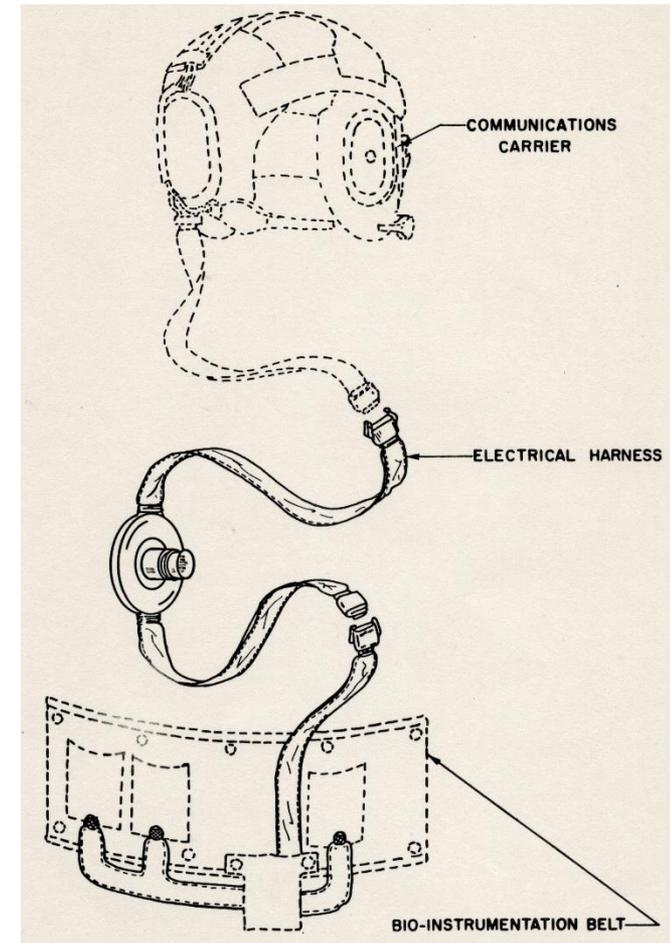


ASTP SPACESUIT DEVELOPMENT

COMPONENTS DESIGN REQUIREMENTS

ELECTRICAL HARNESS:

- 61-pin self-connect-disconnect for PGA to CM umbilical connection.
- Redundant CCA microphones and earphones wiring to 61-pin connector.
- Biomedical instrumentation wiring to 61-pin connector.
- Connectors to attach CCA and GFE biomedical instrumentation sensors.



ASTP SPACESUIT CERTIFICATION

ACCOMPLISHED BY SIMILARITY

- DESIGN LIFE ENDURANCE CYCLES:
 - Analysis showed ASTP mission required fewer cycles than testing successfully performed to certify PGA and components for Apollo 15-17 CMP missions' use.
- ENVIRONMENTS:
 - Analysis showed ASTP mission requirements were successfully met during Apollo launch, orbital operations, and landing missions.
- INTERFACES:
 - Analysis showed ASTP mission interfaces were successfully demonstrated during crew training exercises at NASA JSC and KSC, also during Apollo 15-17 CMP spacesuit certification tests and flights.

ASTP MISSION

July 1975

MISSION OBJECTIVES

- Demonstrate:
 - Compatible U.S. & Soviet rendezvous & docking systems as a standard international system.
 - Crew transfer between spacecraft.
 - Interaction of Control Centers, spacecraft, & crews.
- Conduct engineering & scientific investigations.



APOLLO CREW

Commander – Thomas P. Stafford

CM pilot – Vance D. Brand

Docking module pilot – Donald K. Slayton

SOYUZ CREW

Commander - Alexey A. Leonov

Flight Engineer - Valeriy N. Kubasov



ASTP SPACESUIT PREFLIGHT ISSUE

- During KSC manned CDDT, excessive CM ECS suit loop leakage occurred in the low pressure (vent) mode:
 - No leakage occurred in the high pressure (3.75 psi) mode.
- Excessive leakage isolated to astronaut Vance Brands spacesuit.
- Brands spacesuit was returned to NASA JSC for failure analysis:
 - Source of excessive low pressure leakage found in the crotch radius of the pressure sealing closure.
 - Leakage induced when crewman was strapped in couch position causing closure sealing lips to separate.
- Corrective action implemented was addition of vinyl tubing inserted between closure sealing lips and donning assist/restraint zipper preventing sealing lips from unseating in the couch position.
- Certification testing was conducted to verify adequacy of fix with no adverse effects to the spacesuit in both low- and high-pressurized modes.
- Vance Brand also fit-checked his suits with insert installed to verify acceptability.

