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August 1974

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MSFC SKYLAB NEUTRAL BUOYANCY SIMULATOR

Skylab Program Office

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MSFC - Form 3190 (Rev June 1971)

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Presented in this report is the role of the Neutral Buoyancy Simulator in the development, crew training, and flight operational aspects of Skylab.

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PREFACE

The value of man in space has never been more graphically demonstrated than during the successful Skylab missions. This report documents the important role played by the MSFC Neutral Buoyancy Simulator Facility in development of the EVA systems and in preparing America's astronauts for operations in the weightless environment of space.

The Neutral Buoyancy Simulator (NBS) provides a simulated zero-gravity environment in which astronauts and engineers can perform, for extended periods of time, the various phases of spacecraft operations in order to gain first-hand knowledge of hardware and total system operational characteristics. The simulator assists program organizations in arriving at concept selection, hardware development, design verification, procedure development, and crew training.

Prior to the Skylab I launch, equipment evaluation and normal EVA training were the major functions of the NBS. When Skylab I lost its meteoroid shield and appeared to be unsalvageable, the NBS was used extensively to evaluate potential flight fixes via Extra-Vehicular Activity (EVA) and to provide management with the information necessary to make go/no-go decisions. The contingency procedures thus developed resulted in a successful fix which permitted Skylab to exceed the originally planned mission. This demonstrated EVA training capability indicates the manner in which NBS can serve an important function in future manned space programs and lays the ground work for expanded EVA mission planning on

future programs.

The words "slick", "easy", "just like the tank only deeper", were used often by the astronauts during Skylab EVA's to describe the in-flight tasks performed. These comments in large measure were due to realistic end-to-end EVA training in the NBS. To thoroughly understand the NBS approach to the many complexities of astronaut training in a weightlessness environment, one must first know the facility and its systems. The NBS facility and uses are outlined; trainer design, material selection, corrosion and maintenance problems are explained. Astronaut training and flight procedure development for the Skylab Program are included.

Users of this report will gain descriptive knowledge of the Skylab underwater simulators, particularly the hardware design, problem resolution and knowledge gained. This report will also further the user's understanding of the capability and flexibility inherent in underwater simulation which will minimize the necessity to develop new methods, material selection, and facilities required to support future manned space efforts.

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1.0 FACILITY AND OPERATION

The Neutral Buoyancy Simulator (NBS), at the Marshall Space Flight Center, is unique within the NASA complex because of its size and available support systems. A large water tank, located in Bldg. 4706, is the nucleus of the simulator (Figure 1-1). Integrated into this tank are special systems for underwater audio and video, pressure suit environment control, SCUBA support, and emergency rescue and treatment. Additional systems include data acquisition and recording, underwater lighting, special underwater pneumatic and electrically powered motors, valves, controls, and indicators that are required for high fidelity and functional engineering mock-ups and trainers. Each facility is described in the following sub-sections. Figure 1-2 is a map of the NBS facility.

1.1 Water Tank

The various engineering mock-ups and trainers required for underwater Neutral Buoyancy evaluations and training are installed in a welded steel, polyester resin coated tank. The 1.32 million gallon tank of 22.8m (75ft.) diameter and 12.2m (40ft.) depth, is large enough to accommodate full scale trainers for the required elements of the Skylab orbital assembly. A 1500 gal/min diatomaceous earth filtration system and automatic chlorination unit is used to keep the water clean for the good visibility that is a prime necessity for realistic underwater evaluations and training. Steam heat exchangers control the water temperature to a comfortable 86°F, allowing long term shirt sleeve SCUBA work. Access to the tank is provided by an elevator and stairways to external

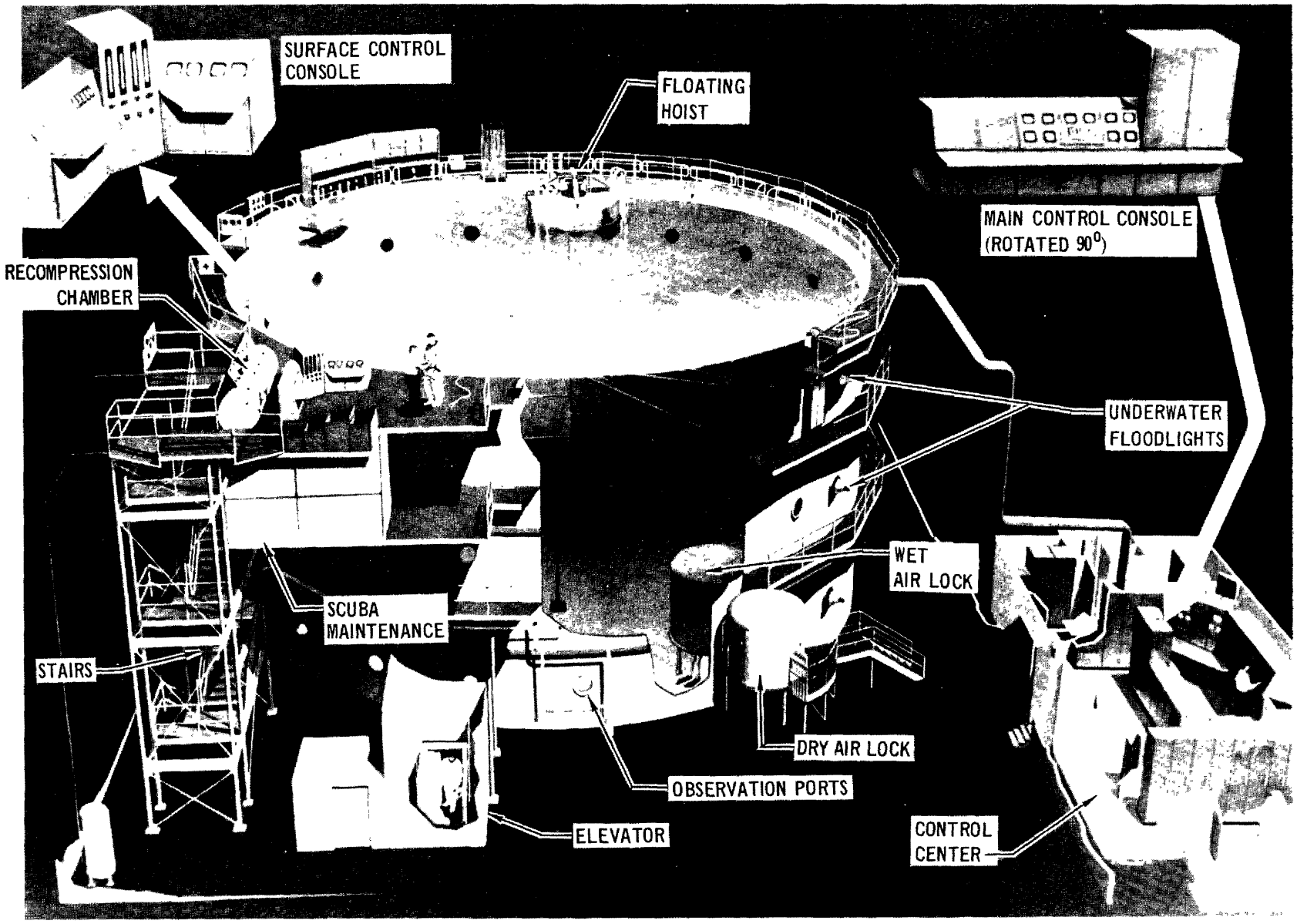


FIGURE 1-1 NEUTRAL BUOYANCY SIMULATOR

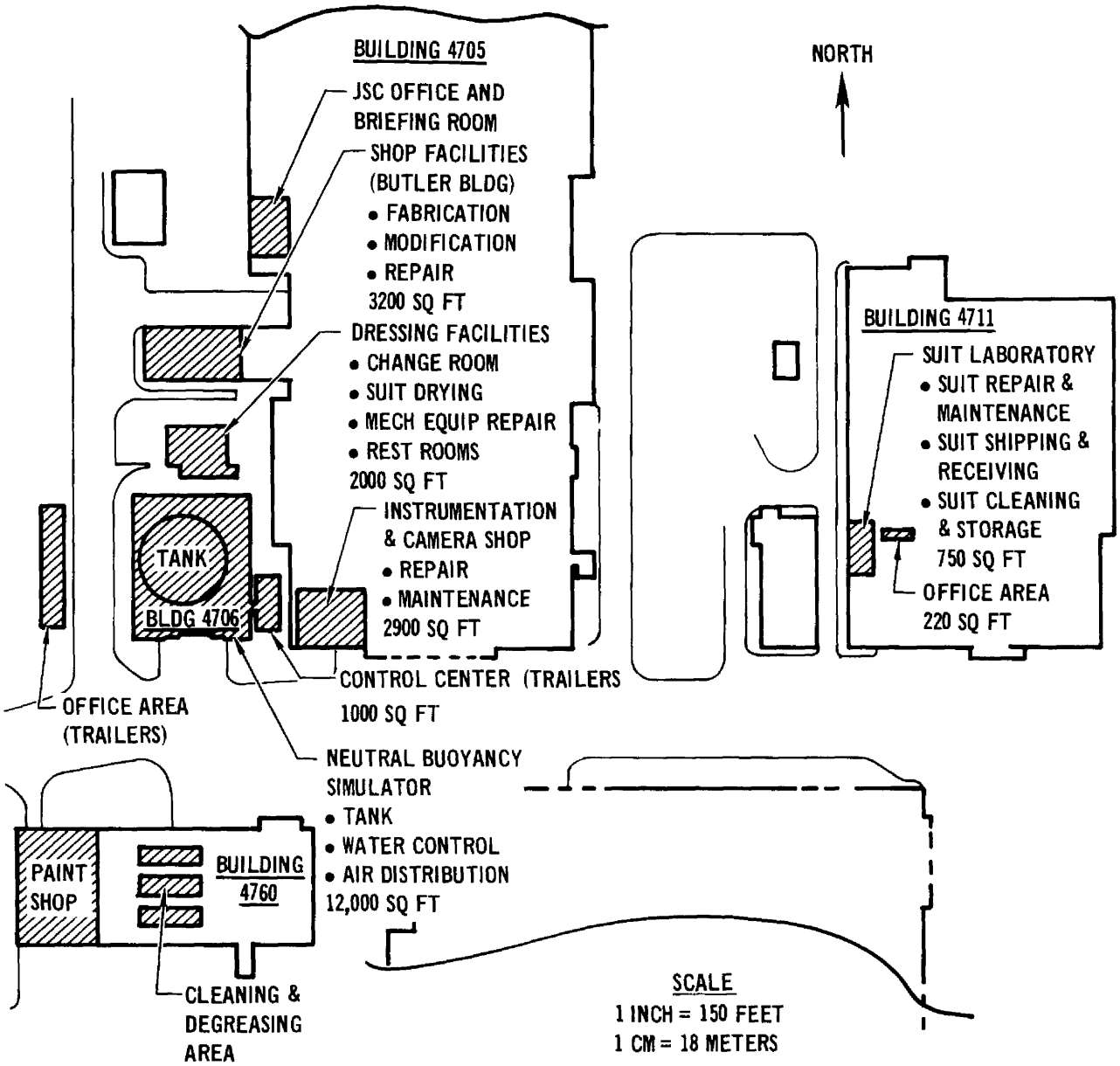


FIGURE 1-2 MSFC NEUTRAL BUOYANCY FACILITIES

platforms around the tank periphery at three levels. The top level is used for diving and equipment support. The second level contains a SCUBA maintenance and stowage crib and is used along with the first level for observation through port holes in the tank wall. Observation port holes are also located around the tank at ground level. Each level contains flood lights mounted at every other observation port to illuminate the tank interior for night simulations.

Since the tank water surface is 12.2m (40 feet) above ground level, moving trainers, mock-ups, and associated hardware into and out of the tank requires special handling techniques. Small equipment that can be carried by one or two men is normally lifted to the tank surface by the tank elevator, then placed in the water and handled by SCUBA divers. Larger equipment is transported to the tank area by fork lift and lifted to the water surface by a 2000 lb pneumatic overhead monorail hoist. Equipment size is limited to 3.7m (12 ft.) vertical clearance due to the low building height above the 12.2m (40-foot) high water tank. The hoist is controlled at tank top-side and once the equipment is hoisted from the ground level to clear the top of the tank, the top tank platform rails are swung open to allow translation along the hoist monorail to the center of the tank. Subsequently, the equipment is lowered to the tank bottom with the assistance of SCUBA divers and transferred to a 2000 lb pneumatic water surface floating hoist. The equipment is then maneuvered to the desired location in the tank by SCUBA divers. Because of the building height restriction, the Skylab trainers could not be lifted

intact and placed in the tank. They were hoisted up in sections and assembled inside the tank by SCUBA divers.

1.2 Air Distribution System

An air distribution system supplies redundant breathing air for all pressure suit operations and pressurization of the Airlock system (Figure 1-3). Missile grade air from the MSFC compressor facility is filtered and monitored for carbon monoxide and oxygen content before it goes into the air distribution system. The system is capable of supporting 4 pressure suits at 6 CFM each, plus 4 HOOKAH's or 4 Kirby-Morgan helmets via connections at the system distribution panel. Air flow for pressure suit operation is monitored and controlled at the air console. An emergency back up air supply is provided from a high pressure tube trailer located near the tank building. In addition, the tube trailer supplies breathing air to the SCUBA refill station and pressurizes the water deluge fire extinguishing system for the recompression chamber. All components of the system are checked daily and air samples are analyzed twice a week.

1.3 Instrumentation System

In order to collect and assimilate data from neutral buoyancy evaluations and training exercises, an instrumentation system, coupled with a network of test monitors and controls, is provided in and around the water tank and at the test control trailer adjacent to the tank (Figures 1-4, 1-5, and 1-6). As many as 200 separate data channels can be handled including

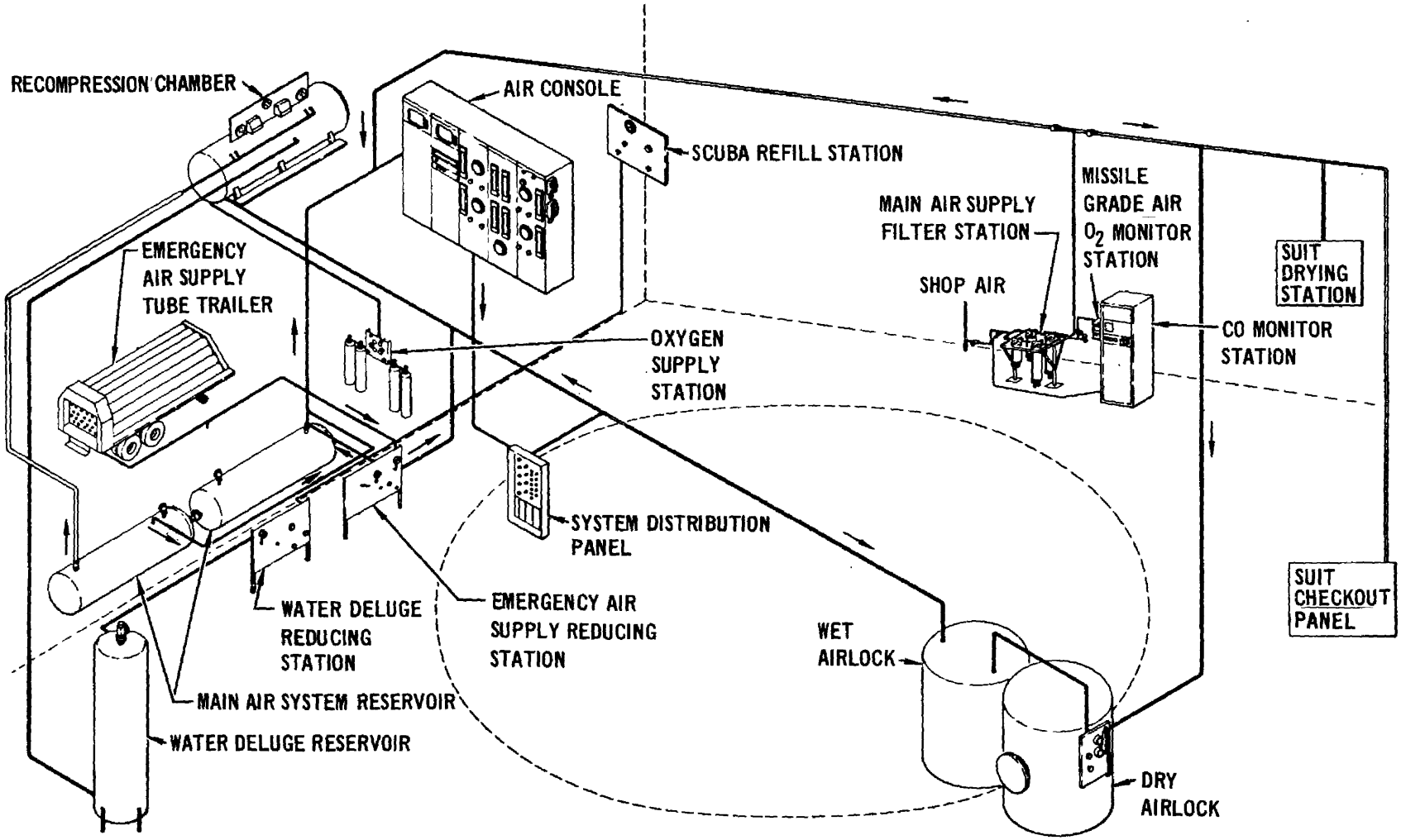
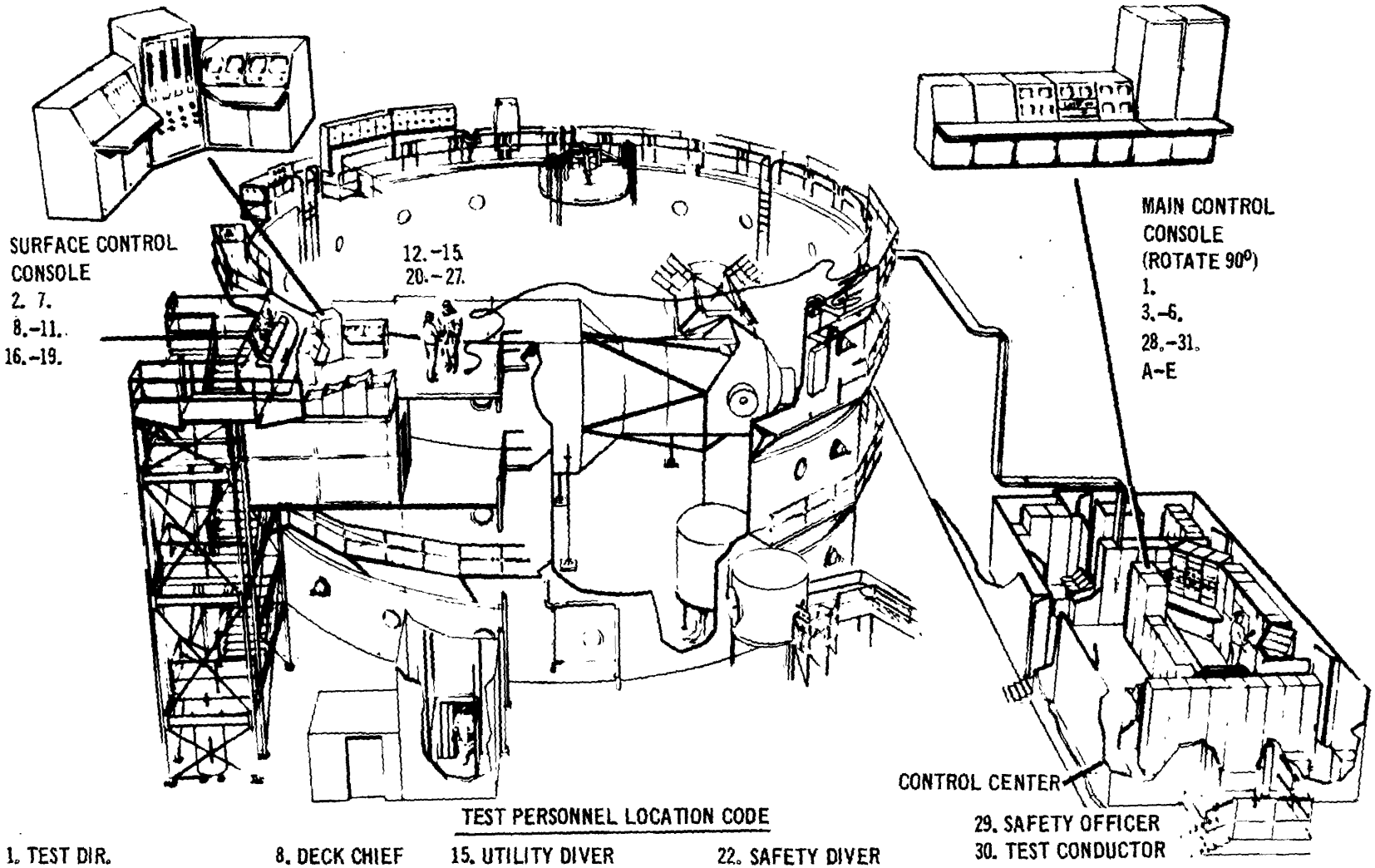


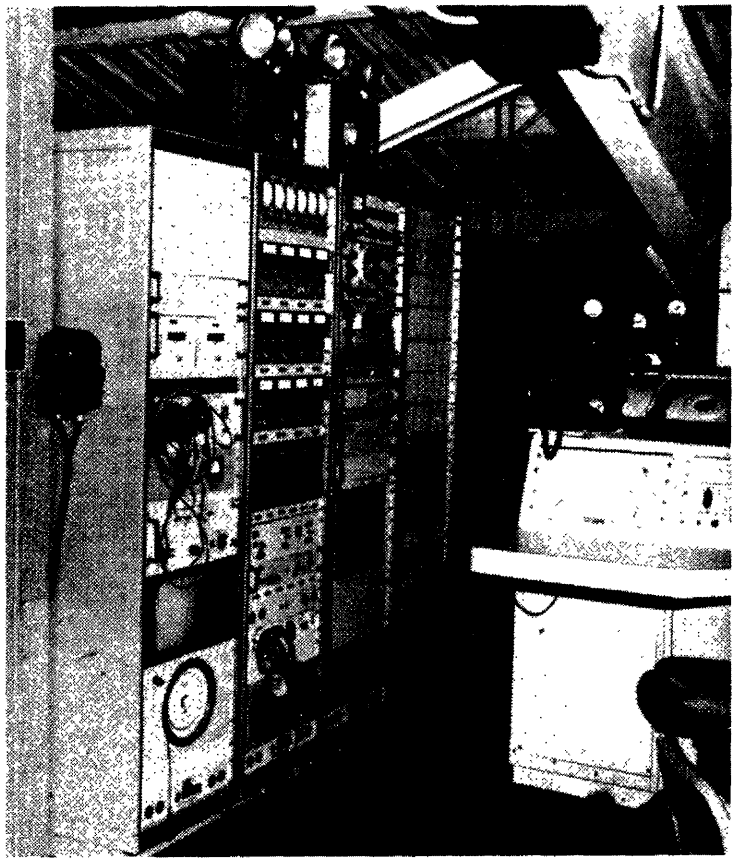
FIGURE 1-3 NBS AIR DISTRIBUTION SYSTEM



TEST PERSONNEL LOCATION CODE

1. TEST DIR.
2. SYSTEMS ENG.
3. INSTRUMENTATION ENGR.
4. INSTRUMENTATION TECH.
5. INSTRUMENTATION TECH.
6. INSTRUMENTATION TECH.
7. INSTRUMENTATION TECH.
8. DECK CHIEF
9. SUIT TECH.
10. SUIT TECH.
11. SUIT TECH.
12. WATER SAFETY
13. WATER SAFETY
14. UTILITY DIVER
15. UTILITY DIVER
16. TIMEKEEPER/RECORDER
17. CHAMBER ENGINEER
18. LOCK ENGR/CREW CHIEF
19. INSIDE ATTENDANT
20. TEST SUBJECT EV1
21. SAFETY DIVER
22. SAFETY DIVER
23. TEST SUBJECT EV 2
24. SAFETY DIVER
25. SAFETY DIVER
26. U.W. VIDEO CAMERAMAN
27. U.W. PHOTO CAMERAMAN
28. MEDICAL OFFICER
29. SAFETY OFFICER
30. TEST CONDUCTOR
31. TEST OBSERVER
A. TEST MANAGER
B. TEST CONDUCTOR
C. CSD REPRESENTATIVE
D. MEDICAL OPERATIONS
E. TEST OBSERVER

FIGURE 1-4 INSTRUMENTATION AND TEST PERSONNEL LOCATIONS



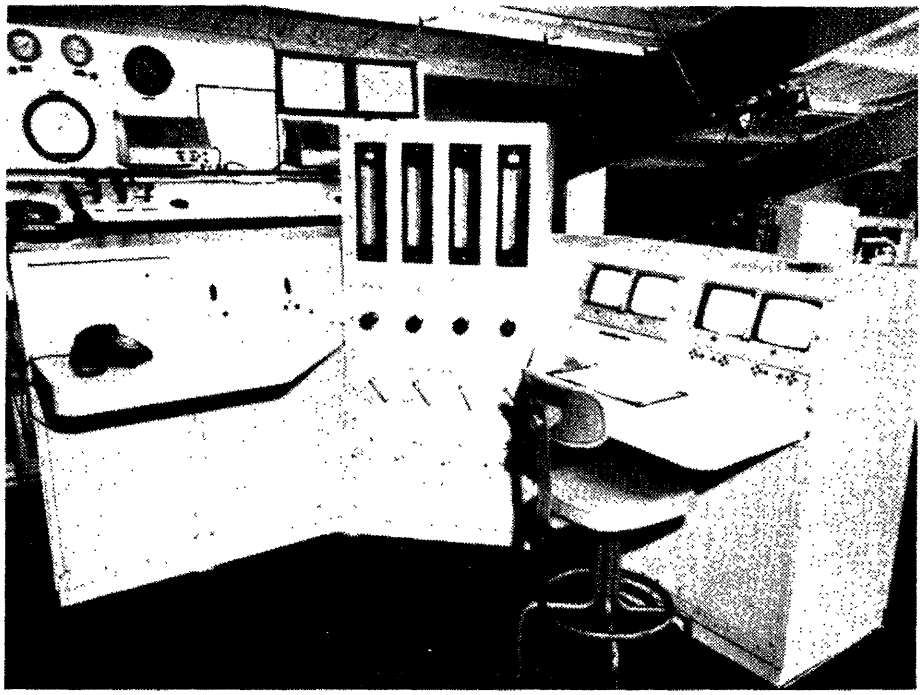


FIGURE 1-5 SURFACE CONTROL CONSOLES

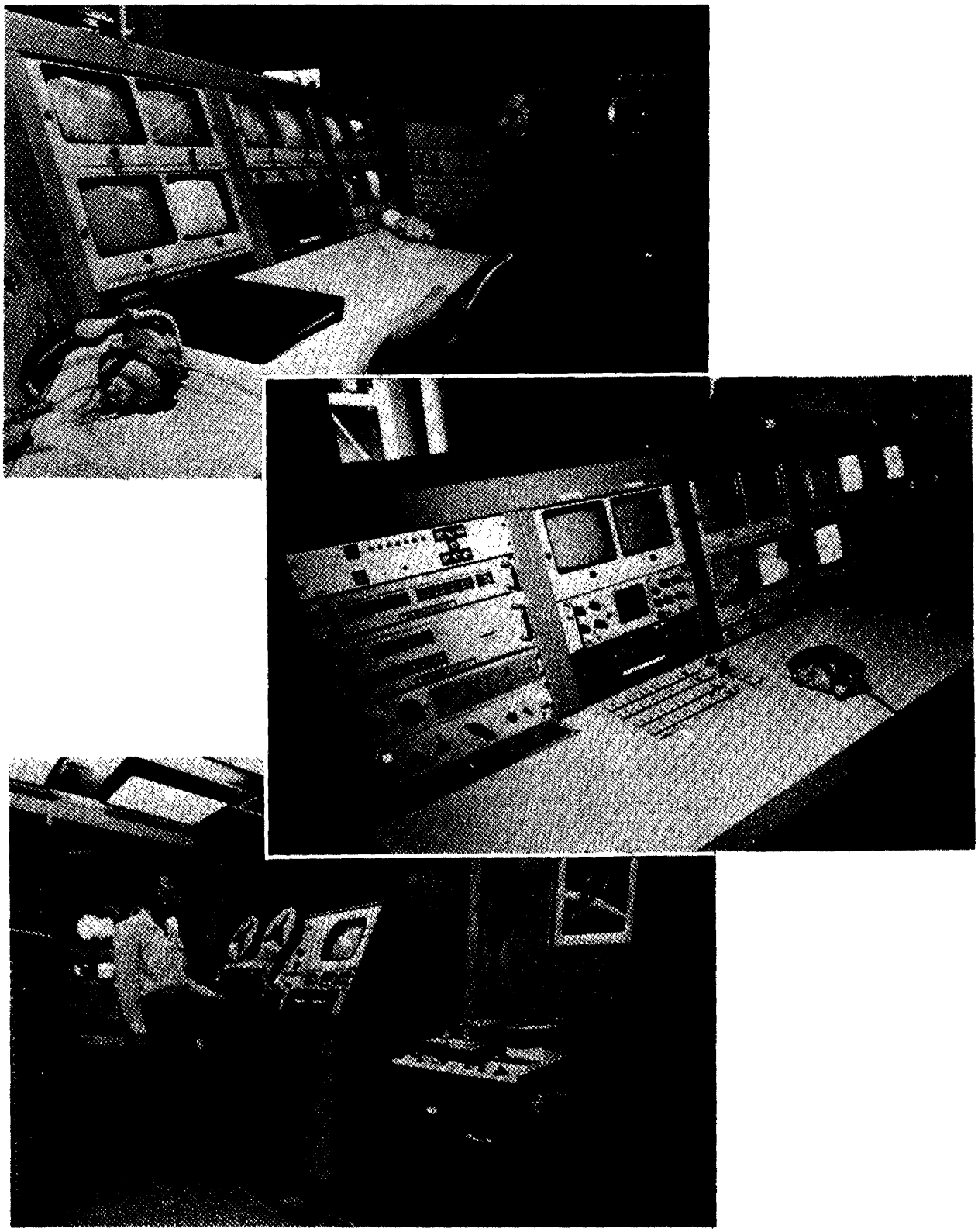


FIGURE 1-6 MAIN CONTROL CONSOLE AND VIDEO TAPE RECORDER

video, audio, EKG, heart rate, LCG flow, LCG inlet temp, LCG outlet temp, air flow to suit, inlet air temp, outlet air temp, respiration rate, differential suit pressure, depth pressure, absolute suit pressure, etc. The signal conditioning equipment, meters, and pressure suit junction panels are located at the tank with the instrumentation monitoring and recording equipment located in the test control center. Inside the water tank during an NBS exercise, there are nine remotely controlled TV cameras, a mobile underwater color video swim cameraman, an underwater photographer, and an underwater speaker system. A remotely controlled video camera is located on top of the tank along with test consoles containing video monitors. The video system has black and white or color recording and playback capability.

For the Skylab Program, an additional fixed TV camera was positioned inside the STS mockup to view the ATM out one of the STS windows. This gave the test conductor the same field of view on his video monitor in the control center as the third crewman had from the STS window during flight.

