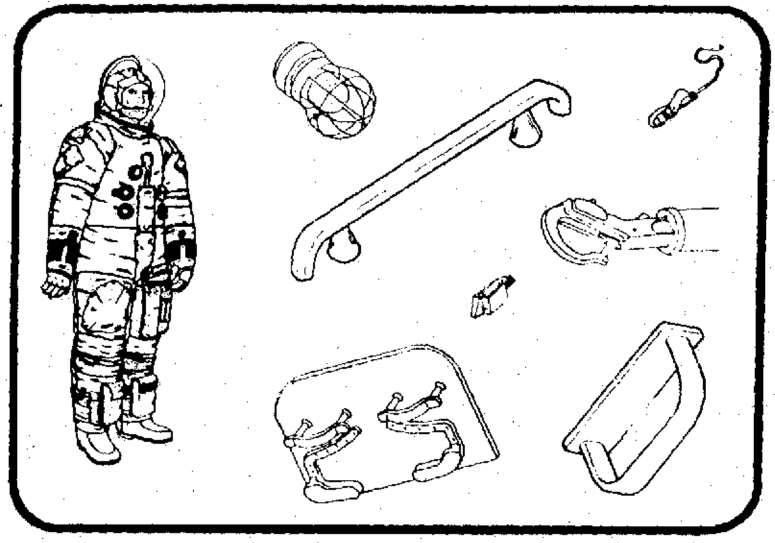

DEVELOPMENT OF AN EVA SYSTEMS COST MODEL

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VOLUME I

DESIGN GUIDES SYNOPSIS-EVA EQUIPMENT

FINAL REPORT
JULY 1974

URS MATRIX

URS/MATRIX COMPANY, LIFE & ENVIRONMENTAL SCIENCES DIVISION, SUITE 103, 1275 SPACE PARK DRIVE, HOUSTON, TEXAS 77058

DEVELOPMENT OF AN EVA SYSTEMS COST MODEL

FINAL REPORT
CONTRACT NAS 9-13790

JULY 1974

VOLUME I

DESIGN GUIDES SYNOPSIS EVA EQUIPMENT

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS 77058

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URS MATRIX

FOREWORD

This design Guides Synopsis--EVA Equipment Report was developed as part of NASA Study Contract No. NAS 9-13790, entitled "Development of an EVA Systems Cost Model." The basic objective of the total study was to provide extravehicular data to assist mission, experiment and payload planners and designers in quantifying the cost of EVA to future vehicles and payloads. The report herein contains practicable data reflecting the characteristics of a sampling of EVA support hardware and general interface requirements that experiments/payloads should acknowledge in order to effectively utilize EVA. The information and data are derived entirely from systems and equipment qualified and used on previous space programs with the exception of Shuttle EVA workstation concepts.

The work was administered under the technical direction of Mr. David C. Schultz of the EVA and Experiments Branch, Crew Procedures Division, Flight Operations Directorate of the Lyndon B. Johnson Space Center, Houston, Texas.

This report (Volume I) is subdivided into the following two areas: (1) EVA equipment design guides and crewman interfaces; and (2) suited crewman mobility capabilities and support requirements summary. The total contract report consists of the following three volumes:

Volume I: Design Guides Synopsis--EVA Equipment

Volume II: Shuttle Orbiter Crew and Equipment Translation Concepts
and
EVA Workstation Concept Development and Integration

Volume III: EVA Systems "Cost" Model

PREFACE

The Space Shuttle Orbiter, scheduled to begin test flights in the late 1970's, will afford the opportunity to perform a variety of tasks outside the spacecraft. Current plans call for an EVA capability to be provided on both the Shuttle orbital test flights and throughout the operational Shuttle era. Based on the Skylab missions, it is anticipated that each future space program will provide for many planned EVA functions, and almost certainly, contingency provisions to enhance mission success. Contingency provisions will include mandatory systems and equipment for crewman safety and rescue.

The planners and designers of Shuttle subsystems and payloads must be cognizant of the characteristics of EVA support equipment and man/machine interfaces in order to effectively design to facilitate EVA servicing. Numerous hardware items have been designed for optimum use by crewmen in weightlessness that reflect characteristics of the extravehicular hardware needed on or near the task being performed. The physical, operational, and performance characteristics of such hardware, properly formatted, would significantly aid the planners and designers in economically designing their systems and perhaps avoid design of incompatible equipment. Such data are available but are widely dispersed in NASA and contractor documentation.

This report provides pragmatic data depicting the characteristics of selected EVA support hardware and man/system interfaces used on the Skylab and Apollo Programs. The number of hardware items and equipment interfaces the EV crewmen have encountered are far too numerous and repetitious to document under a single cover. Therefore, representative equipment and interfaces were selected to represent the range of potential EVA operations, based on early 1974 data, to be conducted during Shuttle Orbiter missions.

The EVA material presented is divided into two major areas: (1) EVA equipment design guides and crewman interfaces; and (2) suited crewman mobility capabilities and support requirements summary. The EVA equipment design guides and crewman interfaces section provides general physical, operational, and/or functional hardware characteristics to allow utilization of previously developed EVA technology and to prevent payload designers and Shuttle users from unknowingly "re-inventing" previously developed, tested, and approved equipment concepts.

The summary of the mobility capabilities and support requirements of the pressure suited crewman includes such quantitative parameters as suit mobility, force application, working volume, lighting, restraints, etc. This design information is presented in table and chart form for easy user access.

ACKNOWLEDGEMENTS

The NASA Technical Monitor for this study was Mr. David C. Schultz, Chief, Procedures Branch (CG2), Crew Training and Procedures Division, Flight Operations Directorate, Johnson Space Center, Houston, Texas. Contract monitoring assistance was provided by Mr. John H. Covington and Mr. Raymond G. Zedekar in the Integrated Procedures Section of the Crew Training and Procedures Division. Appreciation is expressed to Dr. Stanley Deutsch, Director, Bioengineering Division, Office of Life Sciences, NASA Headquarters, for his efforts in arranging for the conduct of the study.

Valuable assistance in obtaining information and photographic material was supplied by personnel within the NASA Johnson Space Center. Special appreciation is due Mr. Lawrence O. Corcoran/EW631, Mr. John H. Covington/CG251, Mr. Robert R. Kain/CG251, Mr. Joseph J. Kosmo/EC921, Mr. Curtis J. LeBlanc/ED121, Mr. James W. McBarron/EC911, and Mr. Charles W. Wheelwright/EW531.

The contractor Pincipal Investigator for the study was Mr. Nelson E. Brown, Division Director, Life and Environmental Sciences Division, URS/Matrix Company, URS Corporation. Principal contributors within the URS/Matrix Company were Mr. Billy K. Richard and Mrs. Betty K. Bielat.

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ACRONYMS AND ABBREVIATIONS

AHR	AMPERE HOURS
ALSA	ASTRONAUT LIFE SUPPORT ASSEMBLY
AM	AIRLOCK MODULE
AMU	ASTRONAUT MANEUVERING UNIT
ASMU	AUTOMATICALLY STABILIZED MANEUVERING UNIT
ATM	APOLLO TELESCOPE MOUNT
BET	BOOM ERECTION TETHER
CM	COMMAND MODULE
CM	CENTIMETER
CMG	CONTROL MOMENT GYRO
CSM	COMMAND SERVICE MODULE
CWG	CONSTANT WEAR GARMENT
DAC	DATA ACQUISITION CAMERA
DEG	DEGREE
DVT	DESIGN VERIFICATION TEST
EMU	EXTRA MOBILITY UNIT
EV	EXTRAVEHICULAR
EVA	EXTRAVEHICULAR ACTIVITY
FAS	FIXED AIRLOCK SHROUD
FPS	FOOT PER SECOND
FSE	FLIGHT SUPPORT EQUIPMENT
FT	FOOT
FTB	FILM TRANSFER BOOM
G	GRAVITY
GSFC	GODDARD SPACE FLIGHT CENTER
HHMU	HAND-HELD MANEUVERING UNIT
IN	INCH
IVA	INTRAVEHICULAR ACTIVITY
JSC	JOHNSON SPACE CENTER
KG	KILOGRAM
LB	POUND

ACRONYMS AND ABBREVIATIONS (CONT'D.)

LM	LUNAR MODULE
LSS	LIFE SUPPORT SYSTEM
LSU	LIFE SUPPORT UMBILICAL
M	METERS
MDA	MULTIPLE DOCKING ADAPTER
MMU	MANNED MANEUVERING UNIT
MSC	MANNED SPACECRAFT CENTER
MSEC	MILLISECOND
MSFC	MARSHALL SPACE FLIGHT CENTER
N	NEWTONS
N/A	NOT APPLICABLE
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
N/S	NOT SPECIFIED
OES	ORBITAL EXTRAVEHICULAR SPACESUIT
OWS	ORBITAL WORKSHOP
PBI	POLYBENZIMIDIZOLE
PCU	PRESSURE CONTROL UNIT
PGA	PRESSURE GARMENT ASSEMBLY
PSIA	POUNDS PER SQUARE INCH ABSOLUTE
PSID	POUNDS PER SQUARE INCH DIFFERENTIAL
PSIG	POUNDS PER SQUARE INCH GAGE
RPM	REVOLUTIONS PER MINUTE
RMS	REMOTE MANIPULATOR SYSTEM
SEC	SECOND
SI	STANDARD INTERNATIONAL
SIM	SCIENTIFIC INSTRUMENT MODULE
SOP	SECONDARY OXYGEN PACK
SPEC	SPECIFICATION
TBD	TO BE DETERMINED
UV	ULTRAVIOLET
V	VELOCITY

ACRONYMS AND ABBREVIATIONS (CONT'D.)

VC	CENTER WORKSTATION
VDC	VOLTS DIRECT CURRENT
VF	FAS WORKSTATION
VS	SUN END WORKSTATION
VT	TRANSFER WORKSTATION

DESIGN GUIDES SYNOPSIS--EVA EQUIPMENT

INTRODUCTION

DESIGN GUIDES--GENERAL

This Design Guides Synopsis--EVA Equipment document compiles and formats selected EVA equipment and man/system interface information into a convenient reference source. The document is intended for use by Shuttle subsystem and payload/experiment planners and designers (i.e., Shuttle user population) to aid in configuring their hardware for optimum compatibility with the EVA crewman. The information presented is designed to provide adequate detail of EVA equipment, operations and interface hardware characteristics to "direct" the design of extravehicular hardware for Shuttle payload bay application.

Effectiveness during extravehicular missions and economic considerations are of prime interest to Shuttle users since a portion of the EVA equipment is payload chargeable. Therefore, a representative cross-section of the EVA equipment qualified and used on the Skylab, Gemini, and Apollo Programs is presented as general design guidelines. Certain physical, operational, and performance characteristics of the EVA hardware requiring an EV crewman interface are considered most important to the user. This descriptive information is provided to urge utilization of off-the-shelf Skylab hardware where possible for economy and to stimulate ideas for applying EVA on future missions. Details of the hardware internal mechanisms are not provided. The configuration, operations, and man/machine interfaces should be of initial importance to Shuttle planners and designers.

In the design/selection of equipment to be used by the EV crewman, it should be recognized that the crewman may face a specific time allocation in completing the necessary payload servicing operations. Therefore, it is imperative that the interfaces be designed to insure that each EVA task is operationally compatible with the crewman's pressurized gloved hand and within the working envelope required by the crewman. As can be recalled from the Skylab Program, a variety of scheduled and contingency EVA tasks can be performed in the zero-gravity environment given proper interface hardware and adequate time. Contrary to many early presumptions concerning EVA interface requirements, elaborate hardware is not necessary for most candidate extravehicular tasks in the Space Shuttle Orbiter payload bay. Crew members from the Skylab Program report that EVA tasks performed in space are less difficult than in available earth simulations. Many EVA tasks can be accomplished using only foot restraints and slightly modified off-the-shelf hand tools, provided adequate procedures, lighting and working volume are considered.

EVA EQUIPMENT AND CREW INTERFACES (SECTION 1.0)

Upon completion of an EVA operational equipment and crewman interface analysis of Gemini, Apollo and Skylab systems, a list of approximately 100 items were identified for possible application to the Space Shuttle Program. Since it was beyond the scope of this study to provide data on all previous EVA systems/hardware to an equivalent depth, 20 items were selected for information compilation. Selection was based on: (1) Design features applicable to the Shuttle vehicle and payloads; (2) prior flight qualification; (3) crew acceptability; and (4) operations/hardware depicting crewman capabilities in the orbital environment. Determination of the applicability of the hardware was derived from an analysis of Shuttle EVA requirements as a part of Contract NAS 9-12997--final report entitled, "Applications of EVA Guidelines and Design Criteria," URS/Matrix Company, April 1973.

The EVA hardware and interfaces selected for the document are classified into the following six (6) sections:

1.1 RESTRAINTS AND MOBILITY AIDS

1.1.1 Handholds and Handrails--Apollo and Skylab

1.1.2 Foot Restraints--Skylab

1.1.3 Temporary Stowage Hardware

- Skylab Equipment Hooks
- S082 Camera Restraint

1.1.4 Deployable Handrail and Pip Pin Restraint Devices--Gemini

1.1.5 Tethers--Wrist, Waist (Apollo, Skylab)

1.2 CREW AND EQUIPMENT TRANSFER SYSTEMS

1.2.1 Film Transfer Boom--Skylab

1.2.2 Endless Clothesline

1.2.3 Astronaut Maneuvering Unit--M509

1.3 WORKSITE PROVISIONS

1.3.1 Workstations--Gemini, Apollo, Skylab

1.3.2 Workstations--Shuttle Concepts

1.3.3 Skylab ATM Panel 160--Canister Roll Control

1.3.4 EVA Panels (Airlock)--Skylab Nos. 317 and 323

1.3.5 Decals--Instruction/Identification

1.4 CREW/EQUIPMENT INTERFACE HARDWARE

1.4.1 Film Magazines--Skylab Astronomy

- S052
- S054
- S056/Hα1
- S082

1.4.2 Film Magazine to Instrument Interface

- S052
- S054
- S056
- S082A

1.4.3 Module Stowage Tree--Skylab Film Tree

1.5 ACCESS DOORS AND PANELS

1.5.1 Skylab Experiment Access Doors
1.5.2 Skylab Airlock Module Hatch

1.6 MISCELLANEOUS EVA HARDWARE

1.6.1 Universal Mount--Skylab
1.6.2 EVA Equipment Brackets--Apollo, Skylab
1.6.3 Special Tools

The EVA equipment/interface design guides data for each of the hardware/interface areas will be formatted as shown below. In some instances, information may not be available in sufficient detail or may not be applicable to the selected format breakdown. These cases will be noted.

A. Purpose: This section describes the function the equipment item provides in supporting extravehicular activities. The previous space program and EV missions where the item was utilized will also be specified.

B. Functional Description and Support Hardware: The functional description provides a narrative overview of the functional and operational characteristics of the EV hardware and equipment interfaces. The operations performed by the equipment and the manipulative operations required by the EV crewman are identified. The passive and active man/equipment interfaces are identified as applicable.

C. Performance Data and Applications to Future Programs: This section provides qualitative information based on crew comments on the performance of the EV equipment items and man/system interfaces. In addition, an evaluation of the item for future use is given, including possible improvements, as applicable. This section is intended to stimulate ideas for utilization of the EV equipment for the Shuttle Orbiter and payload systems.

D. Specifications and Design Data: Quantitative physical data are provided on the hardware in this section. The basic dimensions, weight, volume, actuation forces, component travel (length/degrees), etc. are included where considered beneficial to the document user. Photographs, drawings, and sketches are also included. This section is considered most important to the experiment/payload designer in obtaining desired EV equipment design guidelines.

E. Supplementary Information: Any additional information not covered under the above subsections and considered useful to the designer is presented. The information will generally provide references, drawing numbers, and documents identifying areas in which more detailed information can be obtained.

SKYLAB CONFIGURATION

A large percentage of the EVA equipment discussed in the Design Guides Synopsis section of the document was associated with the Skylab Program. The six (6) planned EVAs for ATM solar astronomy data retrieval and sample collection, plus the four (4) contingency EVAs involved many hardware items and crew interfaces. For identification/location of major Skylab cluster components, Figure 1 shows the intended Orbital Cluster configuration. Figure 2 shows the Skylab cluster as actually flown following loss of one solar array and a portion of the OWS thermal/micrometeoroid protective system.

MOBILITY CAPABILITIES AND SUPPORT EQUIPMENT (SECTION 2.0)

Some of man's performance capabilities in the weightless, orbital environment are degraded to a certain degree from the normal earth gravity capabilities--others are enhanced. His extravehicular performance is highly dependent upon the mobility aids, transfer systems (cargo), worksite provisions (lighting, working volume, restraints, controls/displays), and pressure suit and life support system (LSS) encumbrance. Excluding physical condition and stature extremes, the two most significant factors affecting physical performance are crew restraint systems and pressure suit mobility. Physical performance, in

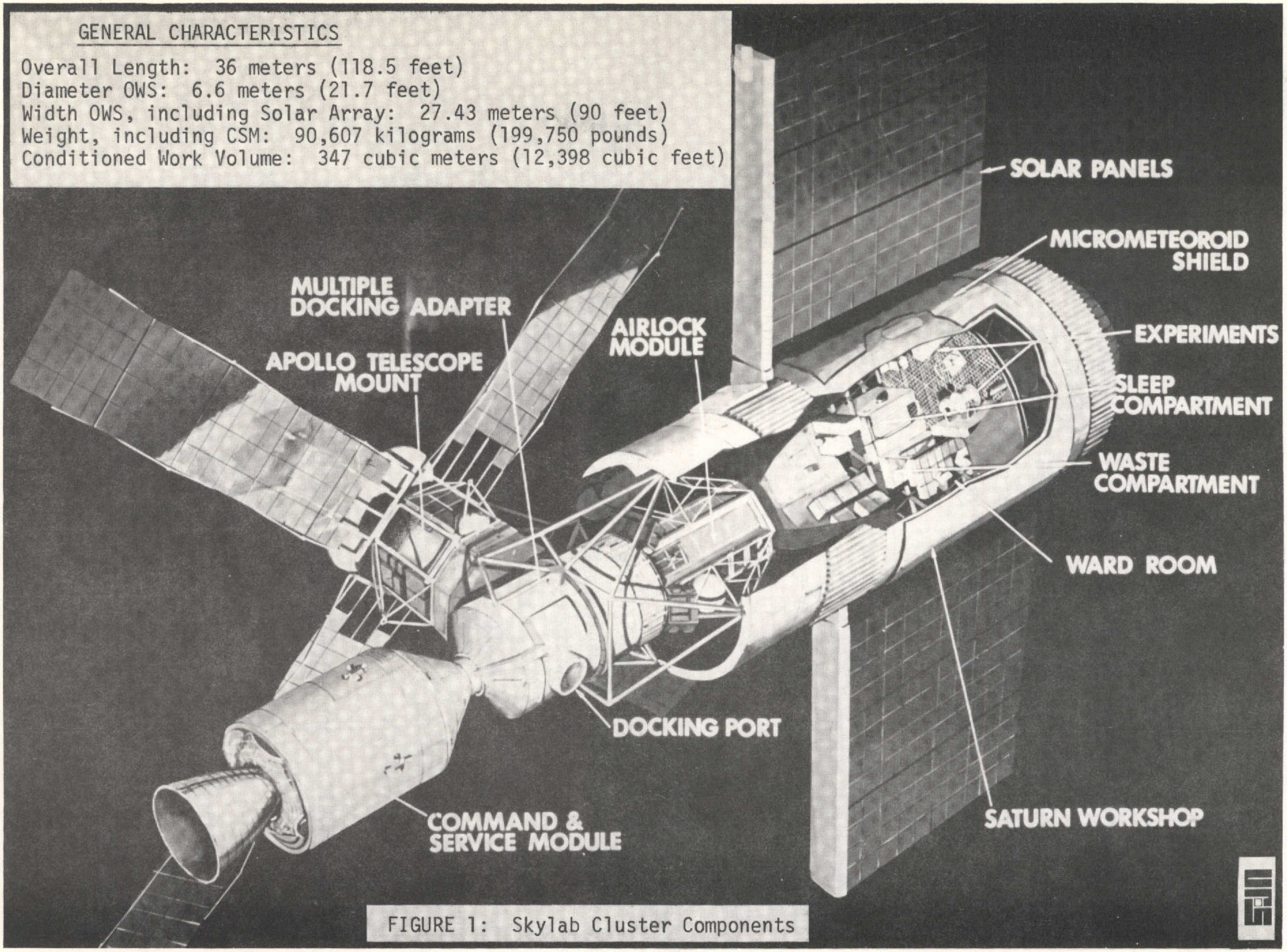


FIGURE 1: Skylab Cluster Components

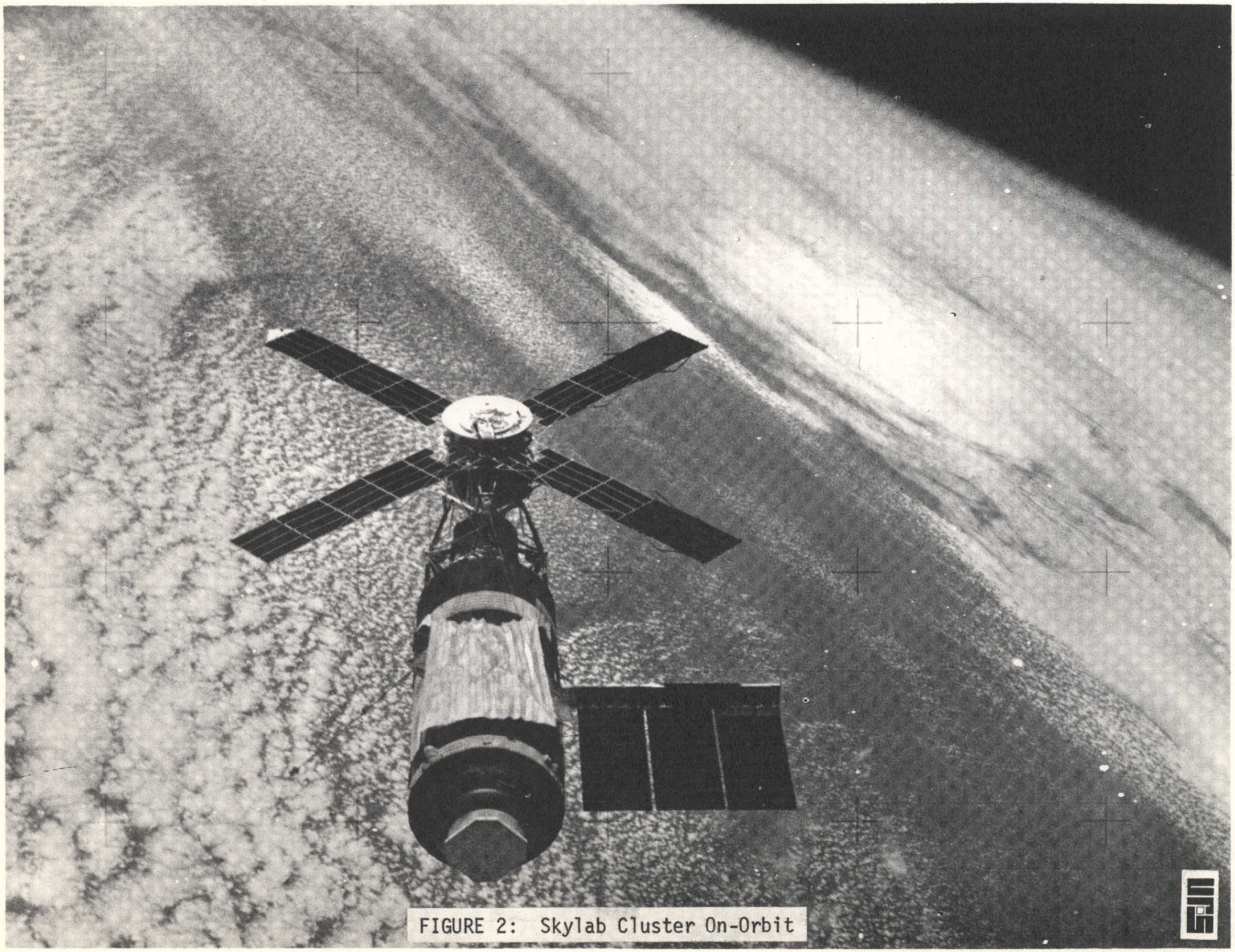


FIGURE 2: Skylab Cluster On-Orbit

this context, refers to the types of tasks the EVA crewman is capable of performing, the forces he can exert, the distances he can reach, visibility, etc.

An overview of the crewman's mobility capabilities in the Shuttle prototype spacesuit and his major support requirements (excluding spacesuits and life support systems) are addressed in Sections 2.1 and 2.2 of the report. The method selected to present the information/data includes photographs, tables, and charts for rapid information retrieval. Data on the following EVA crewman performance characteristics and support requirements are provided in the subsections listed below:

2.1 MOBILITY/PERFORMANCE CHARACTERISTICS
- 2.1.1 Mobility--Shirtsleeve Versus Suited
- 2.1.2 Force and Torque Applications
- 2.1.3 Cargo Transfer Capability
- 2.1.4 Translation Rates

2.2 CREWMAN SUPPORT REQUIREMENTS
- 2.2.1 Illumination
- 2.2.2 Visibility
- 2.2.3 Restraint and Stabilization
- 2.2.4 Working and Translation Volumes
- 2.2.5 Safety

SECTION 1.0

EVA EQUIPMENT AND CREW INTERFACES

SECTION 1.1: RESTRAINTS AND MOBILITY AIDS

Section 1.1 contains a brief description of several of the more successful methods of restraining and transferring crewman and equipment on the Gemini, Apollo and Skylab Programs. These particular restraints and mobility aids were selected for review in this report since it is anticipated that their designs will be considered for use or incorporation into the design of similar functioning hardware on future programs.

The Gemini Program established the need for adequate restraints during EVAs. The Apollo Program proved that particular tasks could be accomplished using proper restraints and mobility aids. The Skylab Program demonstrated that most tasks that can be accomplished in one-g can be accomplished in zero-g, provided sufficient restraints and mobility aids are available. Similar EVA systems will be required on future programs. A review of the following items should be of assistance in the early design phase of Shuttle EVA systems.

Section 1.1 contains information on the following equipment:

1.1.1 HANDHOLDS AND HANDRAILS--APOLLO/SKYLAB

A. Purpose

On previous space programs, handrails and handholds have been a prime means of crew/equipment transfer and stabilization during orbital extra-vehicular missions. In addition, they provide protection to the vehicle components from damage by the crewman. The units also offer convenient locations for temporary restraint of equipment.

B. Functional Description and Support Hardware

Handrails and handholds were used frequently on the Apollo and Skylab Programs for EVA missions (Figures 1.1-1 and 1.1-2). The same general type of handrails and handholds was used for both Programs (Figure 1.1-3). All EVA handrails and handholds were similar in cross-sectional dimensions, but varied in length, weight, construction material, and design specifications. The length of handholds is normally not over 22.8 cm. (9 in.), but not less than 14.75 cm. (5.8 in.) to allow gripping with the EVA glove. The length of handrails depends on the application and loading requirements. The minimum clearance distance between the lower surface of the handrail/handhold and the mounting surface for EV handrails/handholds is 5.72 cm. (2.25 in.). The clearance for IV handrails/handholds is 3.81 cm. (1.50 in.). Single handrails have proved to be sufficient for most translation applications. Dual handrails are necessary where precise body orientation is required or where contact with the vehicle must be avoided.

Portable handholds were investigated on the Skylab Program. These were used only on the interior of the vehicle and required a standard Skylab floor attachment (Figure 1.1-4). All exterior handrails and handholds were permanently fastened to the vehicle before launch (Figures 1.1-5 and 1.1-6).

C. Performance Data and Applications to Future Programs

No problems were encountered with the handholds and handrails on the later Apollo or the Skylab Programs. Crew comments were very favorable.

The first Skylab crew commented that, "The single handrails were a perfectly feasible way to translate, while the dual handrails were like driving the interstate highway." Handholds/handrails have proved their usefulness on past programs and appear to be a reliable and economical approach on future programs. Handrails are being considered on the Shuttle Program for planned EVAs in the payload bay. EVA missions requiring repeated translations to the worksite or involving long transfer distances may require man-assisted modes of travel. Portable powered trolleys and free-flying maneuvering units may be applicable on future missions.

D. Specifications and Design Data

General specifications and design requirements for handholds and handrails are contained in Table 1.1-1. Additional functional requirements and detailed design data can be obtained from the documentation referenced below.

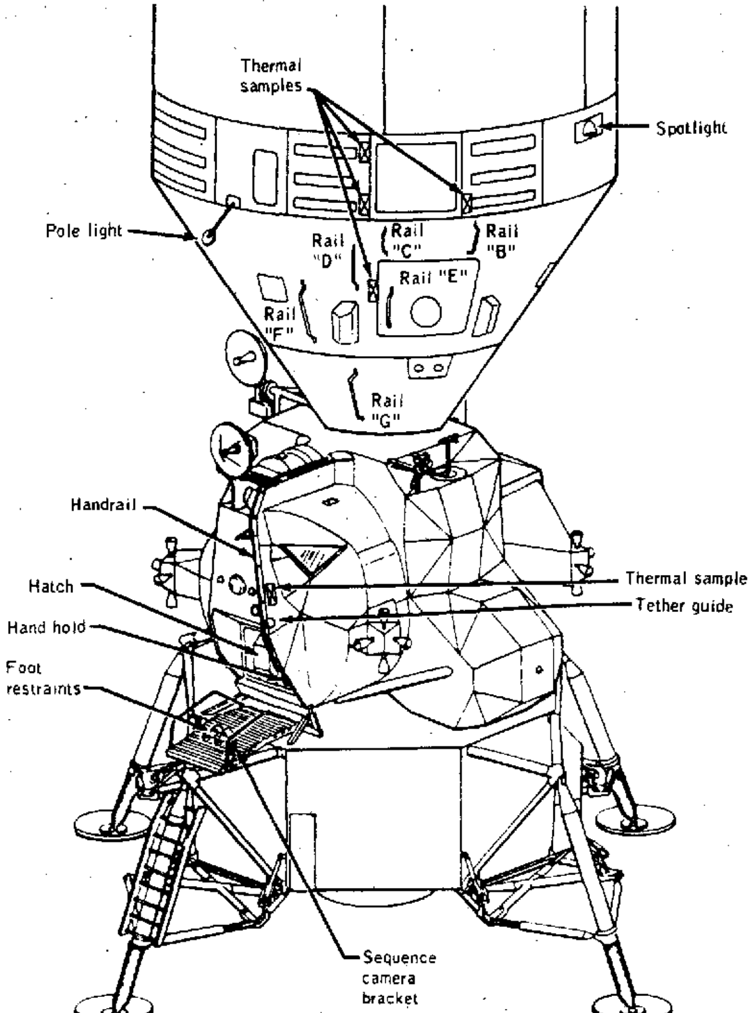
E. Supplementary Information

Documentation:

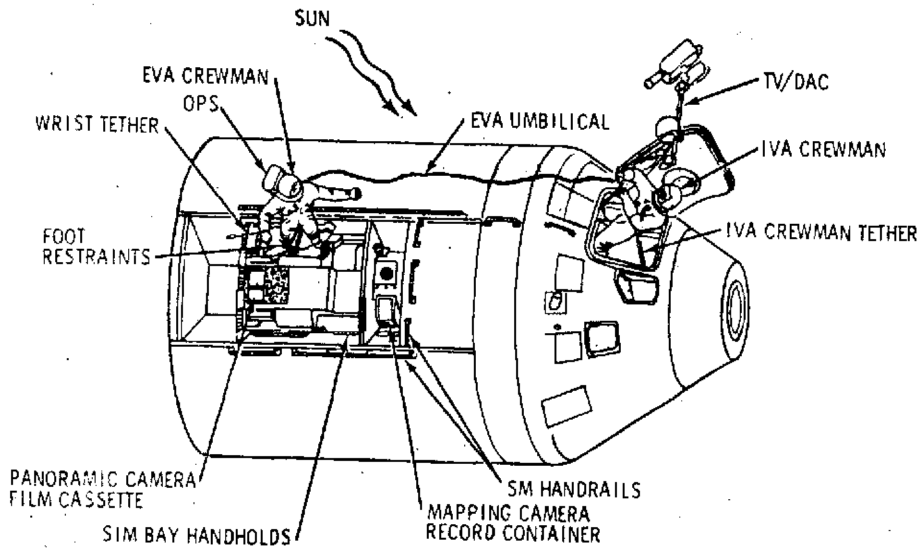
- Manned Spaceflight Extravehicular/Intravehicular Activity Support Equipment, General Specifications, NASA, Manned Spacecraft Center, SC-E-0006, December 1972.
- Skylab Operations Handbook, OWS, AM, MDA; McDonnell Douglas Astronautics Company, Contract NAS 9-11001, Volume I, MSC 04727, 27 January 1972.
- Crew Station Specification, NASA, Manned Spacecraft Center, Flight Crew Integration Division, MSC-07387, October 1972.

Drawing/Part No.:

- Handrail Drawing No.--10M04750



Apollo 9 Spacecraft Handrail and Handholds



Apollo 15 Command Service Module Handrails

FIGURE 1.1-1: Representative Apollo Handhold/Handrail Locations

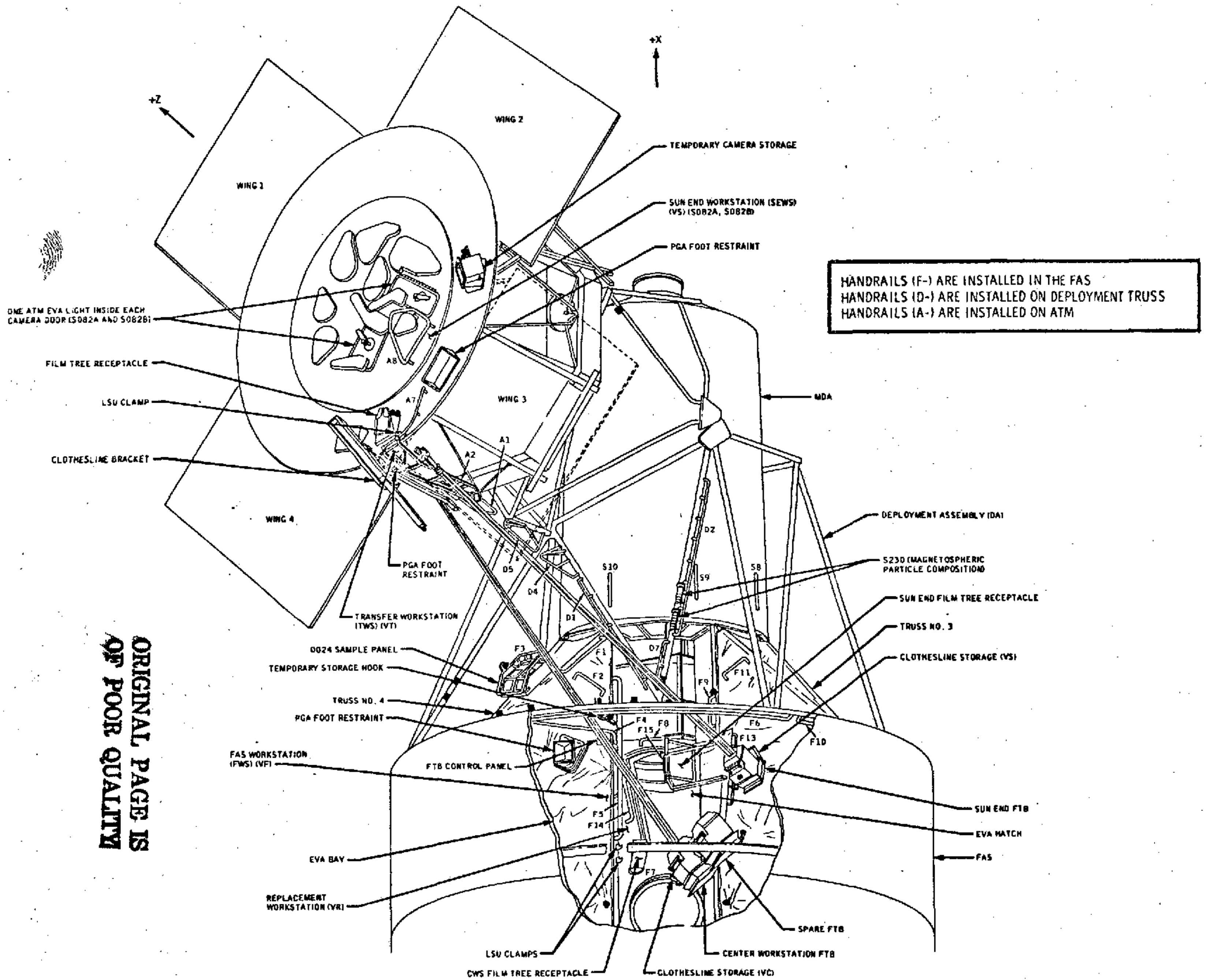
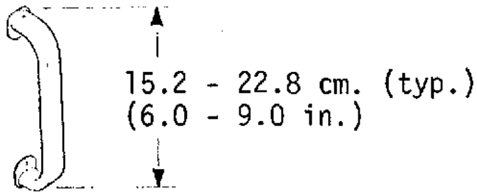
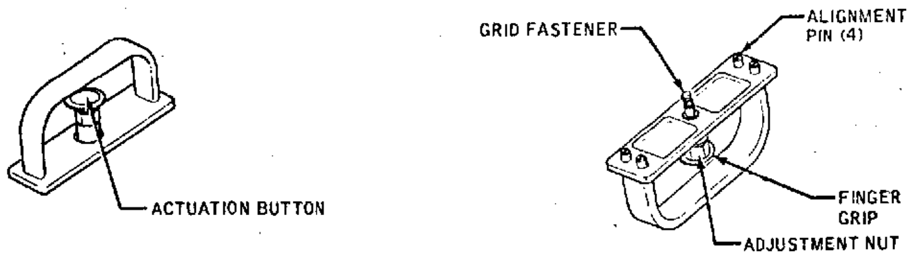


FIGURE 1.1-2: Representative Skylab Handhold/Handrail Locations

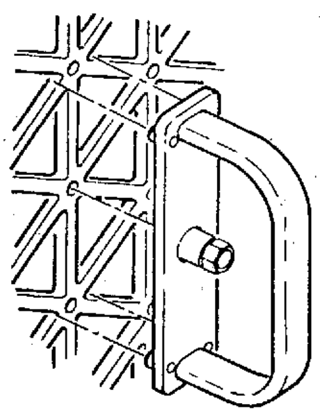


Handhold configuration used on Apollo and Skylab. Attachment to mounting surface may vary.

Handrail configuration used on vehicle interior and exterior surfaces. Standoff and length varies between applications.



Portable handholds used on Skylab



Portable handhold mounting technique used in the Skylab Orbital Workshop (OWS). Technique requires a standard grid pattern for mounting. Similar grids may be used on the Spacelabs' experiment pallets.

FIGURE 1.1-3: Typical Handhold and Handrail Configurations

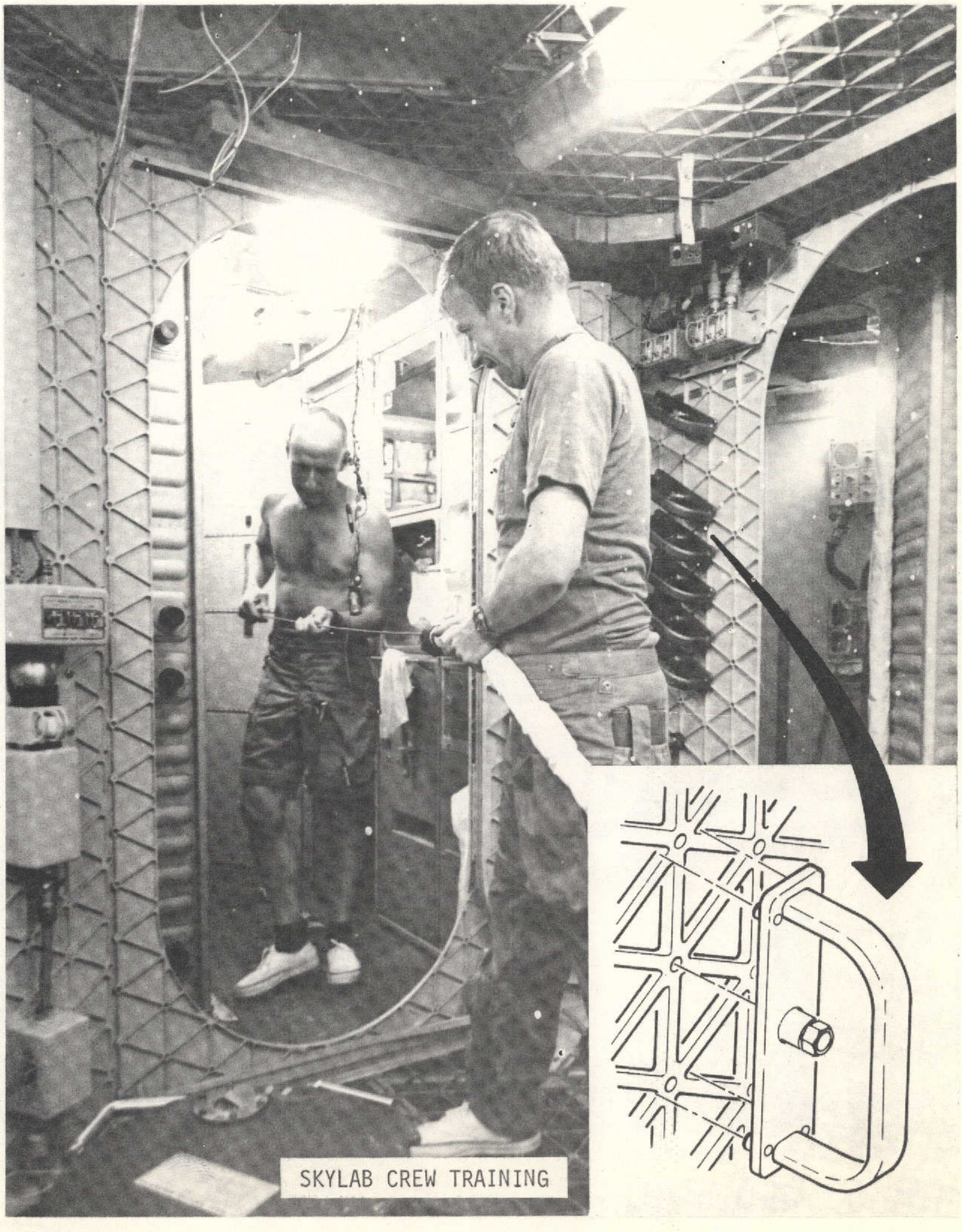


FIGURE 1.1-4: Portable Handhold Grid Attachment and Stowage Location

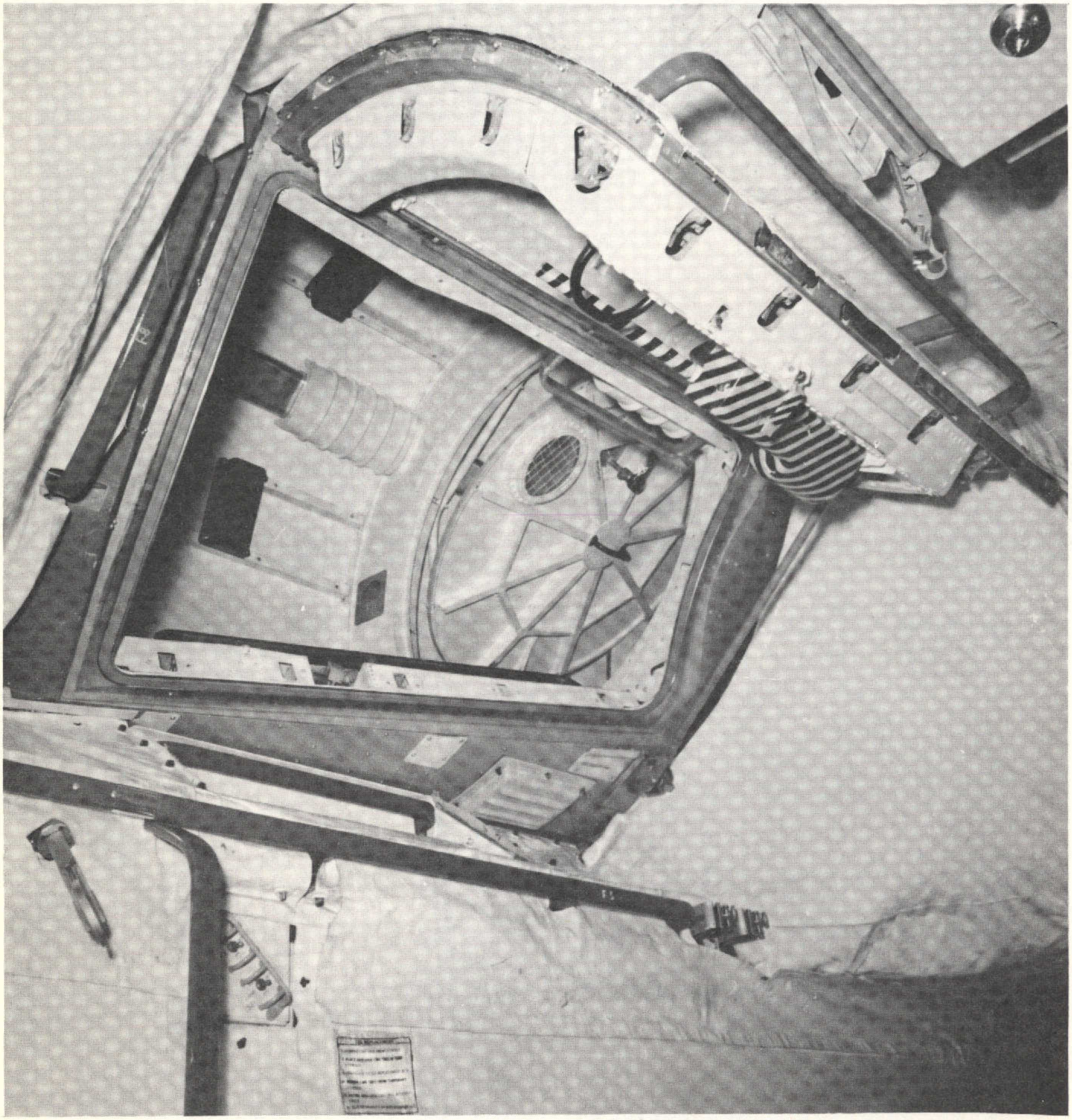


FIGURE 1.1-5: Skylab EVA Airlock Area Handrails

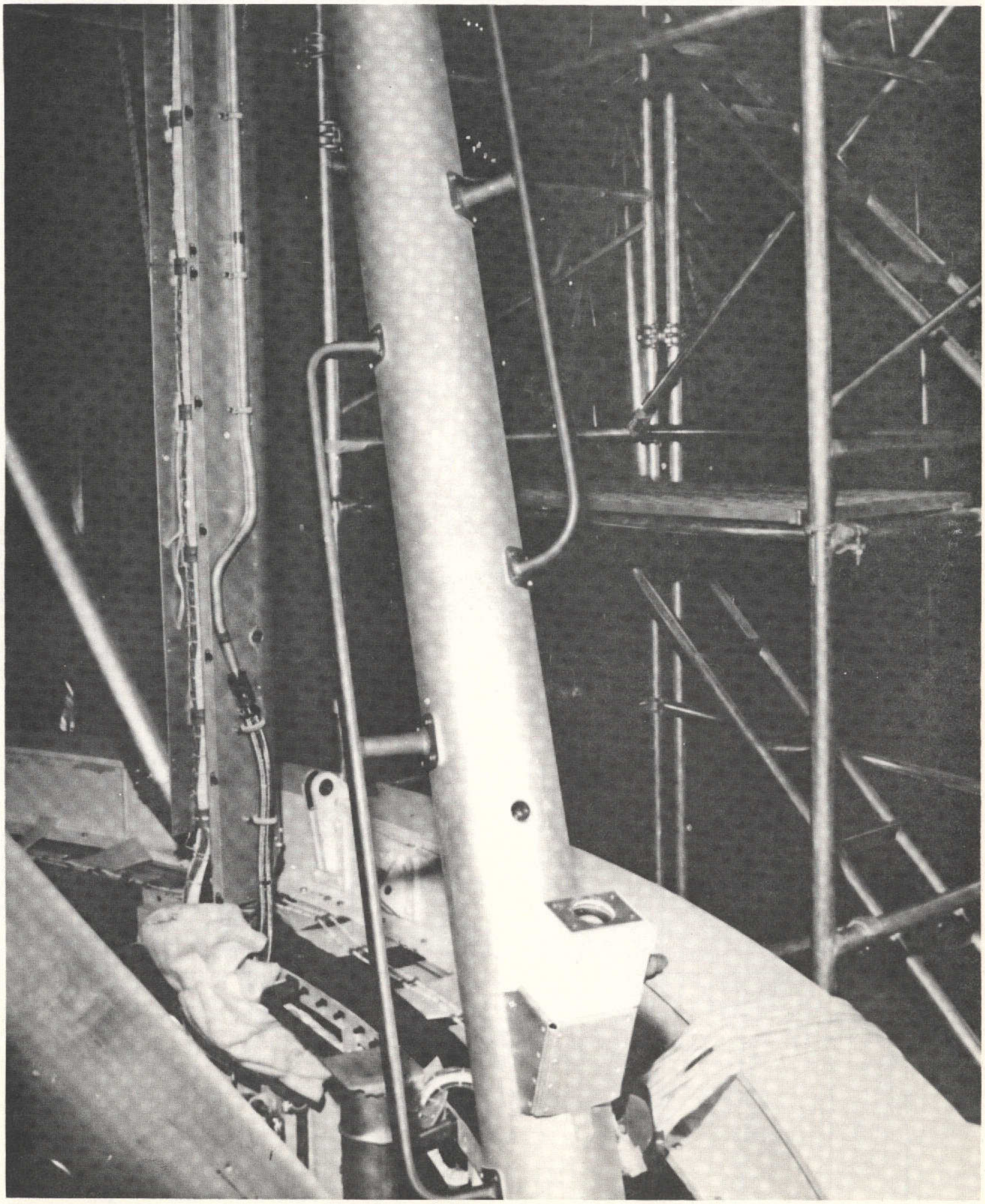


FIGURE 1.1-6: Skylab ATM Deployment Truss EVA Handrails

TABLE 1.1-1: Handhold and Handrail General Design Characteristics

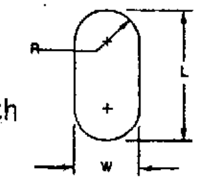
<table>
<tr><th>DESIGN PARAMETER</th><th>DESIGN REQUIREMENT/REMARKS</th></tr>
<tr><td>CROSS SECTIONS</td><td>The handholds/handrails will have a cross section with L/W ratio range of 1.66 to 3.00. The preferred L/W ratio is 2.00 with a corner radius of $\frac{W}{2}$.

L/W Ratio = 1.66 to 3.00
preferred L/W = 2.00
R = 1/2 W</td></tr>
<tr><td>SIZE</td><td>Sizing requirements of handholds/handrails for EVA and intravehicular activity (IVA) are shown in the accompanying table. Minimum grip length for EV handholds is 14.75 cm. (5.81 in.)
<table>
<tr><th rowspan="2">Activity</th><th colspan="2">L Dim (Min)</th><th colspan="2">L Dim (Max)</th></tr>
<tr><th>CM.</th><th>IN.</th><th>CM.</th><th>IN.</th></tr>
<tr><td>EVA</td><td>3.10</td><td>1.22</td><td rowspan="2">3.81</td><td rowspan="2">1.50</td></tr>
<tr><td>IVA</td><td>1.90</td><td>.75</td></tr>
</table></td></tr>
<tr><td>MOUNTING CLEARANCE</td><td>The minimum clearance distances between the lower surface of the handrail/handhold and the mounting surface are as shown:
<table>
<tr><th></th><th>cm.</th><th>in.</th></tr>
<tr><td>Extravehicular</td><td>5.72</td><td>2.25</td></tr>
<tr><td>Intravehicular</td><td>3.81</td><td>1.50</td></tr>
</table></td></tr>
<tr><td>SPACING FOR TRANSLATION</td><td>For extravehicular translation, handholds/handrails shall not be separated more than 122.0 cm. (48.0 in.).</td></tr>
<tr><td>SPACING FOR WORKSITES</td><td>Handholds/handrails spacing shall not exceed 45.8 cm. (18.0 in.) above or below the shoulder or 61.0 cm. (21.0 in.) to the left or right of the body centerline when working in a foot restrained position.</td></tr>
</table>

TABLE 1.1-1: Handhold and Handrail General Design Characteristics (cont'd.)

DESIGN PARAMETER	DESIGN REQUIREMENT/REMARKS
LOADING	1. Intravehicular handholds/handrails will be designed to a minimum ultimate load of 1113 newtons (250 lbs.) in any direction. 2. Extravehicular handholds/handrails will be designed to a minimum ultimate load of 1250 newtons (281 lbs.) in any direction.
TETHER ATTACHMENT	EVA handholds/handrails will accommodate flight EVA tether hooks at a spacing of 61.0 ± 12.7 cm. (24.0 ± 5.0 in.).
TETHER ATTACHMENT LOADING	1. Intravehicular handhold/handrail tether attach points will be designed to a minimum ultimate load of 1113 newtons (250 lbs.) in any direction. 2. Extravehicular handhold/handrail tether attach points will be designed to a minimum ultimate load of 3830 newtons (860 lbs.) in any direction.
GENERAL LOCATION	EVA handholds and handrails should be located to provide crewman protection from thermal, electrical, pyrotechnic, radiological, and electromagnetic equipment. Potentially dangerous equipment located within 30.5 cm. (12.0 in.) of the translation route or worksite will be identified in accordance with SC-M-0003. Thermal control shall be compatible with temperature specifications of the pressure garment assembly (PGA).
LIGHTING	EVA handholds/handrails shall be illuminated in accordance with SC-L-0002.

TABLE 1.1-1: Handhold and Handrail General Design Characteristics (cont'd.)

DESIGN PARAMETER	DESIGN REQUIREMENT/REMARKS
MATERIAL	Handholds and handrails are primarily fabricated from metals. Other rigid, semirigid, or cloth materials may be used in accordance with NHB 8060.1.
GRASP SURFACE	Handholds and handrails shall have a nonslip surface with no sharp edges or protrusions injurious to the crewman, PGA, or equipment.
COLOR	Color coding, lettering, or numbering systems may be used to assist in rapid identification. Colors shall be selected that minimize specular reflections and selected from FED-STD-595A and in accordance with SC-M-0003.

URS

1.1.2 FOOT RESTRAINTS--SKYLAB

A. Purpose

Foot restraints are provided to secure the feet (i.e., heel of spacesuit boot) of a suited crewman allowing hands free performance of tasks in the zero-g environment. Foot restraints have proven to be the most effective restraint for EVA.

B. Functional Description and Support

Two similar types of foot restraints were used on Skylab: (1) Fixed restraints permanently mounted on the outside of the vehicle at a worksite, Figures 1.1-7 and 1.1-8; and (2) portable, normally located inside the vehicle and, on Skylab, mounted to a floor grid, Figure 1.1-9. The Skylab foot restraints basically consisted of a flat plate with a pair of "toe bars" and a set of "heel restraints" rigidly mounted. The toe of the crewman's boot was placed under the toe bar, and the heel clips (which are an integral part of the heel of the boot) slid into the foot restraint heel fittings. The portable foot restraints had tabs on the bottom of the aft end of the plate that fitted under the floor grid and an "Astro pin" near the front that interfaced with the holes in the grid to firmly restrain the plate. The portable restraints were also used to secure the spacesuits during donning and drying. Two pip pins were supplied with the portable restraints for installation on the inside of the heel fittings. These were required when the suit was not pressurized since the boots had a tendency to float out of the restraint (Figures 1.1-9 and 1.1-10). Although the portable restraints were designed for use only inside the vehicle, on two Skylab contingency EVAs, adapters were built to allow temporary mounting to structures on the vehicle exterior.

To ingress or egress the foot restraints, adequate handholds or handrails must be provided. Vehicle experiment hardware, stowage containers which conveniently project from the walls, or standard handrails that are designed for this task, are possible candidates.

C. Applications to Future Programs

If EVAs are to be used effectively on future programs, restraint systems are mandatory. The Skylab foot restraints are simple in design, lightweight, and their performance in flight has been flawless. Several contingency operations outside the Skylab vehicle would have been much easier and less time consuming if a set of "universal mounting" foot restraints had been available. Efforts are being conducted to develop a more versatile mounting system(s) to interface with numerous structural configurations. Skylab type foot restraints are excellent candidates for use on future programs.

D. Specifications and Design Data

General specifications and design requirements for foot restraint systems are contained in Table 1.1-2. The dimensions shown in Figure 1.1-9 are representative of the overall size of EVA/IVA foot restraints. The mounting plate size can vary as required by the worksite. The orientation of the toe and heel restraints on the mounting plate may also vary as in Figure 1.1-7.

E. Supplementary Information

Documentation:

- Manned Spaceflight Extravehicular/Intravehicular Activity Support Equipment, General Specifications, NASA-Manned Spacecraft Center, SC-E-0006, December, 1972.
- Skylab Operations Handbook, OWS, AM, MDA; McDonnell Douglas Astronautics Company, Contract NAS 9-11001, Volume I, MSC 04727, 27 January 1972.

