SPACESUIT KNOWLEDGE CAPTURE SESSIONS

Development of the Spacesuit for the Skylab SL-2 through SL-4 Missions and Suited Missions Experience

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Retired NASA JSC
March 25, 2015

SPACESUIT KNOWLEDGE CAPTURE SESSIONS

Today

- **"Development of the Spacesuit for the Skylab SL-2 through SL-4 Missions and Suited Missions Experience."**

Completed

- "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.

TODAY'S AGENDA

- **Background**
  - Skylab Program Baseline

- **Requirements**
  - Spacesuit Interface Definition Study

- **Apollo A-7LB Extravehicular (EV) Spacesuit Modifications**
  - Design Configuration
  - Verification Testing

- **Skylab 1 through 4 Missions**
  - Skylab Emergency
  - Suited Experience

- **Lessons Learned**

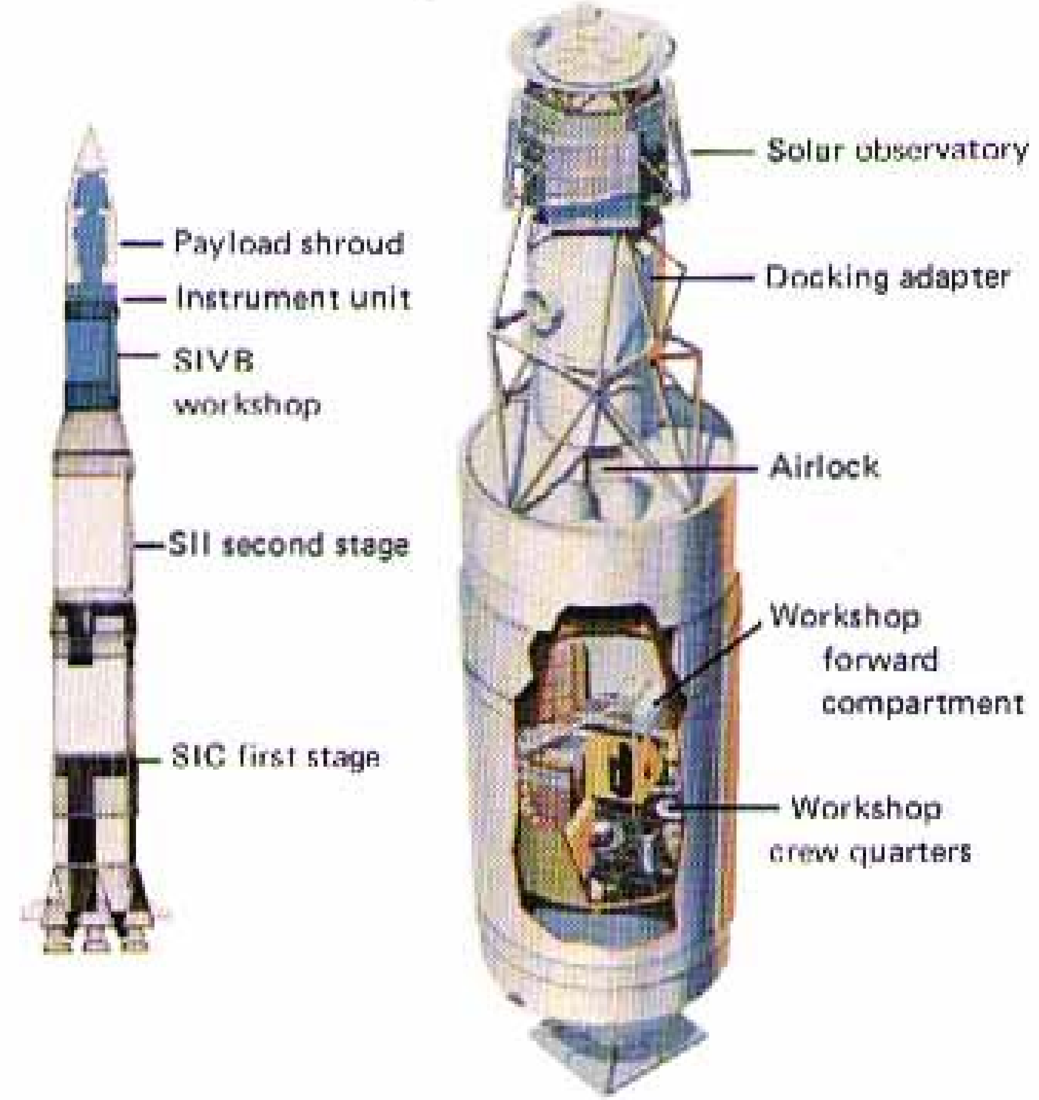
- **References**

SKYLAB PROGRAM BASELINE

- Program provided one unmanned (SL-1) and three manned (SL-2 through SL-4) launches.

- SL-1 Unmanned Launch Configuration
  - Skylab cluster encased in an aerodynamic shroud launched on a two-stage Saturn V launch vehicle.

- SL-1 Earth Orbit Operations
  - Solar observatory rotated to face the Sun.
  - Orbital workshop solar array extended after shroud jettisoned.
  - Micrometeoroid shield fitted snugly around the orbital workshop is extended outward.
  - Shield to provide workshop protection from micrometeoroids and the sun to keep inside temperatures to a habitable level.



Ready for launch, Skylab was encased in a massive aerodynamic shroud, mounted as the upper portion of the launch vehicle.