The top side surface control console supports crew safety during all training exercises, and during design development and hardware evaluation runs. The test control trailer is the nerve center for all suited training exercises. It provides 1000 sq. feet for test consoles, video monitors and controls for the video, communication, and instrumentation systems. The communication system includes a PA system for the entire simulator complex. Two-way communications are provided for suited and

Kirby-Morgan subjects via umbilical. All recorded data is kept on file through the duration of the program.

1.4 Dressing and Suiting Facilities

Dressing facilities to support pressure suit and SCUBA operations for neutral buoyancy test and training exercises are provided in an annex adjacent to the NBS (Figure 1-2). This area contains the suit drying equipment and storage for pressure suits and life support gear. In addition, a suit system laboratory is maintained in Bldg. 4711 for the maintenance and preparation of pressure garment assemblies and their associated life support systems. This laboratory contains pressure consoles for performing structural and leakage tests, work tables for maintenance and repair, equipment for preparation of garments for shipping, a receiving area, cleaning and laundry facilities, and a storage area for pressure suits and their associated components. This area is also used for donning and doffing suits during suit-fitting activities. Special suit support items to make the suited subjects neutrally buoyant are fabricated, assembled, and maintained in this laboratory.

1.5 SCUBA Support Facilities

Facilities to support SCUBA operations (SCUBA tanks, wet suits, fins, cylinder refill station, etc.) are located on top-side of the tank (Figure 1-7). The SCUBA refill station consists of a panel containing supply, delivery, and SCUBA cylinder pressure gauges with delivery and vent valves (Figure 1-8). The high pressure air (2,250 psi max) is

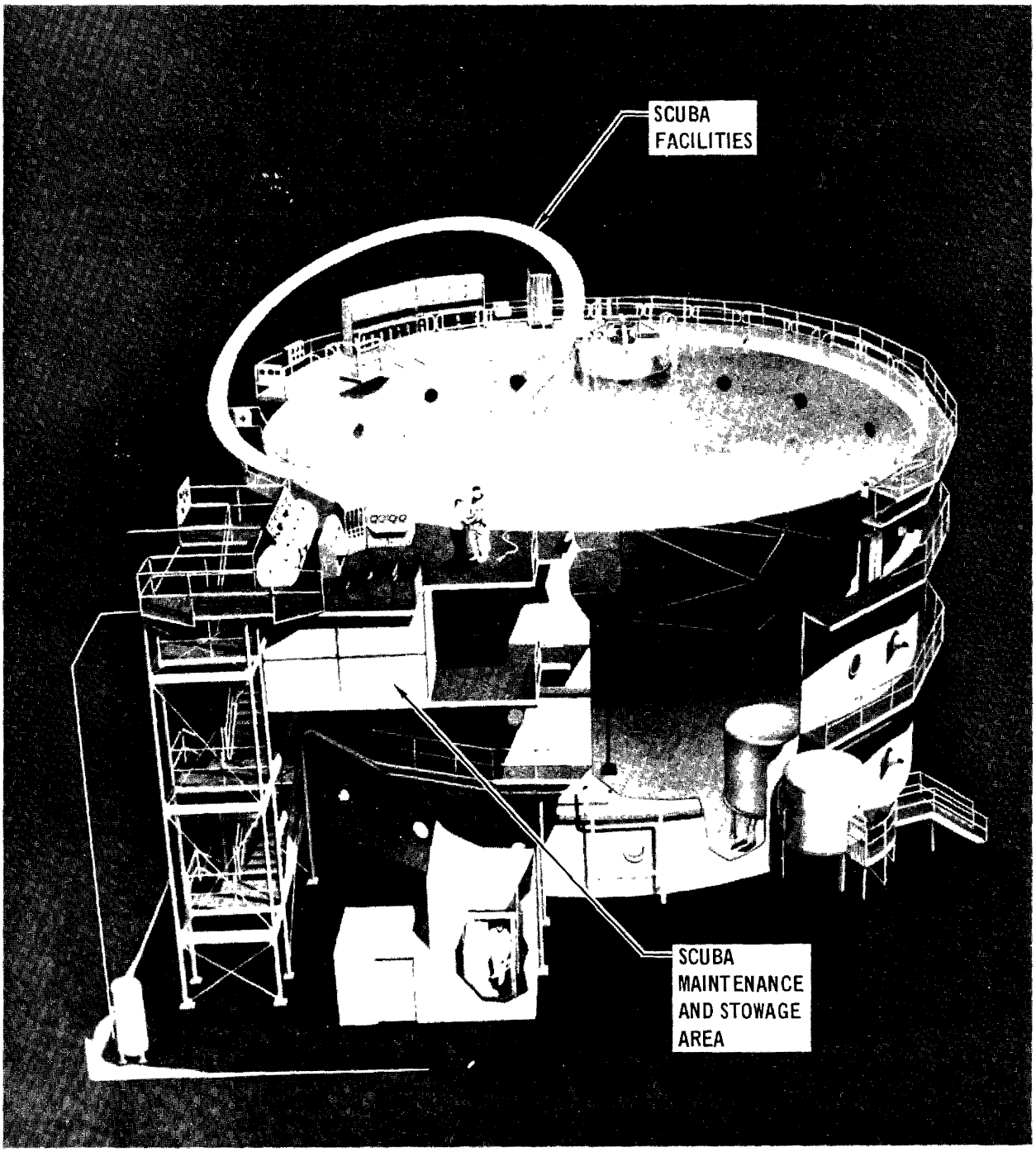


FIGURE 1-7 NBS SCUBA SUPPORT FACILITIES

FIGURE 1-8 SCUBA REFILL STATION

supplied from the emergency air supply tube trailer. A flow diagram on the panel aids the user in refill operations. Refill operating procedures are also printed along side the refill panel. The SCUBA cylinders are submerged in a water container during refills as a safety measure. The water serves as a heat sink during pressurization and provides a protective barrier in case the SCUBA cylinder ruptures.

1.6 Shop Facilities

Shop facilities are provided near the water tank to support trainer/mock-up installations, modifications, and NBS associated equipment repairs (Figure 1-2). The Butler Building (#4705) is equipped with a lathe, grinder, band saw, table sander, sewing machine, work benches, and fastener crib. During the Skylab program, it was mainly used as the repair and modification area for the Airlock trainer and pneumatic operated extendible booms. The machine shop in Building 4705 is equipped to handle any NBS job and was used during Skylab for new hardware development. A paint shop, including a cleaning and degreasing facility, is located in an adjacent building (#4760).

On tank top level, two work benches stocked with assorted nuts and bolts are used to make minor on-the-spot repairs. The second tank level contains a closed off area equipped with work bench and tools for SCUBA gear repair. It also serves as a secure area for stowage of SCUBA regulators, diving masks, snorkels, fins, and wet suits.

1.7 Briefing Facilities

Briefings and debriefings were held in the JSC office and briefing room (Figure 1-2) for each Neutral Buoyancy evaluation or training exercise. To assist in obtaining and documenting information learned from each briefing, the facility was equipped with telephones, black boards, scale models, still pictures, movie and slide projectors, audio recording, and video monitors with video playback of test runs. Conference telephone hookup to the Johnson Space Center was also available.

1.8 Neutral Buoyancy Operations

To simulate zero-G in the NBS, the test subjects and equipment to be handled are made neutrally buoyant or neutralized. This requires that the test subject and equipment be the same weight as the displaced water so that they are in a neutral state, neither rising or sinking. For Skylab EVA evaluations, the crew subject donned a flight pressure suit with a training Pressure Control Unit (PCU) and a mock-up Supplemental Oxygen Pack (SOP). After the suit had been pressurized, weight pouches were fastened around the upper torso, the forearms and legs. Lead weights were then placed in the pouch pockets by the safety divers as required to make the subject neutrally buoyant (Figure 1-9 and 1-10). The training PCU (fabricated by MSFC) was the same envelope and configuration as the flight PCU with a special regulator replacing the flight regulators for underwater operations. This regulator sensed changes in depth maintaining suit pressure at 3.6 psid, the same as in flight, to give similar suit mobility. Since the PCU was located at mid-waist,

FIGURE 1-9 SAFETY DIVER ATTACHING WEIGHT POUCHES TO SUITED CREWMAN

FIGURE 1–10 NEUTRALIZING SUITED CREWMAN USING LEAD WEIGHTS

changes in depth were compensated by the PCU regulator with only minor changes to the crewman's buoyancy and center of gravity.

Quite often it was beneficial to perform a preliminary suited exercise evaluation using the Kirby-Morgan head piece. The Kirby-Morgan helmet seals around the face and is equipped with viewing glass, breathing regulator, and a single umbilical that provides breathing air and communications (Figure 1-11). Neutral buoyancy is achieved by a weighted belt. EVA gloves and boots could be worn to make the preliminary evaluation more realistic in terms of what could or could not be accomplished in an EVA task situation. Using the Kirby-Morgan helmet provided the capability to perform a quick cursory review of hardware orientation and EVA tasks with a minimum impact on NBS systems and personnel. In addition, use of the Kirby-Morgan was more effective than use of SCUBA diving equipment because of the two-way communication capability and absence of bulky air cylinders.

To make equipment neutrally buoyant, flotation units are installed inside the hardware and located so the equipment retains its original center of gravity (CG) (Figure 1-12). Additionally, flotation units must be strategically located so they will not interfere with equipment mechanism operation or disturb the equipment envelope. Also, the flotation units must not change due to changes in water pressure, or the neutral buoyancy will be lost. Location and volume of the floatation units are calculated and temporarily installed so the unit can be "trimmed out" underwater by SCUBA divers. CPR-200-8 styrofoam with

FIGURE 1-11 PRELIMINARY EVALUATION EXERCISE USING KIRBY-MORGAN HELMET

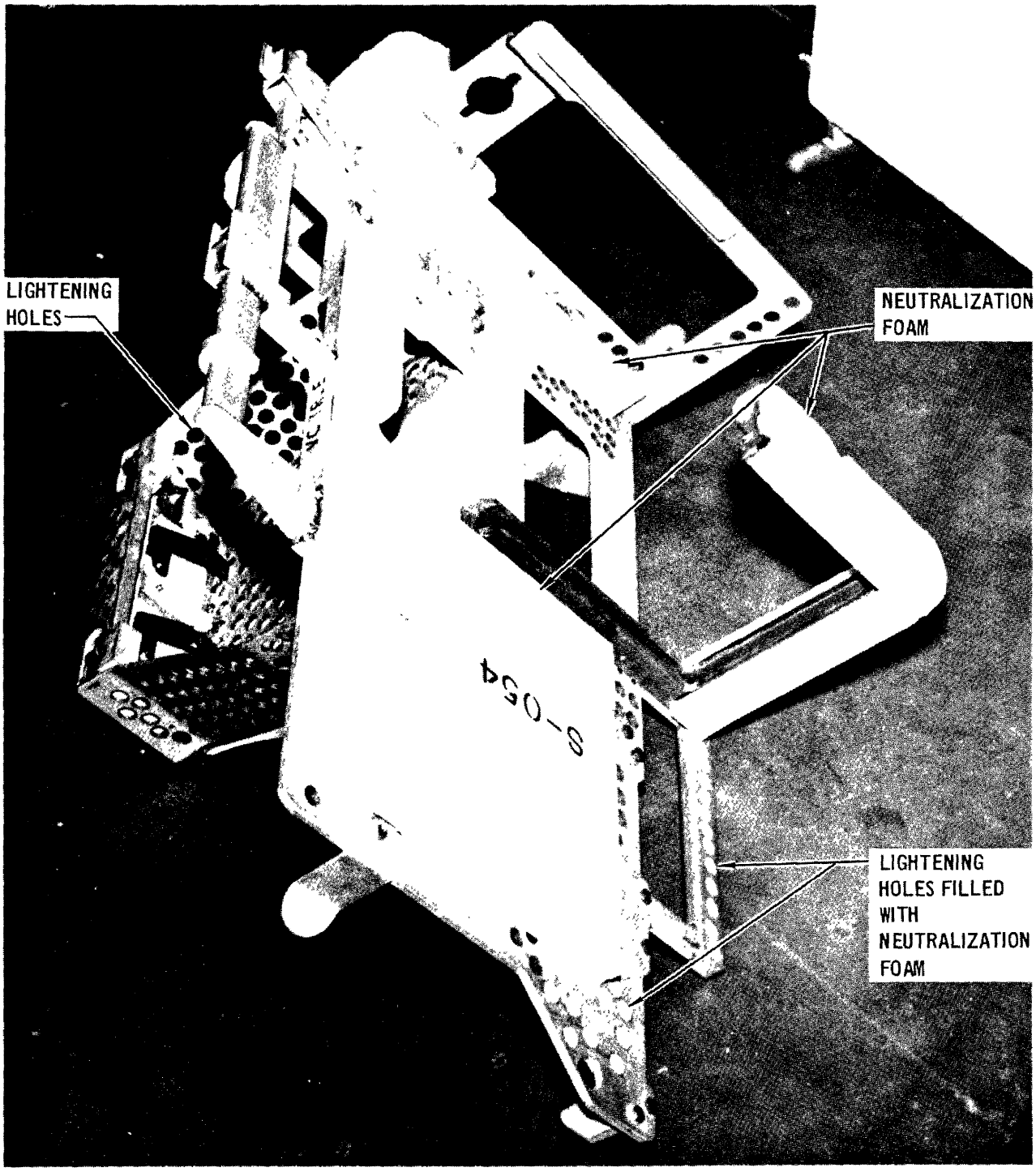


FIGURE 1-12 NEUTRALIZED VC ATM FILM TREE

6-8 lb/cu ft density was found to be the best material for flotation units. It was easily shaped to obtain the desired volume for neutral buoyancy and was easy to install. After shaping, and prior to final installation, it was coated with epoxy resin (Crest 3135) to prevent water absorption.

1.9 Test Procedure

A scheduling system was incorporated to assure the coordination required between all the NASA disciplines and associated contractor personnel to successfully conduct a test or training exercise. For example, a Skylab EVA training exercise started with a JSC initiated trainer utilization request form. This form notified MSFC of the date and type of training exercise, mock-up/training hardware to be used, and names of the participating crew members and JSC support personnel. A detailed test plan outline was then prepared at MSFC and approved by MSFC safety and medical personnel. Prior to the scheduled test, the various neutral buoyancy facilities were readied for operational status. This was accomplished by completion of written check lists of; training hardware, simulator instrumentation system, simulator safety equipment, and pressure suits. These signed check lists were given to the test director prior to initiation of testing. The test director had total responsibility for the NBS exercise. In the event of threatening weather, the MSFC weather office was requested to notify the NBS so that appropriate safety precautions could be taken. An access list was provided to the building Security Guard showing the names of all test personnel and observers. After a briefing with the test personnel, the astronauts were suited and brought

to tank top side. The test director then made a final check to assure that all stations and personnel, including deck chief, systems engineer, instrumentation engineer, test conductor, and suit technician were in a ready condition. After a suit verification check was made, the suit was pressurized. Then a visual suit inspection was performed and the astronaut subject was given approval to enter the water for an underwater suit inspection and neutralization. The deck chief communicated with the safety divers and reported to the test director when the underwater suit check and neutralization was complete. The test director then gave the OK to proceed to the training location and directed the divers to the trainer. After both crewmen were positioned in the trainer, the test conductor in the test control center commenced the test sequence with the reading of EVA procedures. The test conductor acted as the third crewman in this phase and was not responsible for NBS operations. By using a multi-channel communication system, the test director could manage all test operations and at the same time monitor the test conductor's conversations with the test subjects. If, at any time during the training exercise, a problem occurred which involved the support divers or crew safety, the test director would immediately take over and conduct safety operations. At the end of the training exercise, the crewmen were brought to the surface and returned to the suit room and later debriefed. The recompression chamber crew remained on station until all divers were out of the water and the facility was secured.

1.10 Safety

Special safety equipment and training is incorporated into the neutral buoyancy facility to assure successful operations while working in the inherently dangerous water environment at 6.1m - 12.2m (20 to 40 foot) depths. Some of the safety equipment and preventive safety measures are unique within the neutral buoyancy simulator and are explained in the following sub-sections.

1.10.1 Safety Divers

All the divers and test subjects are SCUBA trained by MSFC or by a comparable nationally approved diving school. First aid training is given by MSFC Training Branch with assistance by the NASA medical center; this training is concentrated on medical problems peculiar to neutral buoyancy test operations. During all pressure suited exercises, two SCUBA safety divers accompany each test subject and are responsible for the subject's well being. The safety divers are well trained in pressure suit operations and underwater suit physics. They are knowledgeable in emergencies that require immediate action, i.e., what to do in cases of suit pressure loss or suit over pressure, suit flooding or subject illness, etc. In addition to the safety divers, a two man SCUBA equipped water team swims on the surface using snorkels and maintains surveillance of all tank divers (utility divers, underwater photographer, video swim cameraman, and underwater test observers). They are also qualified safety divers and are ready to assist the pressure suited subjects in an emergency and, if necessary, can replace any diver in the tank if that

diver needs to return to the surface.

1.10.2 Recompression Chamber

A recompression chamber (Figure 1-13), used for treatment of air embolism or the bends, is located on the operations deck. These two serious illnesses associated with diving can only be treated by quick recompression and controlled decompression. The recompression chamber consists of two compartments referred to as a chamber and a lock. The lock provides the capability of moving personnel and/or supplies from outside ambient pressure to depth pressure in the chamber without depressurizing while the patient is undergoing treatment. Both compartments have viewing portholes for observation by the chamber crew. The chamber is manned for all neutral buoyant tests by a chamber engineer, lock operator, inside attendant, and timekeeper-recording engineer. They are trained and certified under the Air Force training program conducted at JSC. The timekeeper-recorder is in charge of the overall recompression chamber operation. He provides the chamber dive profile to the chamber engineer and keeps track of all chamber times. The chamber engineer is the operator of the recompression chamber, controlling the chamber pressurization as directed by the timekeeper-recorder and maintaining communication with inside crew members. The lock operator is responsible for operating the lock section of the recompression chamber. He also notifies the NASA medical center of the accident via the "hot line". As a matter of precaution, the lock is pressurized down to a level slightly less than the chamber so the lock can be used immediately if trouble should develop

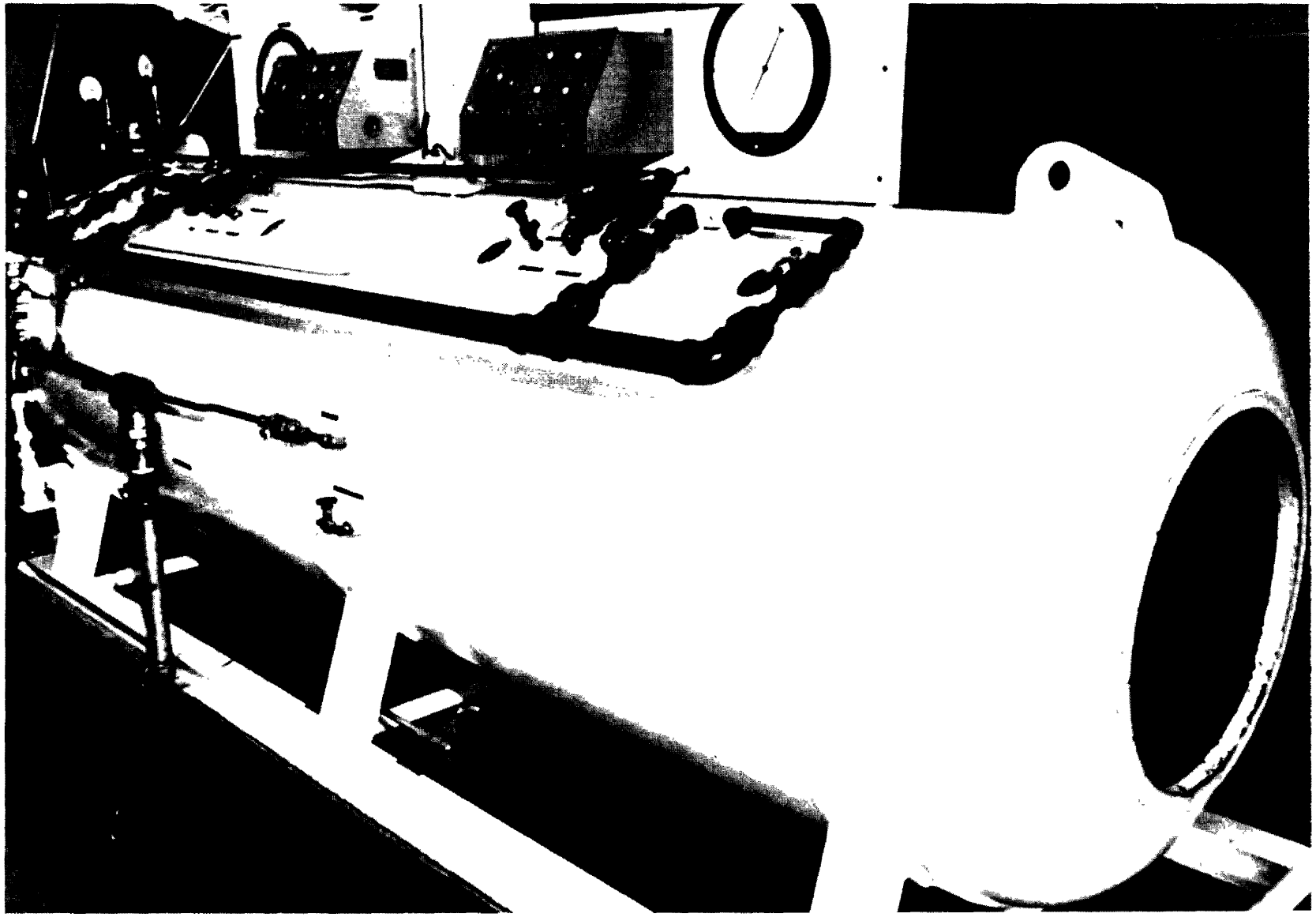


FIGURE 1-13 RECOMPRESSION CHAMBER

in the chamber. The inside attendant makes the dive with the patient to attend to his needs or give medical treatment. He also keeps the outside crew informed of changes inside the chamber and advises on decompression rates.

1.10.3 Airlock System

The Airlock system is made up of two compartments, one inside the water tank (wet Airlock) and one outside (dry Airlock), connected by a hatch through the tank wall. The wet and dry Airlocks are provided for emergency escape from the bottom of the water tank for suited subjects or divers and allows outside access by medical personnel for treatment (sinus blockage, unconsciousness, etc.) without depressurizing the diver and risking air embolism. The compartment inside the tank is entered from the bottom and is automatically pressurized to keep the water level at the bottom of the compartment. Once inside the wet Airlock, the subject can be treated by safety divers or by medical personnel via the dry Airlock and, if necessary, completely removed from the tank. The Airlock system is maintained and kept in a standby condition at all times. Figure 1-14 shows the dry Airlock.

1.10.4 Alarms/Safety Equipment

Several different safety devices in the form of alarms, equipment, and procedures are used in the NBS to guarantee safe operations.

- To assure safe, clean breathing air for neutral buoyancy exercises, missile grade air is filtered and monitored for

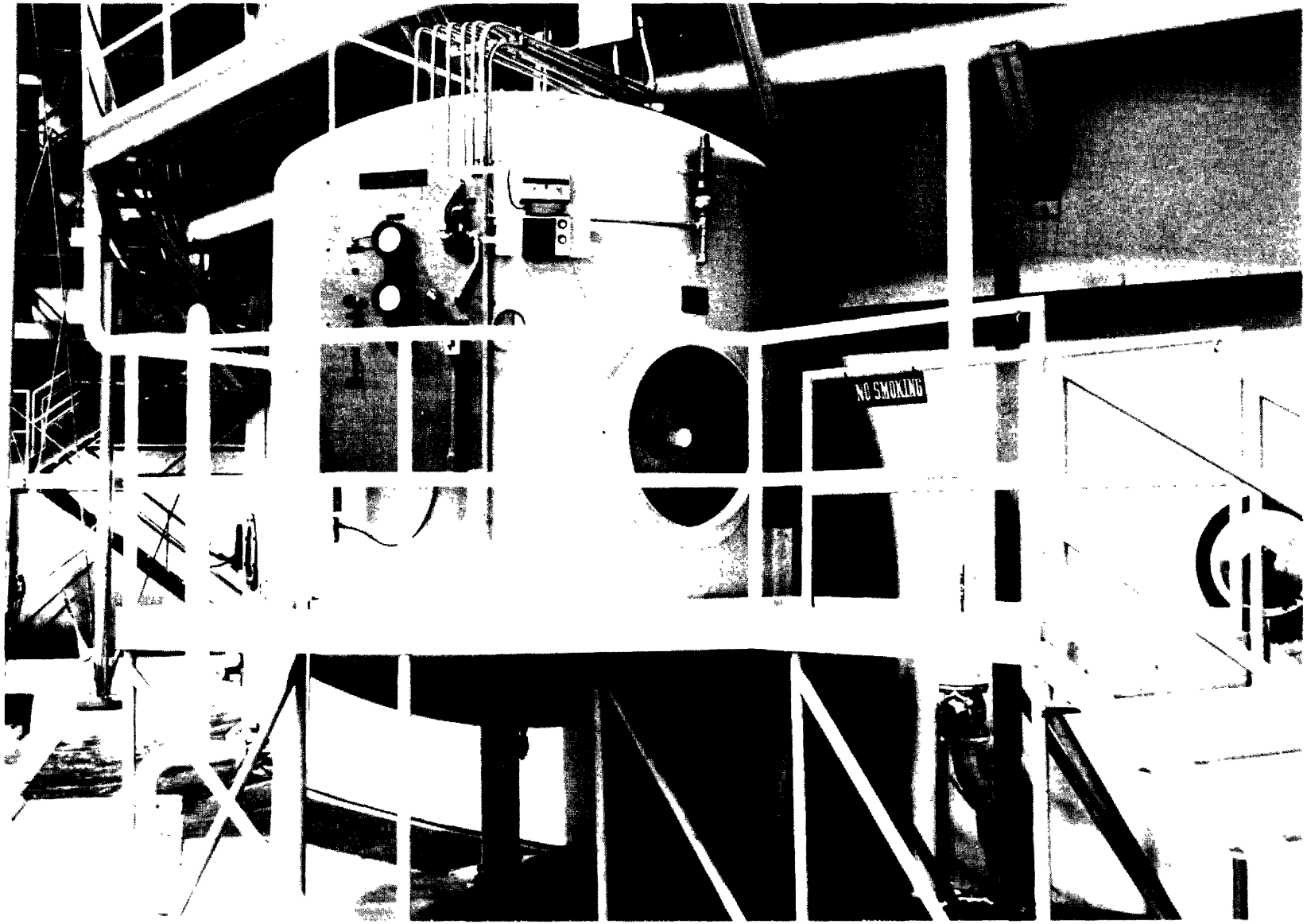


FIGURE 1-14 DRY AIRLOCK

carbon monoxide and oxygen content before it goes into the air distribution system. If the monitored air contains more than 20 PPM of carbon monoxide, or if the oxygen content falls below 18 percent, an alarm is sounded and the backup air system is activated. The CO and O_2 monitor is calibrated once a week and verified before each test. Samples of the primary supply and emergency air are also analyzed twice a week.

- The weather conditions are checked with the local weather bureau before each exercise and if thunderstorms are in the area, the weather bureau keeps the test director informed of conditions so that appropriate decisions may be made concerning neutral buoyancy activities.
- When heavy equipment is hoisted into and out-of the tank, the top rails are removed for equipment clearance. During such operations, a nylon safety harness restraint assembly, with a nylon strap attached to overhead structure, is worn by personnel working on the top deck. The strap allows only lateral movement along the upper platform.
- A manually operated master alarm is located on top of the recompression chamber to alert all personnel of a water emergency. It can be heard outside the water tank area and in the adjacent support buildings.
- An emergency generator automatically supplies electrical power to the critical NBS equipment in case of a power failure.

- Safety procedures were incorporated to check the LSU's for stray voltage before they were connected to the suited subjects.
- Relief valves were incorporated in all underwater cameras with pressurized cases. This safety measure prevented gas build up inside the camera cases.
- The control room is equipped with an automatic CO_2 fire extinguishing system. The automatic system senses and triggers on conditions of high temperature or smoke.
- During pressure suited exercises, the LCG flow is instrumented to illuminate a red warning light in the control center if low LCG flow conditions occur.
- A safety air hose called the "HOOKAH", is carried by each safety diving team during every pressure suited exercise. A SCUBA mouth piece regulator is attached to the end of the air hose and is quickly given to the suited subject in an extreme emergency situation.

1.10.5 Simulator Provisions

Special considerations are given to trainer designs to provide safe operating conditions in areas that could be potentially dangerous. For example, when both suited subjects were in the lock compartment of the Skylab Airlock Module with the EVA hatch closed, the subjects were isolated from the safety divers. To provide immediate access to the subjects by the safety divers, should an emergency occur, a removable panel the full length of the lock compartment was incorporated. The emergency

escape panel had a window in it so the safety diver could maintain visual contact with the subjects and, if necessary, remove the panel by operating a single external latch. In addition, the EVA hatch was specially rigged so;(1), it could not be locked from the inside, and (2), an external handle was added so that the hatch could be opened from the outside by a safety diver. The LSU's for the suited exercises were extra long so they could be routed through the bottom of the modified LSU stowage spheres, through the EVA hatch, and back to the subject on the operation deck. In this way, the LSU's were stowed in the stowage spheres to simulate flight umbilical handling conditions, while the umbilical length allowed the subject to be brought to the surface in an emergency situation.

Special attention is given to the elimination of sharp edges in all areas of the trainers and especially in the high activity crew areas. Sharp edge elimination is important not only for protection of the vulnerable SCUBA divers from cuts, scratches, etc., but was a necessity in the pressure suited exercises because the suit in the tank is subjected to greater abuse than in space flight and a rip or tear could result in an emergency situation.

1.11 Lessons Learned

The Neutral Buoyancy facilities more than met the needs of Skylab through the design and development phase, crew training, and EVA contingencies. Many lessons were learned in meeting these needs that should be noted and employed to help improve the facility for future programs.

- The office area for JSC personnel and the briefing room is adequate, however, it would be more convenient and efficient if it is located closer to the simulator. This area could also double for outside support contractors.
- Color TV was first used during the Skylab Program and provided much better realism than the black and white TV. Color TV has a depth of field which is very helpful in training evaluations. This capability should be maintained and even expanded in the future.
- The general viewing area adjacent to the simulator inside Building 4706 is plagued with glare problems that affect the TV monitors and has poor acoustics, making it difficult to hear the audio. A closed area with good acoustics is needed for engineers, PI's, and management to adequately view the testing operations on TV and to hear the intercommunication.
- Better access control is needed to reduce the number and types of personnel in the control room to avoid overcrowding.
- There should be a better understanding of time limits that a crewman can stay underwater in a test operation. Skylab time limits were variable depending on depth, surface time, and length of time between test and flights back to JSC. Much briefing time was used trying to establish these time limits. This delay could be eliminated with a clear set of rules.
- The daily Operational Readiness Inspection (ORI) works well, and

should be continued in the future.

- o A good filing/retrieval system should be established at the beginning of a program to keep track of video tapes, photos, test plans, briefing notes, suits, hardware and technical data and to allow quick retrieval.
- o There was a constant logistics problem to and from the suit Lab (Bldg. 4711). This could be eliminated by having the suit Lab closer to the NBS.
- o A positive tracking system should be established for all equipment coming into and out of the NBS.
- o The underwater safety team and utility diver concepts works very well and should be continued.
- o The overhead pneumatic hoist was continually breaking down, especially with heavy loads. A more powerful hoist is needed, with control stations located at both ground level and top deck.
- o A larger work space is needed near the top deck. The present area is extremely limited for reworking underwater hardware. This capability is needed to perform on-the-spot minor repairs. The work area should include a drill press, grinder, band saw, and storage for screws, nuts and bolts.
- o The Butler Building (4705) is sufficient for major hardware rework.
- o Having all NBS personnel on-station prior to beginning of suit-up helps assure a smooth training exercise.