Drawing/Part No.:

- Foot Restraint Drawing Numbers
  - Fixed: 10M50019
  - Portable: 1B89027

Item Developed by:

NASA Lyndon B. Johnson Space Center
Houston, Texas

Item Supplied by:

McDonnell Douglas Astronautics Company
Santa Monica, California

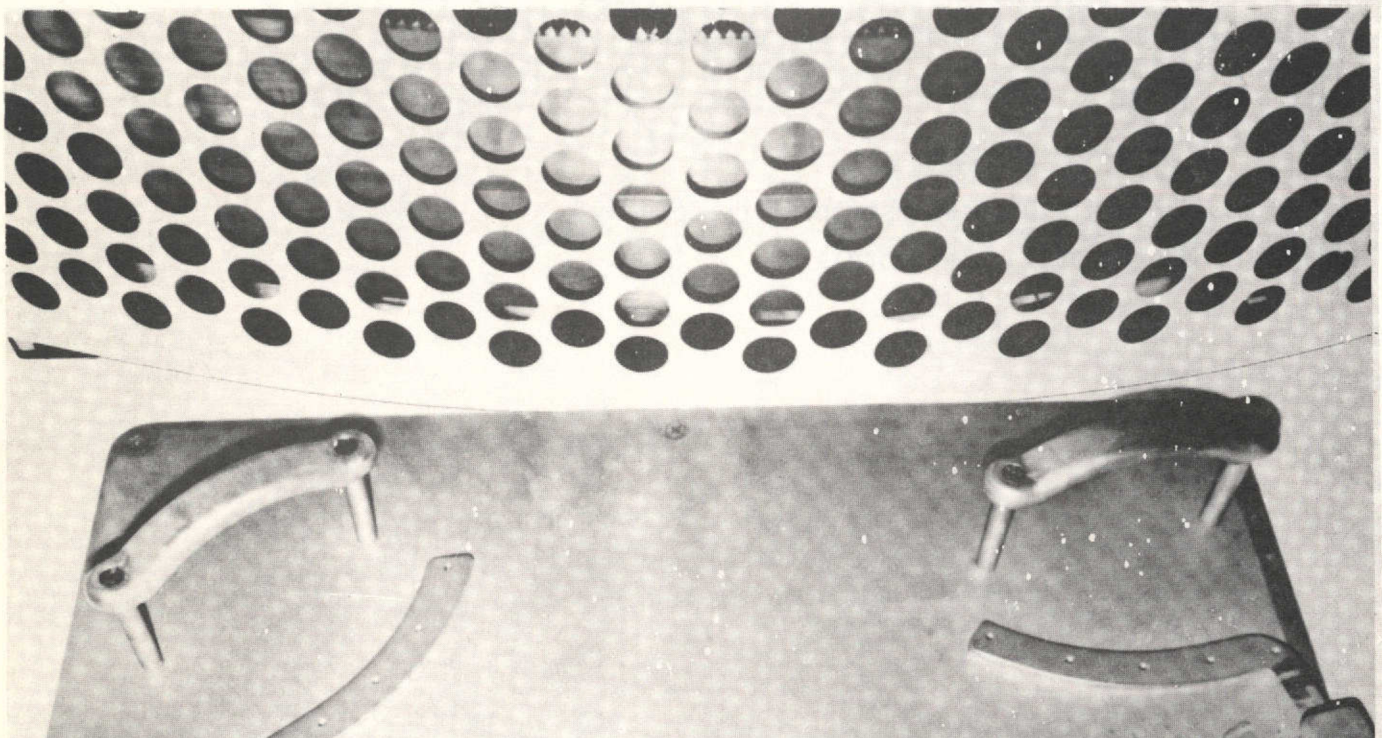


FIGURE 1.1-7: Skylab ATM Center Workstation Foot Restraints

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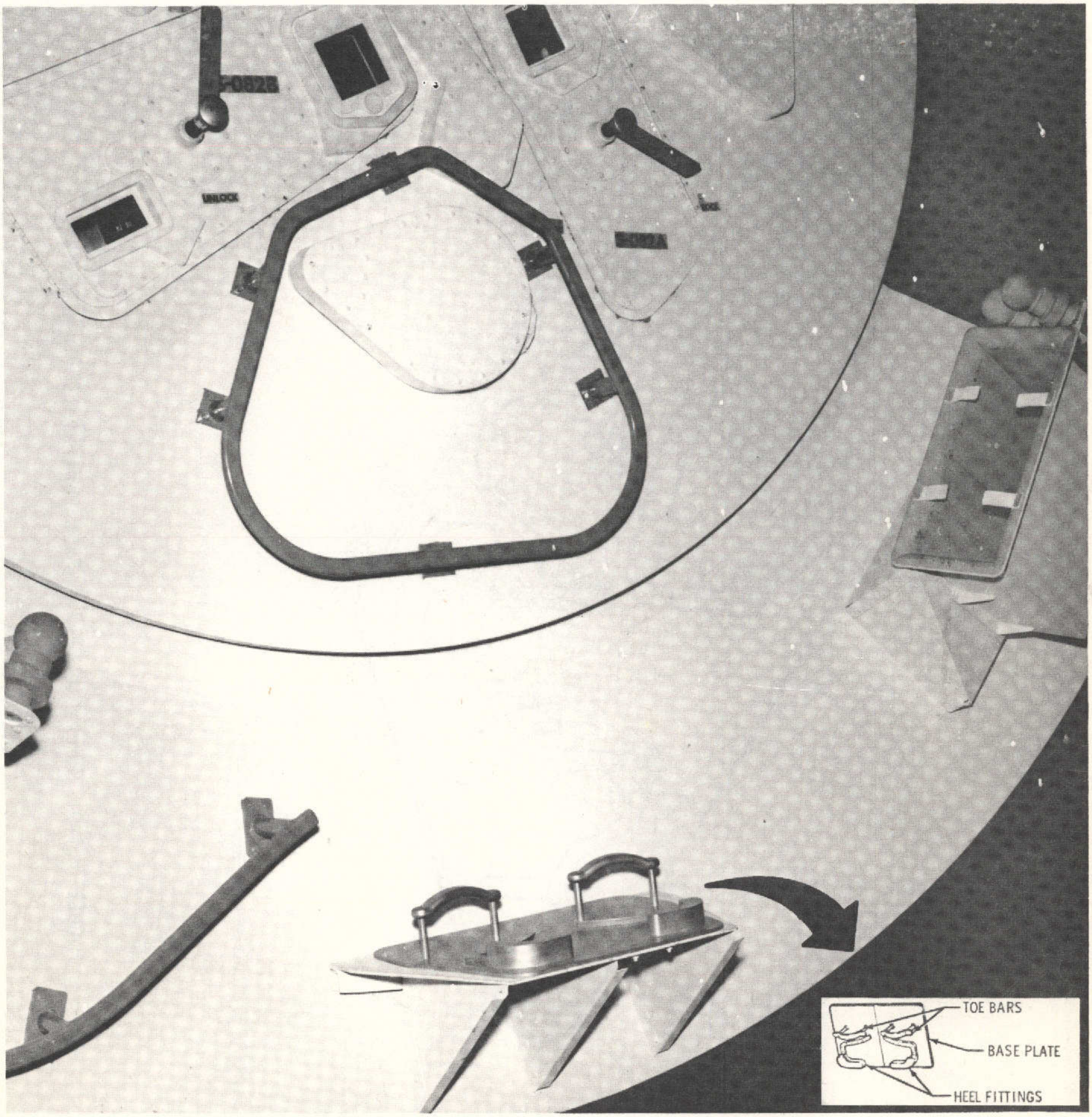

FIGURE 1.1-8: Skylab ATM Sun End Foot Restraints

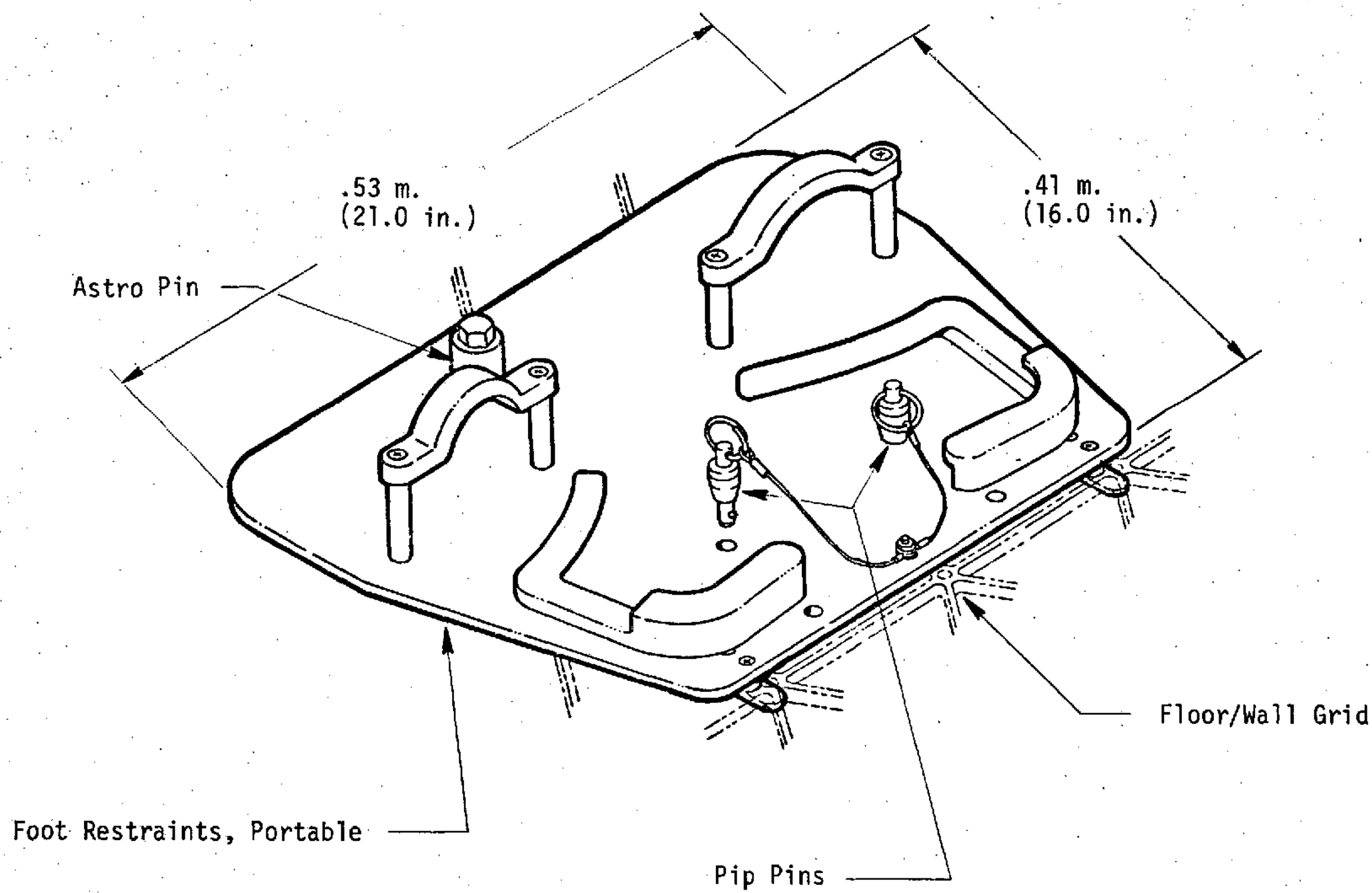

FIGURE 1.1-9: Portable Skylab Foot Restraints (Interior)

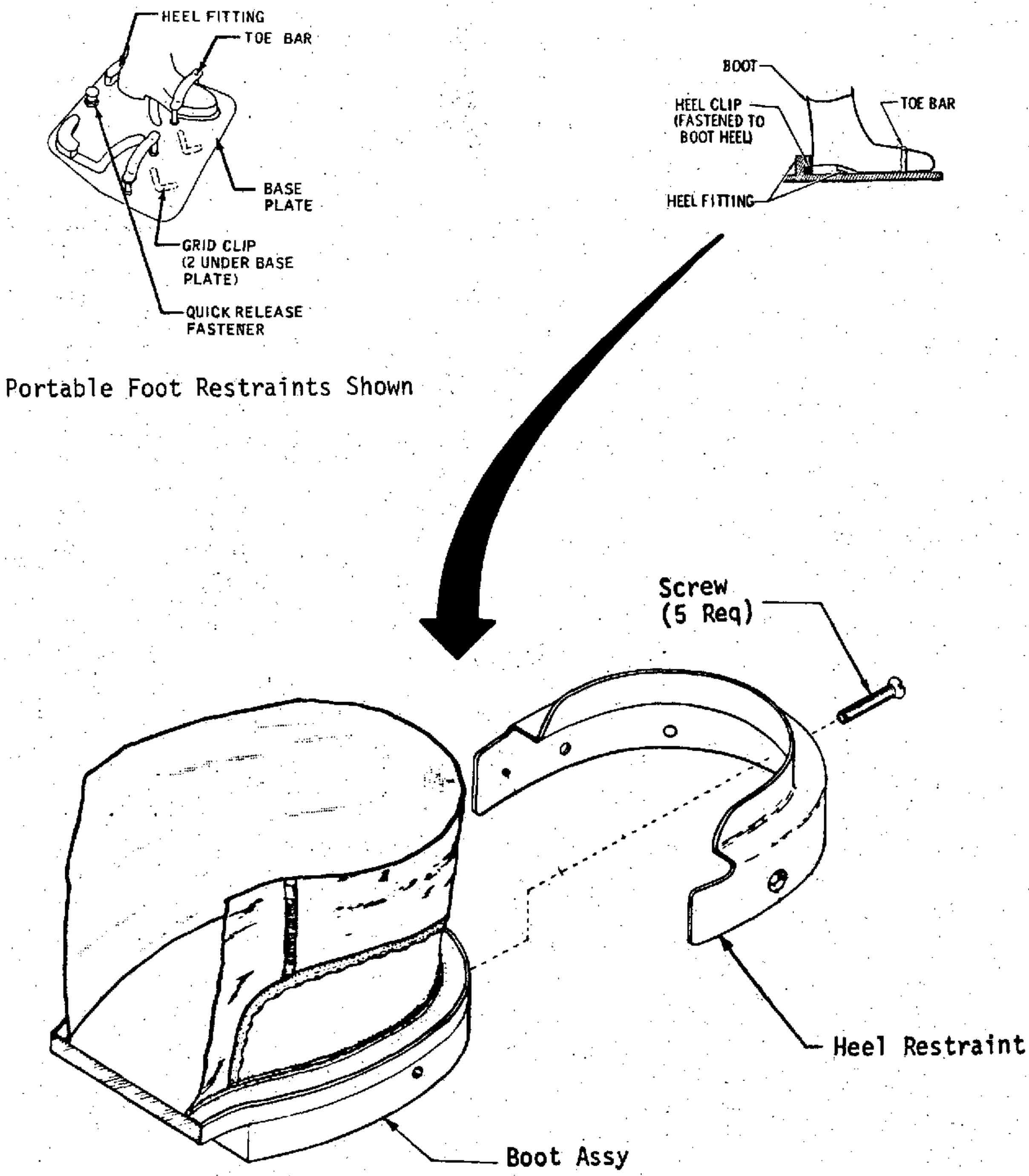

FIGURE 1.1-10: Boot-to-Restraint Interface

TABLE 1.1-2: Skylab EVA Foot Restraint General Specifications

DESIGN PARAMETER	DESIGN REQUIREMENTS/REMARKS
SECURITY	EVA foot restraints shall maintain foot position to allow the crewman a complete range of motion (roll, pitch, yaw) within the constraints of the spacesuit.
RESTRAINT SPACING	• Center to center distance = 25.4 to 43.2 cm. (10.0 to 17.0 in.). • Center dimension shall be determined from analysis of the tasks to be performed.
LOAD CAPACITY	• Ultimate design load = 623 N. (140 lbs.) min. in tension and shear. • Torsion = 203 N-m (1800 in-lb) min.
TEMPERATURE (LOCATION)	Maximum allowable temperature for EVA foot restraints shall be compatible with the space suit being used.
LOCATION	Foot restraints shall be located at all EVA and IVA worksites requiring performance of the following tasks: • Repetitive tasks requiring the use of one or both hands • Long term monitoring tasks • Tasks requiring close control of body position
HAZARDS	Foot restraints located within 30.5 cm. (12 in.) of equipment where failure would cause injury to the crewman will be identified in accordance with SC-M-0003. Potential areas of damage to flight equipment by the crewman will also be identified.
MATERIAL	Metals shall be the primary material for foot restraint fabrication. Other rigid or semirigid materials may be used when warranted by design constraints. Materials must be approved in accordance with NHB 8060.1.

1.1.3 TEMPORARY STOWAGE HARDWARE--SKYLAB EQUIPMENT HOOKS AND S082 CAMERA RESTRAINT

A. Purpose

Equipment stowage hooks and an S082 camera restraint container were used by Skylab EVA crewmen to aid in handling photographic equipment during retrieval/replacement operations. The units provided temporary stowage during multiple camera handling activities at three (3) external work-sites.

B. Functional Description and Support Hardware

The Skylab equipment hooks (Figure 1.1-11) provided temporary stowage capability at two (2) EVA workstations. Tasks at each workstation involved handling untethered packages/modules where a "third hand" was mandatory to avoid possible loss of equipment into space. The units were essentially a large eye hook with a section of the eye spring-loaded to facilitate easy and positive loading. A thumb actuated lock secured the spring-loaded eye section to prevent inadvertent package dislodging (Figure 1.1-12).

A box-like camera restraint provided temporary stowage of a solar astronomy camera during retrieval and replacement activities at the Skylab sun end workstation (Figure 1.1-13). The container also provided thermal and radiation protection for the cameras to avoid film damage. The entrance to the container was "funnel-shaped" for ease of camera insertion. The camera was held in the container by four (4) flexible Lexan 9030-112 strips (Figure 1.1-14).

C. Performance Data and Application to Future Programs

The temporary stowage devices were used routinely on all planned EVAs on Skylab. The equipment stowage hooks were especially helpful furing film magazine handling and were used extensively for Skylab unplanned EVAs.

Future EVA missions in which the crewman handles several articles at a worksite may require temporary restraint/stowage devices. Temporary stowage devices may also enhance EVA maintenance tasks where several hand or power tools are required. Since loose articles must be restrained in zero-gravity, EVA tasks should be studied individually to determine the type and quantity of restraints required.

D. Specifications and Design Data

The solar astronomy camera stowage/restraint container consisted primarily of a rectangular aluminum box open at one end. The unit was designed to accept one specific camera configuration. Requirements for similar devices would necessitate a set of unique dimensions for each module; therefore, specifications for the Skylab unit are not given.

General specifications and design requirements for the Skylab temporary stowage hooks are shown in the table below. Detailed design data can be found from the drawings listed in paragraph E.

PARAMETER	DESIGN REQUIREMENTS/REMARKS
DIMENSIONS	24.4 x 7.7 x 2.5 cm. (9.6 x 2.9 x 1.0 in.)
WEIGHT	.22 kg. (.49 lbs.)
DESIGN LOAD LIMIT	34.0 kg. (75 lbs.) in any direction
OPERATION	Unit must allow one-handed operation by a suited crewman
MATERIAL	Aluminum

E. Supplementary Information

Documentation:

- Skylab Operations Handbook, Apollo Telescope Mount; Martin Marietta Corp., Contract NAS 8-2400, Volume I, 27 March 1972

Drawing/Part No.:

- Stowage Hook - 10M050123
- Restraint Container - 10M04869 (Assy.), 10M04868

Item Developed By:

- Stowage Hook - NASA/Marshall Space Flight Center
- Restraint Container - NASA/Marshall Space Flight Center

Item Supplied To:

- Stowage Hook - McDonnell Douglas Astronautics Co., Eastern Division
- Restraint Container - Marshall Space Flight Center

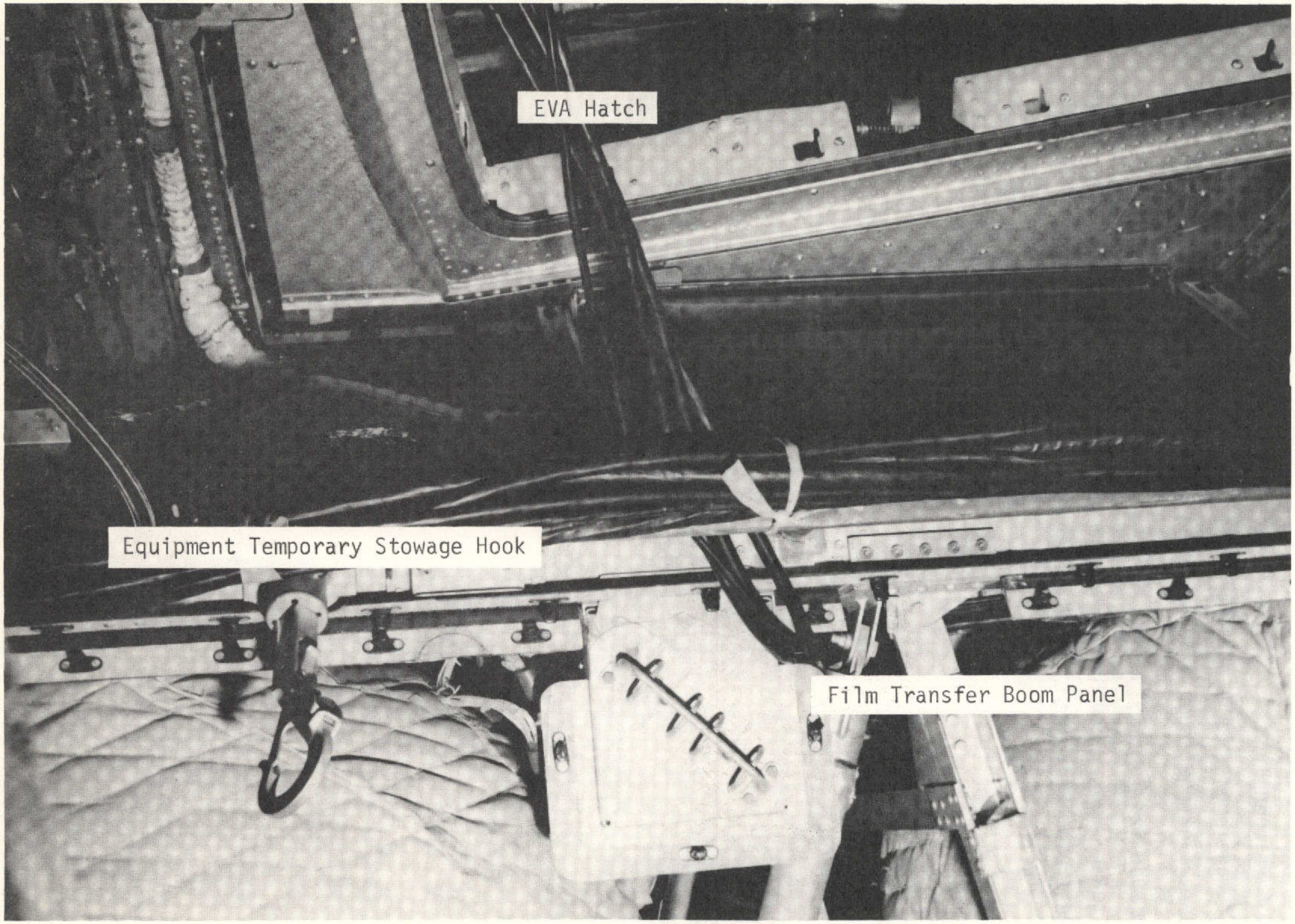

FIGURE 1.1-11: Skylab Temporary Equipment Stowage Hook--Fixed Airlock Shroud Workstation

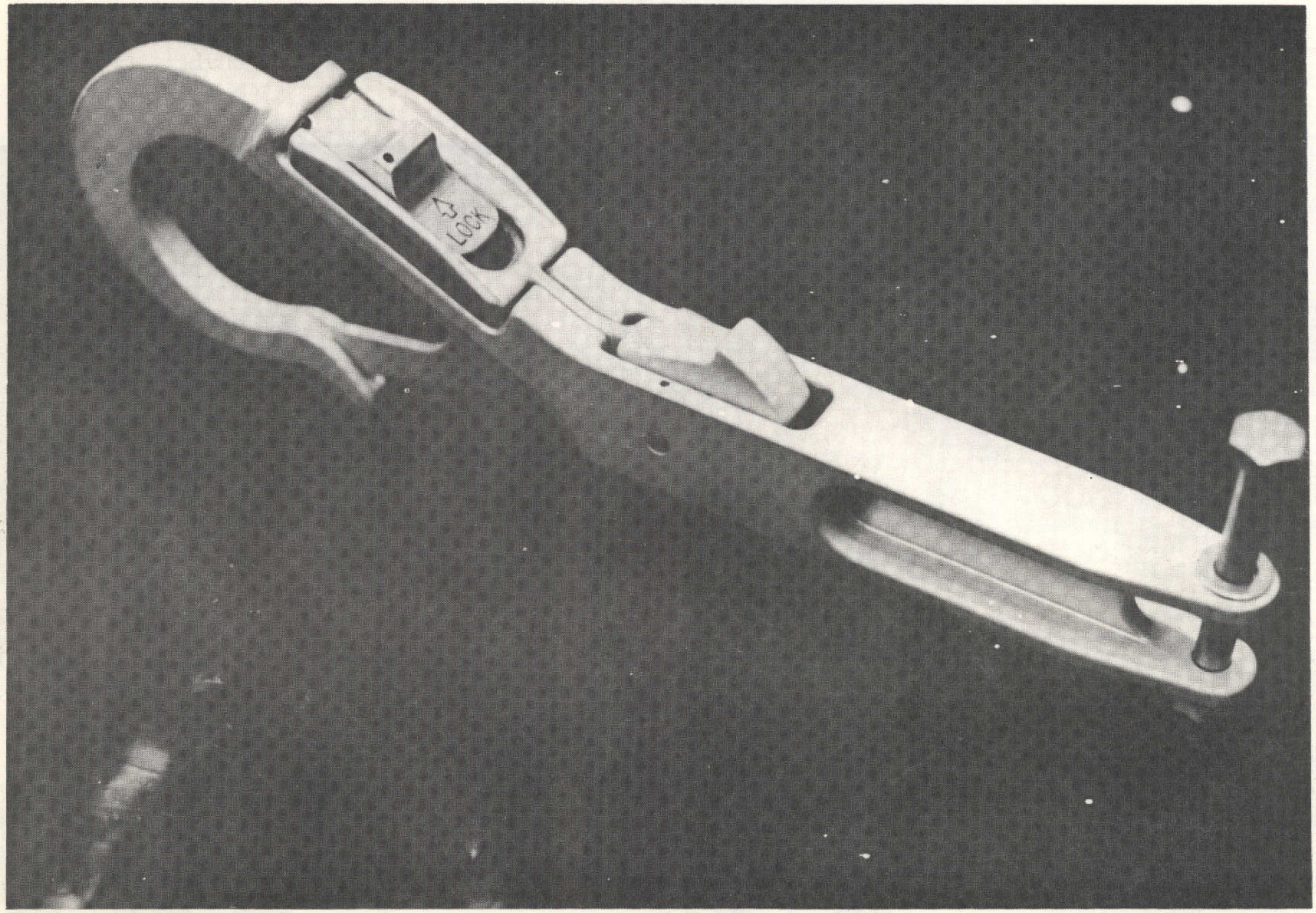

FIGURE 1.1-12: Temporary Stowage Hook Locking Arrangement

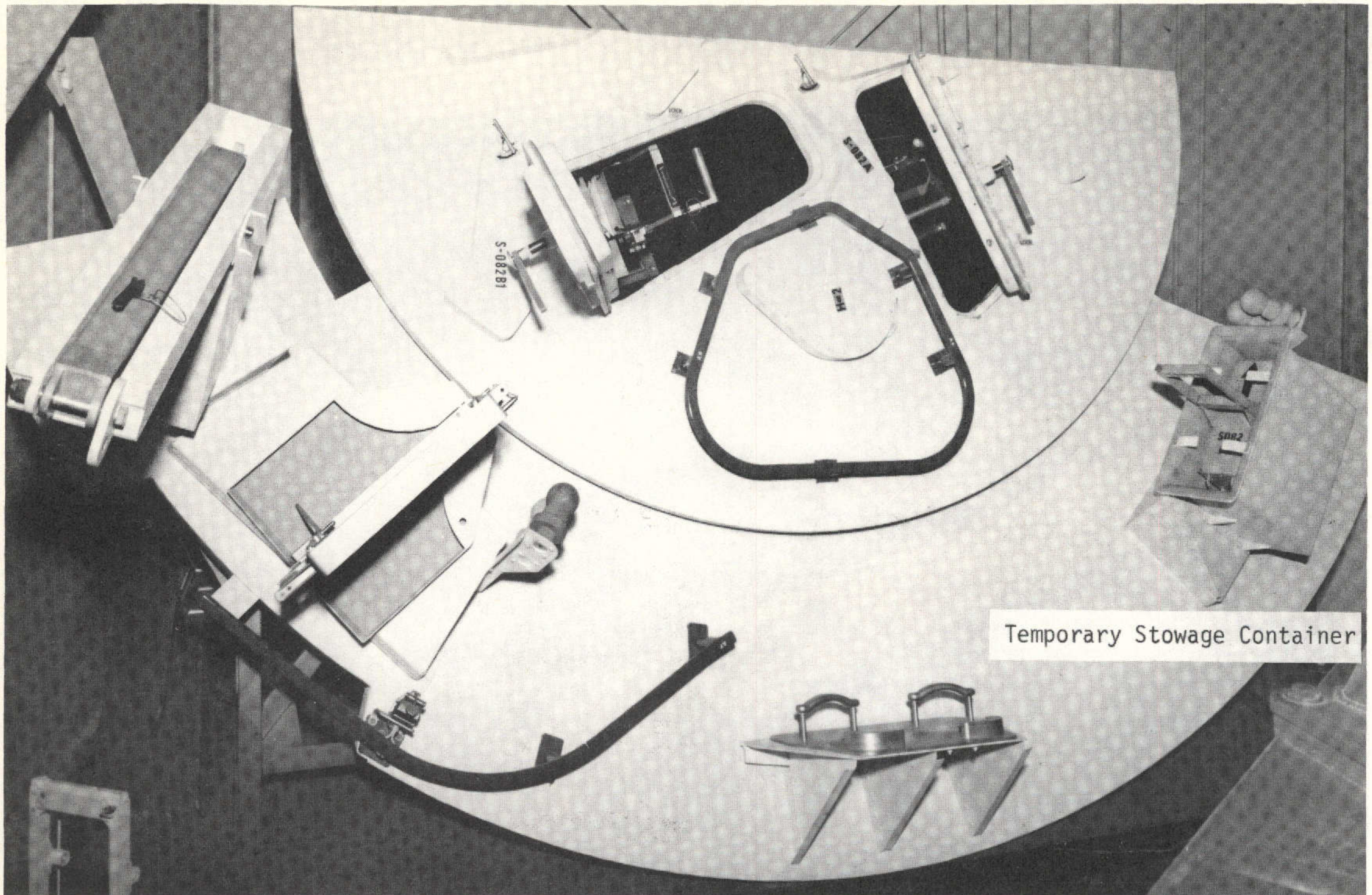

FIGURE 1.1-13: Skylab Temporary Stowage Container For Solar Astronomy Cameras

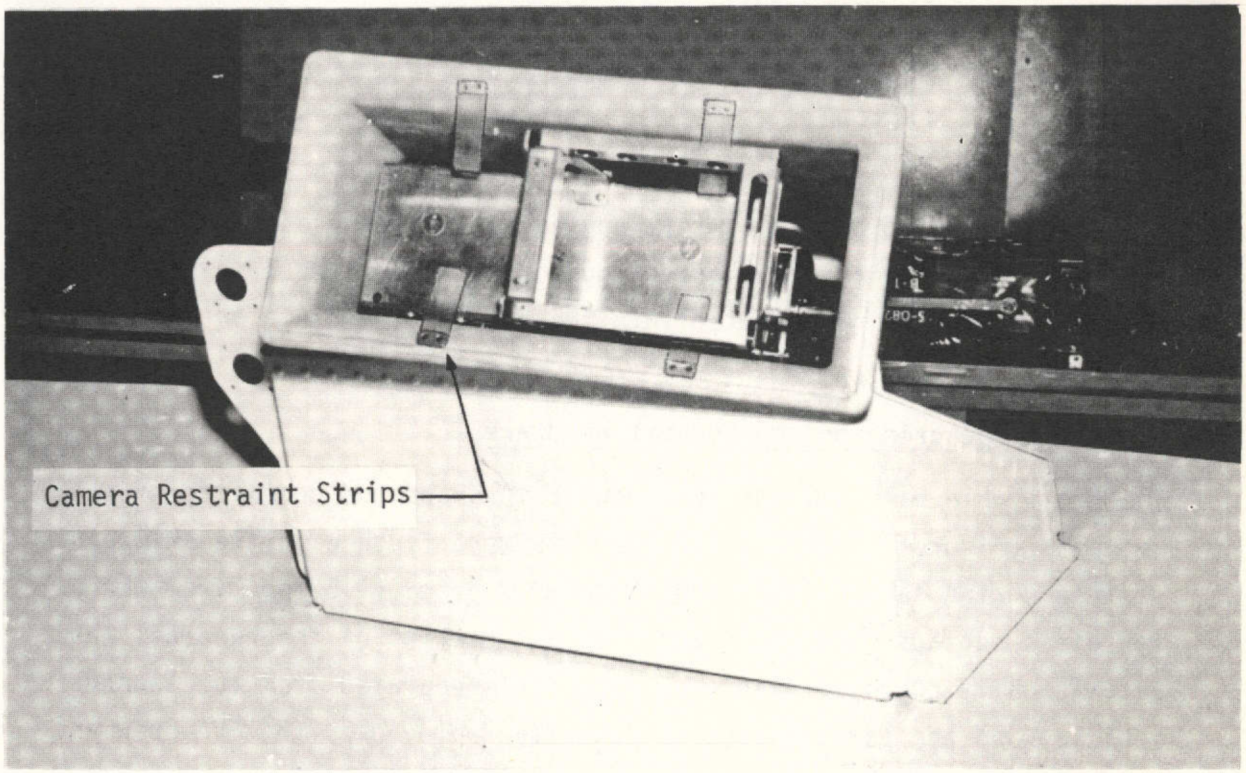

FIGURE 1.1-14: Stowage Container Entrance and Restraining Strips

1.1.4 DEPLOYABLE HANDRAIL AND PIP PIN RESTRAINT DEVICES--GEMINI

A. Purpose

The deployable handrail and the pip pin restraint were two devices among those investigated on the Gemini Program for crewman restraint, orientation and translation development purposes. The items or derivatives thereof have been incorporated into the design of systems on more recent programs.

B. Functional Description and Support Hardware

The deployable handrail was rectangular in shape and consisted of two segments (Figure 1.1-15). Both segments were flush with the skin of the vehicle during launch, and were extended 3.8 cm. (1.5 in.) from the vehicle's surface when deployed. The aft section of the handrail was automatically deployed when the spacecraft separated from the launch vehicle, and the forward section manually deployed by the EVA crewman.

The pip pin restraint devices consisted of a conventional pip pin with a ball-detent type mechanism for attachment to the spacecraft. The T-shaped pip pins were 7.6 cm. (3 in.) wide for utilization as handholds, and a D-ring with an inside diameter of 4.4 cm. (1.75 in.) incorporated for tether attachment (Figure 1.1-16). The pip pins interfaced with the vehicle via receptacles on the vehicle. Antirotational devices were installed over several receptacles to prevent rotation of the pins (Figure 1.1-17), where undesirable.

C. Performance Data and Applications to Future Programs

The rectangular handrail configuration, first introduced on the Gemini Program, proved to be the best design for crewman orientation and stabilization during translation. The handrail basic configuration was incorporated into both the Apollo and Skylab Programs. The pip pins were flown only once for evaluation purposes. The results were favorable; however, there were no further requirements for such devices on the Apollo or Skylab EVA Programs.

Vehicle configurations have allowed fixed handrails to replace deployable types; however, the deployable feature could be useful to payload designers if the projection of fixed handrails interferes with payload operations. The pip pin concept offers interesting applications for future programs. If a number of holes were provided at strategic locations on the vehicle and payloads, equipment or restraints could be positioned at the desired location during a mission. This would enable the crew to perform contingency as well as planned EVAs.

D. Specifications and Design Data

		RECTANGULAR HANDRAIL		PIP-PINS
		FORWARD SECTION	AFT SECTION	
MATERIAL		Metal (Al.)	Metal (Al.)	Aluminum
SURFACE		Painted	Painted	Anodized
LENGTH	cm.	53	117	See Figure 1.1-16 for approximate size
	in.	21	46	
CROSS SECTION	cm.	13.9 x 31.8	13.9 x 31.8	See Figure 1.1-16 for configuration
	in.	.55 x 1.25	.55 x 1.25	
MECHANISM		Manually deployed	Automatically deployed	• Standard pip-pin device • Ball detents for attachment • Actuator-spring loaded push-button

E. Supplementary Information

- Summary of Gemini Extravehicular Activity, NASA SP-149, 1967
- Gemini Summary Conference, NASA SP-138, Feb. 1-2, 1967

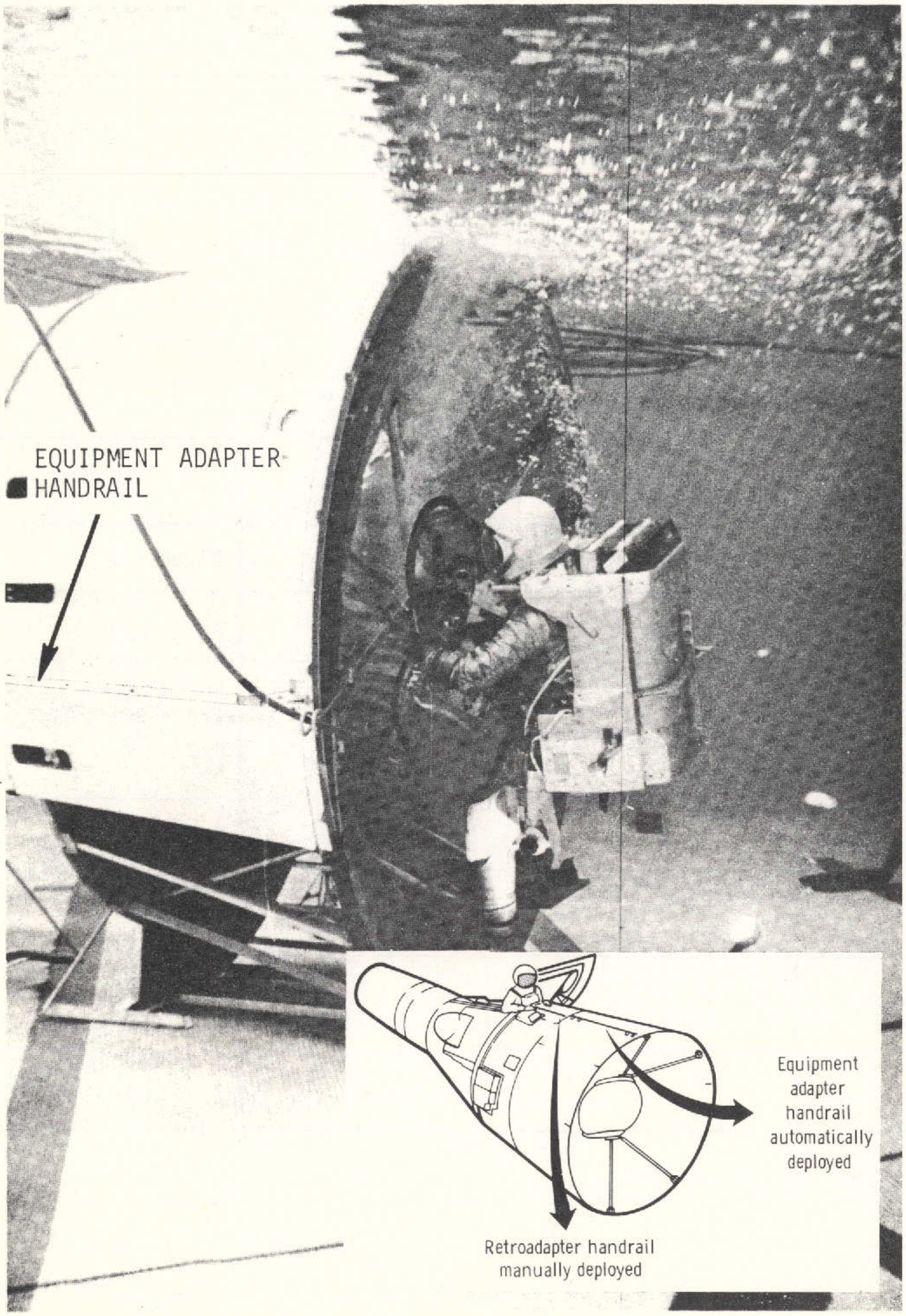

FIGURE 1.1-15: Gemini Deployable Handrail--Water Immersion Task Simulation

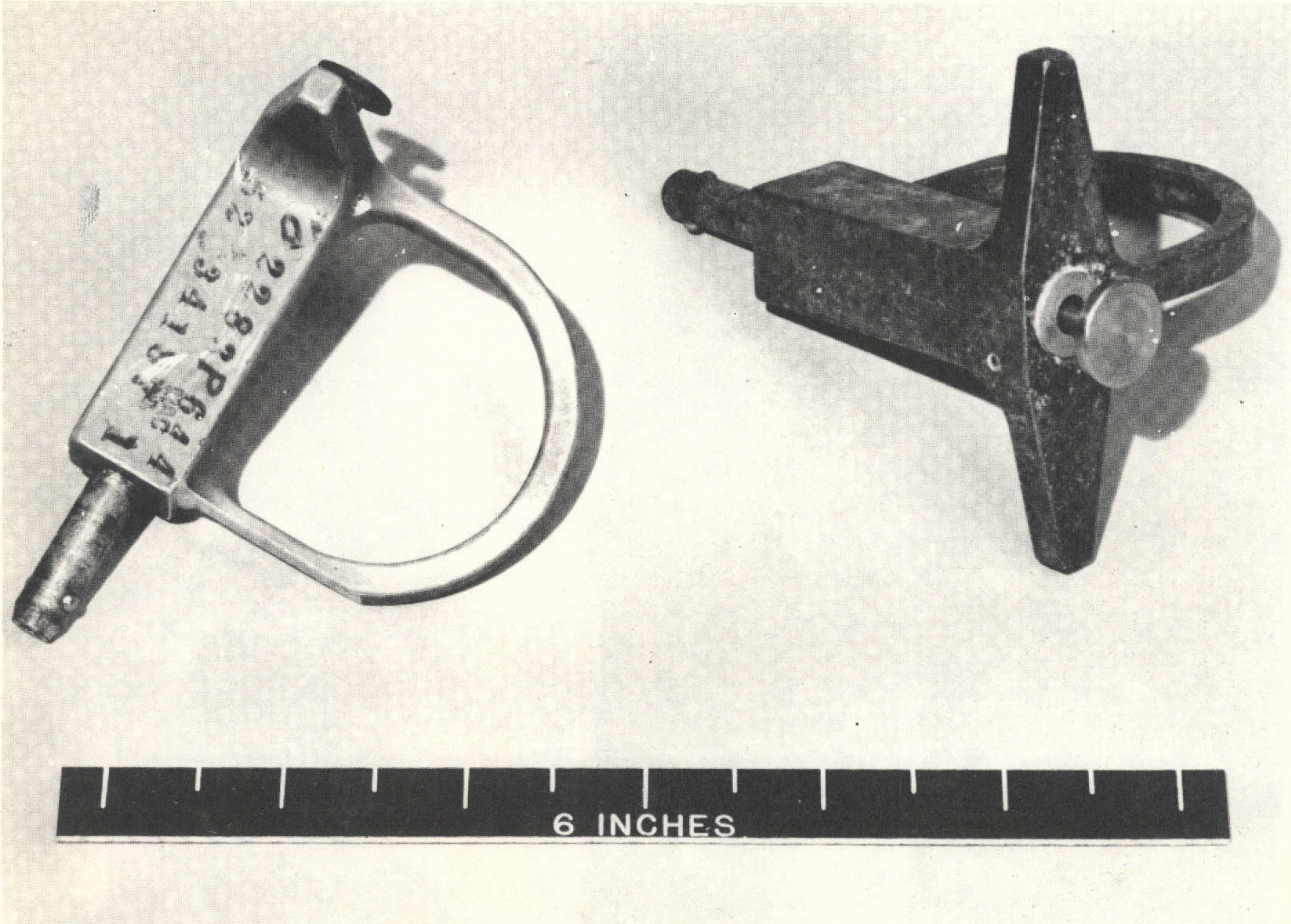

FIGURE 1.1-16: Gemini Pip Pin Restraint Device

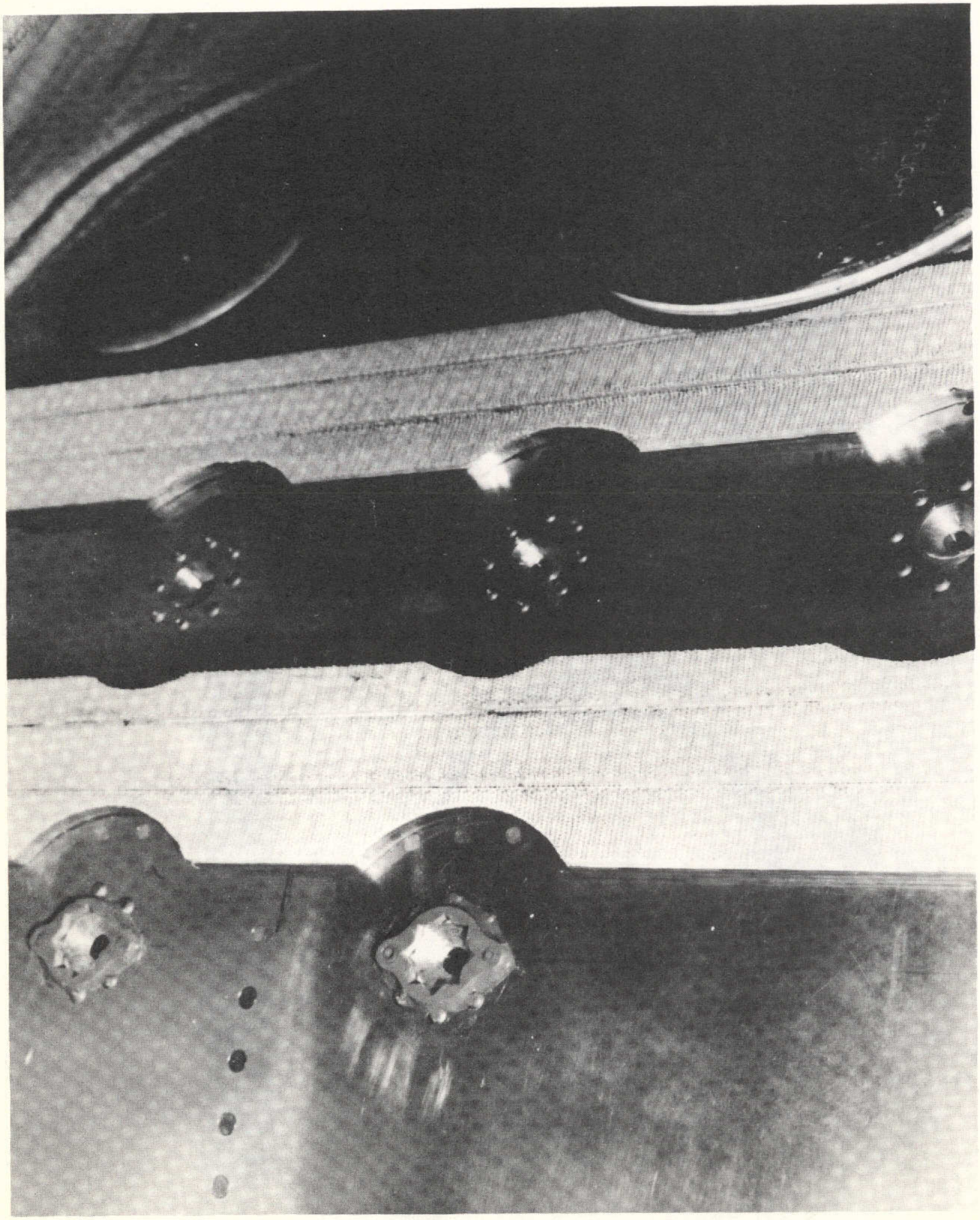

FIGURE 1.1-17: Gemini Pip Pin Receptacle on Vehicle Surface

1.1.5 TETHERS - WRIST, WAIST--APOLLO, SKYLAB

A. Purpose

Wrist tethers were initially designed for the Gemini Program to secure film cassettes to the wrist of the EVA crewman during translation. The waist tethers were designed to tether the EVA crewman to the vehicle at a worksite. The tethers served the same purpose on the Apollo and Skylab Programs and were also used as temporary EVA equipment stowage devices.

B. Functional Description and Support Hardware

The wrist tether consists of a cloth webbing strap approximately 25.4 cm. (10 in.) long with a tether hook attached to one end and a trigger snap hook to the other (Figure 1.1-18). The tether hook had a positive locking device to prevent inadvertent detachment of the tether. The trigger snap hook was designed to attach to a cloth loop on the wrist of the crewman's pressure suit and would also interface with small parts or equipment. Both types of hooks could be operated by a suited crewman.

The waist tether was similar to the wrist tether with a webbing strap and tether hooks on both ends (Figure 1.1-19). One of the end hooks was identical to the wrist tether hook with a larger hook at the opposite end. The large hook had a similar type of positive locking device and a mechanism which allowed the length of the webbing strap to be adjusted. The overall length of the extended waist tether was approximately 1.2 m. (48 in.)

C. Performance Data and Applications to Future Programs

The tethers proved very useful on the Apollo and Skylab Programs. The units were simple in design, easy to operate, and served the necessary function of securing equipment to prevent free-floating into space. The second Skylab crew felt that extra tethers should be accessible during EVA. The units should have many applications on Space Shuttle and future programs.

D. Specifications and Design Data

	WRIST		WAIST	
	S.I.	Conventional	S.I.	Conventional
WEIGHT	.174 kg.	.38 lb.	.226 kg.	.5 lb.
STRAP LENGTH	25.4 cm.	≈10 in.	N/A	N/A
OVERALL LENGTH	N/A	N/A	124 cm.	≈48 in.
LOAD CAPABILITY*	2610 N.	585 lbs.	2610 N.	585 lbs.
STRAP MATERIAL	Beta Cloth		Beta Cloth	
TETHER HOOK MATERIAL	Aluminum		Aluminum	
TRIGGER SNAP MATERIAL	Brass		--	

* Along longitudinal axis

E. Supplementary Information

Documentation:

- Skylab Operations Handbook, Apollo Telescope Mount; Martin Marietta Corporation, Contract NAS 8-2400, MSFC-205, Volume I, 27, March 1972.
- Functional Design Requirements for Manned Spacecraft Extravehicular/ Intravehicular Activity Support Equipment, SC-E-0006, Johnson Space Center, December 1972

Drawing/Part No.:

- Wrist Tether Drawing No.: SEB 33100852
- Waist Tether Drawing No.: SEB 33100192

Item Developed by:

- Engineering and Development Directorate, Crew Systems Division, NASA-Johnson Space Center

FIGURE 1.1-18: EVA Wrist Tethers Used on Apollo and Skylab

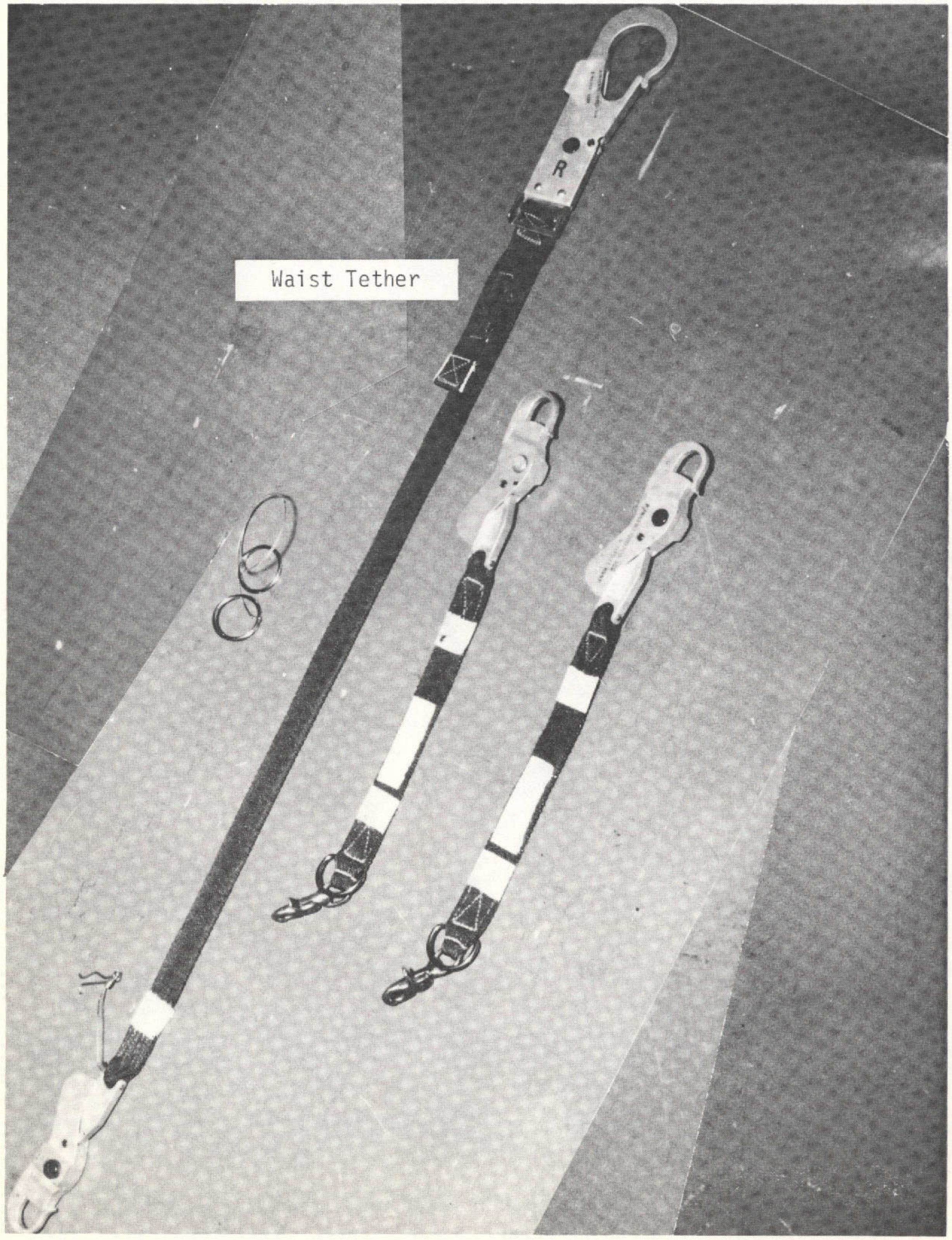

FIGURE 1.1-19: Waist and Wrist Tethers Used During EVA

SECTION 1.2: CREW AND EQUIPMENT TRANSFER SYSTEMS

Descriptive information on the methods and systems used on previous space programs to transfer EV crewmen and their equipment to the EVA worksites are provided in this section. One of the most frequently used means of EV crewman translation on orbital and transearth space missions was handrails and handholds. These items were discussed in Section 1.1. Other methods of transporting cargo/equipment between vehicle modules involved extendible booms and endless "Brookland" clotheslines. Crewman maneuvering units of the "backpack" configuration were evaluated on Skylab. These units offer a means of transporting both the crewman and equipment to external areas of the vehicle and to free-flying satellites.

Section 1.2 contains information on the following equipment:

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1.2.1 FILM TRANSFER BOOM--SKYLAB

A. Purpose

The film transfer booms were developed for the Skylab Program to aid in transferring equipment between workstations during planned extravehicular activities.

B. Functional Description and Support Hardware

The extendible boom (Figure 1.2-1) hardware mounted directly outside the Skylab EVA airlock with the loading hook accessible from an EVA workstation. The booms were designed to be electrically driven; however, a handle was provided for manual backup operation, if necessary. A control panel was mounted on the vehicle exterior and operated by an EVA crewman while secured in his foot restraints (Figure 1.2-2). The controls only allowed the crewman to extend or retract the booms (the rate of travel was constant). Skylab was supplied with three booms: Two were routinely used; one was for backup purposes only. The three booms were identical and could be easily interchanged by an EV crewman; however, the EV crewmen could not change the angle of travel of the Skylab booms. Each boom receptacle was permanently fixed to the vehicle at the required angles for planned operations.

A hook for retaining cargo (Figures 1.2-1 and 1.2-3) was provided for each boom and attached to the boom extension members by a crewman during EVA.

C. Performance Data and Applications to Future Programs

The booms performed well on the Skylab vehicle. No mechanical or electrical problems were reported by the crew members. Several crew members have commented that the boom performance was better than anticipated and the dynamics were excellent.

Based on boom performance on the Skylab Program, application of the units to the Shuttle Orbiter may prove beneficial as crew and cargo translation aids, particularly inside the payload bay. Some important points should be considered to obtain more versatile application of the units than was required on Skylab: (1) The units may be mounted on a moveable base to support a number of payload/vehicle service locations; (2) booms can be fabricated in various extension lengths; (3) the booms can be transported on-orbit to various worksites by the EVA crewman; and (4) several units of various size, strength, and actuation modes have been space qualified.

D. Specifications and Design Data

General specifications on the film transfer booms are contained in Table 1.2-1 and overall dimensions shown on Figure 1.2-4. Detailed data can be obtained by consulting the documents referenced below.

E. Supplementary Information

Documentation:

- Skylab Operations Handbook, OWS, AM, MDA; McDonnell Douglas Astronautics Company, Contract NAS 9-11001, Volume I, MSC 04727, 27 January 1972.
- Skylab Operations Handbook, Apollo Telescope Mount; Martin Marietta Corp., Contract NAS 8-2400, Volume I, 27 March 1972.

Drawing/Part No.:

- Drawing No. 61V820001
- Procurement Specification No. 61B820001

Item Developed By:

Fairchild Hiller Corp.
Space and Electronics Systems Division

Item Supplied By:

McDonnell Douglas Astronautics Company
Eastern Division

Item Supplied To:

National Aeronautics and Space Administration
Marshall Space Flight Center

TABLE 1.2-1: Skylab Transfer Boom General Specifications

	UNITS OF MEASURE		REMARKS
	SI UNITS	CONVENTIONAL UNITS	
Dimensions	.55x.38x.37 m.	21.6x15.0x14.5 in.	For additional dimensions, see Figure 1.2-4
Weight	40.6 kg.	89.5 lbs.	
Rate of Boom Travel	16.5±2.5 cm/sec	6.5±1 in/sec.	At 294.3°K (70°F) and 26 volts
Element Configuration	N/A	N/A	Inside housing--2 flat ribbons on reels; as boom is deployed, ribbons curl together to form a tube with a figure 8 cross-section
Element Material	N/A	N/A	008 carbon type stainless steel (pre-stressed)
Boom Diameter	4.24 cm.	1.67 in.	Each loop
Maximum Extension	8.3 m.	327 in.	Includes mounting structure
Max. Allowable Deflection	.61 m.	24 in.	At full extension with lateral load
Max. Deviation	3.8 cm.	1.5 in.	From theoretical center line through boom exit housing
Max. Torsional Displacement	±15 degrees	±15 degrees	±15 degrees about boom center line within first 6.7 m (22 ft.)
Power Requirement	180 watts	180 watts	Extend or retract
System Reliability	N/A	N/A	R = .9998 (predicted)

TABLE 1.2-1: Skylab Transfer Boom General Specifications (cont'd.)

	UNITS OF MEASURE		REMARKS
	SI UNITS	CONVENTIONAL UNITS	
Weight (Boom Hook)	.145 kg.	3.187 lbs.	Boom hooks are detachable
Length (Boom Hook)	.30 m.	≈ 12 in.	
Boom Capability	N/A	N/A	Transport 56.7 kg. (125 lbs.) package when c.g. is within 25.4 cm. (10 in.) of boom center line
Man-Machine Interfaces			
• Manual Retract Handle	N/A	N/A	Push-pull lever device
• Boom Transport/Release Handle	N/A	N/A	Used by crewman to exchange units if boom fails
• Boom Hook	N/A	N/A	See Figure 1.2-3; used to attach cargo
• Boom Actuation Panel	N/A	N/A	See Figure 1.2-2; boom electrical control panel, standard toggle switches
• Electrical Connector	N/A	N/A	See Figure 1.2-5; used only if boom fails
• Manual Shift Knob	N/A	N/A	Shifts unit to manual backup mode

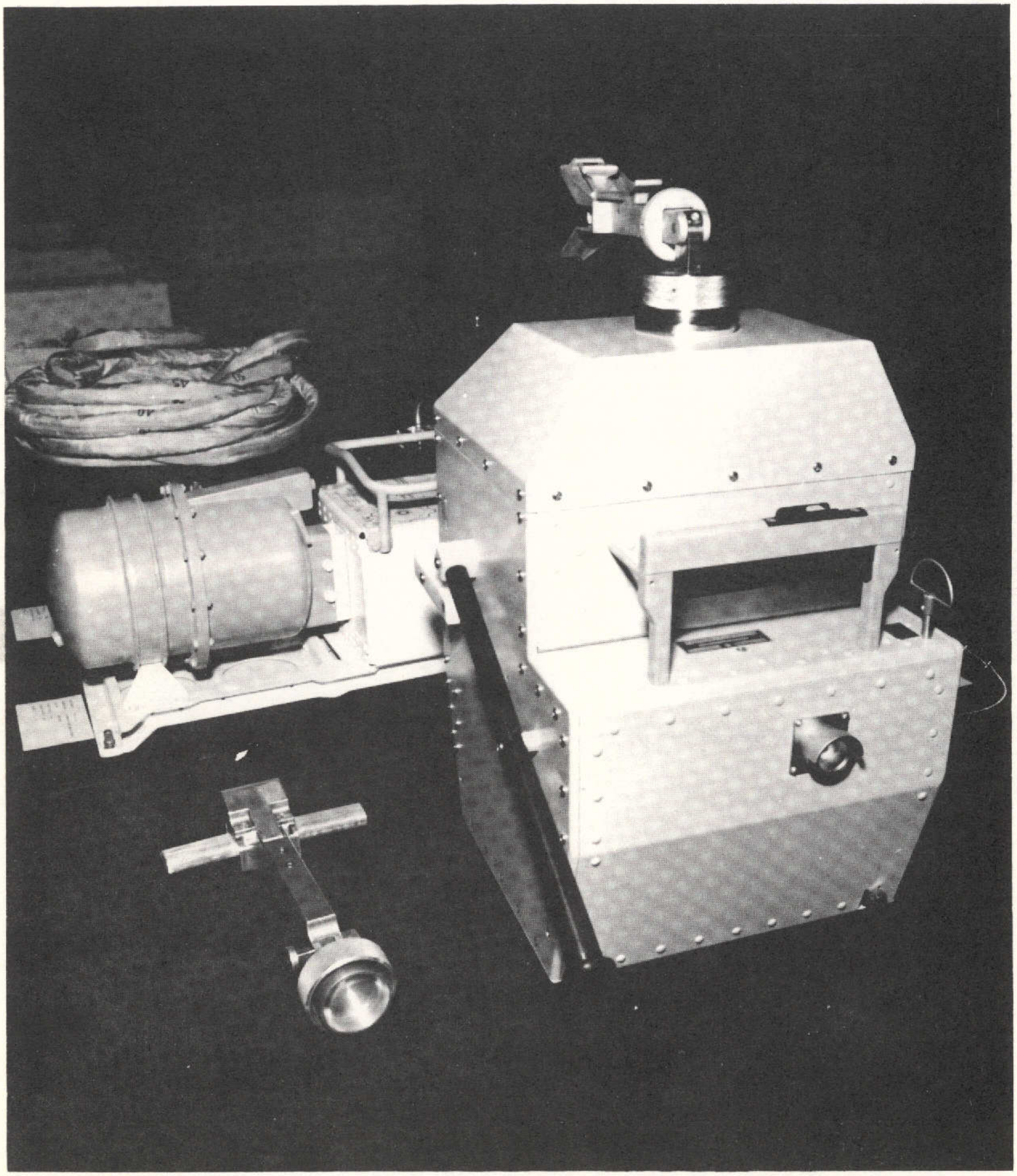

FIGURE 1.2-1: Film Transfer Boom Used On Skylab (Training Mockup)

FIGURE 1.2-2: Film Transfer Boom Control Panel Location

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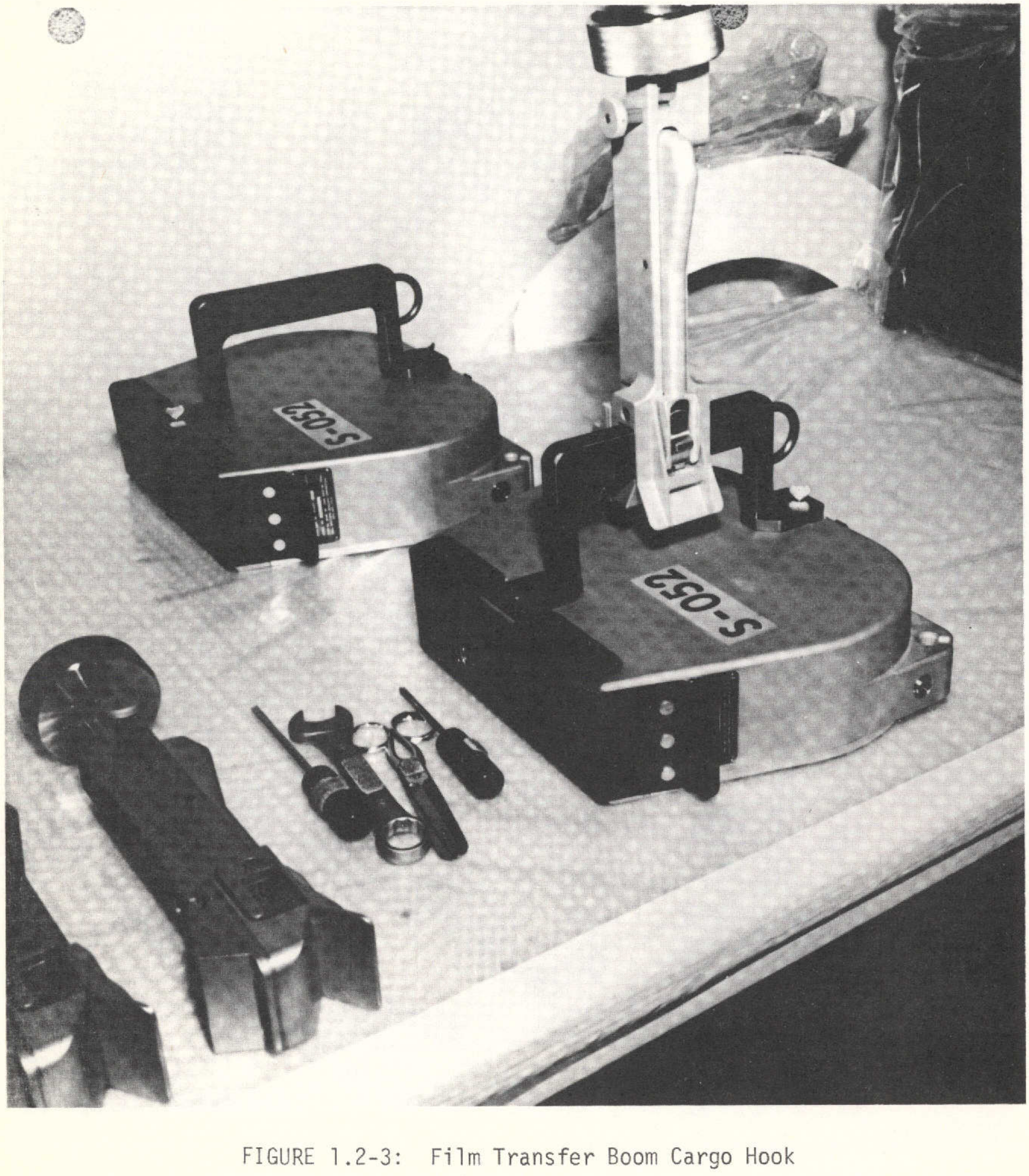
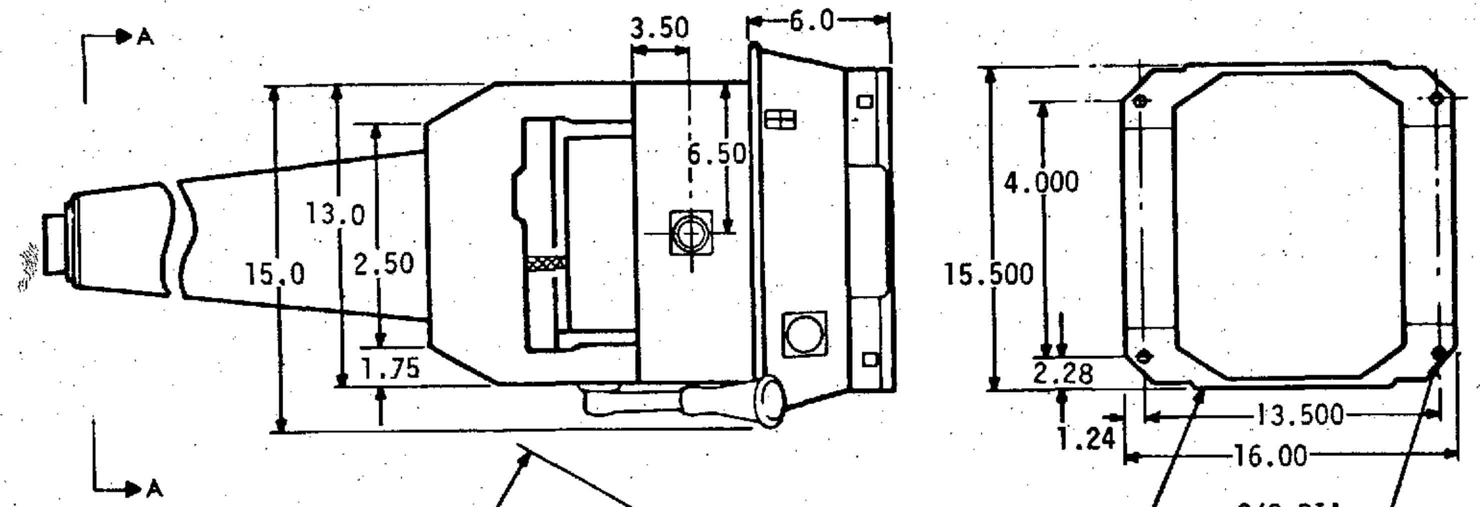


FIGURE 1.2-3: Film Transfer Boom Cargo Hook



CONVERSIONS	
CONVENTIONAL UNITS (in.)	SI UNITS (cm)
(3/8)	.95
(1.24)	3.15
(1.57)	3.99
(1.75)	4.45
(2.28)	5.79
(2.50)	6.35
(3.40)	8.64
(3.50)	8.89
(4.93)	12.50
(4.98)	12.65
(6.00)	15.24
(6.50)	16.51
(7.25)	18.42
(8.00)	20.32
(8.30)	21.08
(9.97)	25.32
(10.75)	27.30
(11.00)	27.94
(11.50)	29.21
(13.00)	33.02
(13.50)	34.29
(14.00)	35.56
(14.50)	36.83
(15.00)	38.10
(15.50)	39.37
(15.56)	39.52
(16.00)	40.64
(19.00)	48.26
(20.00)	50.80
(21.60)	54.86

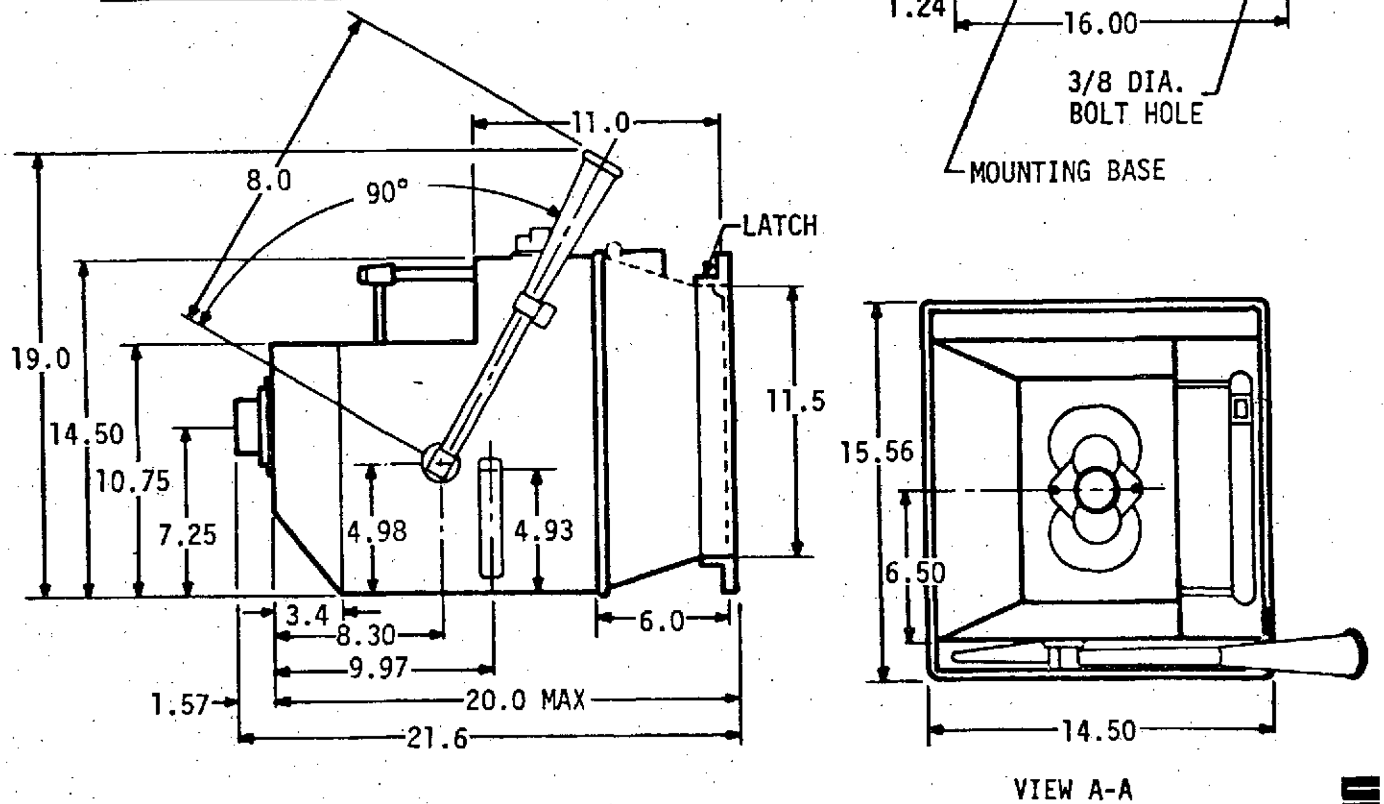


FIGURE 1.2-4: Film Transfer Boom Overall Dimensions

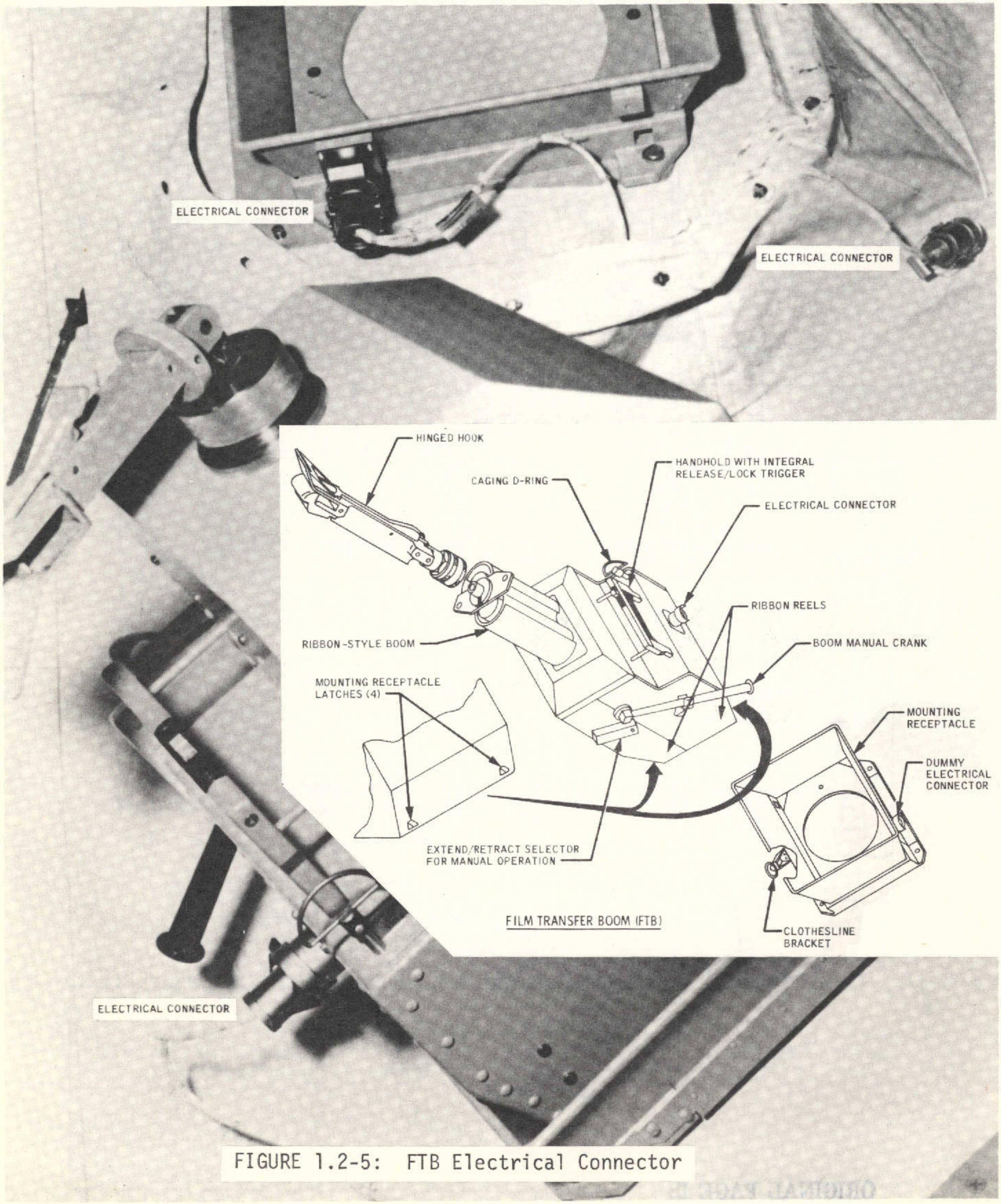


FIGURE 1.2-5: FTB Electrical Connector

1.2.2 CLOTHESLINE - SKYLAB

A. Purpose

The "endless" clothesline is a manually actuated cargo/package transfer device. Clotheslines were used as the prime cargo transfer method on the Apollo lunar mission to transport equipment between the Lunar Module (LM) and the lunar surface. They were used as a backup film magazine transfer system on the Skylab Program.