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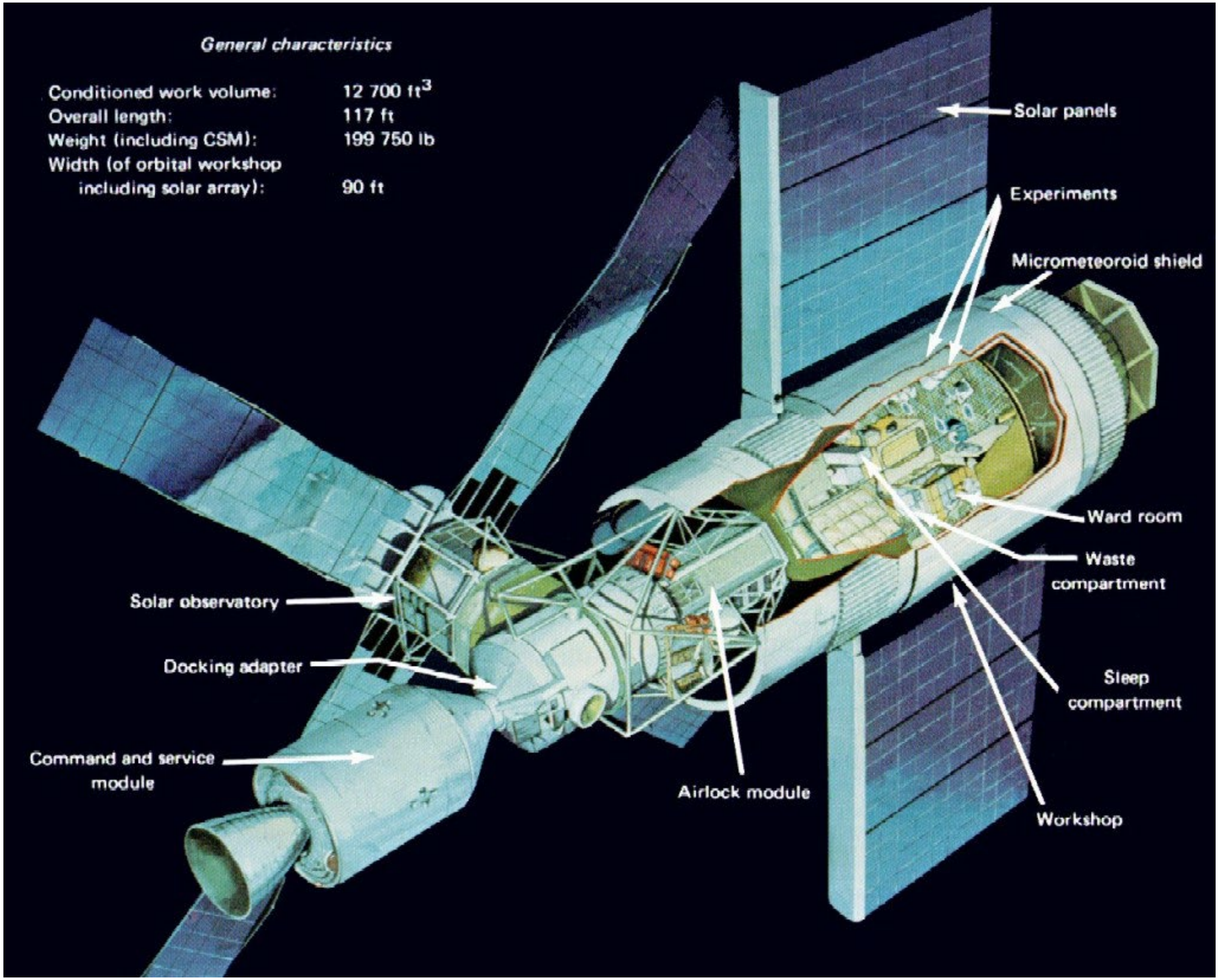
PLANNED SKYLAB SPACE STATION CONFIGURATION



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SKYLAB PROGRAM BACKGROUND

- SL-2 through SL-4 Manned Launches
  - Each Apollo Command and Service Module (CSM) launch transported three crewmen to the Skylab Multiple Docking Module (MDM).
  - Crewmen entered Orbital Workshop (OWS) from the MDM through the Airlock Module (AM).
  - Enabled scientific investigations in the OWS for up to a 120 days.

- No extravehicular activity (EVA) planned from the Apollo Command Module (CM).

- EVA planned only from the AM for film replacement and pinning open Solar Telescope aperture doors.

PLANNED SKYLAB SL-2 MISSSION

- 24 hours after SL-1 launch, an Apollo CSM with crew of three astronauts would be launched to the Station by a Saturn IB.
  - Crew would dock with Station and enter and activate systems for a 28-day manned mission.
  - During a 28-day period, crewmen would conduct experiments and evaluate habitability of the Station and their capability to live and work for long periods in the space environment.

- SL-2 mission crew would prepare the Station for unmanned operation upon mission conclusion, transfer to the CSM, and return to Earth.

PLANNED SKYLAB SL-3 MISSION

- 60 days following return of the SL-2 crew, a second crew of three astronauts would launch to, rendezvous, and dock with the orbiting Station.
- Crew would perform extensive work in solar astronomy and Earth resources observations during a 56-day mission.
- Upon mission conclusion, the crew would prepare the station for unmanned operation, transfer to the CSM, and return to Earth.

PLANNED SKYLAB SL-4 MISSION

- 30 days following the return of the SL-3 crew, the third manned mission would be launched to the Station.
- Additional scientific experiments were to be performed, and additional data would be obtained on the crew's adaptability and performance in the orbital environment.
- Upon conclusion of the SI-4 mission, the crew would prepare the Station for unmanned operation, transfer to the CSM, and return to Earth.

SPACESUIT INTERFACE DEFINITION STUDY

- NASA JSC Crew Systems Division initiated study to identify Skylab system to spacesuit interface requirements in 1969.
- Study was conducted by ILC Industries under NASA JSC Contract NAS 9-6100.
- System interfaces included in study:
  - Skylab Station developed under NASA Marshall Space Flight Center (MSFC) contract with McDonnell Aircraft Corporation.
  - Government Furnished Equipment (GFE) Astronaut Life Support Assembly (ALSA) developed under NASA JSC contract with Air Research Corporation.

IDENTIFIED INTERFACE REQUIREMENTS

- Apollo CM
  – Interfaces same as for Apollo 7 through 17 missions.