2.0 TEST AND HARDWARE DEVELOPMENT

The Neutral Buoyancy Simulator was essential for development and testing of Skylab hardware designs that interfaced with a suited astronaut. Management decided early in the Skylab program that all equipment requiring interface with a pressure suited crewman be evaluated in simulated zero-G conditions. This could only be accomplished in the NBS where the full scale man-machine interface could be assessed for long durations.

2.1 Evaluations

Equipment design evaluation was performed in the NBS using prototype mock-up hardware. These evaluations proved to be very beneficial and in some cases were absolutely necessary to arrive at acceptable designs and locations for EVA equipment. Several important design changes and new design concepts were the direct result of these NBS evaluations. These include, but are not limited to, the following:

- Early Skylab NBS evaluations revealed that a translation device was required to move the ATM film between FAS and ATM workstations.
- One concept was to attach the ATM film to a trolley platform that was connected to a pair of rails extending from the DA to the ATM Sun End(Figure 2-1). The crewman would push the film trolley in front of him as he translated along the dual rails. This concept was tried and proved more complex than methods later developed.

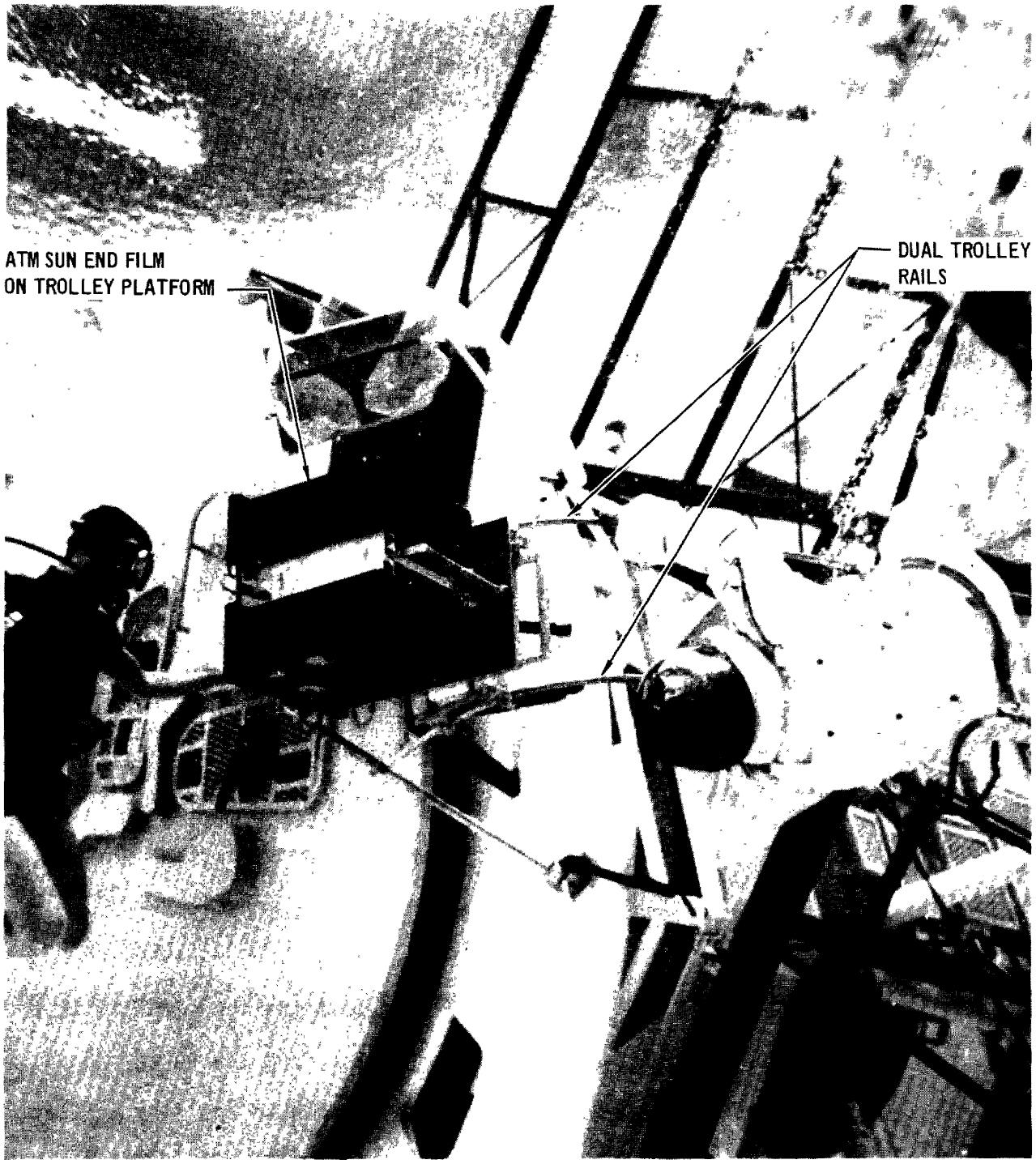


FIGURE 2-1 TRANSLATION OF ATM FILM TO SUN END WORKSTATION USING PRELIMINARY "TROLLEY" CONCEPT

- After many evaluations in the NBS using several different types of prototype translation aids, it was concluded that either an extendible boom or a clothesline type translation device would be feasible to carry out the ATM film replacement task.
- Preliminary evaluations with a "SPAR" pneumatic boom revealed that it was difficult to install the film packages on the rear loading boom hook. This resulted in a hook redesign so the packages could be loaded on the front of the boom hook.
- During film transfer evaluations with the prototype "SPAR" boom, the film packages would intermittently hit the DA and FAS handrails. This was mainly due to the loose fit between the smaller film pack handles and the boom hook. Therefore, a new boom hook was designed by MSFC that would clamp-up on the different size film pack handles. In addition, the DA handrail was rotated away from the boom path and the FAS handrail was redesigned to give more clearance.
- Preliminary mock-up of the Fairchild Hiller extendible boom envelope showed excessive interference with the astronaut when translating between the EVA hatch and the FAS workstation (Figure 2-2). The boom film hook also interferred with the astronauts helmet when he was in the FAS foot restraints. As a result of this preliminary evaluation, a 90° fold back boom hook was designed and the boom housing was shortened approximately .14m (5 inches) and tapered to a smaller profile.

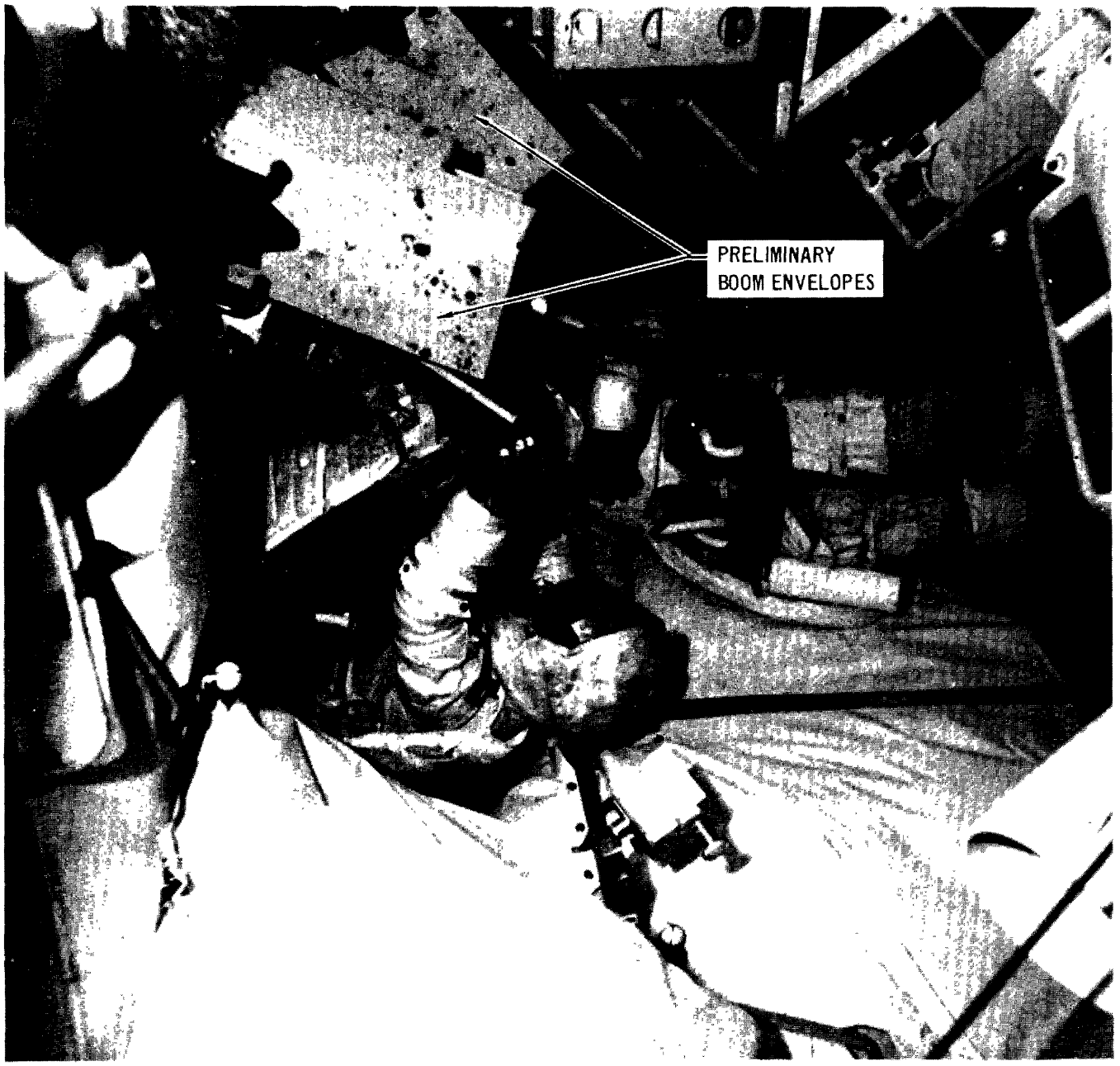


FIGURE 2-2 EVA 1 AT FAS WORK STATION (VF)
EVA 2 EGRESSING FROM EVA HATCH

- During evaluations of extendible boom operations, it was discovered that, periodically, there was interference between the sun end film packages and D024 module. This resulted in redesign of the mounting structure to move the D024 module away from the sun end boom path approximately .16m (6 inches).
- Location of the extendible boom control panel was determined from NBS evaluations. Later NBS evaluations changed the momentary boom control switches to fixed switches and added additional switch guard protection.
- Need for a special foot restraint location was determined and developed in the NBS so the extendible booms could be replaced in flight.
- Design concept for the extendible boom quick release receptacle was developed in the NBS. During boom replacement evaluations it was discovered that the boom handle trigger was too shallow, making it difficult to squeeze with the EVA pressure suit glove. This resulted in a boom handle design change.
- The clothesline translation method was developed and tested in the NBS. A zippered pouch to contain the clothesline was evaluated and discarded in favor of a hard cover container with a spring loaded lid. Where to locate the container, how to package the clothesline and hooks, and how to deploy each to the VC and VS workstations were all determined by NBS evaluations. After both VC and VS clotheslines were deployed, it was found

that the clotheslines would interfere with the astronaut translating back from the ATM. Clothesline clips were then designed and installed on the FAS and AM tunnel handrails to hold the clotheslines out of the EVA trail when not in actual use.

- Foot restraint locations at the FAS and ATM workstations were optimized through NBS evaluations.
- Location of the Life Support Umbilical (LSU) clamps outside of the EVA hatch and at the ATM workstations for LSU management was determined by NBS evaluations.
- All handrail locations were optimized through NBS evaluations.
- Handling and mounting locations for the 16 mm Data Acquisition Camera (DAC) were determined by NBS evaluations.
- Location of the ATM film tree receptacles in both the lock compartment and FAS was the direct result of NBS evaluations.

2.2 Lessons Learned

- NBS personnel have experience useful to evaluation of zero-G hardware and should be consulted in the early design stages on new flight interface hardware.
- The need for NBS testing was not fully recognized until after Skylab flight hardware was designed. Future programs should recognize the need for NBS hardware such that neutral buoyancy equipment can be designed in parallel with flight hardware.
- All new hardware evaluations should be performed by subjects that are experienced in the operation of pressure suits (at least

twenty hours of NBS suited operation is required before meaningful evaluations can be made).

- New hardware should be evaluated first in the NBS by experienced neutral buoyancy personnel before flight crew evaluations, with sufficient time being allocated to work out any hardware discrepancies and water peculiar problems.
- All hardware fabricated for the NBS should go through quality control inspection before being evaluated in NBS.
- All NBS hardware should have a functional check of all mechanical operation parts prior to hardware being placed in the tank for test purposes.
- All NBS hardware should be fit checked before hardware is placed in tank.
- The NBS has proven to be a useful tool in EVA hardware development and its use should be planned into future space programs.

3.0 TRAINING HARDWARE

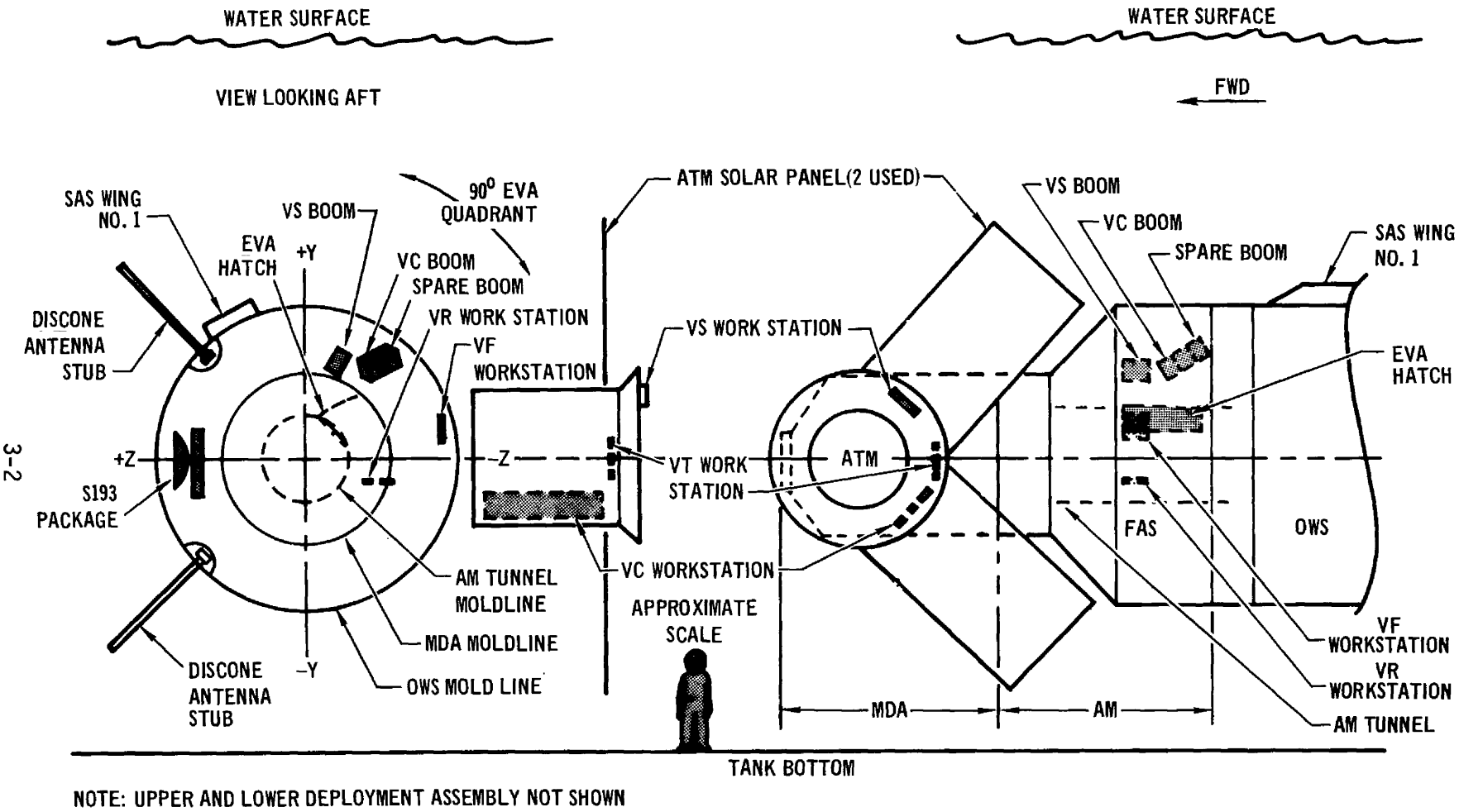
Trainers and mock-ups with special mechanisms were submerged in the water tank so design evaluations and training could be performed utilizing the neutral buoyancy concept. This section covers the design, description, size, materials and use of underwater Skylab hardware. Each module and special type of hardware will be considered separately due to different suppliers involved and separate operational functions required.

Six different Skylab modules were constructed and then assembled underwater in an orbital deployed position for EVA training. See Figure 3-1.

- Orbital Work Shop (OWS)
- Airlock Module (AM)
- Multiple Docking Adapter (MDA)
- Upper and Lower Deployment Assy (DA)
- Apollo Telescope Mount (ATM)
- Fixed Airlock Shroud (FAS)

In addition, many special mechanisms were required to be installed including but not limited to:

- Air Operated Booms
- Neutrally Buoyant Booms
- Clothesline and Containers
- D024 Experiment Module
- Boom Hook Stowage Box
- Cameras and Receptacles



NOTE: UPPER AND LOWER DEPLOYMENT ASSEMBLY NOT SHOWN

FIGURE 3–1 SKYLAB NEUTRAL BUOYANCY TRAINER ELEMENTS

Areas of the Skylab trainers that required interface by a pressure suited crewman were high fidelity with operable mechanisms similar to flight. These areas included the lock compartment, FAS (+Y-Z quadrant), EVA trail, EVA experiments and ATM film workstations. All other areas were low fidelity representing flight geometry only. Some of the low fidelity areas were upgraded after SL-1 launch for the EVA contingency evaluations and will be described later in this section.

3.1 Orbital Work Shop (OWS)

The OWS was a cylindrical structure 6.6m (260 in.) in diameter and approximately 9.1m (360 in.) long. This structure was fabricated by NASA-MSFC using McDonnell Douglas Astronautics Company - West (MDAC-W) drawings. Basic structure consisted of welded aluminum rings and longerons of 6061-T6 alloy. Skins were originally .025m (1.0 in.) square 6061-T6 aluminum wire mesh. Later these were replaced with aluminum expanded metal. Subsequently solid 2042-T3 aluminum skins were installed on top of the expanded metal for more realistic pressure vessel simulation. These solid skins centered about the -Z axis (sun direction and EVA area), covered 180° of the OWS cylinder. Dome portion was .0025m (.10 in.) thick 6061-T6 aluminum. The OWS forward section had the same geometry as the flight article with a high fidelity isogrid floor. Use of this module was originally limited to astronaut EVA preparation activities and Airlock ingress training.

When Skylab I lost its meteroid shield, modifications were made to the NBS OWS element so possible fixes via EVA could be determined and evaluated. These fixes consisted of adding the -Z Scientific Airlock and the number 1 Solar Array System (SAS) wing. Due to tank size limitations only a partial SAS wing mockup could be installed. The SL-1 problem had been determined to the extent that Number 2 SAS wing was lost and Number 1 SAS wing was only partially deployed. It is especially worthy to note that the actual problem (i.e. what was restraining the SAS wing) was not known, however, logical assumptions were made and the appropriate tools procured and then evaluated by the SL-2 crewmen. The success of tnat training was demonstrated by successful deployment of the SAS and restoration of electrical power to permit full completion of the Skylab program. The OWS exterior was used once again when the MSFC designed "twin pole sail" thermal shield was installed on the ATM structure. The "sail" was deployed and then pivoted, from the ATM mounting bracket, until the aft end rested against OWS outer skin. This activity is discussed in detail in Section 5.2.1.

3.2 Airlock Module (AM)

The AM consisted of a tunnel section, a structural transition section (STS) and four (4) trusses that attach the AM to the Fixed Airlock Shroud (FAS). The AM tunnel and STS were cylindrical structures 1.65m (65 in.) in diameter and 3.89m (153 in.) long and 3.2m (126 in.) in diameter and 1.2m (47 in.) long respectively. The tunnel consists of three sections aft, lock, and forward, divided by bulkheads containing internal hatches.

The AM with all interior and exterior equipment was built and maintained by McDonnell Douglas Astronautics Company - East (MDAC-E) except for two low fidelity trusses located at +Z and -Y axis which were fabricated by NASA-MSFC. Interior geometry was the same as the flight article and all equipment, in the lock and aft sections was regularly updated. Forward tunnel and STS section had low fidelity modules to simulate envelope only and were not updated. Lock section equipment included two EVA panels, with fittings, switches, knobs, etc, and an instrument panel complete with switches. Also included were two LSU stowage spheres, TV station, ATM film tree mounting receptacles, handrails, etc. The EVA hatch was high fidelity and regularly monitored for correct latching forces, and used extensively for egress and ingress training. The hatch was a GEMINI training article and was the same as flight hardware except for external handle and release cable added for underwater safety purposes. Hatches are covered in more detail in section (3.7.6). Exterior equipment included all astronaut interface surfaces and equipment, especially in the 90° EVA quadrant (+Y to -Z). All EVA equipment such as boom control box, umbilical clamps, transfer work station (VT), clothesline clips, EVA lights, boom receptacle, clothesline stowage box and all handrails were high fidelity and were regularly updated to reflect current design of flight article. Other external equipment (electronic modules, nitrogen bottles, etc.) were low fidelity to simulate equipment envelope only. Basic structure of the tunnel and STS was 2024-T4 extruded rolled aluminum

rings and channels, riveted to the skins. Original skins were expanded metal 3003-H14 aluminum .003m (.12 in.) thick; these were later replaced with solid 2024-T3 aluminum rolled sheets. Truss structure was .1m (4.0 in.) square 6061-T6 tubing with smaller diameter structural 6061-T6 aluminum tubing welded. See Figures (3-2, 3-3, 3-4, and 3-5).

All formal EVA training exercises began and ended in the AM. The AM was used throughout the hardware development stage and was used extensively to work out equipment handling methods and procedures for the ATM film transfer. After SL-1 was launched, the Neutral Buoyancy (NB) trainer proved extremely valuable in working out techniques and procedures for the successful contingency EVA's .

3.3 Multiple Docking Adapter (MDA)

The MDA was a cylindrical structure 3.2m (126 in.) in diameter and 5.2m (204 in.) long. Fabrication was originally done by NASA-MSFC and subsequently sent to Martin Marietta Corporation (MMC) for update. Original version had five docking ports which were reduced to two during later revision (Figure 3-6).

Basic structure was 6061-T6 aluminum extruded rolled rings and longerons. Skins were originally .025m (1.0 in.) square 6061-T6 wire mesh aluminum; these were later replaced with aluminum expanded metal. Still later, solid 2024-T6 skins were added on top of the expanded metal extending in each direction from +Y axis (top of tank) approximately 110° and for its full length. Area around the docking ports had square extruded tubing

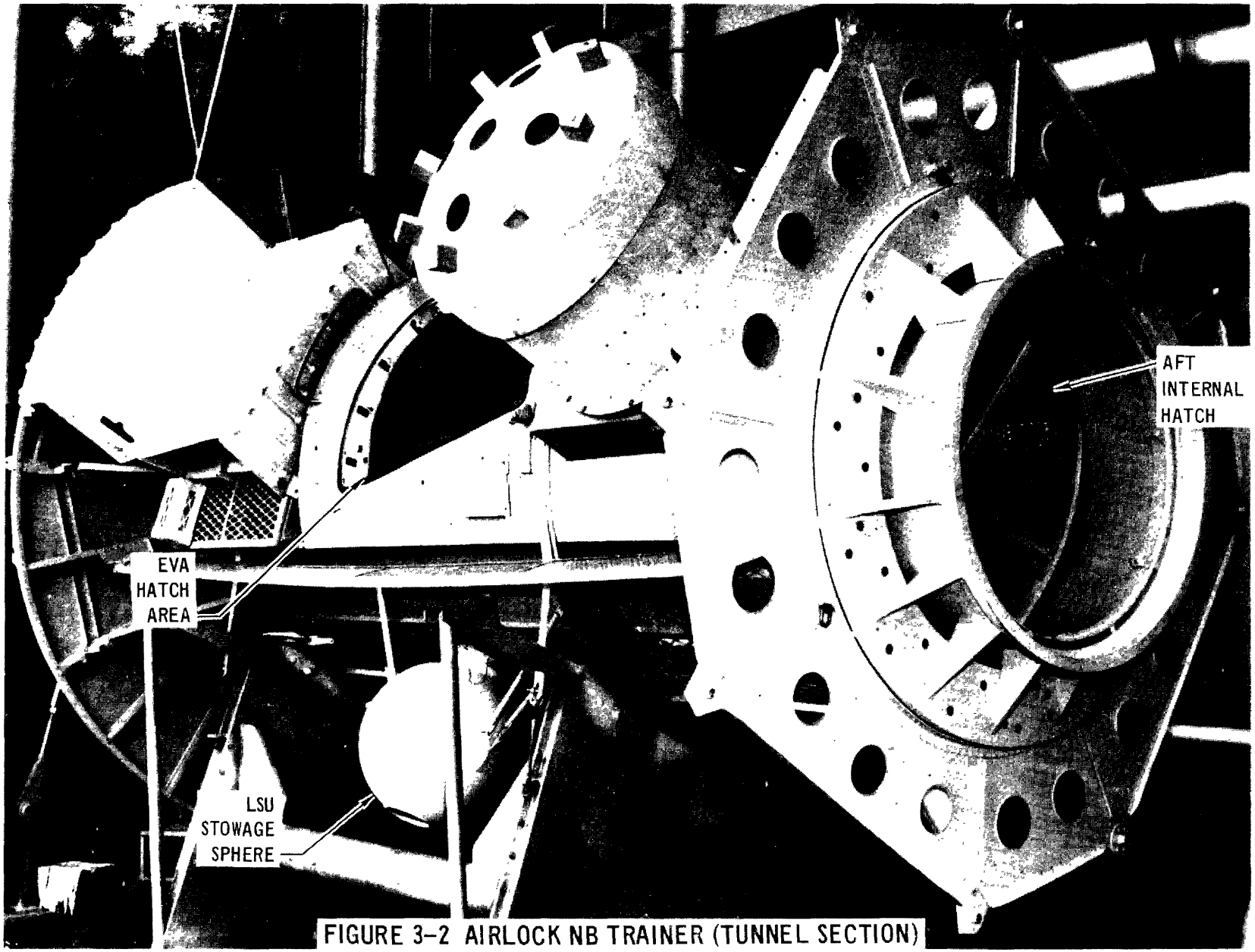


FIGURE 3-2 AIRLOCK NB TRAINER (TUNNEL SECTION)

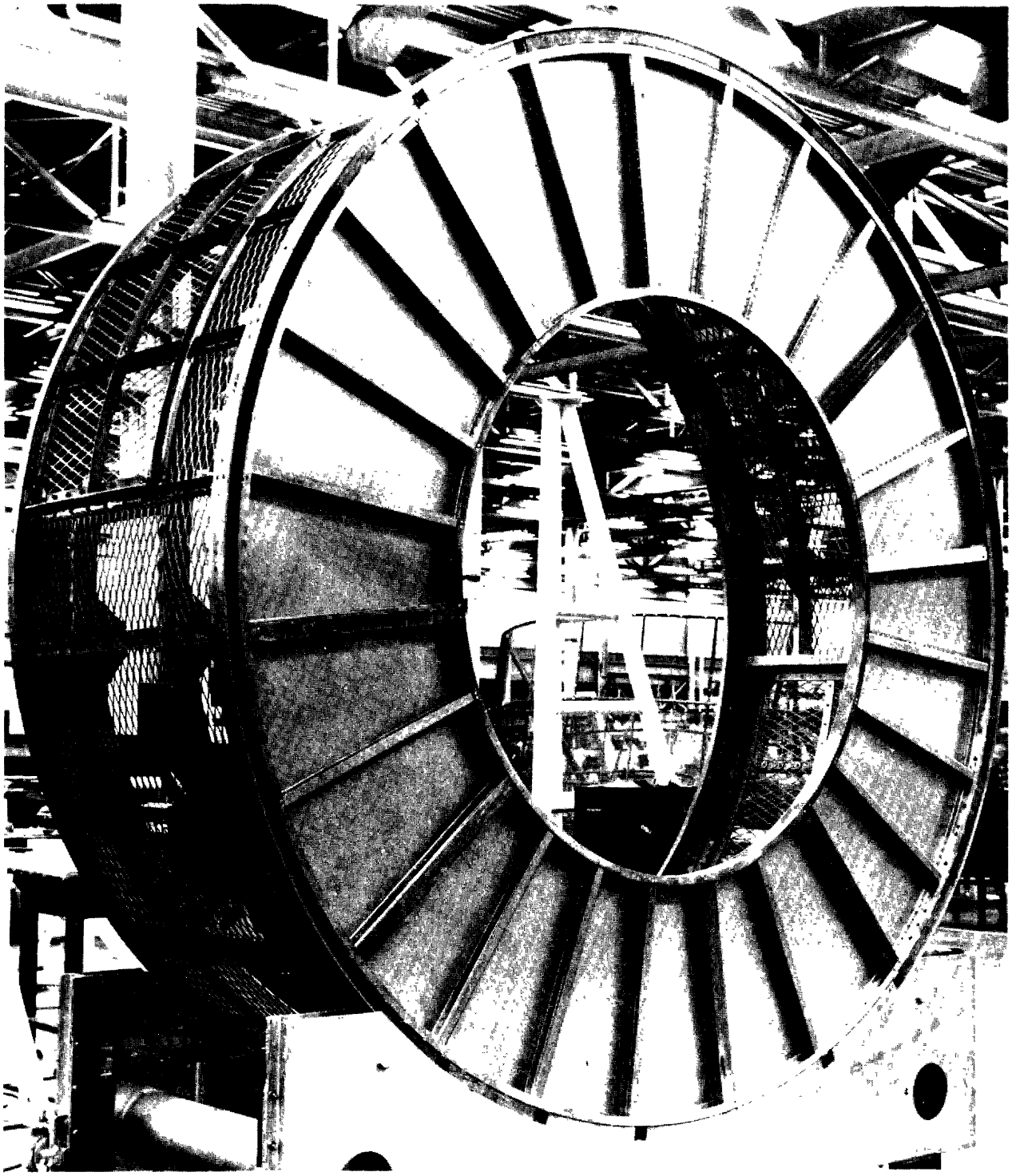


FIGURE 3-3 AIRLOCK STRUCTURAL TRANSITION SECTION (STS) NB TRAINER

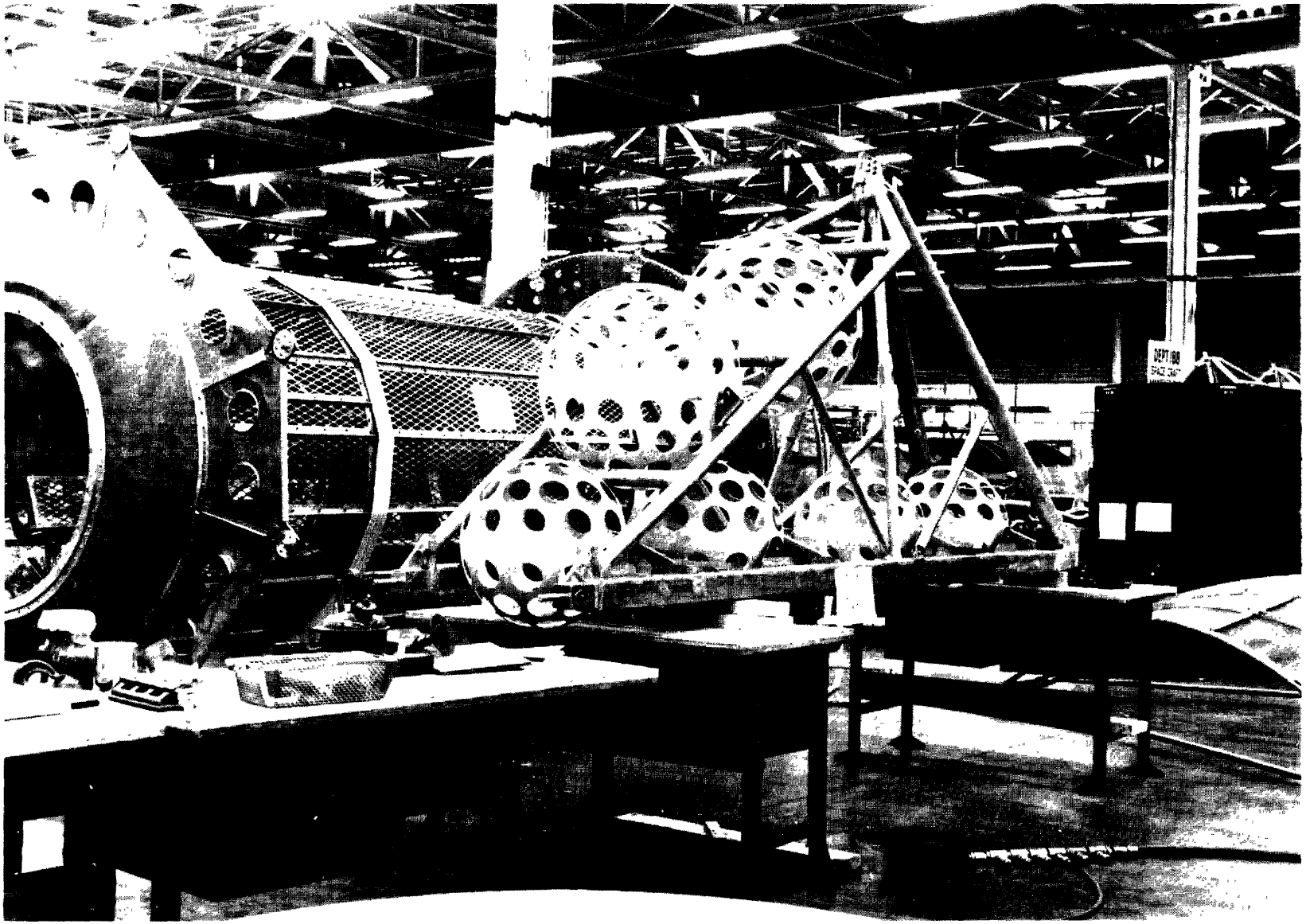


FIGURE 3–4 EARLY NBS AM TRUSS CONSTRUCTION WITH NITROGEN BOTTLES (WET WORKSHOP)