B. Functional Description and Support Hardware

The clothesline consists of a "closed loop" rope system with a set of hooks for cargo restraint and additional hooks for attachment to the spacecraft structure (Figure 1.2-6). All hooks were similar in design (Figure 1.2-7) and could be operated with one hand by a suited crewman. A thumb actuated lock was incorporated on the hooks to avoid inadvertent release. The hooks used to attach the clothesline to the structure were equipped with swivel rings to allow the line to slide through. The cargo retaining hooks were permanently affixed to the line at appropriate intervals for equipment attachment.

Hook attachment provisions were required on the spacecraft at the desired originating and termination points. On Skylab, the clotheslines were stowed in containers which allowed easy and tangle-free deployment by one EVA crewman. The final Skylab film magazine/camera retrieval operations were performed using the clothesline system (Figure 1.2-8).

C. Performance Data and Applications to Future Programs

The clothesline transfer system has proven to be an effective and economical means of transferring cargo between vehicle workstations during EVA operations. Its lightweight and simple design insures reliability and easy operation. No problems were encountered during Skylab deployment and operation. The system should be considered for use on future programs.

D. Specifications and Design Data

PARAMETER	UNITS	
	SI	CONVENTIONAL
WEIGHT	Not Available	Not Available
VOLUME (Including Container)	757.7 $cm.^3$	46.2 $in.^3$
DIMENSIONS (Container)	29.8x27.9x8.9 cm.	12.5x11.0x3.5 in.
EXTENSION LENGTH	8.5 - 10.0 m.	28 - 33 ft.
LINE DIAMETER	6.3 cm.	.25 in.
LINE MATERIAL: POLYBENZIMIDAZOLE (PBI)		

E. Supplementary Information

Documentation:

- Skylab Operations Handbook, OWS, AM, MDA; McDonnell Douglas Astronautics Company, Contract NAS 9-11001, Volume I, MSC 04727, 27 January 1962

Drawing/Part No.:

- Clothesline - 10M50133
- Container - 10M50301

Item Developed By:

National Aeronautics and Space Administration
Marshall Space Flight Center

Item Supplied To:

McDonnell Douglas Astronautics Company
Eastern Division

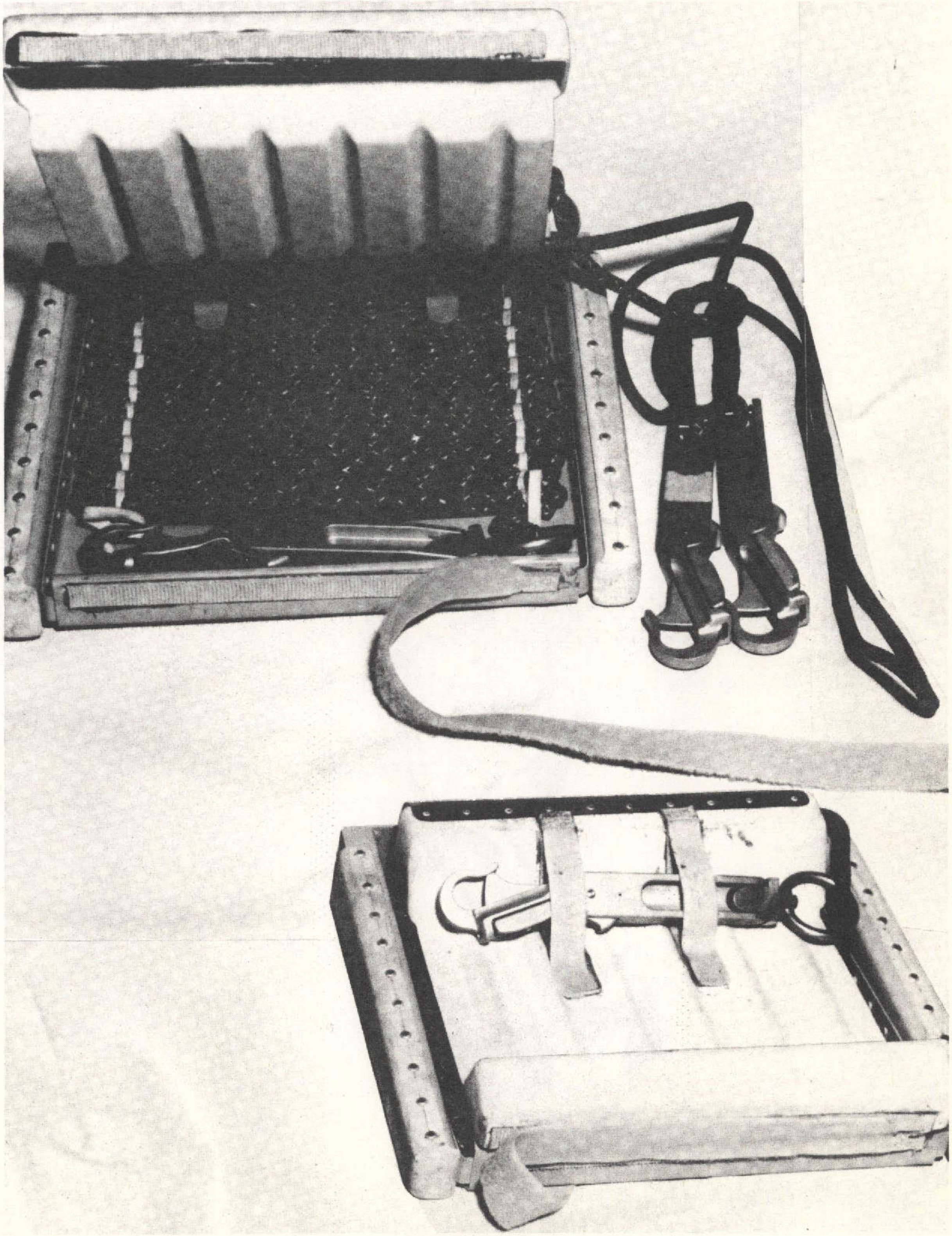


FIGURE 1.2-6: Clothesline Cargo Transfer System--Packaged Configuration

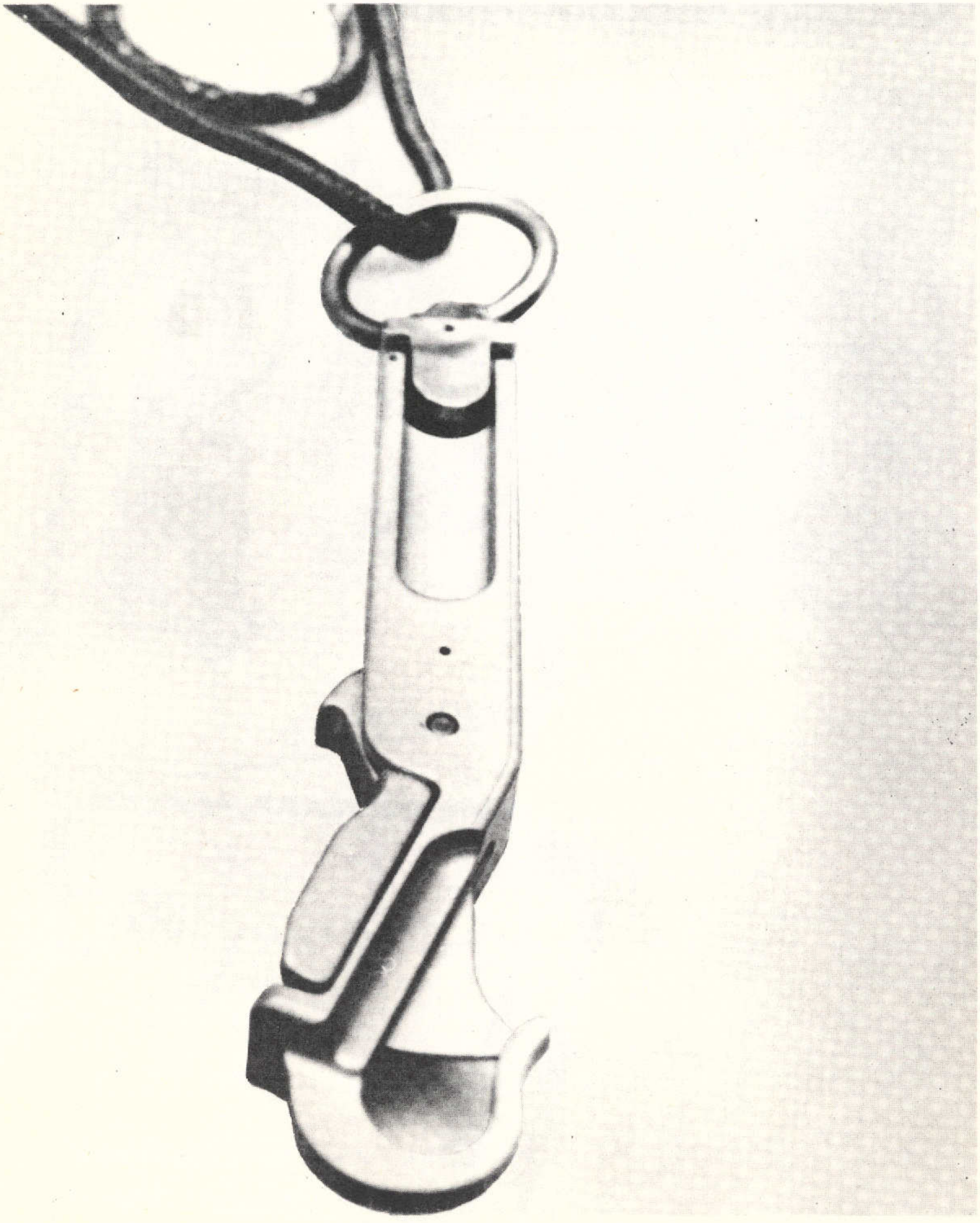


FIGURE 1.2-7: Attachment Hook--Clothesline Cargo Transfer System

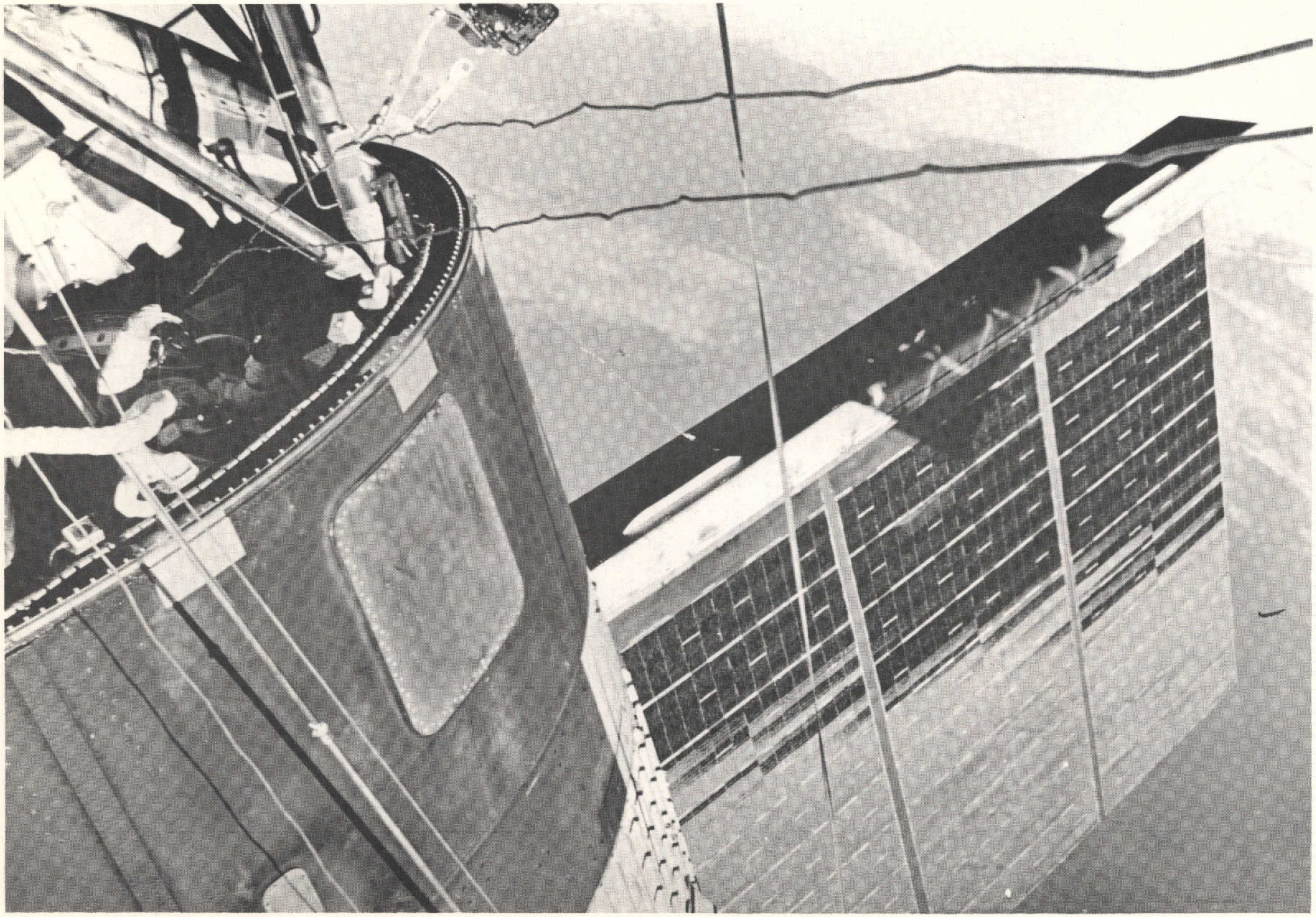


FIGURE 1.2-8: Skylab (SL-4) Clothesline Transfer System

1.2.3 ASTRONAUT MANEUVERING UNIT--M509

A. Purpose

The Astronaut Maneuvering Unit (AMU) was developed to aid the EVA crewman in translating to worksites external to the space vehicle and as a candidate to perform various operations. An experiment designated as M509 was performed on Skylab to evaluate the feasibility of manned maneuvering devices.

B. Functional Description and Support Hardware

The M509 experiment hardware (Figure 1.2-9) consisted of the automatically stabilized maneuvering unit (ASMU), a hand-held maneuvering unit (HHMU), and flight support equipment (FSE). The ASMU contained gyroscopes and a cold gas propulsion system for attitude and translation control (Figure 1.2-10), while the HHMU operated solely on a cold gas propulsion system (Figure 1.2-11).

The ASMU was a back-pack type unit which provided the crewman with control in three translation axes and included pitch, roll and yaw control (Figure 1.2-12). The unit contained a nitrogen bottle which supplied propellent to fourteen cold gas thrusters, and a rechargeable nickel-cadmium battery which powered the rate and control moment gyros. Two hand controllers allowed the crewman to control the translation and rotation of the unit (Figure 1.2-13).

The HHMU (reference Figure 1.2-11) was a completely manual hand-held propulsion device and contained one pusher and two tractor thrusters. The unit operated on nitrogen gas from the ASMU propellent tank. The crewman oriented the HHMU in the proper attitude and manually operated a throttle valve trigger for the desired thrust level and duration. A replaceable handgrip modified the unit for either suited or shirtsleeve operation. A rotary switch enabled the crewman to select one of four operating modes: HHMU; DIRECT; RATE GYRO; or CMG (control moment gyro). Adjustable straps secured the unit to the crewman.

A servicing station was provided to secure the unit during launch and on-orbit stowage and to provide a donning and doffing facility. Three spare propellent bottles were provided in addition to provisions for recharging the bottles on board the vehicle.

C. Performance Data and Application to Future Programs

The AMU performed extremely well on Skylab, particularly in the automatically stabilized control mode. The crew was capable of maneuvering with pin point accuracy and accomplished such tasks as translation, rotation, attitude hold, station keeping, docking, mass transfers, and tumble recovery. A total of 12.5 hours were logged on Skylab with 3 hours in the spacesuit mode.

Manned maneuvering units (MMU) are being developed for application to future programs (Figure 1.2-14). The units have the capability to provide access to exterior areas of space vehicles without permanent EVA mobility aids and to other free-flying satellites. Vehicle-to-vehicle rescue operations can also be accomplished with the units.

D. Specifications and Design Data

- Table 1.2-2: Skylab Astronaut Maneuvering Unit (AMU)--Experiment M509 General Data
- Table 1.2-3: CMG/Rate Gyro Performance Data
- Table 1.2-4: ASMU Thruster Performance Data
- Table 1.2-5: Advanced Manned Maneuvering Unit (MMU) Projected Characteristics

E. Supplementary Information

Documentation:

- Operational Data Book, NASA-Johnson Space Center, Skylab Program Office, MSC-01549, Vol. I, Revision A, 8 November 1972
- Preliminary Report on Skylab Experiment M509, Skylab Results and Future Applications, NASA-S-74-156B, Maj. C. E. Whitsett, Jr., 14 May 1974, Houston, Texas

Item Developed By:

Martin Marietta Corporation
Denver Division

Item Supplied To:

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center

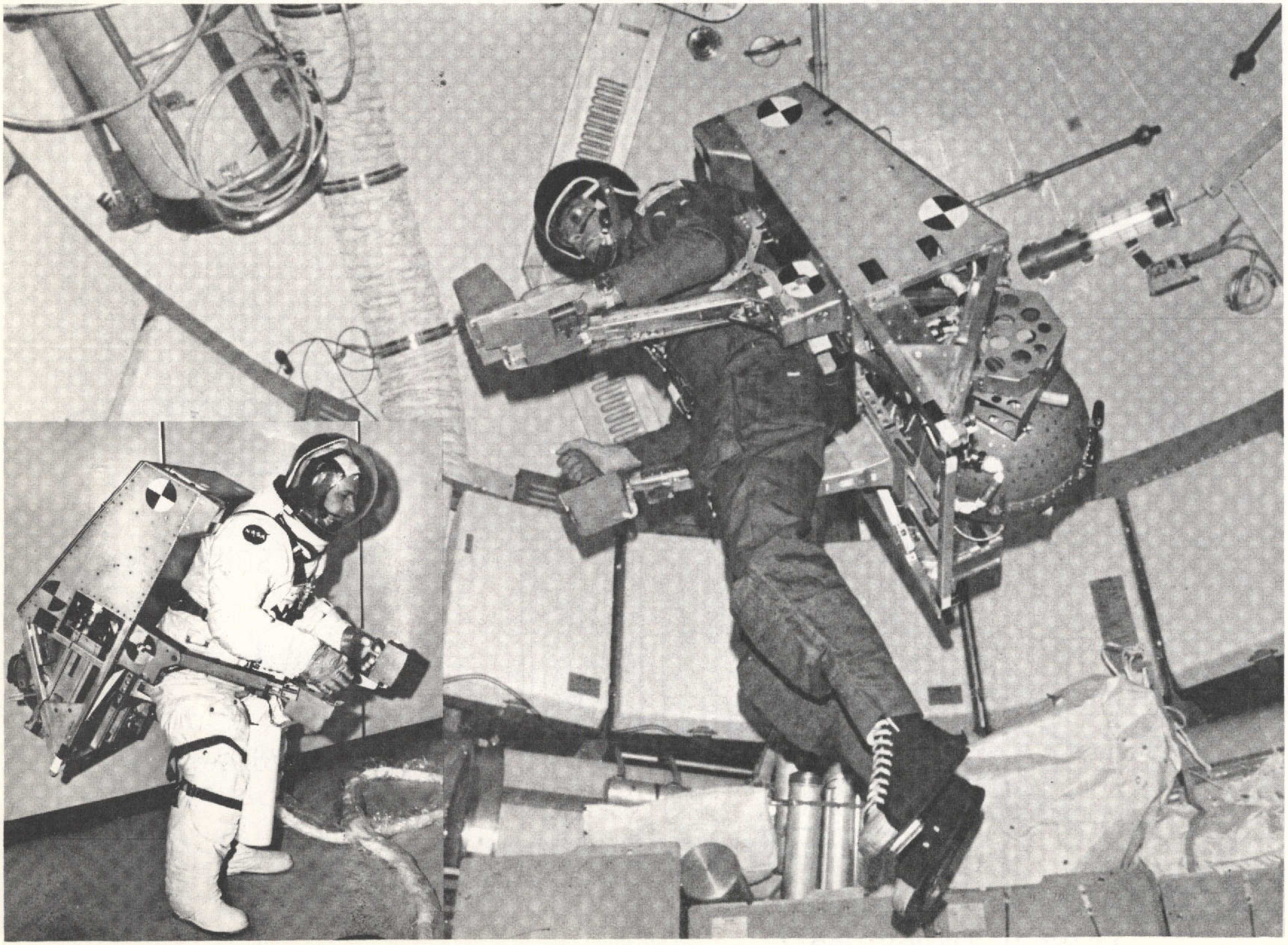


FIGURE 1.2-9: Automatically Stabilized Maneuvering Unit--M509 Experiment

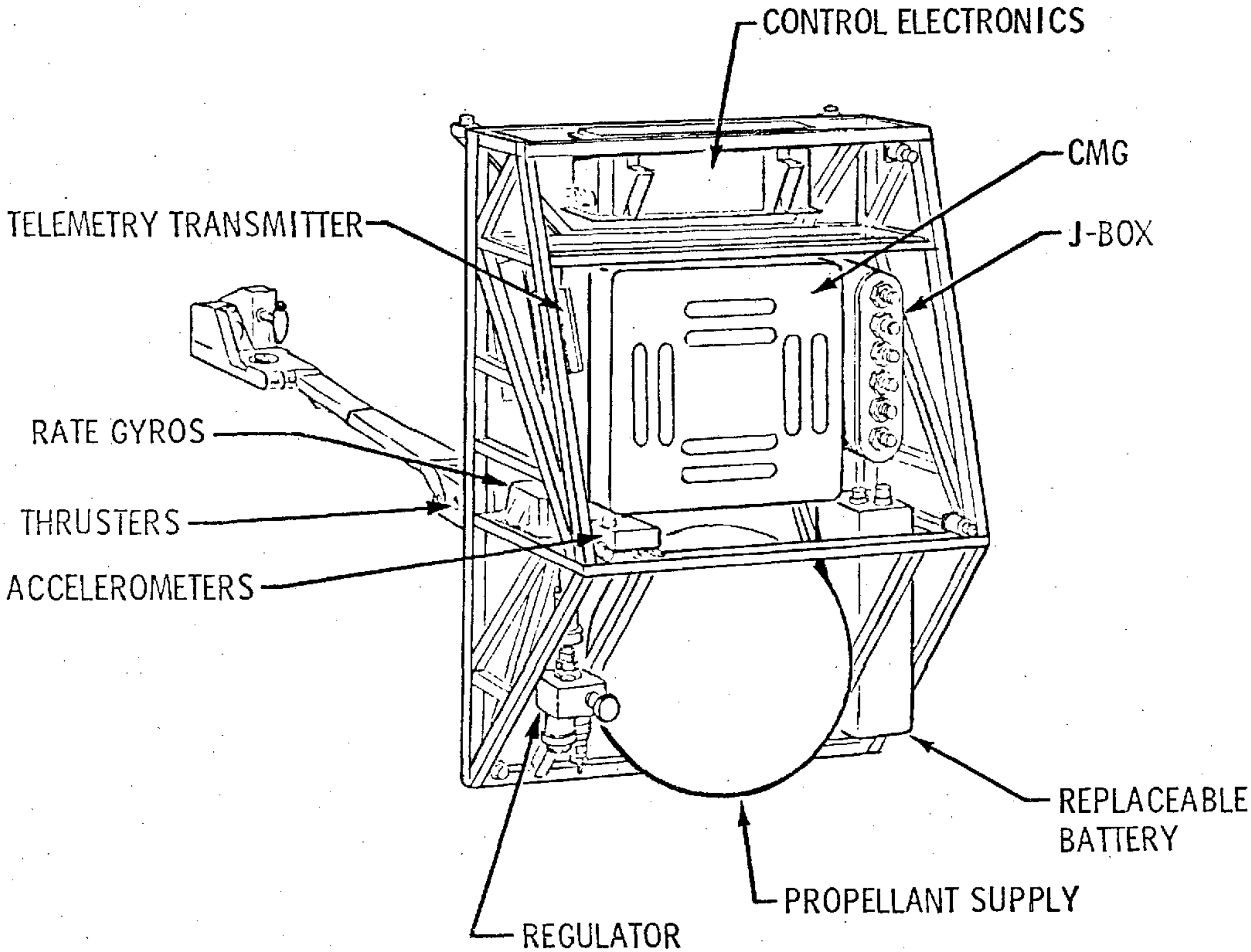


FIGURE 1.2-10: Skylab ASMU Major Components

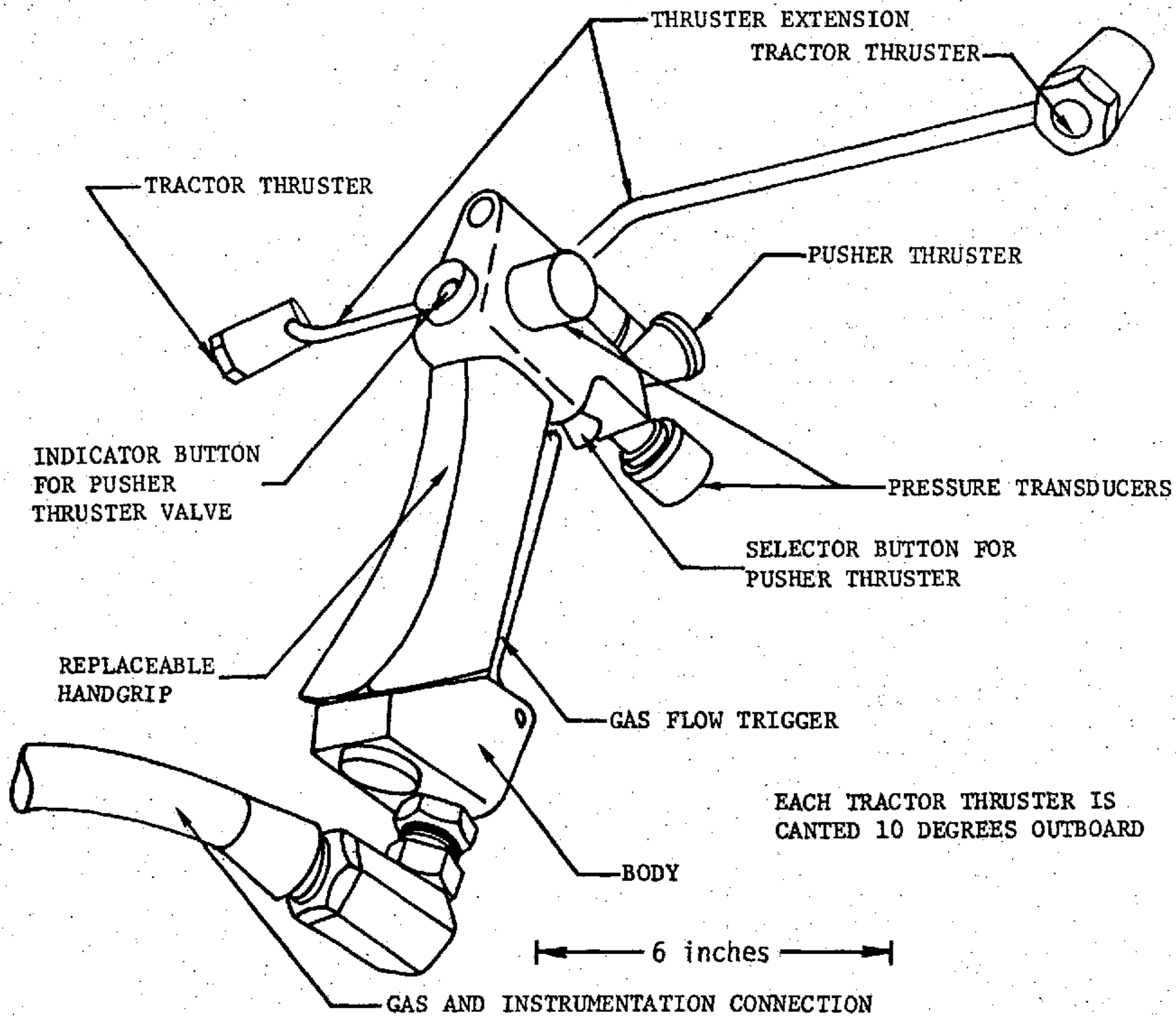


FIGURE 1.2-11: Hand-Held Maneuvering Unit for Skylab Program

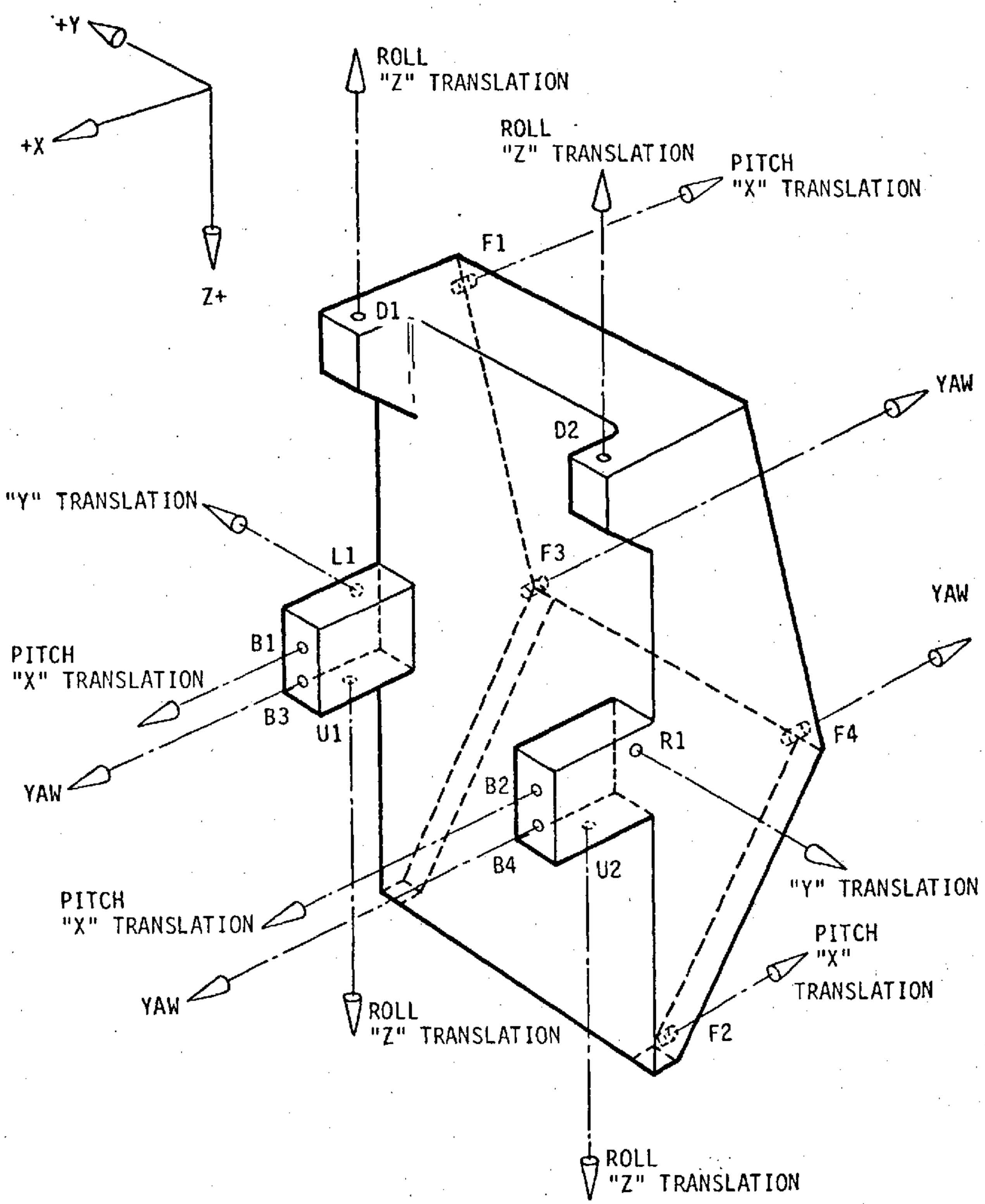


FIGURE 1.2-12: Skylab ASMU Translation Control Axes

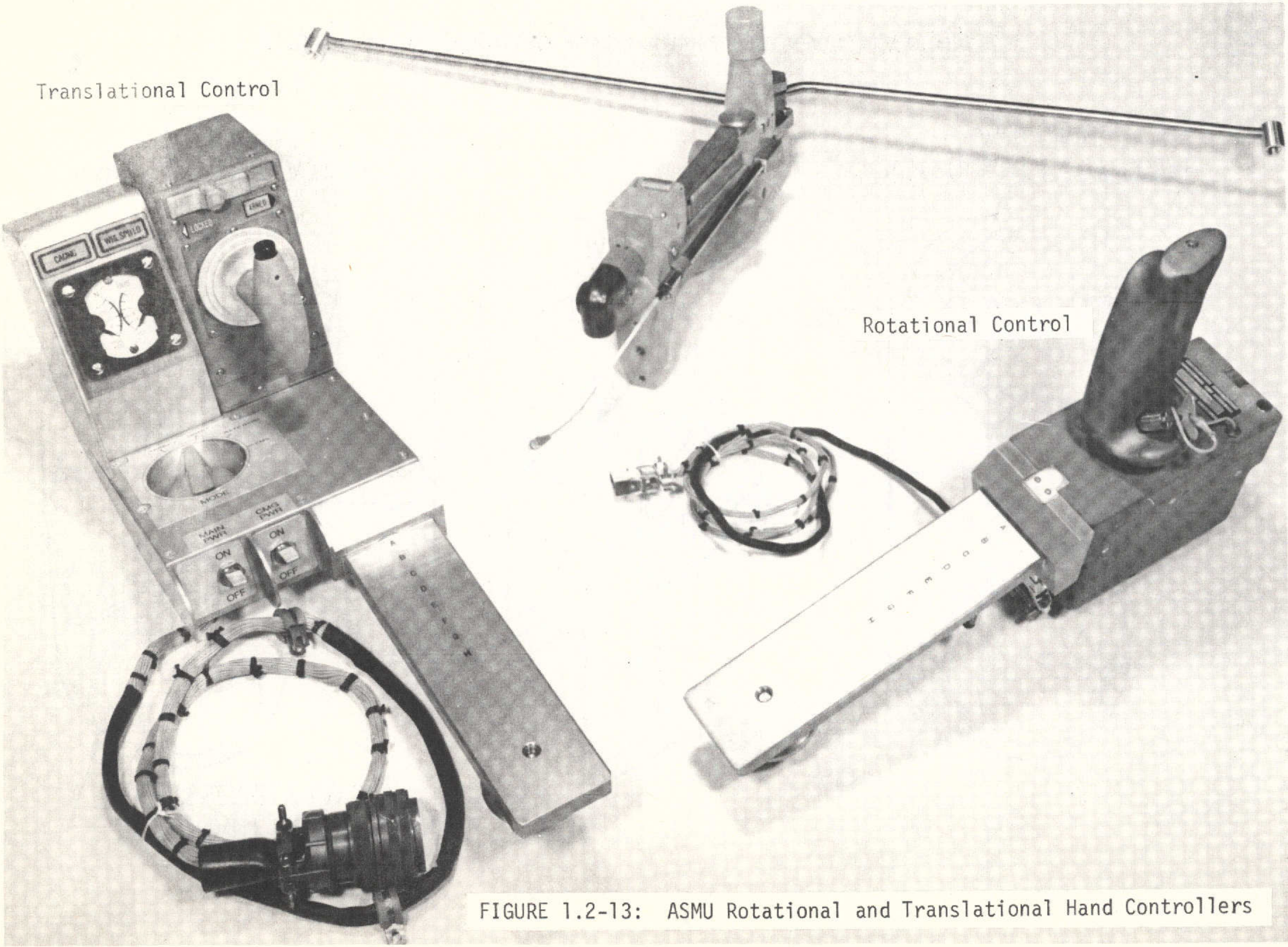


FIGURE 1.2-13: ASMU Rotational and Translational Hand Controllers

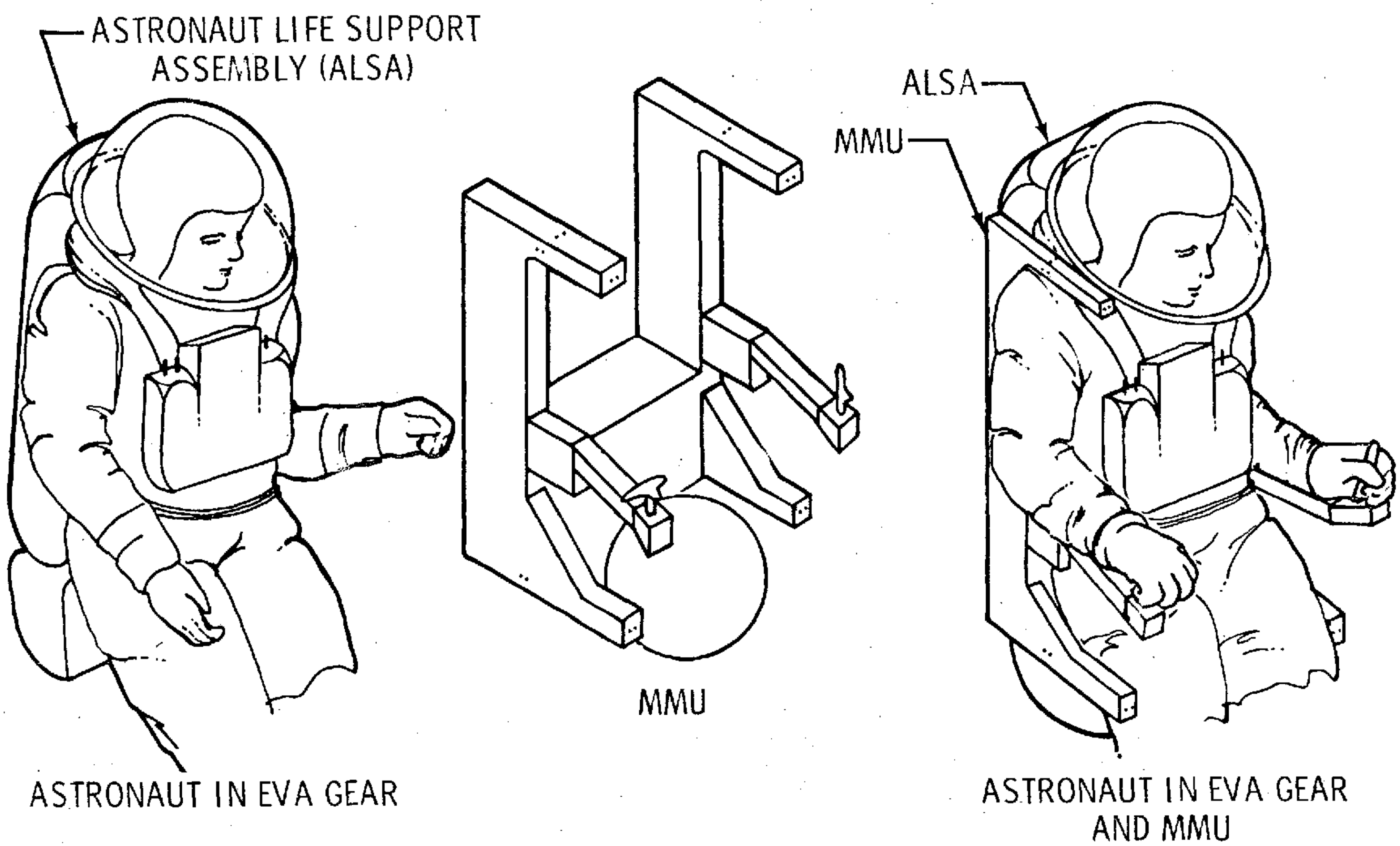


FIGURE 1.2-14: Manned Maneuvering Unit (MMU)--Artist Concept

TABLE 1.2-2: Skylab Astronaut Maneuvering Unit (AMU)--Experiment M509 General Data

	WEIGHT		ENVELOPE	
	kg.	lbs.	cm.	in.
ASMU				
LAUNCH	78.5	173.65	138x107x132	54.5x42x52
OPERATION	107.8	237.9	105x122x68	41.5x48x27
STOWED	78.5	173.65	221x107x132	87x42x52
HHMU				
LAUNCH	3.9	8.6	--	--
OPERATION	2.3	5.0	56x30x7.6	22x12x3
STOWED	2.3	5.0	--	--
GAS BOTTLE				
LAUNCH	21.1	46.5	63.5x43	25x17
OPERATION	26.2	57.8	63.5x43	25x17
STOWED	21.1	46.5	63.5x43	25x17
BATTERIES				
LAUNCH	9.4	20.8	42x114x10	16.5x4.5x4.0
OPERATION	9.4	20.8	42x114x10	16.5x4.5x4.0
STOWED	9.4	20.8	42x114x10	16.5x4.5x4.0

BATTERY CHARACTERISTICS:

- Useful Life - 12 months (after max. 2 years stowage)
- Charge/Discharge - 100 cycles (min.)
- Recharge Time - 20 hours at 0.55 $\pm$ 0.05 ampere
- Capacity - 6 AHR at 0.025 to 6.0 ampere discharge at 80°F
- Voltage - 33.0 VDC (max.)

TABLE 1.2-3: CMG/Rate Gyro Performance Data

CMG/RATE GYRO PERFORMANCE DATA	COMMAND MOMENT GYROS (CMGs)	RATE GYROS
NUMBER PER UNIT	3 pair	3
DEGREES OF FREEDOM	1°	1°
WHEEL SPIN SPEED	22,500 rpm	24,000 rpm
MAXIMUM RATE	5°/sec	50°/sec *
THRESHOLD RATE	0.2°/sec	0.01°/sec *
DRIFT RATE	0.1°/sec	0.02°/sec *
SENSITIVITY	1 V/deg/sec	1.1 V/deg/sec **
MAXIMUM TORQUE	2.9 kg-m (21 ft-lb)	--

* Output ** Input

TABLE 1.2-4: ASMU Thruster Performance Data

THRUSTER PERFORMANCE ASMU	STANDARD INTERNATIONAL UNITS (SI)	CONVENTIONAL UNITS
OPERATIONAL PRESSURE (MAXIMUM)	22.1 kg/cm^2	300 psig
OPERATIONAL PRESSURE (DESIGN)	9.49 kg/cm^2	135 psig
PROOF PRESSURE	42.2 kg/cm^2	600 psig
BURST PRESSURE	84.4 kg/cm^2	1200 psig
OPERATIONAL LIFE	30,000 cycles	30,000 cycles
VALVE RESPONSE @ 28 VDC OPENING	8 - 12 millisecond (msec.)	8 - 12 msec.
CLOSING	13 - 20 millisecond	13 - 20 msec.
VALVE FLOW RATE (MAXIMUM)	0.034 kg/sec.	0.075 lb/sec.

TABLE 1.2-5: Advanced Manned Maneuvering Unit (MMU) Projected Characteristics

SYSTEM AND OPERATIONAL REQUIREMENTS
• DELTA V: 16 m/sec. (52 ft/sec.) • MISSION DURATION: 6 hours • WEIGHT: 75 kg. (165 lbs.) • CONTROL SYSTEM - Six Degrees of Freedom Control Authority - Spacecraft Piloting Logic - Automatic Attitude Hold: Rate Gyro (Prime) * Rate & Displacement Deadband: TBD * Drift: 0.05°/sec. - Attitude Rate Command: TBD - Manual Attitude Hold (Backup) • PROPULSION - Gaseous Nitrogen - Acceleration * Translational: 0.1 ± 0.01 m/sec^2 ($0.3 \pm .05$ ft/sec^2) * Rotational: 10 ± 3°/sec^2 • ONE MAN SERVICE, DON/DOFF EVA • WORKSITE ATTACHMENT PROVISIONS • CARGO TRANSFER CAPABILITY • SELF CONTAINED SYSTEM • SAFETY TETHER (OPTIONAL) • FAIL OPERATIONAL/FAIL SAFE

SECTION 1.3: WORKSITE PROVISIONS

Analogous to the worksites in modern industry, the EVA crewman must have adequate support provisions to ensure maximum performance. The more common worksite provisions such as lighting, control panels, and identification and instruction labels are as necessary in zero-gravity as the earth environment. Given the more common support provisions, the most important item in zero-gravity is restraining the crewman (see Section 1.1). This section provides general information and photographs of several worksites and support equipment for conducting extravehicular operations on the Skylab missions. Concepts for modular, portable EVA workstations for Shuttle Orbiter payload bay application are included:

Section 1.3 contains information on the following equipment:

1.3.1 WORKSTATIONS--GEMINI, APOLLO, SLYLAB

A. Purpose

The purpose of an EVA workstation is to provide crewman restraint and support provisions necessary to perform required tasks in the zero-gravity environment.

B. Functional Description and Support Hardware

The Gemini EVA Program established basic requirements for workstations by using several types of EVA tasks having various support equipment to evaluate performance. One of the most important results of the EVA Program was establishment of the necessity of an adequate restraint system. A typical Gemini EVA workstation is shown in Figure 1.3-1.

The Apollo Program shifted EVA emphasis from the experimental to the application stage as EVAs were employed to retrieve film from the exterior of the CSM vehicle. The Apollo EVA workstation locations are shown in Figure 1.3-2. The workstations used foot restraints similar to those used on the Gemini Program.

EVA became an integral part of the Skylab Program as the prime method of retrieving solar astronomy data from the Apollo Telescope Mount (approximately 25% of the total scientific data compiled on Skylab). Photographs of the workstations used for film retrieval on Skylab are shown in Figures 1.3-3 through 1.3-6.

Workstation provisions on previous space programs have included:

- Restraints--Usually foot restraints for the EVA crewman and mounts, brackets, tethers, etc. for equipment stowage. Handrails are also used for crew/equipment stabilization.
- Lighting--Intensity and location vary with the type of task required.
- Interfaces and equipment--Handles, doors, booms, clotheslines, electrical outlets, protective screens, etc.
- Controls and displays--Operational control panels (switches, buttons, levers and displays (flags, lights, gages).
- Decals--Procedural (includes operational and emergency) and identification (nomenclature, numbers, etc).

- Adequate working volume and accessibility to all equipment.

C. Performance Data and Applications to Future Programs

Crew performance capabilities using the Gemini workstations initiated refinements in workstation/restraint design. Workstations on Apollo and Skylab were completely adequate for the planned tasks. These workstations were fixed in their launch locations and could not be moved to support unplanned tasks.

For future programs, it is recommended that Apollo and Skylab workstation hardware and design guidelines be incorporated with consideration to more mobile workstation concepts.

D. Specifications and Design Data

Restraints: See Restraints and Mobility Aids, Section 1.1
Lighting: See Illumination, Section 2.2.1
Special tools and equipment: See Miscellaneous EVA Hardware, Section 1.6
Decals: See Worksite Provisions, Section 1.3
Working volume: See Working and Translation Volume, Section 2.2.4

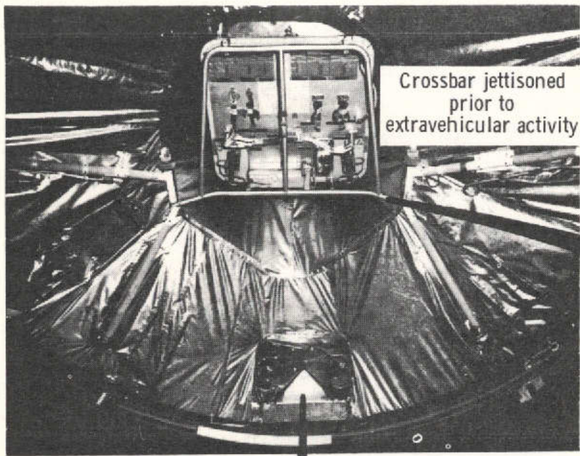
E. Supplementary Information

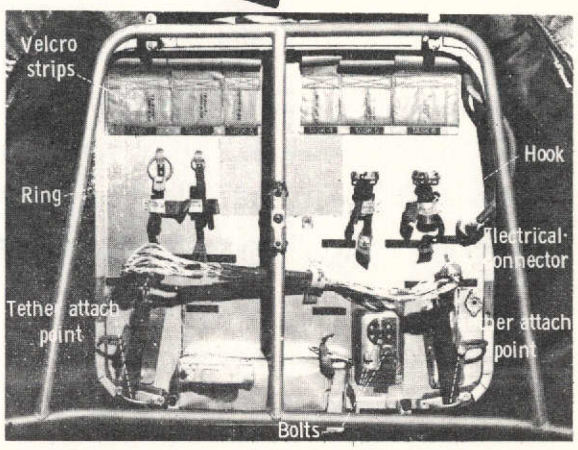
Documents:

- Summary of Gemini Extravehicular Activity, National Aeronautics and Space Administration, NASA SP-149, Washington, D.C., 1967
- Gemini Summary Conference, National Aeronautics and Space Administration, NASA SP-138, Washington, D.C., 1969
- Apollo 9 Mission Report, Manned Spacecraft Center, MSC-PA-R-69-2, Houston, Texas, May 1969
- Skylab Operations Handbook, Apollo Telescope Mount; Martin Marietta Corp., Contract NAS 8-2400, Volume I, 27 March 1972

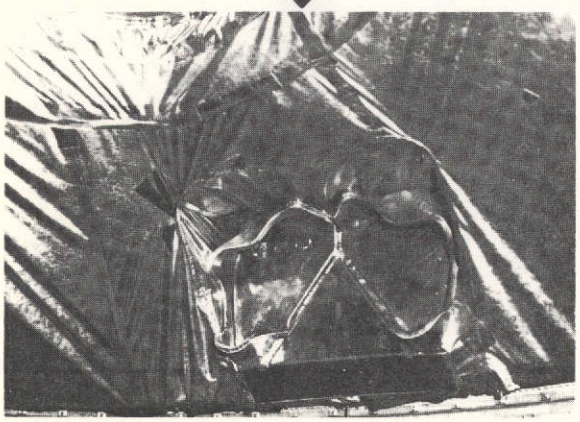
Items Developed For:

National Aeronautics and Space Administration



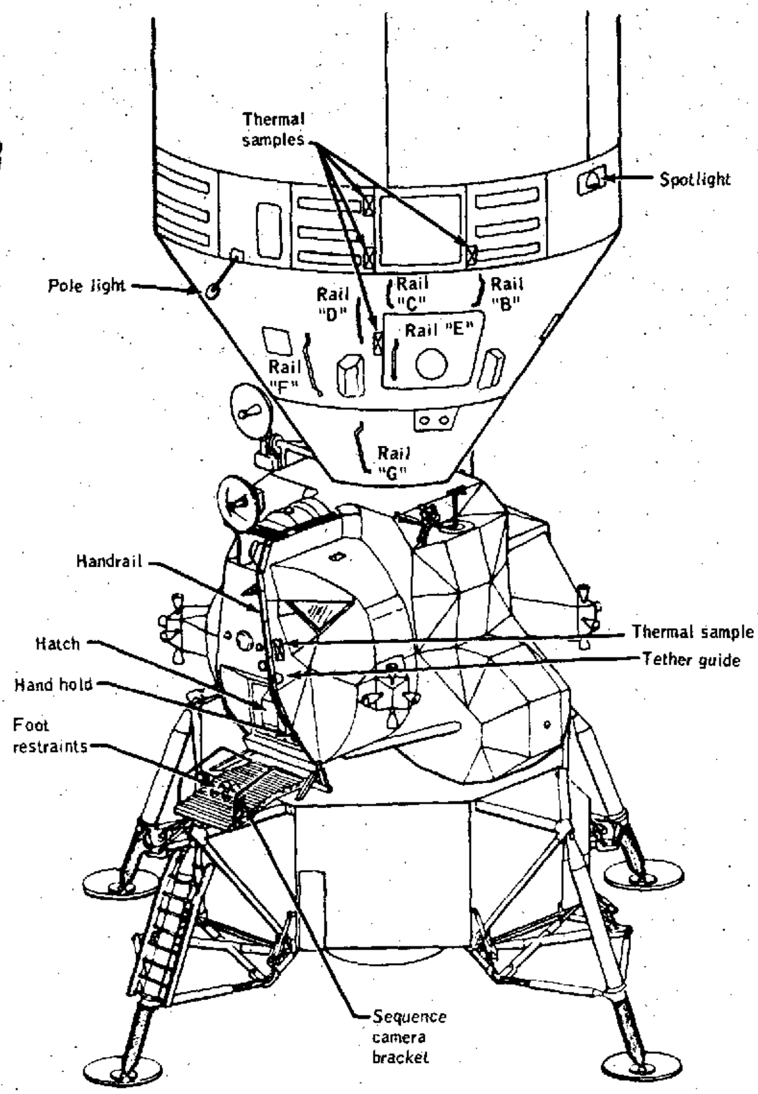


Gemini Adapter EVA Task Panel

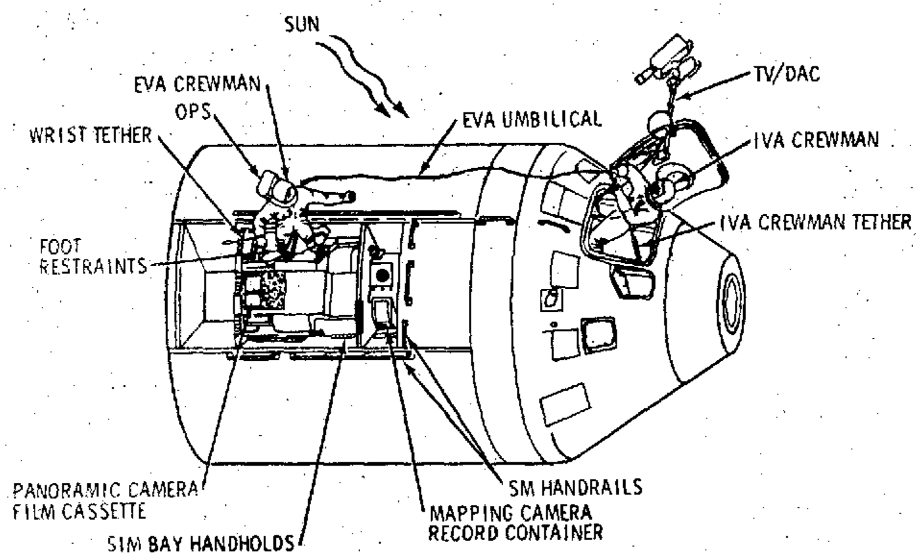


Gemini Foot Restraints

FIGURE 1.3-1: Gemini EVA Workstation (Gemini Adapter Section)

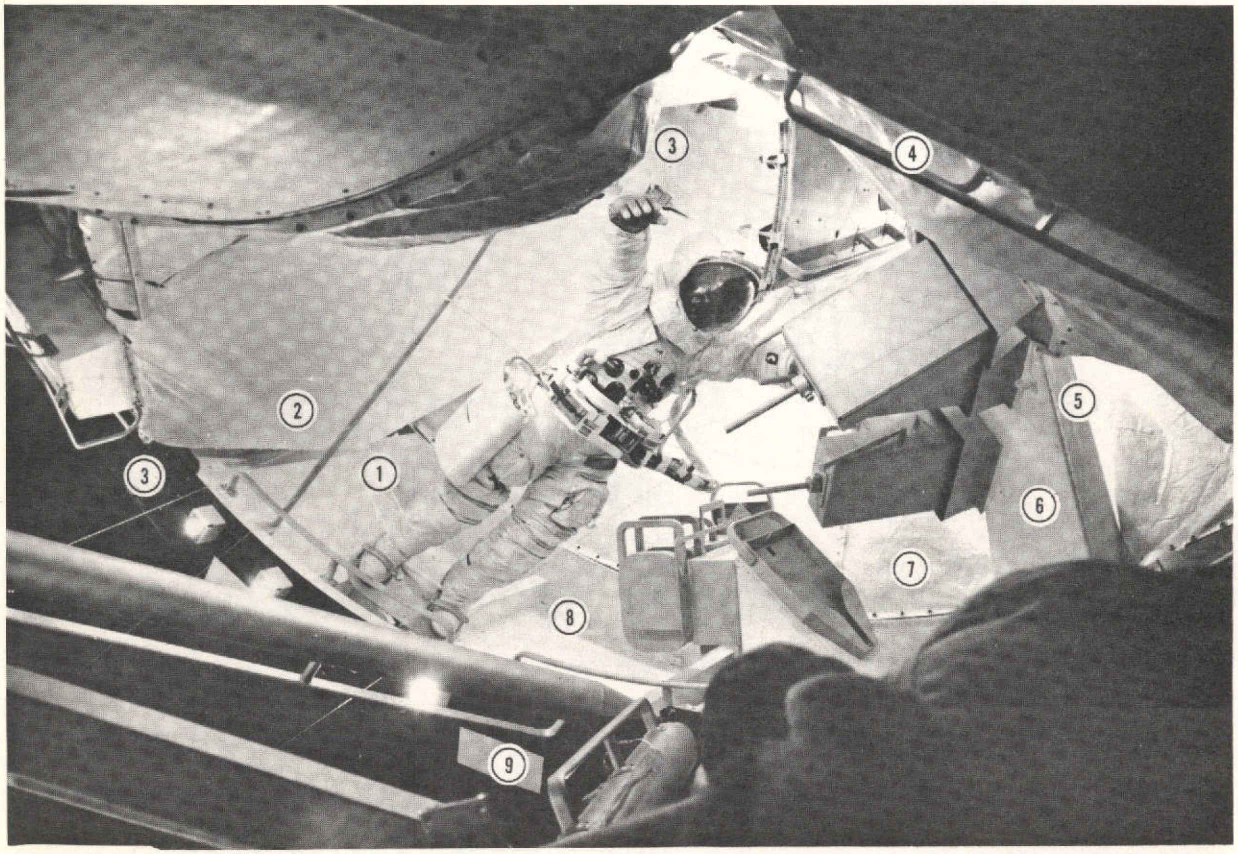


Lunar Module Worksite



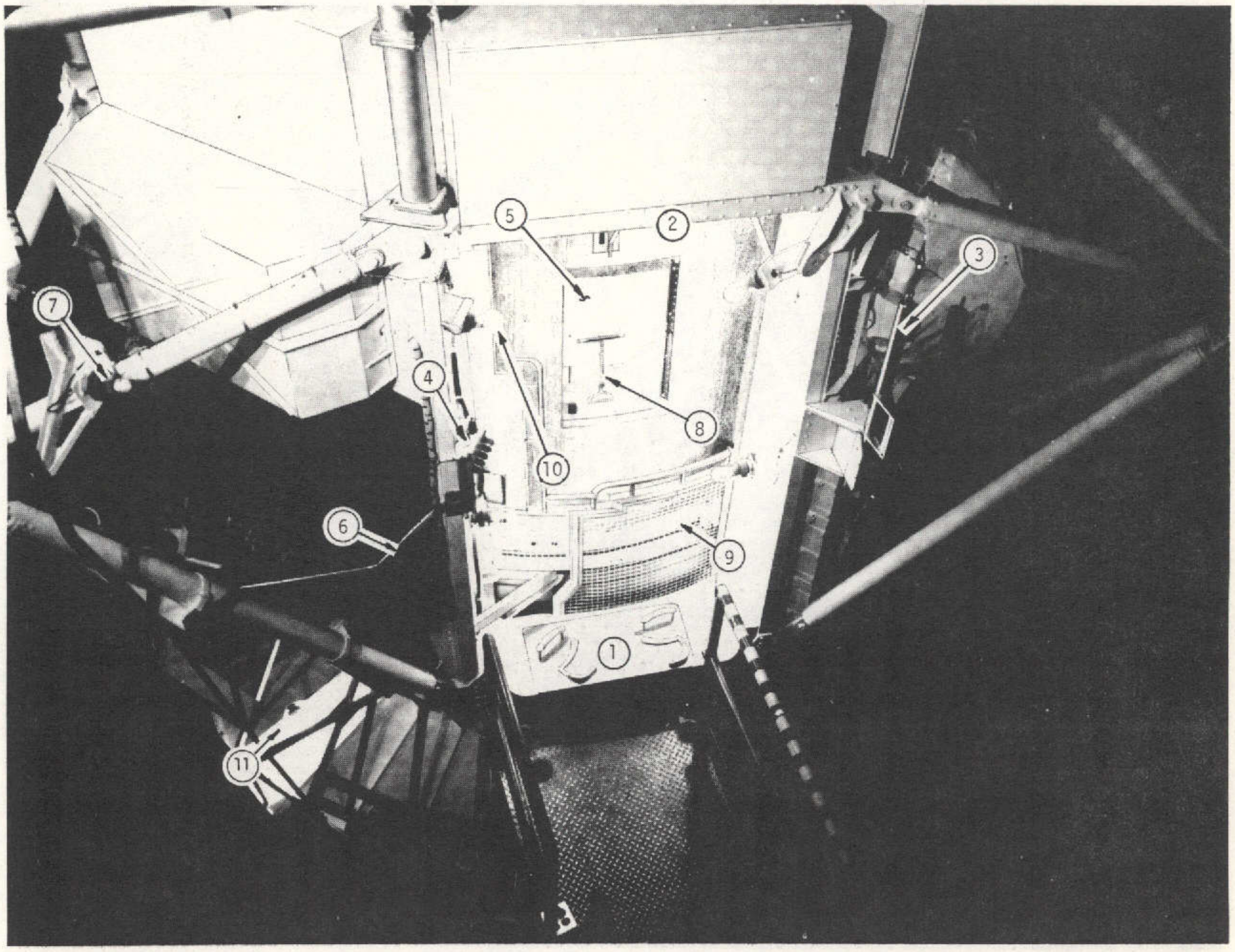
Apollo SIM Bay Worksite

FIGURE 1.3-2: Apollo EVA Workstation Locations



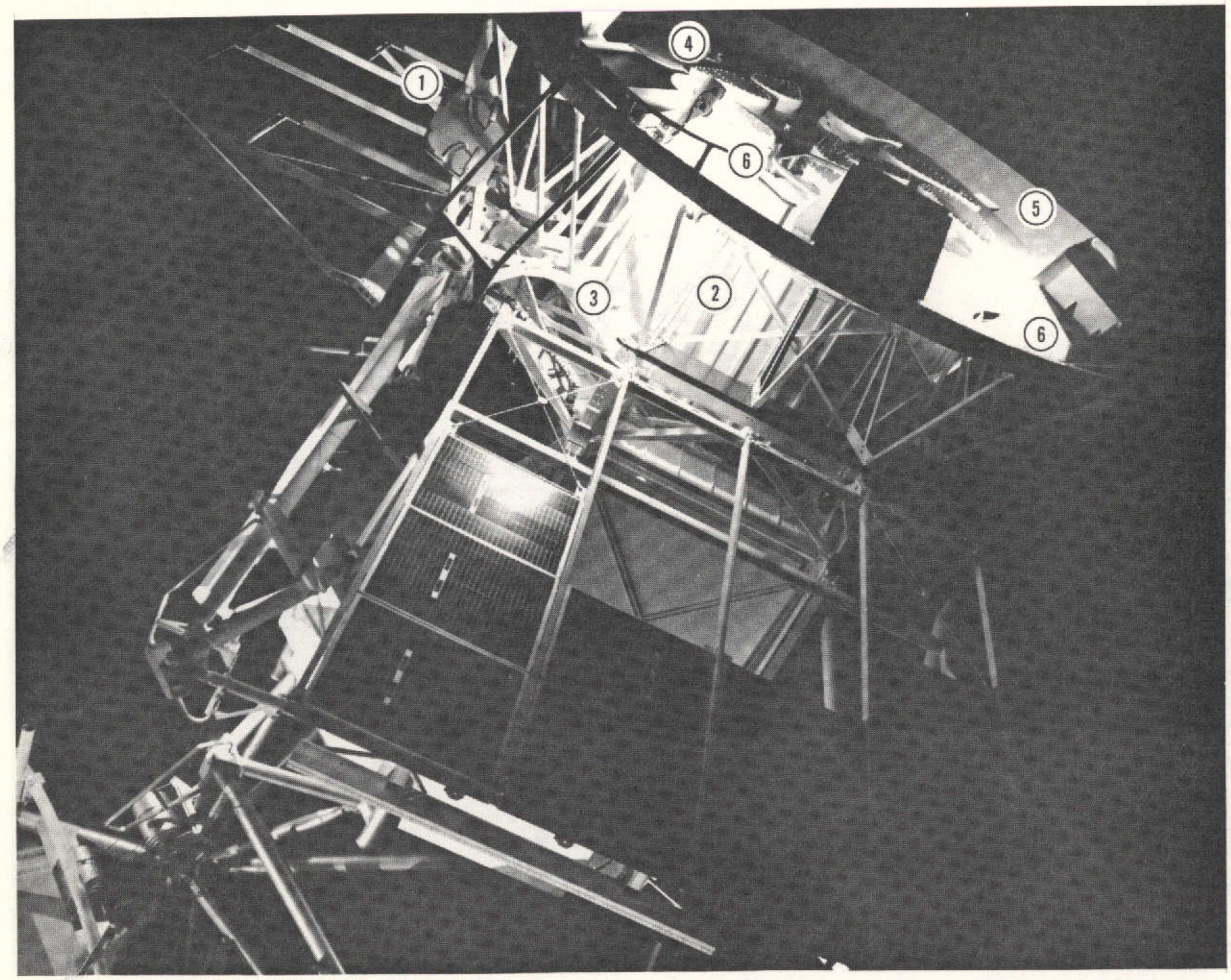
FAS Worksite Support Equipment: (1) Primary Foot Restraints; (2) Handrails; (3) EVA Lights; (4) Airlock Hatch; (5) Sun End Workstation Cargo Transfer Boom; (6) Center Workstation Cargo Transfer Boom; (7) Sun End Cargo Temporary Stowage Receptacle; (8) Center Workstation Cargo; and (9) Translation Rail to ATM Center Workstation.