SUMMARY LESSONS LEARNED

APOLLO 7-17, SKYLAB 2-3, AND ASTP MISSIONS

- **Limited flexure cycle life of PGA mobility joints restraint cables at terminal attachment cable swage fittings:**
 - Numerous cable breakage failures occurred at mobility joints termination during endurance cycle certification testing and crew training.
 - Resulted in numerous cable termination swage redesigns.
- **Recommendation:**
 - Eliminate use of load restraint cables using swage termination fittings at mobility joints for future spacesuits design.
 - Shuttle EMU Request for Proposal (RFP) specified cables and swages were to be excluded in EMU spacesuit design.

SUMMARY LESSONS LEARNED

APOLLO 7-17, SKYLAB 2-3, AND ASTP MISSIONS

- **Molded and dipped rubber components (proprietary compound) and pressure bladder (Neoprene) materials:**
 - Limited spacesuits reuse because of 4 years materials' age life.
 - Copper containment in dipping compound resulted in preflight problem requiring replacement of affected components and a dipping compound modification and recertification.
- **Recommendation:**
 - Specify longer age life requirements based on then-current materials' technology for future spacesuits development.
 - Preclude use of proprietary materials in future spacesuit designs.

SUMMARY LESSONS LEARNED

APOLLO 7-17, SKYLAB 2-3, AND ASTP MISSIONS

- **Significance of crewman-induced man-loads first identified during A-6L and A-7L PGA's manned endurance life cycle testing:**
 - Increased crewman mobility resulted in higher man loads being applied to spacesuit structure.
 - Instrumented spacesuit with load cells identified man-loads significantly greater than pressure plug loads.
 - Induced man-loads measured and requirement incorporated in A-7L and A-7LB PGA's design, and verified during endurance cycle certification testing.
- **Recommendation:**
 - Recommend load cells instrumentation and measurement of induced man-loads to establish crewman-induced man-loads requirement for design and certification for all future advanced spacesuit designs.

LESSONS LEARNED

APOLLO 7-17 AND ASTP MISSIONS

- **Excessive leakage and limited cycle life of B.F. Goodrich type spacesuit pressure sealing closure:**
 - Frequent factory required pressure sealing closure replacement necessary in training and flight spacesuits because of excessive leakage caused by nicks and cuts in sealing lips.
 - One instance of excessive spacesuit leakage at vent pressure (0.2 psi) during ASTP CDDT.
 - Vendor implemented 100% visual source inspection for NASA applications.
 - In-process manufacture upgrading not implemented because of commercial customers' cost impact.
- **Recommendation:**
 - Implement low pressure leakage interface design requirement and testing for spacecraft ECS condition when B.F. Goodrich type sealing closure is used in intravehicular and/or extravehicular spacesuits.
 - Develop new don/doff pressure sealing closure design or different don/doff method for future spacesuits.

SUMMARY LESSONS LEARNED

APOLLO 7-17, SKYLAB 2-3, AND ASTP MISSIONS

- **Self-abrasion and leakage of pressure bladder and molded rubber components during flexure:**
 - Reinforcement (orange-colored) patches added at high abrasion areas on A-7L PGA mobility convolutes to fix leakage problems.
 - Reinforcement scuff layer added to cover A-7LB EV PGA pressure bladder and mobility convolutes to prevent abrasion and wear leakage to meet increased pressurized use hours requirement.
- **Recommendation:**
 - Verify design adequacy of spacesuit pressure integrity by performing endurance life cycle testing at required suit pressure in future spacesuit development to identify high wear areas for correction.
 - Life-cycle adequacy testing needs to be successfully completed before any manned hazardous use.
 - Formula: Total Cycles = 2x Mission/Test Cycles + Contingency Cycles found acceptable for spacesuit mission certification or hazardous use testing.

SUMMARY LESSONS LEARNED

APOLLO 7-17, SKYLAB 2-3, AND ASTP MISSIONS

- **Lock-Locks are necessary at all pressure integrity connections:**
 - Accidental connector disconnects at ground level conditions during Gemini and early Apollo spacesuits crew training and testing.
 - Accidental visor opening at vacuum condition during pressure suit testing in the low vacuum chamber facility at the Aero Medical Laboratory, Wright-Patterson Air Force Base.
 - Accidental disconnection under vacuum conditions could result in loss of life.
- **Recommendation:**
 - Incorporate disconnect lock-locks at each pressure integrity connection in all future IV and EVA spacesuits.
 - Included connections are helmet to neck ring and pressure visor, gloves, ECS gas connectors, LCG internal suit water, and pressure sealing closure lock head.