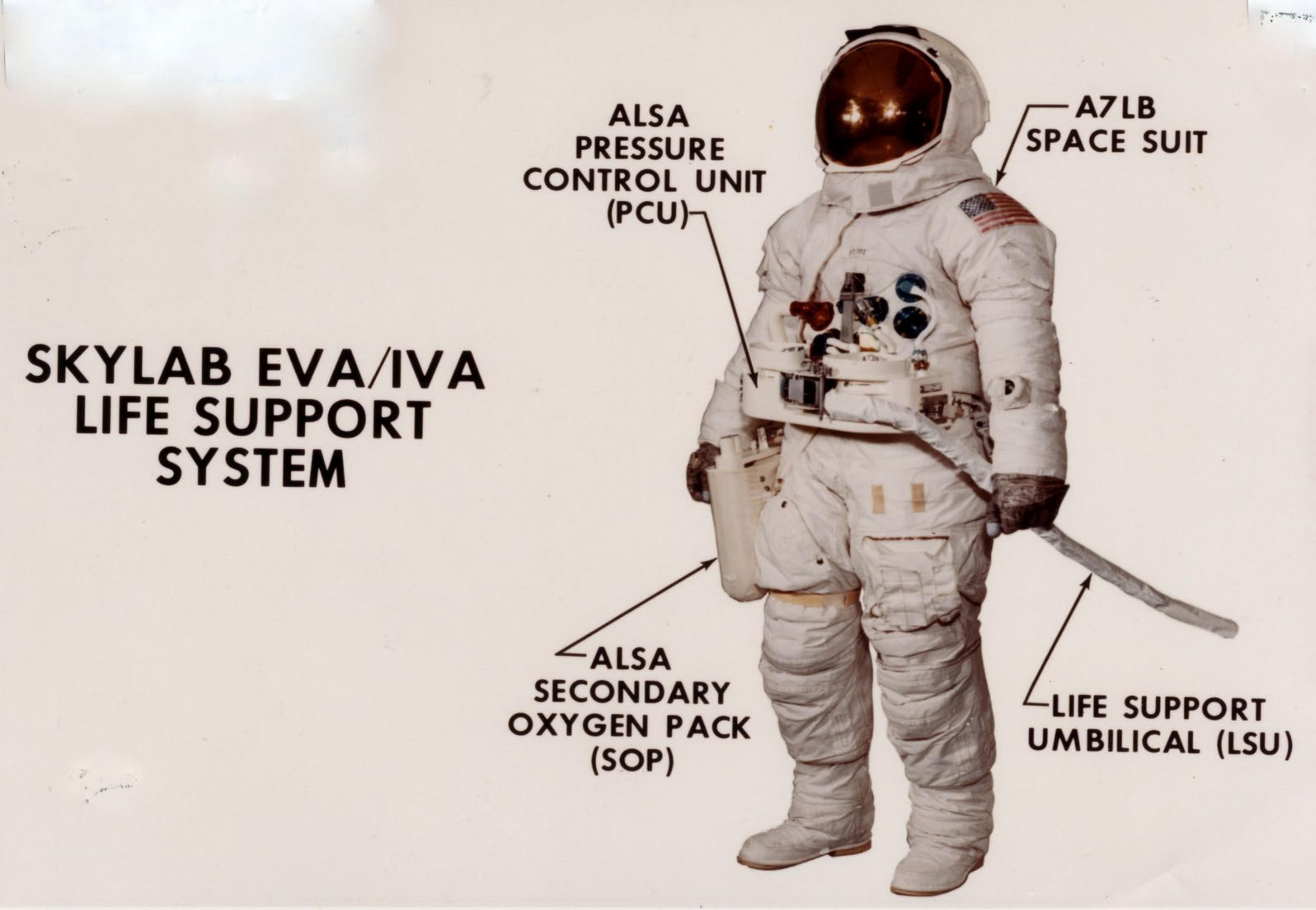
- Orbital Space Station and Workshop
  - Provide crewmen intravehicular transfer into/from the combination Station Multiple Docking Module (MDM) and AM, and the Apollo CM.
  - Provide crewmen EVA from the AM.
  - Provide OWS spacesuit equipment post use drying and stowage.
  - Provide ground communication and instrumentation with CM, OWS, and ALSA.
  - Provide crewmen vacuum transfer between the AM and ALSA without loss of suit pressure.
  - Provide crewman restraint in OWS and AM EVA foot restraints.

IDENTIFIED INTERFACE REQUIREMENTS

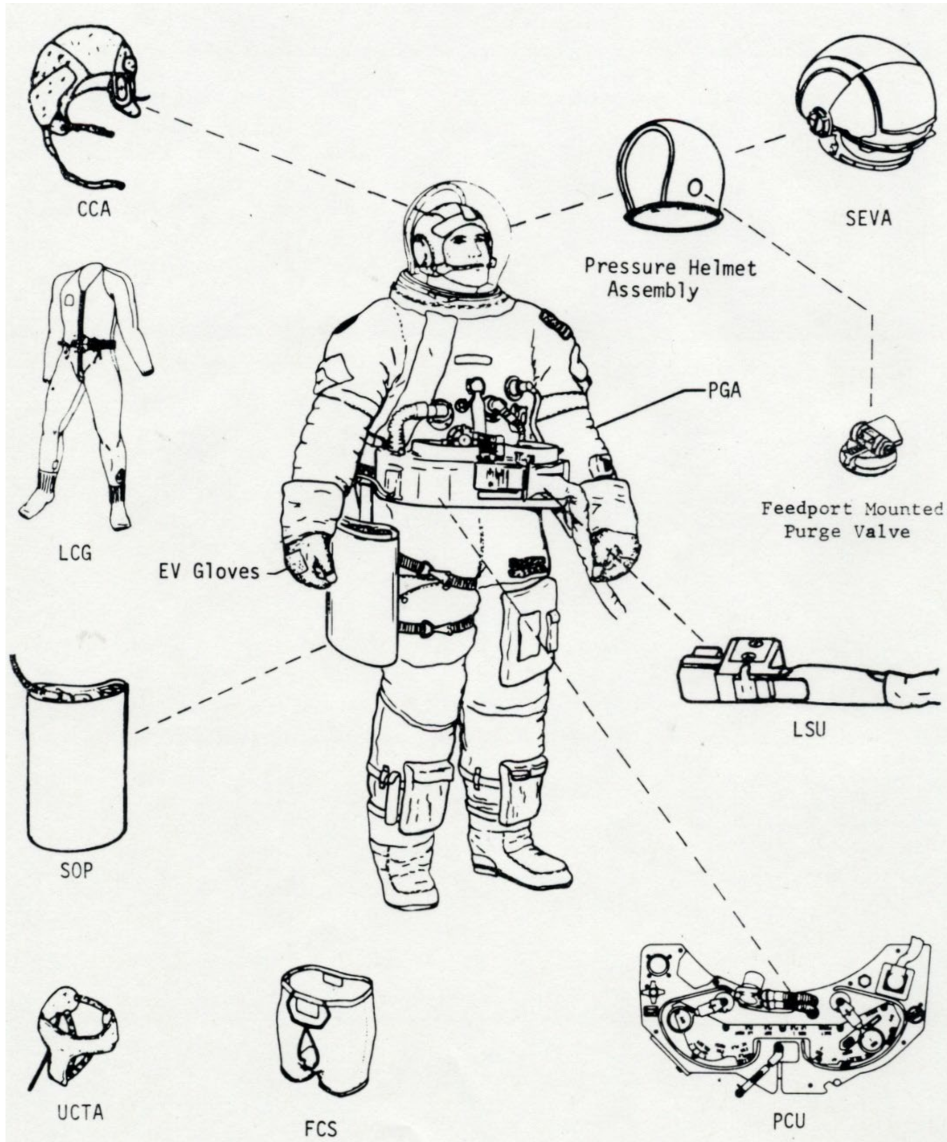
- ALSA
  - Self donning and doffing with attachment provision for the chest-mounted Pressure Control Unit (PCU).
  - Attachment of PCU ventilation inlet and outlet oxygen, Liquid Cooling Garment (LCG) water, and electrical communication and biomedical instrumentation connectors.
  - Self donning and doffing and attachment of a leg-mounted Secondary Oxygen Pack (SOP).
  - Self donning and doffing, and self connect-disconnect-reconnect for all spacesuit connectors (gas, water, urine, and electrical) and an oxygen purge valve.

IDENTIFIED INTERFACE REQUIREMENTS

- Spacesuit
  - Latest in-production and flight certified configuration A-7LB EV Pressure Garment Assembly (PGA) and components recommended as baseline spacesuit configuration.
  - Provide adequate crewman mobility and visibility for self-operation of necessary CM, AM, and ALSA controls.
  - Provide vacuum transfer capability between the spacesuit and CM Environmental Control System (ECS).
  - In-suit urine transfer to OWS waste storage.
  - Spacesuit drying and stowage in the OWS.