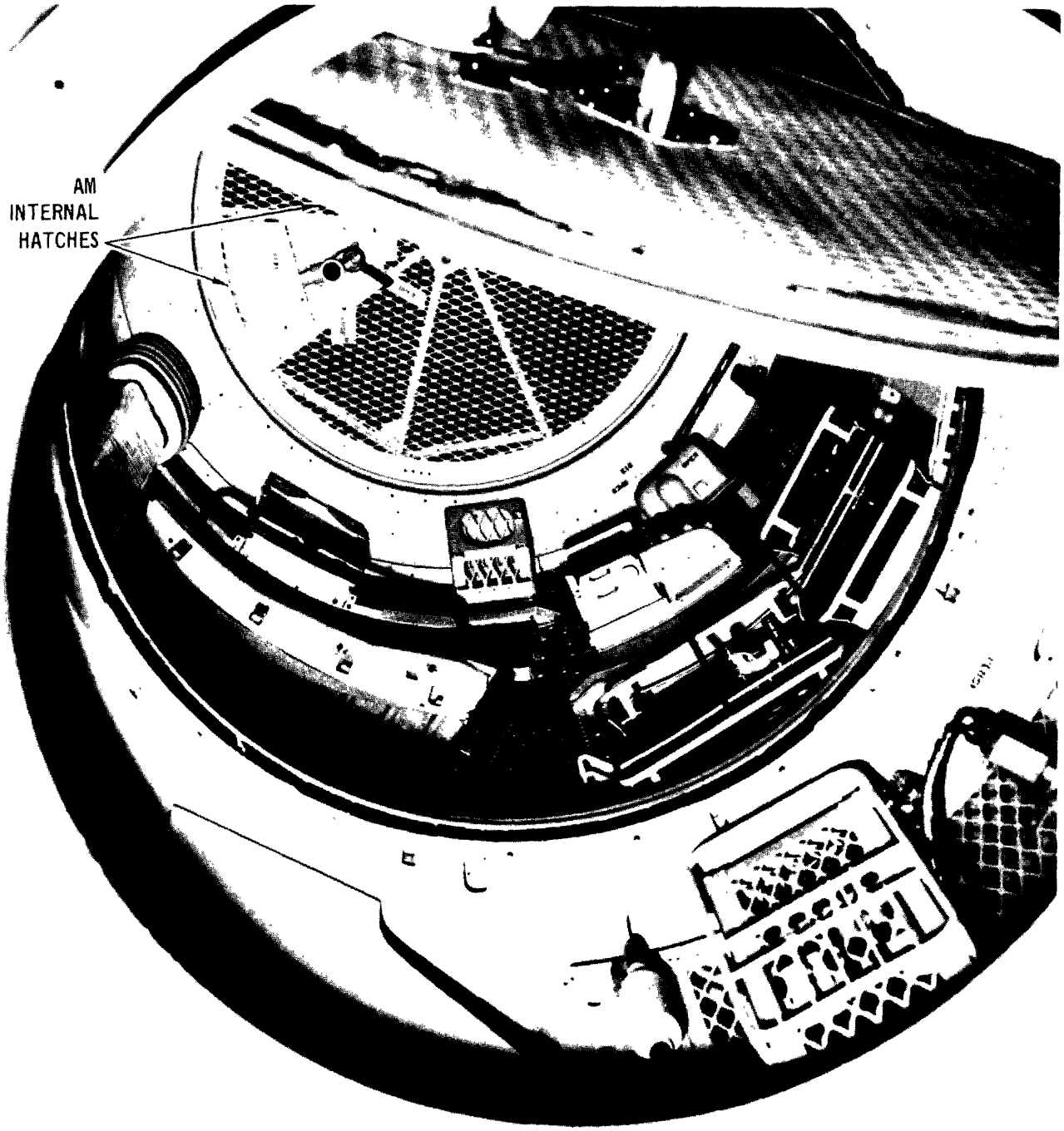


FIGURE 3–5 AM NB TRAINER-INTERIOR OF LOCK AND AFT COMPARTMENT

FIGURE 3-6 ORIGINAL MDA NB TRAINER

to simulate flight configuration. Use of the MDA module was minor for normal NBS purposes, however the exterior envelope was necessary for development of EVA translation methods and added realism to EVA training. Interior MDA equipment was low-fidelity, only partially simulating interior envelope since no IVA training was planned. During Skylab mission contingency training, the MDA aft +Z section was updated by adding external experiment modules so that the SL-4 crew could practice S193 antenna repair (Section 5.2.5 covers this in more detail).

3.4 Deployment Assembly (DA)

The DA consisted of an upper and lower truss assembly. After orbit insertion, the upper DA truss was deployed 90 degrees around two trunnion points at the +Y and -Y axis, toward the -Z axis (sun direction). The NBS DA was a duplicate of the flight article, except that it was fixed in the orbit deployed position (see Figure 3-7). Also two additional struts were installed on the NBS DA for structural support from the floor of the tank. Original NBS units were fabricated by NASA-MSFC; later new, high fidelity assemblies were fabricated and installed by MDAC-E. Basic structure was welded bipods of 6061-T6 aluminum tubing. The lower truss assembly was attached to the FAS with welded 6061-T6 aluminum fittings. The upper truss was attached to the ATM with welded fittings and adapter rings. The two assemblies were joined together in the orbit position, with two stainless steel trunnion bolts and brass nuts. The DA contained high fidelity handrails that were essential in

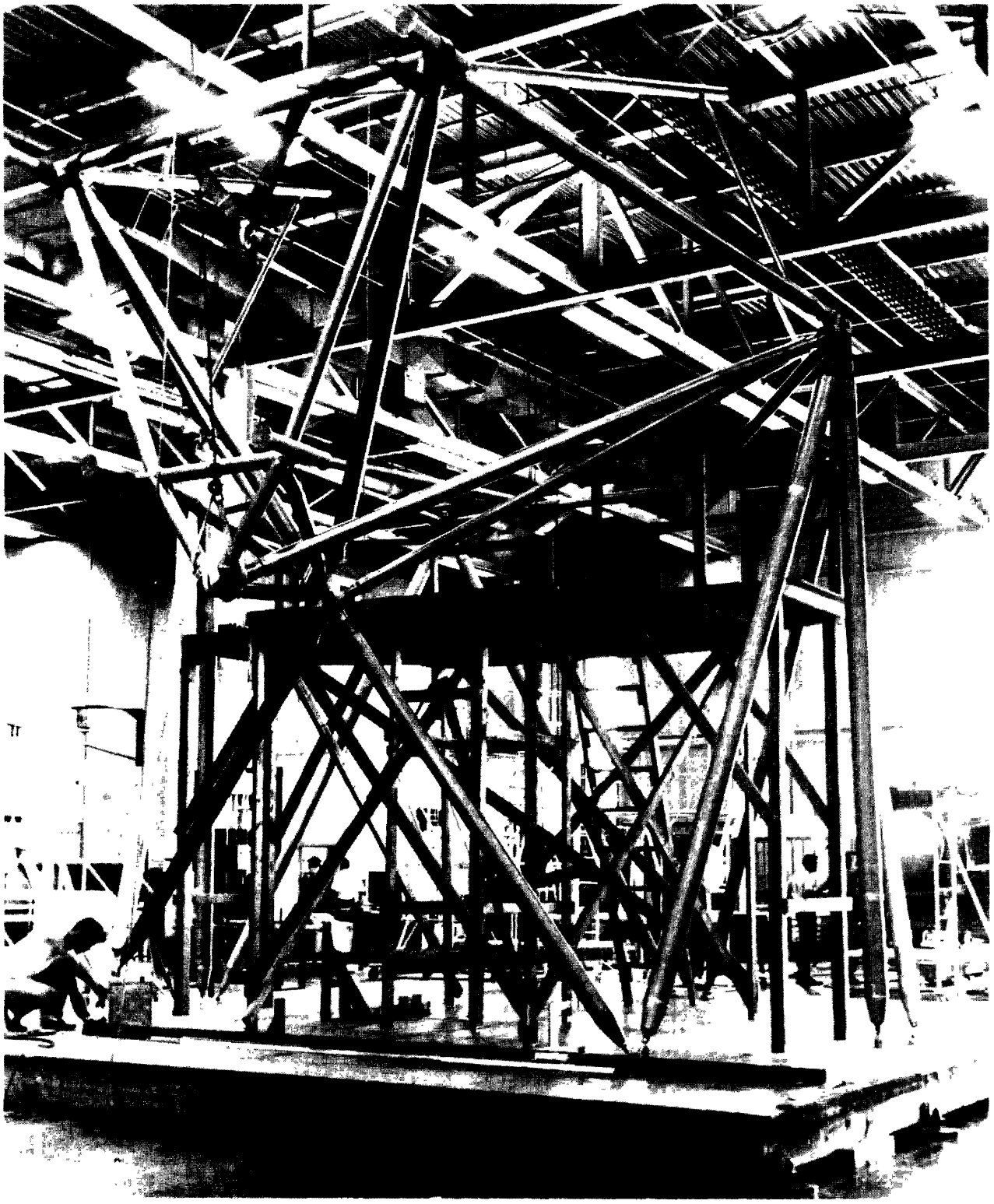


FIGURE 3–7 NBS DEPLOYMENT ASSEMBLY (DA)

evaluating the EVA trail out to the ATM workstations. Low-fidelity equipment was mounted on the DA trusses to simulate flight article geometry only. D021 experiment (expandable Airlock) was originally installed on the NBS DA truss but was removed when D021 was cancelled (Figure 3-8). The handrails, that were installed for D021 access, were not removed from the flight article or the NB trainer and proved to be valuable during contingency EVA's and aided installation of S230 experiment late in the program.

During EVA contingency training, a high fidelity S193 antenna training unit was provided by General Electric Company (GE) and installed in the tank on the DA to replace the original NBS unit. This unit was used extensively by SL-4 prime and back-up crews for contingency training. (See section 5.2.5).

3.5 Apollo Telescope Mount (ATM)

The ATM contained the sun oriented experiments for project Skylab. The NBS ATM closely simulated the flight article, with astronauts capable of controlling roll of the experiment canister from the VC work station. The NBS ATM was fabricated, updated, and maintained by Brown Engineering under direction of NASA-MSFC.

The ATM was an octagonal structure 3.35m (132 in.) across and 3.66m (144.0 in.) long (Figure 3-8). An experiment canister, 2.13m (84.0 in.) in diameter and 3.0m (120.0 in.) long, was inside this octagonal structure.

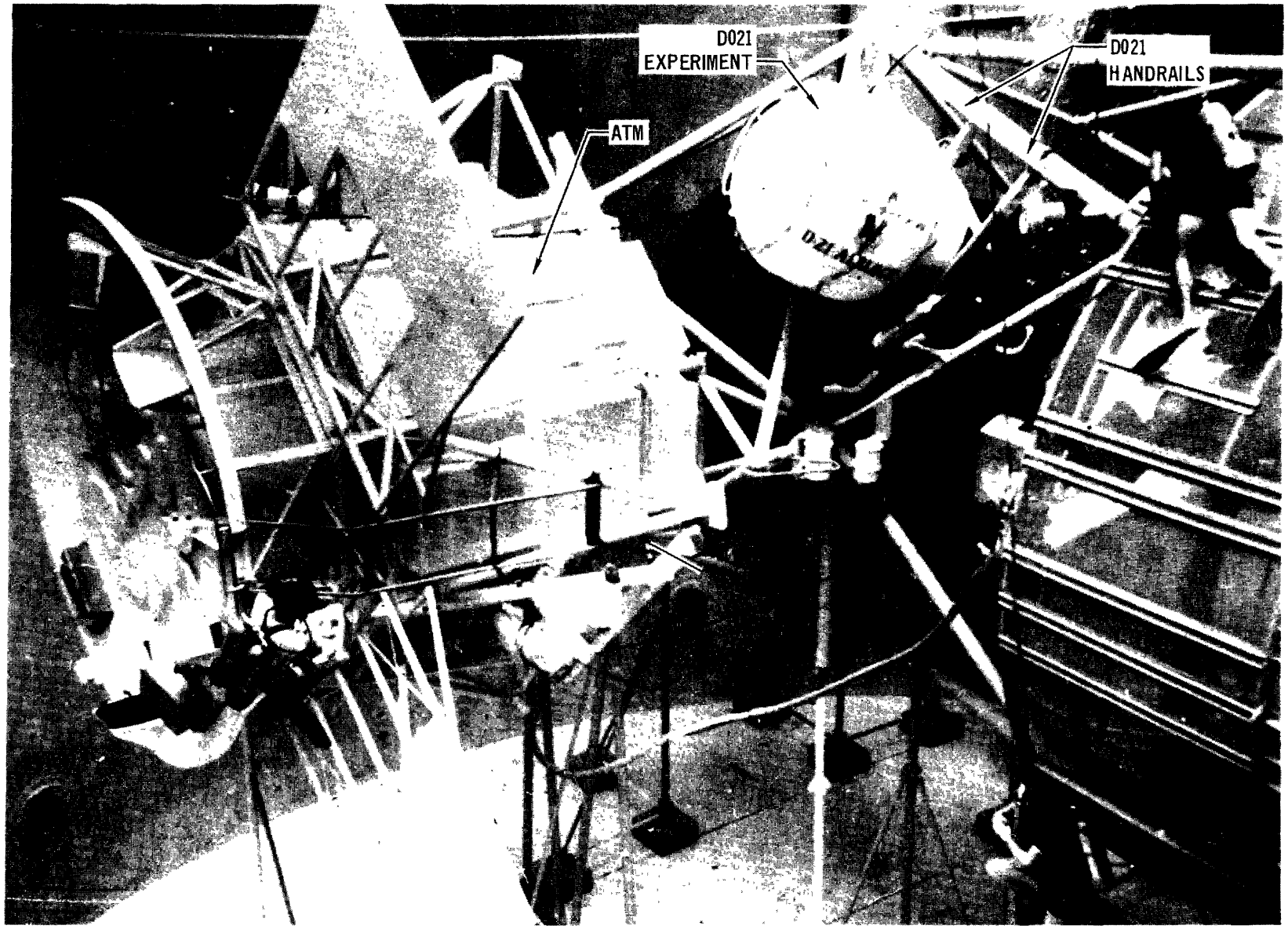


FIGURE 3–8 SKYLAB NBS TRAINING EXERCISE

The experiment canister was made neutrally buoyant and gimbal mounted to simulate flight article roll capability. This feature was accomplished underwater by an air motor through a chain drive.

Basic ATM structure was 6061-T6 aluminum welded rings with expanded aluminum metal skins. Support rollers originally were phenolic; these were subsequently changed to hard anodized 7075-T4 aluminum. Gimbal ring support rollers were 300 series stainless steel, utilizing FAFNIR needle bearings. The stainless steel drive chain was manufactured by McCullough Corp. The two workstations represented on the ATM, center (VC) and sun end (VS) were high fidelity. Remainder of equipment was low fidelity

The NBS ATM proved very valuable in normal EVA training. Each normal EVA exercise utilized both workstations and trainer roll capability. The workstations contained provisions for film exchange exercises and NBS served as the only facility to adequately train crewmen for ATM film changeout. During EVA contingency training, the ATM was used to support MSFC "twin pole sail" and rate gyro six-pack installation training.

3.6 Fixed Airlock Shroud (FAS)

The FAS was a cylindrical structure 6.6m (260 in.) in diameter and 2.03m (80.0 in.) long. The FAS was initially fabricated by NASA-MSFC and later the EVA quadrant (+Y to -Z) was structurally rebuilt by MDAC-E. MDAC-E also installed and maintained all equipment in the EVA quadrant. Basic structure was welded 6061-T6 aluminum rings and longerons with

expanded aluminum skins (Figure 3-9). Later, to add a more "realistic feel" to training in the EVA quadrant, solid 2024-T3 aluminum skins were installed on top of the expanded aluminum.

The EVA quadrant of the FAS contained all the high-fidelity crew interface equipment required for EVA's. This included, the extendible booms, boom control panel, ATM film tree receptacles, clotheslines, boom hooks, temporary stowage hook, boom nook container, umbilical clamps, handrails and film transfer and boom replacement work stations. Original concepts and design finalization of the above equipment was the result of many development exercises performed in the NBS. This is where design concepts were initially tested and equipment locations evaluated to provide good crew interfaces. Later in crew training, the NBS FAS was used to develop procedures and train the flight crews in ATM film transfer including umbilical management, clothesline deployment and operation, extendible boom operation, failed boom replacement, failed extended boom jettison, ATM film handling, sequence of package transfers, etc. During flight contingency evaluations, the remaining quadrants were updated by installing low fidelity O_2 bottles, discone antennas, thermal curtains, and forward lip of the FAS with the payload shroud attachment ring. These additions proved to be very valuable in developing methods and procedures for the EVA contingencies.

3.7 Special Mechanisms

Equipment designed for the vacuum of space was not always compatible with

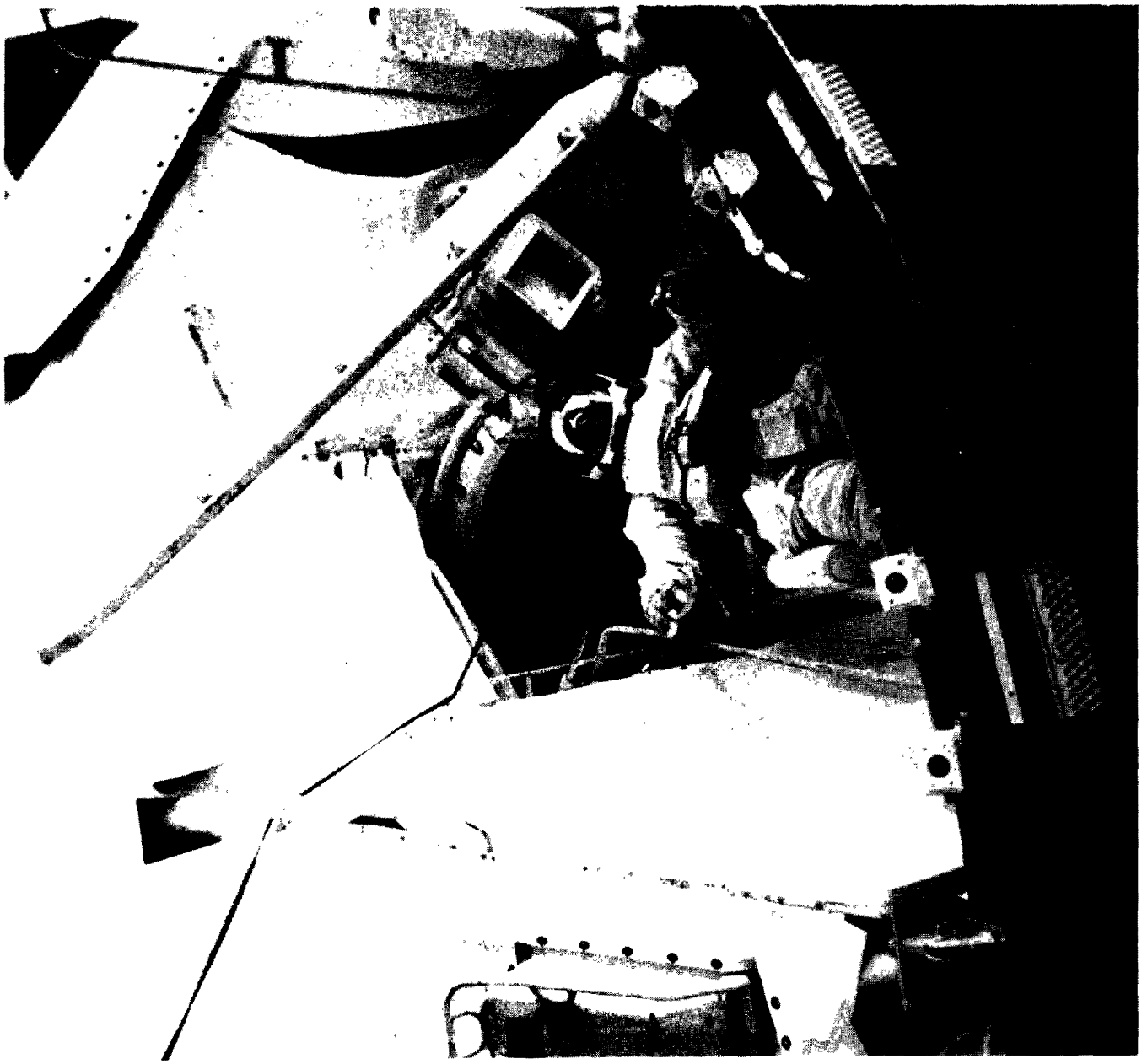


FIGURE 3–9 FAS EVA QUADRANT – ASTRONAUT AT FAS WORKSTATION (VF)

the inherently corrosive water environment in the NBS. For NBS design evaluations and training to be meaningful it was essential that the equipment operate and feel the same way it would in space. To accomplish this task special mechanisms were incorporated into the flight hardware so the NBS equipment would operate similar to flight equipment.

3.7.1 Air Operated & Neutrally Buoyant Booms

Two inflight replaceable extendible booms were used on Skylab as the primary means to transfer the ATM film between the FAS workstation and the ATM VC and VS workstations. A spare boom was located adjacent to the VC boom to serve as a replacement for either the VC or VS booms in the event of a failure. To make the extendible booms compatible with the NBS environment and yet maintain realistic design evaluation and crew training, it was necessary to make the following equipment changes prior to delivery:

- The flight boom electric motor was replaced by a pneumatic motor to eliminate motor sealing problems and electric current hazards in the water (Figure 3-10).
- Special back-up drive rollers were incorporated, pressing harder on the boom element to prevent slippage underwater.
- The NBS booms were modified by adding a check valve to the pneumatic drive system to permit extend/retract cycles (Figure 3-11).
- Special sealing processes were developed by NASA-MSFC to seal the electric switches in the extendible boom control panel. The

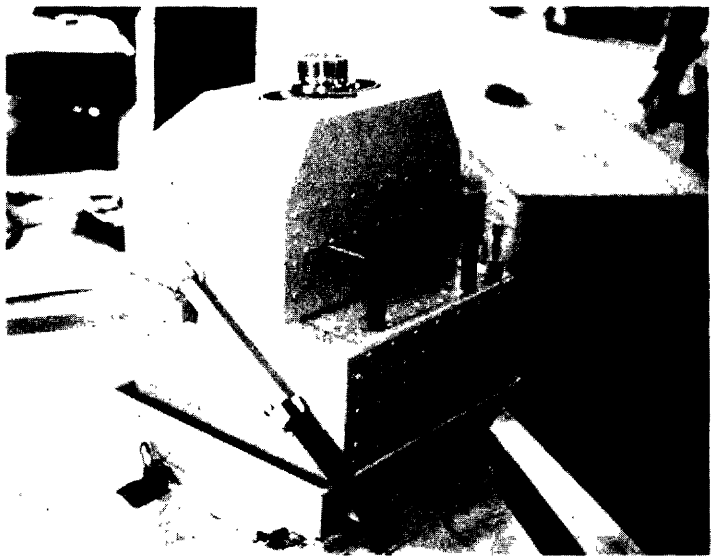


FIGURE 3-10 **NBS PNEUMATIC EXTENDIBLE BOOMS**

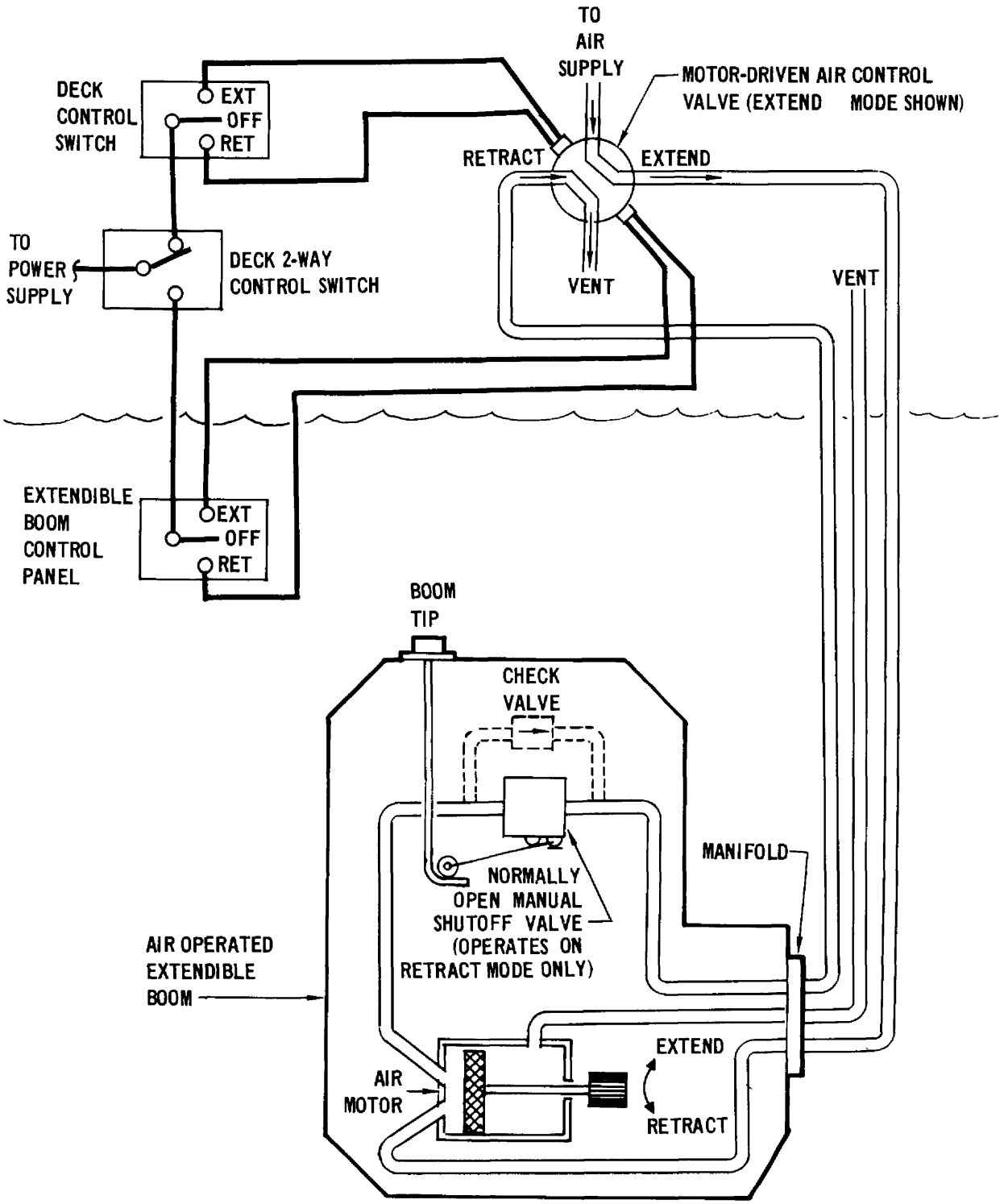


FIGURE 3-11 SCHEMATIC OF NBS AIR OPERATED EXTENDIBLE BOOM

submerged switches were wired to operate an air control valve located outside the tank which supplied air (at 80 psi) to the pneumatic motors for extension or retraction. A spare sealed and wired control panel was kept on standby status for quick replacement by SCUBA divers (Figure 3-12).