SUMMARY LESSONS LEARNED

APOLLO 7-17 MISSIONS

- **Lunar Dust Particles Contamination:**

- Spacesuit disconnects and connectors found difficult to actuate on Lunar Module entry and preparation for next lunar surface EVA.
- Chest-mounted Remote Control Unit read-out lens was visually obscured by lunar dust.
- Dust contamination occurred mostly on lower spacesuit legs and boot surfaces.
- Lunar Module cabin surfaces and atmosphere breathing concerns.



- **Recommendation:**

- Develop effective dust protection method for future Lunar or other surface dust-prone missions.

SUMMARY LESSONS LEARNED

SKYLAB 2-3 MISSIONS

- **Skylab crew reported they observed body growth of ~1.5 inches, which made suit donning more difficult.**
- **Recommendation:**
 - Design of spacesuits for future programs needs to include provision for human body torso growth sizing during long duration microgravity missions.
 - Space Shuttle EMU spacesuit design provided a 1-inch waist-size change capability from ground to in-flight suit use configuration.
- **Skylab crew reported that they felt a fecal containment system (FCS) was not necessary for a 6-hour duration EVA:**
 - One commander reported he did not wear the FCS on any of the EVAs.

SUMMARY LESSONS LEARNED

APOLLO 7-17, SKYLAB 2-3 MISSIONS

- **DESIGN OF FUTURE MANNED SPACECRAFT SHOULD INCLUDE A MANDATORY ROBUST AND VERSATILE EVA CAPABILITY:**
 - Apollo CM Standup contingency EVA capability was necessary to enable the crew to visually inspect and photograph Skylab Station launch damage and attempt to deploy the damaged Orbital Workshop Solar Wing.
 - Apollo CM drogue probe removal by suited crewmen in a decompressed cabin allowed hard docking to the Skylab Station Multiple Docking Adapter. Resulted in crew capability to enter Orbital Workshop and deploy the Parasol thermal shield reducing interior temperature level to a habitable level saving the Skylab Program.
 - Orbital Workshop contingency EVA capability enabled crew to deploy the damaged Solar Wing and the Twin Pole thermal shield providing electrical power and thermal protection for the remainder of the Skylab Program.

CONTRACTS NAS 9-5332 AND NAS 9-6100 - ILC INDUSTRIES INC.