SKYLAB EVA/IVA LIFE SUPPORT SYSTEM
ALSA PRESSURE CONTROL UNIT (PCU)
A7LB SPACE SUIT
ALSA SECONDARY OXYGEN PACK (SOP)
LIFE SUPPORT UMBILICAL (LSU)

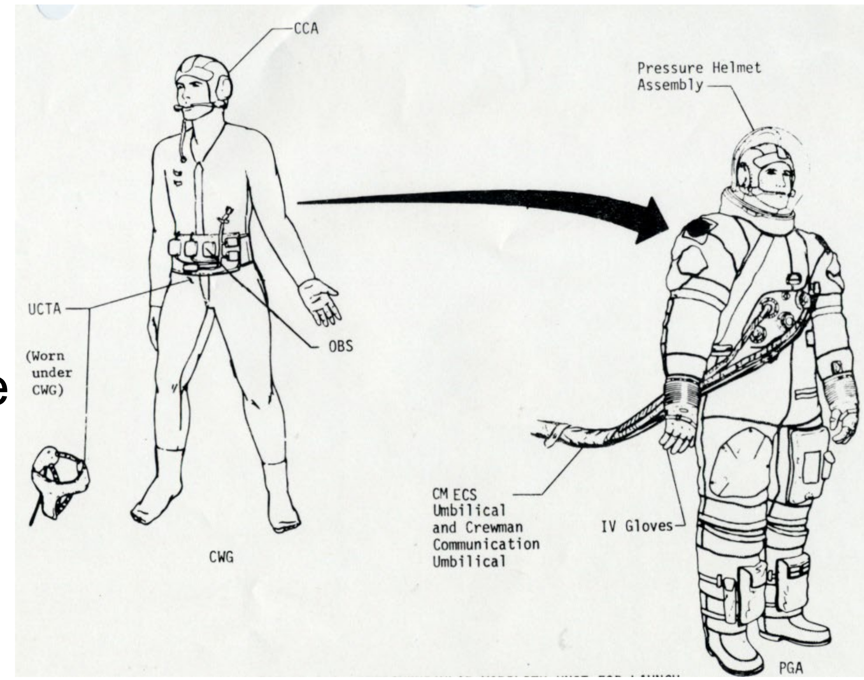
SKYLAB EVA SPACESUIT AND ALSA



ADDED SKYLAB MISSION REQUIREMENTS

Apollo Command Module

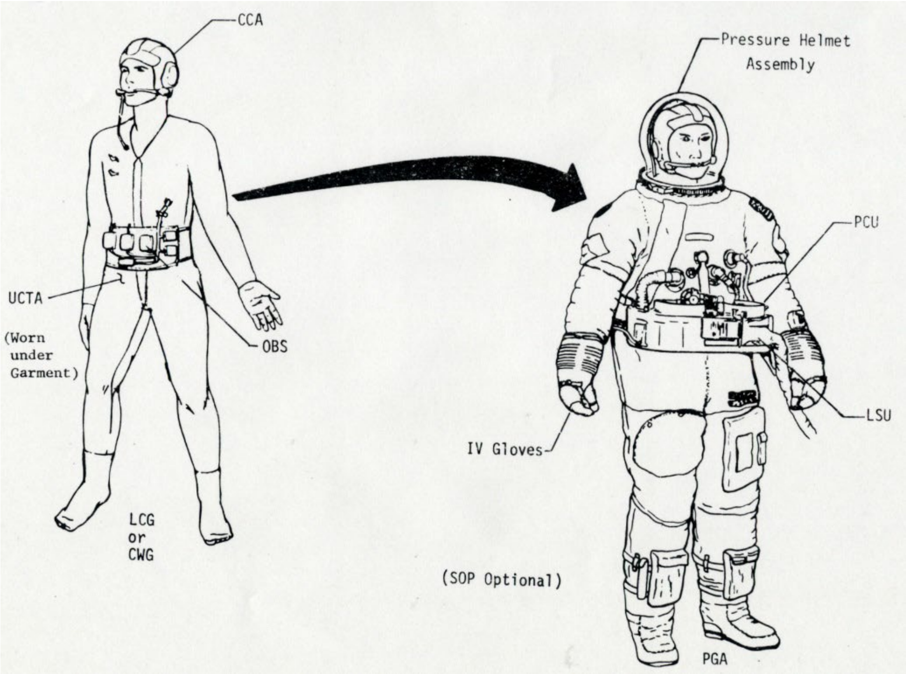
- Provide CM post-docking intravehicular activity (IVA) transfer to an unpressurized Skylab AM with CM umbilical and the spacesuit at 3.75 psi.
- Support 18 hours of decompressed CM EVA contingency operations.



ADDED SKYLAB MISSION REQUIREMENTS

Skylab Orbital Workshop

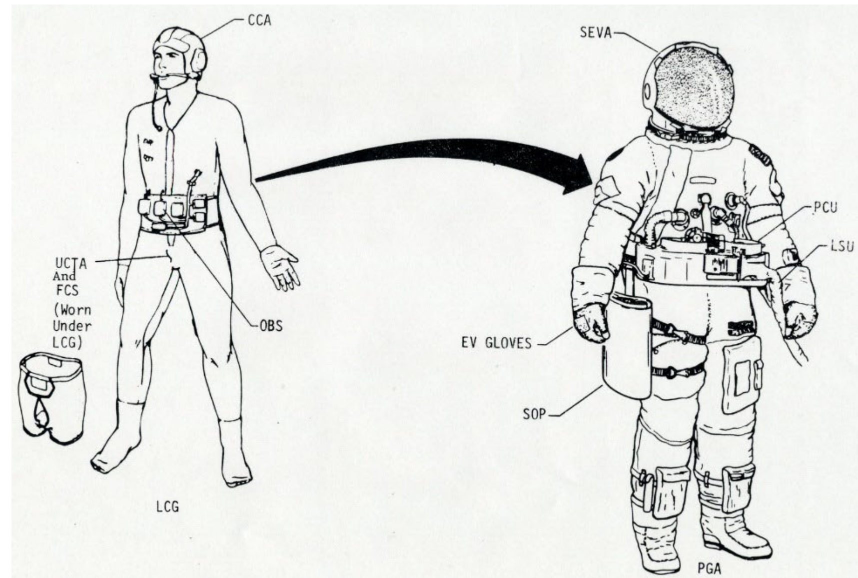
- IVA Support
  * 4 hours with spacesuit at 3.75 psi and ALSA PCU for manual OWS pressurization.
  * 4 hours with spacesuit at 0.2 psi and 3.75 psi with PCU in pressurized OWS for Manned Maneuvering Unit (MMU) and TO20-Foot Controlled Maneuvering Unit experiments.



ADDED SKYLAB MISSION REQUIREMENTS

Skylab Orbital Workshop
- EVA Support with ALSA.
  * Perform Apollo Telescope Mount (ATM) film retrieval and replacement.
  * 12 hours of EVA.
  * 30-minute contingency return time to AM pressurization.