FIGURE 1.3-3: Skylab Fixed Airlock Shroud (FAS) Workstation (VF)



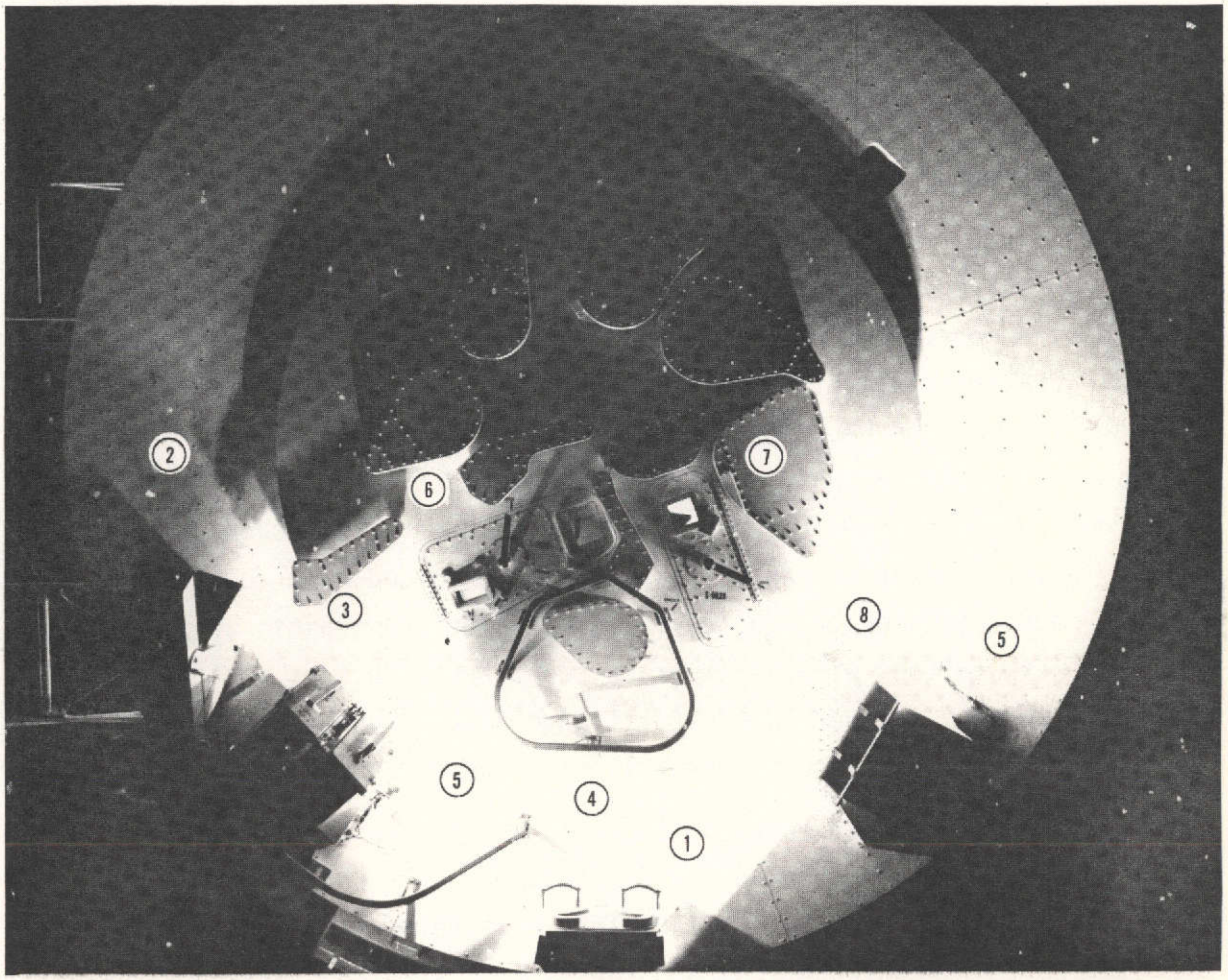
Center Worksite Support Equipment: (1) Primary Foot Restraints; (2) ATM Canister Alignment Indicator; (3) Contingency Transfer Interface Bracket; (4) ATM Canister Roll Control Panel (5) Film Package Access Door; (6) Translation Rail to/from Dual Translation Rails; (7) EVA Translation Path Light; (8) Access Door Handle; (9) VC Handrail and Protective Grid; (10) VC Lights; and (11) Transfer Workstation Light.

FIGURE 1.3-4: Skylab Center Workstation (VC)



Transfer Worksite Support Equipment: (1) Primary Foot Restraints; (2) Transfer Workstation Light; (3) Dual Translation Rails; (4) Sun End Primary Cargo Stowage Receptacle; (5) Sun End Cargo Temporary Stowage; and (6) Sun End Workstation Lights.

FIGURE 1.3-5: Skylab Transfer Workstation (VT)



Sun End Workstation Support Equipment: (1) Primary Foot Restraints; (2) Contingency Transfer Interface Bracket; (3) Sun End Cargo in the Primary Stowage Receptacle; (4) Handrails; (5) Sun End Workstation Lights; (6) S082B Film Package Access Door; (7) S082A Film Package Access Door; and (8) Sun End Cargo Temporary Stowage.

FIGURE 1.3-6: Skylab Sun End Workstation (VS)

URS

1.3.2 WORKSTATIONS--SHUTTLE CONCEPTS

A. Purpose

Shuttle EVA workstation concepts were developed for consideration by Shuttle Orbiter and payload planners as a candidate for on-orbit systems servicing hardware.

B. Functional Description and Support Hardware

Workstation concepts (Figures 1.3-7 through 1.3-10) of varying complexity were developed to satisfy certain portions of the total Shuttle task requirements. The workstations are intended to be modular in design and transportable either by the EVA crewman, Manned Maneuvering Unit or Remote (attached) Manipulator System. The workstations may be hard mounted prior to vehicle launch for planned EVA servicing operations. Foot restraints developed for the Skylab Program are shown on the base of each workstation concept. Forces/torques and task duration identified by candidate Shuttle EVA tasks indicate foot restraints are required. The workstations will incorporate support hardware as dictated by the task and may include temporary stowage hooks, handholds, umbilical/tether clips, tool containers, lights, photographic equipment, etc.

For manual on-orbit mounting the crewman will position the workstation using temporary retention devices followed by positive locking system actuation. The crewman will deploy an ingress/stabilization aid (integral to the workstation) and ingress the station. The portable workstations could be stowed inside the Shuttle Orbiter cabin or in the payload bay.

C. Performance Data and Applications to Future Programs

At the date of document publication, performance data was not available, however, mockup fabrication had been initiated on the lesser complex workstation concepts.

Since the Shuttle Orbiter payload bay will be configured differently for each launch and numerous payloads of various configurations will be accommodated, a versatile EVA approach to servicing operations must be

C-2

maintained. Consideration should be given to a modular, portable EVA workstation that offers versatility and economy in both planned and contingency operations outside the Shuttle cabin.

D. Specifications and Design Data

The following table depicts preliminary estimates of the workstation concept physical characteristics:

WORKSTATION PARAMETER	WORKSTATION CONCEPT	VALUES (ESTIMATED)	
		SI	CONVENTIONAL
WEIGHT	No. 1	10 kg.	22 lb.
	No. 1 (alt.)	11.3 kg.	25 lb.
	No. 2	20.0 kg.	44 lb.
	No. 3	24.5 kg.	54 lb.
VOLUME (STOWED)	No. 1	.04 m^3	1.5 ft^3
	No. 1 (alt.)	.06 m^3	2.2 ft^3
	No. 2	.08 m^3	2.8 ft^3
	No. 3	.17 m^3	6.0 ft^3
DIMENSIONS (STOWED)	No. 1	.62x.43x.13m.	24.5x17.0x5in.
	No. 1 (alt.)	.94x.43x.15m.	37x17x6in.
	No. 2	.66x.66x.25m.	26x26x10in.
	No. 3	.91x.66x.28m.	36x26x11in.

E. Supplementary Information

Documents:

- Application of EVA Guidelines and Design Criteria, Volume II--EVA Workstation Conceptual Designs, URS/Matrix Company, Final Report, April 1973

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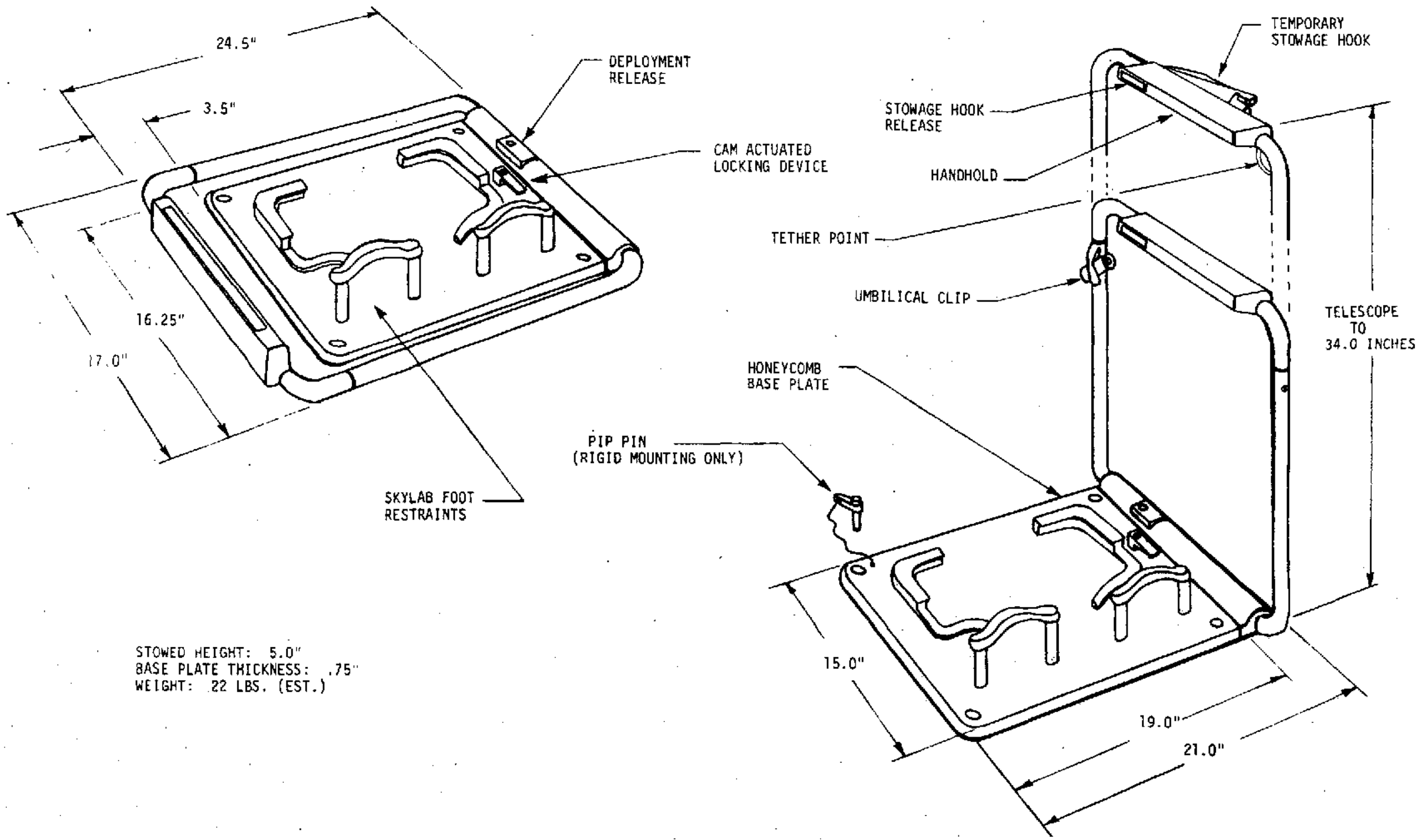


FIGURE 1.3-7: Shuttle EVA Workstation--Concept No. 1

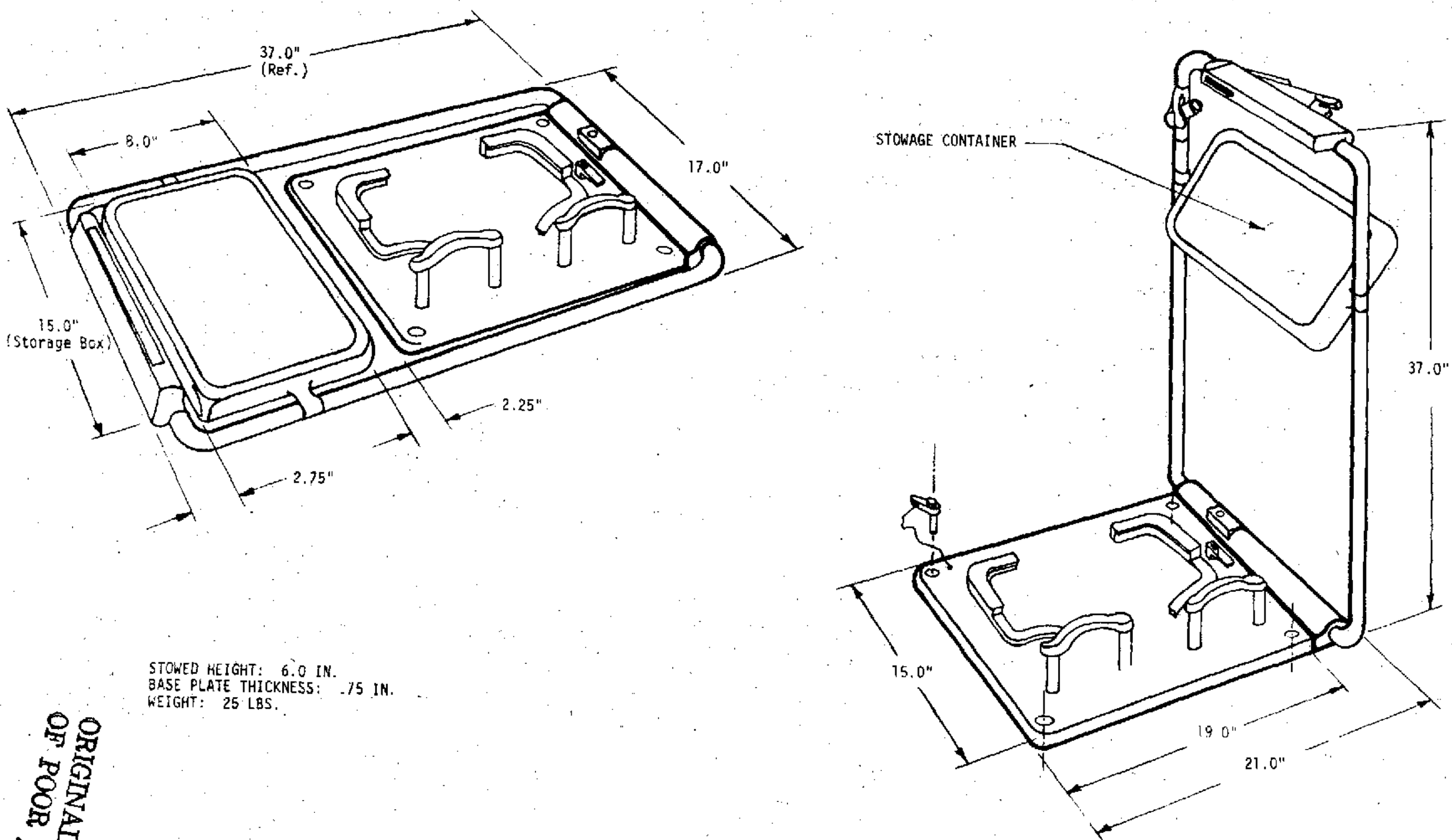
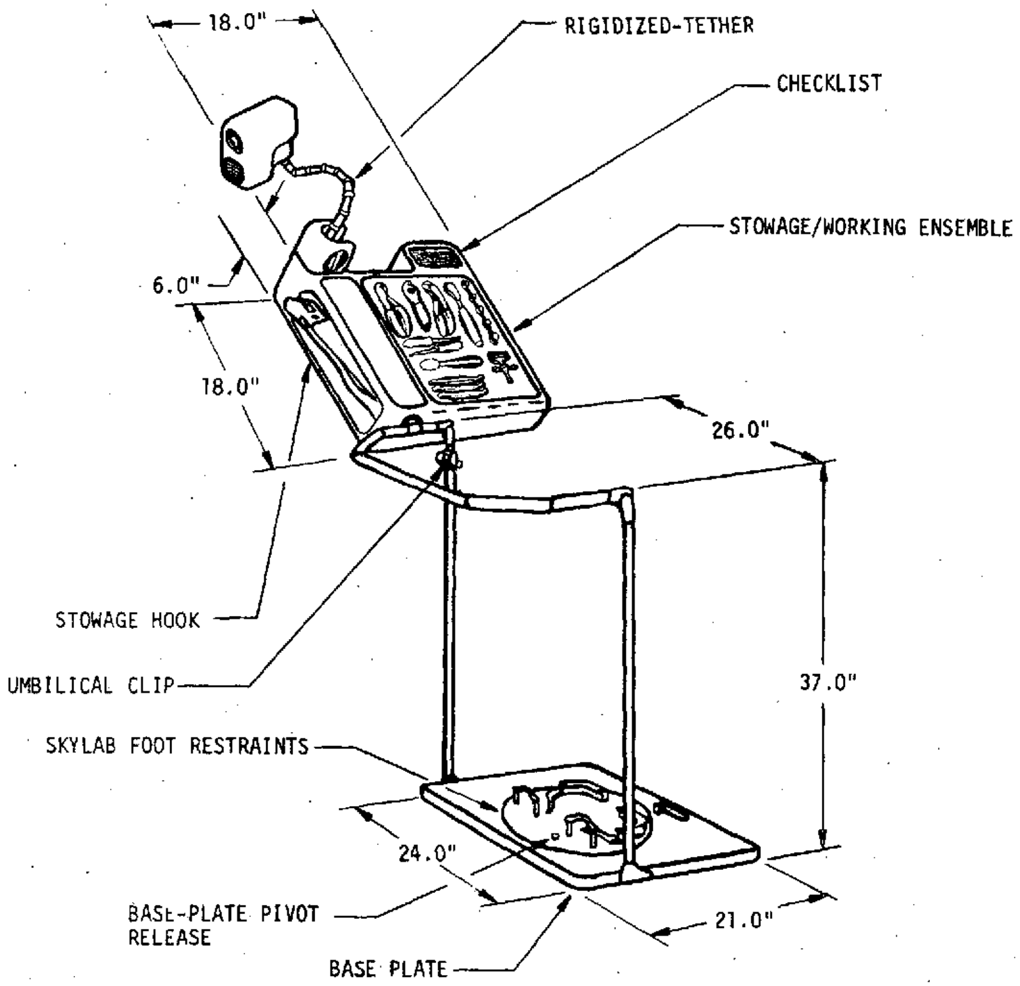


FIGURE 1.3-8: Shuttle EVA Workstation--Concept No. 1 Alternate



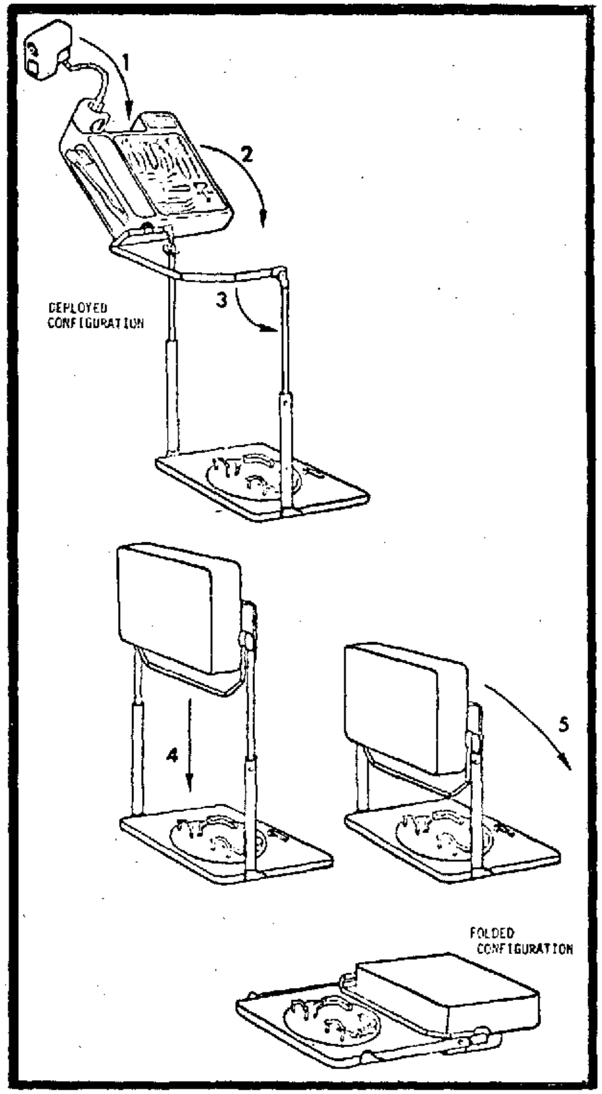


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FIGURE 1.3-9: Shuttle EVA Workstation--Concept No. 2

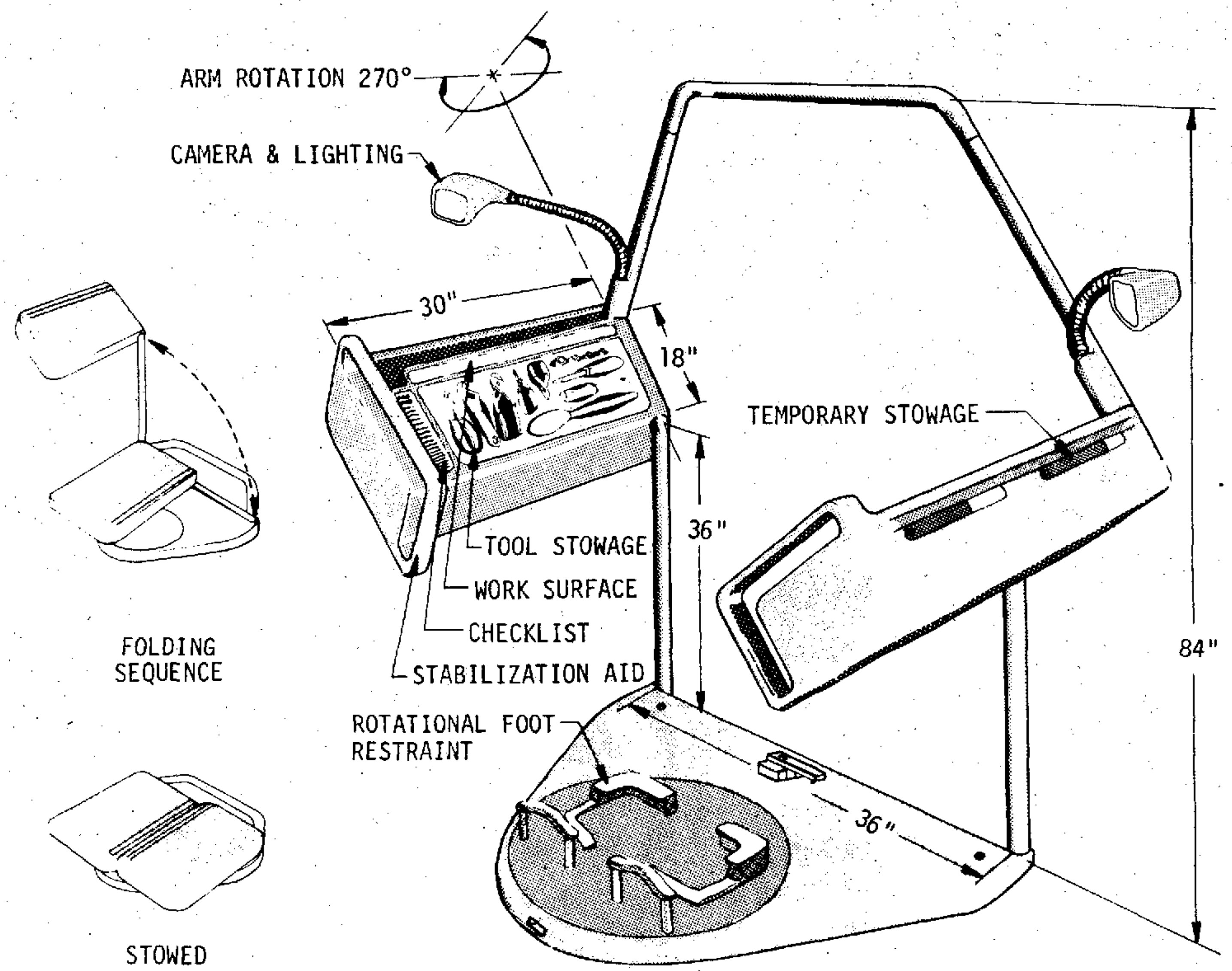


FIGURE 1.3-10: Shuttle EVA Workstation--Concept No. 3

1.3.3 EXPERIMENT ROTATION CONTROL PANEL--SKYLAB PANEL 160

A. Purpose

A rotation control panel (Panel 160) was developed for the Skylab ATM to enable an EVA crewman to position the experiment canister for replacement/retrieval of film packages.

B. Functional Description and Support Hardware

The rate and direction of roll of the ATM canister and the open-close position of two experiment aperture doors were controlled from the panel. The control panel primarily consisted of four two-position switches and a hand control lever (Figure 1.3-11). The crewman directed power to the panel by actuating either the primary or secondary switch. The panel was normally operated in primary, and the secondary switch controlled a redundant system. A roll enable/inhibit switch powered a solenoid which operated a mechanical brake on the canister roll drive and brake assembly. To roll the canister, the mechanical brake must be released by positioning the roll switch to enable. The crewman rotated the canister either to the left or right and at either a "high" or "low" rate using the hand control lever.

Foot restraints were used by the crewman while operating the panel, however, all controls on the panels were designed for one-handed operation and could be actuated with only a handhold for restraint.

C. Performance Data and Applications to Future Programs

No problems were encountered in the operation of the ATM control panel. The rotational control panel enabled the EVA crewmen to conveniently and efficiently service the Skylab ATM experiments at the worksite. Real time visual observations of canister status and access door position could be monitored. Control panels of this class may be desirable on future programs where Shuttle docked payloads utilizing powered turntables are inspected or serviced via EVA.

D. Specifications and Design Data

Skylab Panel 160 characteristics are shown in Table 1.3-1.

E. Supplementary Information

Documents:

- Operational Data Book, Volume IV, Skylab Performance Data, MSC-1549, Manned Spacecraft Center, Houston, Texas
- Skylab Operations Handbook, Apollo Telescope Mount, Volume I; Martin Marietta Corp., Contract NAS 8-2400, MSFC-205, 27 March 1972
- Crew Station Specifications, Flight Crew Integration Division, NASA-Manned Spacecraft Center, MSC-07387, October 1972

Drawing/Part No.:

- Panel 160--Drawing No. 40M37795, Revision B

Item Supplied By:

Sperry-Rand, Space Support Division
Huntsville, Alabama

Item Supplied To:

National Aeronautics and Space Administration
Marshall Space Flight Center

TABLE 1.3-1: Skylab ATM Rotation Control Panel (Panel 160) Physical/Performance Characteristics

PANEL 160	PERFORMANCE AND DESIGN DATA		COMMENTS
	SI	CONVENTIONAL	
ENVELOPE HEIGHT	34.8 cm. max.	13.7 in. max.	
WIDTH	20.1 cm. max.	7.9 in. max.	
DEPTH	16.3 cm. max.	6.4 in. max.	Including handle
WEIGHT	8.25 kg. max.	18 lb. max.	
HANDLE TORQUE MAXIMUM	.29 kg-m.	25 in-lb.	± 40° rotation off position 0±5° linearly increasing torque
OPERATIONAL	.068±.046 kg-m.	6±4 in-lb.	
ROTATION SPEEDS HIGH X1	.75°/sec		X1/X2 is selected from inside vehicle
HIGH X2	7.5°/sec		
LOW X1	.35°/sec		X1/X2 is selected from inside vehicle
LOW X2	3.5°/sec		
RELIABILITY	0.997 for 3360 hrs		Intermittent operation

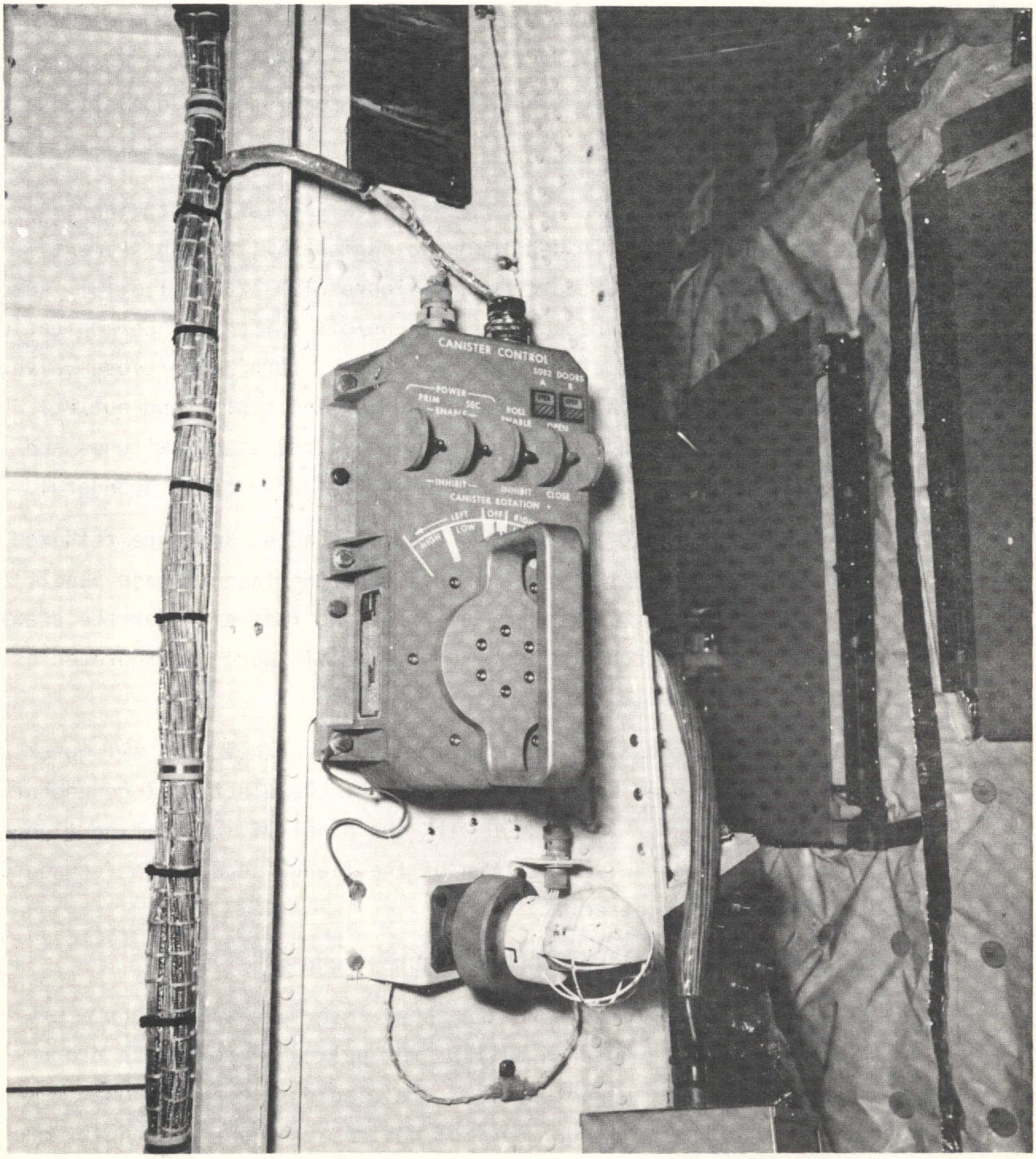


FIGURE 1.3-11: Skylab ATM Experiment Canister Rotation Control Panel

1.3.4 EVA PANELS--SKYLAB LIFE SUPPORT

A. Purpose

The Skylab EVA panels (Panels 317 and 323) contained the life support interfaces (electrical, oxygen and water) for space suited operations.

B. Functional Description and Support Hardware

The EVA panels were located inside the airlock, accessible to the EVA crewman. Each panel was divided into two segments with each segment capable of supporting a suited crewman (Figures 1.3-12 and 1.3-13). Each segment contained a power receptacle with on/off switch for communications, an oxygen (O_2) supply receptacle with a "push-to-turn" open/close valve, and two receptacles for the liquid cooling garment (inlet and outlet). All switches were the toggle type with two-position power switches and three position liquid coolant pump switches (primary, off, secondary).

Dust covers were provided for each of the receptacles and were tethered to the panels. A guardrail was located around the face of each panel, providing protection for the panel equipment and restraint for the crewman making or breaking connections. Smaller rails were incorporated as switch guards over the toggle switches.

The umbilical connectors that interfaced with the panel were all quick connect/disconnect types with the exception of the electrical connector. The electrical connector interfaced with the panel via a rotating flange. After alignment, a clockwise rotation of the flange secured the connector, the opposite action released it.

C. Performance Data and Applications to Future Programs

No problems were encountered with the panel interface operations. EVA panels similar to those used on Skylab are applicable to future programs only if umbilical life support systems are used during EVA. However, the types of connections and manual control devices used on the panels were effective on Skylab, and the components should be investigated where similar interfaces are required on future programs. A particular Skylab panel design was preferred by the crewmen: Panel 225 (O_2/N_2 Gas Control System) located in the STS carried a system schematic on the panel face.

D. Specifications and Design Data

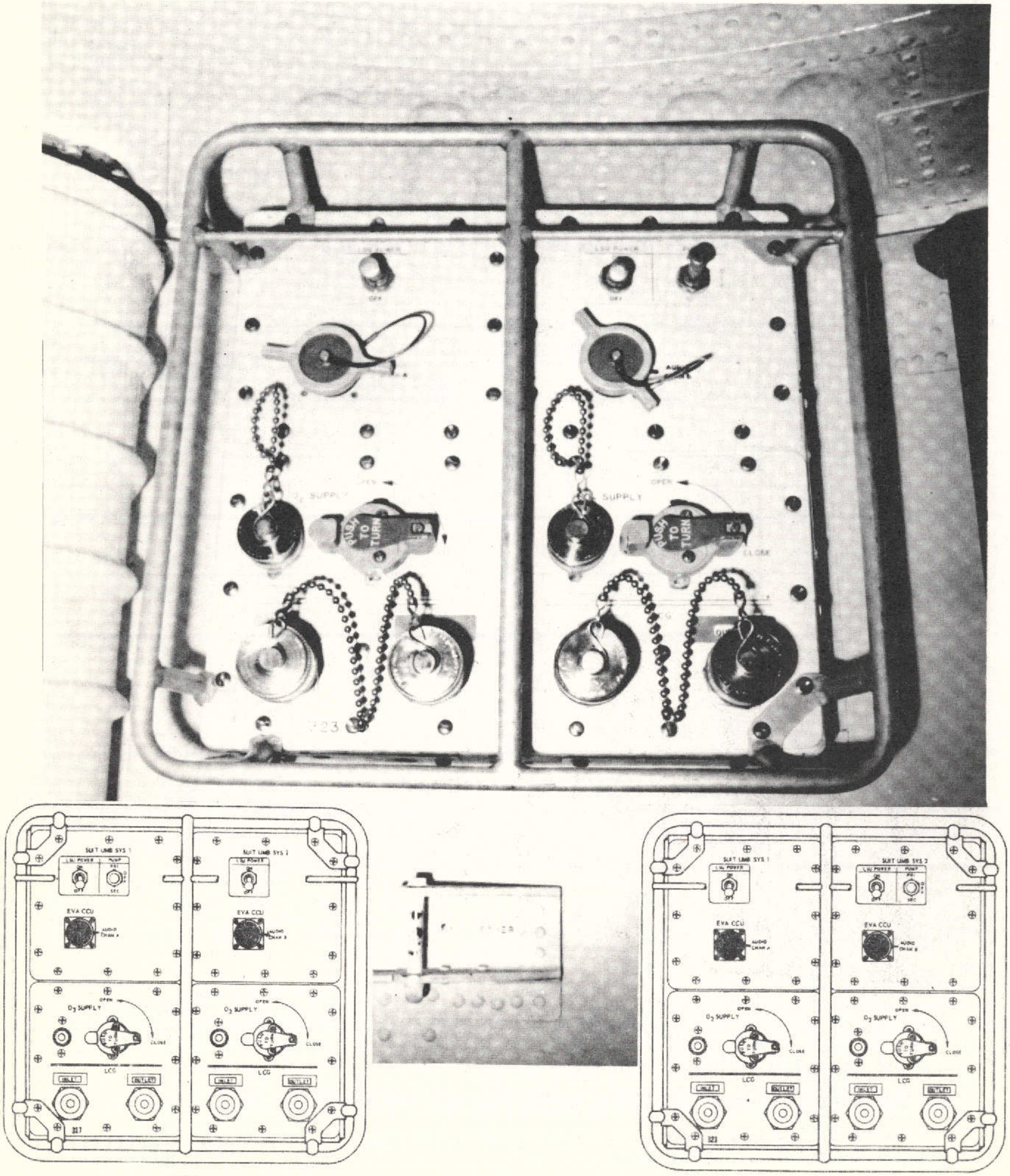
Detail specifications of each panel interface item is beyond the scope of this document. General panel features and connector forces are of interest in future designs. The water receptacles are self-sealing and color coded--blue for inlet and red for outlet. The oxygen shutoff valve is a push-to-turn and rotates through 90^o from full open to full close. The oxygen receptacles are not self-sealing. The forces required to actuate the receptacles are shown in the following table:

INTERFACE		REQUIRED FORCE		REQUIRED ACTION
		SI	CONVENTIONAL	
OXYGEN	CONNECT	6.8 kg. max.	15 lb. max.	Push
	DISCONNECT	5.4 kg. max.	12 lb. max.	Pull
WATER	CONNECT	11.3 kg. max.	25 lb. max.	Push
	DISCONNECT	9.1 kg-m. max.	20 lb. max.	Pull
ELEC-TRICAL	LOCKING	.4 kg-m. max.	36 in-lb. max.	Twist CW
	UNLOCKING	.4 kg-m. max. .08 kg-m. max.	36 in-lb. max. 7 in-lb.	Twist CCW
SWITCHES		Conform to NASA Spec. SC-C-0005		Standard
O_2 VALVES		Conform to NASA Spec. SC-C-0005		Push-to turn (90°)

E. Supplementary Information

Documentation:

- Airlock Design Data Book, McDonnell Douglas Astronautics Company-East (no number), 10 September 1971
- Skylab Operations Handbook, OWS, AM, MDA; McDonnell Douglas Astronautics Company, Contract NAS 9-11001, Volume I, MSC-04727, 27 January 1972
- Crew Station Specifications, Flight Crew Integration Divison, NASA - Manned Spacecraft Center, MSC-07387, October 1972



317

323

FIGURE 1.3-12: Skylab EVA Space Suit Control Panel

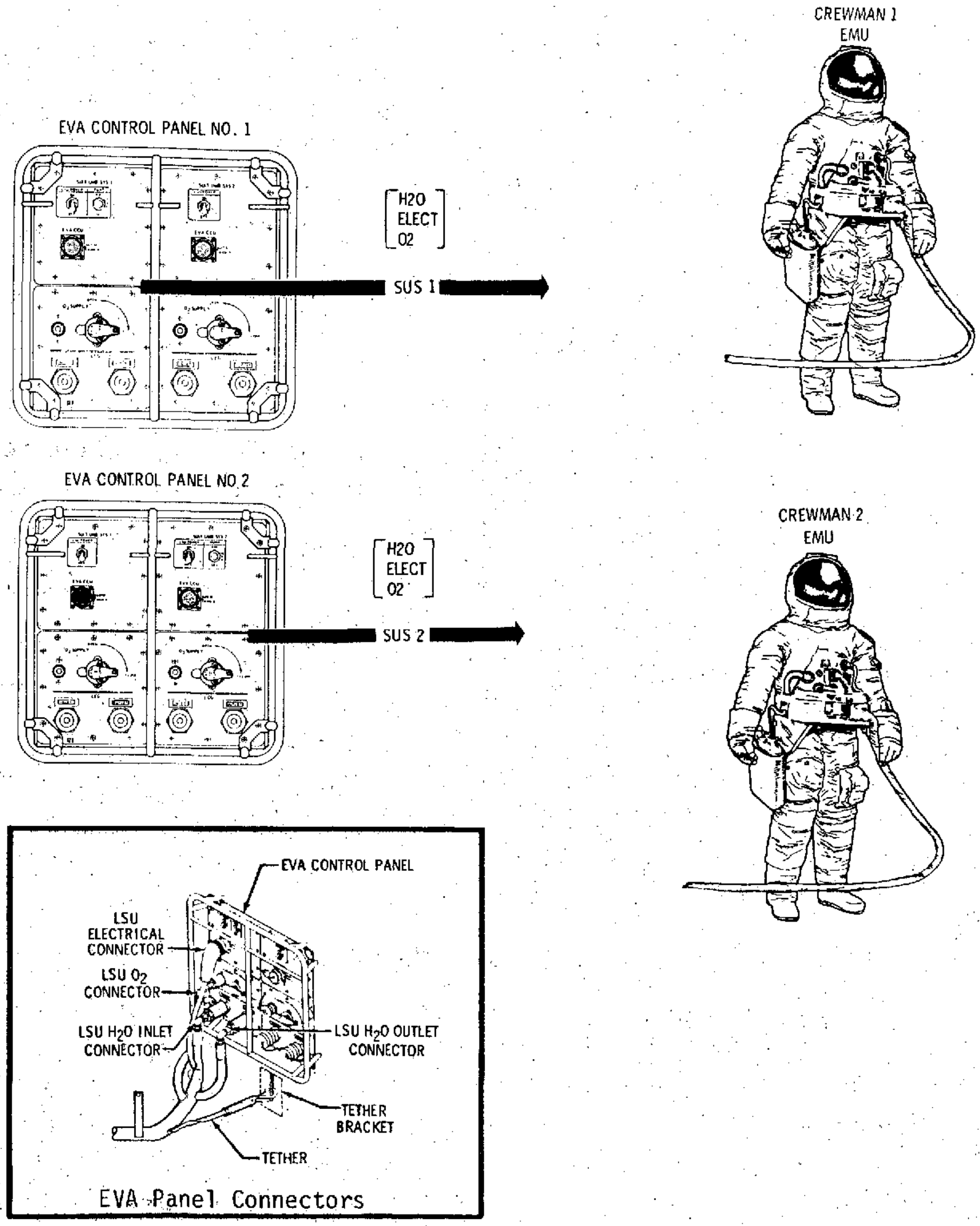


FIGURE 1.3-13: EVA Space Suit Umbilical-to-Control-Panel Interface

1.3.5 DECALS - METAL FOIL INSTRUCTION/IDENTIFICATION

A. Purpose

Decals for supporting EVA operations are mounted on the vehicle clearly visible from the worksite and serve the following functions: (1) Equipment identification; (2) crew/equipment operational procedures; or (3) hazardous area/equipment identification. Decals provide the crewman with a convenient, concise, on-the-worksite reference for performing EVA functions.

B. Functional Description and Support Hardware

Decals for Skylab were fabricated from aluminum foil and were used where sharp legibility was required and when direct marking methods could not be used. The foil decals were fabricated with pressure-sensitive adhesive backing for mounting to most smooth surfaces.

Decals provided to support the Skylab EVA mission included: (1) Experiment replacement/retrieval procedures, located on the access doors of the experiment receptacles; (2) extendible boom operating procedures, located near the boom control panel; (3) boom replacement and clothesline operation contingency procedures, located near the EVA hatch; (4) center workstation operation procedures, located at the worksite; (5) clothesline deployment procedures, located at the center workstation; and (6) loss of communication procedures, also located near the EVA hatch. Decals used on Skylab are shown in Figures 1.3-14 and 1.3-15.

C. Performance Data and Applications to Future Programs

The Skylab crews were thoroughly trained in all operations that were contained on the procedural decals; therefore, their dependence on the decals was slight. However, it is unlikely that the crews of the Shuttle and future programs will receive the intense training on specific tasks as the crews of previous space programs. Procedural decals, particularly for contingency operations, may be more applicable on the short-duration, multiple-payload missions. Decals for the Shuttle Orbiter are managed by a Crew Procedures Control Board located at the NASA Johnson Space Center.

D. Specifications and Design Data

Metal foil decals were frequently used on Skylab and mounted to the vehicle prior to launch. If foil decals are used, the following criteria must be acknowledged:

- Characters clearly visible at .71 m. (28 in.)
- Avoid requirements for transposing, computing, interpolating, etc.
- Avoid lower case letters
- Color finish and contrast must be compatible with expected visual environment
- Avoid "mirror" finishes
- Trim rectangular decals to 0.254 cm. (0.10 in.) of marking extremities corners to 0.32 cm. (.0125 in.) radius
- All marking sharp and clean
- Surface of material free from defects
- Uniform in color and gloss
- Foil material to be 0.007 cm. (0.003 in.) thick
- Apply markings by painting (masking, stenciling, etc.)
- Provide pressure sensitive adhesive backing
- Avoid moisture, heat, etc. for application or removal of backing materials

E. Supplementary Information

Documentation:

- Crew Station Specifications, Flight Crew Integration Division, MSC-07387, Section II, Metal Foil Decals, SC-D-0001, February 1971
- Human Engineering Design Criteria for Military Systems, Equipment, and Facilities, MIL-STD-1472

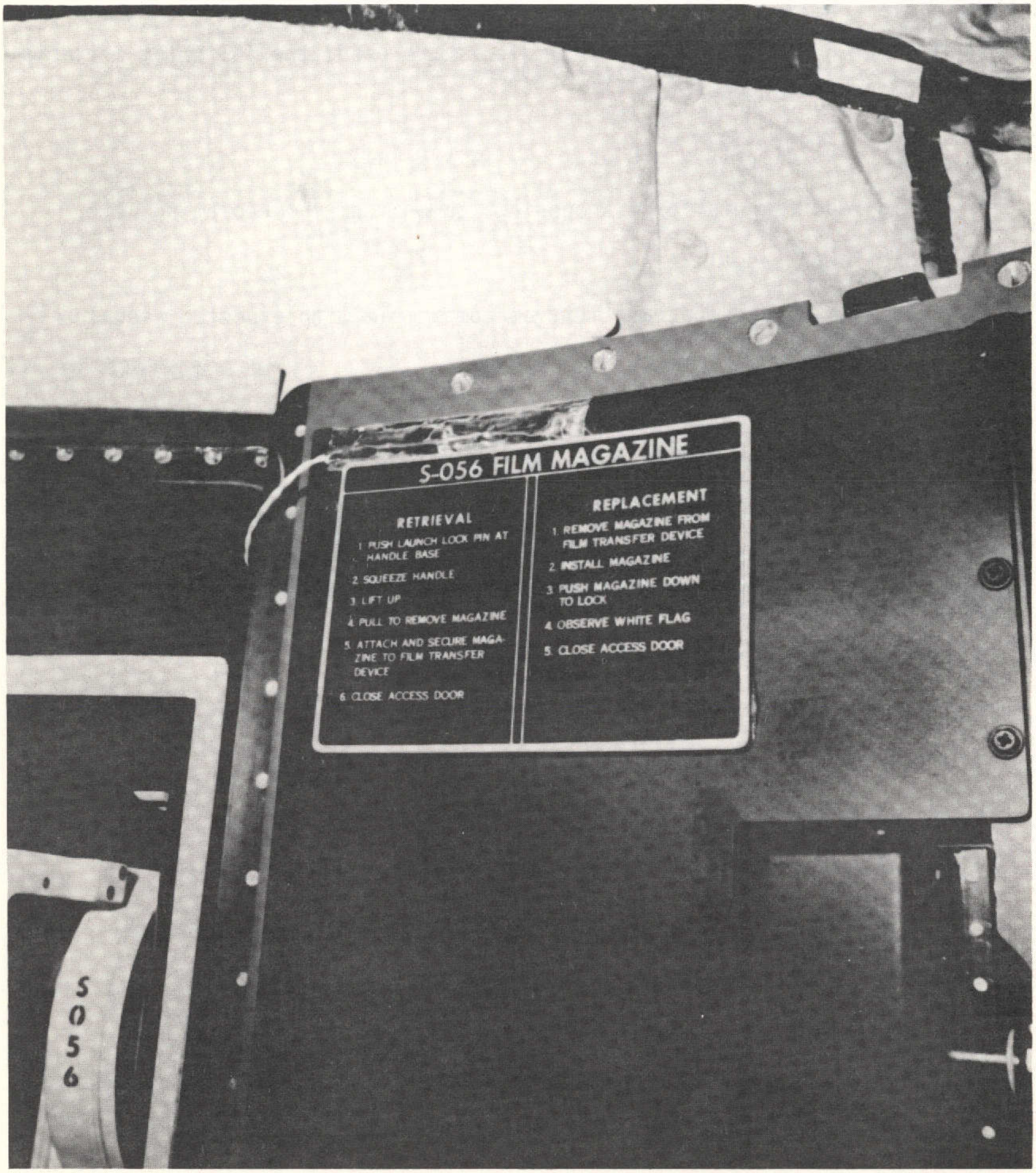


FIGURE 1.3-14: Skylab EVA Procedural Decals for Retrieval and Replacement of Film Magazine

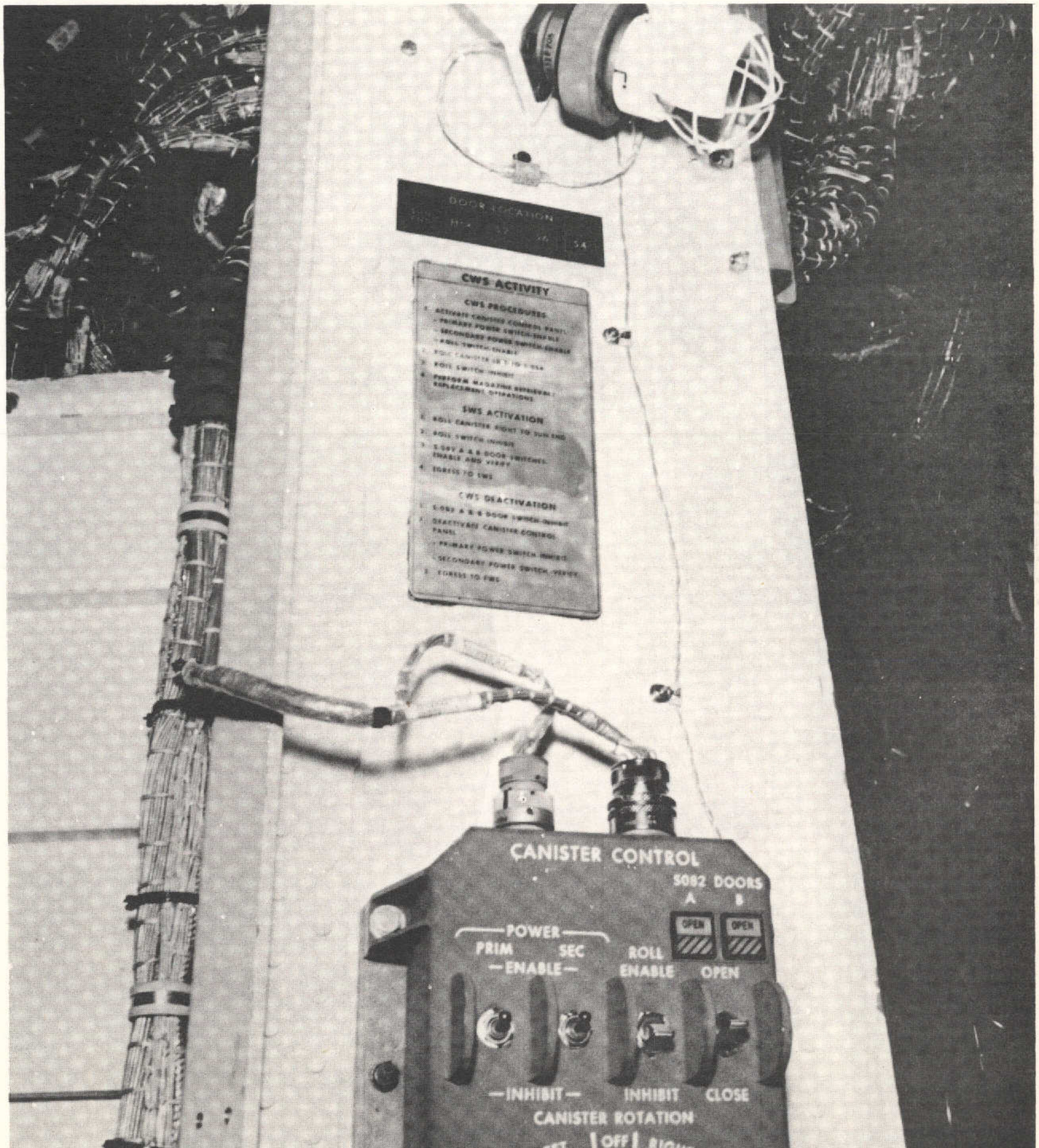


FIGURE 1.3-15: Skylab Operational Procedures Decal at ATM Center Workstation

SECTION 1.4: CREW/EQUIPMENT INTERFACE HARDWARE

This section provides an overview of several EV man-machine interfaces required in the EVA retrieval of Skylab solar astronomy data located inside an unpressurized experiment canister. The information primarily concerns the gloved hand-to-film magazine interface and the film magazine-to-scientific instrument interface. The section depicts the types of interface hardware that can be easily manipulated by the EVA crewman in data retrieval, module replacement, or comparable tasks. Each interface was exercised during the Skylab EVA missions and proven fully adequate. Similar interface requirements for the Space Shuttle Program should consider this equipment as used on Skylab. Such space flight qualified hardware could represent significant savings in design and development costs of future experiments and payloads.

Section 1.4 contains information on the following equipment:

1.4.1 FILM MAGAZINES--SKYLAB SOLAR ASTRONOMY

A. Purpose

The Skylab film magazines were used for the collection of solar astronomy video data. Of major interest in this section are the man-machine interfaces developed for package/module handling during EVA.

B. Functional Description and Support Hardware

Several Skylab solar astronomy film magazine/camera configurations and operational interfaces were used in data retrieval tasks. The configurations and interfaces were dictated by the specific requirements of the experiment.

S054: The S054 instrument (Figure 1.4-1) required an electrical connection with each film magazine. The handle of the S054 film magazine provided the crewman a gloved-hand interface for handling the magazine and a mechanism for installing the electrical connector. A linkage system allowed the connector to be mated as the handle was rotated. The operation also allowed the magazine to be locked into the experiment receptacle or onto the module stowage tree. A push-to-release type latch prevented the handle from being inadvertently actuated. Guiderails on the magazine assisted the crewman in aligning the magazine during installation operations. To prevent the crewman from installing a damaged or previously exposed magazine, indicators were provided on the housing to display the status of the film used and the internal pressure of the magazine.

S056/Hα1: The designs of the S056 and H Alpha 1 (Figure 1.4-2) film magazines were the simplest from operational and crew interface standpoints. Two teflon pins allowed the crewman to align the magazines for installation in the experiment receptacle or on the module stowage tree. The handle incorporated a trigger latch-release mechanism for unlocking the magazine from the receptacle or stowage tree. Installation required the crewman to push the magazine onto a set of capture latches. A locking push button on the handle prevented inadvertent dislodging of the magazine. The handle also contained a tether attach point. To reduce weight and volume on re-entry, the handle was detached from the magazine and discarded.

S082: The S082 film cameras/magazines (Figure 1.4-3) were highly sensitive to heat and radiation and required protective containers (Figure 1.4-4) during stowage. Each magazine employed a folding handle which could be locked in the deployed position to allow installation in the experiment receptacle or folded for installation in the stowage container. Guiderails and directional arrows on the magazines assisted the crewman in installation operations. The S082 containers provided protection for the magazines and also stowage and handling provisions. Four lugs interfaced with pins on the sun end module stowage tree for restraint during EVA operations. Each container incorporated a handle (integral with the lid) which could be operated with one hand by a suited crewman. A locking mechanism on the lid prevented inadvertent opening of the container. Tether attachment rings were provided on the handles of the containers and magazines.

S052: The S052 camera (Figures 1.4-5 and 1.4-6) contained a lens that was easily damaged and required an electrical connection with the instrument. From the EVA crewman interface, the S052 camera was the passive element. With the exception of alignment holes on the camera, the instrument contained all of the guiding and locking mechanisms. A metal cover was supplied for lens protection and removed prior to installation on the module stowage tree. The handle was also removed prior to re-entry.

C. Performance Data and Applications to Future Programs

With the exception of a malfunction of an S054 film magazine filter wheel (repaired by an EVA crewman), the film cameras/magazines on Skylab performed as anticipated. There was no damage to data or experiment equipment due to handling by the EVA crewmen. Similar equipment interfaces should be considered for future applications. Man-machine interface standardization should be stressed in future designs.

D. Specifications and Design Data

General characteristics of the solar astronomy film cameras/magazines and containers are shown in Table 1.4-1. Film characteristics are contained in Table 1.4-2.

E. Supplementary Information

Drawing/Part No.:

- S054 Drawing No.--481-202001 (Hycon Mfg. Co.)
- S056 Drawing No.--50M73658 (NASA/MSFC)
- Hα1 Drawing No.--50M13189 (NASA/MSFC)
- S082A Drawing No.--36360 (Ball Brothers Co.)
- S082B Drawing No.--36361 (Ball Brothers Co.)

Additional information may be found by contacting the personnel listed in Table 1.4-3.