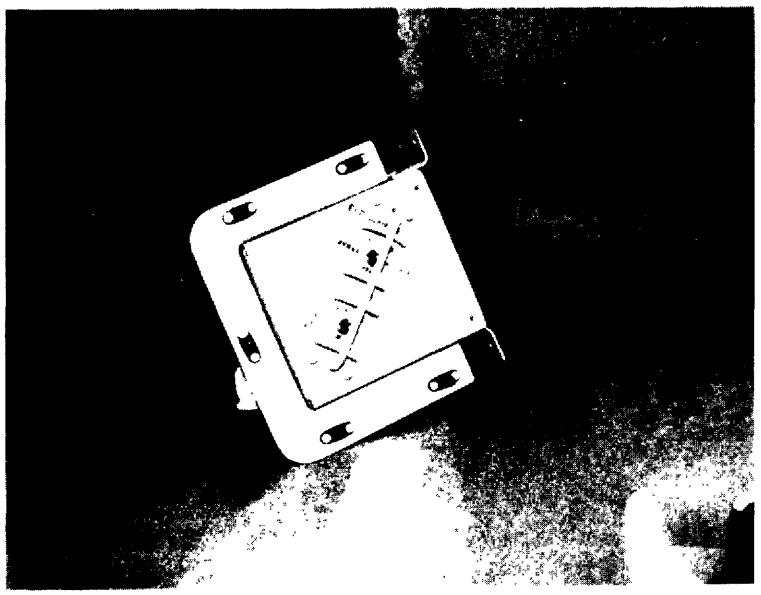


FIGURE 3-12 EXTENDIBLE BOOM CONTROL PANEL

- Dummy extendible booms were fabricated with flight latching mechanisms and dummy zero-G electrical connectors to train the crew in replacement procedures. The dummy units were made neutrally buoyant and had the same envelope and latching forces as the flight units. The motorized units utilized cumbersome air hoses and were too heavy (80 lbs) to make neutrally buoyant.
- Since there was no extend stop, yellow tape was added to the boom element which appeared outside the boom housing at full extension.

- An air hose was added for a return line to prevent air bubbles in the water and decrease back pressure in the pneumatic motor.
- Continuous air flow had to be supplied through the pneumatic motor to prevent water seepage into the motor.

The extendible booms were designed and manufactured by Fairchild Hiller Corp. as subcontractor for MDAC-E. The pneumatic control system for boom operations was the responsibility of NASA-MSFC with MDAC-E assistance. Original specifications were for two units, but due to the extensive maintenance required in the water environment, a third unit was purchased for a backup. After receiving the NBS units, several modifications were made at MSFC that were essential to support training:

- The dummy electrical zero-G connector on the neutrally buoyant booms had to have a hole drilled through the connector to prevent a hydraulic lock during connector mating.
- A flotation collar had to be installed on the boom tip by SCUBA divers before boom extension to keep the boom element from bending (Figure 3-13).
- Special paint was applied to a .025m (1.0 inch) wide strip down the element center section to increase friction and help prevent element slippage.
- Four additional side mounted guide rollers were added to keep the boom element on track and from becoming entangled in the drive gears.

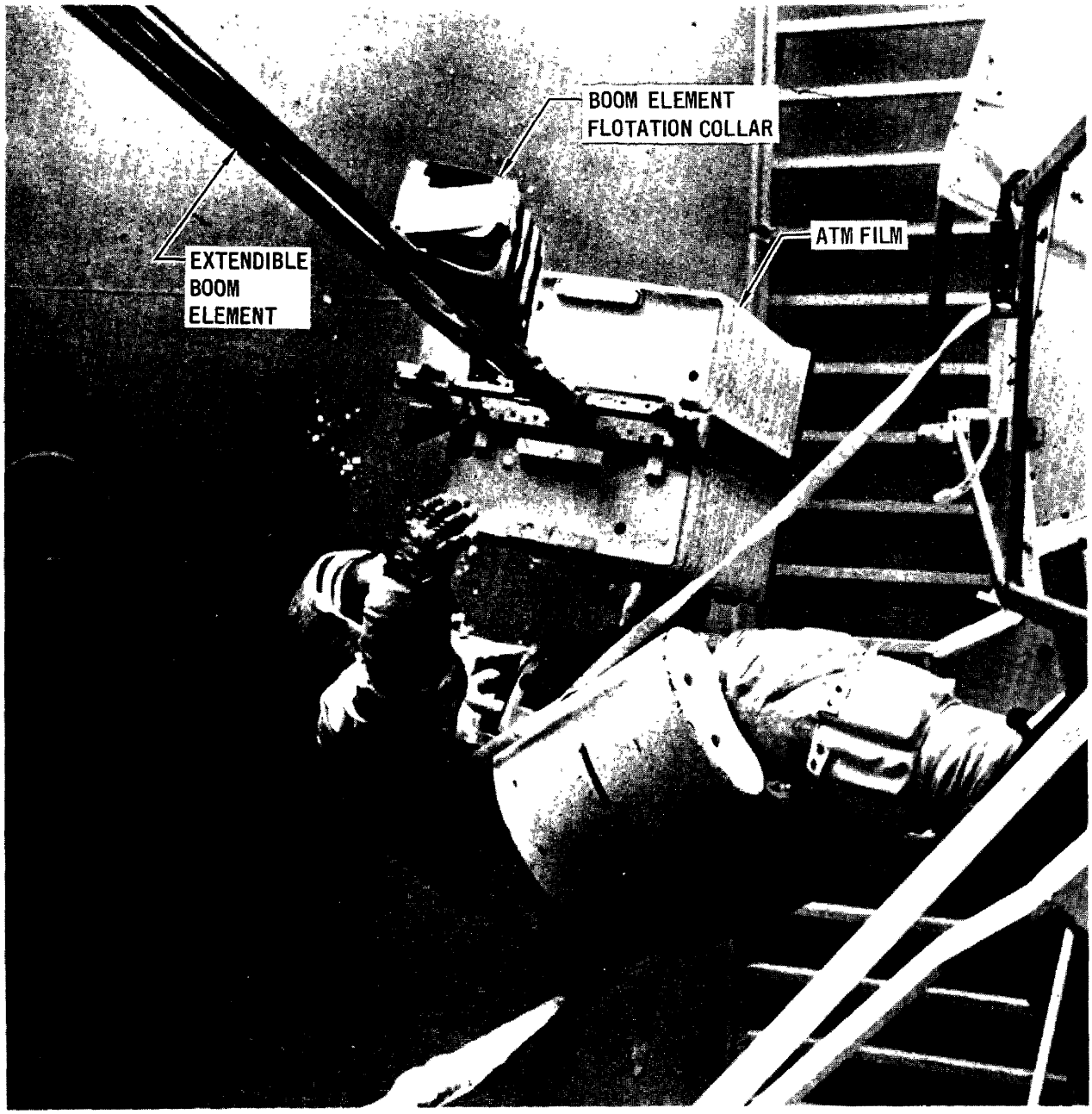


FIGURE 3-13 ASTRONAUT AT ATM TRANSFER WORKSTATION (VT)
WITH BOOM ELEMENT FULLY EXTENDED

- The extendible booms would only operate without slippage for two days and would have to be removed from the water, cleaned and wiped down with alcohol to remove grease from the boom element.
- Two additional back-up drive rollers were added to decrease slippage.

3.7.2 Clotheslines and Containers

Two clotheslines of different lengths were provided as a backup ATM film transfer system. The VC clothesline was the shorter unit and was stowed adjacent to the VC boom. The VS clothesline was stowed adjacent to the VS boom (Figure 3-14). The clotheslines were endless ropes with two package hooks tied directly into the rope approximately 1.0m (40.0 inches) apart.

Each clothesline also contained two swivel eyelet attachment hooks. One hook was connected directly to the structure of the boom mounting plate and the other hook was stowed in a special fiberglas container along with the clothesline. The clothesline ropes were folded back and forth in the container and held at the folds with elastic straps similar to the method used in parachute packing to retain the shroud lines. In use, the crewman pulled a velcro strap which opened the container's spring loaded lid, exposing the eyelet hook. In translating with the hook to the ATM, the crewman automatically deployed the clothesline from its container. When at the appropriate ATM work station, the crewman attached the hook to the clothesline deployment arm (Figure 3-15).

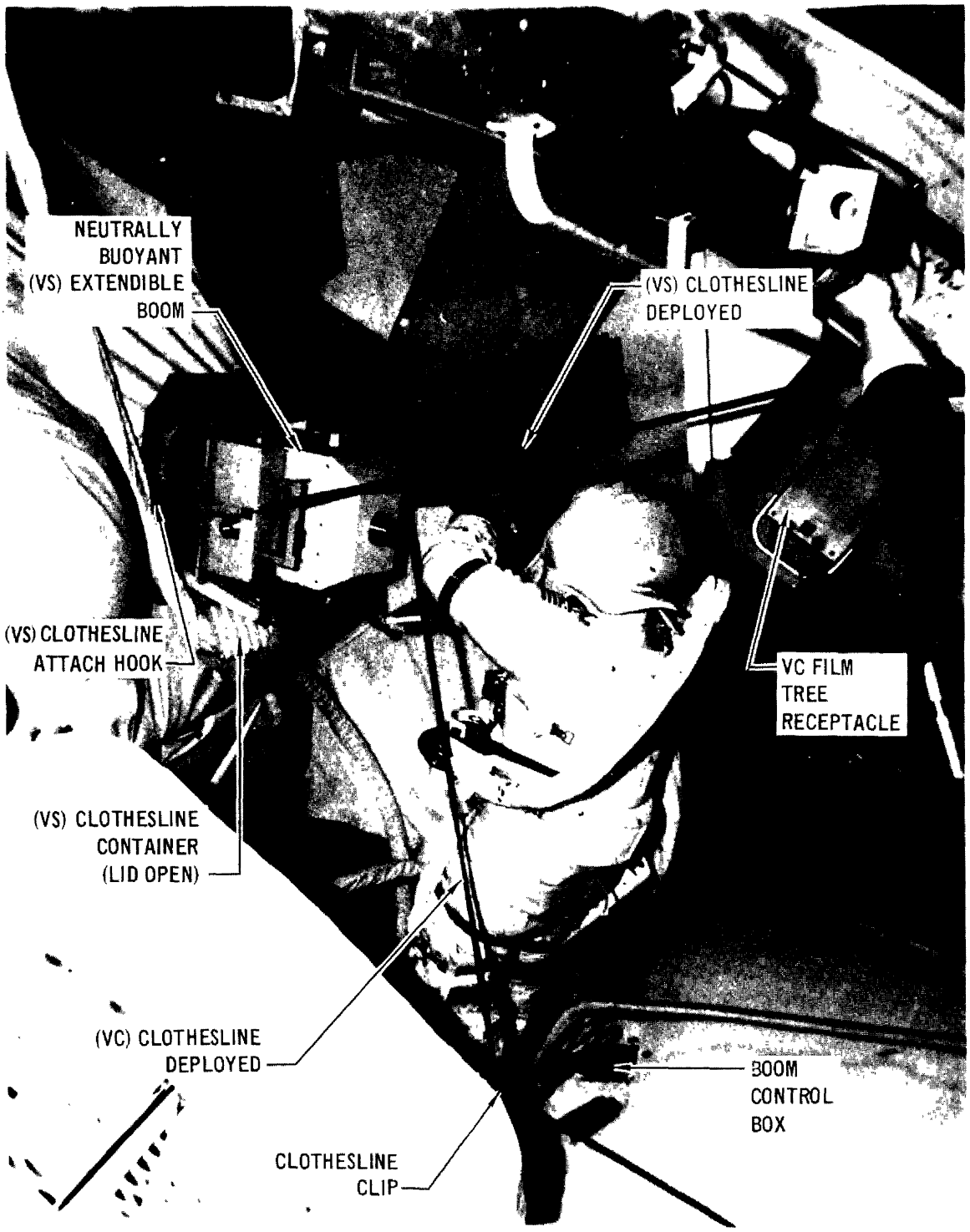


FIGURE 3–14 ASTRONAUT IN THE REPLACEMENT WORKSTATION (VR) PERFORMING EXTENDIBLE BOOM REPLACEMENT

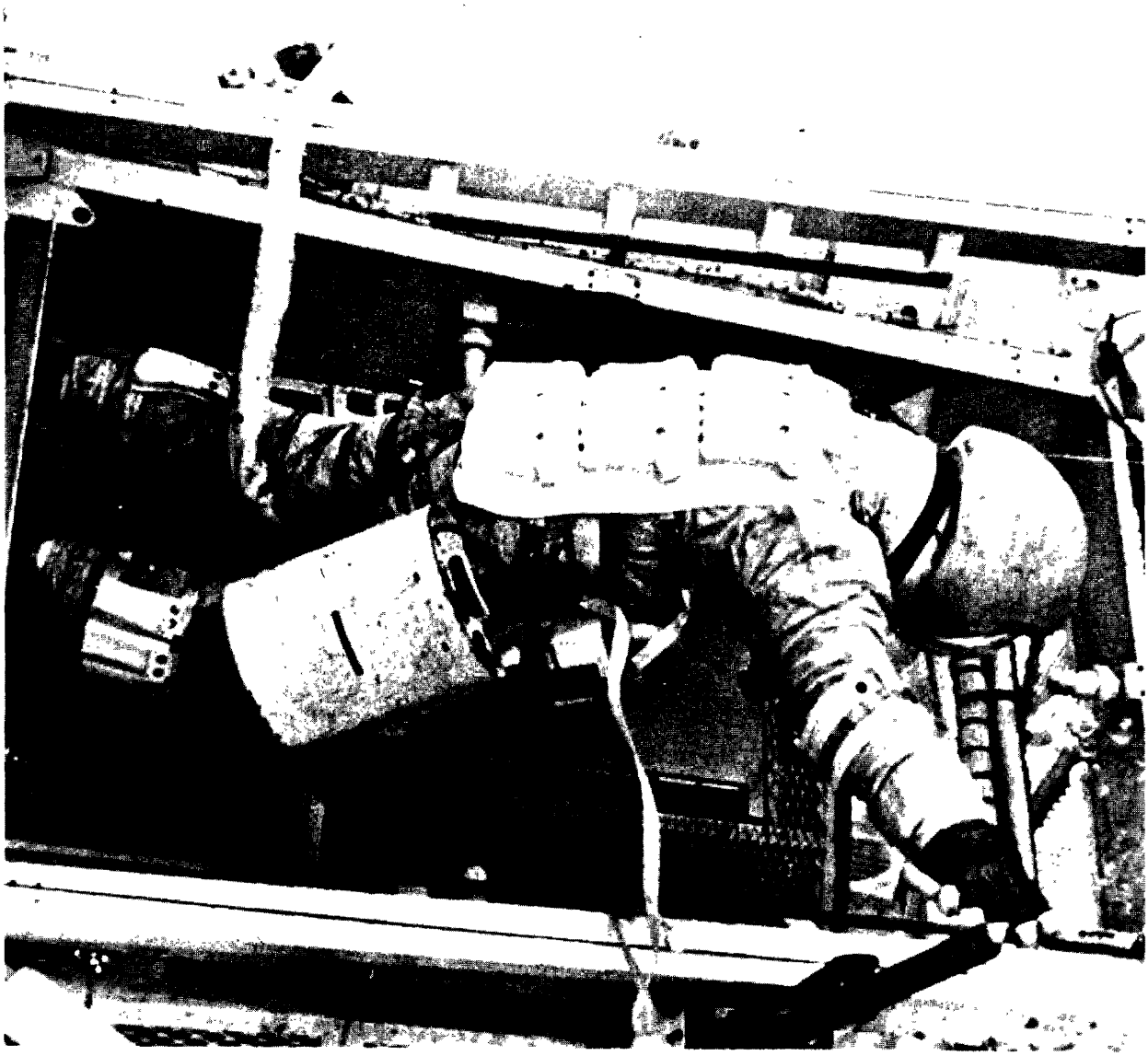


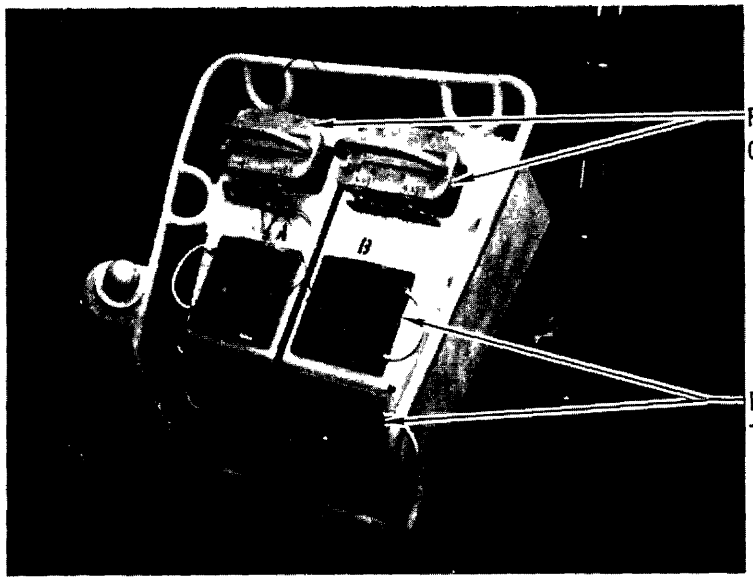
FIGURE 3–15 ASTRONAUT AT ATM WORK STATION (VC) UNFOLDING VC CLOTHESLINE DEPLOYMENT ARM

The NBS clothesline and containers had to be removed from the tank each time they were deployed so they could be dried and repackaged. Repacking two clothesline into their containers required approximately two hours each so two extra container assemblies were built to support consecutive NBS clothesline exercises. A different attachment method was also incorporated to facilitate replacement underwater by SCUBA divers. This was accomplished by reversing the four mounting screws so they could be used as threaded studs. The container assembly was packed on the bench with the hook that attaches to the boom baseplate temporarily stowed on top of the container with nylon velcro. When the container was taken underwater, the four threaded studs were installed through clearance holes in the boom mounting plate and fastened with brass wing nuts from the back side. The hook was then removed from the top of the container and attached to the baseplate.

Several changes were made to the flight articles because of clothesline evaluation and training in the NBS. These changes included addition of clips in the box corners to insure smooth clothesline deployment. Also, the swivel hook was relocated in the container so the astronaut would have easy access to the hook before EVA translation. The NBS perfected clothesline procedures were successfully proven in flight during the last SL4 EVA.

3.7.3 D024 Experiment Module

The D024 experiment module was a rectangular box with a guard rail extending around three sides (see Figure 3-16). One end of the module



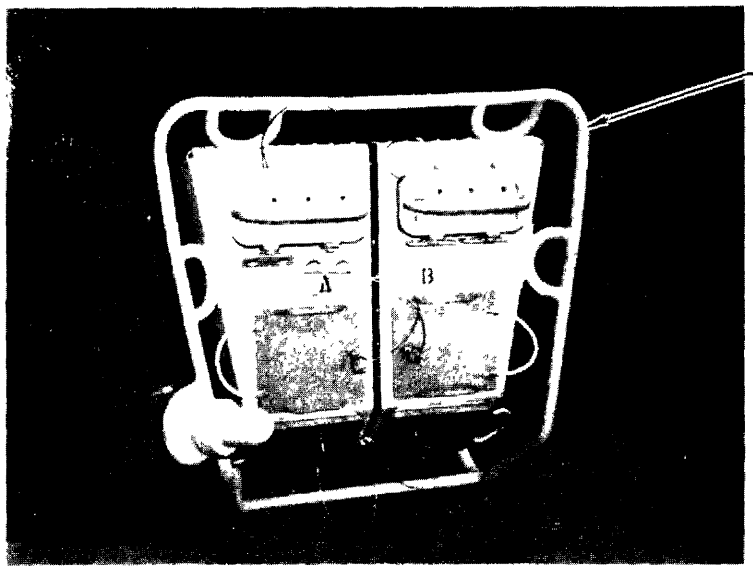


FIGURE 3-16 NBS D024 MODULE

contained two experiment return canisters, locked with pip pins. Four experiment trays were each attached on the module with four snaps and a pip pin. The module was mounted to structure of -Z Airlock truss and subsequently was relocated off center due to protrusion into the ATM film transfer path.

The module was fabricated and maintained by MDAC-E. The return canisters and experiment trays were furnished to NBS by NASA-JSC. The basic structure of the module was 6061-T6 aluminum and was identical to flight article except experiment trays were non-functional. The snaps on the experiment trays corroded underwater and required replacement. DC6 grease was applied to snaps to retard corrosion but it did not completely solve the problem. A hardware procedure was initiated to remove the trays from the water except during actual use in training.

The D024 experiment module was used during retrieval exercises of the return canisters and experiment trays by both prime and back-up crews. The EV2 crewman restrained himself on lower deployment assembly (DA) by wrapping his legs around the strut. He then removed the experiment trays (one of each type) and installed them into the return canister. After removal of return canister, EV2 passed the entire canister to EV1 crewman. The EV1 crewman installed return canister onto temporary stowage hook and then passed it back to EV2 after ingress into Airlock. This procedure was proven and perfected underwater prior to flight.

3.7.4 Boom Hook Stowage Box

The boom hook stowage box became a necessity when vibration tests showed the boom element would not carry launch loads of installed hooks. The decision was made to remove hooks, launch them in a special box and install them onto booms via first SL-2 EVA. A quick disconnect coupler incorporating a locking collar was used with the male end attached to the boom element and the female end attached to the boom hook (Figure 3-17). Alignment marks were added to the couplers to aid installation by the suited crewman. Prototype boom hooks and hook stowage box were made for NBS evaluations. The NBS booms were revised to accept the new hooks and the box location and flight installation procedures were developed in the NBS.

The stowage box was fabricated and maintained by MDAC-E and the boom hooks were furnished by NASA-MSFC. The basic structure was 6061-T6 aluminum with stiffening beads. Two slide locks and one pip pin with lanyard were mounted on the lid. The box was filled with soft foam with cutouts for boom hooks; this soft foam was unsuitable for underwater use because the foam would absorb water and lose its retaining qualities; therefore nonabsorbing hard foam inserts were fabricated and installed only for underwater use.

3.7.5 Cameras and Receptacles

All cameras, film cassettes, and receptacles for NBS service were fabricated by NASA-MSFC and maintained by Brown Engineering. MDAC-E

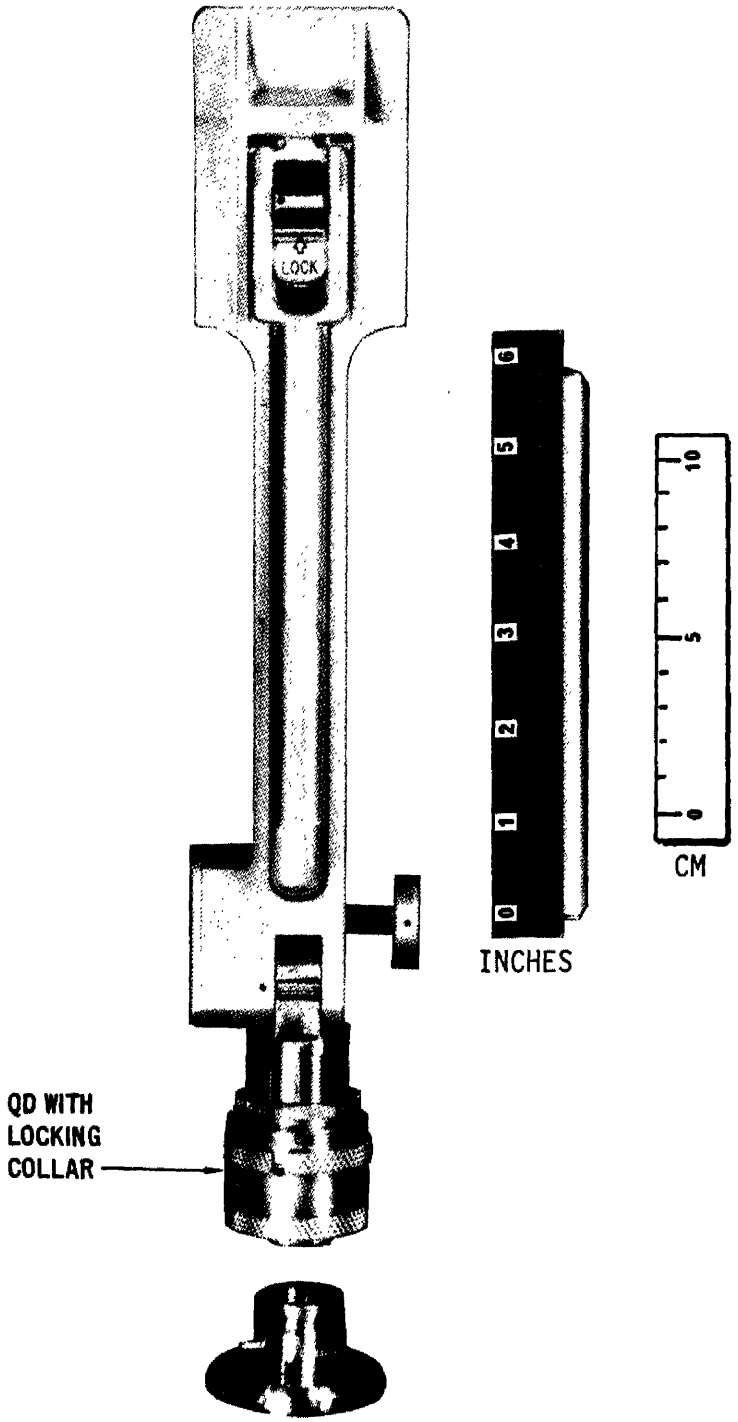


FIGURE 3-17 QUICK DISCONNECT BOOM HOOK

built and maintained all receptacle mounting structures in the AM and FAS. The camera and receptacle equipment was high fidelity and continually updated to project changes. Basic structure was different types of aluminum with some steel parts such as inserts, locking pins, etc. Steel parts were held to a minimum due to corrosion. Lightening holes were drilled wherever possible to facilitate neutralization. The NBS equipment was used extensively for development of film tree receptacle locations, for verification of film tree latching and locking mechanisms, developing flight procedures and training. Due to NBS exercises, one film tree receptacle inside the Airlock was relocated to avoid interference with the forward internal hatch. During normal EVA training, all NBS cameras film trees and receptacles were used for changeout procedure development in the Airlock, FAS and the ATM work-stations.

3.7.6 Internal & EVA Hatches

NBS hatches present unique problems for underwater simulators. Simulation of flight type actuation and correct loads are difficult. Moving an article, such as a hatch, through water created drag, therefore internal hatches were initially designed with expanded metal skins installed on an aluminum frame (see Figure 3-5). Design of the hatch yoke (hinge) was such that in one-G the hatch would not center itself as it would in a zero-G environment. Foam was added to hatch structure to give it neutral buoyancy, but this realized only partial success. After astronaut training began, expanded metal and foam were removed and

solid aluminum skin was installed to simulate confinement of the flight article. Astronaut hatch closing functions was abandoned in favor of real "feel" of lock compartment.

A high fidelity latching mechanism was installed on bulkheads and latching forces were regularly monitored and maintained. The latch dog mounting base was aluminum and had to be replaced once (in a two-year period) due to corrosion (see Figure 3-18). Latch dogs were covered by debris guards and as such presented an enclosed area that accumulated loose hardware and particle debris created by corrosion. The area was difficult to maintain since bulkheads were part of the basic tunnel and remained underwater except for one major update in April 1972.

Internal hatches were low fidelity trainer articles and did not contain a sealing bead that compresses into the seal as on the flight article. Therefore a different type seal of slightly porous neoprene rubber was used. These seals presented load problems with internal hatches because the neoprene rubber continually absorbed water and swelled, which increased latching forces. A portion of the seal that protruded beyond the sill was trimmed completely off except for four pads approximately .072m (3.0 inches long. These pads closely simulated flight latching forces until water was absorbed in the open cell neoprene rubber seal. In approximately 60 days underwater, the latching force was out of spec. During the majority of training exercises, internal hatches were placed in the correct flight position by utility divers prior to beginning EVA procedures.

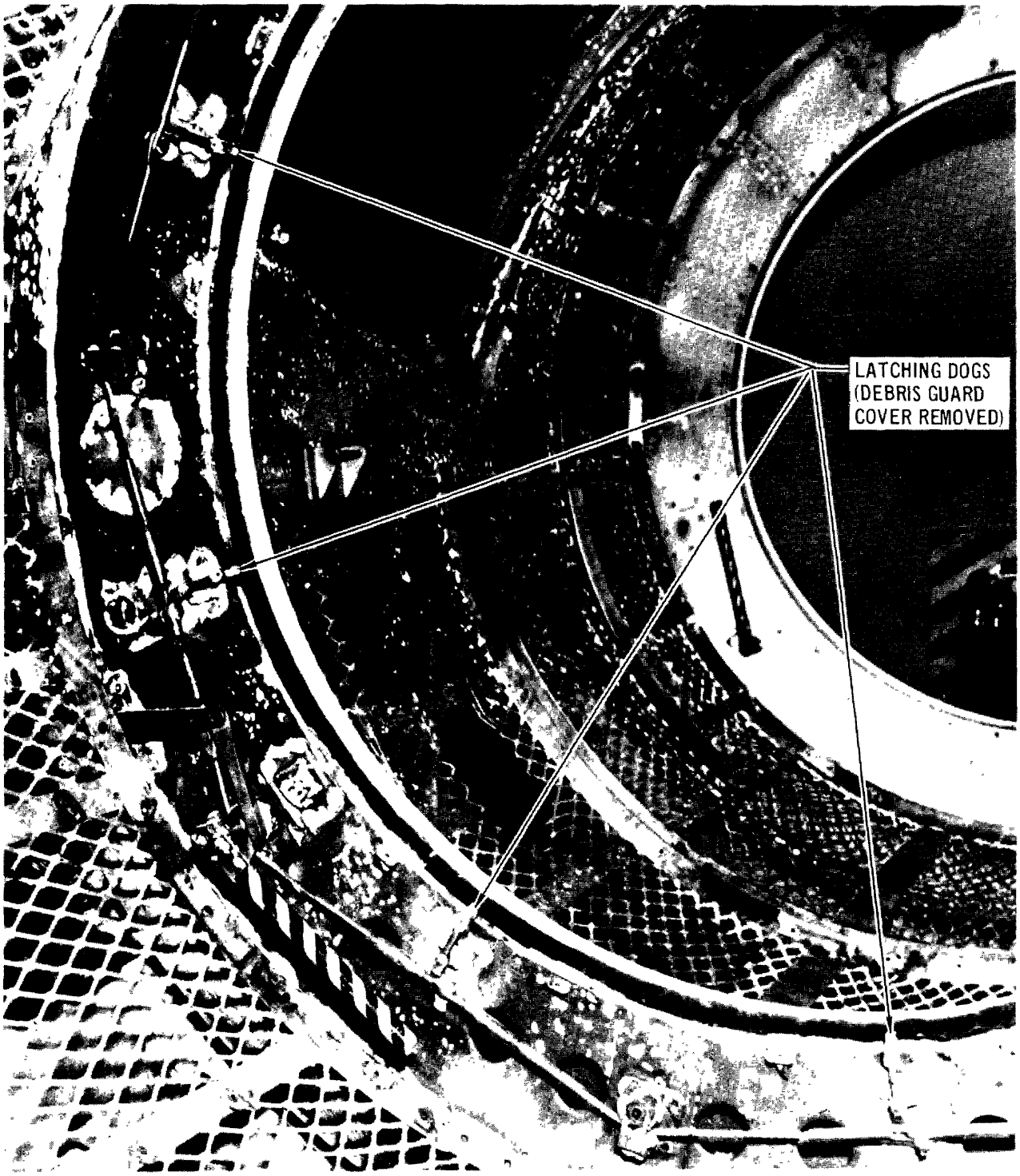


FIGURE 3-18 AM HATCH LATCHING MECHANISM

When EVA training began in early 1972, flight procedures called for the aft internal hatch to be kept closed during EVA. NBS exercises revealed that is was difficult to restow the LSU's in the stowage spheres while hard suited. It was found to be much easier to temporarily stow the LSU's in the aft compartment and after the EVA hatch was closed to stow the LSU's soft suited. The decision was then made to close the OWS hatch, leaving the AM aft hatch open so that the entire tunnel could be used for stowage of LSU's during ingress. The flight procedures were revised to reflect the experience gained from the NBS exercises.