- OWS drying and stowage of spacesuit for up to 56 days.



CHANGED ILC CONTRACT DELIVERY REQUIREMENTS

- Conduct manned design verification test (DVT) and Life Cycle Certification testing of A-7LB EV spacesuit configuration changes.
- Support manned ALSA interface and certification testing, and crewman training at vacuum and thermal/vacuum at NASA MSC.
- Support manned CM vacuum and OWS interface tests at NASA Kennedy Space Center (KSC).
- Support launch at NASA KSC and NASA MSC in-flight mission analysis.

CHANGED APOLLO ENVIRONMENTAL REQUIREMENTS

- Lunar Surface Environment
  - Requirements deleted

- Earth Orbital Environment
  - Thermal vacuum and micrometeorite exposure
  - Solar light and space darkness visibility

ADDED OR CHANGED APOLLO DESIGN REQUIREMENTS

- PGA
  - Helmet-mounted integral oxygen purge valve and feed port for emergency CO2 control and in-suit nourishment.
  - Integrated covering over torso limb suit assembly (TLSA) to provide flammability and Earth orbital thermal/micrometeoroid protection.
  - Interface provision for boots attachment to OWS foot restraints.
  - Lanyard added to pressure sealing closure to aid self donning.
  - ALSA PCU attachment bracket replaced upper Apollo Portable Life Support System (PLSS) bracket.
  - Lower Apollo PLSS attachment bracket deleted.
  - Arm wrist tether attachment added.

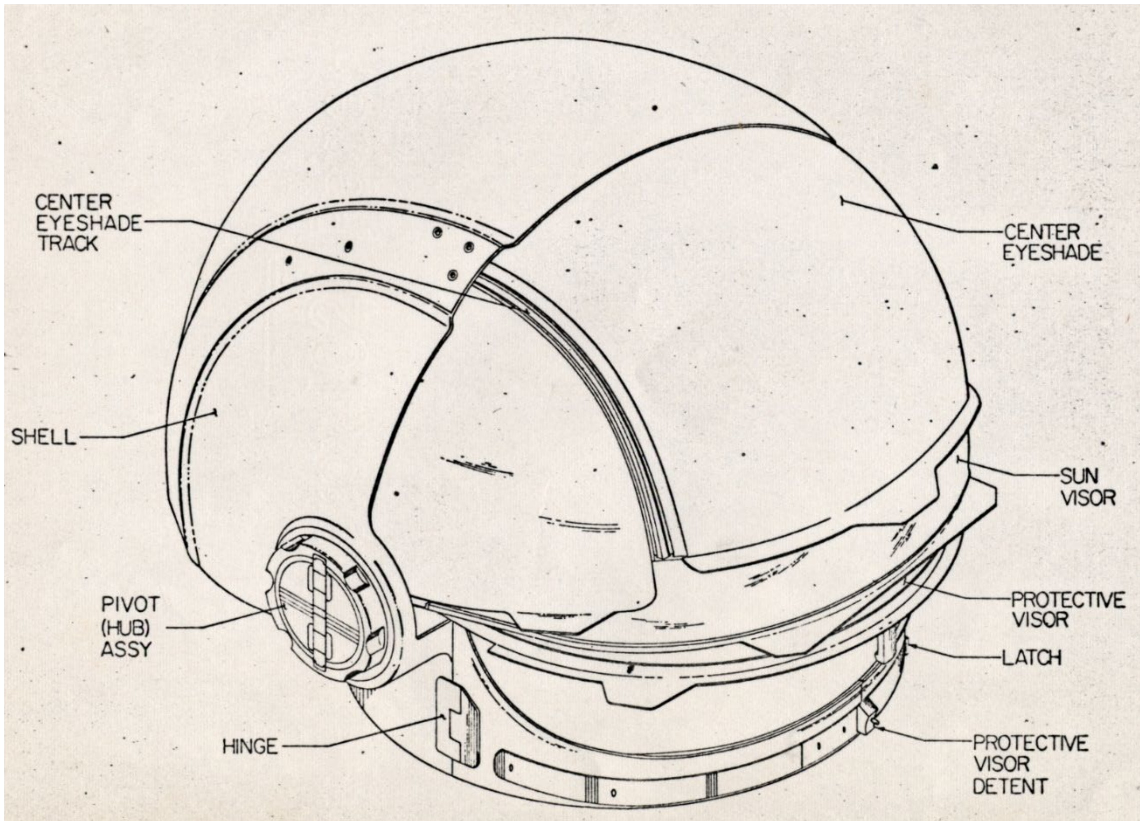
ADDED OR CHANGED APOLLO DESIGN REQUIREMENTS

- LCG
  - Provide water cooling during suited OWS IVA/EVA from ALSA PCU and OWS umbilical.
  - Tubing compatibility for OWS water recharge.
  - OWS drying and 56 days stowage.

- Extravehicular Visor Assembly
  - Less severe Earth orbital thermal environment requirement allowing redesign to reduce cost by elimination of the thermal collar and replacement of the Polysonfone sun visor material with Polycarbonate.
  - Capability to replace visors in-flight.
  - Apollo 11-17 Lunar Extravehicular Visor Assembly (LEVA) redesign name change to Skylab Extravehicular Visor Assembly (SEVA).

SKYLAB A-7LB EV SPACESUIT DEVELOPMENT

Extravehicular Visor Assembly



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APOLLO DESIGN REQUIREMENTS

Spacesuit Components not Changed

- Constant Wear Garment (CWG)
- GFE Communications Carrier Assembly (CCA)
- Electrical Harness (EEH)
- Waste Collection System (WCS)