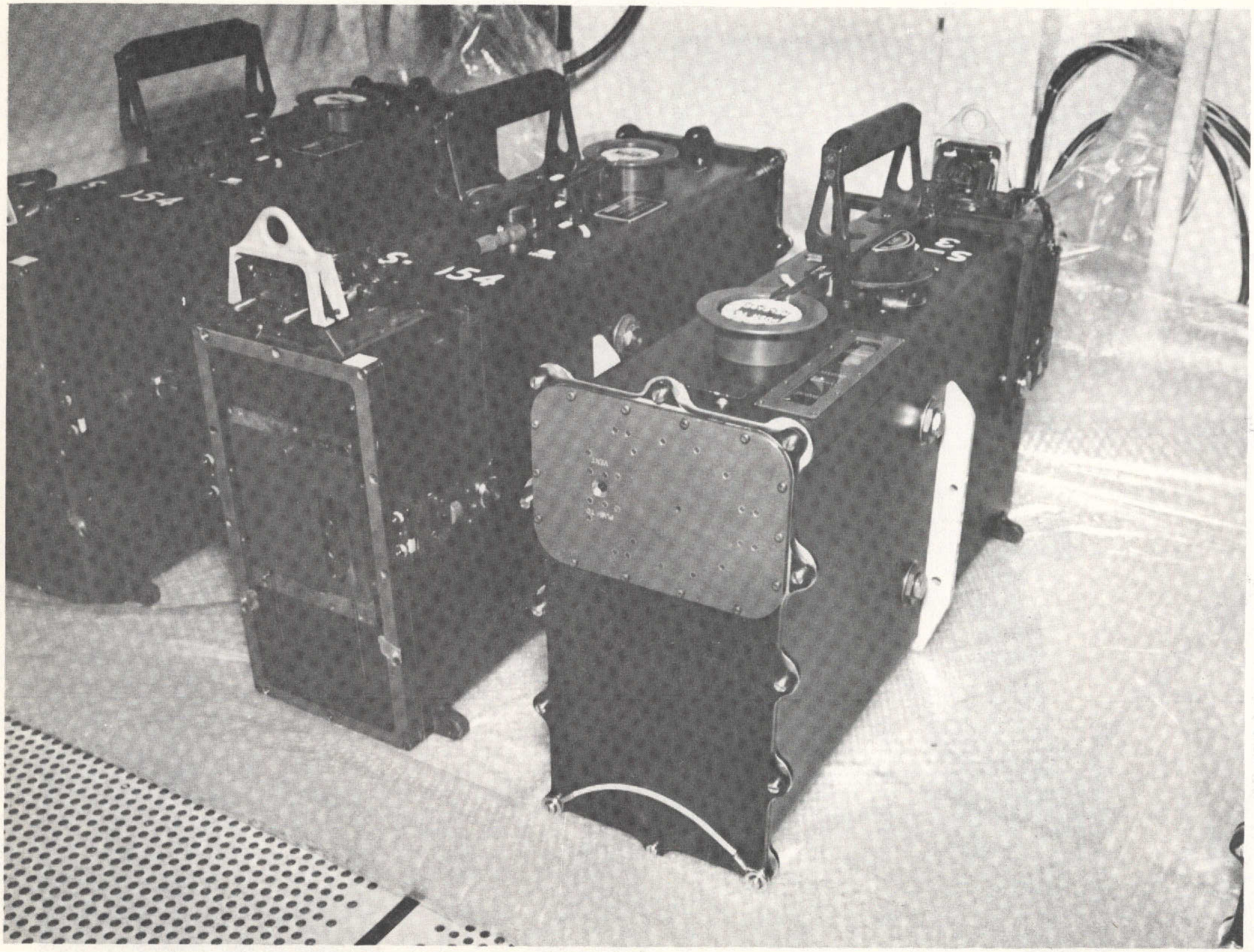


FIGURE 1.4-1: Skylab S054 Film Magazine/Camera (X-Ray Spectrographic Telescope)

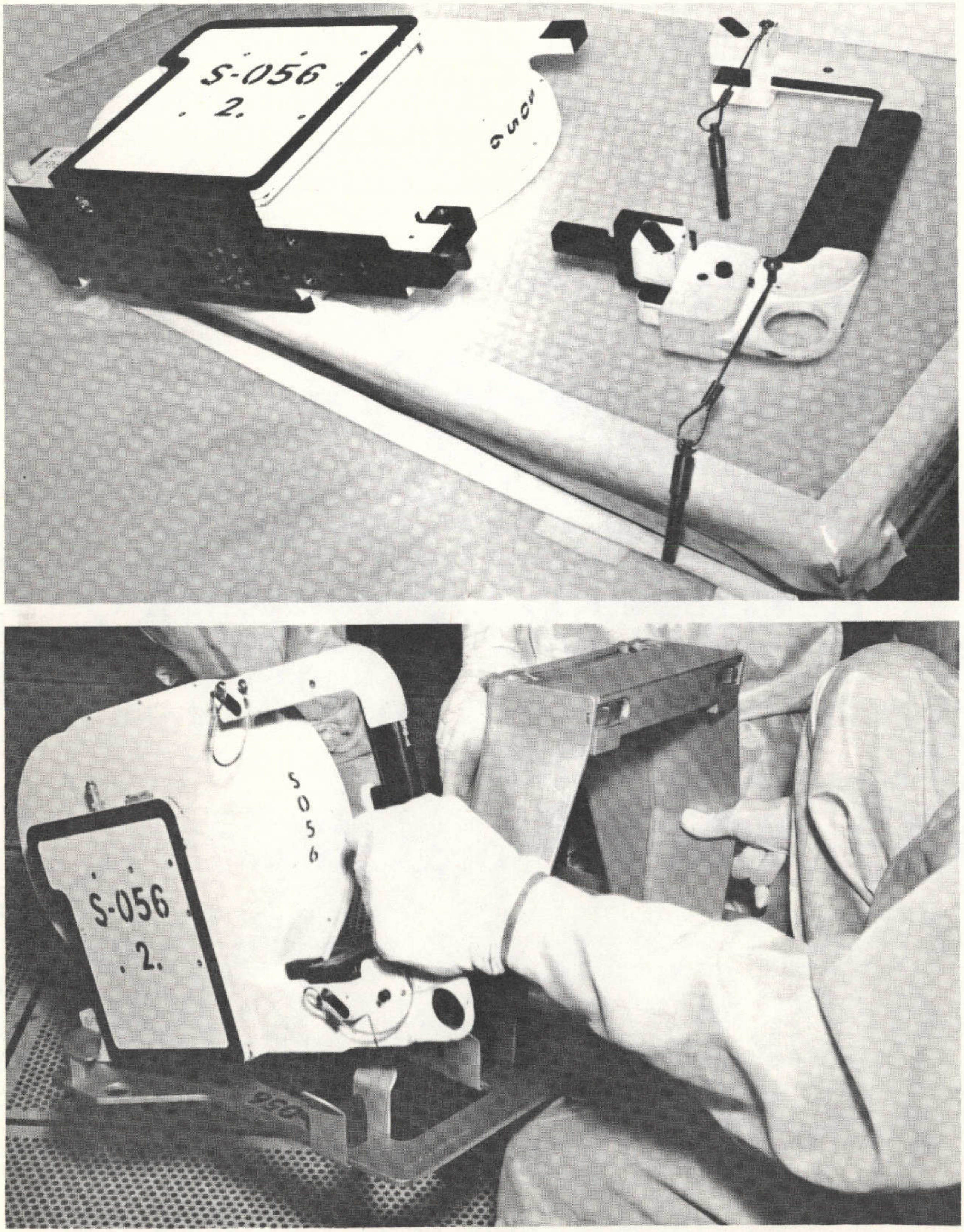


FIGURE 1.4-2: Skylab S056 Film Magazine (Dual X-Ray Telescopes)

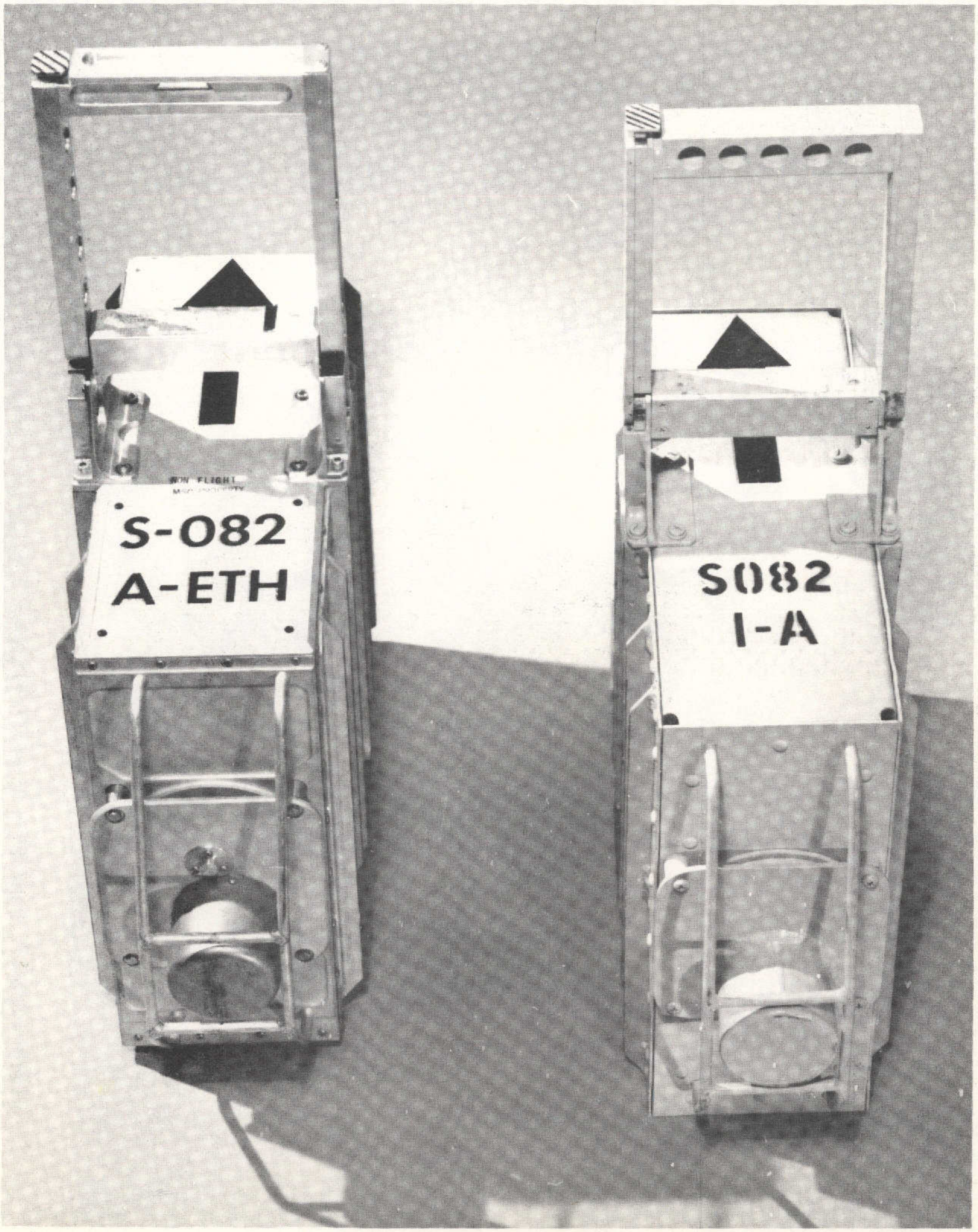


FIGURE 1.4-3: Skylab S082A Film Magazine/Camera (UV Spectrograph/Heliograph)--Training Hardware

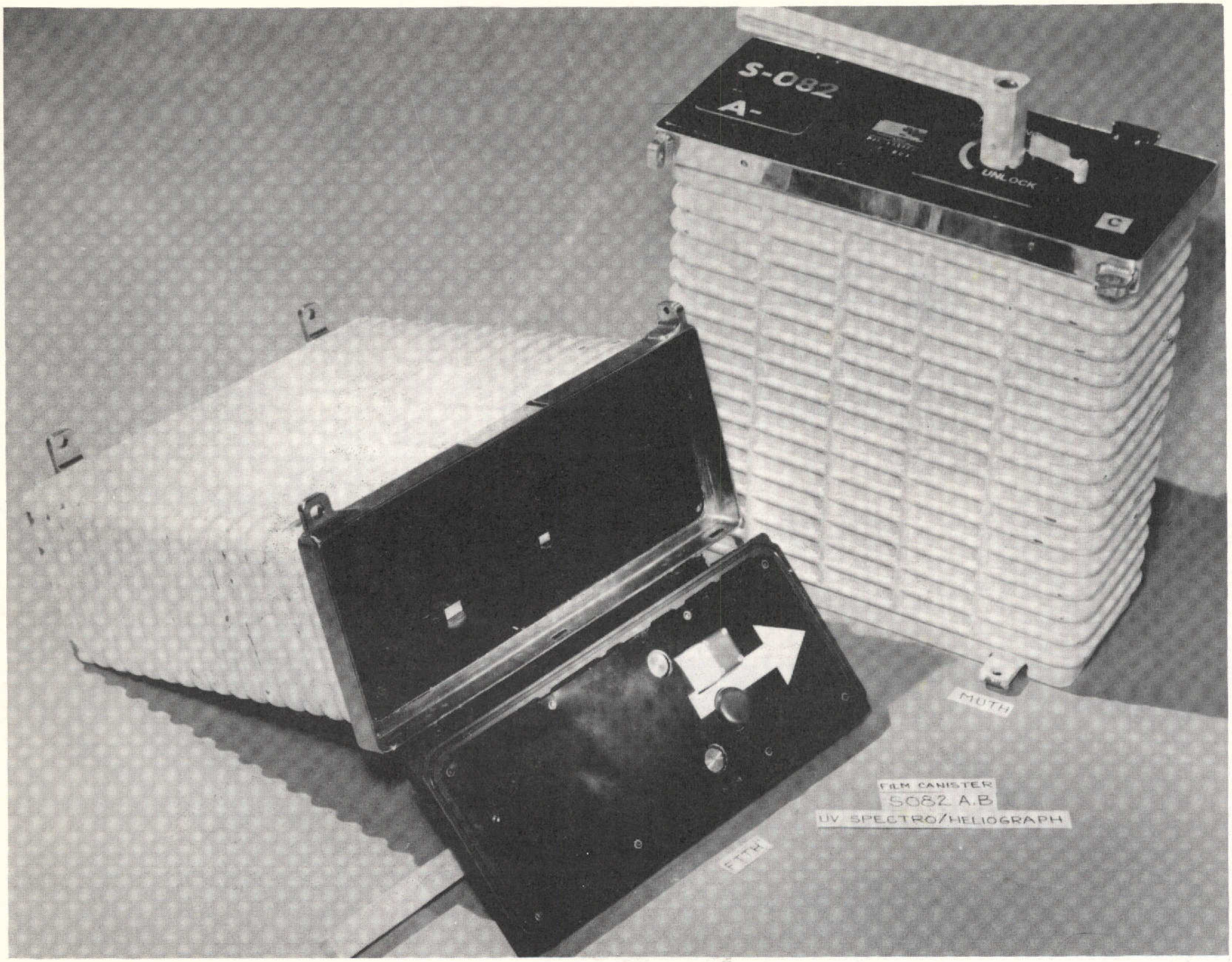


FIGURE 1.4-4: S082 Film Magazine/Camera Protective Containers (Training Hardware)

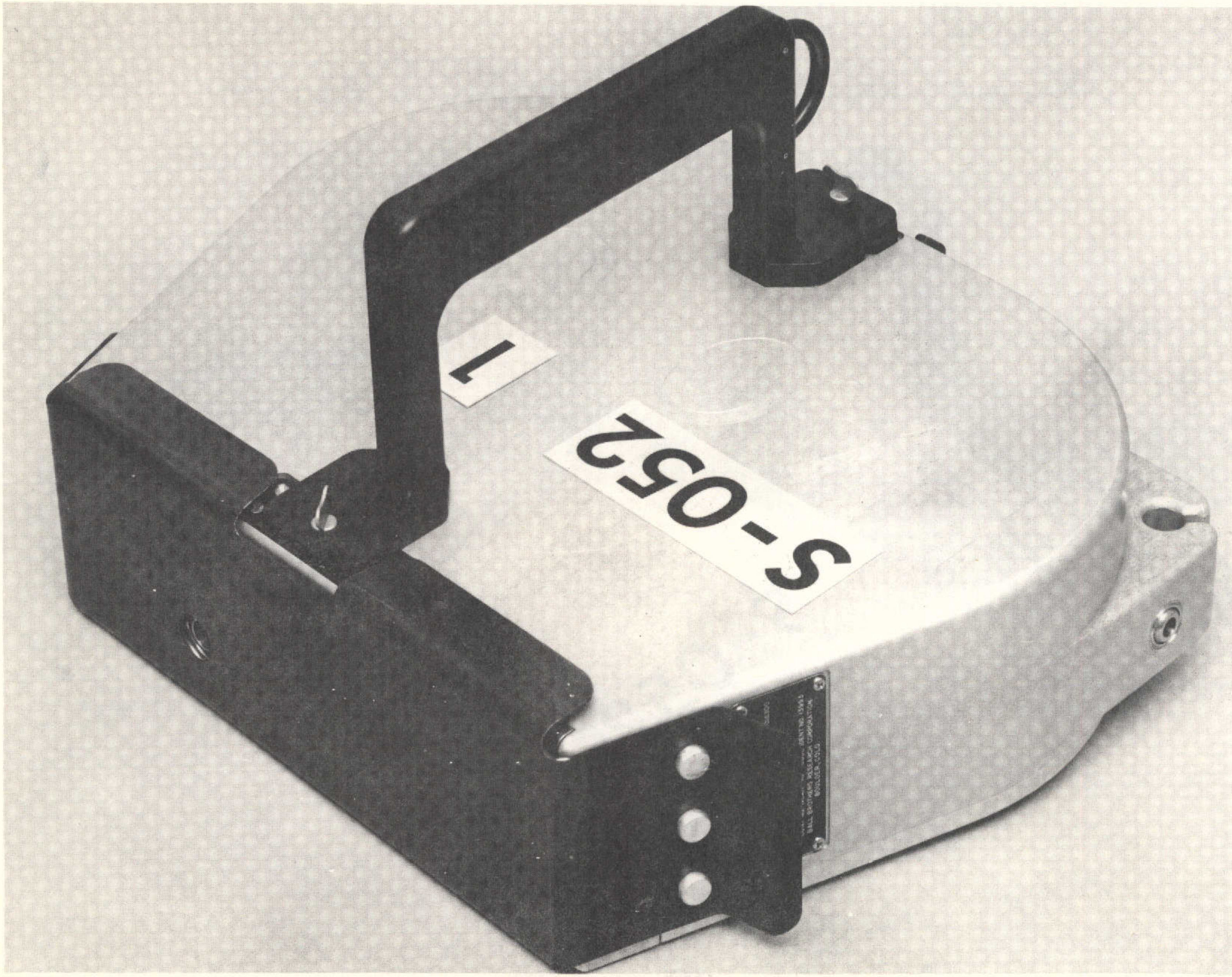


FIGURE 1.4-5: Skylab S052 Film Camera (White Light Coronagraph)

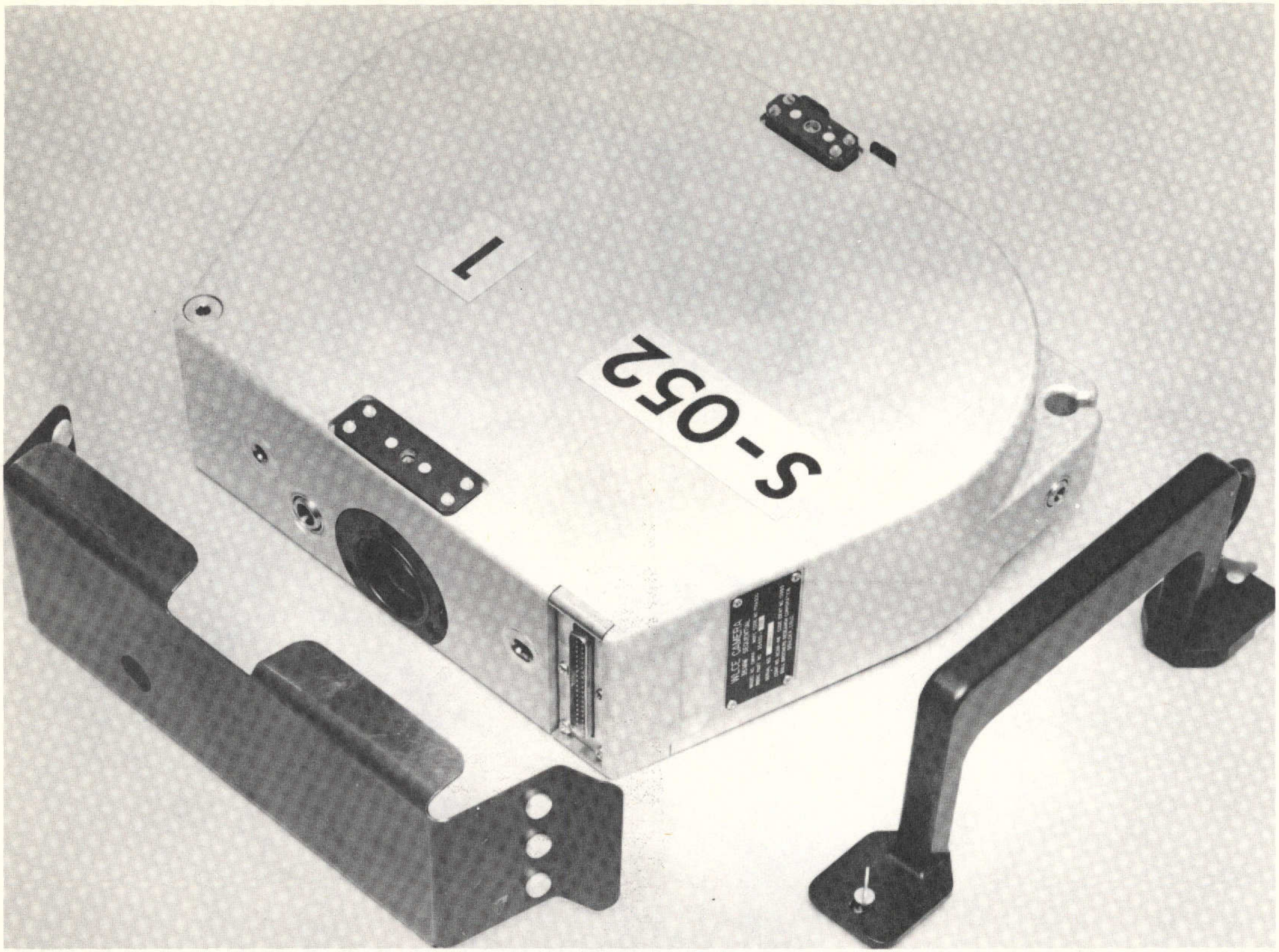


FIGURE 1.4-6: S052 Film Camera--Handle and Lens Protective Cover Removed

TABLE 1.4-1: Skylab Film Camera/Magazine and Container Characteristics

	ENVELOPE		WEIGHT		CREW INTERFACE	CREW ACTION
	cm.	in.	kg.	lb.		
S052	32x20.8x8.1	12.6x8.2x3.2	10	22	Removable handle (thumb screws)	Push magazine to install
S054	62x45.8x20.2	24.5x18x8	17.7	39	Integral handle	Push mag to install, twist handle to lock mag
S056	26.7x47x9.9	10.5x18.5x3.9	7.1	15.6	Removable handle (pip-pins)	Push mag to install, squeeze handle to unlock mag
H ALPHA 1	26.7x47x9.9	10.5x18.5x3.9	5.7	12.5	Removable handle (pip-pins)	Push mag to install, squeeze handle to unlock mag
S082 A	43.2x42x165	17x16.6x6.5	14.9	33	Folding handle (push button actuator)	Rotate handle to de-ploy, push handle to install mag
S082 A CONTAINER	53.2x45.7x 22.8	21x18x9	11.8	26	Integral handle (lever)	Rotate handle 180° and swing lid open
S082 B	43.2x42x165	17x16.6x6.5	15.9	35	Folding handle (push button actuator)	Rotate handle to de-ploy, push handle to install mag
S082 B CONTAINER	53.2x45.7x 22.8	21x18x9	11.8	26	Integral handle (lever)	Rotate handle 180° and swing lid open

TABLE 1.4-2: Skylab Solar Astronomy Film Characteristics

	WIDTH	LENGTH		NUMBER OF FRAMES	TYPE OF FILM
		SI	CONVENTIONAL		
S052	35 mm.	229 m.	750 ft.	8025	Kodak 026-02 thin base
S054	70 mm.	426 m.	1400 ft.	7200	Panatomic - X type emulsion
S056	35 mm.	304.8 m.	1000 ft.	8000	Kodak SO212 Estar Base 2.5 mil
H ALPHA 1	35 mm.	304.8 m.	1000ft.	16,000	SO 101
S082A	35 mm.	258 mm. (each strip)	10.2 in. (each strip)	200 strips (4 exposures per strip)	Kodak plus X (identification) and 104-06 short wavelength radiation film
S082B	35 mm.	258 mm. (each strip)	10.2 in. (each strip)	200 strips (8 exposures per strip)	UV sensitive

TABLE 1.4-3: Skylab Solar Astronomy Experiment Cognizant Personnel

EXP. NO.	NOMENCLATURE PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	TECHNICAL MONITOR	MSFC/JSC MONITOR
S052	WHITE LIGHT CORONAGRAPH HIGH ALTITUDE OBSERVATORY BBRC	Dr. R. MacQueen High Altitude Observatory P. O. Box 1558 Boulder, Colo. 80302 (303) 444-5151	R. F. Harwell MSFC	J. C. O'Loughlin JSC/KW
S054	X-RAY SPECTROGRAPHIC TELESCOPE AMERICAN SCIENCE AND ENGINEERING INC.	Dr. R. Giacconi American Science & Eng., Inc. 11 Carleton St. Cambridge, Mass. 02142 (617) 868-1600	T. Ponder MSFC	J. C. O'Loughlin JSC/KW Ray Morse MSFC
S056	DUAL X-RAY TELESCOPES GSFC/MSFC	Mr. J. Milligan MSFC/SE-SSL-T National Aero. & Space Adm. MSFC, Alabama 35812 (205) 453-3100	J. Douglas MSFC	J. C. O'Loughlin JSC/KW
S082	UV SPECTROGRAPH/HELIOGRAPH NAVAL RESEARCH LABORATORY/ BBRC	Dr. R. Tousey Naval Research Laboratory Code 7140 Washington, D.C. 20390	R. M. Simpson MSFC	J. C. O'Loughlin JSC/KW

1.4.2 FILM MAGAZINE-TO-INSTRUMENT INTERFACE--SKYLAB

A. Purpose

The solar astronomy experiment equipment on Skylab included receptacles for cameras/magazines to resupply the telescopes with replacement film and/or cameras. The man-machine interfaces associated with magazine/camera exchange are of interest in this section.

B. Functional Description and Support Hardware

The various experiment magazine configurations necessitated different interface designs for each receptacle. There were similarities in each of the magazine-to-instrument designs: All receptacles provided guides for easy alignment and installation; and each receptacle (excluding S054) contained a mechanical flag to indicate the magazine had been properly installed. In addition, since a full complement of magazines was launched on the experiment, "launch locks" were provided on each receptacle to prevent disloding of the magazines during launch loading.

The S052 receptacle (Figure 1.4-7) incorporated four rails to guide the magazine into place. A sliding mechanism interfaced with a fitting on the bottom of the magazine to keep the magazine aligned during insertion. The unit was locked into place by manually rotating a lever. The lever locking action deployed a mechanical flag into view to assure the crewman the magazine was properly installed and locked.

The S054 receptacle (Figure 1.4-8) used two alignment guides which interfaced with the rails on the sides of the magazine for proper alignment during installation. Two holes in the receptacle, one on each side of the electrical connector, interfaced with two pins on the magazine to assure proper alignment of the electrical connectors as they were mated. The pins and holes also served as the locking mechanism to restrain the magazine in the receptacle. A mechanical flag integral to the magazine signaled the crewman when the magazine was locked into place.

The box-like receptacles for S056 and H Alpha 1 magazines were esentially identical (Figure 1.4-9). The front edges of each receptacle were flared to make installation of the magazines easier. The edges were painted white to contrast with the flat black of the interior. A "shoe" was provided in each receptacle to interface with and restrain the magazines. Two pins on the front of the shoe restrained the front of the magazine in place. The locking action deployed a mechanical flag into view to assure the crewman the magazine was properly installed.

The two S082 receptacles on the sun end of the telescope canister were similar. Each provided guiderails which were flared at the entrance for easy magazine installation. Lugs interfaced with projections near the face of the magazines to latch them into place. The lugs were operated by a handle on the receptacle that actuated an over-center device. A mechanical flag near the center of the receptacle indicated the magazines were properly installed (Figures 1.4-10 and 1.4-11).

C. Performance Data and Applications to Future Programs

The film magazine/camera interfaces to the instruments were totally adequate for servicing the Skylab solar astronomy experiments. The alignment mechanisms, locking devices, and visual indicators aided the crewman in terms of EVA time expenditure and a visual indication of properly installed and operational units. No problems were encountered with the crewman's gloved handling of the magazines or actuation of the instrument subsystems. Design features of the Skylab solar astronomy equipment enhanced mission and EVA success and should be considered for future application. However, standardization of the man-machine interfaces is recommended.

D. Specifications and Design Data

Design data on each of the Skylab solar astronomy magazine-to-instrument interfaces are not reproduced in this document. Reference to such material is contained in the following Supplementary Information Subsection. Representative actuation forces resulting from the interface designs are presented in the following table:

OPERATION	FORCE REQUIRED		EXPERIMENT
	kg.	lb.	
LATCH-UNLATCH, LATCH HANDLE (PUSH-PULL)	1.6 - 1.8 Operational	3.5 - 4 Operational	S052
LOCK-UNLOCK, LAUNCH LOCK TEE-HANDLE (PUSH-PULL)	5.2 - 5.7 Operational	11.5 - 12.5 Operational	S052
INSTALL CAMERA TO INSTRUMENT (PUSH-PULL)	4.5 Maximum	10 Maximum	S052, S056, H Alpha 1
OVERCOME LATCH LEVER DETENTS (PUSH-PULL)	5.5 - 7.3	12 - 16	S082A, S082B
OPERATE LATCHING HANDLES (TANGENTIAL FORCE) SUSTAINED	8.2 Maximum	18 Maximum	S082A, S082B
IMPULSE	16.4 Maximum	36 Maximum	S082A, S082B

E. Supplementary Information

Documentation:

S082A

Design and Performance Specification XUV Coronal Spectroheliograph Instrument 1-A, ATM-A Experiment S082A, Ball Brothers Research Corporation, CP 25905, Boulder, Colorado

S082

XUV Spectroheliograph Video Taped Briefing (handout), NASA, Manned Spacecraft Center, March 1972, Houston, Texas

Description and Operating Instructions NRL/ATM XUV Coronal Spectroheliograph ATM Experiment S082A, Ball Brothers Research Corporation, 620-53, Boulder, Colorado

S082B

Astronaut Operation Requirements Document for the Chronospheric XUV Spectrograph and XUV Monitor Experiment S082B - Apollo Telescope Mount A, Naval Research Laboratory, 26 June 1969

Design and Performance Specification XUV Spectrograph Instrument 1-B, ATM-A Experiment S082B, Ball Brothers Research Corporation, CP-2100, Boulder, Colorado

Description and Operating Instructions NRL/ATM XUV Spectrograph ATM Experiment S082B, Ball Brothers Research Corporation, 620-54, Boulder, Colorado

MSFC Drawing No. 50M02462 (interface requirements and limitations of camera latch and guiderail assembly)

Skylab SL-ATM-EXP-6, Spectrograph and XUV Monitor (S082B) Video Taped Briefing, NASA, Manned Spacecraft Center, March 1972, Houston, Texas

S054

ATM Experiment Interface Defining Document (EIDD) S054, X-Ray Spectrographic Telescope, NASA, Marshall Space Flight Center, Drawing No. 50M02429

Skylab ATM Classroom Training, SL-ATM-EXP-2, X-Ray Spectrographic Telescope (S054), American Science and Engineering, AES-2687-FO, September 1971, Cambridge, Mass.

S052

S052 Design and Performance Specification, Ball Brothers Research Corporation, CP 22876, Boulder, Colorado

S052 Experiment Interface Defining Document, NASA, Marshall Space Flight Center, Drawing No. 50M02414

S052 White Light Coronograph Video Taped Briefing, NASA, Manned Spacecraft Center, March 1972, Houston, Texas

H Alpha I

ATM Experiment Interface Defining Document, NASA, Marshall Space Flight Center, Drawing No. 50M02463

Interface Control Document Mechanical, H Alpha Film Camera, NASA, Marshall Space Flight Center, Drawing No. 50M01089

S056

Extreme UV and X-Ray Telescope Video Taped Briefing, NASA, Manned Spacecraft Center, March 1972, Houston, Texas

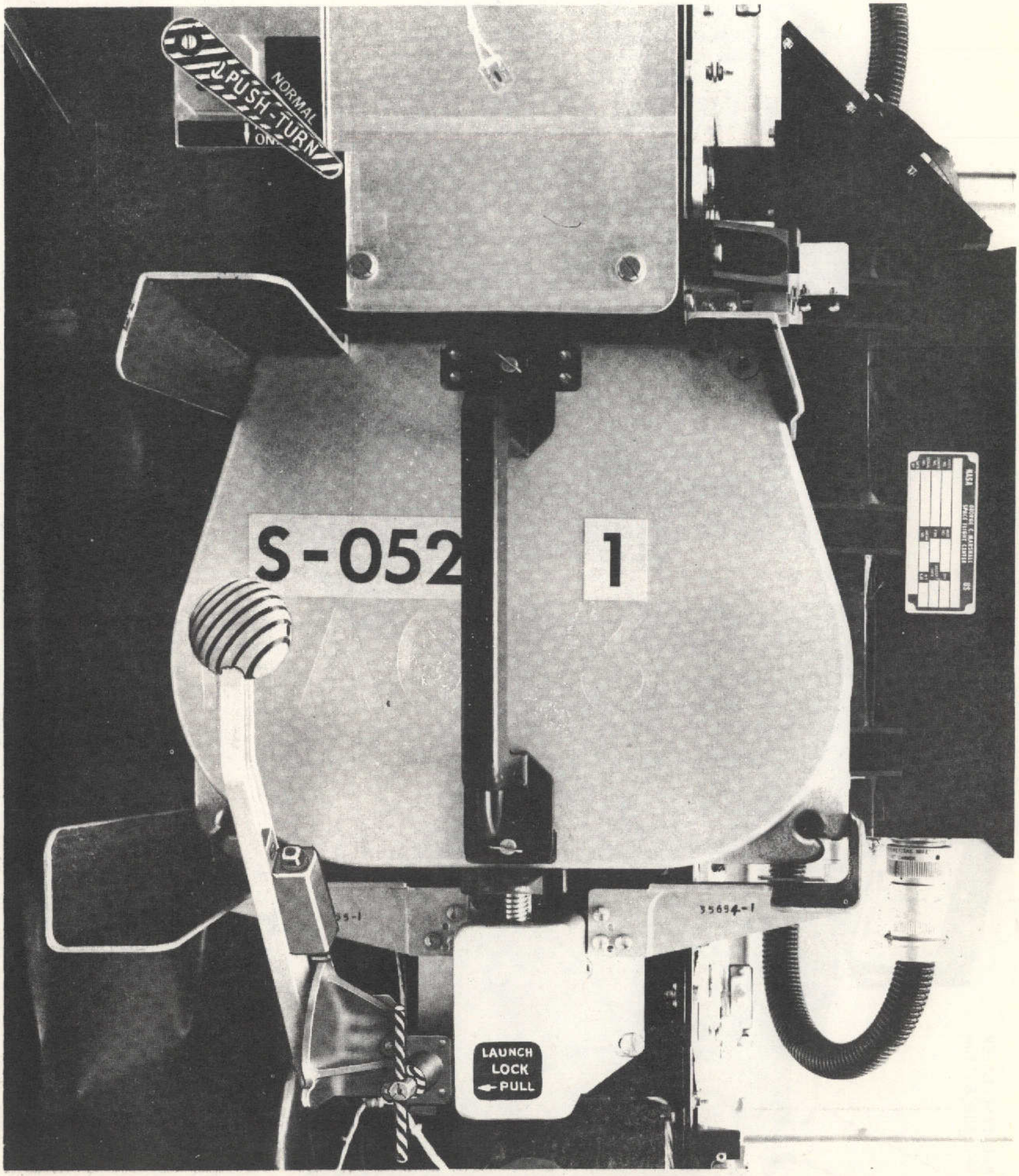


FIGURE 1.4-7: Skylab S052 Camera-to-Instrument Interface

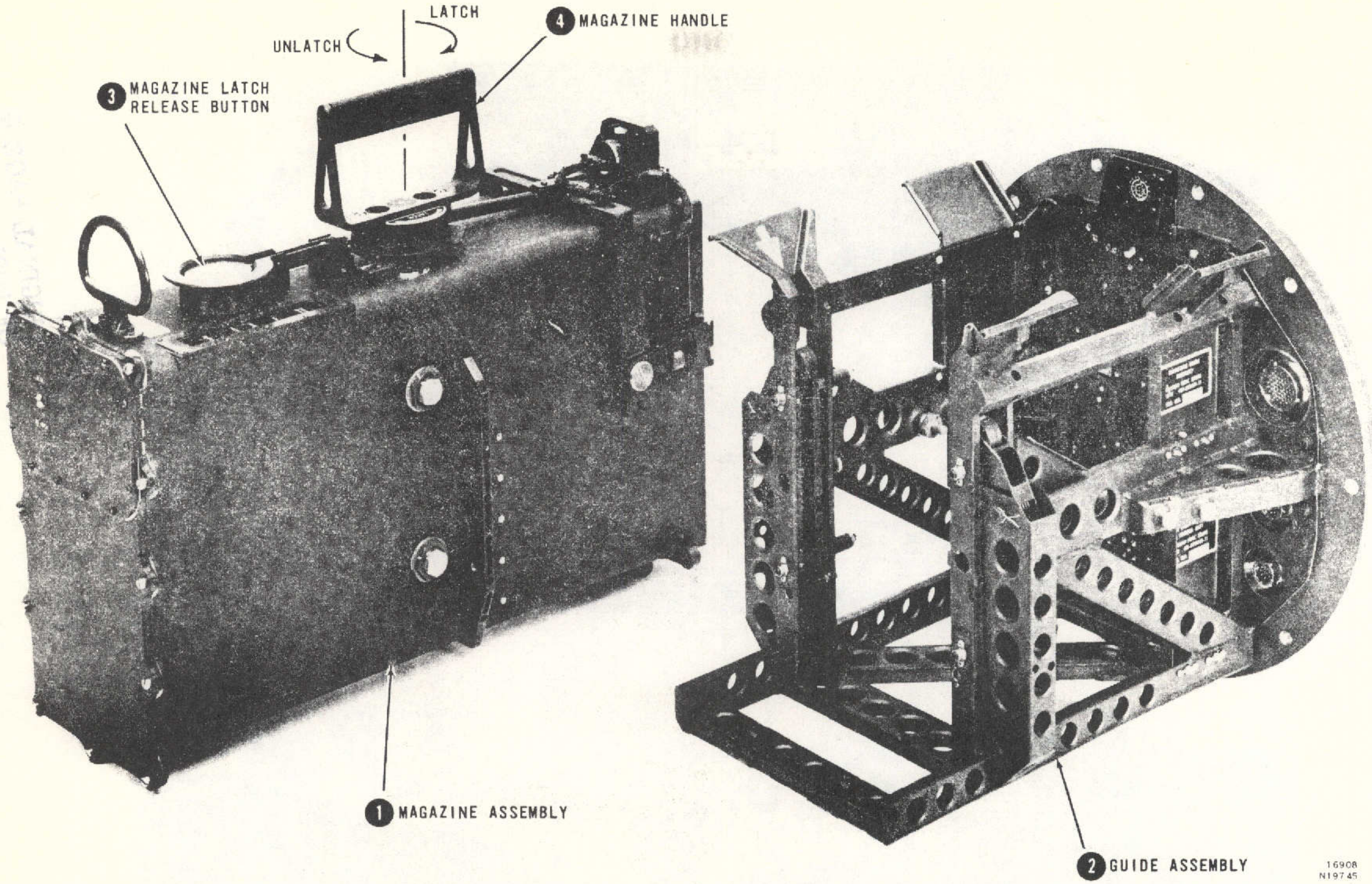


FIGURE 1.4-8: Skylab S054 Film Magazine and Instrument Interface

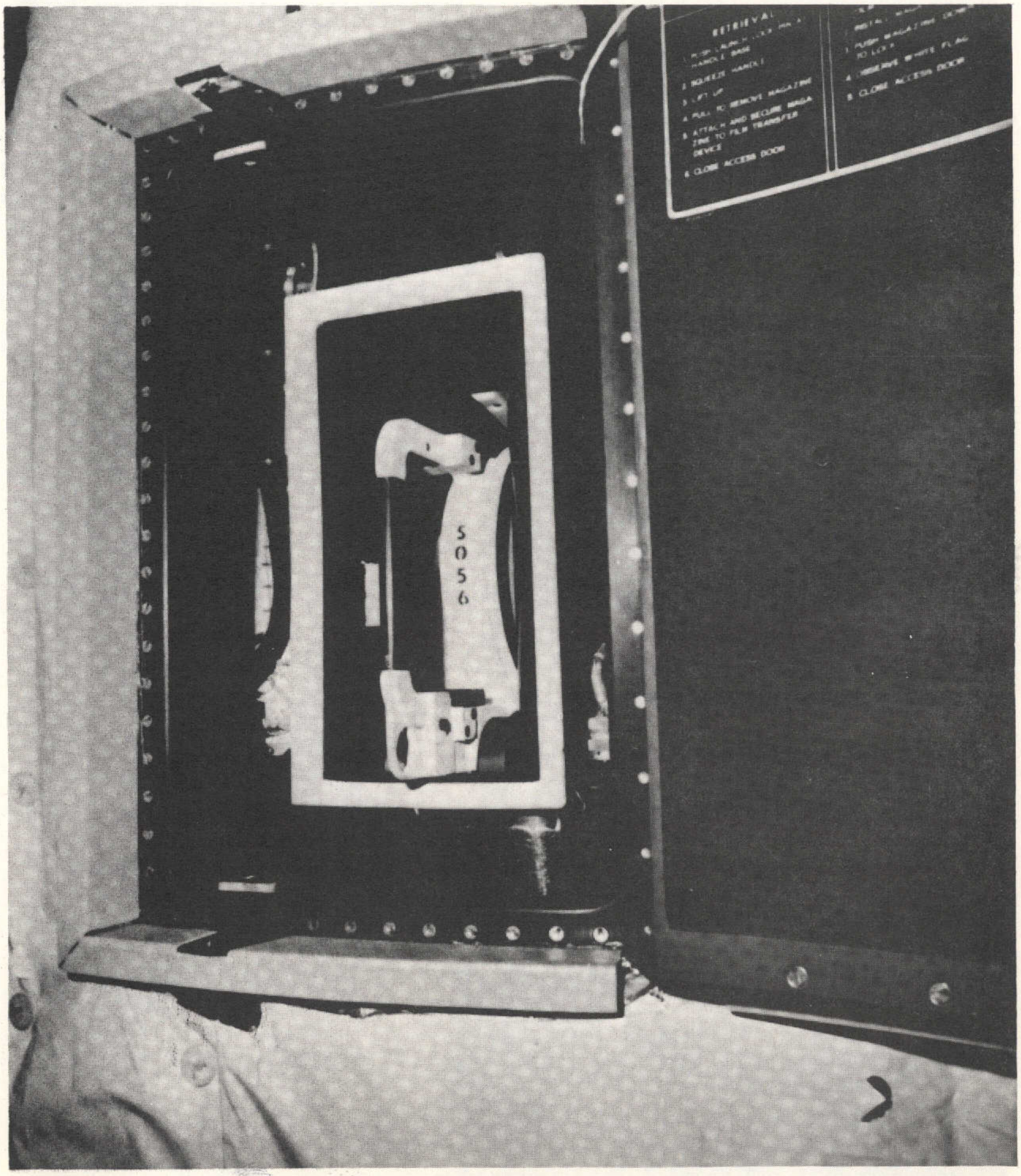


FIGURE 1.4-9: Skylab S056 Film Magazine and Receptacle Entrance

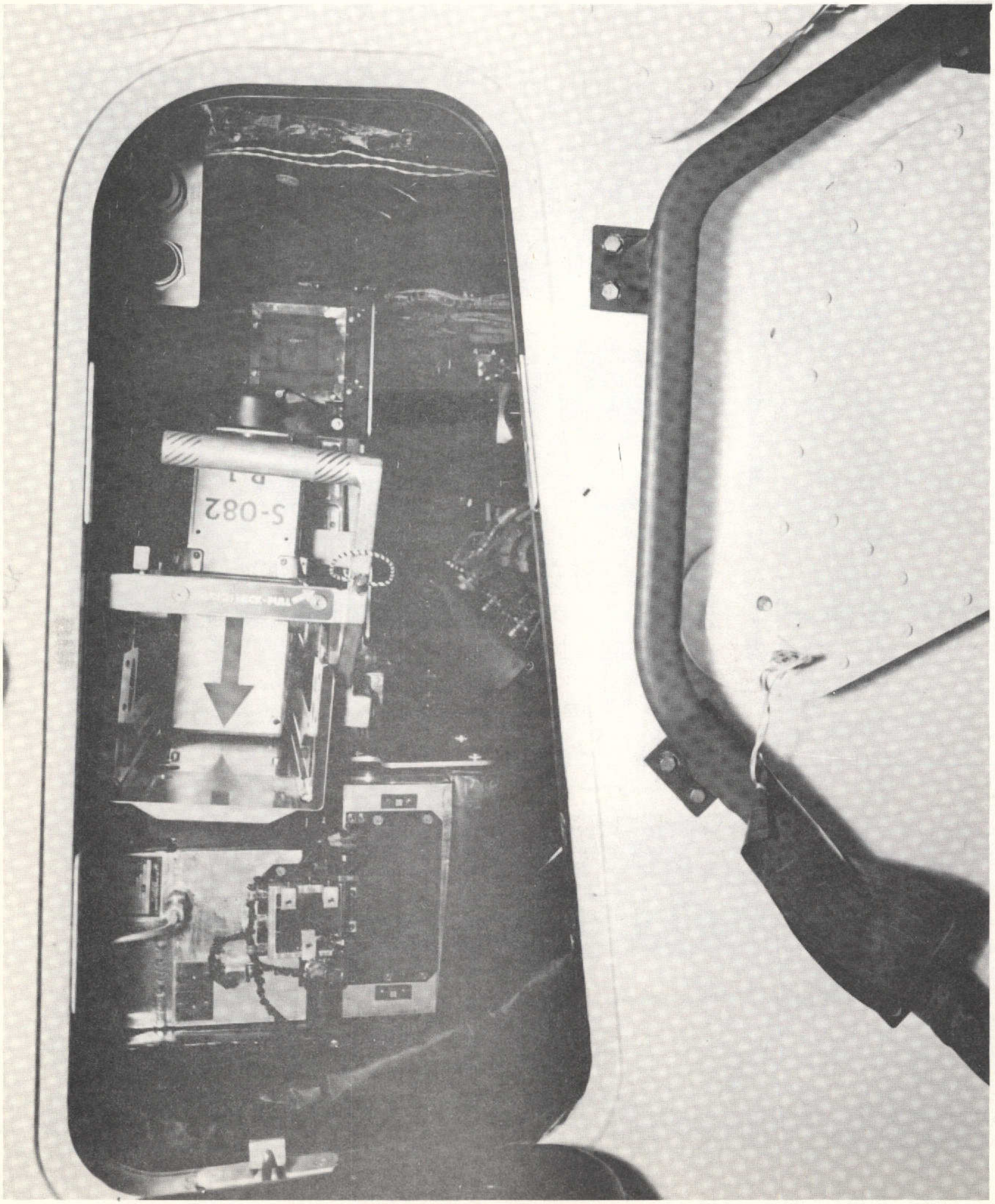


FIGURE 1.4-10: Skylab S082 Camera-to-Instrument Interface

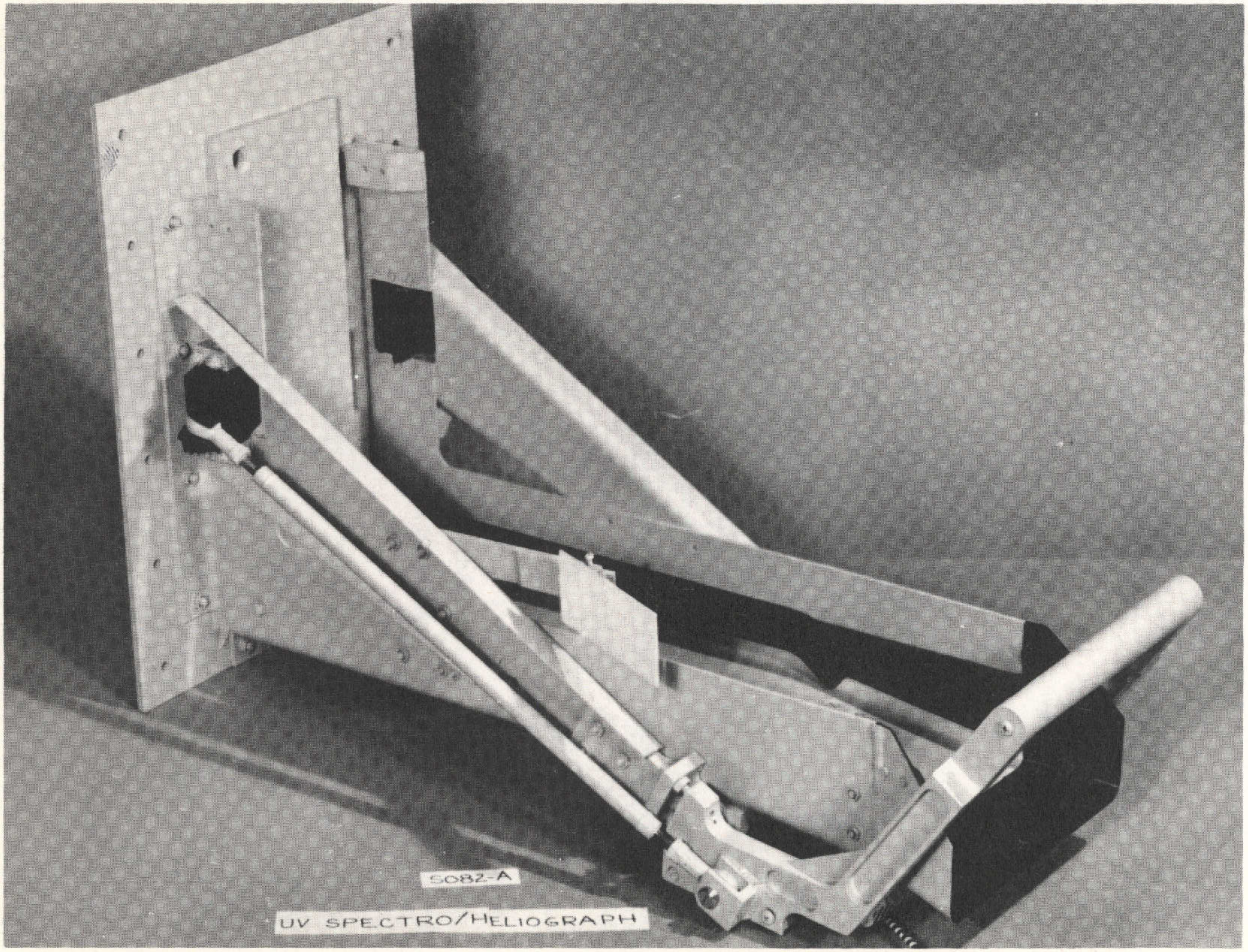


FIGURE 1.4-11: S082 Camera Receptacle--Design Mockup

1.4.3 MODULE STOWAGE/TRANSFER TREE--SKYLAB FILM TREE

A. Purpose

The Skylab stowage trees were designed to temporarily stow and conveniently handle specific groups of ATM solar astronomy cameras/film magazines replaced and retrieved during Skylab EVAs.

B. Functional Description and Support Equipment

The Skylab ATM VC (center workstation) tree (Figures 1.4-12 through 1.4-14) had provisions for restraining four experiment packages of various configuration and latching devices. The VS (sun end workstation) tree provided restraint for two special experiment camera containers (Figure 1.4-15). Both trees incorporated quick connect/disconnect devices for ease of crewman operation and positive locking mechanisms to avoid inadvertent camera/magazine dislodging. The positive locking devices were usually part of the experiment package that interfaced with the tree. The film trees were attached to the vehicle via permanently mounted receptacles (Figure 1.4-16). A T-bar on the trees interfaced with a "V-shaped" groove on the receptacles to provide a guide for installation. A latch on each tree interfaced with a slot in the receptacle to provide a firm attachment. The latches were operated by a trigger device on the handle of each tree. Each handle also incorporated a thumb operated safety latch to prevent inadvertent dislodging of the tree from its receptacle.

C. Performance Data and Applications to Future Programs

The trees were used routinely on Skylab experiment servicing missions. Each unit performed satisfactorily with no recorded problems. The trees have proven to be an effective means for the EVA crewman to transport or stow several experiment packages. Similar equipment may be applicable on future programs when multiple packages are handled on-orbit.

D. Specifications and Design Data

	VC (Center Workstation)	VS (Sun End Workstation)
Weight	.87 kg. (19.25 lbs.)	.33 kg. (7.2 lbs.)

	VC (Center Workstation)	VS (Sun End Workstation)
Material	aluminum	aluminum
Dimensions	.67x.53x.52 m. (26.3x20.75x20.5 in.)	.57x.48x.20 m. (22.4x18.75x8.0 in.)

E. Supplementary Information

Documentation:

- Skylab Operations Handbook, Apollo Telescope Mount, Volume I; Martin Marietta Corporation, Contract NAS 8-2400, MSFC-205, 27 March 1972
- Skylab Operations Handbook, OWS, AM, MDA; McDonnell Douglas Astronautics Company, Contract NAS 9-11001, Volume I, MSC 04727, 27 January 1972

Drawing/Part No.:

- VC Tree - Drawing Nos.: 10M04900; 13M13422
- VS Tree - Drawing Nos.: 10M04760; 13M13423

Item Developed By:

- VC Tree - NASA/Marshall Space Flight Center
- VS Tree - NASA/Marshall Space Flight Center

Item Supplied To:

- VC Tree - Martin Marietta Corporation, Denver Division
- VS Tree - Martin Marietta Corporation, Denver Division

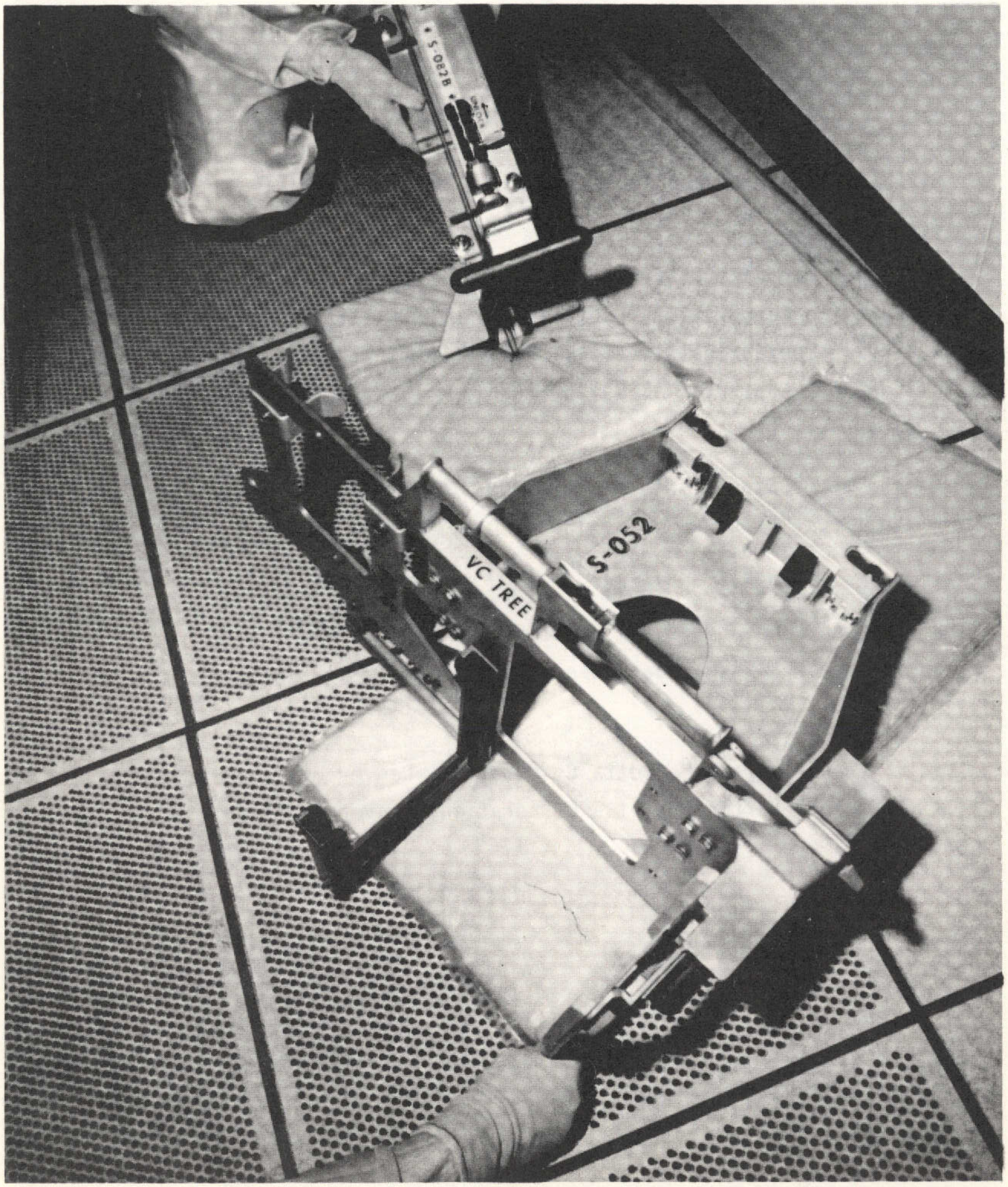


FIGURE 1.4-12: Center Workstation Film Magazine Tree (Skylab)

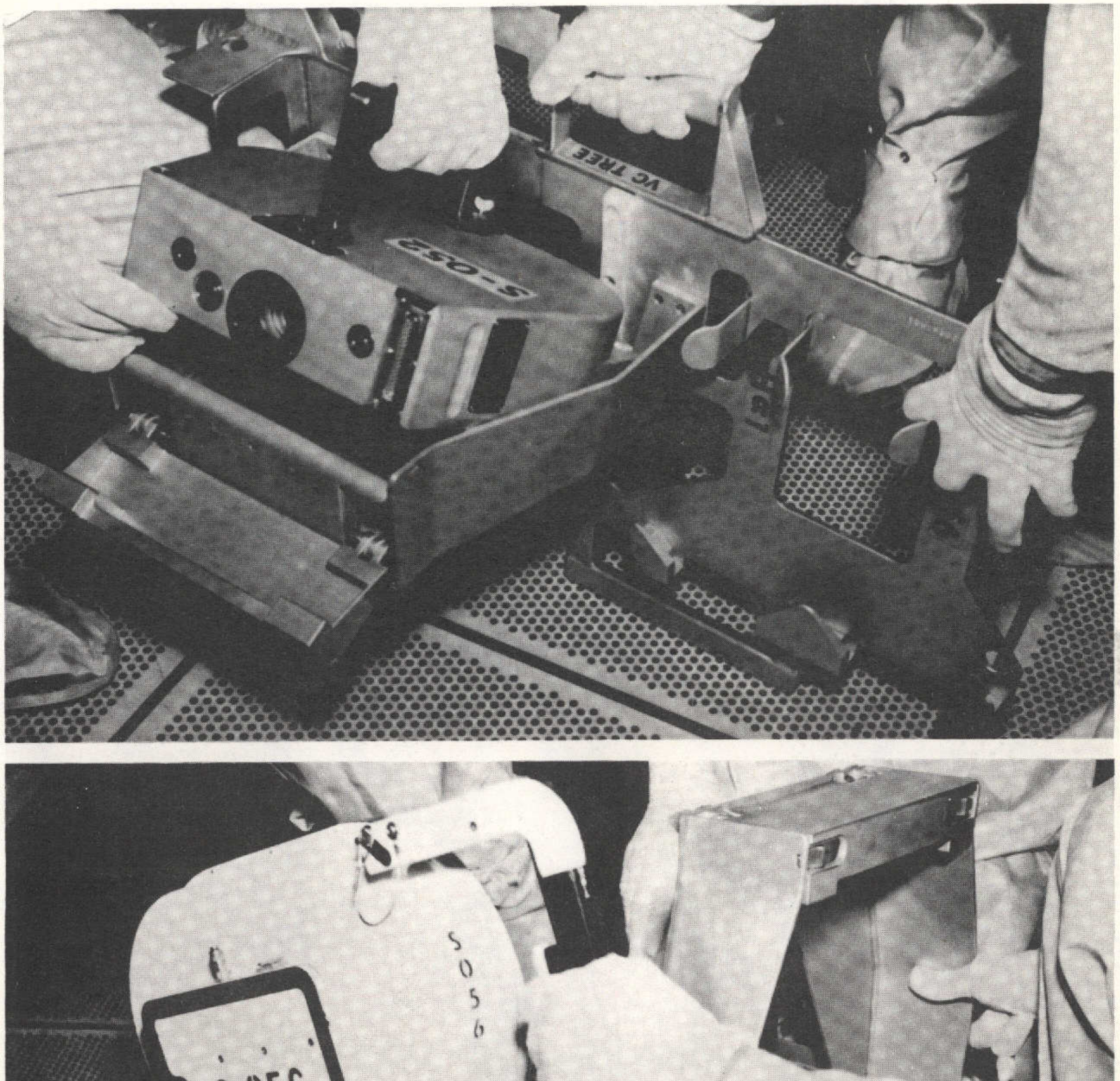


FIGURE 1.4-13: Film Magazines/Cameras Being Loaded on VC Tree (Ground Simulation)

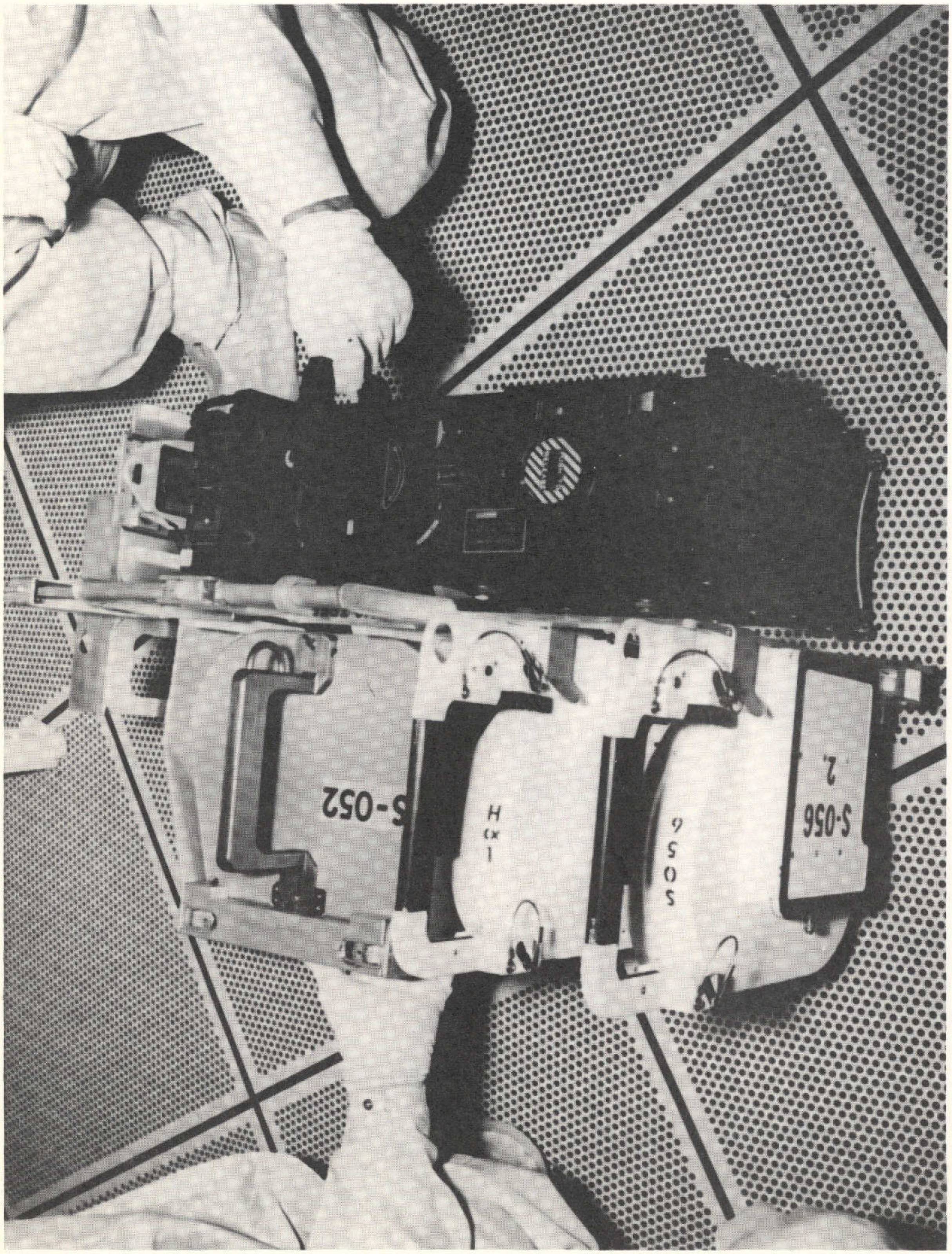


FIGURE 1.4-14: Skylab VC Tree Fully Loaded

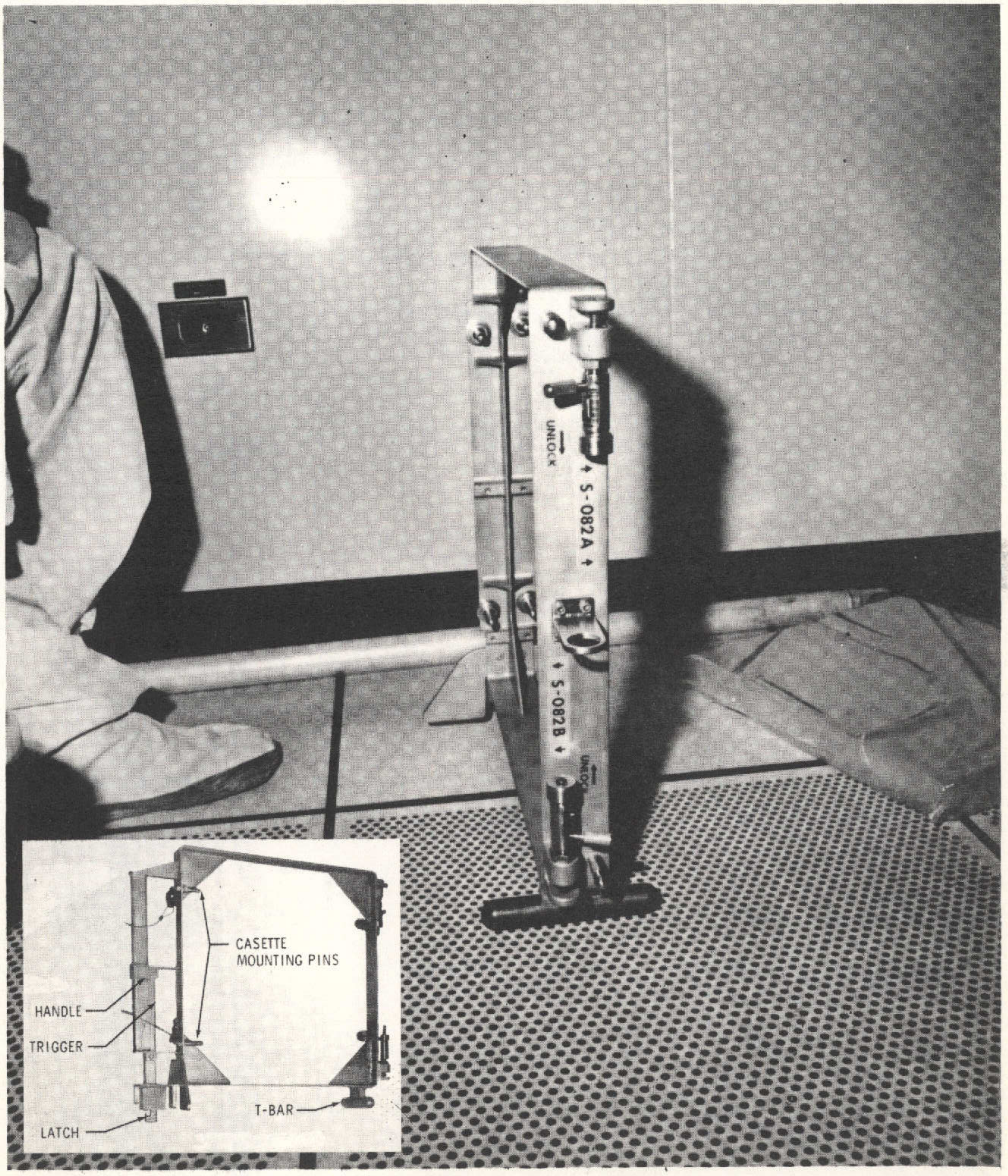


FIGURE 1.4-15: Sun End Workstation Film Camera/Magazine Tree (Skylab)

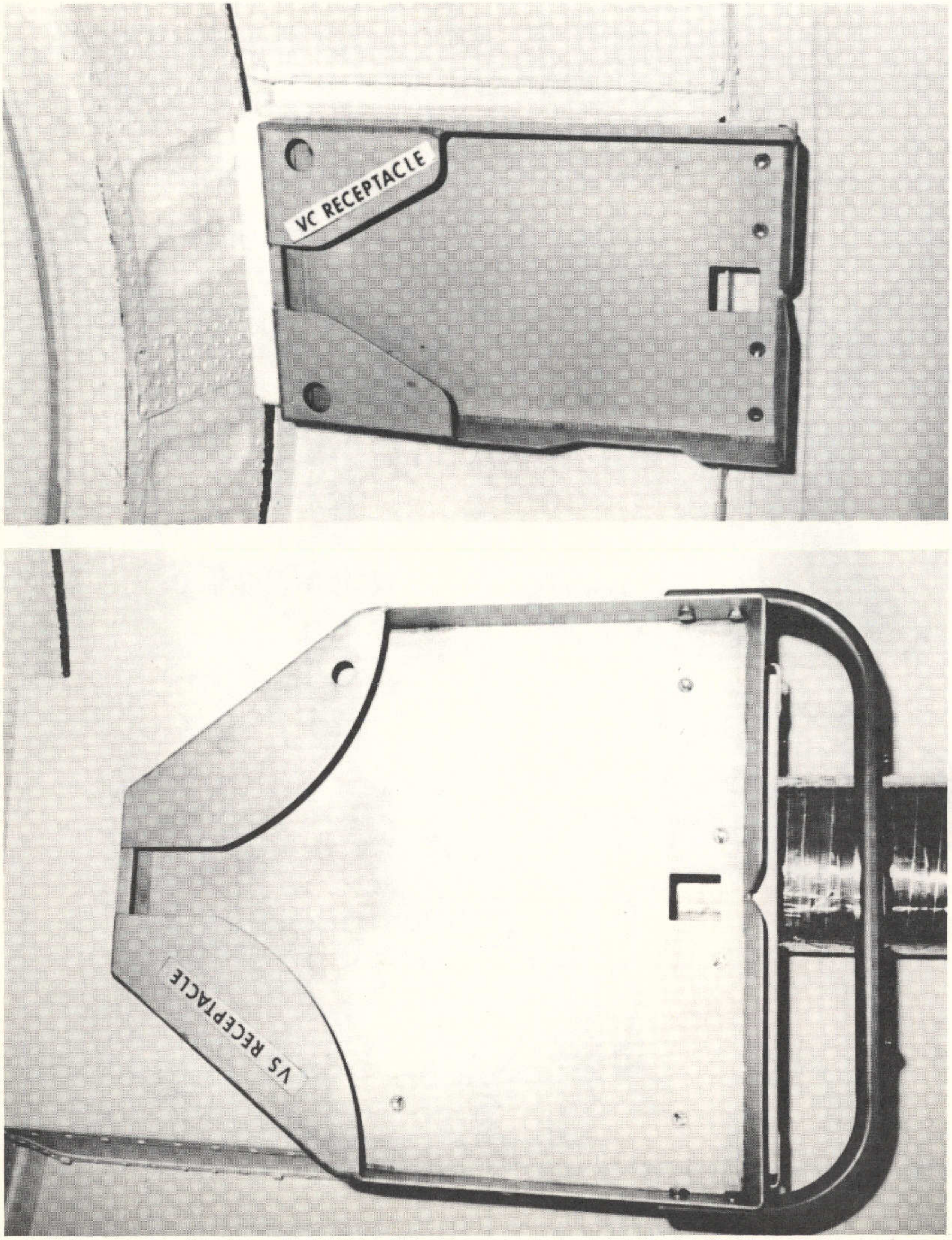


FIGURE 1.4-16: Skylab Film Tree Receptacles

SECTION 1.5: EXPERIMENT ACCESS DOORS AND CREW EVA HATCHES

Many of the Space Shuttle experiments and payloads will require protection during launch and while exposed to the space environment. Access doors and hatches will be provided for on-orbit planned and contingency operations which meet the man-system interface requirements of the EVA crewman and his protective equipment. Several such access provisions were included on previous space missions, particularly on the Skylab Program. Six solar astronomy experiments on Skylab required periodic EVA retrieval of data and replacement of film magazines and cameras. This section contains physical and operational characteristics of the experiment access doors located on the Skylab Apollo Telescope Mount (ATM) and the Airlock Module EVA hatch. Similar door mechanisms and interfaces may be applicable to experiments and payloads on the Space Shuttle Program.