Trainer orientation in the NBS placed the hinge line of the 90 lb EVA hatch across the top so the hatch swung upward to open. For neutralization all allowable foam was installed between structure of hatch and outer skin (Figure 3-19). With foam installed, astronauts could open and close the hatch while pressurized , but simulation of zero-G was never attained through full travel. Other neutralizing methods were considered, such as counterbalancing with weights on opposite side of tunnel, but discarded because it would require cables and pulleys in the EVA quadrant of the FAS and would have interferred with normal training.

The flight article EVA hatch had a retainer mechanism that allowed the hatch to open approximately .018m (.7 inch) when the handle was placed to the open position. This unit was installed to insure the hatch would not be blown open by lock residual pressure vented from the pressure suits.

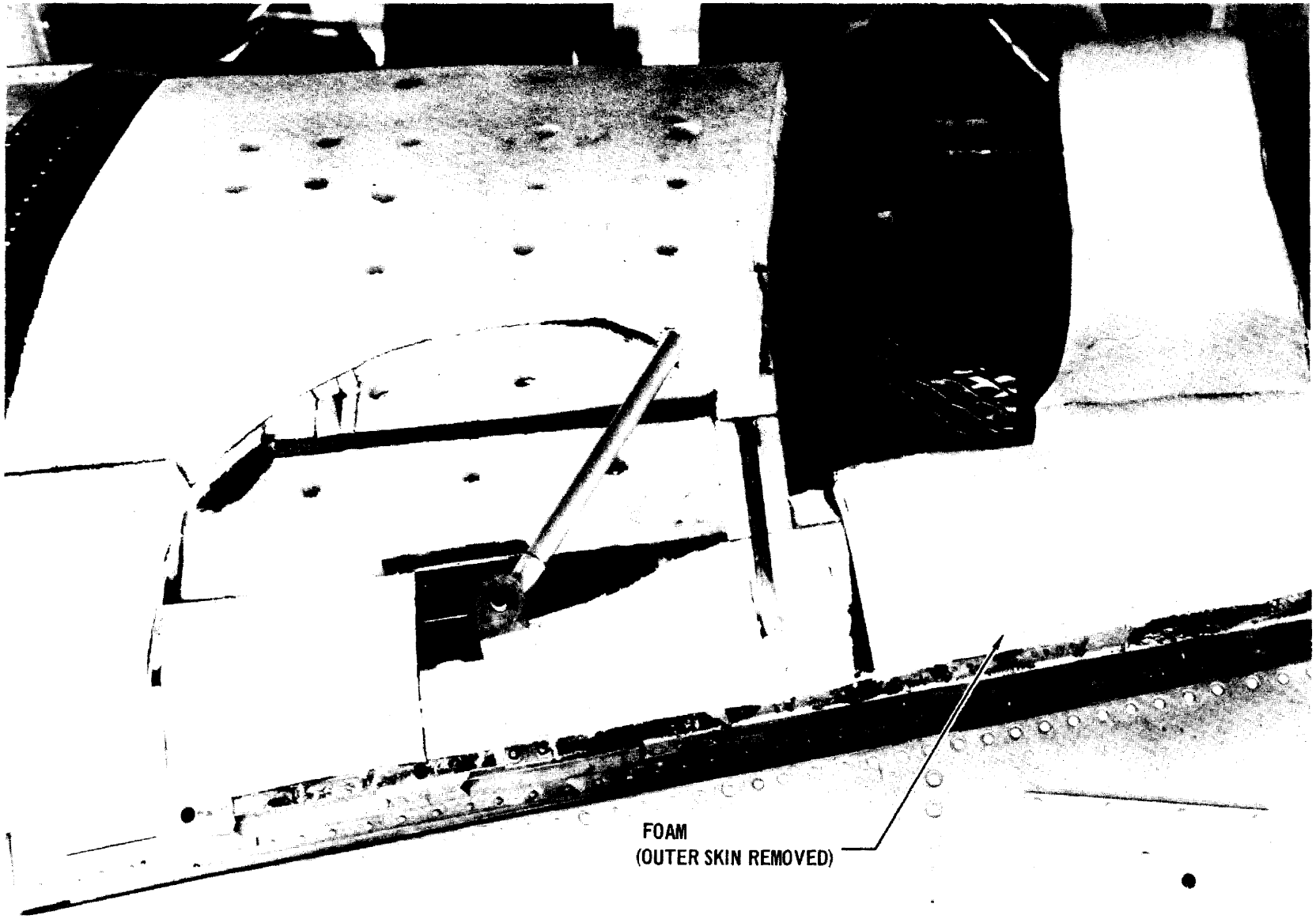


FIGURE 3-19 NBS EVA HATCH

The retainer mechanism was initially omitted from the NBS hatch because it prevented hatch opening from the outside by SCUBA divers and was against safety regulations. Since normal EVA training began in the lock compartment with the crewman opening the EVA hatch, the absence of this assembly created difficulty in following flight procedures. MDAC-E then designed a method which was agreeable with MSFC safety office where the retaining mechanism could be installed and the hatch could be opened from the outside. This was accomplished by a cable arrangement that connected the inside latch to a ring on the outside of the hatch. With this installed, safety divers could push slightly on the outside of hatch, pull the ring so the latch retainer would not catch and open the hatch if an emergency should occur (see Figure 3-20).

3.8 Training Hardware - Lessons Learned

The planning, fabrication and maintenance of Skylab NBS training hardware covered (7) years in which much experience was gained. Many early ideas were discarded and new ideas implemented. The trial and error method was used when no precedent could be found. The following recommendations are summations of the experience gained through several years of Skylab hardware being used underwater.

- Skins - Solid aluminum is preferred over expanded metal. It is more durable, facilitates replacement, modification and addition of equipment and provides realistic closure for crew.

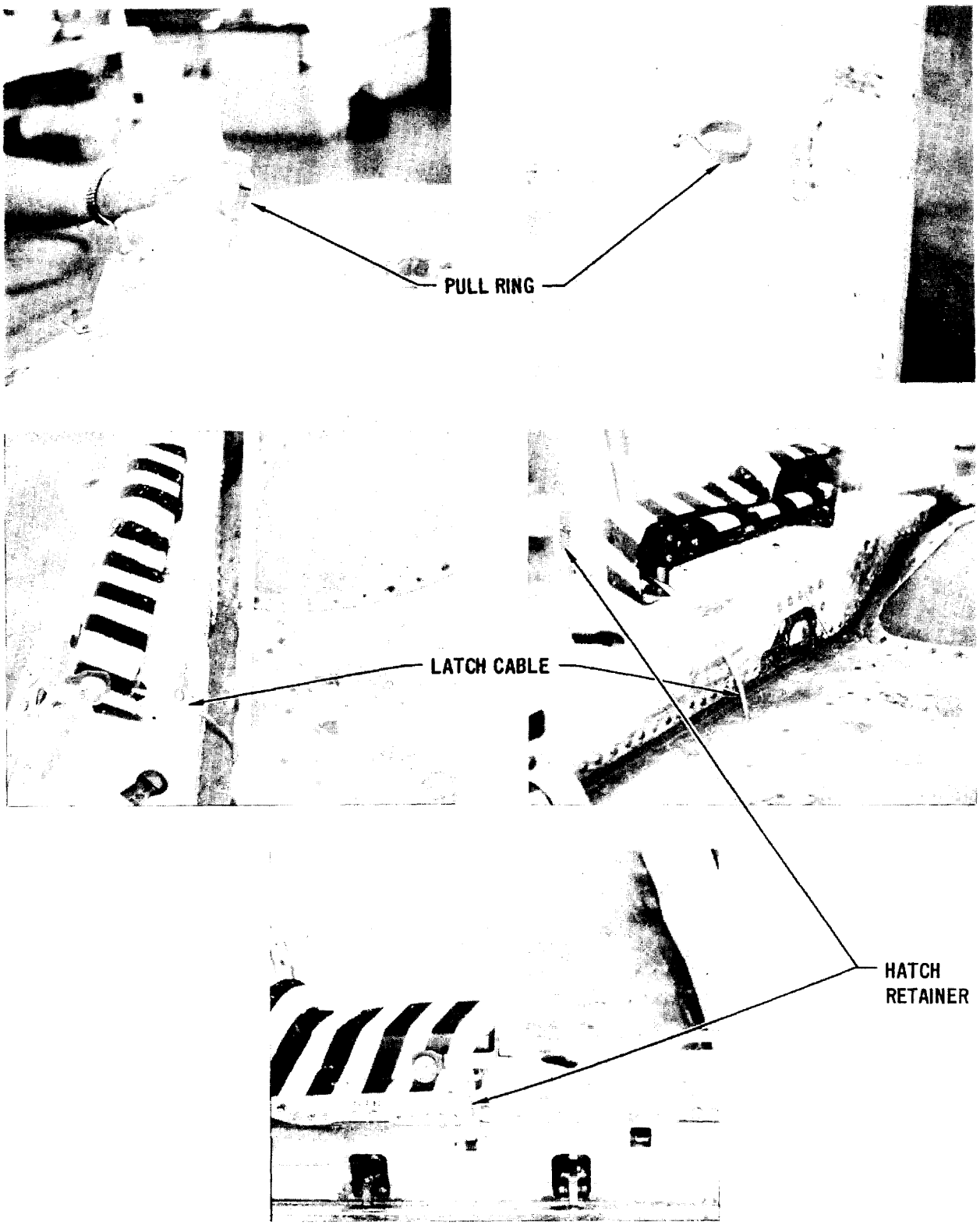


FIGURE 3–20 NBS EVA HATCH SAFETY RELREASE

- Functional hardware should be configured for on-site repair and not for return to vendor facility because training schedules are very tight.
- All trainer modules should be electrically bonded together and grounded external to tank to help retard corrosion from "battery action". Without grounding, hardware installed underwater will act as an anode for the tank structure.
- Riveted or bolted assemblies can be disassembled for replacement or repair and are therefore easier to maintain than welded assemblies. Only use welded assemblies when absolutely necessary.
- Hoisting lug locations should be included in NBS trainer designs and must be compatible with in-tank assembly procedures.
- Tapered guide pins are desired for mating modules underwater.
- Refrain from using aluminum alloy sheet, bar or rivets with high-magnesium content ($\geq$5%); these disintegrate rapidly underwater.
- Avoid "closed cell" in design of locking devices, connectors or any functional equipment to preclude "water lock" during underwater operations.
- Flight configuration lighting designed for underwater usage should be included in NBS trainers. With solid skins installed, lights are required for closed areas and night EVA training exercises.
- Fabric parts should be fabricated from water-compatible material such as Vinyl Laminated Facilon.

- Alodine all hidden surfaces of aluminum parts (inside tubes, handrails, closed areas, etc.) to retard aluminum hydroxide formation.
- Complex mechanism should be designed with regular maintenance planned and with emphasis on replaceability.
- Hardware use cycle and duration in the water, plus schedule slips, should be considered in the initial design and sufficient spare parts included.
- NBS peculiar design consideration should be made early in design stage. An example was the three air-operated booms. Although NBS requirements differed greatly from the flight article, units were fabricated as "spin-offs" of flight design and presented many difficulties for NBS operation and maintenance. Units had to be completely disassembled many times for corrosion, bearings, bushings, water seepage, boom element slippage, etc. Units were not adequately designed for high usage water service and had to have complete overhauls three times each during astronaut training period January 1972 through October 1973. This was in addition to many minor difficulties encountered such as broken elements, bearings, gears, bushings, etc. Much more design consideration should be given to training hardware as complex as booms.

4.0 SPECIAL HARDWARE REQUIREMENTS

Zero-G simulation in a water environment presents many hardware problems not found in other types of zero-G simulations or even in the space environment. Therefore, designing and fabricating test and training hardware for NBS usage is often a more difficult task than developing the actual flight hardware. Different materials and fasteners are used, special lubrication and surface coatings are required and special maintenance is needed to keep the trainers operational.

In all cases it is absolutely necessary to keep the mechanical forces on crew operated latches, connectors, etc. the same as on the flight items. Consideration has to be given to water corrosion, sealing of electrical components and hydraulic lock problems in certain types of mechanisms. It is also necessary to keep crew replaceable equipment neutrally buoyant and representative of the flight item.

4.1 Corrosion

Corrosion was the major problem with NBS Skylab hardware. Corrosive properties of the NBS water are above average due to the slightly acidic (low PH) Tennessee river water and the 1.0 parts per million (PPM) chlorine content required to kill bacteria and control algae. Soda ash is used to raise the PH between 7.2 and 7.6 which is less corrosive and ideal for diver comfort. Corrosion from galvanic activity was inconsistent from area to area and difficult to control because of the wide variation of materials used in the trainers. A change of materials in the tank will change

the corrosion rate from galvanic action. For example, the steel tank walls always exhibited corrosion and had to be painted once each year. In 1971 the tank walls were coated with a polyester resin which gave good corrosion protection to the tank walls but the hardware installed inside the tank immediately began corroding at an accelerated rate.

In the NBS, any aluminum surface would oxidize rapidly if not adequately protected. The aluminum oxide that formed on aluminum surfaces was extremely hard and rough and was not only unsightly but was a very real hazard to divers. Oxide would also quickly appear on protected surfaces if the coating was thin or had been scratched.

The initial approach to aluminum protection was to paint the basic structure with a coat of Super Koropon fluid resistant, clear enamel (#520-016) and curing solution (910-014) in a one to one mixture. To control tank galvanic action, sacrificial anodes of magnesium were attached with nylon screws onto bare aluminum in the AM and DA modules. Similar anodes of zinc were attached to the ATM basic structure. All aluminum detail parts were brush alodined and painted with MMS 405 Desoto light gull gray epoxy enamel. Fiberglass parts were also painted with epoxy paint.

During the major update and refurbishment period in 1972, it was discovered that the protective paint was not providing adequate protection. After sandblasting to remove all corrosion, all items except fiberglass parts were undercoated with Sherman Williams Hi-Bold Primer No. 96008 (16) and

painted with rubber based moisture and chemical resistant enamel (fiberglass parts were left unpainted). Experience showed that the rubber based enamel held up much better than the epoxy enamel. Even so, the problem remained that if a surface was scratched, corrosion would quickly form.

It was also discovered that the installation of sacrificial anodes provided relatively little corrosion protection.

During the hardware update period, aluminum expanded metal skins were found to be so corroded that they were easily broken exposing very sharp, ragged edges. The expanded metal skins were replaced by solid aluminum skins for diver safety and to give the crew the correct "feel" for the compartment.

Although relatively few steel parts, except fasteners, were used in the NBS Skylab, corrosion protection was a similar problem.

Aluminum handrails, due to extensive use and abuse, normally had a poor appearance because of corrosion. Originally, handrails were installed with Jo-Bolts the same as the flight vehicle. It was quickly discovered that handrails required frequent removal and refurbishment, so the attaching method was changed to screws. Tubes or plates onto which handrails were installed were tapped and the holes in the handrail mounting pad were drilled oversize to accommodate the attaching screws. With this installation method, handrails were easily removed and installed underwater. Handrails that were used considerably more than others were sandblasted and painted approximately six times each. This included all of the FAS area handrails and two in the EVA path to the ATM.

4.2 Materials

4.2.1 Metals

Stainless steel was the only metal that did not corrode in the NBS. It was mainly used for small fittings, latches, gears, fasteners, etc.

Selection of 2024-T4 aluminum for basic parts and 6061-T6 aluminum for welded parts proved to be a wise choice. Items fabricated from other types of aluminum were much more susceptible to corrosion and required replacement; for example, three deployment assembly fittings were inadvertently fabricated from tooling stock aluminum (TM673) and after a short time in the water they completely exfoiliated (see Figure 4-1). These fittings were replaced with 6061-T6 aluminum.

4.2.2 Fiberglass

Several pieces of the NBS hardware, not requiring high structural strength, were fabricated from fiberglas. Some examples are: the debris guards and valve covers inside the AM module; the electronics module cover, the ECS dome cover, and the LSU spheres outside of the AM module; and the EVA hatch crank cover. Fiberglass held up remarkably well with no signs of corrosion, and except for painting, required no maintenance. Several types of paint were applied to the fiberglas to reflect flight configuration, but none could be found that would not peel. Paint, including the rubber base enamel, bubbled and peeled especially when the parts were removed from the water. This experience led to the

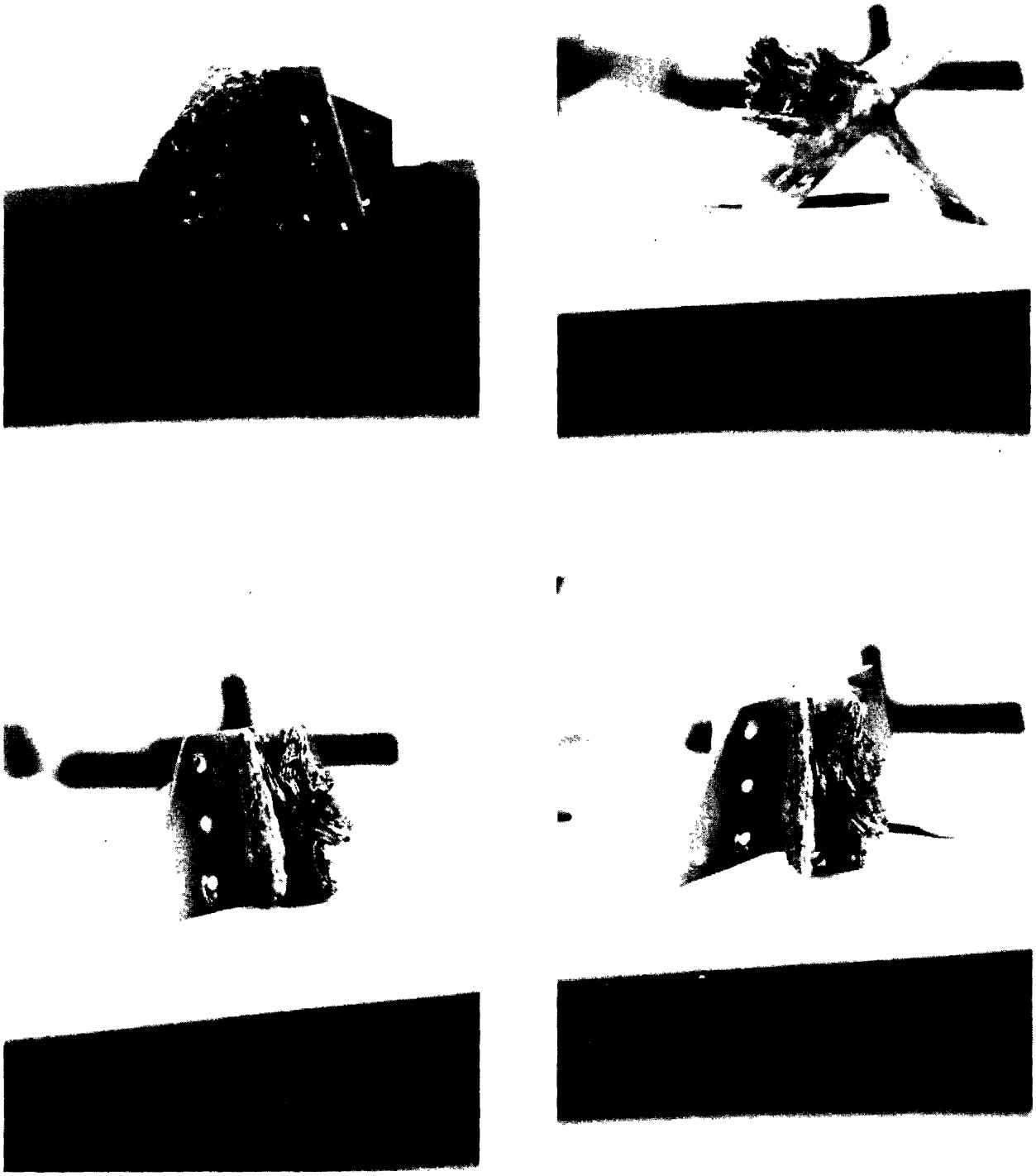


FIGURE 4-1 TM673 ALUMINUM FITTING EXFOLIATION

decision to leave all fiberglass parts unpainted, except the cover on the EVA hatch crank. This cover was painted with black and yellow diagonal stripes to signify "Caution", as on the flight article.

Commercial pigments are available to fabricate colored fiberglass, eliminating the need for painting. Suggested procedure for ordering such material is specifying the desired color "Ground-in-Epoxy Resin". The colored resin is then applied to the clear laminate cloth and becomes an intergral part of the fiberglass.

4.2.3 Plastics

A few pieces of the NBS hardware were fabricated from plastics and experienced no problems from the corrosive properties of the water. Some examples are: a simulated wire bundle attached to forward FAS ring; hose clamps; and a clear plexiglass disc used to take the place of the OWS hatch. The clear plexiglass disc was used instead of the NBS OWS hatch (which is closed for EVA) to allow TV coverage of the crewmen inside the lock compartment. Clear plexiglass is so transparent underwater that tape had to be added so scuba divers would realize it was there.

4.2.4 Rubber

NBS hatch seals, the original dummy wire bundle around forward FAS ring, and the flexible portion of the ATM nitrogen purge line were fabricated from rubber. A rubber hose (MIL-H-6000) was used for the dummy wire bundle but after a short time underwater, contact with the hose resulted in a black substance on the divers' hand, suit, etc. This dummy wire

bundle hose was replaced with a plastic hose held in place with plastic clamps. No problems were experienced with the plastic hose.

The NBS EVA hatch seal was exactly like the flight article. The material was SHORE "A" 16 durometer silicone rubber. No problem was experienced underwater with this material.

The two internal hatch seals were fabricated from silicone sponge rubber (open cell). The seals absorbed water and bulged, increasing the latching forces; they were trimmed several times in attempts to eliminate the problem, but the final decision was to eliminate the seals, except for four small pads on each hatch ring to retain the hatch in the correct position.

4.2.5 Tape - Aluminum & Mylar

Several ducts in the NB trainers were wrapped with tape to simulate the flight article. These included the circulation ducts inside the Airlock and the MOL Sieve overboard vent on the outside of the STS section. Flight type MYLAR No. 850 aluminum tape was used until the supply was exhausted. A commercial aluminum tape was then substituted. Both types of aluminum tape retained their adhesive qualities, but the commercial tape became discolored after approximately 90 days underwater, becoming very dark and presenting an unsightly appearance. The Mylar aluminum tape showed no color change.

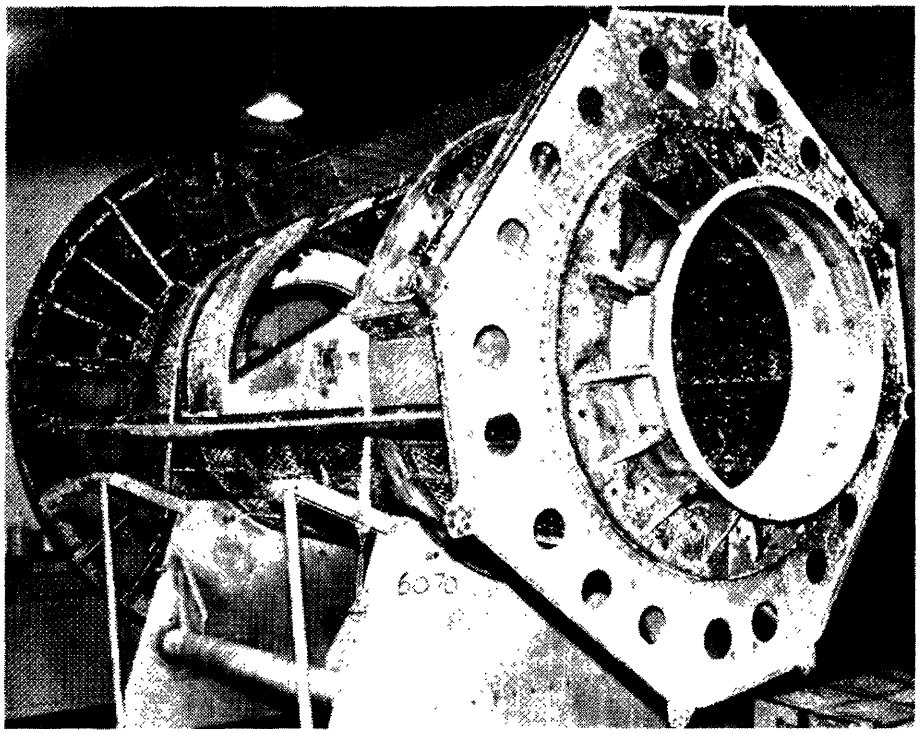
4.2.6 Fasteners

Fastener selection began as a duplicate of flight articles, but it soon became apparent that underwater hardware usage demands special considerations. Cadmium plating on standard fasteners was easily cracked on installation. Every crack in the protective finish began to corrode and soon became very unsightly and hazardous to divers (see Figure 4-2). The only satisfactory solution to the fastener problem was to use stainless steel fasteners. A combination of stainless steel bolts and brass nuts was best for large fasteners.

Rivets were used extensively throughout the flight article and the NBS hardware. Little initial consideration was given to the material of the rivets used for NBS. Some rivets (5056 aluminum alloy) which contained 4.5 to 5.6 percent magnesium were used in the NBS; these rivets deteriorated underwater in approximately 90 days. They deteriorated to the extent that any plates, skins, etc, that they were used on, would have fallen off. Periodic inspections of NBS hardware prevented any such occurrance during Skylab. Subsequently, during the major update, all corroded rivets were replaced with aluminum "pop" rivets.

4.2.7 Lubricants

Lubricants such as DC-6 grease have a definite place in underwater hardware and were used for many moving parts such as gears and springs. When the protective finish is worn off moving surfaces, corrosion quickly begins. One disadvantage of DC-6 grease is that it attracts loose metal particles in the water and presents an unsightly appearance. DC-6



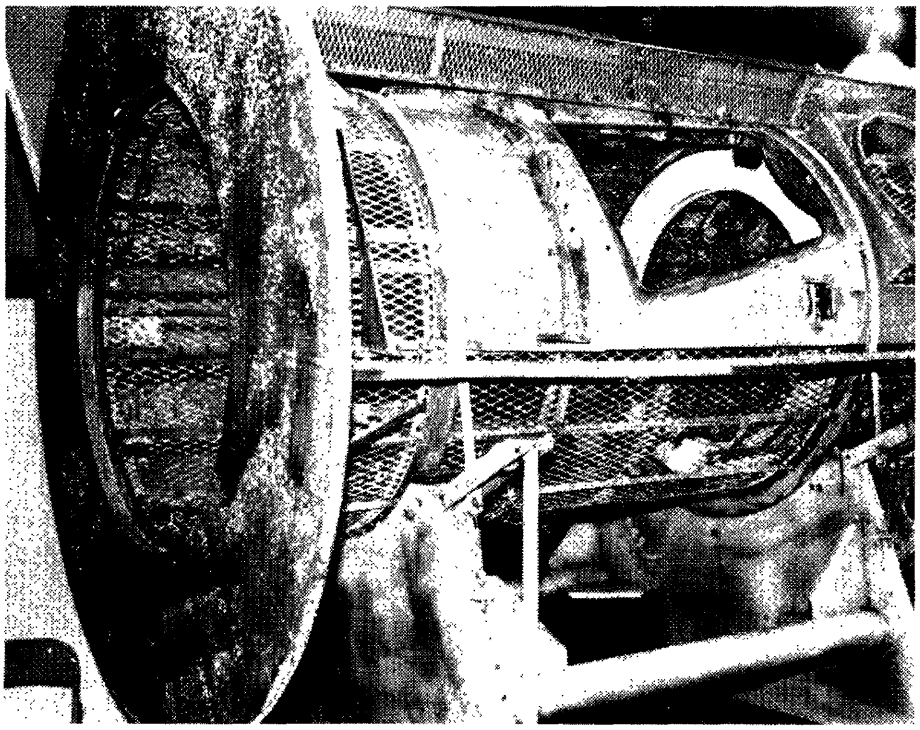


FIGURE 4-2 FASTENER CORROSION

grease was applied to the gear train in the air operated booms and created a slight problem by adhering to the elements and causing the rollers to slip. Units were cleaned with alcohol many times to remove grease from elements.

4.2.8 Velcro

Nylon velcro lost its' effectivity after approximately 90 days underwater; the hook portion became soft and would not retain the pile. Velcro parts, such as straps to restrain open internal hatches and closures that secure clothesline containers, were replaced as required.

4.3 Maintenance

All NBS hardware required periodic maintenance and complex mechanisms such as booms, required special attention and care to avoid problems with corrosion. A major hardware update and maintenance was performed on all NBS Skylab hardware in early 1972. All hardware was removed from tank, cleaned, updated to latest project changes, repainted and reinstalled underwater.

It was found that after a module was removed from the water for modification the painted surfaces bubbled and sandblasting was required to remove old paint.

- If the metal part was .0005m (.020 inches) or less thick, the sandblasting operation destroyed the part; therefore, these parts required replacement.

- If the part was wood, it would not hold up under sandblasting; therefore, wooden parts had to be cleaned and sanded separately by hand.

Maintenance plays a major role in underwater hardware to insure maximum benefit from the facilities. The only metal that will withstand corrosive properties found in the water is stainless steel. Training schedules should reflect planned maintenance periods for underwater hardware at approximately six to nine month intervals. Complex mechanisms should be so designed that they can be easily removed from water and kept dry as much as possible.

4.4 Fabrication and Fidelity

4.4.1 Fabrication

Design and fabrication of detail parts was the responsibility of a relatively small number of people within each contributing organization. Because trainer funding was limited, standard fabrication methods and available materials were used whenever possible. Probable length of planned service was considered, but little consideration was given to program stretch-out, thus many items required replacement.

4.4.2 Hardware Fidelity

The fidelity of each detail was determined by the planned activity to the following fidelity code:

A = Flight Type - All functional and physical aspects of the component or subsystem will be representative of the flight design and will be operable and demonstrated within the appropriate environment. Example: Switch must turn on specific items of equipment as indicated on control panel.

B = Functional Only - All functional aspects of the component or subsystem will be representative of flight design and will be operable and demonstrated within the appropriate environment. Example: Switch must turn on specific items of equipment. Switch configuration will not represent flight hardware.

C = Physical Only - All physical aspects of the component or subsystem will be representative of the flight design (Installation and crew interfaces only) and will be operable and demonstrated within the appropriate environment. Example: Switch must operate functionally but need not operate other hardware.

D = Envelope Only - Exterior shape of the component or subsystem will be representative of the flight design. In general, this hardware is used only to verify compartment location within the appropriate environment. Example: A wire bundle shall be a "3-D" volumetric representation for external appearance.

Normal planning was for astronaut interface equipment, especially that in the 90 degree EVA quadrant, to be complete and of high fidelity. The majority of structure was of "B" type fidelity and non-EVA hardware was generally

"D" fidelity. Exceptions were the EVA hatch ("A") & latching mechanism ("A"). EVA hardware was generally of the "B" type, except booms which are described in Section 3.7.1. Control panels in the lock section of the Airlock and all ATM control switches were "C" type.

Contingency training for repairing Skylab hardware discrepancies was not planned for during the initial design and problems frequently occurred in areas where fidelity was too low for adequate training. These areas included the outer skin of the OWS, equipment located in the non-EVA quadrant of the FAS, the S193 experiment module, thermal curtains, discone antennas, and others. Areas required for contingency training were upgraded from "D" to "B" fidelity.