3 YEAR

SCHEDULE RESPONSIBILITY James W. McBarron

STATUS RESPONSIBILITY R. L. Jarboe

MANNED SPACE FLIGHT SCHEDULE

SKYLAB A7LB SPACE SUIT

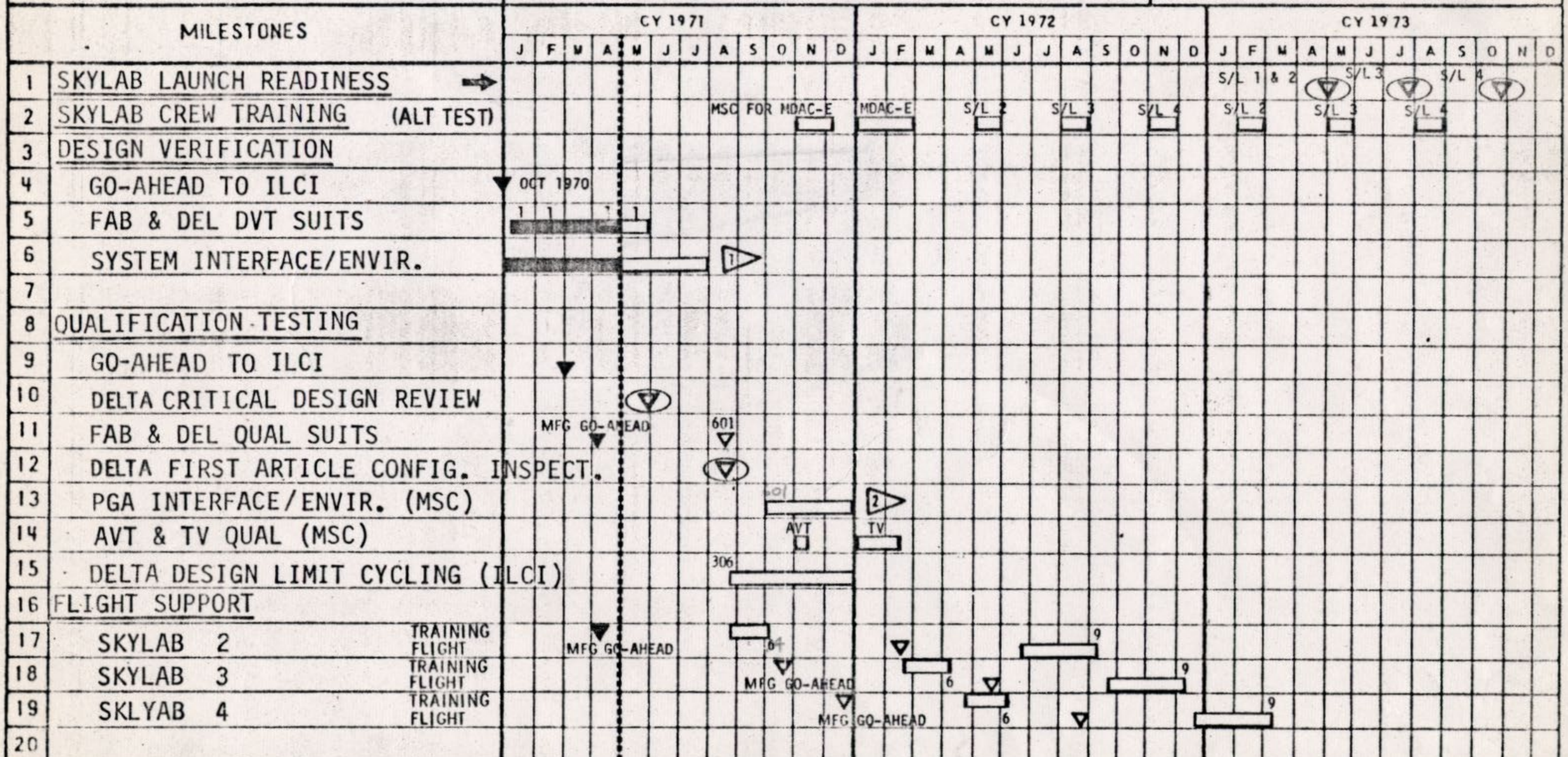
PROGRAM PLAN

3 LEVEL

ORIGINAL SCHEDULE APPROVAL 4-22-71 (DATE)

LAST SCHEDULE CHANGE 4-27-71 (DATE) (NO.) (INITIALS)

STATUS AS OF 5-1-71 (DATE) (INITIALS)



NOTES

1 DVT SYSTEM INTERFACE ARE ACCOMPLISHED ON A CONTINUOUS BASIS.

2 QUAL INTERFACE TESTING IS ACCOMPLISHED ON A CONTINUOUS BASIS.

MSC FORM 985D (JAN 68)

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SKYLAB A-7LB EV SPACESUIT

3-LAYER Integrated Thermal Micrometeoroid Garment

Design Verification Tests

December 1970

- Conducted in three parts:
  - First part a new instrumented Integrated Thermal Micrometeoroid Garment (ITMG) exposed to thermal vacuum; second part manned PGA/ITMG life cycle testing; third part repeat of the first part.
  - Comparison of first and third parts established ITMG thermal performance design adequacy.
- Quantity of PGA life cycles based on Apollo 16 preflight and nominal Lunar mission model, except for use of the Lunar Rover.

PGA COMPONENT	DESIGN LIMIT	NOMINAL
Shoulder	4,114	29,827
Arm bearing Rotation	18,200	42,472
Elbow	9,100	21,236
Torso Trunk	1,173	2,728
Hip	5,917	7,470
Knee	1,309	N/A
Steps	125,770	N/A

SKYLAB SPACESUIT and LIFE SUPPORT SYSTEM
Design Verification Tests
April 2–10, 1973

- Unmanned and manned tests performed in Crew Systems Division 11-foot chamber. All test objectives were successfully accomplished.

Evaluate simulated EVA O_2 system performance with severed O_2 umbilical.

Evaluate PGA pressure oscillations when the PCU is switched between PCU regulators at vacuum conditions.

Obtain normal and contingency performance data on the EMU suit cooling system when interfaced with a partially simulated vehicle coolant system.

Obtain performance data on the EMU when interfaced with a simulated vehicle oxygen system.

Obtain performance data for use in the integrated EMU thermal model.

Perform a verification test of the helmet feedport mounted purge valve.

A7LB EV SUIT EXPERIENCE
(AS OF 6/30/72)

	APOLLO		SKYLAB
DVT INTERFACE TESTING	186.16		115.33
DVT CYCLE TESTING	176.99		NONE
QUALIFICATION CYCLE TESTING	645.11		6.16
GROUND LEVEL CREW TRAINING	1,053.55		115.35
ALTITUDE TRAINING	583.86		109.02
MISSION USE - APOLLO 15	105.65		N/A
APOLLO 16	99.00		N/A
TOTAL	2,850.32	TOTAL	345.86

SL-1

May 14, 1973

Unmanned Launch Problems

- 63 seconds after launch ground instrumentation indicated premature deployment (loss) of the OWS micrometeoroid shield.
  - Mission Control observed abnormal micrometeoroid shield temperatures.

- Shield served as part of workshop heat shield protection system.
  - Loss resulted in **e**<u>xternal</u> workshop temperature ~200°F higher than design condition.

- One of two OWS solar wings also torn away with the micrometeorite shield, and the second OWS solar wing did not fully deploy.
  - Loss of both solar wings resulted in all electrical power being provided by the Solar Observatory Array.

SL-1

May 14, 1973

Unmanned Launch Problems

- Observatory solar array produced full power only when perpendicular to the Sun's rays.
  - This orientation not possible because of need to turn the workshop away from the sun to minimize internal OWS heating.

- Ground controllers placed orbiting workshop into a position ~45 degrees from the Sun's rays.
  - Resulted in substantial decrease in solar power production and a less rapid increase in workshop temperatures.
  - OWS internal temperature stabilized at intolerable ~126 degrees F.

- Problem became one of protecting Skylab while determining what should be done to save it.