Section 1.5 contains information on the following equipment:

1.5.1 SKYLAB EXPERIMENT ACCESS DOORS

A. Purpose

Experiment access doors were provided on the Skylab ATM to enable on-orbit exchange of solar astronomy film.

B. Functional Description and Support Hardware

Five (5) rectangular access doors of various sizes were provided on the side of the Skylab ATM canister and two "irregularly" configured doors on the sun end. All doors (excluding one side door) were employed in on-orbit EVA film exchange functions. The ATM side access doors latching mechanisms and crew interfaces were basically identical. The sun end door crew interface differed from the side doors.

The side doors (Figures 1.5-1 through 1.5-3) provided a push-pull type latching mechanism integral with each door. A fracture-wire launch lock device was incorporated to restrain the doors during launch loading. The wires were fractured by the EVA crewman via a D-ring on each door. All operations associated with the side doors were operable by a suited crewman with one hand. The hinge line of the side doors were parallel to the vertical axis of the ATM canister. Spring loaded retractable dogs enabled the doors to be opened or closed with a maximum force of 4.3 kg. (10 lbs.). A restraint was provided to hold the doors open in any position; a mechanical flag at the bottom of each door indicated proper door closure. A magnetic latch was also provided to hold the doors in the closed position. The door openings were designed to allow a minimum of 5.1 cm. (2.0 in.) clearance on each side of the cameras for ease of replacement/retrieval operations. A decal was located on each door which provided film magazine/camera removal/retrieval procedures.

The sun end access doors (Figures 1.5-4 and 1.5-5) incorporated a bar type handle which rotated approximately 90° to open. A mushroom shaped push-button served as a launch lock and required depressing before the handle could be rotated. A friction device retained the door in an open position during experiment servicing. Each sun end access door contained an experiment aperture opening and a film magazine removal/replacement procedures decal. The ATM sun end doors, located on the solar disc, were designed to withstand the extreme heat, direct sunlight, and solar radiation.

C. Performance Data and Applications to Future Programs

No major problems were encountered with the sun end access door operations on the Skylab Program. About mid-point in the program, the second EVA crew reported slight difficulty in opening one door. However, the final crew indicated no problems. The ATM side doors also functioned satisfactorily. The first EVA crew reported difficulty in locking one door; however, no subsequent difficulty was reported. Design features of the Skylab access doors should be studied for incorporation into future designs.

D. Specifications and Design Data

The reader is referred to the material listed under Supplementary Information below for design data.

E. Supplementary Information

Documentation:

- Skylab Operations Handbook, Apollo Telescope Mount, Volume I; Martin Marietta Corporation, Contract NAS 8-2400, MSFC-205, 27 March 1972

Drawing/Part No.:

- VS (Sun End) Doors Drawing Nos.:
  - S082A: 10M24100
  - S082B: 10M24120
- VC (Center Workstation) Doors Drawing Nos.:
  - S052: 20M02147
  - S054: 20M02149
  - S056: 20M02146
  - Hα1: 20M02145

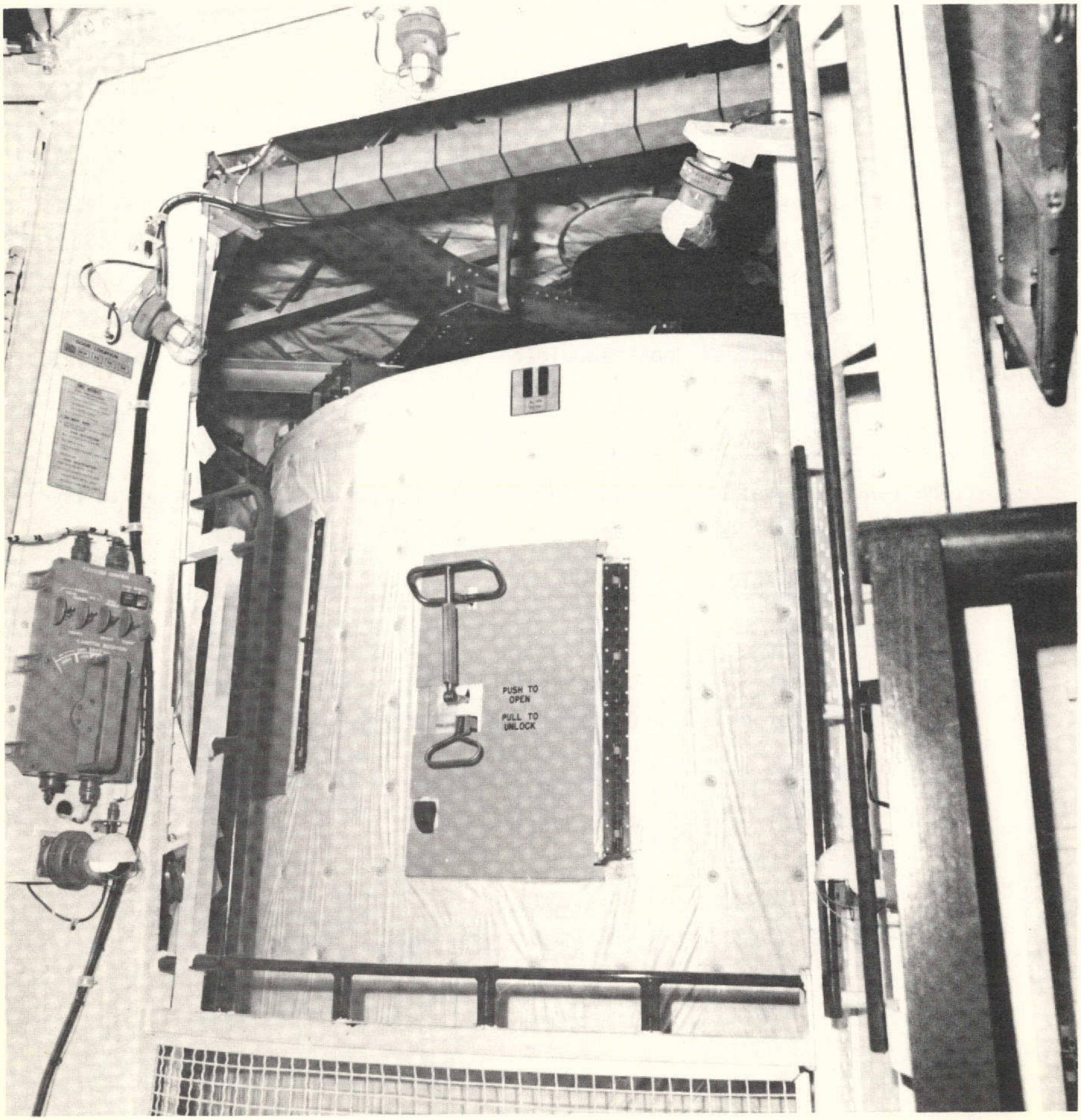


FIGURE 1.5-1: Skylab ATM Side Access Door - Single Door

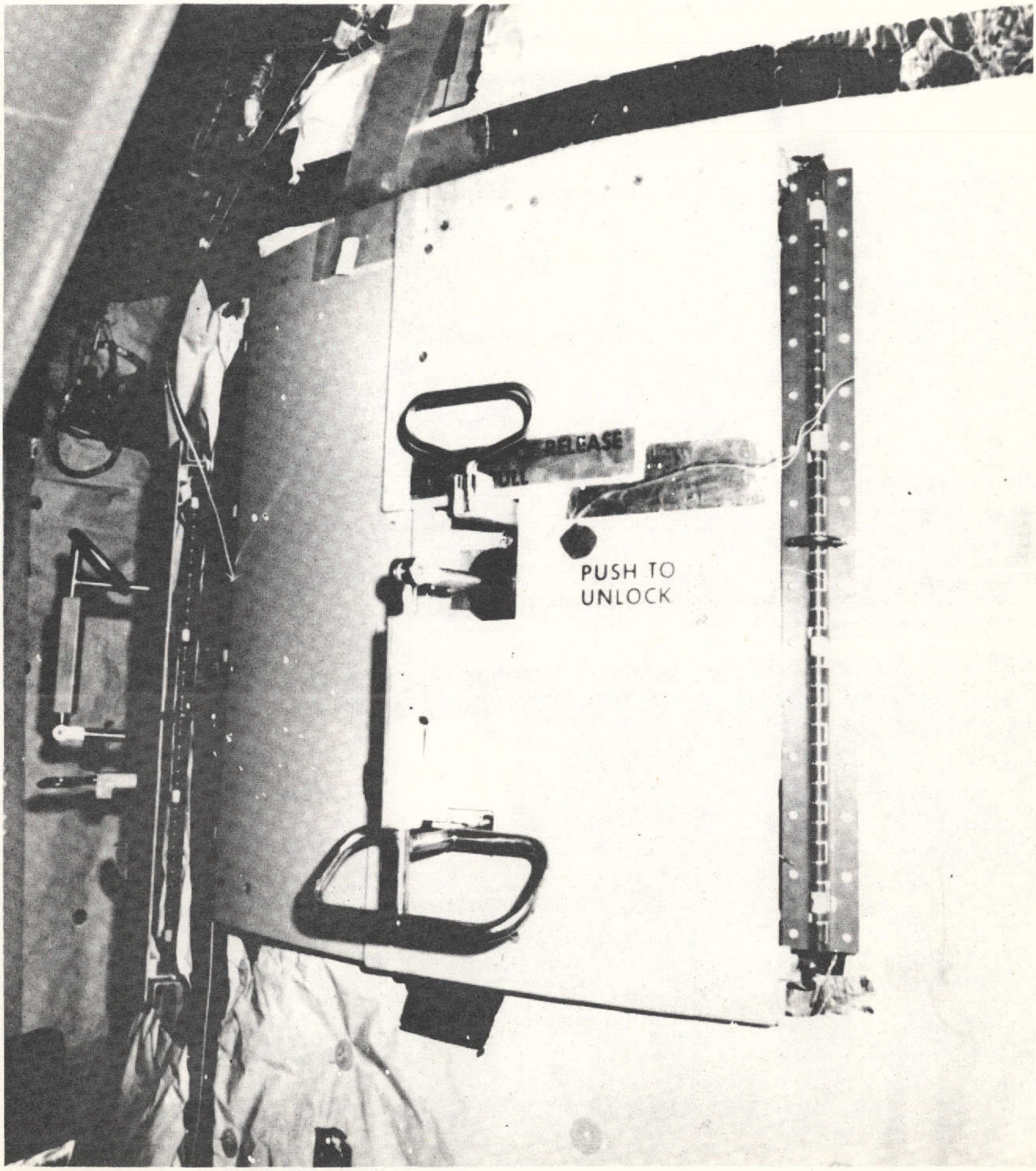


FIGURE 1.5-2: Skylab ATM Side Access Door - Double Doors

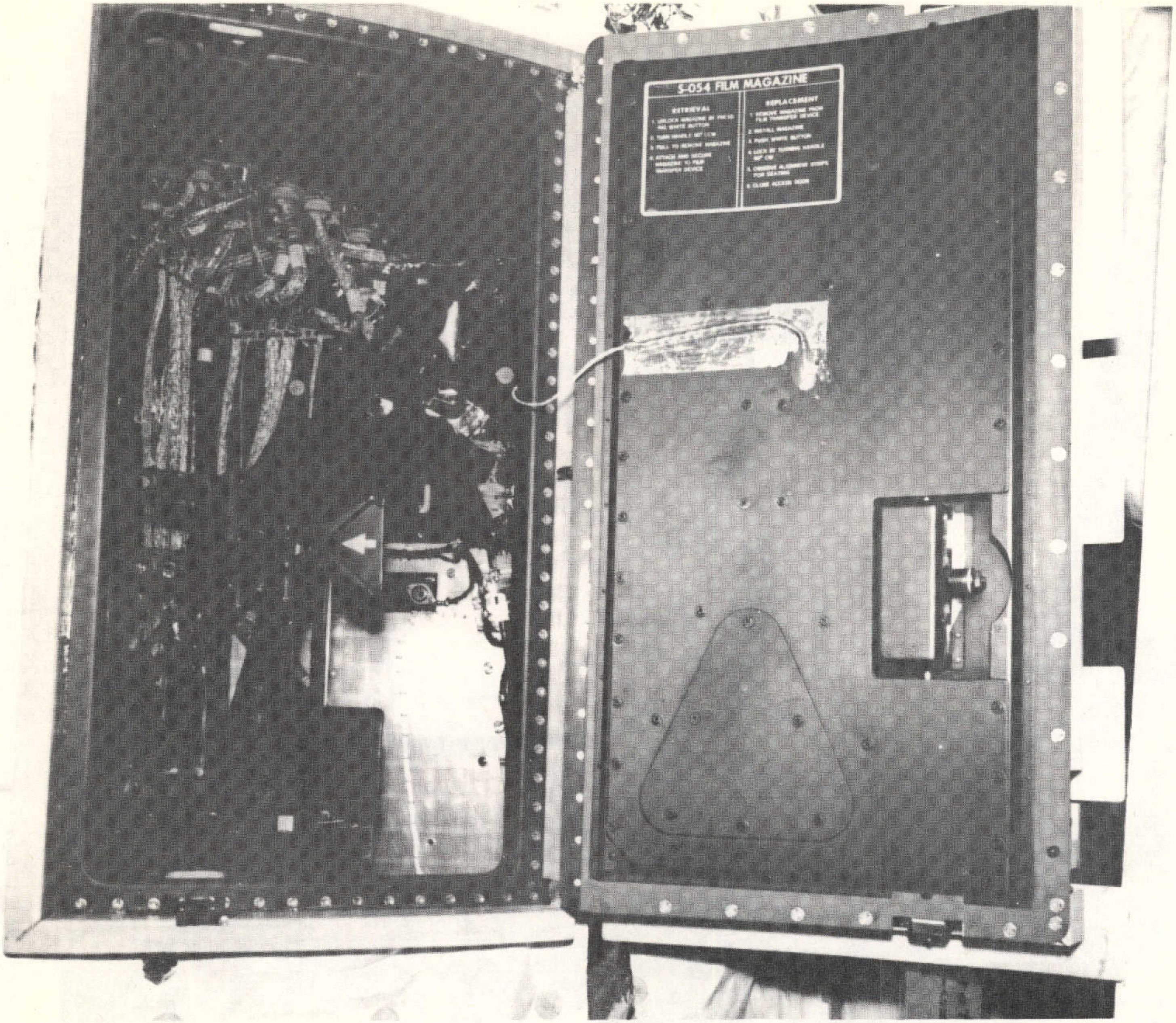


FIGURE 1.5-3: S054 Experiment Access Door Interior

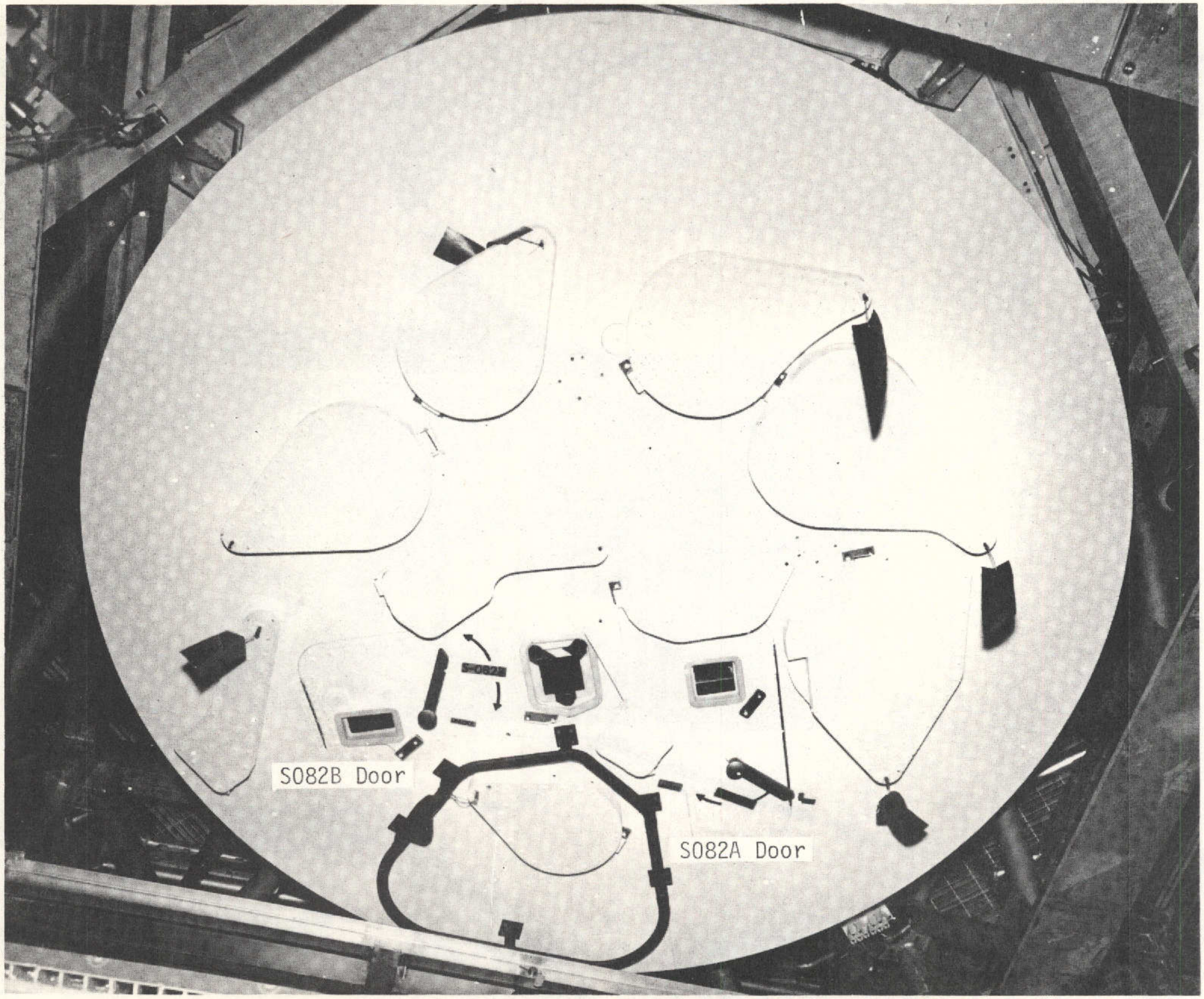


FIGURE 1.5-4: Skylab ATM Sun End Access Doors

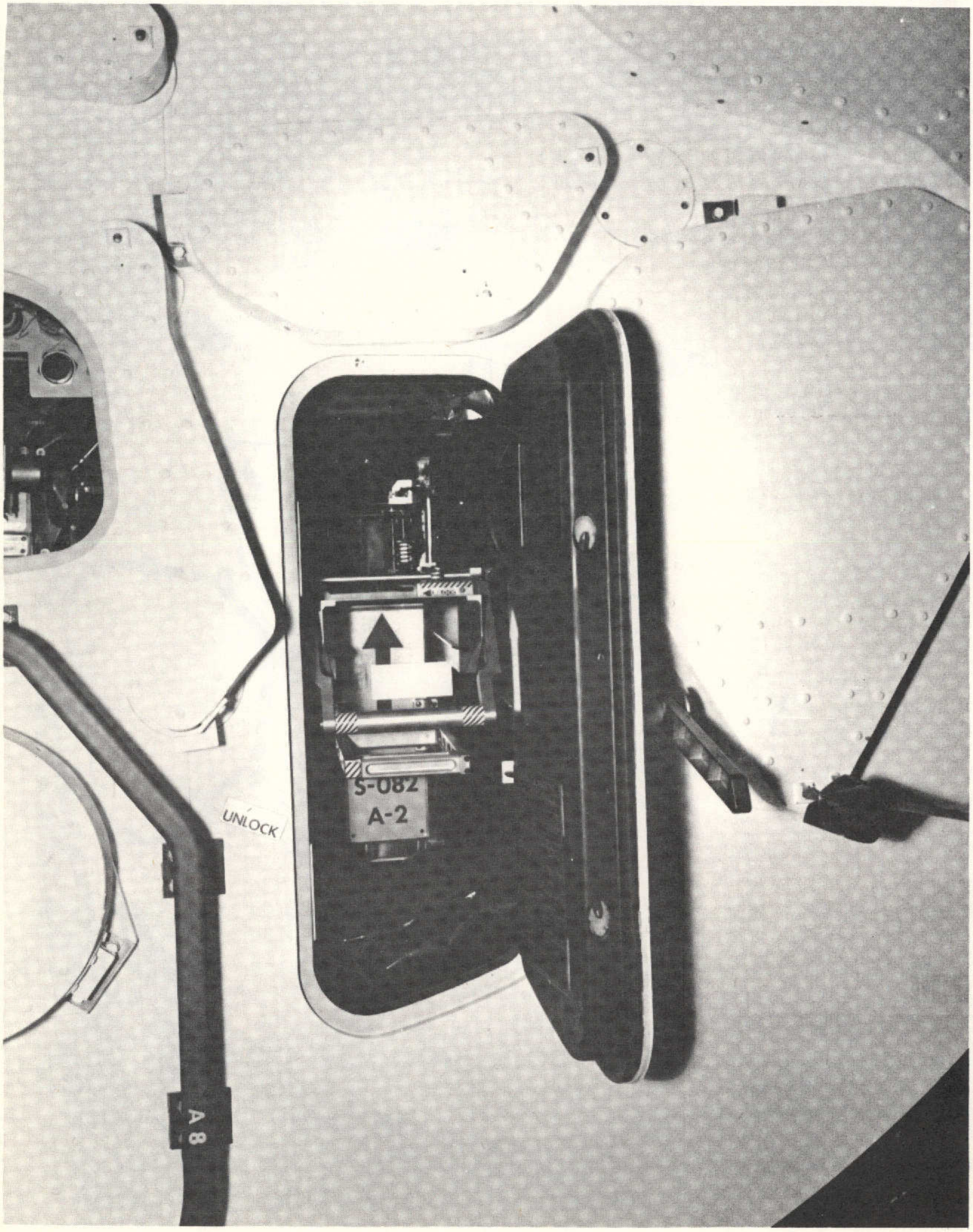


FIGURE 1.5-5: Skylab S082A Experiment Access Door - Open Position

1.5.2 SKYLAB AIRLOCK MODULE HATCH

A. Purpose

The Skylab Airlock Module (AM) hatch provided a means of access to the exterior of the vehicle. The AM hatch was used for all Skylab EVA missions except an initial EVA from a Command Module (CM) hatch.

B. Functional Description and Support Hardware

The EVA hatch (Figures 1.5-6 and 1.5-7) used on the Skylab Program was identical to the units developed for the Gemini missions. The hatch consisted of a trapezoidal-configured titanium door hinged to a torque box on the vehicle exterior, appropriate elastomer seals, a latching handle/mechanism, and window. The hatch was actuated by rotating a handle located on the hatch interior structure. A double pane window in the hatch enabled exterior viewing. The hatch opened outward and was secured in the open position during EVA missions. The hatch was sufficiently large to allow a pressure-suited astronaut to egress/ingress with either a portable or umbilical life support system.

C. Performance Data and Applications to Future Programs

The exterior hatch design performed problem-free during the Gemini and Skylab missions. The hatch was used 9 times for EVA on the Skylab Program for planned and unplanned missions. Design features of the Gemini/Skylab hatch may be applicable to both experiment airlocks and crew egress provisions on future programs.

D. Specifications and Design Data

PARAMETER	UNITS/REMARKS
HATCH SIZE	.61 to .79 m. wide x .86 m. high (24 to 31 in. wide x 34 in. high)
HATCH ROTATION	≈153 degrees
HANDLE FORCE	≈21 kg. (45 lbs.) max.

E. Supplementary Information

Documentation:

- Extravehicular Activities Guidelines and Design Criteria, NASA Contractor Report NASA CR-2160, URS/Matrix Company, Huntsville, Alabama, January 1973
- Skylab Operations Handbook, OWS, AM, MDA; McDonnell Douglas Astronautics Company, Contract NAS 9-11001, Volume I, MSC 04727, 2 January 1972

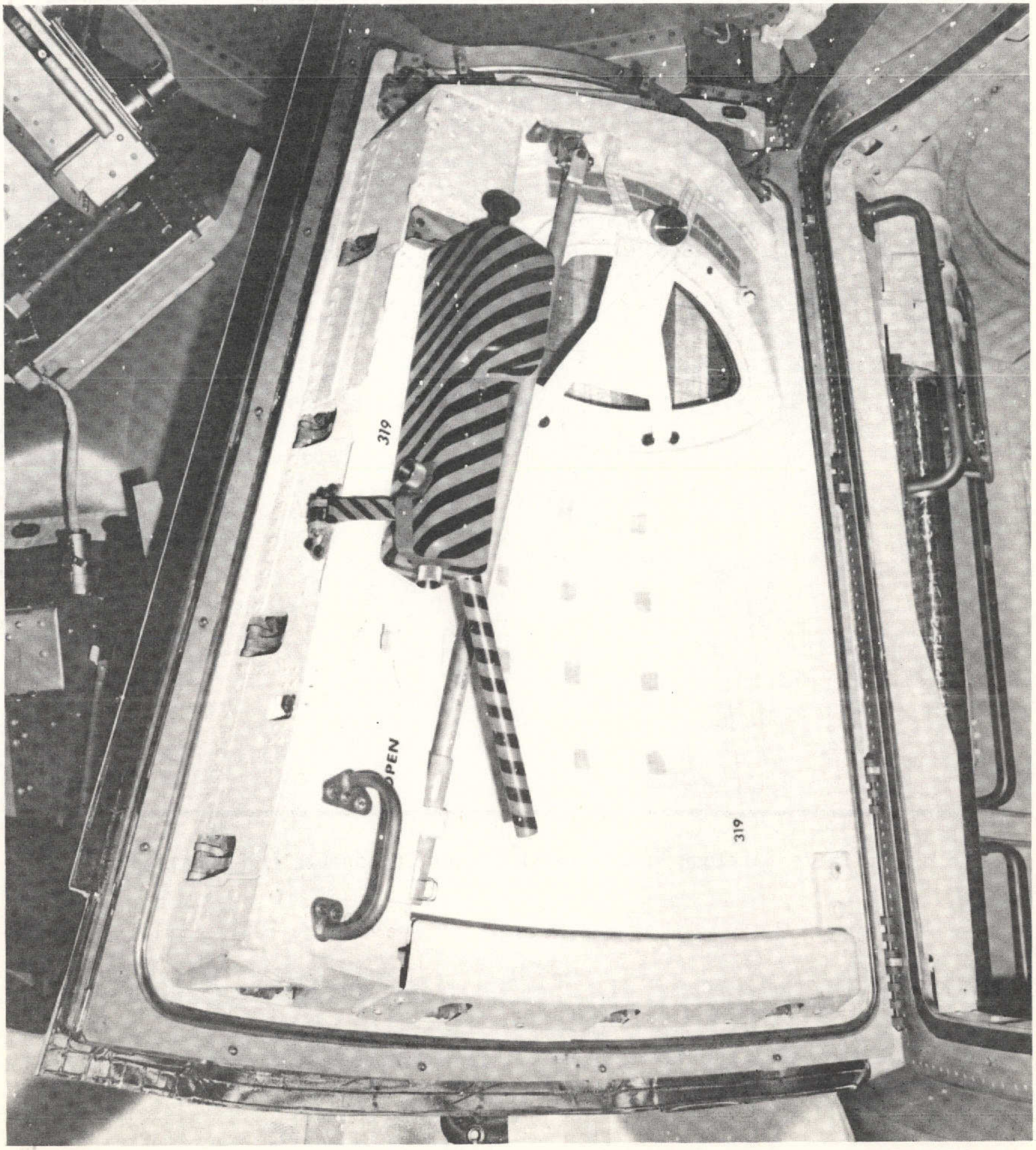


FIGURE 1.5-6: Skylab Airlock Module Hatch--Interior

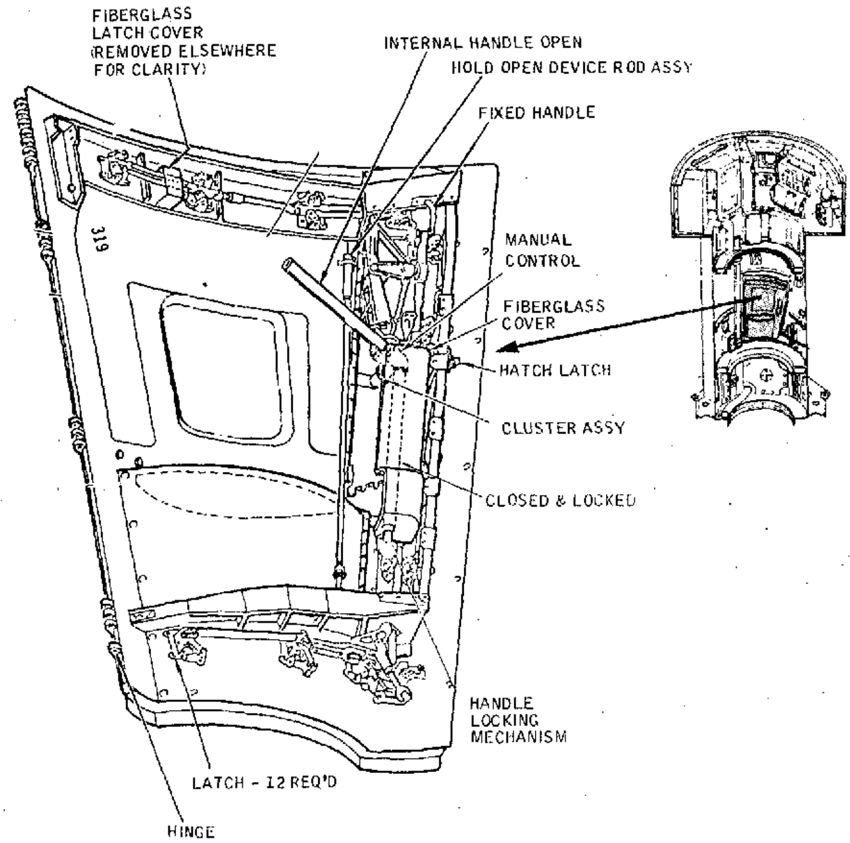


FIGURE 1.5-7: Airlock Module Hatch--Major Components and Location

SECTION 1.6: MISCELLANEOUS EVA HARDWARE

Numerous hardware items were conceived, particularly during the early development of EVA, to assist the crewman in efficiently performing EVA tasks. Many items were successful; others tended to exceed the needs of the EVA crewman, ultimately becoming overly complicated both in design and operation. Among the more useful designs were: (1) Devices to aid the EVA crewman in retaining and managing loose (hand-carried) equipment; and (2) hand tools for backup or contingency operations. The quantity of equipment items developed to assist in EVA operations are far too numerous to address in this document. Several typical items have been selected in order to provide a general overview of the hardware features, configurations and interfaces.

Section 1.6 contains information on the following equipment:

1.6.1 UNIVERSAL MOUNT--SKYLAB

A. Purpose

The universal mount was designed for Skylab to aid in temporarily securing equipment to the spacecraft. The mount was used for routine tasks inside the vehicle and for extravehicular tasks.

B. Functional Description and Support Hardware

The universal mount (Figures 1.6-1 and 1.6-2) consisted of a portable bracket which mounted either to a standard hole pattern or on a handrail and interfaced with portable lights, cameras, tool boxes, work tables, and assorted experiment hardware.

Two alignment pins were located on the base of the mount which interfaced with holes in the floor and wall grid pattern on Skylab. The base of the mount incorporated a set of brackets which interfaced with the handrails. Trigger action separated the alignment pins and handrail brackets for installation and removal of the mount. A locking lever located on the handle locked the mount firmly in place.

The universal mount had three swivel joints which allowed movement in two axes; pitch and yaw. The joints were calibrated (discs and cylinders) in degrees for pointing reference and were friction type joints which allowed the mount to be easily adjusted. The joints could be oriented for compact stowage. The mount was designed for one-handed suited operation.

An adapter was required to attach the universal mount to the equipment. Each equipment item to be restrained was equipped with a mounting bracket. The bracket slid into the mounting adapter and a spring actuated lock secured the equipment to the mount.

C. Performance Data and Applications to Future Programs

The universal mounts were routinely used on Skylab and proved to be viable candidates for use on future programs. On Skylab the mount was used with hand-held cameras, food trays, tool boxes, repair kits, work tables, portable lights and high intensity lights. For future applications, a more rigid mounting device for gripping handrail-type configurations may be required. If rigidity is not critical, a number of flight-qualified Skylab units were fabricated and may be available for future use.

D. Specifications and Design Data

PARAMETER	UNITS/REMARKS
WEIGHT	.88 kg. (1.95 lbs.)
DIMENSIONS	29.6x11.3x11.0 cm. 11.65x4.50x4.35 in.
MATERIAL	Aluminum

E. Supplementary Information

Documentation:

- Skylab Operations Handbook, OWS, AM, MDA; McDonnell Douglas Astronautics Company, Contract NAS 9-11001, Volume I, MSC 04727, 2 January 1972

Drawing/Part No.:

- Drawing No.: 13M13406
- Part No.: SEC39106239

Item Developed By:

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center

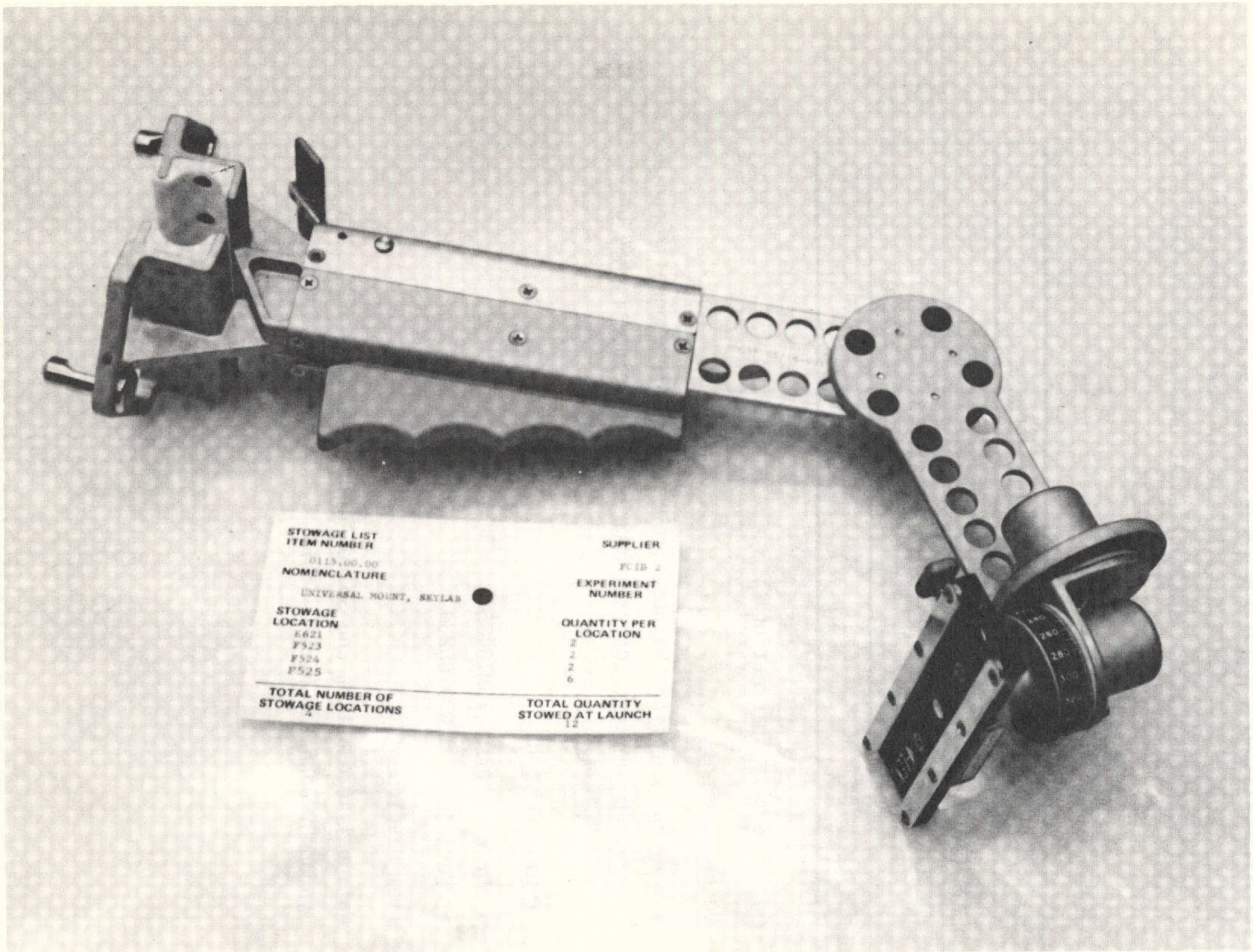


FIGURE 1.6-1: Universal Equipment Mount - Skylab Program

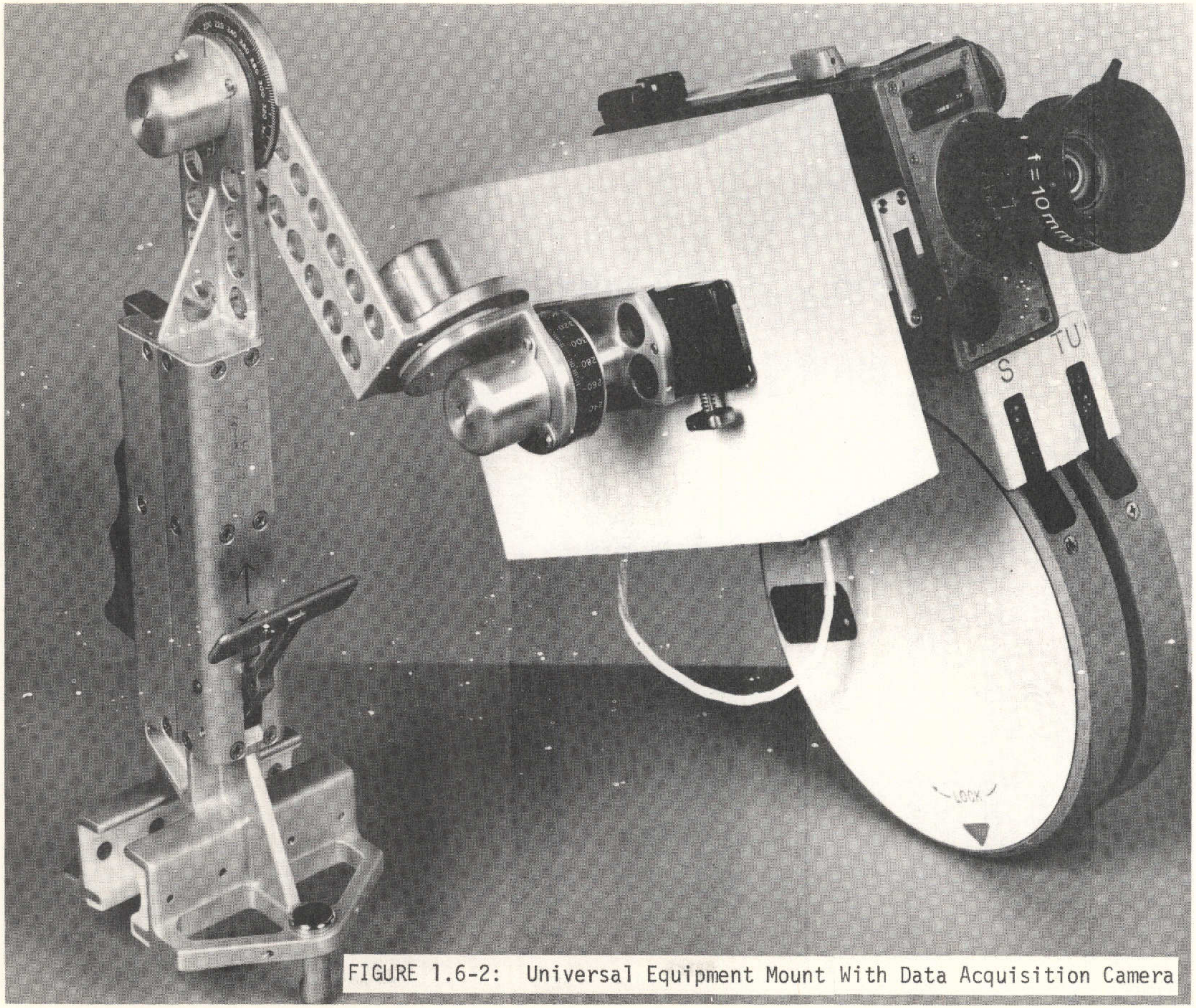


FIGURE 1.6-2: Universal Equipment Mount With Data Acquisition Camera

1.6.2 EVA EQUIPMENT MOUNTING BRACKETS--APOLLO, SKYLAB

A. Purpose

Several special purpose mounting brackets were used on Skylab to temporarily attach small experiments to the vehicle exterior for operation by EVA crewmen.

B. Functional Description and Support Hardware

The special brackets designed for the Skylab Program consisted primarily of mounting hardware for carry-on experiments. The carry-on experiments were necessitated due to the contingency erection of thermal covers over a solar oriented scientific airlock. The thermal covers were erected over a portion of the Orbital Workshop following loss of the original insulation shield during vehicle launch. Most of the special brackets were simple in design and bolted to the experiments. The brackets then interfaced with various vehicle struts, handrails, structural shapes, etc. A variety of clamps, pip pins and quick connect/disconnect fasteners were used. The brackets designed for Skylab were usually controlled by the pointing requirements, the availability of attach points on the structures accessible to the EVA crewman, and the limited volume during launch in the Command Service Module (CSM). Mounting brackets for the following Skylab experiments are shown in Figures 1.6-3 through 7.

- S020 Ultraviolet X-Ray Solar Photography
- S149 Particle Collection
- T025 Coronagraph Contamination Measurement

C. Performance Data and Applications to Future Missions

Each of the experiments listed above were manually deployed and retrieved by the EVA crewmen several times during the Skylab Program. No problems were encountered with the supporting brackets which were largely responsible for the success of the experiments. Similar brackets for small, limited exposure experiments may be applicable for attachment to the Shuttle Orbiter payload bay.

D. Specifications and Design Data

Most of the special brackets were fabricated under a strict time frame or as a backup system to an assumed low system-failure probability. Therefore, design data and specifications were not highly published or readily obtainable. The reader is directed to the NASA organization listed in the Supplementary Information section below for detailed data.

E. Supplementary Information

The S020, S149 and T025 brackets were built and supplied by:

National Aeronautics and Space Administration
Johnson Space Center
Engineering and Development Directorate
Experiments Systems Division
Houston, Texas 77058

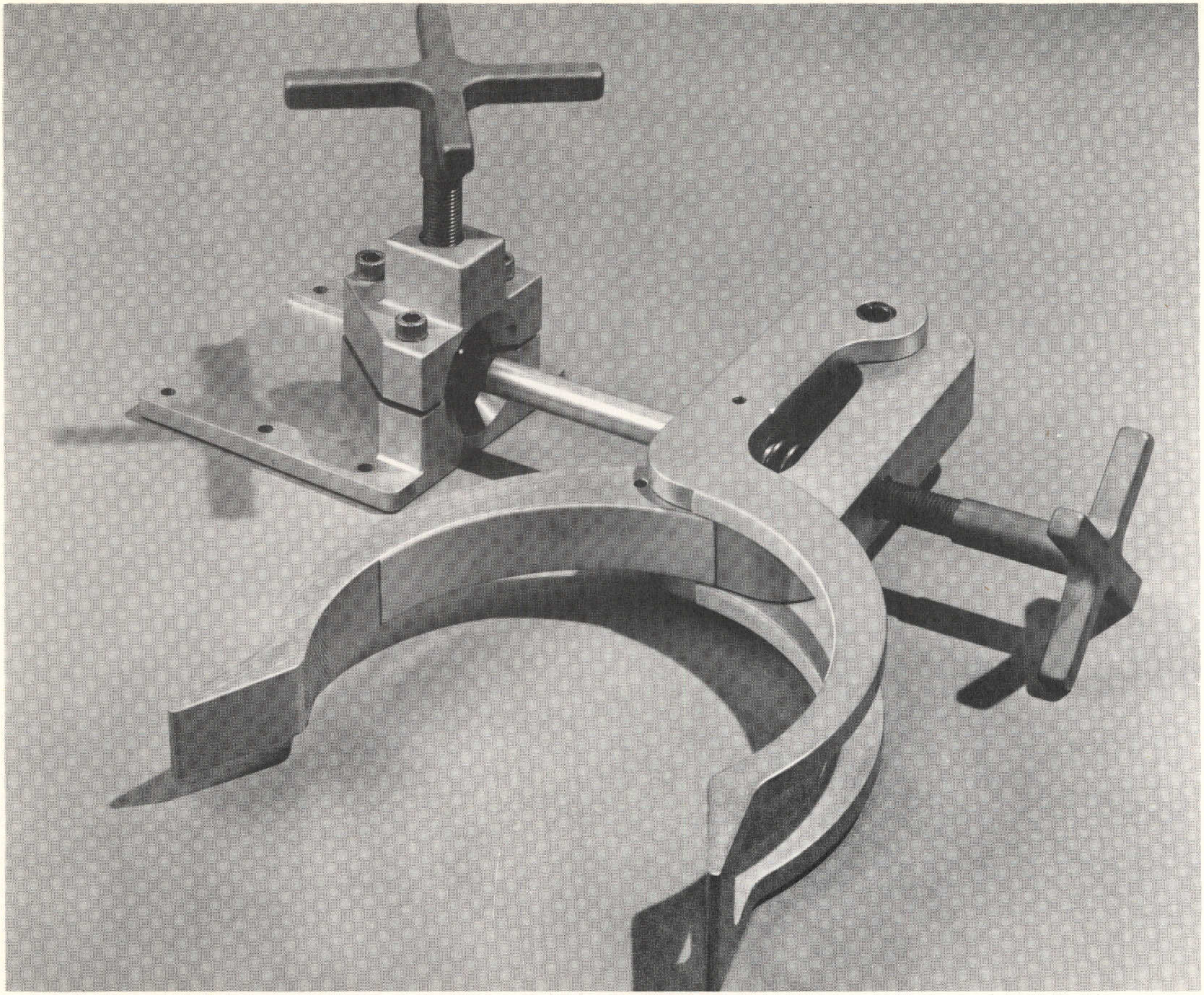


FIGURE 1.6-3: External Mounting Bracket for Skylab S020 Experiment

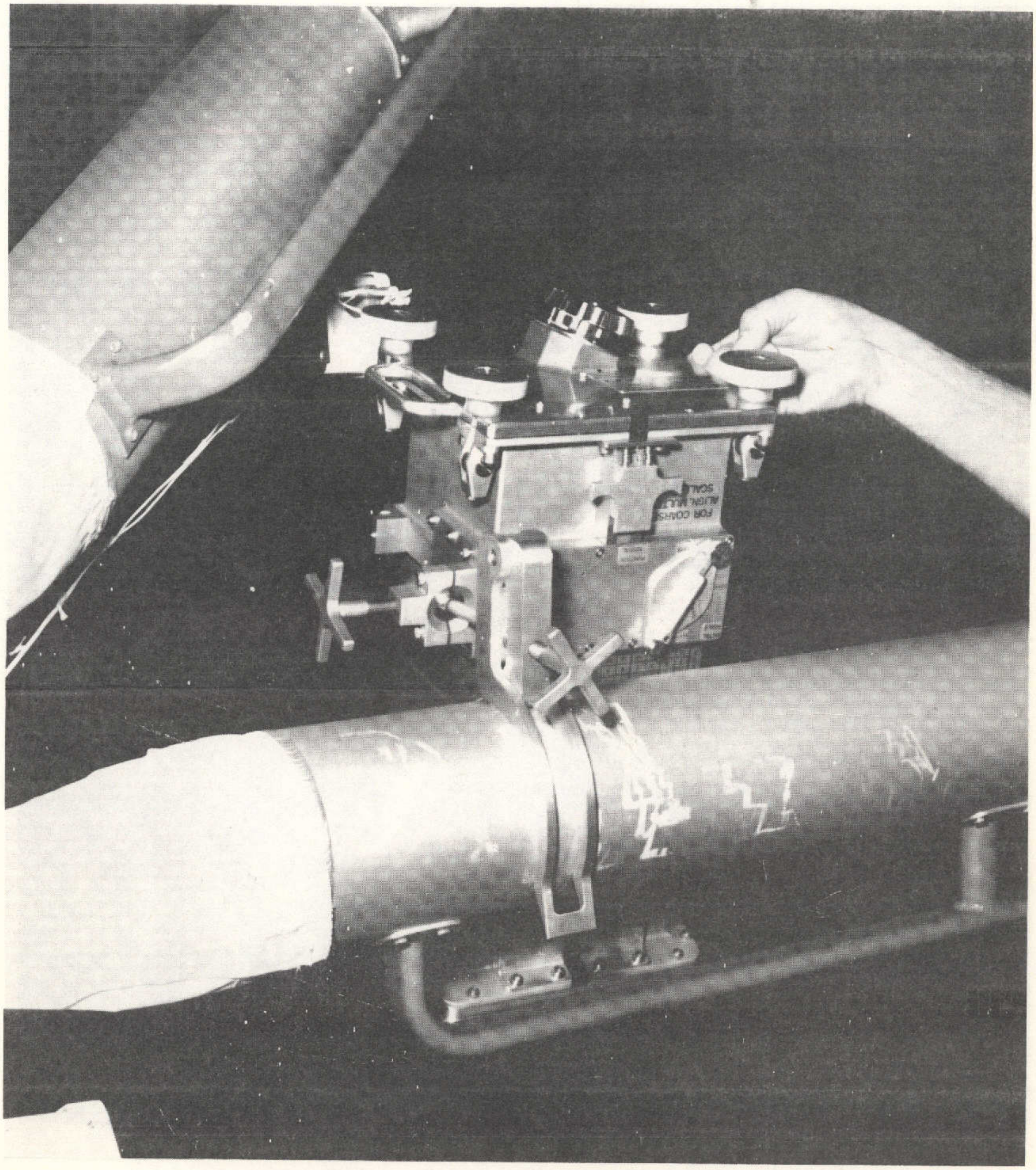


FIGURE 1.6-4: S020 Experiment Installed on Exterior Strut

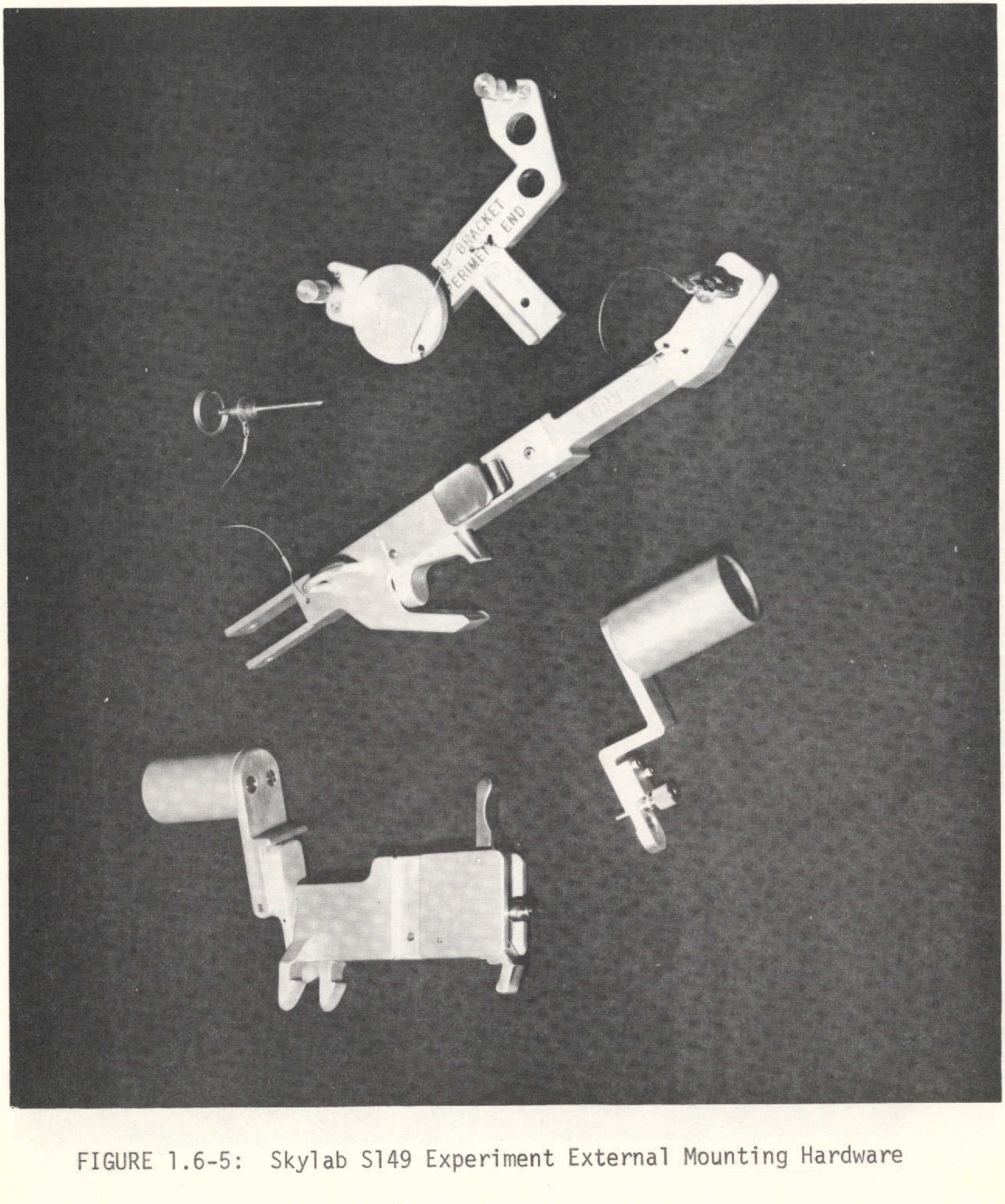


FIGURE 1.6-5: Skylab S149 Experiment External Mounting Hardware

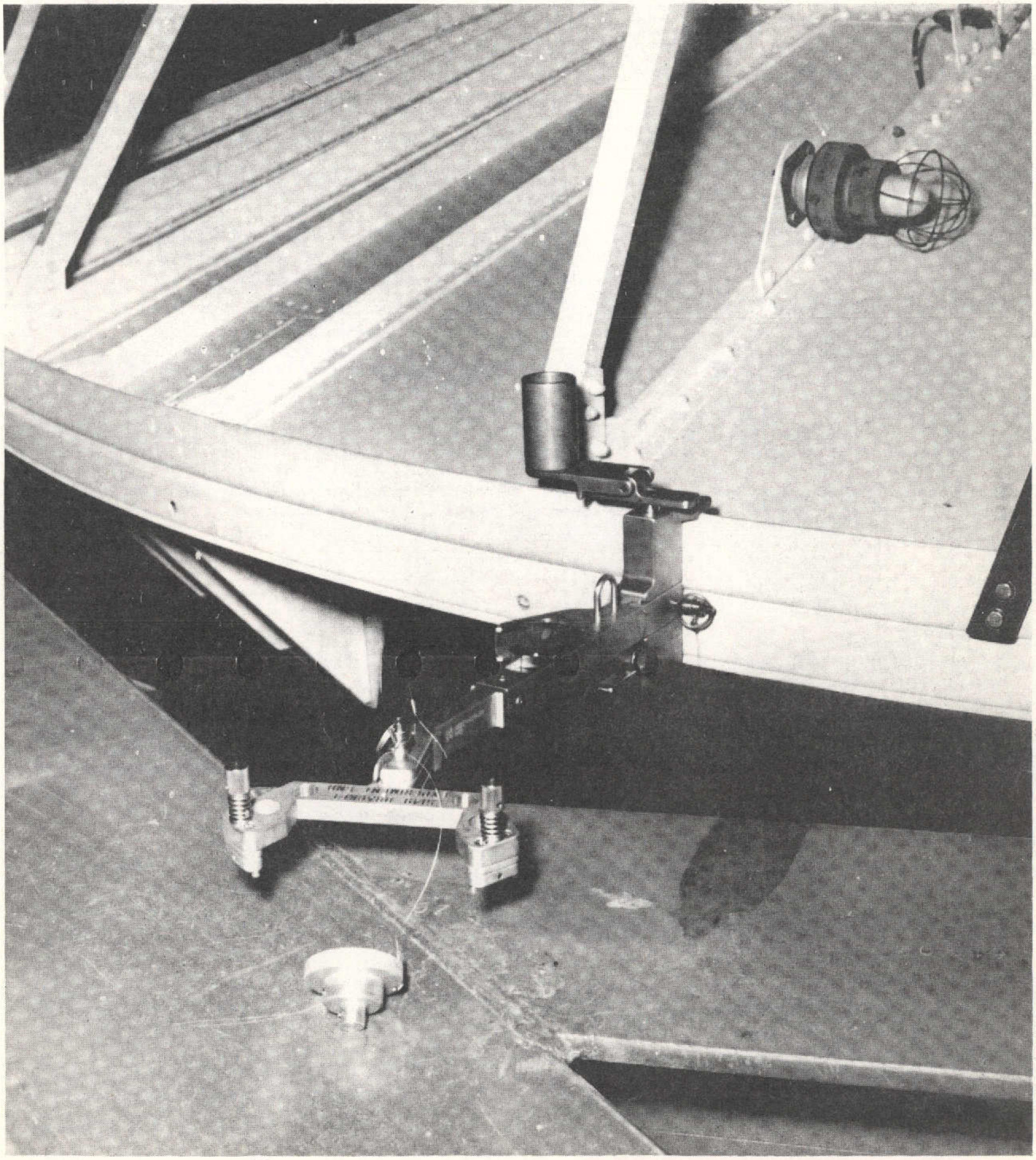


FIGURE 1.6-6: S149 Experiment Brackets Installed on ATM Solar Shield

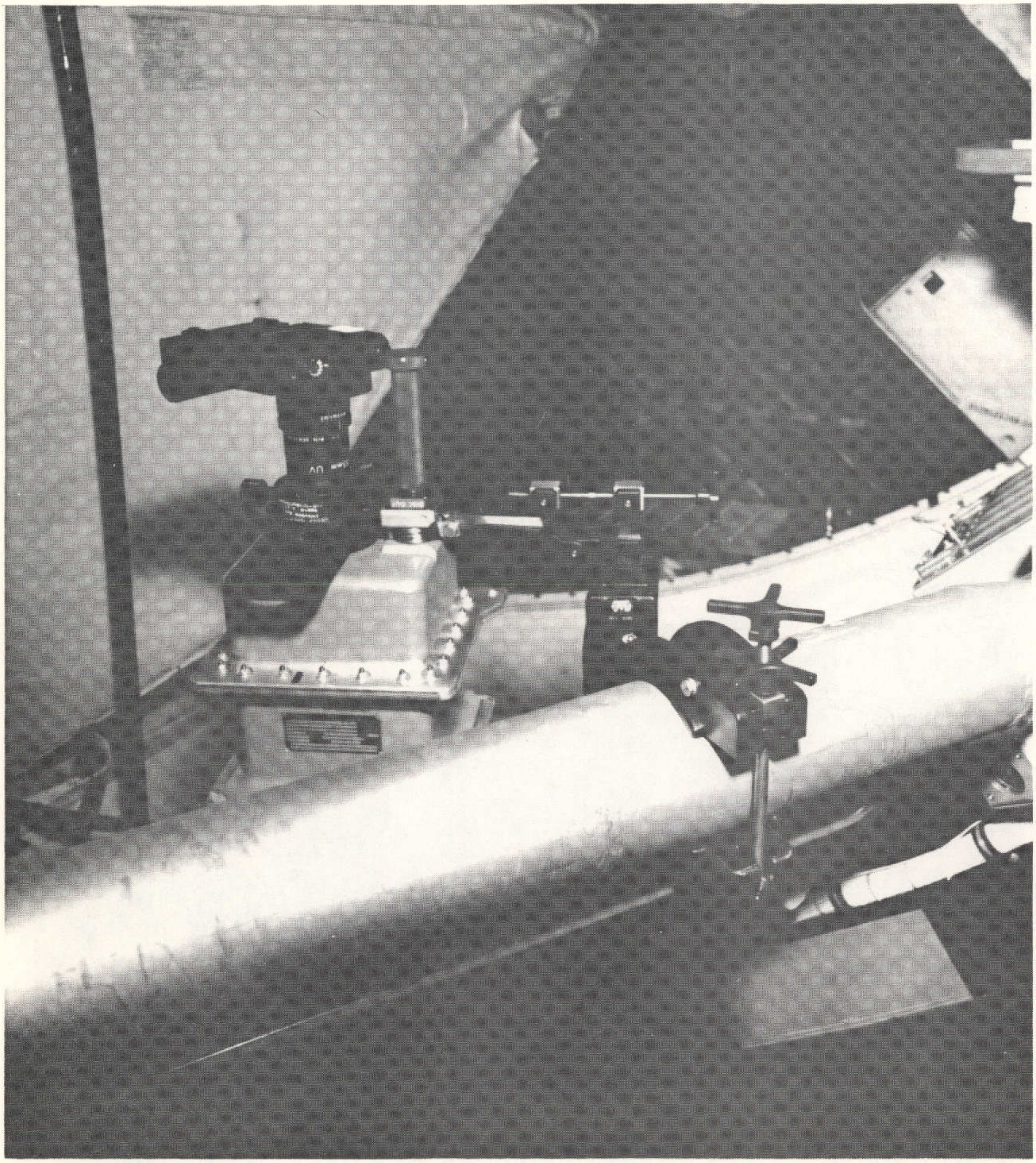


FIGURE 1.6-7: S149 Experiment Installed on Exterior Skylab Strut

1.6.3 SPECIAL TOOLS--SKYLAB

A. Purpose

Several special tools and support equipment items were assembled for use by the Skylab EVA crews for salvage operations on the Skylab cluster which had been damaged during launch.