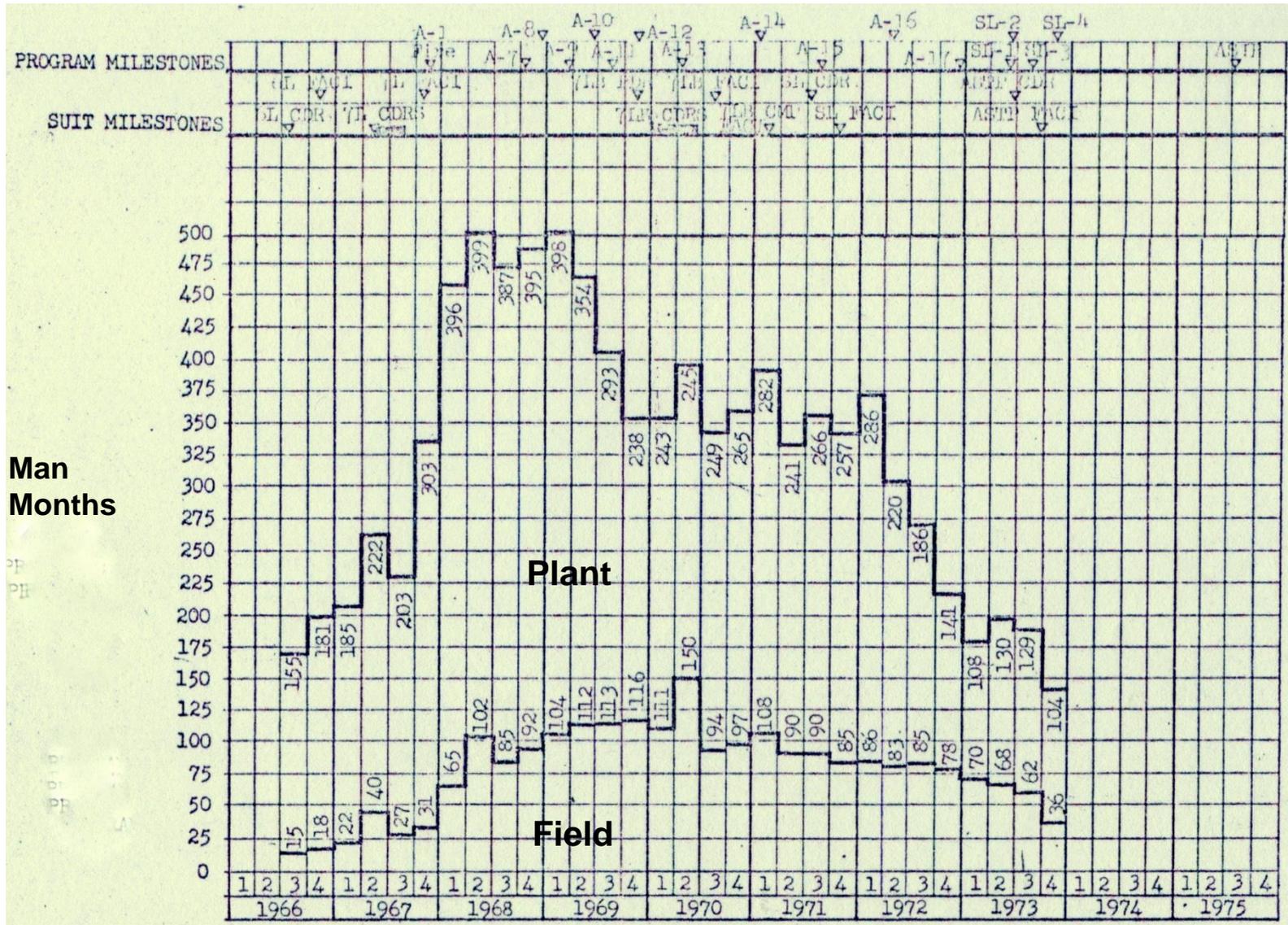
APOLLO-SKYLAB-ASTP SPACESUIT PROGRAM

TOTAL NUMBER OF SUITS DD250'd

<u>TYPE OF SUIT</u>	<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>Total</u>
A-5L (NAS-9-5332)	14								14
A-6L	8	13	4						25
A-7L		1	44	41	6	1			93
A-7LB CMP						11	3		14
A-7LB EV (300 Apollo Series)					9	18	3		30
A-7LB EV (600 Skylab Series)						11	26		37
A-7LB IV (ASTP)								9	9
Total each year	22	14	48	41	15	41	32	9	222
Cumulative	22	36	84	125	140	181	213	222	

Reference: Apollo/Skylab Suit Program
Management Systems Study Report
Contract NAS 9-6100, April 30, 1974

NAS9-6100 CONTRACT APOLLO-SKYLAB-ASTP PROGRAM



Years By Quarter - GFY 1966 to 1975

NAS 9-6100 CONTRACT APOLLO-SKYLAB-ASTP SPACESUIT PROGRAM

	FY '66	FY '67	FY '68	FY '69	FY '70	FY '71	FY '72	FY '73	FY '74	FY '75 '76 '77	TOTAL
Production	493	3,039	3,914	5,093	2,928	2,311	2,761	1,219	416	-	22,174
Development	269	1,360	1,973	1,909	2,583	1,692	934	8	6	-	10,734
Mission Support	-	-	-	601	790	1,109	1,556	1,491	695	75	6,317
Program Management	366	1,292	1,200	1,437	1,980	1,261	1,132	902	577	71	10,218
Field Support	46	259	551	1,274	1,756	1,607	1,485	1,382	493	908	9,761
Maintenance Repair & Retrofit	4	45	61	62	189	386	245	127	12	-	1,131
Spares	<u>15</u>	<u>127</u>	<u>221</u>	<u>926</u>	<u>372</u>	<u>211</u>	<u>148</u>	<u>237</u>	<u>31</u>	<u>3</u>	<u>2,291</u>
TOTAL	1,193	6,122	7,920	11,302	10,598	8,577	8,261	5,366	2,230	1,057	62,626

NAS 9-6100 CONTRACT APOLLO-SKYLAB-ASTP SPACESUIT PROGRAM

MANHOURS BY PRIMARY LABOR DIVISIONS BY PHASE (IN 000'S)