SL-2

Manned Launch Delayed

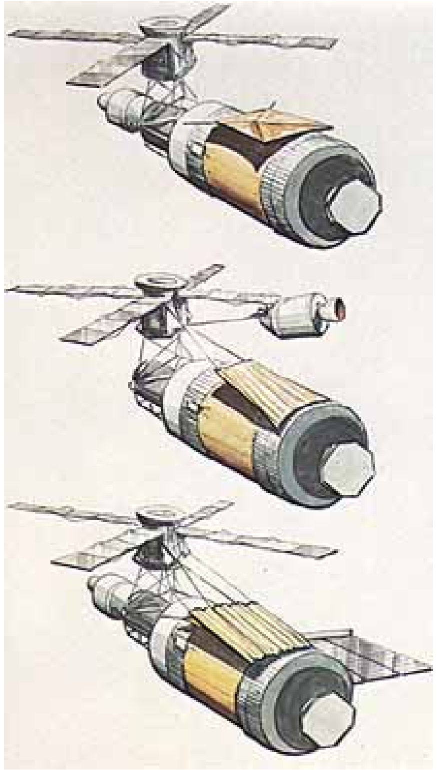
- SL-2 launch originally scheduled for next day after SL-1 launch was postponed for 10 days.
  - Allowed time for problem analysis and to establish a means for corrective action.

- Teams at NASA Johnson Space Center (JSC) and NASA MSFC (and contractors) were established to identify and implement corrective actions for SL-1 launch problems.

10 DAYS SAVING SKYLAB

Reflections by a Participant

- Teams brainstorming sessions conducted to establish concepts to provide OWS exterior thermal protection. Favored concepts:
  - IVA thermal shield deployment from OWS interior using the scientific airlock.
  - Standup EVA from CM deploying thermal sail while flying around OWS.
  - EVA from AM deploying a thermal sail.



SAVING SKYLAB

Reflections by a Participant

- Candidate thermal shield material identified by materials personnel.
  - Made a late evening telephone call to the manufacturer of Nylon coated Aluminized Mylar material.
  - Resulted in supplier opening plant and overnight production of required material ready for delivery the next morning.

- Skilled sewers and sewing machines needed by NASA MSFC for thermal shield fabrication.
  - Made late evening telephone call to ILC Spacesuit Program manager resulting in availability and readiness of sewers and machines to travel the next morning.

SAVING SKYLAB

Reflections by a Participant

- NASA Gulfstream Aircraft made stops the next morning at the fabric manufacturer in Minnesota, to pick up fabric, and then at Dover Air Force Base, Delaware to pick up ILC sewers and sewing machines.
  - Thermal material and ILC personnel and machines were delivered to NASA MSFC and a sewing shop capability was established to manufacture MSFC thermal sails.

- That afternoon the Gulfstream delivered thermal material to Ellington Air Force Base where it was picked up and delivered to MSC to support Parasol Thermal Canopy Manufacture.

SAVING SKYLAB

Reflections by a Participant

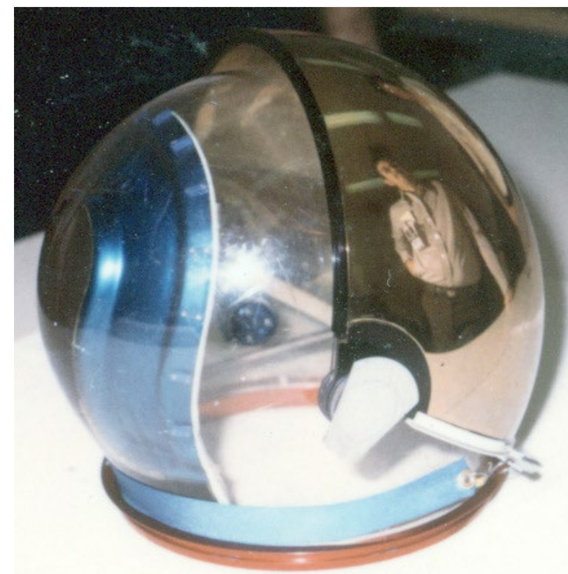
- Parasol Canopy Fabrication area set up in Bldg. 29 Rotunda.
  - Tables were moved from Bldg. 7 offices to Bldg. 29 to provide large workspace.
  - Suit engineer led canopy fabrication on top of tables workspace.
  - He provided directions to sewing technicians and assembly personnel located around tables periphery while at the time standing on the tables.
  - He expedited assembly of large surface canopies in support of JSC Technical Services Bldg.10 parasol deployment tests, and later for flight.

SAVING SKYLAB

Reflections by a Participant

- Another suit engineer obtained and upgraded Class III WETF helmet shields to flight status.

- Suit engineer also modified a SEVA by removing inflight sun visor assembly and adding an elastic strap.
  - Modified in-flight visors provided direct attachment over the helmet providing crewman solar protection during a standup EVA.



SL-2

May 24, 1973

CREW

Charles Conrad, Jr., commander (CDR)
Paul J. Weitz , pilot (PLT)
Joseph P. Kerwin, scientist pilot (SP)

MISSION EXPERIENCE

DAY ONE

- Before docking, CM fly-around confirmed OWS shield and one array missing, one array damaged.
- PLT standup EVA conducted to deploy damaged solar wing with 15-foot pole was unsuccessful.
  - Helmet shield protected helmets visibility while setting up for the standup EVA.
  - Modified Sun Visor successfully used by CDR during the EVA attempt.

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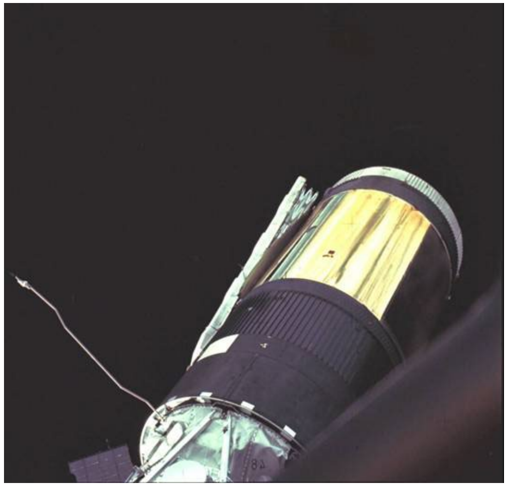
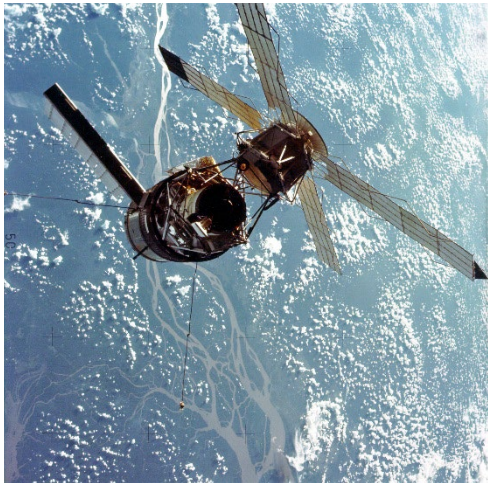
SL-2

May 24–June 22, 1973





MISSION EXPERIENCE

DAY 2

- Depressurized CM Intravehicular activity to remove docking probe and conduct hard dock to Multiple Docking Adapter (MDA) successful on 5th attempt.
- Crew entered OWS and tested air quality.
- Parasol thermal shield was immediately deployed out of scientific airlock.
- Temperature inside OWS dropped to comfortable level.