B. Functional Description and Support Hardware

Two major problems resulting from damage during the launch of the Orbital Workshop threatened early cancellation of the Skylab Program. The crews were able to make repairs and continue with an almost as-scheduled program by using a combination of specially designed tools and modified on-board equipment. Two major problems were: (1) A thermal shield was torn off causing temperatures inside the workshop to rise to an uninhabitable level; and (2) the vehicle was under-powered since one of its energy-supplying solar arrays was completely lost and another was only partially deployed. The thermal problem was temporarily relieved by deploying a huge "parasol" device from one of the vehicle's scientific airlocks. Later, the parasol was covered with a thermal sail system that was assembled and deployed by two crewmen during an EVA. To overcome the power problem, the partially deployed solar array wing was released using special tools modified from off-the-shelf commercial hardware.

Some of the tools that were assembled for the repairs and a brief description of each are listed below.

Solar Wing Deployment Tools

- Extension Poles: Three poles, each 1.5 m. (5 ft.) in length. The poles could be connected to form a 4.5 m. (15 ft.) extension bar. The ends were designed to accept a variety of tools.
- Cable Cutter: This tool was connected to the end of the poles and was actuated by pulling a rope, similar to tree-pruning shears. (Figure 1.6-8).
- Sheet Metal Cutters: The tool was basically a pair of tin snips designed to be operated in the same manner as the cable cutter (Figure 1.6-9).

- Universal Tool: This two pronged tool also mounted on the end of the poles and was used by the EVA crewman as a prying tool (Figure 1.6-10).
- Shepherd's Hook: The shepherd's hook was also used as a prying tool (Figure 1.6-11).
- Bone Saw: This item was taken from the in-flight medical kit for releasing the solar array but was not used.
- Boom Erection Tether (BET): The BET (Figure 1.6-12) consisted of a long rope with a large hook on one end and two small tether hooks on the other. The device was connected between a vent module on the solar array wing and an antenna launch bracket on the vehicle. By raising the tether the crewman succeeded in deploying the solar array wing.

Thermal Shield Equipment

- Thermal Sail: The sail was coated with thermal protective material and became the primary thermal shield for the vehicle. It was 7.4 m. (24.28 ft.) by 6.8 m. (22.31 ft.) and was stowed in a bag to facilitate handling.
- Sail Poles (twenty-two): These poles were identical to the three supplied for the wing deployment task. The poles were connected together to form two 16.8 m. (55 ft.) sections and became the basic support structure for the sail. The poles were mounted on two pallets for easy handling and stowage.
- Sail Pole Base Plate: This item was mounted to the vehicle structure and secured the aft end of the poles.
- Portable Foot Restraint Adapter: The adapter was used with the portable foot restraints on-board the vehicle to provide a temporary workstation for one of the EVA crewman during thermal sail deployment.

C. Performance Data and Applications to Future Programs

The tools performed as anticipated on the Skylab Program as evidenced by the success of the missions. The fact that the tools were simple in design, yet effective, indicates that elaborate designs are not mandatory for use by a suited crewman. It is suggested, in view of the experiences of the Skylab Program, that consideration be given to incorporating a set of general-purpose contingency tools on-board future manned space vehicles.

D. <u>Specifications and Design Data</u>

Not available. The equipment was assembled on a contingency basis with minimum formal documentation. See supplementary information below for suppliers.

E. <u>Supplementary Information</u>

<u>Documentation:</u>

- AIAA Paper 73-1331, EVA Workstation Provisions for Skylab and Space Shuttle Missions, N. E. Brown, URS/Matrix, Houston, Texas, and E. L. Saenger, URS/Matrix, Huntsville, Alabama

<u>Items Supplied By:</u>

National Aeronautics and Space Administration
Marshall Space Flight Center
Lyndon B. Johnson Space Center

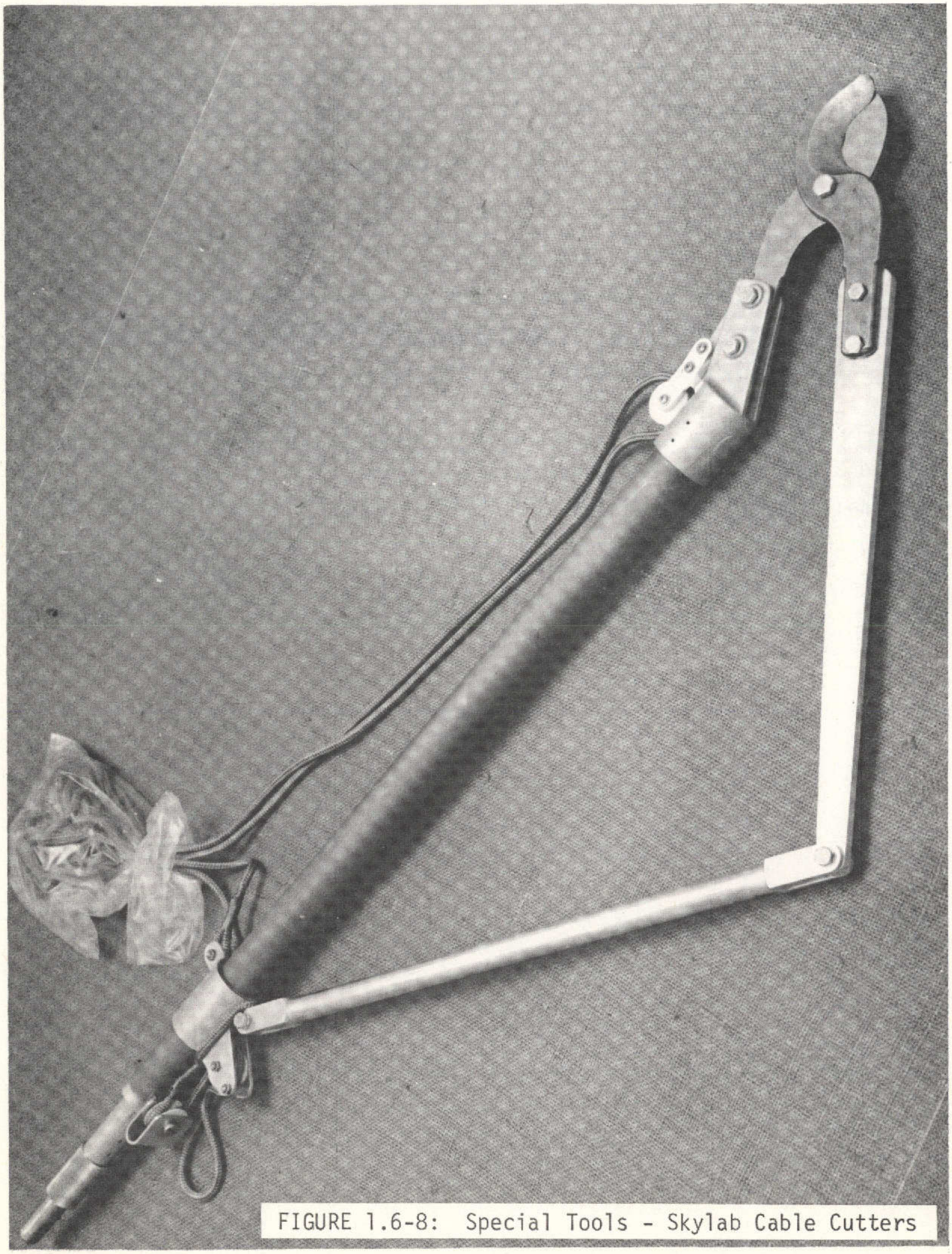


FIGURE 1.6-8: Special Tools - Skylab Cable Cutters

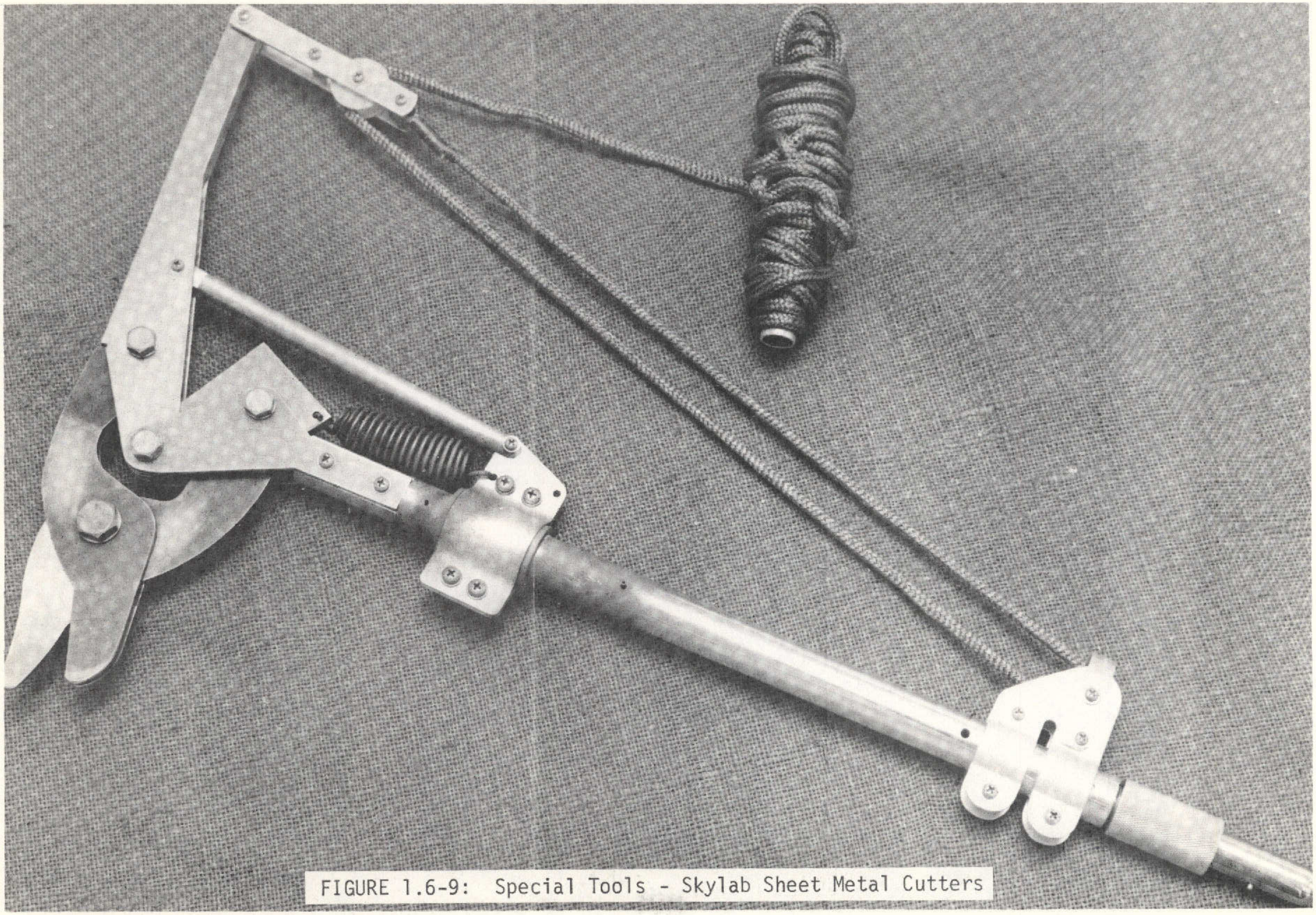


FIGURE 1.6-9: Special Tools - Skylab Sheet Metal Cutters

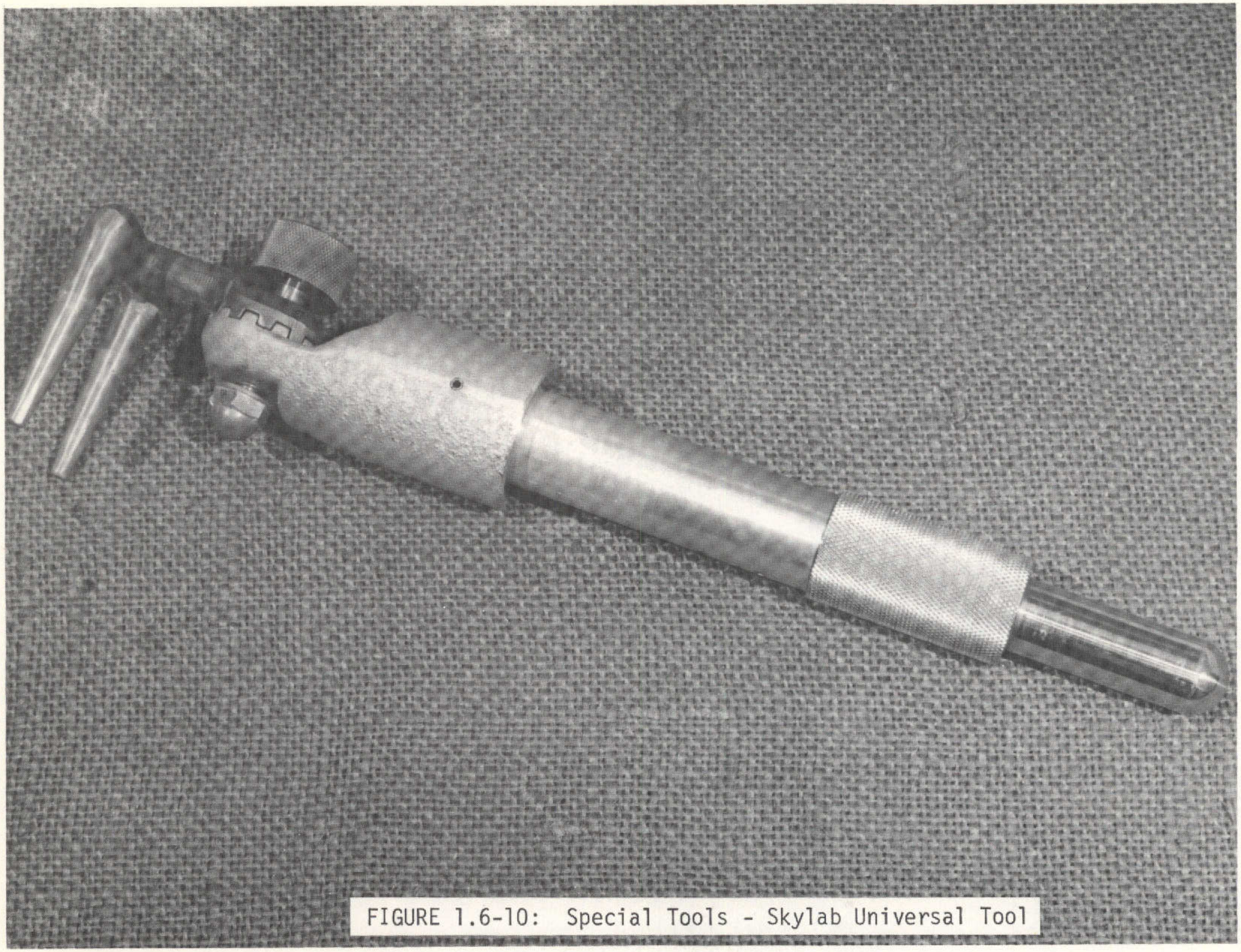


FIGURE 1.6-10: Special Tools - Skylab Universal Tool

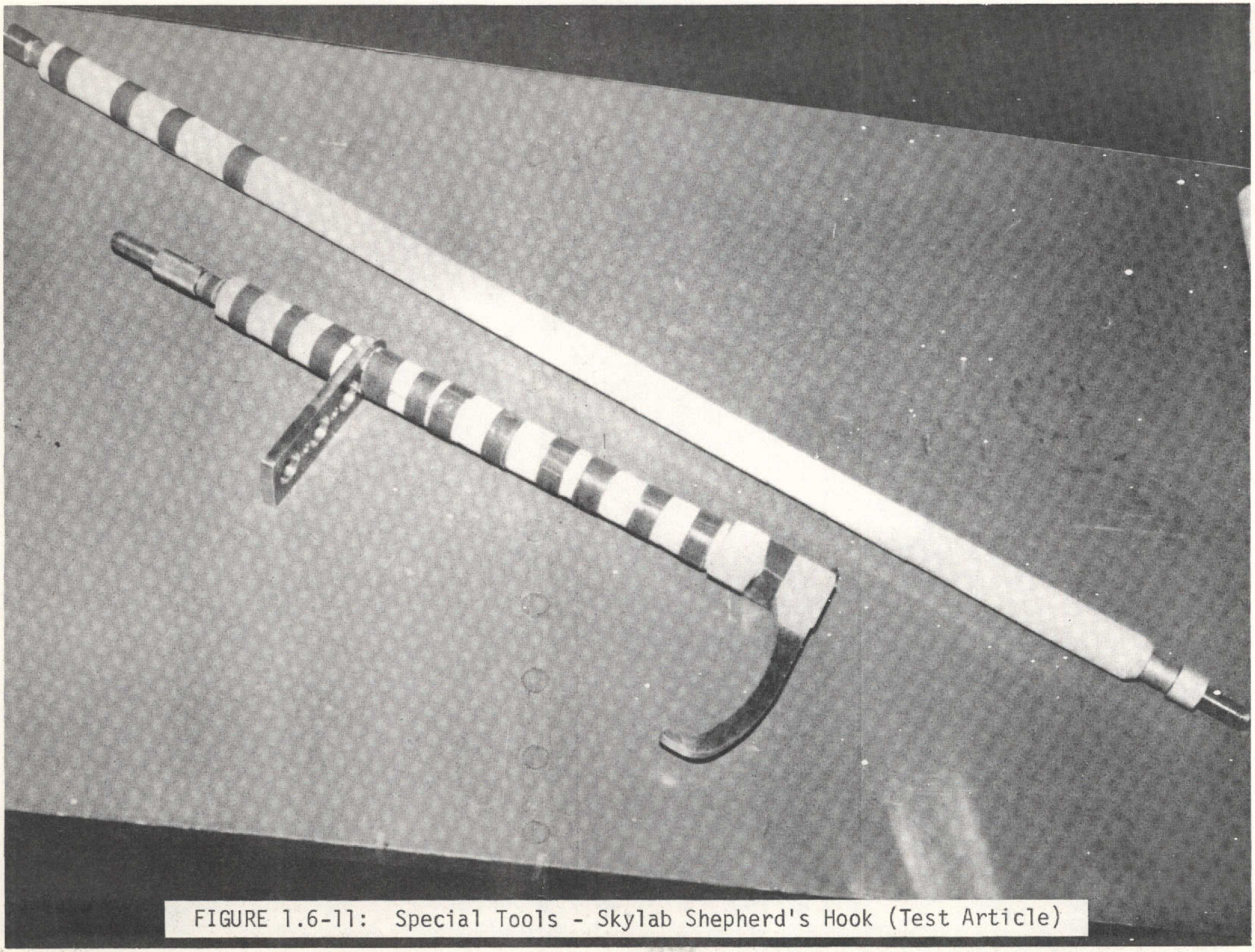


FIGURE 1.6-11: Special Tools - Skylab Shepherd's Hook (Test Article)

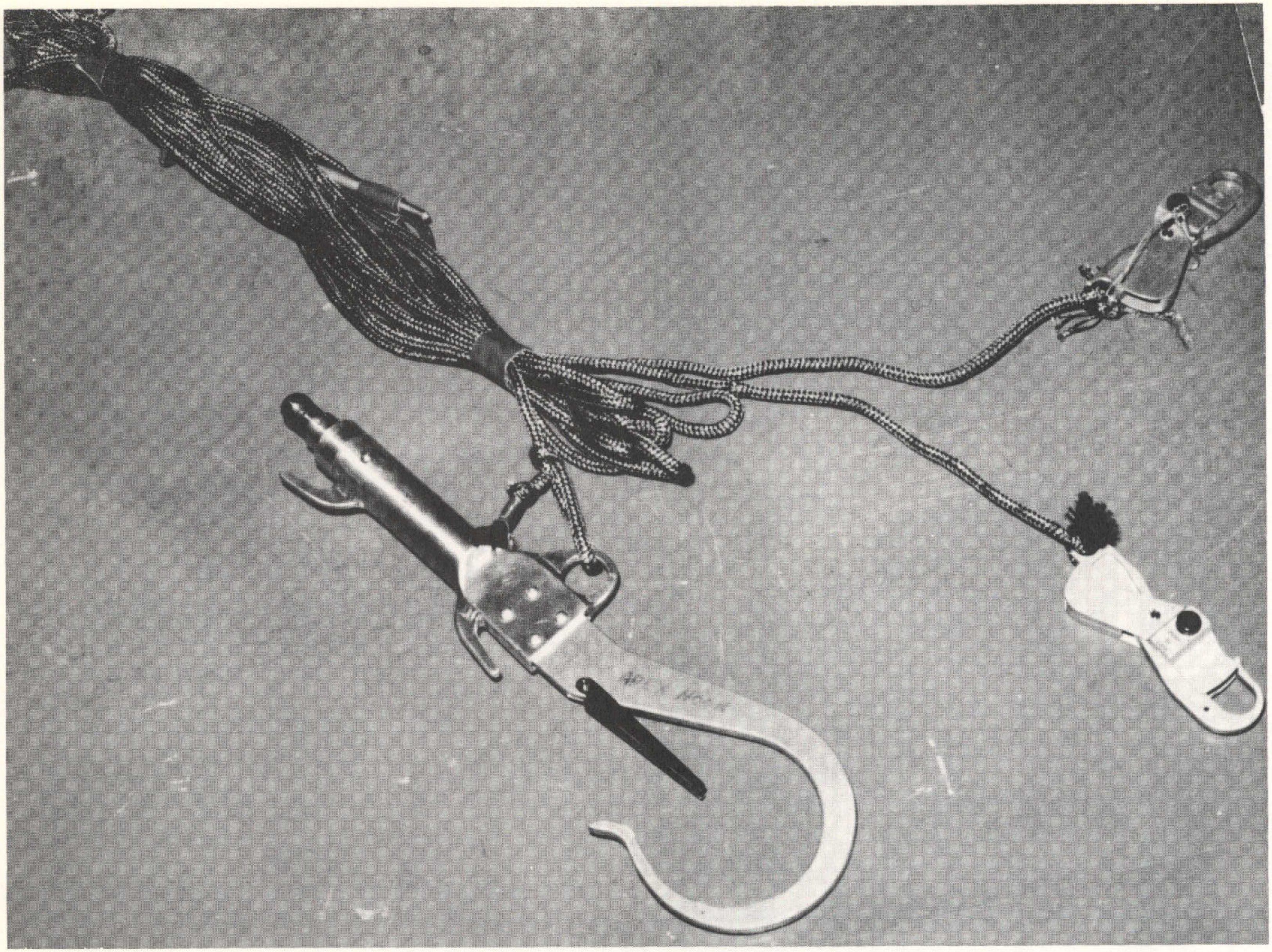


FIGURE 1.6-12: Special Tools - Skylab Boom Erection Tether (BET)

URS

SECTION 2.0

EVA MOBILITY CAPABILITIES AND SUPPORT REQUIREMENTS

1.6-19

2.0 a

ADDENDUM TO SECTION 2.1

MOBILITY PERFORMANCE CHARACTERISTICS

Pages 2-2 through 2-12

All of the measured mobility data for the A7LB suit, in Figures 2.1-1 through 2.1-11, were obtained using a liquid cooling garment (LCG) inside the suit, and a protective cover layer (ITMG) on the outside of the suit. The data for the OES, on the other hand, were obtained without the protective cover aid using a constant wear garment (CWG) instead of the LCG.

Pages 2-2, 2-5, 2-9 and 2-10

In Figures 2.1-1, 2.1-2, 2.1-8 and 2.1-9, the values for the A7LB measured mobility were obtained with the addition of an Apollo PLSS and OPS to the suited configuration.

2.1 MOBILITY PERFORMANCE CHARACTERISTICS

2.1.1 Mobility--Shirtsleeve Versus Suited

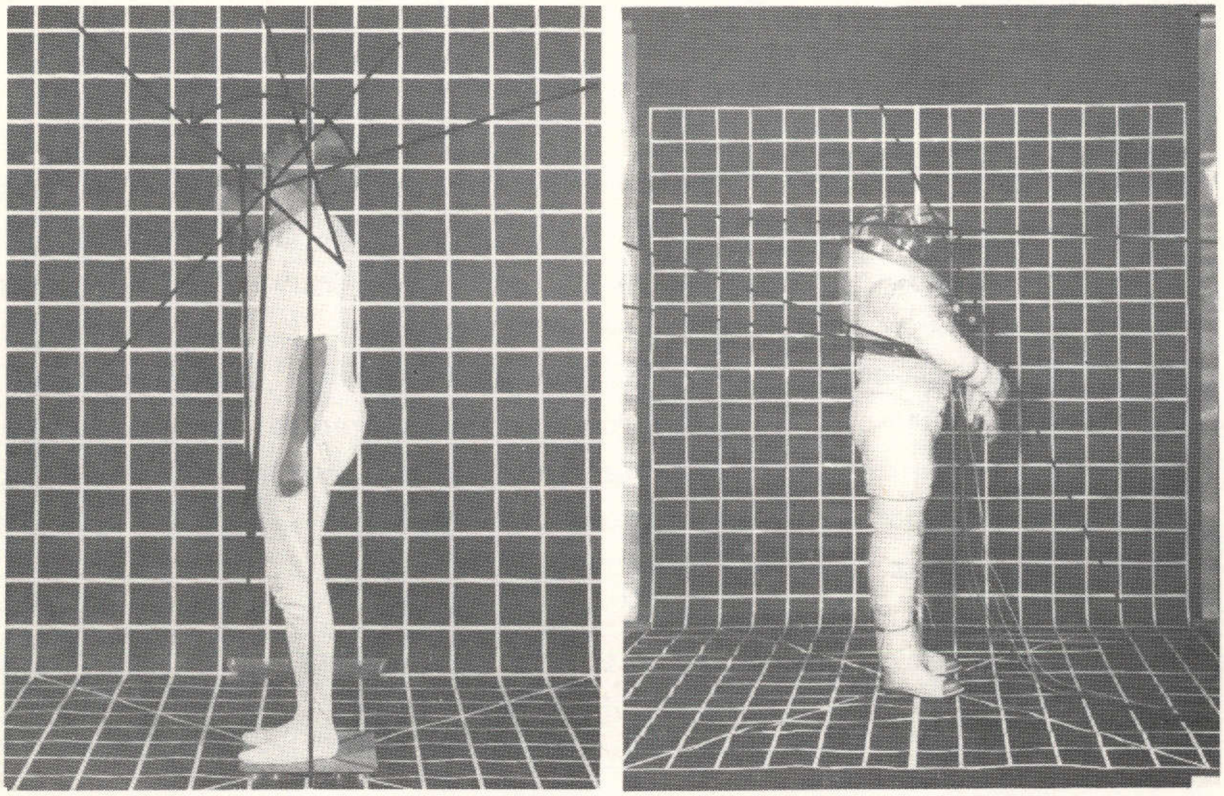
The purpose of this section is to present an overview of suit mobility characteristics through a comparison of shirtsleeve and spacesuited movements. Thirteen (13) movements were selected to present those considered most applicable while performing future EVA tasks. Of primary interest is the shirtsleeve (Constant Wear Garment) mobility compared to the phase B prototype Orbital Extravehicular Spacesuit (OES). However, mobility characteristics of the A7LB pressure suit used on the Skylab Program are presented for comparison. Since the data relative to the OES suit was obtained at a suit pressure of .28 kg./cm.^{2} (4.0 psig), an additional blank column is provided for subsequent updating by the reader as suit development continues.

The information provided in this section was derived from the following documents:

- A7LB DVT Test Report Mobility and Torque Test, ILC-M-DVT-012R
- DVT Test Report, Orbital Extravehicular Spacesuit (OES) Mobility Evaluation, ILC-J-SS-003

Test conditions relative to the OES mobility evaluation were somewhat unique; therefore, the introduction to Document ILC-J-SS-003 is included as Appendix A of this document. The reader is urged to review this material for a complete understanding of the test purpose and conditions.

The Orbital Extravehicular Spacesuit (OES) is a phase B prototype currently being evaluated by NASA/Johnson Space Center personnel for use in the Space Shuttle Program. The mobility characteristics are subject to change as development and testing progress. Mobility data presented in Figures 2.1-1 through 2.1-11 are intended only to brief the reader relative to man's performance capabilities in the spacesuit. Detailed data can be obtained from References 2.1 and 2.2. The effects of a portable life support assembly on crewman mobility is currently undefined. Only minimal mobility degradation is anticipated for the Shuttle EVA system. The major impact will be the EVA access volume required for operations.



NUDE BODY (CWG) Subject 1 OES @ 4 PSIG Subject 2

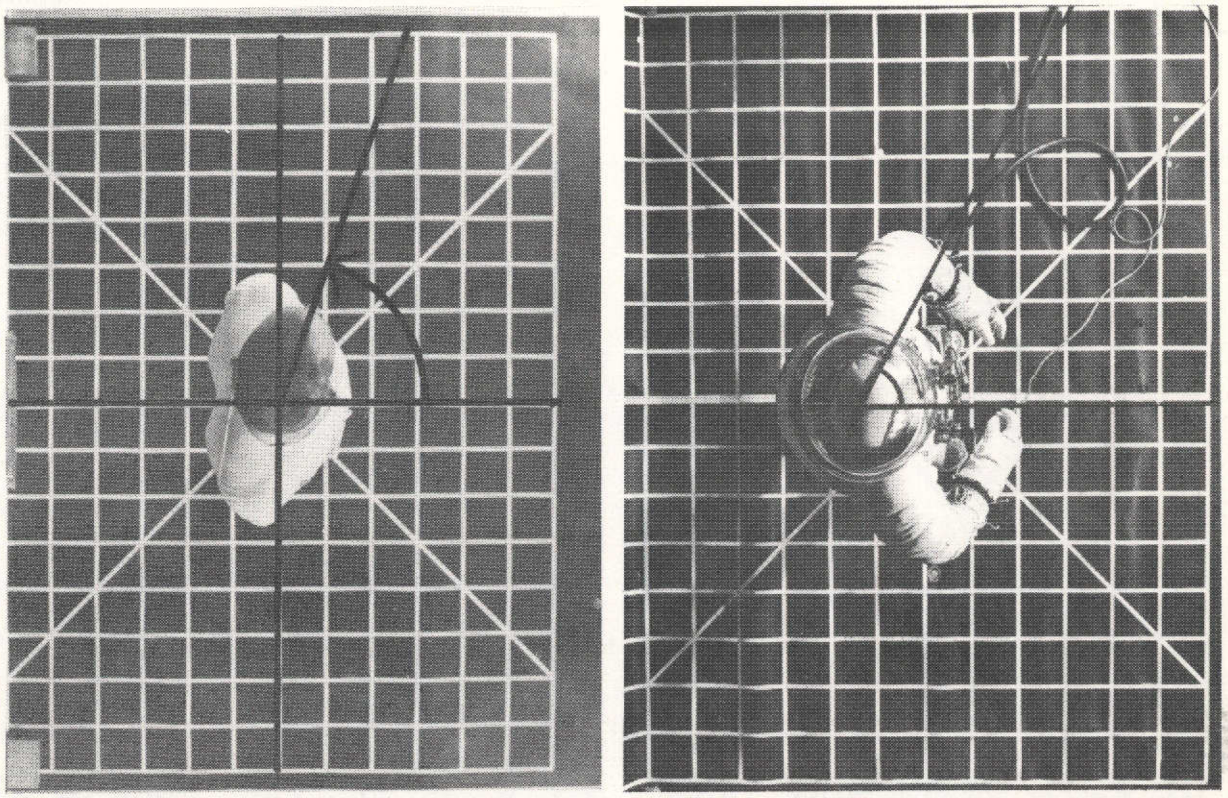
MOBILITY CAPABILITIES

	NUDE (CWG) *	A7LB *	OES **	
MEASURED	117°	46°	49°	
SPECIFICATION	--	135°	N/S***	

Comments: This neck movement is not required on the part of the OES unit but only by the man inside the suit envelope. The visibility range allowed by the OES is considered adequate.

* See Reference 2.1
** See Reference 2.2
*** Not Specified

FIGURE 2.1-1: Neck Flexion (Forward-Backward)



NUDE BODY (CWG) Subject 1 OES @ 4 PSIG Subject 2

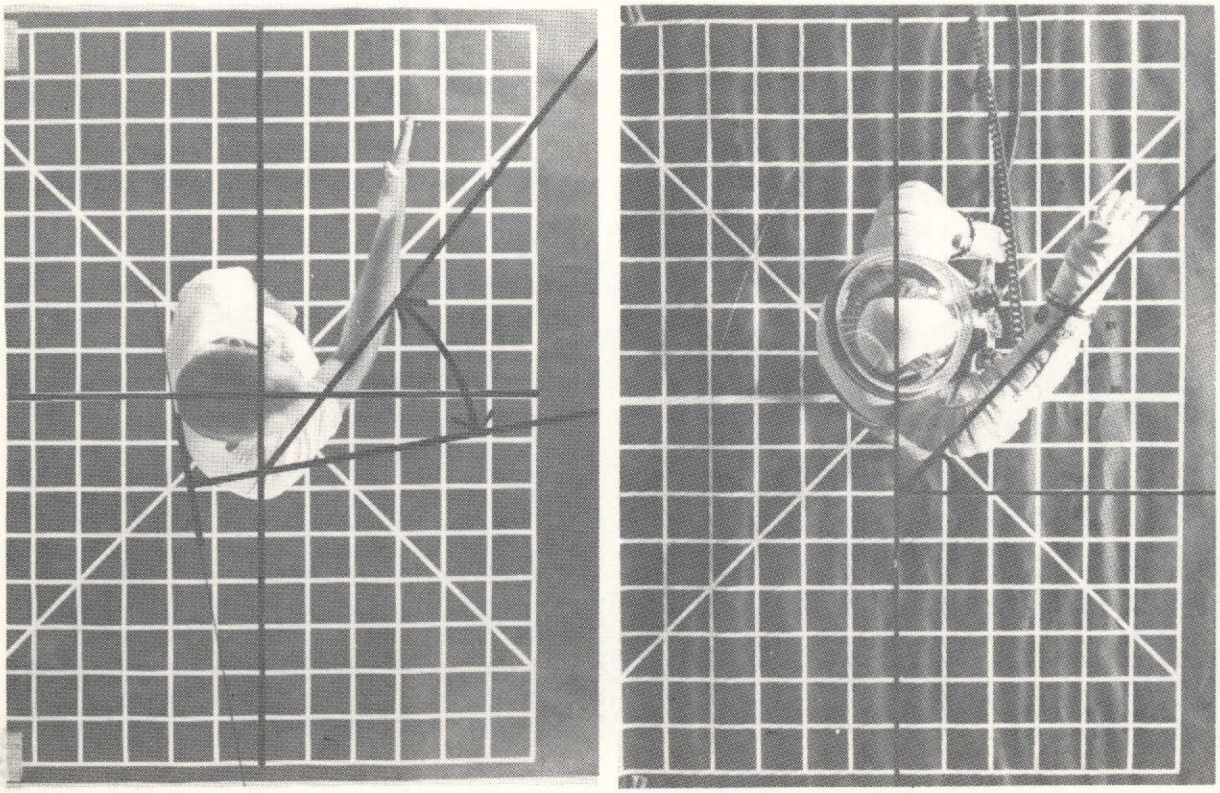
MOBILITY CAPABILITIES

	NUDE (CWG)*	A7LB*	OES**	
MEASURED	163°	165°	103°	
SPECIFICATION	--	140°	N/S***	

Comments: This neck movement is not required on the part of the OES unit but only by the man inside the suit envelope. The visibility range allowed by the OES is considered adequate.

* See Reference 2.1
** See Reference 2.2
*** Not Specified

FIGURE 2.1-2: Neck Rotation



NUDE BODY (CWG) Subject 1 OES @ 4 PSIG Subject 3

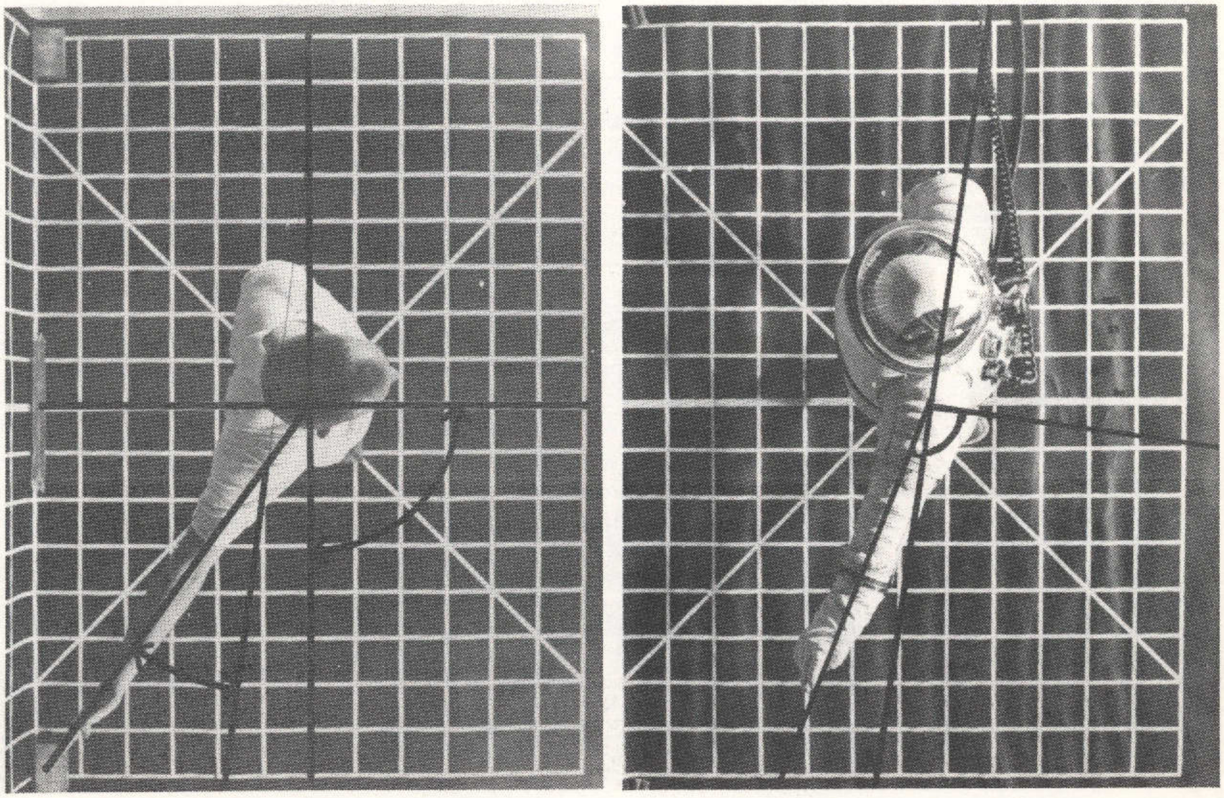
MOBILITY CAPABILITIES

	NUDE (CWG)*	A7LB*	OES**	
MEASURED	42°	-8°	47°	
SPECIFICATION	--	60°	165°***	

Comments: The OES mobility exceeds the nude capability in this movement which is attributed to differences in subject capabilities or techniques used. The OES mobility is improved over the A7LB for this movement.

* See Reference 2.1
** See Reference 2.2
*** Total for both shoulder adduction and abduction.

FIGURE 2.1-3: Shoulder Adduction



NUDE BODY (CWG) Subject 1 OES @ 4 PSIG Subject 3

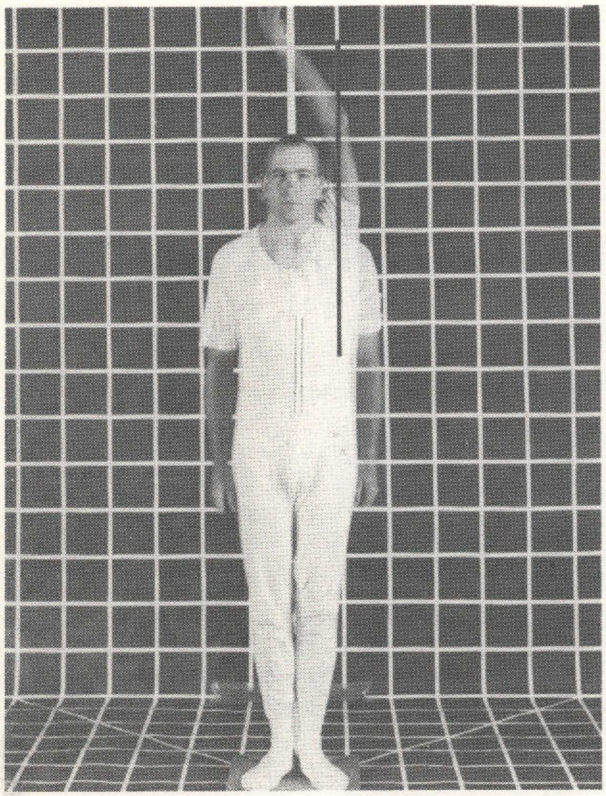
MOBILITY CAPABILITIES

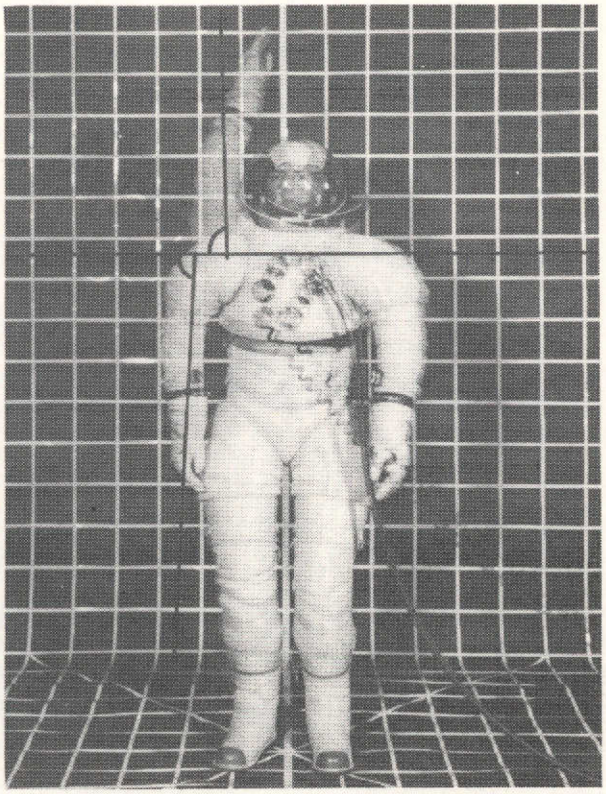
	NUDE (CWG)*	A7LB*	OES**	
MEASURED	118°	90°	104°	
SPECIFICATION	--	95°	165°***	

Comments: The OES mobility for this movement is fully adequate and is an improvement over the A7LB.

* See Reference 2.1
** See Reference 2.2
*** Total for both shoulder adduction and abduction.

FIGURE 2.1-4: Shoulder Abduction





NUDE BODY (CWG) Subject 1 OES @ 4 PSIG Subject 3

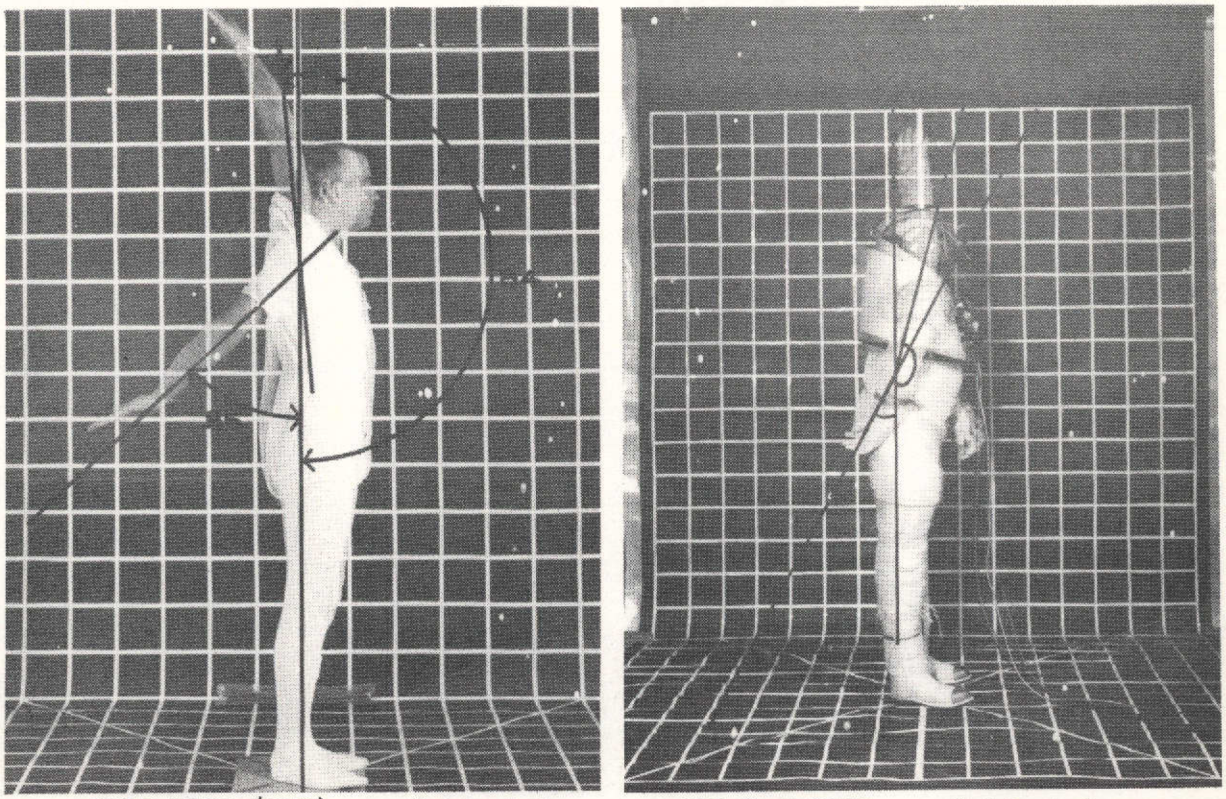
MOBILITY CAPABILITIES

	NUDE (CWG)*	A7LB*	OES**	
MEASURED	180°	142°	177°	
SPECIFICATION	--	155°	150°	

Comments: The OES has a negligible effect on nude mobility for this shoulder movement.

* See Reference 2.1
** See Reference 2.2

FIGURE 2.1-5: Shoulder Movement (Lateral - Medial)



NUDE BODY (CWG) Subject 1 OES @ 4 PSIG Subject 2

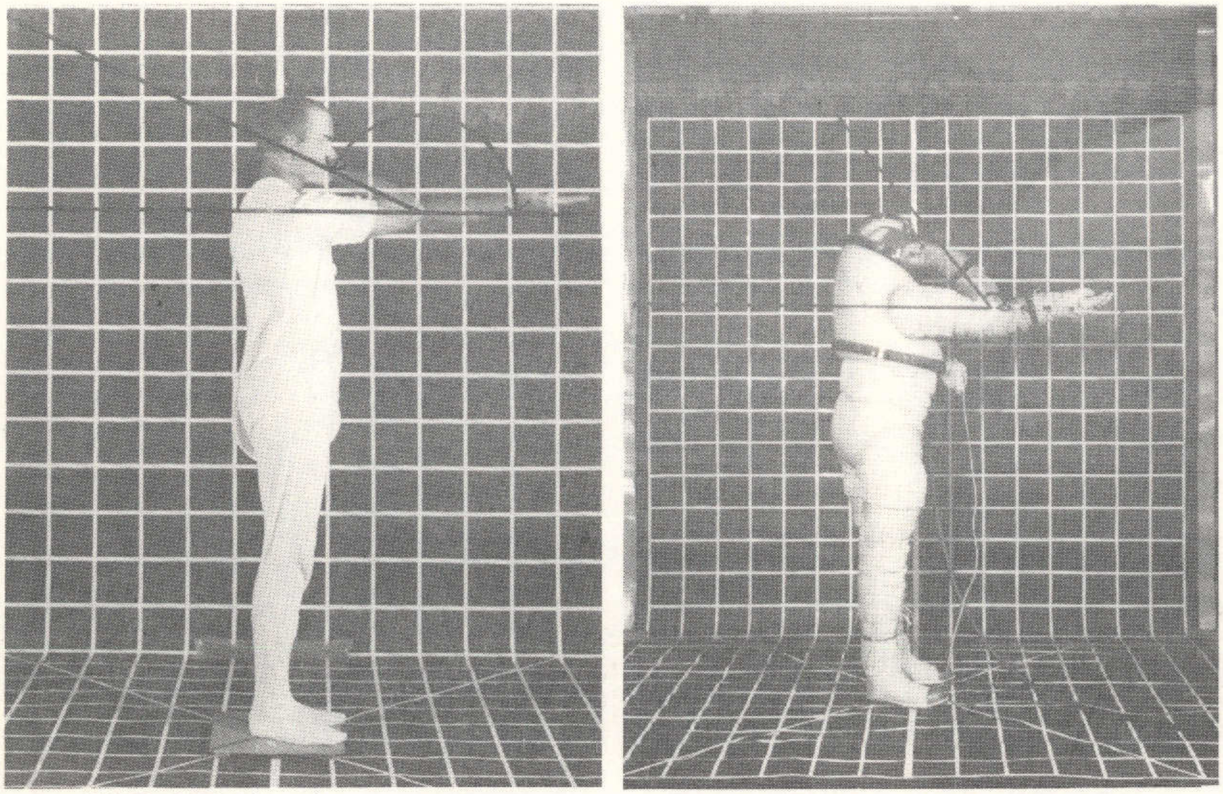
MOBILITY CAPABILITIES

	NUDE (CWG)*		A7LB*		OES**		
MEASURED	Flex. 185°	Exten. 47°	Flex. 170°	Exten. 18°	Flex. 165°	Exten. 29°	
SPECIFICATION	--	--	150°	35°	180° total		

Comments: The OES exceeds the design requirement for this movement (180° combined). The OES is in the same mobility range as the A7LB, but due to improved suit design, much less torque is required to perform this movement.

* See Reference 2.1
** See Reference 2.2

FIGURE 2.1-6: Shoulder Flexion/Extension



NUDE BODY (CWG) Subject 1 | OES @ 4 PSIG Subject 2

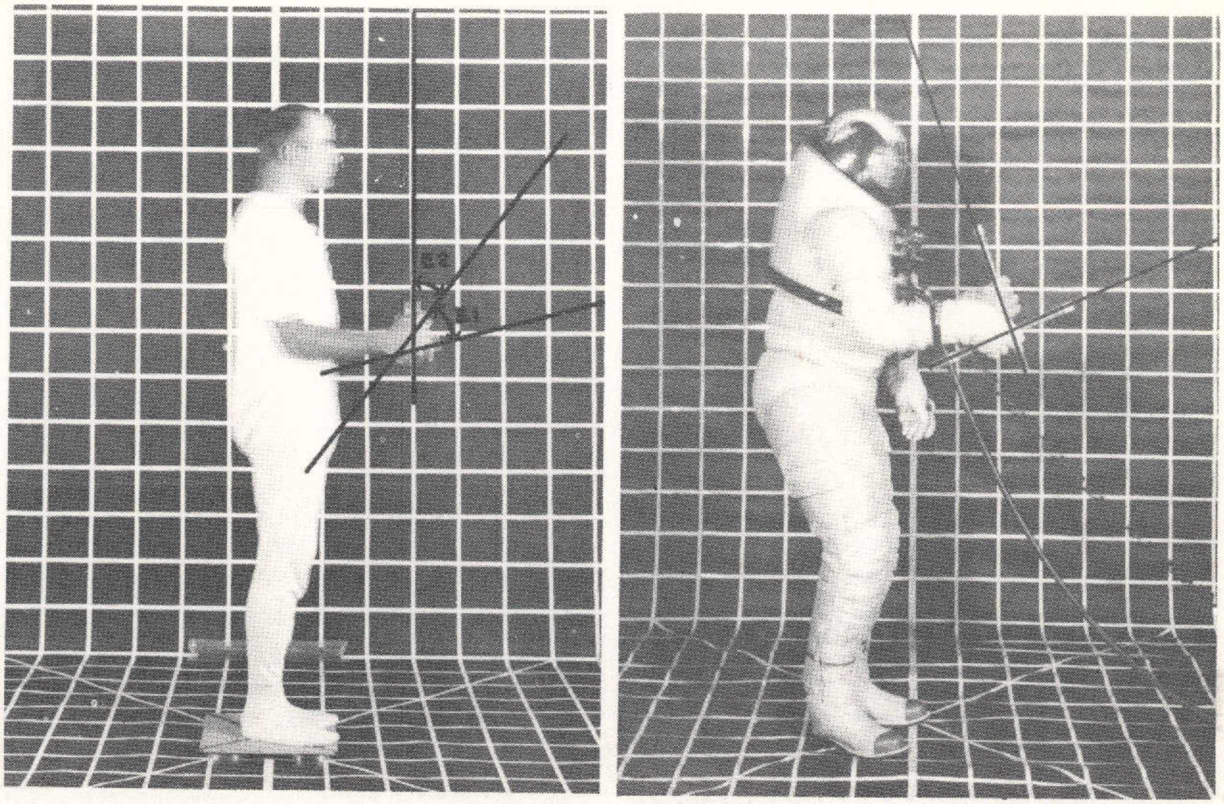
MOBILITY CAPABILITIES

	NUDE (CWG)*	A7LB*	OES**	
MEASURED	155°	129°	129°	
SPECIFICATION	--	115°	150°	

Comments: The OES appears to degrade nude mobility by approximately 25° for this movement. The OES does not meet the design requirement for this movement (150° required); however, the OES has the same range as the A7LB.

* See Reference 2.1
** See Reference 2.2

FIGURE 2.1-7: Elbow Flexion/Extension



NUDE BODY (CWG) Subject 1 OES @ 4 PSIG Subject 3

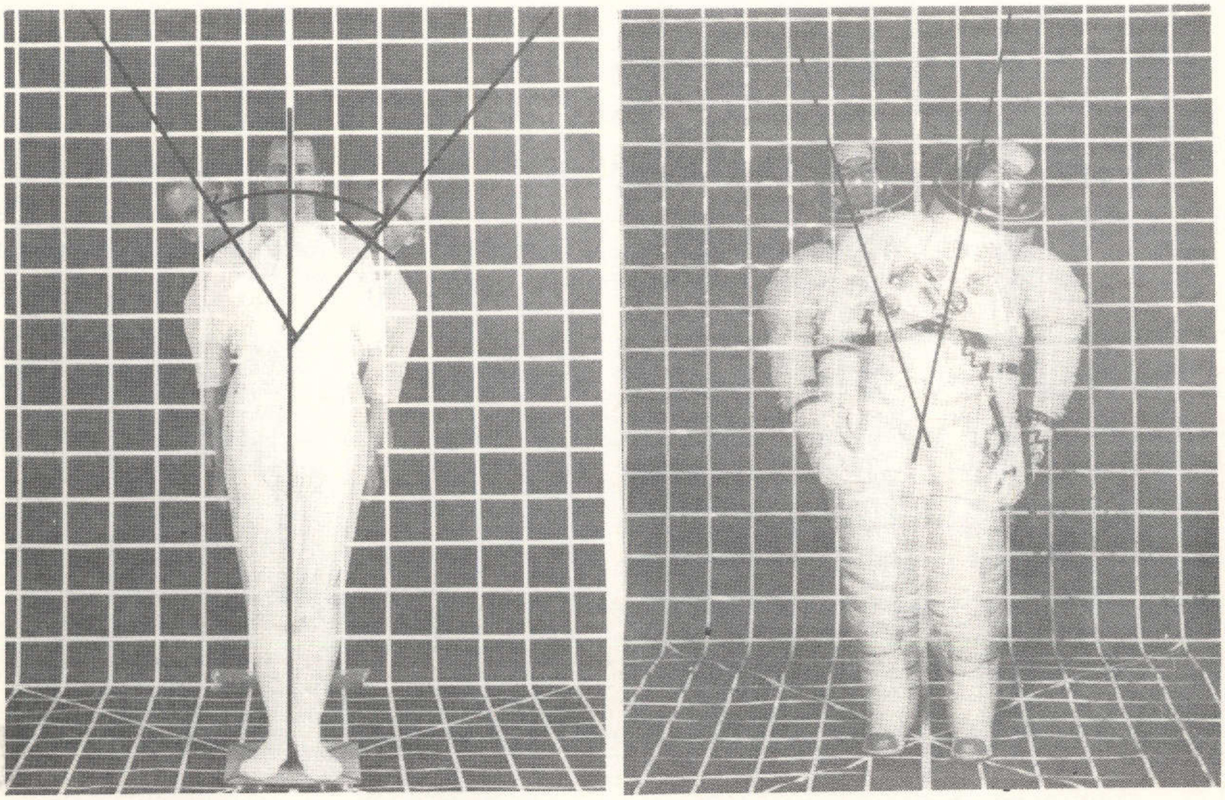
MOBILITY CAPABILITIES

	NUDE (CWG)*		A7LB*		OES**	
	Exten.	Flex.	Exten.	Flex.		
MEASURED	38°	38°	55°	37°	86°	
SPECIFICATION	--	--	56°	57°	N/S***	

Comments: The OES does not degrade nude mobility for the movement. The apparent increase in mobility can be attributed to subject technique, body re-positioning in the suit, and/or subject ability.

* See Reference 2.1
** See Reference 2.2
*** Not Specified

FIGURE 2.1-8: Wrist Extension/Flexion



NUDE BODY (CWG) Subject 1 OES @ 4 PSIG Subject 3

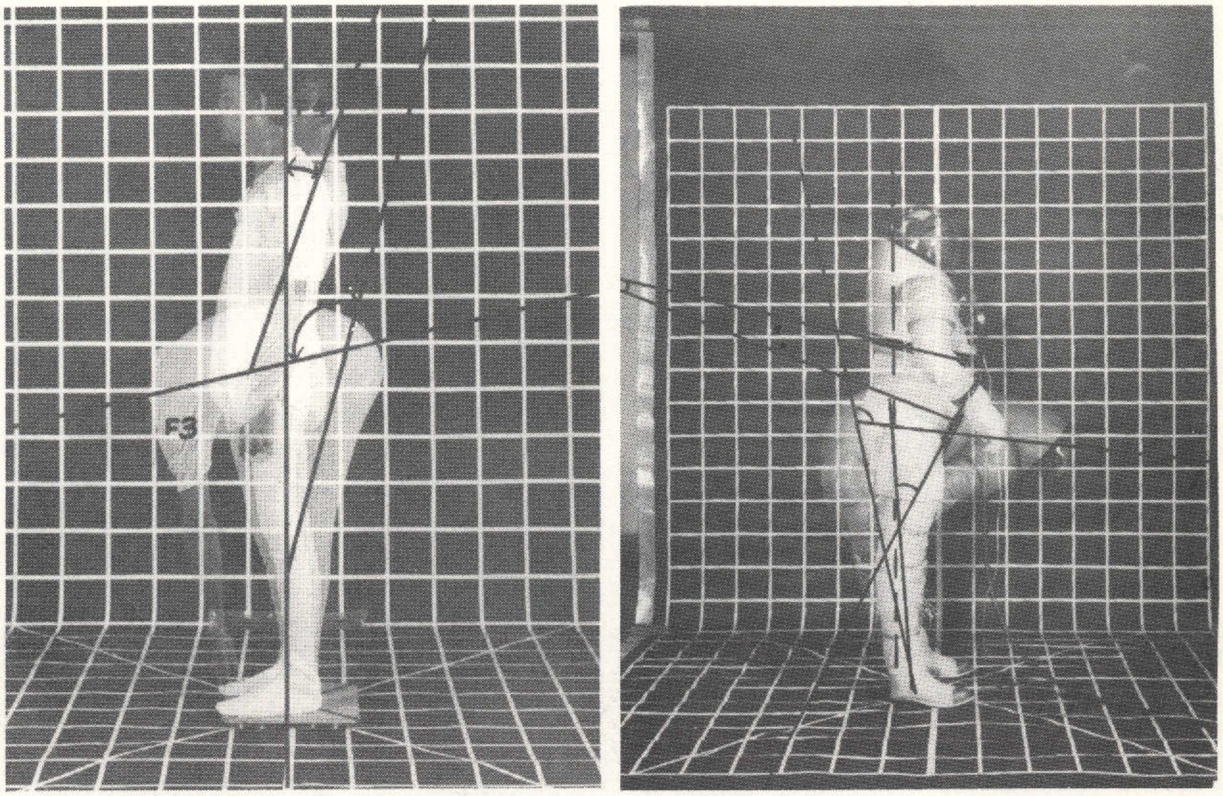
MOBILITY CAPABILITIES

	NUDE (CWG)*	A7LB*	OES**	
MEASURED	72°	60°	31°	
SPECIFICATION	--	35°	30°	

Comments: The OES meets the design requirement for this movement (30° required) even though nude mobility is degraded approximately 50%.

* See Reference 2.1
** See Reference 2.2

FIGURE 2.1-9: Torso Flexion (Left-Right)



NUDE BODY (CWG) Subject 3 OES @ 4 PSIG Subject 2

MOBILITY CAPABILITIES

	NUDE (CWG)*	A7LB*	OES**	
MEASURED	118°	112°	119°	
SPECIFICATION	--	130°	45°	

Comments: The OES mobility exceeds the design requirement for this movement (45° required). The nude mobility for this movement is not degraded by the OES.