4.5 Lessons Learned

Hardware destined for long duration underwater usage must be well planned and fabrication methods must avoid production "spin-offs" since water peculiar problems such as corrosion, special materials, neutralization, water lock and protective paints are very important. Handling and installation procedures must be a prime consideration. Planned maintenance will be especially necessary for complex mechanisms.

Corrosion is the worst enemy of underwater hardware. Any corrosive material will present complex problems, but a well planned program will keep it to a minimum. Incorporation of a bonding strap arrangement between modules with grounding external to the tank will help maintain hardware.

Fidelity planning early in the program will cut maintenance costs and high fidelity hardware should be designed so installation will be simple. If this is accomplished, complex mechanisms can be kept out of water except for actual use.

Material selection lessons learned include the following:

- 2024 and 6061 aluminum (for welded parts) are the preferred aluminum material and should be used throughout the trainers to minimize galvanic activity.
- Zinc or magnesium sacrificial anodes are of <u>no use</u> for aluminum corrosion protection.
- Stainless steel bolts/nuts are preferred for small fasteners and stainless steel bolts with brass nuts for large fasteners.
- 17-7PH (AMS 5673) stainless steel is the preferred spring material.
- The most effective surface coating is a rubber based enamel and primer.
- Stainless steel is impervious to NBS corrosion and should be used in high wear mechanical components.
- Fiberglass will not corrode in the NBS. It is an excellent material for non-structural equipment and low fidelity envelopes. In addition it is easily fabricated with rounded corners offering excellent sharp edge protection. If colors are required, they should be incorporated in the resin during fabrication.

- Closed cell silicone rubber retains its resilient qualities underwater and will not deteriorate in the NBS environment. Open cell rubber or foam absorbs water and should not be used as hatch seals or in any mechanism where crew operating forces must be consistent.

5.0 TRAINING

Fifteen astronauts (three primary crews and two back-up crews) received Skylab EVA training totaling 543 hours in the NBS (Figure 5-1). In addition, 95 hours were spent in the NBS for contingency EVA training after SL-1 launch (Figure 5-2). This section covers both the normal (planned) and the contingency (unplanned repair) training of the Skylab crews. Normal EVA training contained malfunction procedures, "Built In", to accommodate possible equipment failures. These malfunction procedures were practiced as part of the normal exercises and are not to be confused with training for Skylab repair EVA's, herein designated as "Contingency EVA".

Two pressure suited crewmen were trained at a time in the NBS with the 3rd crewman in the control room narrating the EVA procedures. Each exercise involving two suited crewmen required a minimum of nine to eleven additional divers in the water with the astronauts. These included four safety divers, two utility divers, two water safety divers and one to three photographers depending on the data requirements. In addition, a suited exercise required four chamber and pressure suit qualified personnel on the top deck and a fully staffed control room. In total, twenty-one personnel were required to support a NBS training exercise, not including MSFC medical, safety, and JSC personnel.

DATE	TOTAL HOURS *	CREW	TYPE OF TRAINING
9-11 FEB 72	28.0	SL-2 PRIME & BACKUP	AO BOOM/CLOTHESLINE/EXP. D024
8-10 MAR 72	24.0	SL-2 PRIME & BACKUP	AO BOOM/CLOTHESLINE/EXP. D024
22-24 MAR 72	24.0	SL-3 PRIME & BACKUP	AO BOOM/CLOTHESLINE/EXP. D024
11-12 APR 72	18.0	SL-4 PRIME	AO BOOM/NB BOOM "CHANGEOUT"/CLOTHESLINE
16-18 MAY 72	24.0	SL-3 PRIME & BACKUP	AO BOOM/CLOTHESLINE
20-22 JUN 72	24.0	SL-3 PRIME & BACKUP	AO BOOM/EXP. D024
18-19 JUL 72	15.0	SL-2 PRIME & BACKUP	AO BOOM/NB BOOM "CHANGEOUT"
1-2 AUG 72	18.0	SL-4 PRIME	AO BOOM/CLOTHESLINE
29-31 AUG 72	30.0	SL-2 PRIME & BACKUP SL-3 PRIME	AO BOOM/NB BOOM "CHANGEOUT"/EXP. D024
17-20 OCT 72	36.0	SL-3 PRIME & BACKUP	AO BOOM/CLOTHESLINE/EXP. D024
7-10 NOV 72	39.0	SL-2 PRIME & BACKUP SL-4 PRIME	AO BOOM/CLOTHESLINE/EXP. D024
23-26 JAN 73	39.0	SL-2 PRIME & BACKUP SL-4 PRIME	AO BOOM/CLOTHESLINE/EXP'S. D024 & S230
13-16 FEB 73	48.0	SL-3 PRIME & BACKUP	AO BOOM/CLOTHESLINE/EXP'S. D024 & S230
27-29 MAR 73	40.5	SL-2 PRIME & BACKUP SL-4 PRIME	AO BOOM/NB BOOM "CHANGEOUT"
9-11 APR 73	23.0	SL-2 PRIME & BACKUP	AO BOOM/CLOTHESLINE/EXP. D024
14 MAY 1973	SKYLAB SL-1 LAUNCH		
25 MAY 1973	SKYLAB SL-2 LAUNCH		
22-26 JUN 73	13.5	SL-3 PRIME & BACKUP	AO BOOM/NB BOOM "CHANGEOUT"/CLOTHESLINE/ EXP'S. D024, S230, & S020
25-26 JUL 73	24.0	SL-4 PRIME	AO BOOM/NB BOOM "CHANGEOUT"/CLOTHESLINE/ EXP'S. S149, S230, S020, & T025
28 JULY 1973	SKYLAB SL-3 LAUNCH		
12-13 SEP 73	24.0	SL-4 PRIME & BACKUP	AO BOOM/CLOTHESLINE/RATE GYRO REPLACE-MENT/EXP'S. D024, S149, S201, S228, S230, & T025
9-12 OCT 73	51.0	SL-4 PRIME & BACKUP	AO BOOM/CLOTHESLINE/EXP'S. D024, S149, S193, S201, S228, S230, & T025
16 NOV 1973	SKYLAB SL-4 LAUNCH		

NOTES:

*Total Suited Astronaut manhours underwater = 543.0

AO BOOM = AIR OPERATED BOOM

NB BOOM = NEUTRALLY BUOYANT BOOM

FIGURE 5-1 NORMAL EVA-NBS TRAINING SCHEDULE

DATE	TOTAL HOURS *	CREW	TYPE OF TRAINING
22 MAY 73	5.5	SL-2 PRIME	FLIGHT CONTINGENCY/TWIN POLE SAIL DEPLOYMENT
25 MAY 1973		SKYLAB SL-2 LAUNCH	
2-4 JUN 73	27.0	SL-4 PRIME	SL-2 PROCEDURES
22-26 JUN 73	52.5	SL-3 PRIME & BACKUP	SL-3 PROCEDURES
28 JULY 1973		SKYLAB SL-3 LAUNCH	
2-9 AUG 73	7.0	SL-3 BACKUP	FLIGHT CONTINGENCY
13 SEP 73	3.0	SL-4 PRIME & BACKUP	RATE GYRO REPLACEMENT
16 NOV 1973		SKYLAB SL-4 LAUNCH	

NOTES:

*Total Suited Astronaut manhours underwater = 95.0

FIGURE 5-2 FLIGHT CONTINGENCY EVA – NBS TRAINING SCHEDULE

5.1 Normal EVA Training

There were six planned two-man EVA's for the Skylab missions and each crew, plus the backup crews, were trained to perform any combination of EVA tasks. This training was successfully accomplished by conducting NBS exercises with a typical test sequence consisting of two suited astronauts twice per day for three consecutive days (Refer to Figure 5-1). When possible, at least two weeks was allotted between each three day training exercise for NBS facility maintenance and to prepare the hardware for the next training exercise. Also, as a standard practice, the NBS personnel would run through the planned training exercise three to five days before the astronauts arrived for actual training. This allowed time to correct any anomalies and to suggest procedure changes which helped assure a more successful training exercise. As a result, the

entire Skylab NBS training program was conducted with only two interruptions. The element of one air operated boom was destroyed when it became entangled in the gears; this stopped the training exercise until the spare boom could be installed (Figure 5-3). The other interruption to training occurred when a support diver had to enter the recompression chamber and the medical representative stopped the exercise for safety precautionary reasons.

The normal NBS EVA training exercise started with the two suited astronauts in the Airlock "lock Compartment" ready for egress and ended with ingress and closing of the EVA hatch. Some EVA preparation training (i.e., translating to the lock compartment from the OWS) was conducted underwater but the majority of the IVA training was accomplished in the "One-G" trainer at NASA-JSC, Houston, Texas. EVA hatch training (opening and closing) was done with a combination of the NBS and the One-G trainer. All training for ingress and egress through the EVA hatch was conducted underwater in pressure suits.

A normal, planned-flight EVA was for two crewmen to perform the EVA with the third crewman observing the activity through a STS window and narrating the procedures. EVA crewmen were designated EV1 and EV2 with the IVA crewman designated EV3. A normal NBS film retrieval/installation EVA exercise consisted of the following sequence of events:

- o EV1 opens Airlock EVA hatch and inserts hatch restraint.
- o EV1 egresses Airlock to FAS workstation (Figure 5-4).

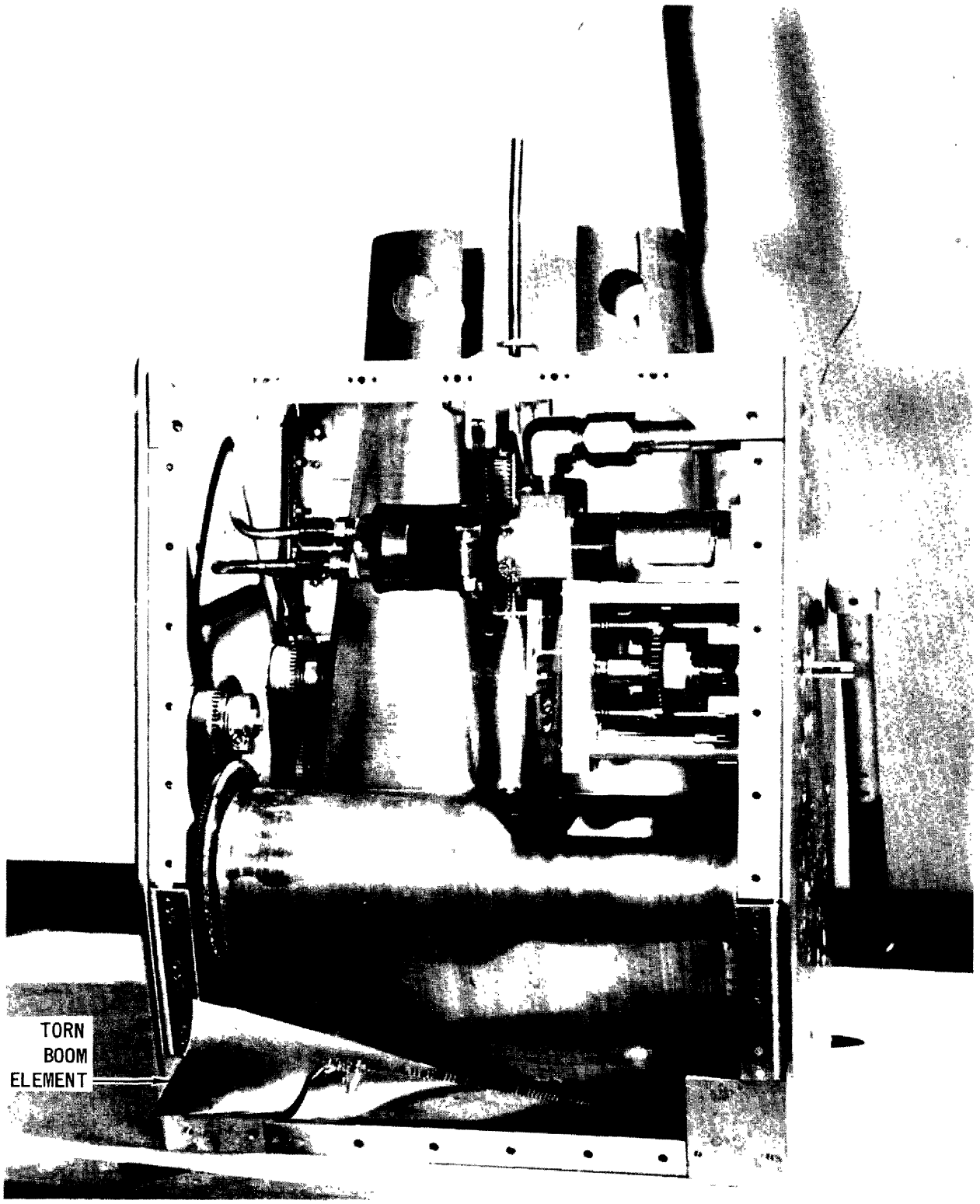


FIGURE 5-3 NBS EXTENDIBLE BOOM (COVER REMOVED)

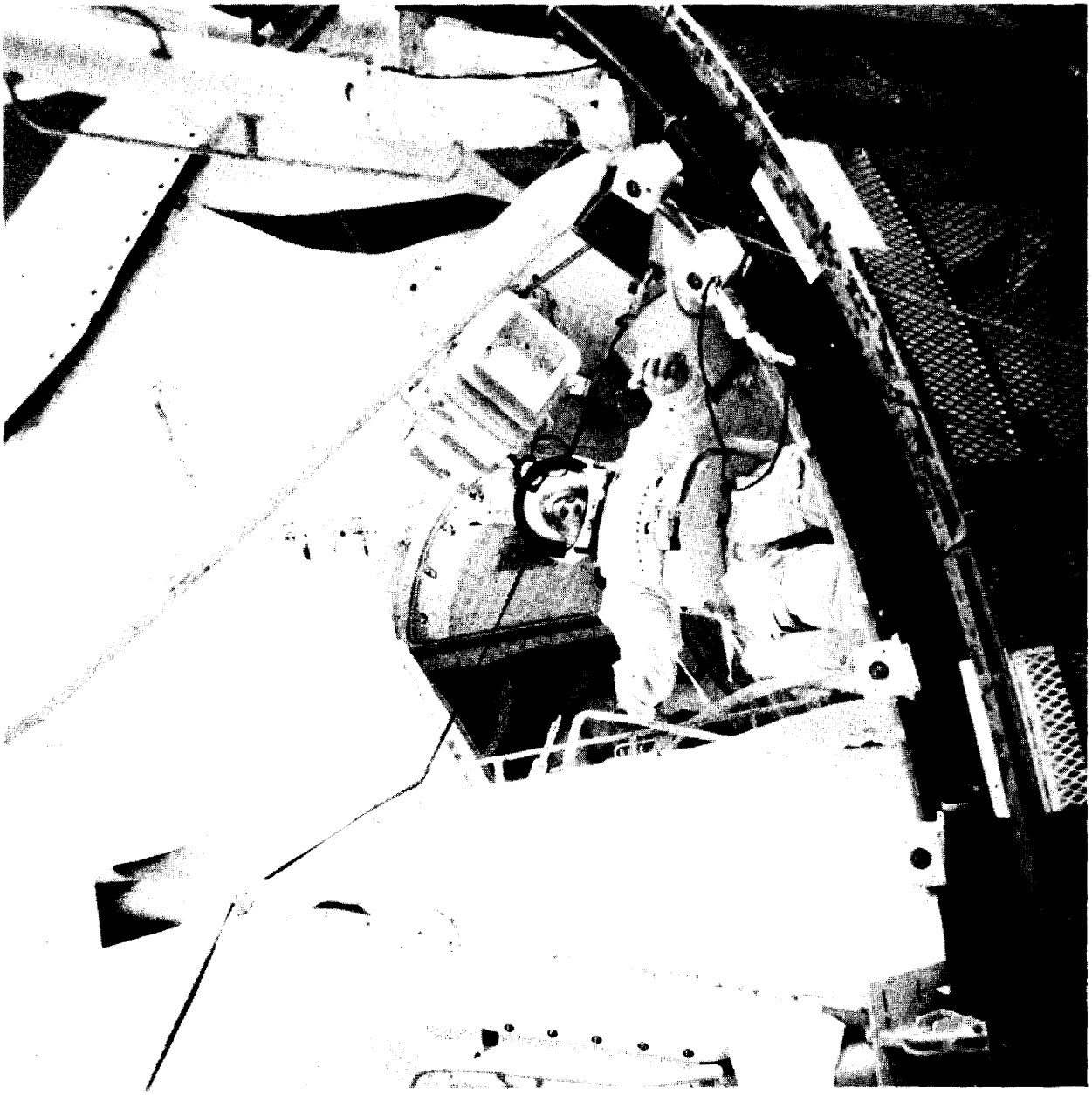


FIGURE 5–4 ASTRONAUT AT THE FAS WORK STATION (VF)

- EV2 passes all appropriate film packages, etc., to EV1.
- EV1 stows equipment in FAS area (Figure 5-5).
- EV2 egresses Airlock and goes to ATM center workstation (VC) (Figure 5-6).
- EV1 verifies booms operational and installs hooks.
- Changeout of film via boom (or clothesline).
- EV2 moves to ATM sun and transfer workstation (VT) to receive sun end film via boom (or clothesline) (Figures 5-7 and 5-8).
- EV2 moves to sun end workstation (VS) to changeout film (Figures 5-9 and 5-10).
- EV2 moves to appropriate experiment (D024, S230, etc.)
- EV2 ingresses Airlock and stows equipment from EV1.
- EV1 ingresses Airlock and closes EVA hatch.

Different combinations of equipment were required underwater since there were six different planned-flight EVA's. Prior to each EVA exercise, a knowledgeable SCUBA diver physically checked all underwater hardware. This assured a smooth exercise and any anomalies could be explained to the astronaut crew during the briefings.

The possibility of in-flight failure of EVA film transfer equipment was recognized and plans and procedures were developed for NB training to cope with such events. Should one transfer boom fail, the flight plan called for use of a spare boom by exchanging units, or jettison of the unit should it fail in the extended position. A clothesline was to be

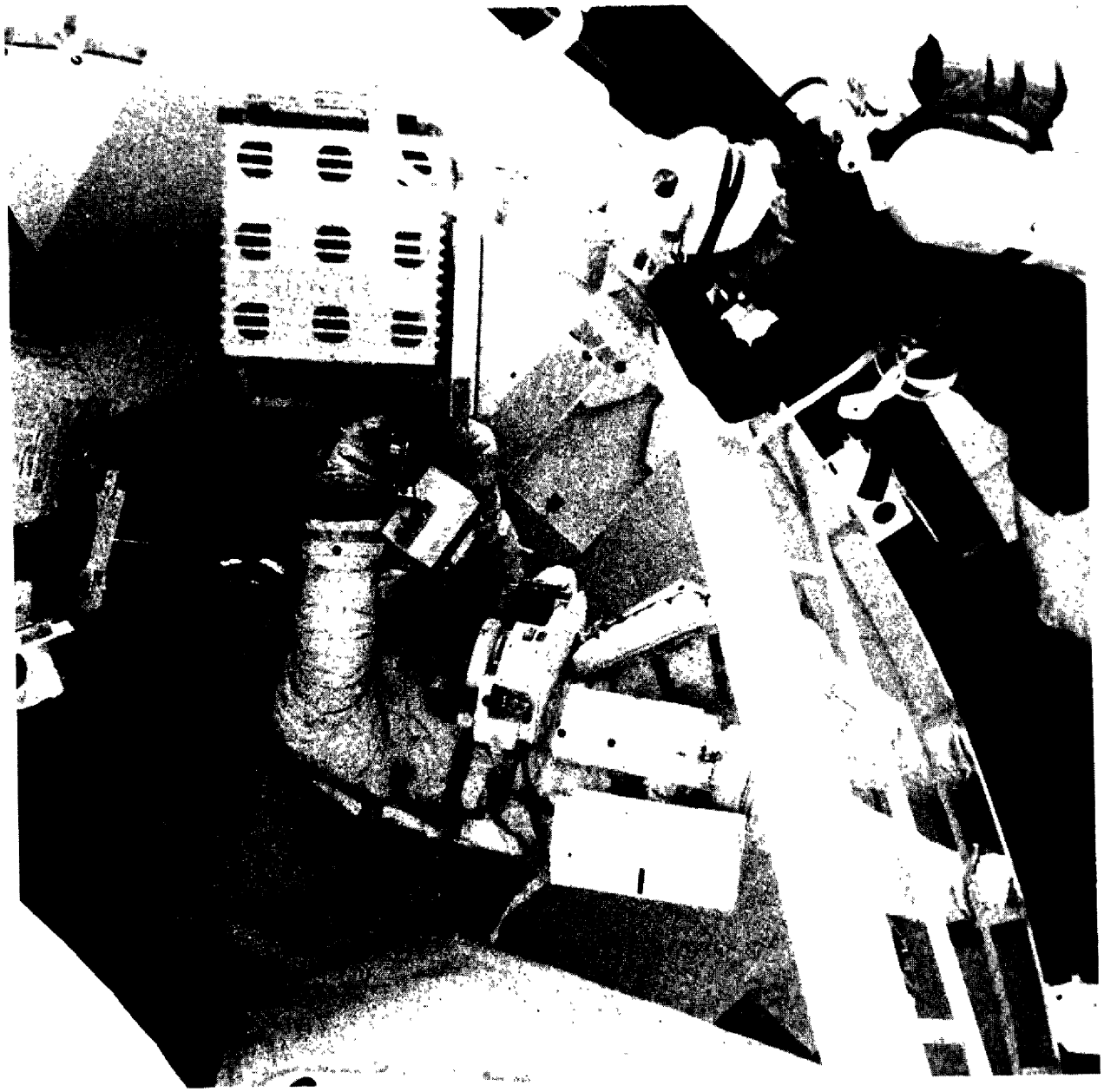


FIGURE 5-5 ASTRONAUT AT FAS WORK STATION (VF) INSTALLING ATM FILM TREE IN FAS RECEPTACLE

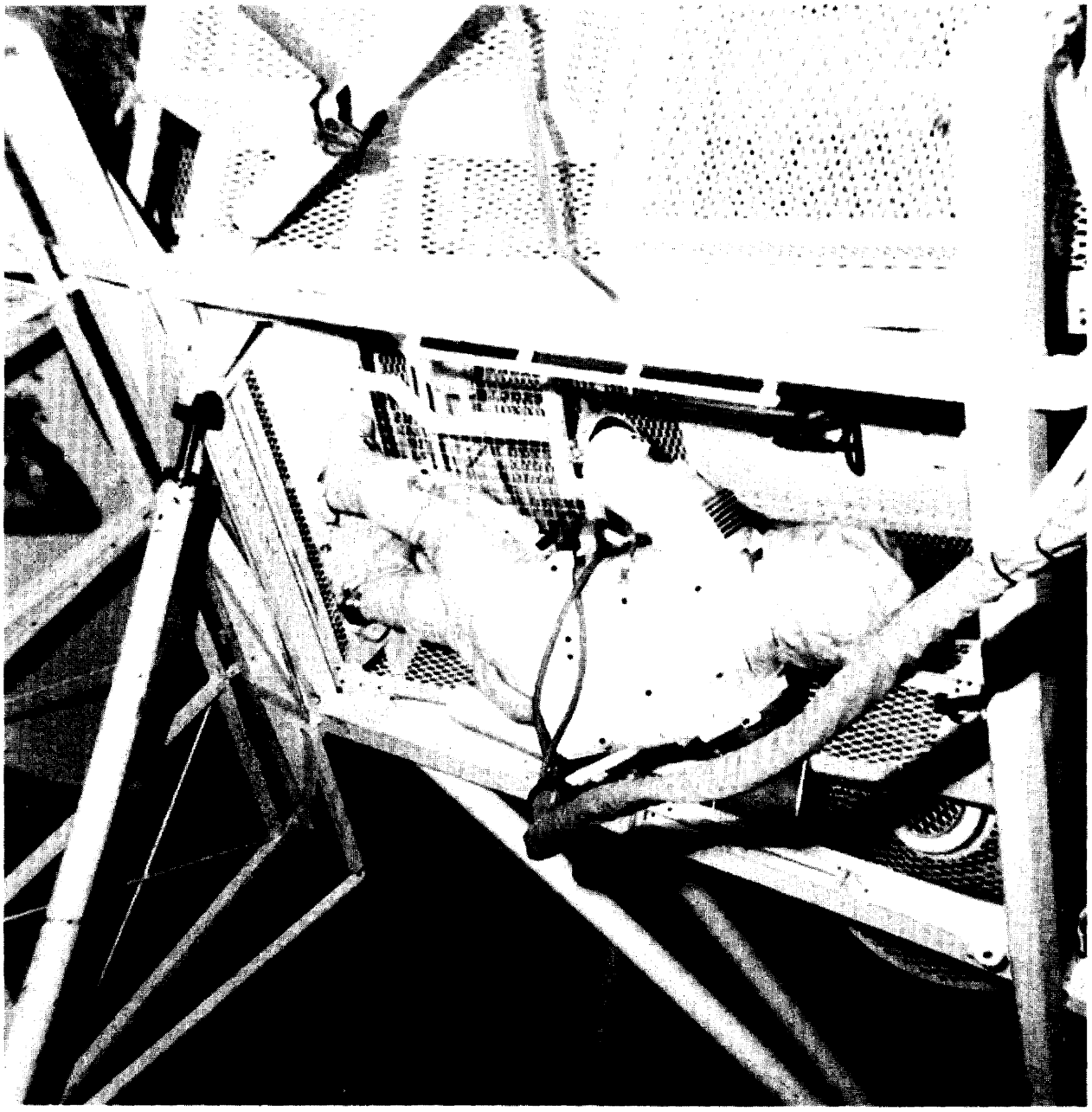


FIGURE 5-6 ASTRONAUT AT ATM CENTER WORK STATION (VC)

FIGURE 5-7 ASTRONAUT RECEIVING ATM FILM FROM EXTENDIBLE BOOM AT SUN TRANSFER WORK STATION (VT)

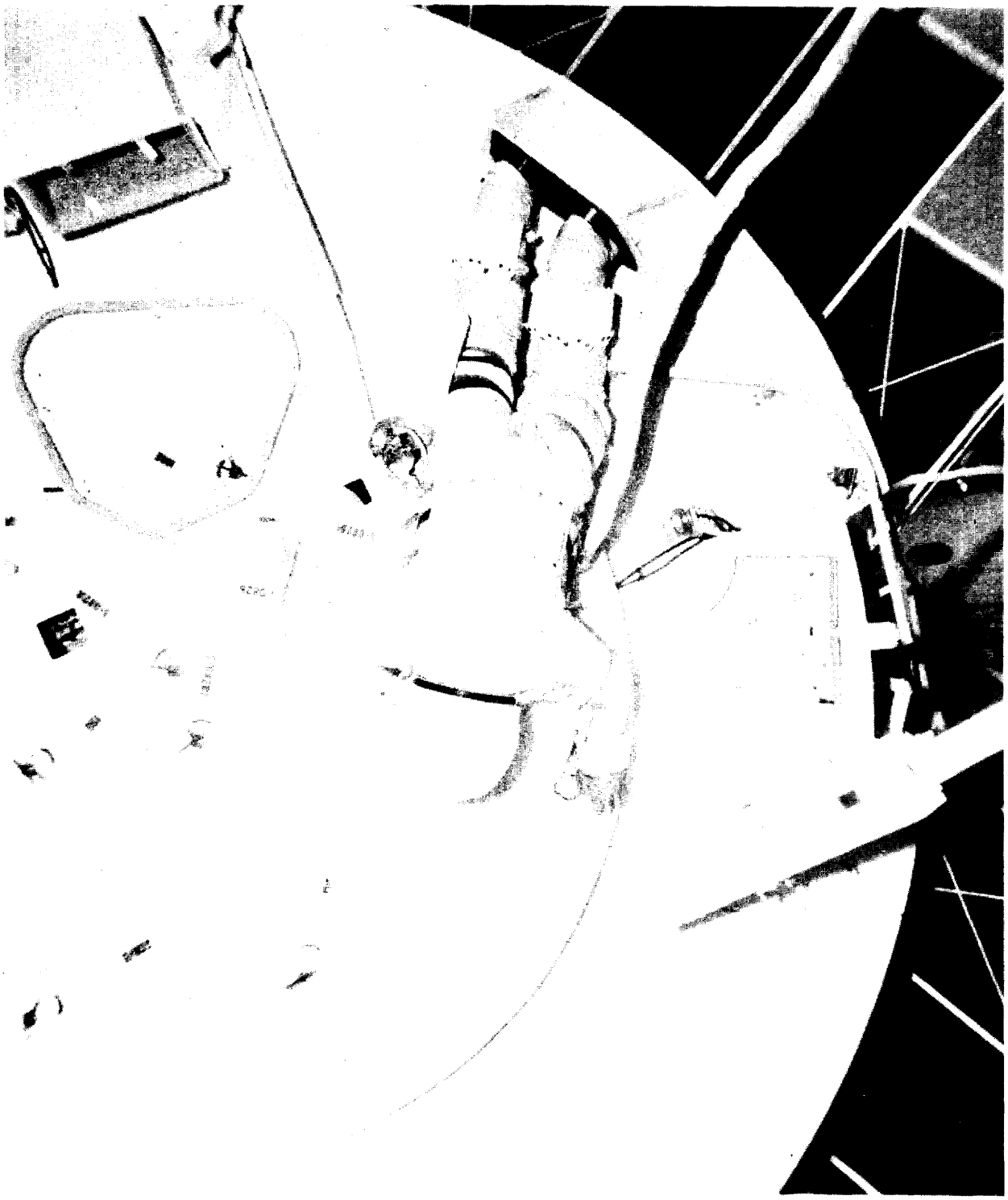


FIGURE 5–10 ASTRONAUT AT THE SUN WORK STATION (VS)

used in the event that both booms failed. The procedures for these operations were incorporated into normal NBS film transfer exercises and improved upon as zero-G techniques were developed. Figure 5-11 depicts a boom exchange procedure in progress.

Astronaut and support team confidence and efficiency greatly increased during training. The efficiency gained reduced actual underwater time by as much as 50 per cent in some cases. This was in part due to a learning process in becomming familiar with pressure suit operations in simulated zero-G; in fact, many procedures were rewritten to include tasks not considered possible by a suited subject at the start of training. It was discovered that once the crew became familiar with pressure suit operations and had the opportunity to practice and work out firm procedures, many difficult tasks were possible; this fact made possible the Skylab in-orbit repairs.

FIGURE 5-11 ASTRONAUT REPLACING EXTENDIBLE BOOM AT THE REPLACEMENT WORK STATION (VR)

5.2 Contingency EVA

NBS evaluations and training for contingency EVA's began after it was apparent that repairs via EVA's were necessary to salvage Skylab. The NBS was the only facility available where possible Skylab fixes could be developed and fully evaluated. These facilities were utilized to the maximum by all the NASA and Skylab industry teams. The results of the NBS contingency exercises with the prime and backup crews provided numerous real-time hardware improvements and "fixes" during the Skylab missions. These repairs covered a broad spectrum of EVA tasks, some of which were not thought possible before the launch. Program management was able to witness both the hardware and procedures during the NBS training periods, making real-time decisions on the risks involved. The final success of Skylab's nine EVA's, including the contingencies, reflect on the diligent efforts of the NASA and industry teams. The following sub-sections describe Skylab's problems and the contingency EVA's that were developed in the NBS that solved these problems.