Primary Labor Divisions	Apollo 7 - 14		Apollo 15 - 17		Skylab		ASTP		Total	
	Total Manhours	% of Factory Total	Total Manhours	% of Factory Total	Total Manhours	% of Factory Total	Total Manhours	% of Factory Total	Total Manhours	% of Factory Total
Manufacturing	1082.9	54.4%	389.7	38.9%	160.0	30.9%	60.6	50.7%	1693.2	46.3%
Engineering	370.2	18.6	313.1	30.5	187.6	36.3	24.3	20.3	895.2	24.5
Program Management	319.8	16.1	223.6	21.7	76.9	14.9	20.2	16.9	640.5	17.5
Quality Assurance & Reliability	<u>217.1</u>	<u>10.9</u>	<u>101.7</u>	<u>9.9</u>	<u>92.5</u>	<u>17.9</u>	<u>14.5</u>	<u>12.1</u>	<u>425.8</u>	<u>11.7</u>
Factory Subtotal	1990.0	100.0%	1028.1	100.0%	517.0	100.0%	119.6	100.0%	3654.7	100.0%
Field Support	<u>409.2</u>		<u>519.6</u>		<u>111.0</u>		<u>67.2</u>		<u>1107.9</u>	
TOTAL	<u><u>2399.2</u></u>		<u><u>1547.7</u></u>		<u><u>628.9</u></u>		<u><u>186.8</u></u>		<u><u>4762.6</u></u>	
No. of Suits	115		40		37		9		201	

Excludes 14 A-5L and 8 A-6L Development Model PGAs

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U.S. SPACESUIT KNOWLEDGE CAPTURE SESSIONS

COMPLETED:

- “Apollo A-7LB EV Spacesuit Modifications and Development for the Skylab Program,” April 2015.
- “Apollo A-7LB Spacesuit Development for Apollo 15-17 Missions,” February 2015.
- “Apollo A-7L Spacesuit Development for Apollo 7-14 Missions,” January 2015.
- “Apollo Block I Spacesuit Development and Apollo Block II Spacesuit Competition,” January 2013.
- “Spacesuit Development and Qualification for Project Gemini,” December 2012.
- “Spacesuit Development and Qualification for Project Mercury,” November 2012.

ASTP REFERENCES

- Trip Report, Review of ASTP Suit Program Cost and Technical Proposal, July 1973.
- NASA Press Conference on ASTP, April 11, 1975.
- ASTP Information for Press, and ASTP Press Kit, 1975.
- NASA JSC Engineering and Development Weekly Activity Report, July 6-12, 1975, page 3.

APOLLO-SKYLAB-ASTP SIGNIFICANT REFERENCES SUMMARY

- NASA Developmental Study of Apollo Helmet Assembly, CSD-65-13, July 16, 1965.
- Extravehicular Mobility Unit Master End Item Specification for Apollo Block II Missions, CSD-A-096, January 31, 1966.
- Study of the Apollo Spacesuit Electrical Fire Hazard, CSD-A-518, January 8, 1968.
- Carbon Dioxide Build-up Characteristics in Spacesuits, Aerospace Medicine, Vol. 40, No. 8, August 1968.
- Test Report, Apollo Suit Cover-layer Candidates, CSD-A-928, May 5, 1969.

APOLLO-SKYLAB-ASTP SIGNIFICANT REFERENCES SUMMARY

- Summary Test Report, Manned Thermal-Vacuum Qual Test, Apollo J Missions, CSD-A-1157, conducted during 1971.
- Final Report, Environmental Qualification of the A-7LB Pressure Garment Assembly, CSD-A-1197, February 14, 1972.
- Skylab Operations Handbook, EMU, Volume 1 System Description,” CSD-S-043- (1), Revision A, April 1973.
- Summary Report, Skylab EMU Engineering Evaluation, CSD-S-126, Aug.16, 1973.
- Skylab 4 Mission Report and Total Skylab Summary, April 16, 1974.
- Apollo/Skylab Suit Program, Management Systems Study, NAS 9-6100, April 1974.
- Apollo Program Summary Report, Lyndon B. Johnson Space Center, Houston, Texas, April 1975.
- NASA Technical Note D-8093, Apollo Experience Report – Development of the Extravehicular Mobility Unit, November 1975.
- Living and Working In Space, A History of Skylab, NASA SP-4208, 1983.
- Author’s personal knowledge and records, 1965 - 2015.