* See Reference 2.1
** See Reference 2.2

FIGURE 2.1-10: Torso Flexion (Forward)

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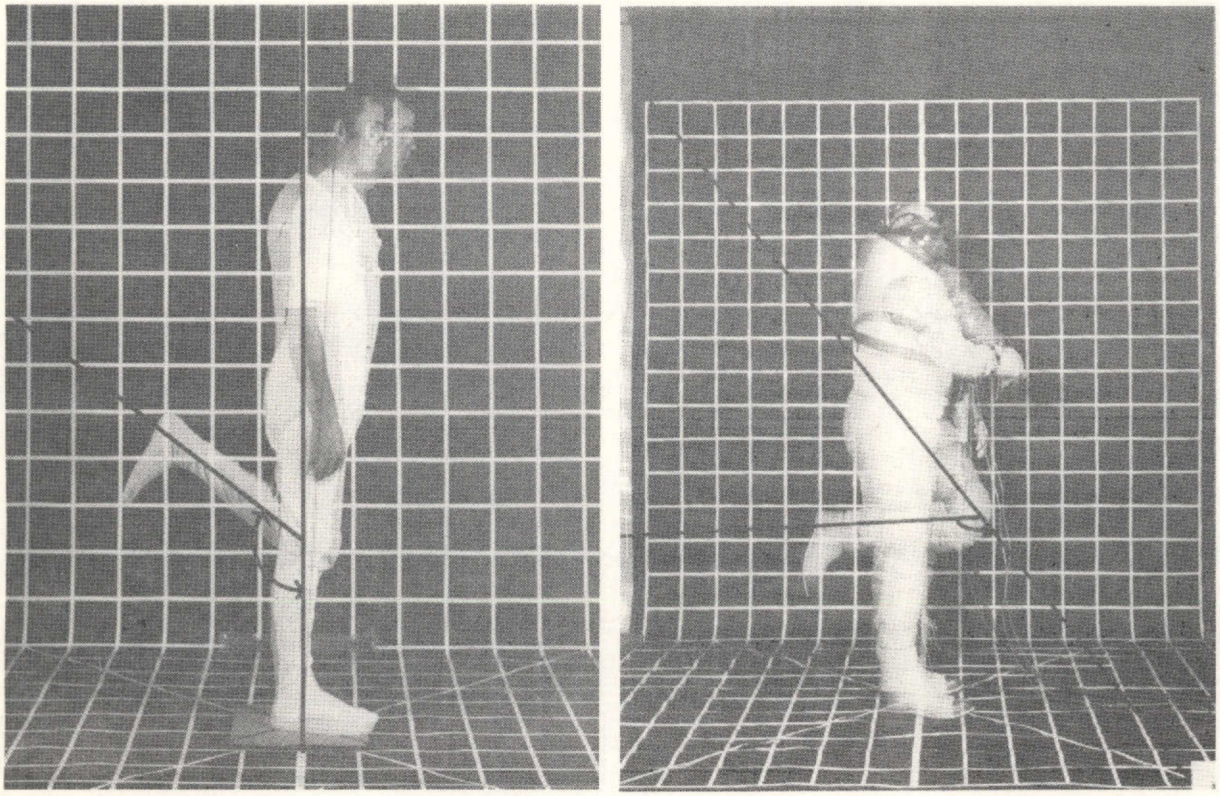


NUDE BODY (CWG) Subject 3 OES @ 4 PSIG Subject 2

MOBILITY CAPABILITIES

	NUDE (CWG)*	A7LB*	OES**	
MEASURED	124°	111°	126°	
SPECIFICATION	--	110°	110°	

Comments: The OES exceeds the design requirement for this movement (110° required). Nude mobility is not restricted by the OES.

* See Reference 2.1
** See Reference 2.2

FIGURE 2.1-11: Knee Flexion

2.1.2 Force and Torque Applications

The questions, "How much force and/or torque can an EVA crewman exert in orbit?" and "What are the design limits for force on man-operated equipment in the weightless environment?", are often asked by designers of man-machine systems for use in space. Many complex variables affect strength and force outputs for any given population. Among the most important factors are physical condition, body stature (height and weight), motivation, age, and body attitude with respect to the work surface. When performing tasks in a zero-g environment, additional factors are introduced. The most evident are: (1) Crewman restraints at the worksite; and (2) encumbrance associated with the spacesuit and life support equipment.

Suit mobility degradation from the normal shirtsleeve condition is not of sufficient magnitude to directly affect crew force-torque application. An important element when designing equipment or worksites for spacesuited operation is to provide adequate workspace and limb access for the crewman to attain a position which maximizes his force output. The crewman should not be forced to use poor biomechanical body configurations where, in many instances, poor performance is erroneously attributed to suit or life support system encumbrance. Given a properly designed extravehicular man-machine interface, the most significant factors are access to the workpiece and proper crewman restraint--not internal "suit torques" or equipment encumbrance on the crewman.

The most critical EVA hardware items affecting force-torque performance in weightlessness are crew restraints. Several studies have been performed to determine the requirement and type of restraints required for various levels of force application in zero-gravity. An analysis by the URS/Matrix Company (ref. 2.3) has shown that the maximum force capability without restraint is a function of the subject's mass and the distance (arm reach) the force is applied. The maximum distance a force can be applied by a free floating crewman is approximately .6 m. (2 ft.) since the crewman's arm will no longer be in contact with the work structure after his mass center has moved this distance. Using a subject mass of 73 kg. (160 lbs.), it was determined that the unrestrained crewman can apply a force of .45 kg. (1 lb.) for approximately 4.5 sec., a 2.3 kg. (5 lb.) force for 2.1 sec., and a 4.5 kg. (10 lb.) force for 1.4 sec. before his mass center moves outside of the .6 m. (2 ft.) envelope. A Restraint-No Restraint Threshold family of curves is shown in Figure 2.1-12 below.

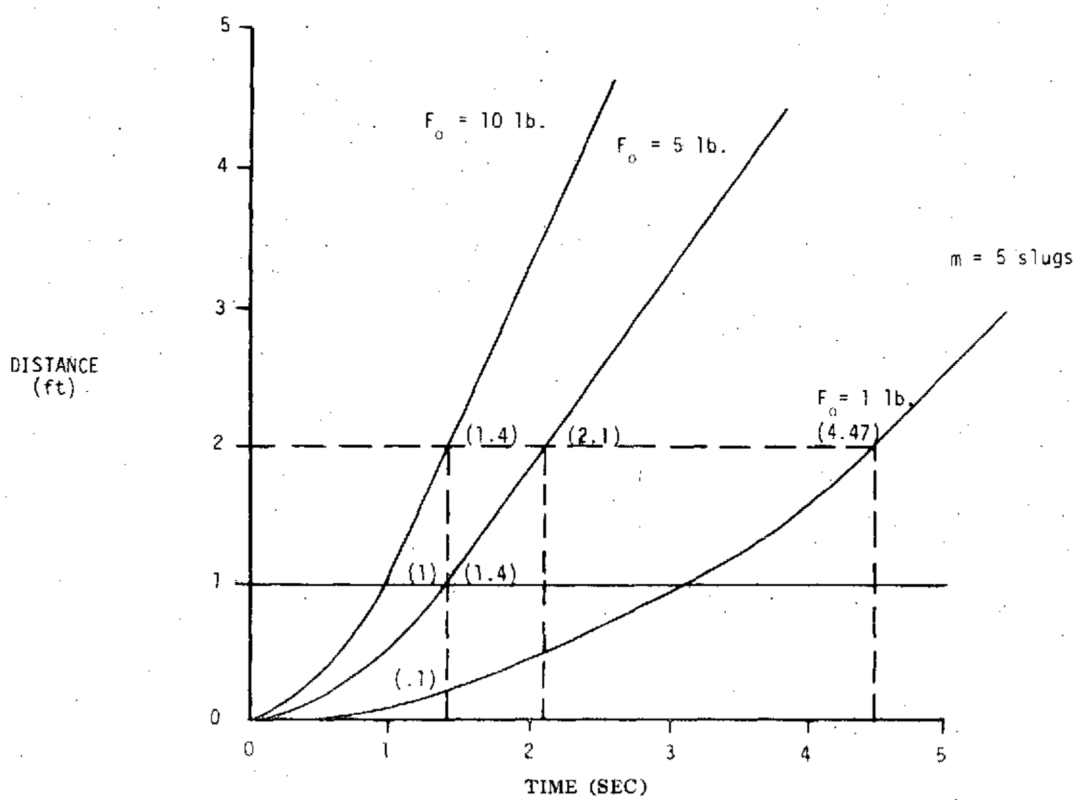


FIGURE 2.1-12: Restraint - No Restraint Threshold Curves

Low force, low time operations such as actuation of toggle and rotary switches, surveillance of controls and displays, visual inspections, etc., can be performed by an unrestrained crewman in a weightless environment.

Studies on the force application capabilities of a weightless crewman using only a handhold for restraint were conducted by the Air Force (ref. 2.4 and 2.5). These tests indicate that wrist strength is not adequate to compensate for the reactions to forces exerted in the operation of simple hand tools, and that an 18.1-kg. (40-lb.) push force can only be applied effectively for approximately 0.5 sec., while 2.3 to 18.0 kg. (5 to ≈ 40 lbs.) can be applied for periods up to 1 second. Again, the impulse is limited by the movement of the man away from the point of application.

Other studies conducted by the Air Force (ref. 2.6) on torque capabilities in a weightless environment indicate that, using only a handhold, the torque a crewman can exert by applying a sudden twist to a fixed handle varies as a half-sine wave, and is approximately 67% of his maximum torque under normal gravity conditions.

Many human force/torque capability and limitation studies have been conducted under various pressure suited conditions. The results of one such test (ref. 2.7) are contained in Table 2.1-1 and depict maximum torque applications (seated and supine positions) under three suited conditions. High crewman force applications have formerly been the subject of considerable study by the NASA and various contractors. Although maximum crew force application may be required under certain emergency conditions, the design of equipment to be operated by an EVA crewman is normally much less than the maximum attainable (25% or less) under simulated conditions.

The Air Force Systems Command Design Handbook on personnel subsystems (AFSC DH 1-3) recommends that in selecting a strength value to use in designing equipment, the maximum force which can be exerted by the weakest 5% of normal American males aged 18 to 30 should be the criteria. On previous space programs, the NASA has designed many of the EVA man-machine operational interfaces based on subjective comments of the astronaut user population. The designs were developed and approved as the result of repetitive simulations and evaluations during systems development cycles. Major factors influencing the design of past EVA operational hardware included:

- Interface accessibility
- Crew restraint system
- User muscular strength
- Biomechanics
- Crew safety
- Physiological comfort

TABLE 2.1-1: Torque, Rotation, and Grip Values For Three Suited Conditions

HAND TORQUE, ROTATION, AND GRIP STRENGTH VALUES		CONDITION* 1 MEAN		1 STANDARD DEVIATION		2 MEAN		2 STANDARD DEVIATION		3 MEAN		3 STANDARD DEVIATION	
		DEGREES		DEGREES		DEGREES		DEGREES		DEGREES		DEGREES	
	MAXIMUM ROTATION: SUPINATION	221.7		33.0		188.5		35.0		120.2		27.3	
	MAXIMUM ROTATION: PRONATION	157.8		28.8		128.5		28.2		78.3		20.4	
		kg.	lb.	kg.	lb.	kg.	lb.	kg.	lb.	kg.	lb.	kg.	lb.
	GRIP STRENGTH	48.0	105.8	8.6	18.9	35.8	79.0	6.4	14.1	30.2	66.5	4.8	10.5
		kg-m	in-lb	kg-m	in-lb	kg-m	in-lb	kg-m	in-lb	kg-m	in-lb	kg-m	in-lb
	MAXIMUM TORQUE: SUPINATION	1.4	121.5	.35	30.1	1.4	119.4	.29	25.1	1.1	95.9	.33	29.0
	MAXIMUM TORQUE: PRONATION	1.8	153.9	.52	45.0	1.9	161.5	.55	47.6	1.7	151.3	.57	49.9

* Condition 1: Subject wearing unpressurized suit but barehanded.
Condition 2: Subject wearing unpressurized suit and gloves.
Condition 3: Subject wearing suit and gloves pressurized to 3.5 psi.

Since each EVA interface and hardware operation on previous space vehicles was unique in many respects, detailed specifications, standards, or design requirements were not compiled/developed for areas such as force and torque applications in EVA. General guidelines, human factors principles, and space flight personnel experience were used.

There has been a tendency in the past to design equipment for use by the "average man"; however, no person is "average" in all dimensions. In a test of the middle 30% of a population of 4000 men, measurements were taken on 10 dimensions: Only one-fourth were "average" in a single dimension; and fewer than 1% were average in 5 dimensions (height, chest circumference, arm length, crotch height, and torso circumference). Attempting to establish a design "standard" for EVA force and torque limits will encounter human variations (e.g., physical condition, motivation, age) in addition to the basic, but most important, body stature. Therefore, it is obvious that the "average person" concept is not a sound basis for EVA systems/interface design, even when the user population is controlled.

Establishment of design guides for EVA forces and torques will not be attempted in this document through the usual anthropometric and biomechanical tables or testing techniques. Instead, a number of representative forces and torques required to operate equipment on the Skylab EVA missions are presented. Table 2.1-2 provides typical forces required to actuate various Skylab mechanisms while Table 2.1-3 presents torque values for representative control and connector operation. Table 2.1-4 depicts the torque characteristics of the Astronaut Maneuvering Unit hand controllers used on Skylab. The values shown in Table 2.1-4 were taken from NASA Specification SC-C-0005 (ref. 2.7). The table identifies an interface configuration (handle type) required for a certain torque range--torque limits for manned operation are not specified. Finally, Table 2.1-5 notes torque/handle design values for valve type controls in three torque ranges.

The Skylab extravehicular equipment force and torque operation values are compiled in this document for general guideline purposes only. The values

TABLE 2.1-2: Representative Force Values For Skylab EVA Hardware

FORCE DATA OPERATION	FORCE REQUIRED		COMMENTS
	kg.	lbs.	
OPEN-CLOSE EVA HATCH	20.4 max.	45.0	
OPEN-CLOSE INTERIOR HATCHES	16.0 max.	35.0	
ACTUATE HATCH LATCHES	11.3 max.	25.0	Lever type handle
OPEN-CLOSE ATM ACCESS DOORS	4.5 max.	10.0	
LATCH-UNLATCH S052 LATCH HANDLE	1.6 nom. 1.8 max.	3.5 4.0	Push-pull
LOCK-UNLOCK S052 LAUNCH-LOCK TEE HANDLE	5.2 nom. 5.7 max.	11.5 12.5	Push-pull
INSTALL ATM CAMERA TO INSTRUMENT LATCHING MECHANISM	4.5 max.	10.0	S052, S056, Hα1 experiments push-pull required by crewman
OVERCOME ATM S082 LATCH LEVER DETENTS	5.4 nom. 7.3 max.	12.0 16.0	Detents restrain the experiment when in the unlocked position - push-pull required
OPERATE S082 LATCHING HANDLES SUSTAINED IMPULSE	 8.2 max. 16.3 max.	 18.0 36.0	 Tangential force required
ACTUATE S082 CONTAINER LOCKING MECHANISM	1.37 max.	3.0	Thumb operated lever device
OPERATE S082 CONTAINER OPEN-CLOSE LEVER	6.8 max.	15.0	Applied at 8.5 in. from pivot
OPEN S082 CONTAINER LID	1.37 nom. 3.6 max.	3.0 8.0	Pull against a friction hinge
ACTUATE S056 TRIGGER MECHANISM	13.6 max.	30.0	Required a squeezing motion

TABLE 2.1-3: Representative Torque Values For Skylab EVA Hardware

LEVER TYPE CONTROLS	TORQUE REQUIRED		COMMENTS
	kg-m.	in-lb.	
ROTATION CONTROL LEVER (ATM PANEL 160)	.29 .07 $\pm$ .05	25.0 6.0 $\pm$ 4.0	Maximum Operational
REGULATOR SELECTOR VALVE (PRESSURE CONTROL UNIT)	.17	15.0	Operating and break-away torque @ 8.44 kg/cm^2 (120 psi)
FLOW CONTROL VALVE (PRESSURE CONTROL UNIT)	.17	15.0	Operating and break-away torque @ .028 kg/cm^2 (4 psid)

CENTRAL PIVOT VALVE CONTROL	TORQUE REQUIRED		COMMENTS
	kg-m.	in-lb.	
FILL AND SHUTOFF VALVE (SECONDARY OXYGEN PACK)	.29	25.0	Max operating torque @ 48.05 kg/cm^2 (6850 psig)

CONNECTORS	TORQUE REQUIRED		COMMENTS
	kg-m.	in-lb.	
GAS FILL (ASTRONAUT MANEUVERING UNIT)	.12 (max)	10.0	$\pm$ 140° rotation
PROPELLENT SUPPLY (ASTRONAUT MANEUVERING UNIT)	.35	30.0	$\pm$ 3.32 revolutions
ELECTRICAL (LIFE SUPPORT UMBILICAL TO EVA PANEL)	.41 .08	36.0 7.0	maximum minimum

TABLE 2.1-4: Torque Characteristics of Astronaut Maneuvering Unit Hand Controller

HAND CONTROLLERS (ASTRONAUT MANEUVERING UNIT)		TORQUE REQUIRED kg-m.	TORQUE REQUIRED in-lb.	COMMENTS
ROTATIONAL HAND CONTROLLER				
PITCH	Minimum	.13	11.0	Increase in torque from 0° to 12° displacement
	Maximum	.35	30.0	
YAW	Minimum	.12	10.0	Increase in torque from 0° to 12° displacement
	Maximum	.22	19.0	
ROLL	Minimum	.14	12.0	Increase in torque from 0° to 12° displacement
	Maximum	.25	22.0	
TRANSLATIONAL HAND CONTROLLER				
Y and Z axes	Minimum	.12	10.0	Increase in torque from 0° to 7° displacement
	Maximum	.20	17.0	
X axis	Minimum	.12	10.0	At 1.5° abduction
	Maximum	.22	19.0	> 1.5°
	Maximum	.26	23.0	> 1.5° adduction

TABLE 2.1-5: Torque/Handle Design For Valve Controls (NASA Spec. SC-C-0005)

TORQUE CLASS	TORQUE RANGE	HANDLE TYPE	HANDLE SIZE
LOW TORQUE	< 1.13 n-m (10 in-lb)	Central Pivot	< 5.72 cm. (2.25 in) dia.
INTERMEDIATE TORQUE	< 2.26 n-m (20 in-lb) > 1.13 n-m (10 in-lb)	Central Pivot or Lever	> 5.72 cm. (2.25 in) dia. > 7.62 cm. (3 in) length
HIGH TORQUE	> 2.26 n-m (20 in-lb)	Lever	> 7.62 cm. (3 in) length

should not be construed as limiting factors for equipment design or maximum force applications of crewmen in a zero-gravity environment. Each EVA task must be studied relative to work piece accessibility, crewman restraints, special tools, etc. Many crewmen with previous flight experience feel that if properly restrained, their maximum force/torque applications in zero-gravity will closely approximate those produced on earth.

2.1.3 Cargo Transfer Capability

The capability of the EVA crewman to transport equipment modules, experiments, rescue systems, etc., independent of assisting mechanisms other than mobility aids, is of interest to the Shuttle payload planners. The design of cargo requiring on-orbit transfer must consider module size, number, configuration, mass, handhold/grasp location relative to the mass center of gravity, transfer distance, time, temporary stowage, and number of EVA crewmen.

Upper limits have not been established regarding the size and mass of modules that can safely be handled in zero-g by one crewman. Spacesuited simulations conducted on the KC-135 "zero-g" aircraft with packages of .76 x 1.02 m. (40 x 30 in.) frontal dimensions and mass of 82 kg. (180 lbs.) did not disclose translational, positioning or control problems other than those associated with aircraft perturbations. Shirtsleeve KC-135 simulations indicated (test subject evaluation) that packages with a moment of inertia in excess of .4 kg-m. sec^2 (350 in-lb. sec^2) became increasingly more difficult to control and position (ref. 2.8). Other simulations conducted at the NASA/Langley Research Center investigated EVA crewman transport of packages with moments of inertia up to 115 kg-m. sec^2 (10,000 in-lb. sec^2) with satisfactory results (ref. 2.9). Hand-held packages of .61 m. (24 in.) in diameter and 38.6 kg. (85 lbs.) were easily transported by the crewmen during transearth Apollo EVA missions. Spacesuited water immersion simulations have handled 3,856 kg. (8,500 lbs.) Shuttle payload mockups during manned payload deployment evaluations.

The limited cargo transfer simulations conducted appear to leave significant gaps in information necessary to formulate baseline cargo transfer guidelines. Most simulation results, however, agree on the following:

- The mass moment of inertia can be the most significant factor in package control during translation and positioning.
- The location of handholds and grasp areas with respect to the package center of gravity is important in the design of on-orbit transferable equipment.
- The package size should not significantly limit crew visibility, particularly during one-man transfer.
- The transfer velocity should be decreased as the package mass increases to ensure safe transporting.
- Factors such as crewman strength, mobility aids, package configuration, etc. affect cargo transfer performance.
- Manned cargo transfer capability exceeds that shown in simulations conducted to date.
- Two-man cargo transfer teams should be employed where large massive equipment may injure the crewman or damage vehicle/payload hardware.

Manned cargo transfer and equipment handling requirements on previous orbital space programs have not approached the EVA crewman's maximum capabilities. Ground based simulations are not sufficiently conclusive at this time to place limitations on the size, mass, and moment of inertia of equipment handled and transported by EVA crewmen. Additional simulations are planned by NASA; however, simulation schedules and release dates of data are not presently available. In the interim, designers of on-orbit transferable hardware should consult previous designs but not be limited by present simulation or previous in-space experience.

2.1.4 Translation Rates

The distance translated and frequency of translation were not major factors relative to crew timelines on previous space programs. The 18.3 m. (60 ft.) Shuttle Orbiter payload bay and the frequent .5-fortnight (7-day) missions may require more accurate planning of crew time than on the previous space missions. The forces required to handle cargo in a gravity-free environment are those induced by the inertial properties of the cargo and man. There are no theoretical limits on the mass of cargo which can be transported. Limits are imposed only within the constraints of transport time, safety (crew and vehicle), control requirements, acceleration limits, vehicle geometry, positioning accuracy, etc. Nominal or maximum (i.e., safe) EVA crewman translation rates have not been established for either the unencumbered crewman or cargo transfer tasks/functions. Each transfer task must be studied relative to the constraints cited above.

Spacesuited water immersion cargo transfer simulations have reported crewman velocities ranging from .09 m/sec. (.3 fps) for 744 kg. (1,650 lbs.) mass transfer to .21 m/sec. (.7 fps) for transporting the smaller (<.03 m^3; <1.0 ft^3) components/modules (ref. 2.9). Transfer of cargo during KC-135 "zero-g" simulations recorded velocities in excess of .3 m/sec. (1.0 fps). The simulation utilized both single and dual handrail systems usually configured in a straight translation path (ref. 2.8).

Although considerable data are available from the Skylab Program, EVA time and motion studies have not been conducted. Most EVA documentation addressing translation times indicates EVA crewman translation rates of .21 to >.31 m/sec. (.7 to >1.0 fps) for transferring small packages (<.03 m^3; <1 ft^3 and <45 kgm.; <100 lbm.) over various vehicle surface geometries using non-continuous handrails (ref. 2.10 and 2.11). Transfer routes for larger and more massive cargo ranged from .09 to .21 m/sec. (.3 to .7 fps) with package moments of inertia up to 115 kg-m. sec^2 (100,000 in-lb. sec^2).

Transfer rates for an unencumbered spacesuited crewman over exterior vehicle surfaces and handrail routings must be studied relative to safety, tethering requirements, life support system constraints, transfer volume, time constraints, etc. Under conditions of a straight handrail translation path through the Shuttle Orbiter payload bay, it is the author's opinion that translation rates in excess of .6 m/sec. (2 fps) can safely be attained.

2.2 CREWMAN SUPPORT REQUIREMENTS

Basically, the same support requirements are necessary to safely perform tasks in the weightless space environment as in numerous earth based industrial operations conducted at planned worksites. All workstations, whether space or earth based, have a set of standard requirements which include proper tools, lighting, operator-to-workpiece visibility, working volume, safety equipment, etc. The most significant differences are, as previously acknowledged, the necessity of a portable life-supporting environment/protective system and restraint/stabilization systems for the crewman and equipment.

Each candidate EVA mission will involve studies to determine the type and quantity of supporting equipment required for each task. These requirements will vary depending on the type of manipulative tasks involved. Illumination level requirements will vary between gross and fine manipulative tasks; restraint systems will differ for tasks which range from experiment monitoring to crewman force applications; working/access volume requirements will change relative to the task; and EVA safety precautions will require consideration during vehicle/payload design and development (e.g., equipment and structural sharp edges, corners, and protrusions, pyrotechnic devices, moving parts, etc.).

Essentially, the application of basic techniques and a general knowledge of requirements for earth based manned worksites can be applied to EVA. The following paragraphs contain an overview of the major parameters to be considered, including guidelines used on previous EVA missions.

2.2.1 Illumination

General illumination standards have been developed by NASA for crewman working in an extravehicular environment. EVA work in deep space or on the "dark side" of earth/lunar orbit requires artifical lighting. Lighting in partial or direct sunlight requires supplementary visors and shields to protect the crewman's eyes from glare and ultraviolet radiation during EVA (see Section 2.2.1).

Two general illumination levels for artifical lighting are specified for extravehicular activities; traverse routes and exterior worksites. Table 2.2-1 depicts minimum brightness levels for each condition (ref. 2.11).

TABLE 2.2-1: Minimum Brightness Levels for Extravehicular Functions

EXTRAVEHICULAR ACTIVITY	BRIGHTNESS	REMARKS
TRANSLATION	>3.4 candela/m^2 (1 ft.-lamberts)	• Brightness values are minimum requirements
WORKSITE ACTIVITIES	17.1 candela/m^2 (5 ft.-lamberts)	• Measurements made off vehicle surface at the visual interface

EVA floodlighting for worksites may be incandescent or other lamp types which meet the illumination requirements.

The following lighting definitions are provided to aid in identifying appropriate lighting terms:

<u>ACHROMATIC:</u> Light without color, equal energy white light.

<u>CANDLEPOWER:</u> Luminous intensity of any light source

<u>CAUTION ANNUNCIATOR:</u> A signal light used to indicate the occurrence of an impending dangerous condition requiring attention, but not necessarily immediate corrective action.

<u>FLOODLIGHTING:</u> Light provided by a fixture separated from a display, indicator or panel assembly.

<u>ILLUMINATION:</u> The amount of light falling on a unit area measured in foot candles.

<u>LUMINANCE:</u> Brightness of the reflected light from a surface given off in the direction of the observer; expressed in candela per square meter or foot-lamberts.

2.2.2 Visibility

Visibility requirements for the spacesuit helmets on the Skylab missions specified an unrestricted field of vision (with head mobility) of 120° left and 120° right in the horizontal plane and 105° down and 90° up in the vertical plane. The helmet and visor units were also required to protect the eyes from ultraviolet radiation and glare during EVA operations (ref. 2.12). General requirements for helmets used on the Space Shuttle specify unrestricted visibility and head movement much like Skylab (ref. 2.13). Helmet assemblies for EVA are equipped to provide a protective visor, sun visor, and a quantity of blinders to maintain a comfortable level of light for optimum visibility.

Many evaluations/tests have been conducted that determines the crewman's visibility limits using various helmets. These tests were conducted with restrictions, such as: (1) Fixed head, no eye movement; (2) fixed head with eye movement; and (3) head movement plus eye movement. Although these data are useful in the design of certain intravehicular functions, they are not as applicable for EVA operations. In all EVA missions to date, the crewmen have essentially had unrestricted body, head and eye movement capability. This has allowed good visual access on all EVA missions.

For general information purposes, the optical characteristics of the helmet visors and blinders for the late Apollo and Skylab Programs are shown in Table 2.2-2 (ref. 2.14).

TABLE 2.2-2: Helmet Visor Optical Characteristics

PARAMETER	HELMET	PROTECTIVE VISOR	SUN VISOR	BLINDERS
SPECTRAL TRANSMITTANCE ULTRA-VIOLET (2000 - 3000 A)	--	<0.1%	N/A	None
LUMINOUS (4000 - 7000 A)	>80%	>60%	16±4%	None
SOLAR REFLECTANCE	N/A	--	>30%	100%
EMITTANCE	N/A	.12 Max	.08 Max	0

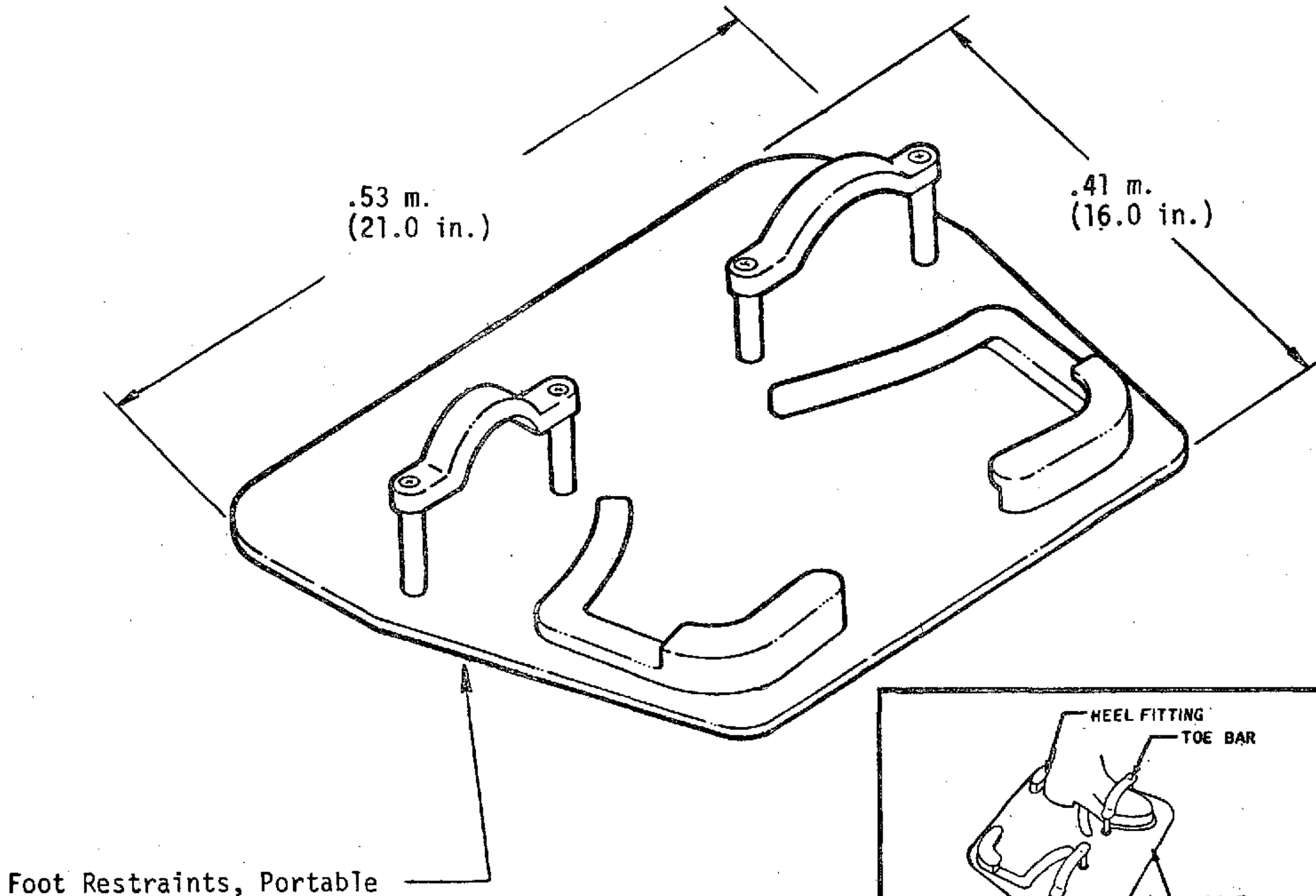
2.2.3 Restraint and Stabilization

Many studies have been conducted to determine the requirement for EVA crewman restraints and stabilization aids for various levels of task performance in weightlessness. (Several are cited in Section 2.1.1 of this report.) In addition, numerous restraint devices have been designed and tested for weightless application; fewer have been qualified, and even less have proven satisfactory for performing multiple EVA tasks.

The most versatile and efficient single restraint system developed to date for zero gravity EVA application is the foot restraint unit used during the Skylab Program (Figure 2.2-1). The restraints allowed easy foot entry and exit, were lightweight and provided positive restraint for a wider range of body work attitudes than previous concepts. The restraint components are normally mounted on a flat plate in an orientation relative to the worksite that will enhance task performance. These units are being considered for Space Shuttle and future space applications requiring long duration low force tasks, repetitive tasks, high force tasks, extended monitoring tasks, tasks requiring both hands, etc. Only those EVA functions requiring little or no force application can be accomplished efficiently without restraints. Skylab foot restraints have proven to be the most effective units of those used on previous space programs.

Crew body tethers attached to the vehicle structure are required for EVA crewmen where drifting to free space is possible. Only a few exceptions are recognized. Among the exceptions are when employing a manned free-flying maneuvering unit or in certain rescue operations. In rescue operations, where possible, either the crewman being rescued or the rescuing crewman will be tethered to a vehicle. Body tethers are also required as a backup safety feature when working from foot restraints.

All "loose" EVA equipment and cargo must be firmly secured or tethered at all times during extravehicular handling. Loose equipment for EVA purposes may be defined as equipment/cargo handled/transported during EVA by the crewman and not permanently attached to the vehicle.



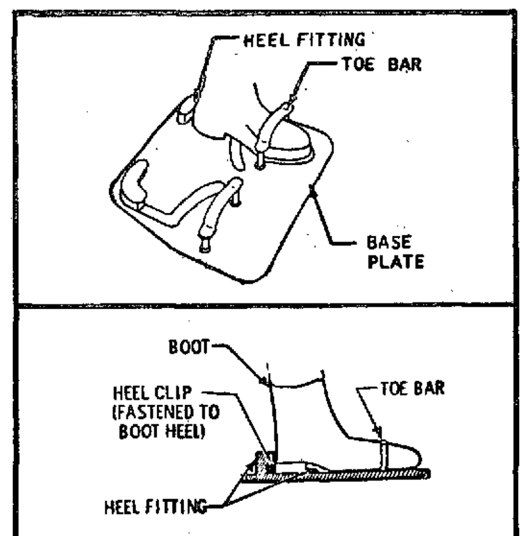


FIGURE 2.2-1: Foot Restraints Used On Skylab Program

A description of EVA restraint and stabilization equipment used on previous space programs is contained in Section 1.1 of this document.

2.2.4 Working and Translation Volume

The minimum translation corridor for the crewman in full EVA gear has been established as .76 m. (30 in.) diameter (see Figure 2.2-2, ref. 2-15). This minimum corridor is for straight line translation either through a tunnel-like structure or free-floating without translation aids. A translation path requiring the crewman to use handrails is recommended to be not less than .96 m. (38 in.) in diameter to avoid contact between crewman support gear and vehicle structures (see Figure 2.2-3). The translation corridors above do not allow movements other than straight line translation. Additional volume is required when changes in direction of travel are required. Figure 2.2-4 depicts the estimated volume required for a change in direction normal to the corridor being traversed.

The worksite volume, in excess of that needed for initial access, is dependent on the type of tasks to be performed by the EVA crewman. Tasks requiring body and arm manipulations for module/package handling, force/torque application, servicing and maintenance operations, etc. will require additional working volume. A minimum envelope of 1.2 m. (48 in.) diameter is recommended for manipulative tasks in the above category (Figure 2.2-5).

It should be acknowledged that the above specified volumes are guidelines and recommendations only and may be varied to satisfy different applications. Major EVA equipment items affecting working/translation volume on the Shuttle are spacesuits and life support systems. The design of advanced units may decrease the EVA volume required.

2.2.5 Safety

One of the major safety concerns during orbital EVA on the Skylab Program was the compatibility of vehicle structural and experiment hardware interfaces with the crewman's pressure suit and life support systems. Experiment equipment, structures along translation routes, worksite provisions, or

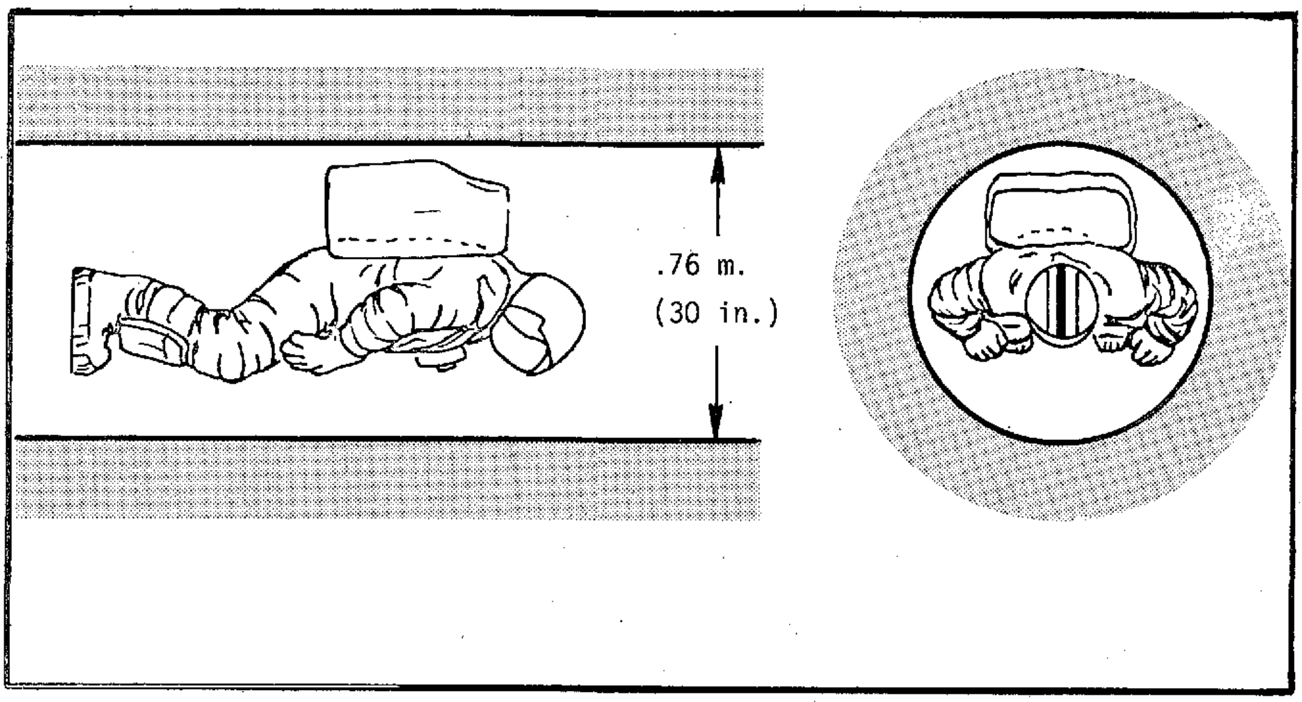


FIGURE 2.2-2: Minimum Recommended Corridor for Straight Line Translation

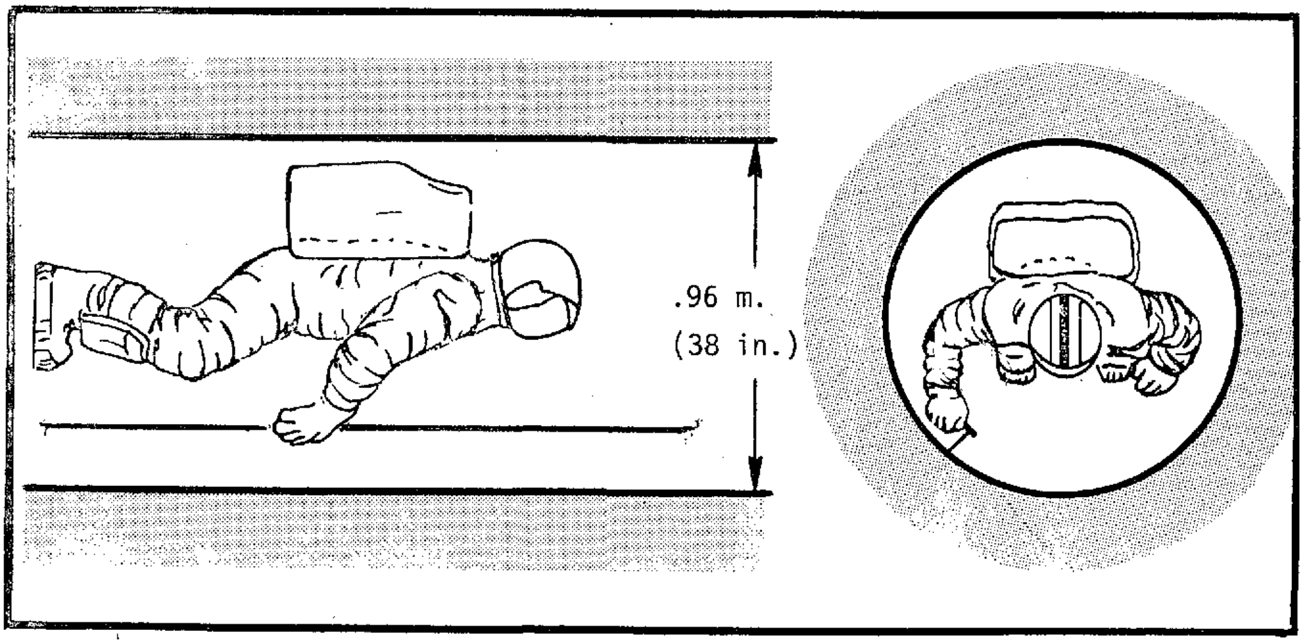


FIGURE 2.2-3: Minimum Recommended Corridor for Handrail Assisted Translation

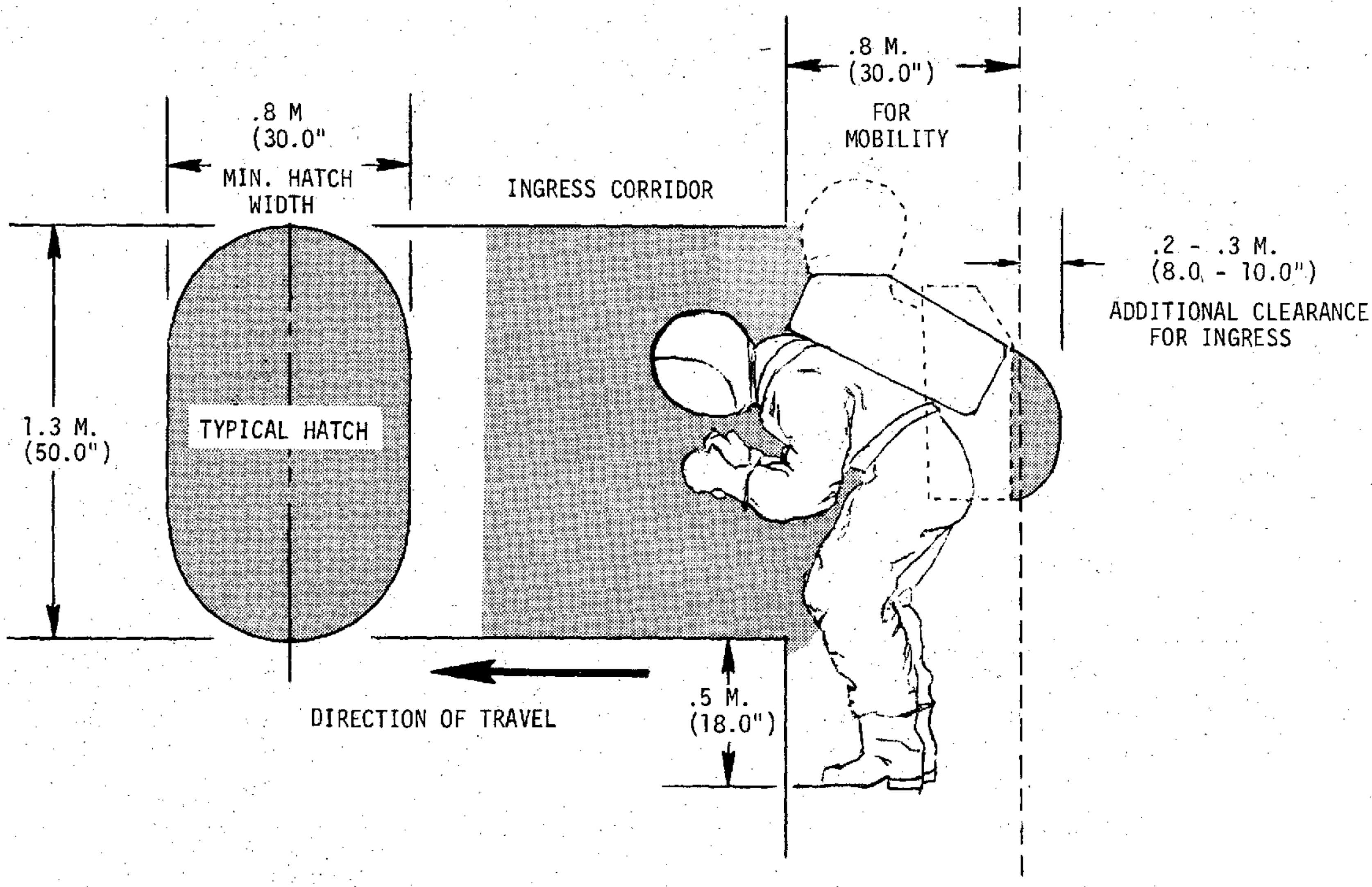


FIGURE 2.2-4: Recommended Access Corridor for Direction Change Normal to Traverse Path

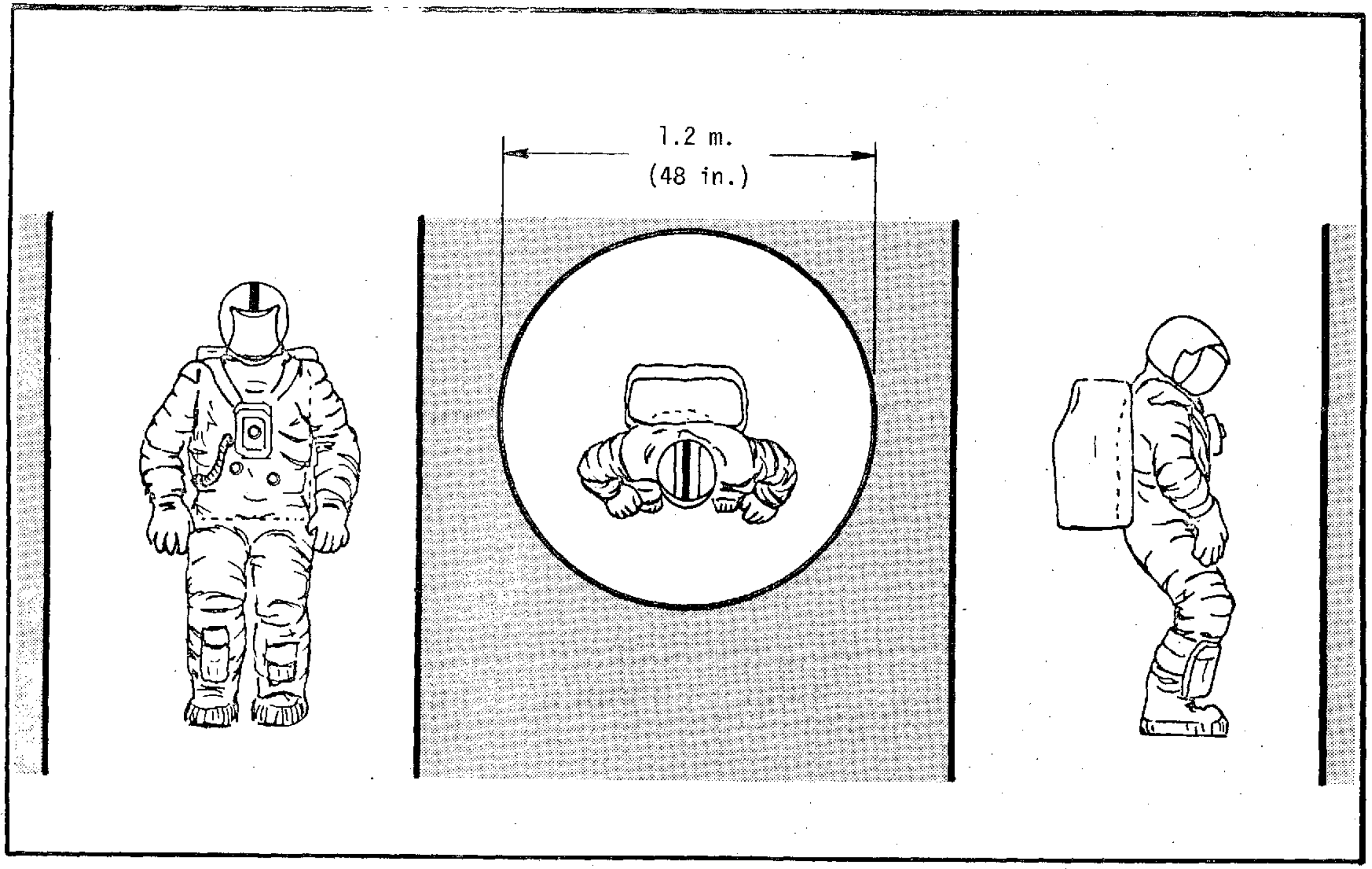


FIGURE 2.2-5: Recommended Envelope for Manipulative EVA Tasks

any equipment requiring an EV man-machine interface must be subjected to design constraints which ensure compatibility with the crewman's support equipment. From a safety standpoint, equipment edges, corners and protrusions within access of the crewman during extravehicular activities should meet the criteria listed in Table 2.2-3 (ref. 2.16).

Other safety considerations must be acknowledged when using EVA to perform tasks outside the vehicle. A listing of the major equipment/structural associated safety considerations (excluding suits and life support systems) are shown in Table 2.2-4. Table 2.2-4 was derived from reference 2.17. Many of the EVA safety requirements are satisfied during equipment design from the designer's general knowledge of potential hazards to man in the industrial environment on earth.

TABLE 2.2-3: Edge, Corner and Protrusion Criteria

APPLICATION (Edge and In-Plane Corner Radii)	RADIUS				REMARKS
	OUTER		INNER		
	cm.	in.	cm.	in.	
Openings, panels, covers (corner radii in plane of panel)	0.64 0.31	0.25 0.12	0.30 0.15	0.12 0.06	Preferred Minimum
Exposed sheet metal edges and flanges, latches, controls, hinges and other small hardware operated by the pressurized-gloved hand	0.15	0.06	--	--	Minimun required to prevent glove snagging
Small protrusions (less than approximately .48 cm. (3/16") on toggle switches, circuit breakers, connectors, latches and other manipulative devices	0.15	0.06	--	--	Absolute minimum unless protruding corner is greater than 120 degrees

NOTE: A 45 degree chamfer x .15 cm. (.06") (minimum) with smooth broken edges is also acceptable in place of a corner radius. The width of chamfer should be selected to approximately the radius corner described above.

TABLE 2.2-3: Edge, Corner and Protrusion Criteria (continued)

APPLICATION (Protrusions, Outside Corners)	CRITERIA/REMARKS
Screw heads, bolts, nuts, and nut plates, excess threads and rivets that can be contacted by crewman.	All screw and bolt heads shall face the outside of the experiment, if possible. Where nuts, nut plates and threads are exposed they shall be covered in a secure manner. Recessed heads or the use of recessed washers is recommended. Overall height of heads shall be within .32 cm. (.125") or covered unless over 7 head diameters apart from center to center. Height of round head or oval head screws is not limited. Screw or bolt heads over .64 cm. (.25") deep must be recessed or have a fairing over them. Rivet heads shall face out on all areas accessible to crewmen and shall protrude no more than .15 cm. (.06") unless spaced more than 3.5 head diameters from center to center. In all exposed areas where unset ends of rivets extend more than .31 cm. (.12"), or 1.27 cm. (.50") of unset and diameter if over .31 cm. (.12"), a fairing shall be installed over them. This applies to explosive, blind or pull rivets, etc. Unset ends of rivets must have edges chamfered 45 degrees or ground off to a minimum radius of .15 cm. (.06"). A maximum gap of .05 cm. (.02") will be allowed only between one side of a fastener head and its mating surface. Burrs must be prevented or eliminated. Use of Allen heads is preferred. Torque-set, slotted or Phillips head screws must be covered with tape or other protective materials or be individually deburred prior to flight.

TABLE 2.2-3: Edge, Corner and Protrusion Criteria (continued)

APPLICATION (Protrusions, Outside Corners)	CRITERIA/REMARKS
Latching Devices	All latching devices shall be covered in a manner that does not allow gaps or overhangs that can catch fabrics or pressure suit appendages, or shall be designed in a manner to preclude the catching of fabrics and pressure suit appendages. All surface and edges shall be smooth, rounded and free of burrs.
Lap joints in sheet metal and mismatching of adjacent surfaces	All surfaces shall be mated within .08 cm. (.03") of flat surface at edges, or shall be butted or recessed. All exposed edges must be smooth and radiused .15 cm. (.06") minimum (as above), chamfered 45 degrees, or shall be covered with an appropriate material to protect PGA gloves.
Sheet metal structure, box and cabinet three plane intersecting corners.	Spherical welded or formed radii are required unless corners are protected with covers.

TABLE 2.2-4: EVA Safety Considerations

SAFETY CONSIDERATIONS	REMARKS/COMMENTS
Illumination	EVA work areas and translation routes insufficiently illuminated
Moving Parts	Structural or mechanical rotating devices or linkages in motion during EVA
Stored Energy Devices	Structural or mechanical devices that could be inadvertently actuated through mechanical or electrical interfaces (deployment mechanisms, rotating elements, spring loaded devices, etc.)
Manipulators Remotely Operated	Remotely operated manipulator systems engaged in transporting the crewman or handling cargo/payloads in crewman-assist operations
Pyrotechnic Devices	Explosive devices that if actuated could cause injury to EVA crewmen (explosive release systems, bolts, etc.)
Radioactive Material	EVA in areas exposed to radioactive sources such as nuclear systems, areas of high radioactive material in space, etc.
Cargo Size/Mass	Handling cargo with size or mass properties that may impair control or visibility
Spacecraft Maneuvers	Extensive spacecraft maneuvers during extravehicular functions
Fluid Handling	Handling of fluids not compatible with EVA support systems and equipment

REFERENCES

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2.3 Study of Astronaut Restraints and Mobility Aids in a Weightless Shirtsleeve Environment, URS/Matrix, September 1972; PRL 339, NAS 9-12574, DRL No. T64, DRD No. TM-208T

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2.12 Performance and Design Requirements for Skylab Extravehicular Mobility Unit, Master End Item Specification, Manned Spacecraft Center, MSC-02806, October 6, 1971, Houston, Texas

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2.14 Performance/Design and Products Configuration Requirements, Extravehicular Mobility Unit for Lunar Module Crewman, Master End Item Specification, Manned Spacecraft Center, CSD-A-1059, August 30, 1971, Houston, Texas

2.15 Preliminary Design Requirements for Shuttle EVA/IVA Orbiter Support, Internal Note MSC-EC-R-71-10, Manned Spacecraft Center, September 30, 1971, Houston, Texas

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2.17 Application of EVA Guidelines and Design Criteria, Volume I, Final Report, URS/Matrix Company, April 1973, Houston, Texas

APPENDIX A

Appendix A is a direct reproduction of the introduction to ILC Industries, Inc., Document No. ILC-J-SS-003, dated May 22, 1974. The material is provided in this document for reader convenience. Notations in the reproduced material refers to the original document, not to this Design Guides Synopsis--EVA Equipment Report.

ILC INDUSTRIES, INC. / 350 PEAR STREET, DOVER, DELAWARE 19901 TELEPHONE (302) 674-4020

DOC NO ILC-J-SS-003

DATE May 22, 1974

DVT TEST REPORT

ORBITAL EXTRAVEHICULAR SPACESUIT (OES) MOBILITY EVALUATION

(4.0 PSIG BASELINE EVALUATION)

ILC INDUSTRIES:

Prepared By

Approved By

NASA:

5/22/74

NASA TECHNICAL MONITOR

ORBITAL EXTRAVEHICULAR SPACESUIT (OES) MOBILITY EVALUATION

INTRODUCTION

The development of the Orbital Extravehicular Spacesuit (OES), reference Figure 1, under contract NAS 9-13257 required that a Design Verification Test (DVT) Program be conducted at JSC to evaluate the End Item. The first of these tests was a mobility evaluation of the Phase B prototype OES to be conducted in accordance with the OES DVT Mobility Evaluation Test Plan No. ILC-J-SS-001.

PURPOSE

The purpose of this mobility study was to establish the mobility performance of the OES, to determine its limitations, and provide data for design evaluation. In addition, for those joints which had mobility requirements specified in the contract, an evaluation of performance vs. requirements was made.

SCOPE

This test was a one-G, sea level, single subject (per joint) evaluation of the OES elementary body movements. Specific range of movement limits were obtained for the OES PGA. In order for the data to be more useful and have relative significance, however, it was taken in a similar manner as had previously been accomplished for the A7LB and A7L model PGA's. The nude body mobility data was taken from previous mobility studies and consequently does not necessarily represent the nude body capabilities of the subjects used for this test and should only be considered as an approximation of the actual subject's range. Two test subjects were used for the mobility sequences when it was discovered that the first subject could not achieve the limits of the suit for certain movements.

TEST CONDITIONS

The mobility sequences were conducted with the Phase B prototype OES PGA without a coverlayer and without EMU life support equipment. A CWG was used as the undergarment. Suit operating pressure throughout the photography portion of the test was maintained at 4.0 psig. The two subjects for this test were Jack Mays (NASA) and Walt Salyer, Jr. (ILC), both experienced suit subjects and both right handed. All testing was conducted under NASA-JSC Technical Monitor surveillance.

REFERENCES

1. ILC-M-DVT-012R, A7LB DVT Test Report Mobility and Torque Test
2. ILC-ER-00-218, A7L/A7LB Mobility Analysis
3. ILC-J-SS-001, DVT Test Plan Orbital Extravehicular Spacesuit (OES) Mobility Evaluation
4. NASA Contract NAS 9-13257: Statement of Work, OES

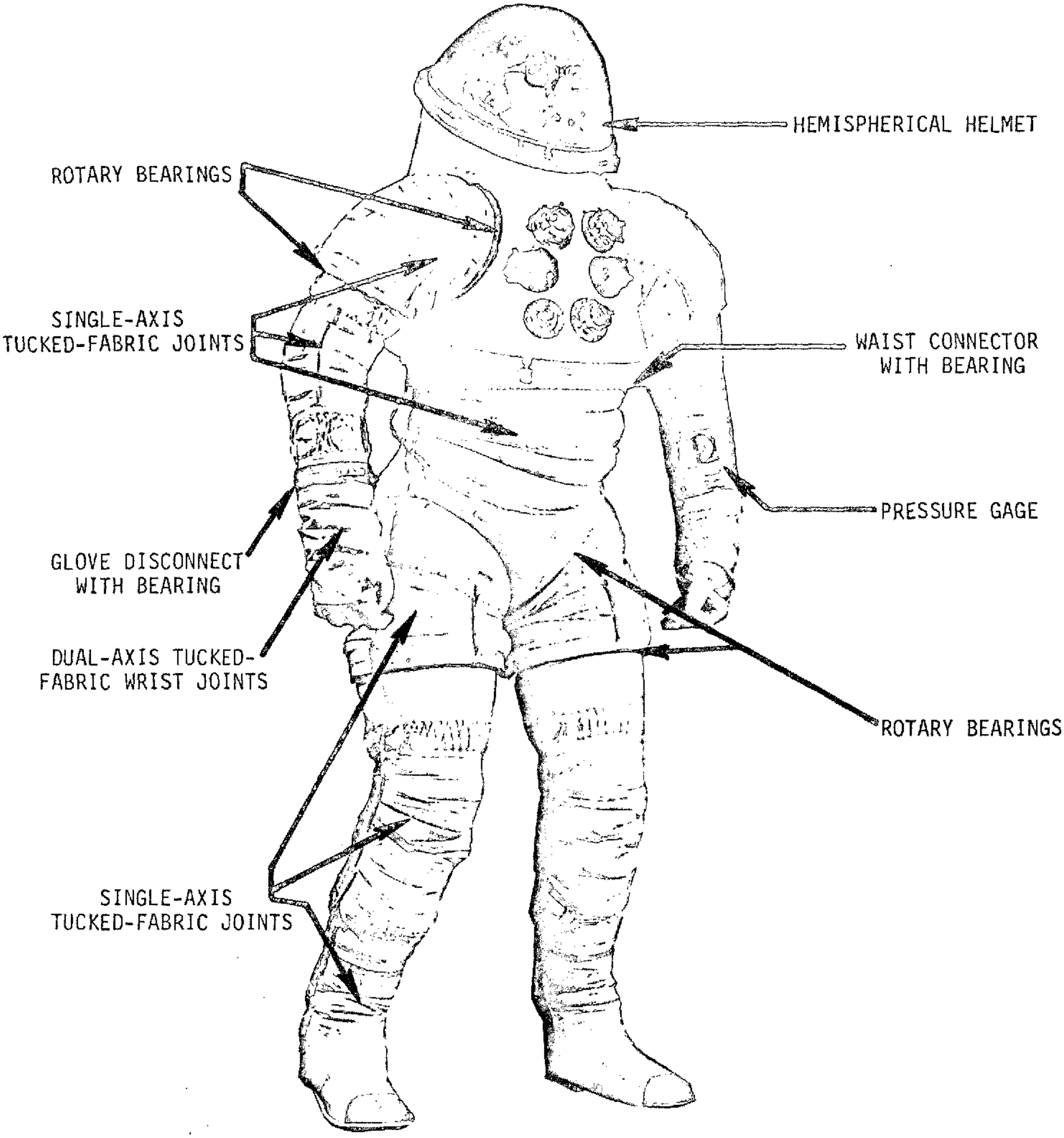
DISCUSSION

The photography portion of this study was conducted in the southwest corner of building 7 at JSC. The background consisted of an eight foot by eight foot grid divided into six inch squares. The background for the overhead photographs was an eight foot wide by six foot deep grid with six inch squares.

After the first series of photographs were taken with Jack Mays as the subject, a review of these photographs was conducted and a comparison made to known OES capabilities and A7LB suit capabilities. When obvious and significant differences occurred for which no explanation was apparent, or when the photographs did not adequately present the joint movement, the photographs were retaken with Walt Salyer as the suit subject. In some cases the measured movement increased and in some cases it remained approximately the same or decreased. This will be mentioned in the discussion of each particular movement.

When measuring the angular displacement of the joint in question, every effort was made to isolate that particular joint movement. In many instances, joint movement appears greater than that actually measured due to movement of the suit during the photography. In these cases, the action taken to reduce the error, if any, is explained in the discussion of the particular movement involved.

A discussion of each individual elementary body movement follows, with the photographs and angular displacement measurements provided with the discussion. It should be noted that the angular displacements depicted are slightly less than the maximum obtainable. This is due to a peaking effect which could not be photographed. The static displacements shown, however, should prove more useful in evaluating the suits mobility since they are more repeatable and more accurately depict the normal range of movement. All references to "the contract" refer to item 4 of the references. Nude body capabilities refer to those reported in item 1 of the references and are contained in Table 1 of this test report.



ORBITAL EXTRAVEHICULAR SPACESUIT

FIGURE 1

TABLE 1

MOVEMENT NO.	NOMENCLATURE	SPECIFICATION A7L	SPECIFICATION A7LB	OES DESIGN REQUIREMENT	MEASURED A7L	MEASURED A7LB	MEASURED OES	NUDE BODY
A.1	Neck Flexion - Forward/Backward	120	135	N/S	23	46	49	117
A.2	Neck Flexion - Left/Right	30	30	N/S	19	53	42	82
A.3	Neck Rotation	140	140	N/S	122	165	103	163
B.1	Shoulder Adduction	35	60	165 (B.1–B.2)	-6	-8	47	42
B.2	Shoulder Abduction	125	95		90	90	104	118
B.3	Shoulder Movement (Lateral-medial)	145	155	150	131	142	177	180
B.4	Shoulder Flexion	170	150	180 (B.4–B.5)	146	170	165	185
B.5	Shoulder Extension	47	35		12	18	29	47
B.6	Shoulder Rotation X-Z Plane	135	140	-	-	-	-	-
B.7	Shoulder Rotation Y-Z Plane (Lateral)	35	35	130 (B.7–B.8)	31	61	31	31
B.8	Shoulder Rotation Y-Z Plane Medial	95	100		131	126	163	117
C.1	Elbow Flexion - Extension	137	115	150	132	129	129	155
D.1	Forearm Supination, Palms Up	90	145	180 (D.1–D.2)	97	-	87	-
D.2	Forearm Pronation	75	25		159	-	95	-
E.1	Wrist Extension, Forward	56	56	N/S	62	55	86	38
E.2	Wrist Flexion, Backward	57	57	N/S	33	37		38
E.3	Wrist Adduction	42	42	N/S	70	79	40	69
E.4	Wrist Abduction	30	30	N/S	32	49	56	50
F.1	Truck Rotation, Left-right	5	5	N/S	45	49	157	126

TABLE 1

MOVEMENT NO.	NOMENCLATURE	SPECIFICATION		OES DESIGN REQUIREMENT	MEASURED			NUDE BODY
		A7L	A7LB		A7L	A7LB	OES	
F.2	Torso Flexion, Left-right	5	35	30	19	60	31	72
F.3	Torso Flexion Forward	90	130	45	72	112	119	118
F.4	Torso Extension Backward	5	25	N/S	19	24	-	20
G.1	Hip Abduction	45	20	60	22	26	85	61
G.2	Hip Adduction, Hip Bent	30	5	N/S	-14	- 3	8	23
G.3	Hip Abduction, Hip Bent	35	15	N/S	22	13	38	49
G.4	Hip Rotation, Lateral, Sitting	30	30	N/S	17	28	24	37
G.5	Hip Rotation, Medial, Medial, Sitting	30	30	N/S	25	22	56	31
G.6	Hip Flexion	115	90	140	53	71	94	119
G.7	Hip Extension	20	20	N/S	-21	0	-	20
H.1	Knee Flexion	110	110	110	118	111	126	124
H.2	Knee Rotation, Medial	15	15	N/S	17	-	34	45
H.3	Knee Rotation, Lateral	15	15	N/S	8	-	34	45
H.4	Knee Flexion, Kneeling	140	140	170	146	151	152	162
J.1	Ankle Extension	40	45	45	38	-	42	63
J.2	Ankle Flexion	35	45	45	48	-	61	31
J.3	Ankle Abduction	25	25	N/S	-	-	11	22
J.4	Ankle Adduction	25	25	N/S	-	-	19	18