DAY 14

- CDR and SP conducted EVA from AM and successfully removed debris and fully extended the jammed main solar wing restoring electrical power to OWS.

SL-2

May 24–June 22, 1973

MISSION EXPERIENCE

DAY 26

- CDR and SP performed EVA to retrieve and replace film from solar telescopes and repaired a circuit breaker module, and maintenance on experiment packages.

DAY 28

- Crew entered CSM for return to Earth. PGAs worn until undocking completed, then donned hypertensive garments for reentry and splashdown.
- Crew established new manned spaceflight endurance record.

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SL-3

July 28–September 25, 1973

CREW

Alan L. Bean, CDR
Jack R. Lousma, PT
Owen K. Garriott, SP

MISSION EXPERIENCE

DAY 10

- PT and SP conducted an EVA to extend an external twin-pole thermal shield over the Parasol deployed during the SL-2 mission.
- Also they retrieved and replaced film from the space telescopes and installed experiments.

SL-3

July 28–September 25, 1973

MISSION EXPERIENCE

DAY 21

- CDR conducted shirtsleeve IVA to evaluate M509 Astronaut Maneuvering Unit experiment.

DAY 28

- CDR and SP conducted an EVA to retrieve and replaced film on space telescopes, install rate gyro cable and solar sail samples, replace S-149 experiment, and inspect aperture door ramps.

DAY 48

- CDR conducted shirtsleeve IVA to evaluate T020 controlled Maneuvering Unit.

DAY 57

- CDR and SP conducted EVA to retrieve and replace solar telescope film, clean SO52 camera lens, retrieve DO24 experiment S230 collector, sail sample, and S149 experiment.

SL-4

November 16, 1973–February 3, 1974

CREW

Gerald P. Carr, CDR
William R. Pogue, PT
Edward G. Gibson, SP

MISSION EXPERIENCE

DAY 7

- PT and SP conducted EVA to deploy twin pole sail sample, take photos of Earth's atmosphere, installed ATM film and experiments, and repaired S193 antenna.

DAY 40

- CDR and PT conducted EVA to retrieve and replace ATM film, operate experiments, and photograph comet Kohoutek.

SL-4

November 16. 1973–February 3, 1974

MISSION EXPERIENCE

DAY 44

- CDR and SP conducted EVA retrieved thermal sail samples and AM meteoroid cover sample, operated experiments and photographed come Kohoutek.

DAY 63

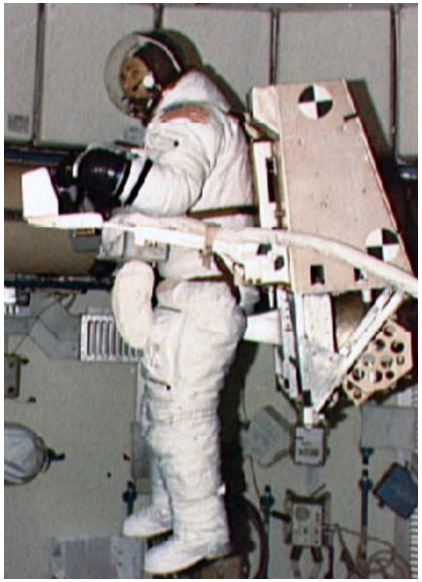
- First suited M509 Manned Maneuvering experiment using OWS umbilical and ALSA SOP for life support.

DAY 66

- Second suited M509 Manned Maneuvering experiment using only OWS umbilical for life support.

DAY 80

- CDR and SP conducted EVA to retrieve ATM film and twin pole materials samples, and scientific experiments.



SKYLAB EVA CHRONOLOGY

MISSION	DATE	CREWMEN	EVA TIME
SL-2	**5/25/1973**	**Paul Weitz** **(CM Standup)**	**0:40**
SL-2	**6/7/1973**	**Joseph Kerwin** **Charles Conrad**	**3:23**
SL-2	**6/19/1973**	**Charles Conrad** **Paul Weitz**	**1:34**
SL-3	**8/6/1973**	**Owen Garriott** **Jack Lousma**	**6:37**
SL-3	**8/24/1973**	**Jack Lousma** **Owen Garriott**	**4:37**
SL-3	**9/22/1973**	**Alan Bean** **Owen Garriott**	**2:45**
SL-4	**11/22/1973**	**William Pogue** **Edward Gibson**	**6:36**
SL-4	**12/25/1973**	**Gerald Carr** **William Pogue**	**7:00**
SL-4	**12/29/1973**	**Gerald Carr** **William Pogue**	**3:34**

SKYLAB SPACESUIT OPERATIONAL DATA

MISSION	PGA s/n	Pre-flight Leakage scc/min	Post flight Leakage scc/min	Pre-flight Hours 0.2 psi	Pre-flight Hours 3.75 psi	Flight Hours 0.2 psi	Flight Hours 3.75 psi
SL-2	614	65	200	36.9	19.7	14.2	6.3
	615	30	40	40.3	17.9	14.7	6.3
	616	75	25	29.5	15.9	18.2	2.3
SL-3	632	67	47	24.1	7.3	20.0	6.8
	633	49	37	28.2	10.1	6.0	16.0
	634	40	35	28.2	9.2	9.5	12.5
SL-4	626	55	0.27 cfm	39.5	17.4	13.3	17.8
	627	53	50	34.5	13.5	15.8	18.3
	628	70	35	30.7	14.8	13.3	13.0

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LESSONS LEARNED

- 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 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 MDA. Resulted in crew capability to enter Orbital Workshop and deploy the Parasol thermal shield reducing interior temperature level to a habitable level.
  - 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.

LESSONS LEARNED

- Design of spacesuits for future programs needs to include provision for human body torso growth during long duration microgravity missions.
  - Skylab crew reported they observed body growth of ~1.5 inches during the mission, which made suit donning difficult.
  - Space Shuttle Extravehicular Mobility Unit (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.
  - CDR reported he did not wear a FCS on any of the EVAs.

EVA CAPABILITY SAVED THE MULTI-BILLION DOLLAR SKYLAB SPACE STATION PROGRAM

SPACESUIT KNOWLEDGE CAPTURE SESSIONS

Session Briefings In-work

- "Spacesuit Development for the Apollo Soyuz Test Project"
- "Space Shuttle EMU Spacesuit Development for Initial Space Shuttle Program Flights"
- "Space Shuttle EMU Spacesuit Development for the International Space Station Program"