5.2.1 Thermal Shield (Sail)

Approximately 63 seconds after launch of Skylab 1 on 14 May 1973, the OWS meteoroid shield malfunctioned, resulting in the loss of the shield and the #2 Solar Array System (SAS) Wing Assembly. The #1 SAS Wing Assembly remained intact, although it was partially deployed and jammed. As a result of the malfunction, the Skylab was left without adequate thermal protection and dependent on the ATM solar arrays for operational power.

The thermal problem was given first priority and deployment of a thermal shield capable of reducing the extreme heat inside the OWS, was considered the most feasible solution.

NASA and contractor personnel began working round-the-clock. Several potential shielding methods were evaluated and, as a result of this evaluation, a management decision was made to fly two concepts. The first was the JSC "Parasol" concept, so called because of its appearance and operation. This was first choice because it could be installed soon after docking to give quick thermal protection without subjecting the crew to an EVA right after a fatiguing first day (launch, rendezvous, docking activation, zero-G sickness, etc.). The system consisted of a ribbed, cone-shaped covering supported by an extendible rod and equipped with a springloaded mechanism for automatic opening. This concept was designed to allow installation from within the OWS, through the Scientific Air Lock (SAL).

The second concept selected for flight was the MSFC twin-pole sail. This shielding method utilized a covering of aluminized mylar film, coated with a special thermal compound (designated S-13G). The deployment/assembly for the replacement thermal shield consisted of a simple mounting bracket "Base plate" which attached to the ATM A-frame trusses (Figure 5-12). Two 16.6m (55-foot) poles mounted in a "V" position were installed in the "Base plate" and extended to the OWS. A Thermal Shield (sail) 6.7m by 7.3m (22 ft by 24 ft), which was packaged in a large retaining bag, (Figure 5-13), was unfurled by attaching the forward edge of the

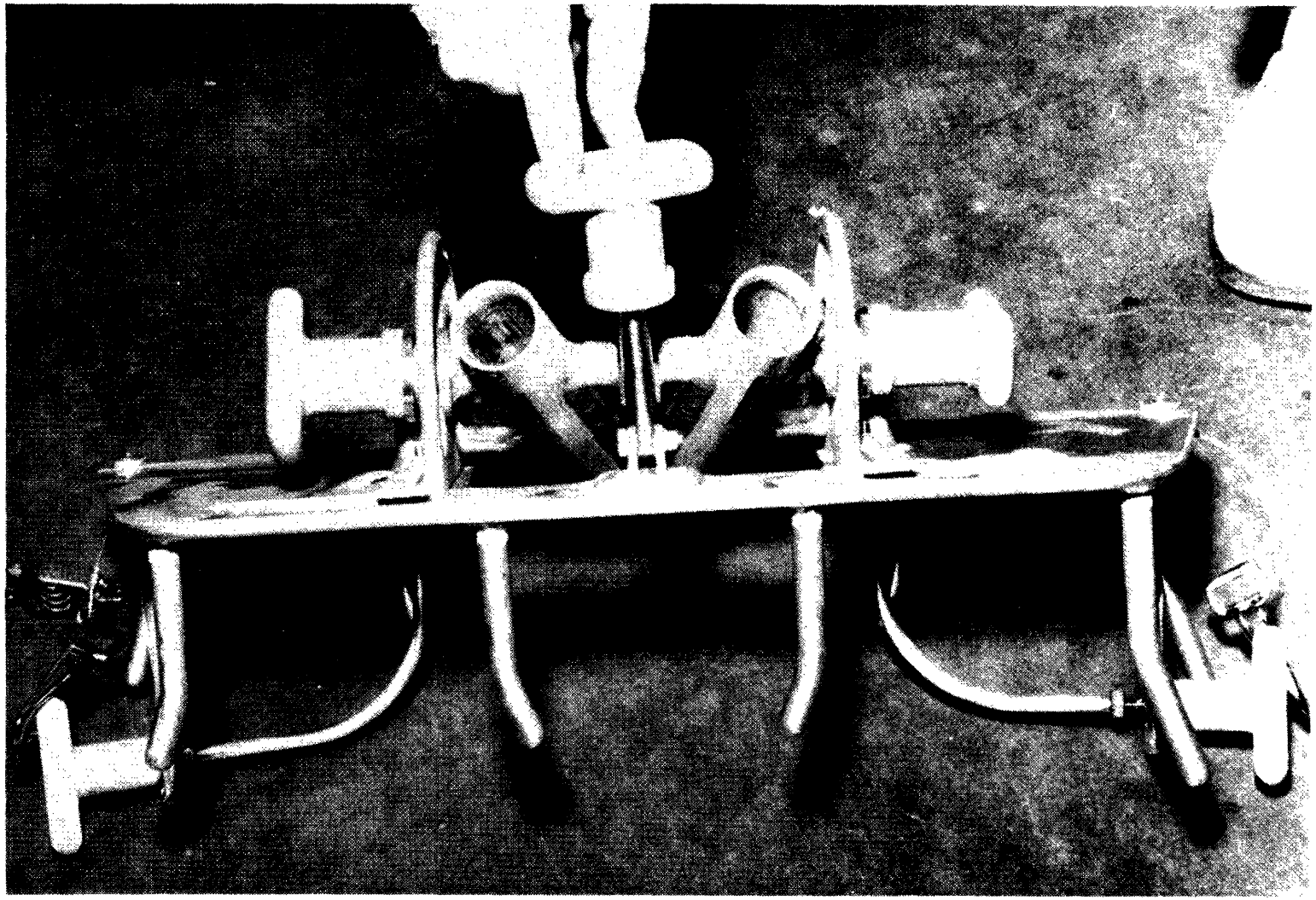


FIGURE 5–12 MSFC TWIN-POLE SAIL "BASE PLATE"

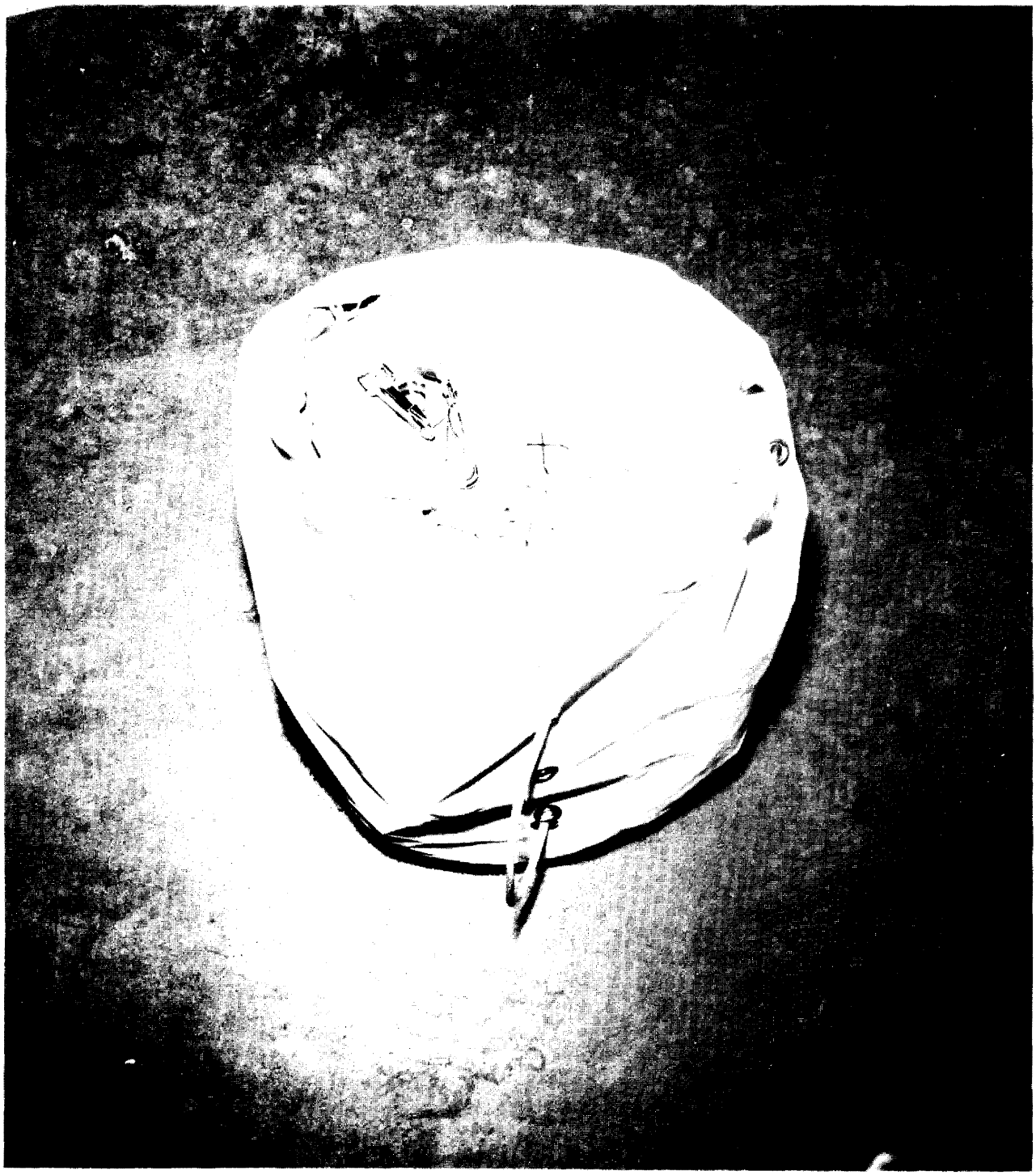


FIGURE 5–13 THERMAL SHIELD (SAIL) BAG

sail to the clothesline hooks on each pole. Next, the thermal sail was positioned by drawing the ropes (i.e. endless clothesline) until the leading edge of the sail was positioned against the far end of the extended poles. The trailing end of the sail, with attached reefer lines, was stretched and tied tautly to the ATM outriggers (Figure 5-14). The sail was capable of being deployed over the "Parasol", if required.

As soon as MSFC management had selected the configuration of the sail (twin-pole concept) and preliminary hardware had been designed and fabricated, the backup and prime crews were requested to participate in the NBS evaluations.

An extensive Neutral Buoyancy testing program was conducted to evaluate the sail's design philosophy and the training of the astronauts. Neutral Buoyancy twin-pole preliminary concept, test hardware design, and fabrication began 15 May 1973, i.e., one day after SL-1 launch, and the NBS was prepared for the development testing and training exercises. On 16 May 1973, the NBS personnel began neutralizing hardware for the sail simulator activities. Astronauts R. Schweickart and J. Kerwin made a "Look-See" Skylab NB trainer exercise in SCUBA gear for orientation, general volume assessments, and to evaluate the potential areas for mounting hardware for the sail deployment. In the debriefing that followed this exercise, astronaut Schweickart suggested significant changes which firmed up the twin-pole sail concept. Representatives at this debriefing were from S&E-ASTN-E, S&E-ASTN-S, S&E-PE-M, Skylab Program Office,

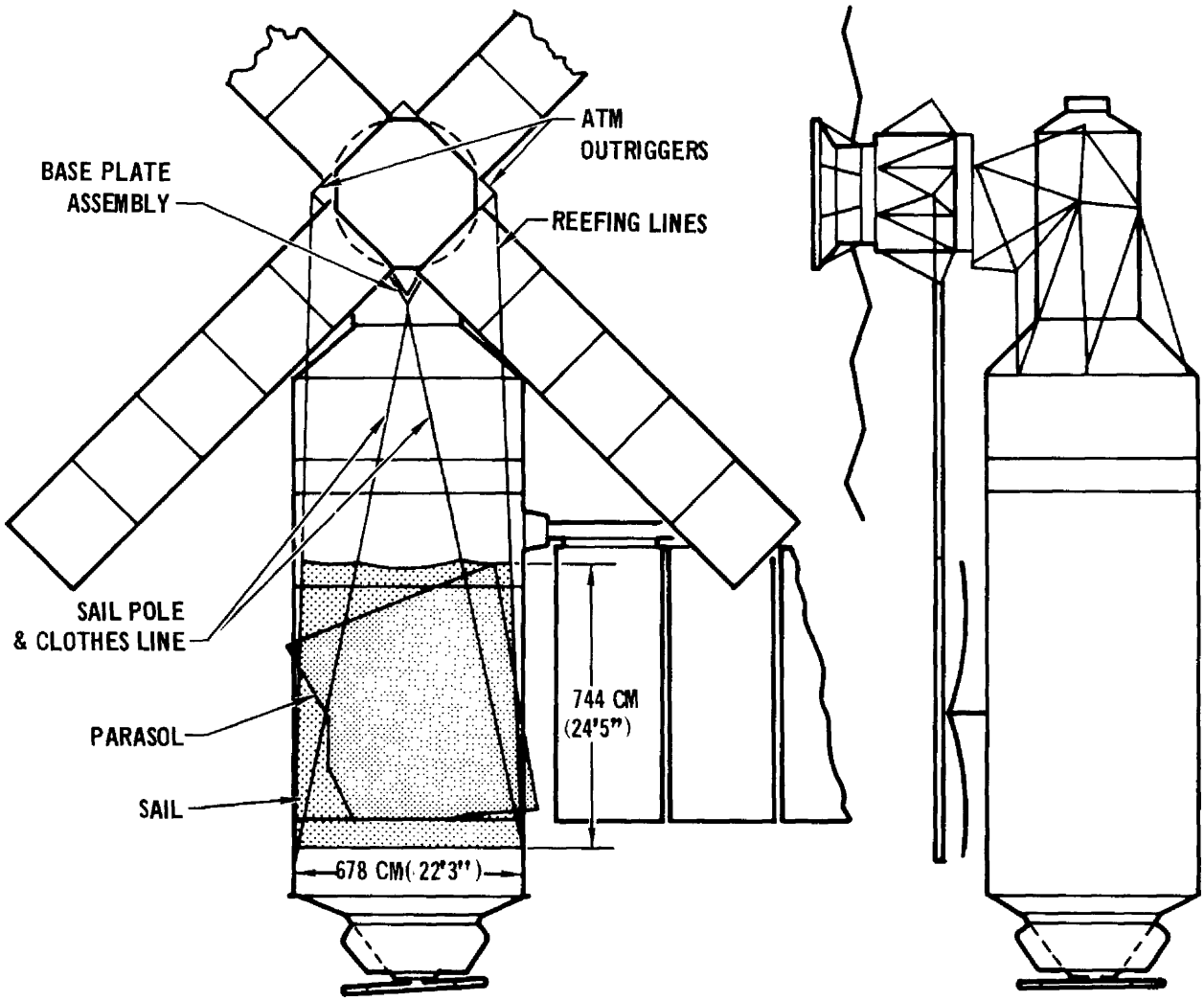


FIGURE 5-14 THERMAL SHIELD DEPLOYMENT CONFIGURATION "TWIN-POLE"

contractors, and astronaut flight crews. Designers and manufacturing personnel worked through the night. The next day, 17 May, test hardware was delivered to the NBS where all components were neutralized to permit accurate and meaningful zero-G simulations. The 16.6m (55 ft) pole, consisting of eleven interlocking 1.55m (5 ft) segments (Figure 5-15), was fit checked and the tolerance requirements of the pole connections were evaluated during dynamic action of the pole assembly. Personnel assigned to the NBS, who had parachute rigging experience, folded the numerous sail designs for deployment tests (Figure 5-16). These men ultimately packed and stowed the flight sail for shipment to KSC. Another NBS man was assigned the task of packing the continuous clotheslines used with the twin-pole arrangement (Figure 5-17); he also packed the flight clothesline.

On 18 May 1973, an end-to-end simulation was conducted in the NBS on the twin-pole sail concept. Astronauts R. Schweickart and S. Musgrave were the pressure suited subjects. Astronaut E. Gibson observed the exercise in SCUBA gear. The rod segments were modified as a result of this exercise, which determined that the rod segments could be inadvertently separated during the sail deployment operation. A positive lock was added to the male end of each rod (Figure 5-15).

Most of the day, 19 May 1973, was spent modifying the sail hardware (rod segments, pole base plate assembly, sail pole pallet assembly, etc.) as dictated by the NB exercises. In addition, work started on the rigging of a 1.22m by 3.05m (4 ft by 10 ft) section of the OWS aft skirt with

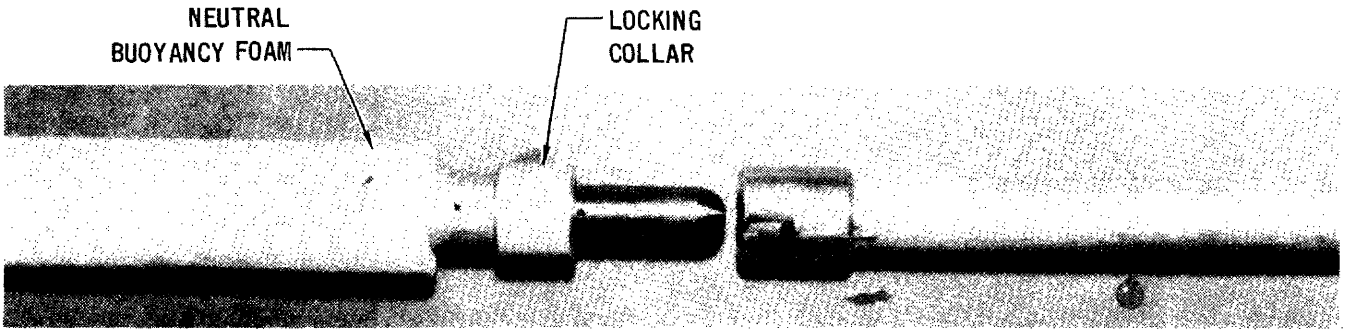


FIGURE 5-15 INTERLOCKING 1.55M (5 FT) SAIL POLES

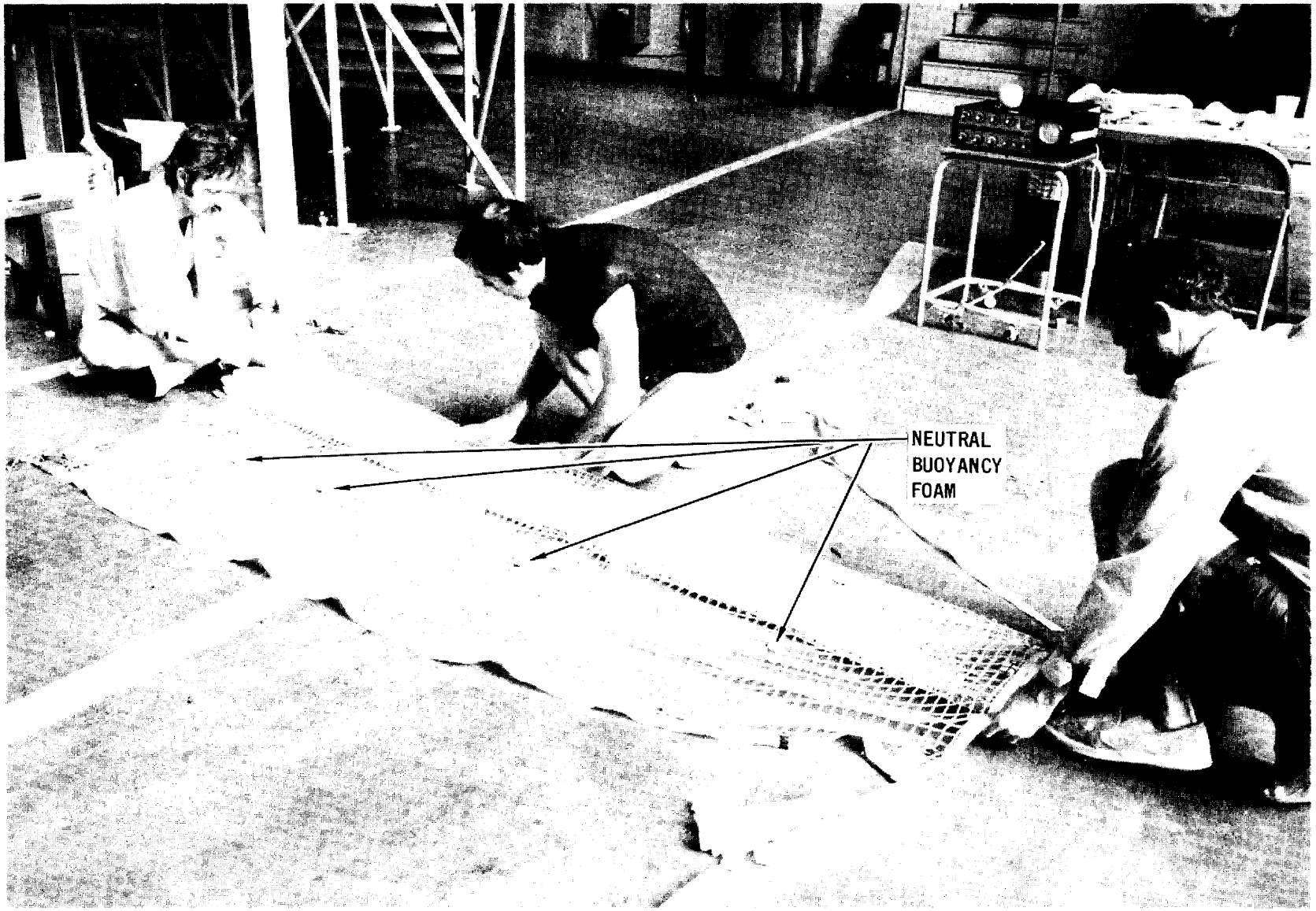


FIGURE 5-16 FOLDING THE NBS TWIN-POLE SAIL

FIGURE 5–17 PACKING THE TWIN-POLE SAIL CLOTHESLINE

fragments of the micrometeoroid shield, wire bundles, etc., (called the "Junk Pile") to permit the evaluation of the type of tools required for clearing debris from the OWS prior to deploying the thermal sail.

On 20 May 1973, another end-to-end NB exercise was conducted with Astronaut E. Gibson and S&E-PE-MS Engineer C. Cooper serving as pressure suit test subjects. This exercise was to evaluate the modified hardware. Astronaut A. Bean observed the exercise in SCUBA gear. The following modifications resulted from this exercise: Tighter restraint around the top of the sail stowage bag and addition of tether devices to the twin-pole base plate assembly for securing the clothesline after sail deployment.

A complete NB twin-pole exercise, from end-to-end, with hardware modifications incorporated was conducted on 21 May 1973, with flight type hardware by Astronauts A. Bean and E. Gibson. Additional modifications were required: 1) positive locking device was added to the twin-pole base plate assembly; 2) color coding of the OWS portable foot restraints mounting bracket was added to insure proper mounting to the ATM outrigger; 3) teflon inserts were added to the pole segment eyelets to reduce friction of the clotheslines during the sail deployment; and 4) all stowage locations in the FAS were finalized including the appropriate restraint devices. The entire night was spent in final "tuning" of the hardware for the SL-2 crew training exercise the next day, 22 May 1973. All hardware was fit-checked on the One-G Trainer and ATM flight backup article.

The underwater Command Module (CM) was flown from JSC to MSFC on 17 May 1973, and installed in the NBS after a special support structure was designed and fabricated for mounting the 2000 lb CM. Late in the day, 21 May, S&E-PE-MS Engineer C. Cooper performed a suited Standup-EVA (SEVA) from the CM forward hatch (Figure 5-18). This exercise was to evaluate the SAS deployment and the debris removal tools (sheet metal cutters designed by MSFC S&E-ASTN-ETA, mushroom head and shepherds hook designed by JSC, and cable cutters and the two-pronged universal tool designed by A. B. Chance Company, as shown in Figures 5-19 and 5-20. These tools were developed to be adapted to the thermal sail poles (Figure 5-21). The 1.22m by 3.05m (4 ft by 10 ft) section of the SIV-B aft skirt "junk pile" and 3.66m (12 ft) section of the #1 SAS wing high fidelity mock-up had been mounted to the S-IVB.

The positioning of these tools, on the end of three 1.55m (5 ft) sections of the sail pole, was difficult; however, the task could be accomplished; SAS deployment by this method appeared to be marginal.

The following training schedule was prepared for 22 May 1973 at the MSFC NBS:

9:00 A.M.	NB Hardware Bench Review (Figure 5-19)
10:00 A.M.	Thermal Sail Contingency EVA Training in NBS - Astronauts C. Conrad and J. Kerwin
2:00 P. M.	SEVA, Debris Removal and SAS Deployment - Astronaut P. Weitz
3:00 P. M.	Flight Hardware Bench Review
4:15 P. M.	Sail Pole Stability Test, Building 4619 (One-G)

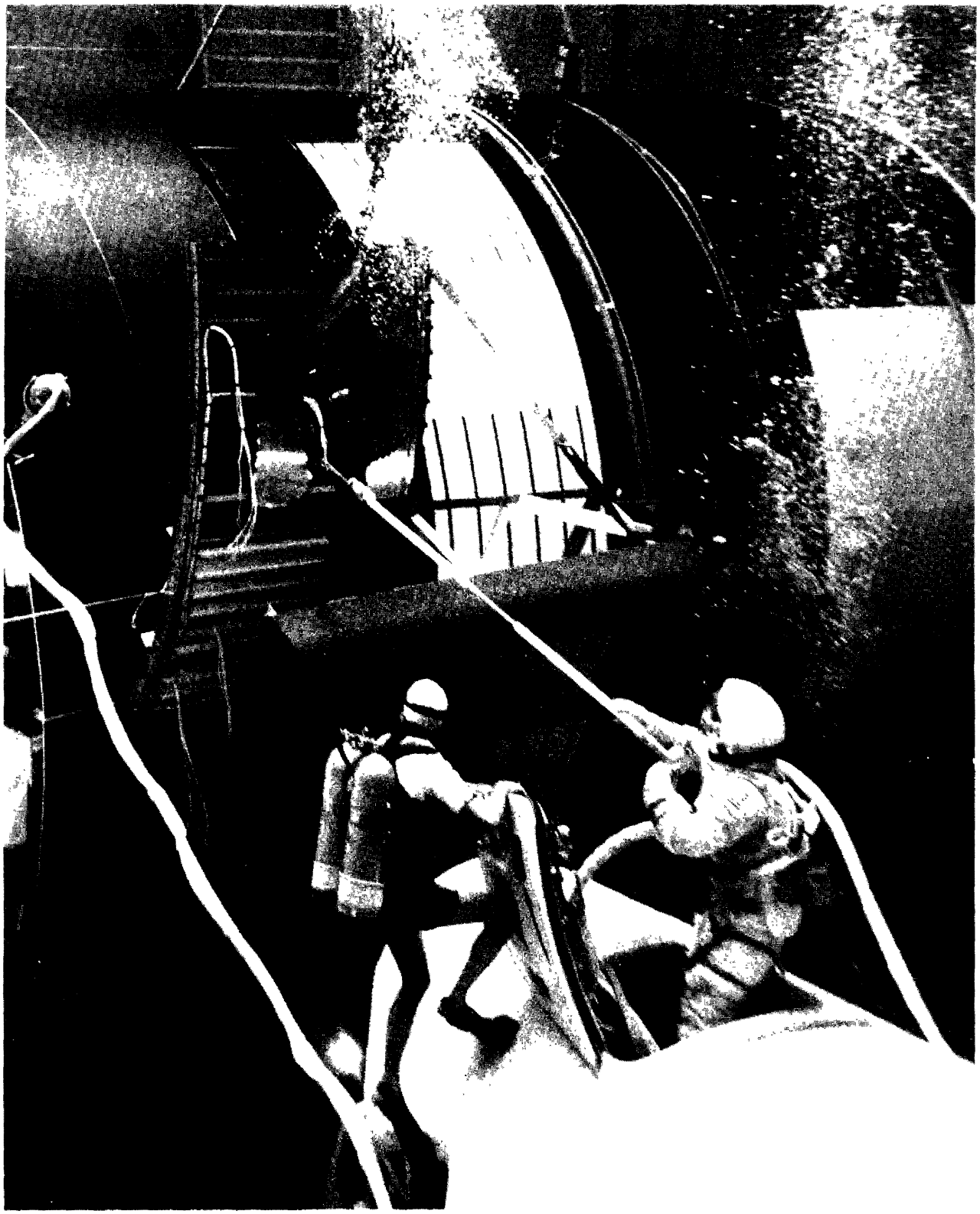
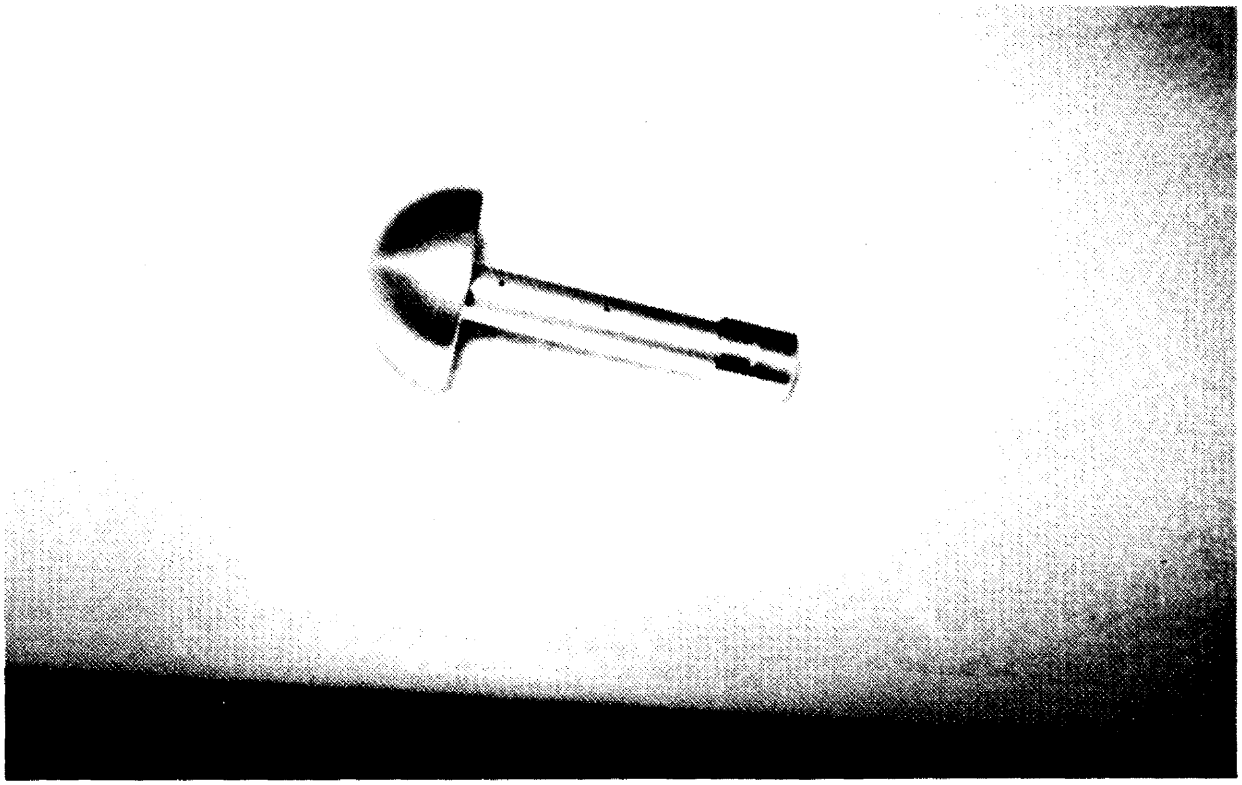


FIGURE 5-18 NBS STANDUP-EVA (SEVA) EXERCISE

FIGURE 5-19 DEBRIS REMOVAL TOOLS



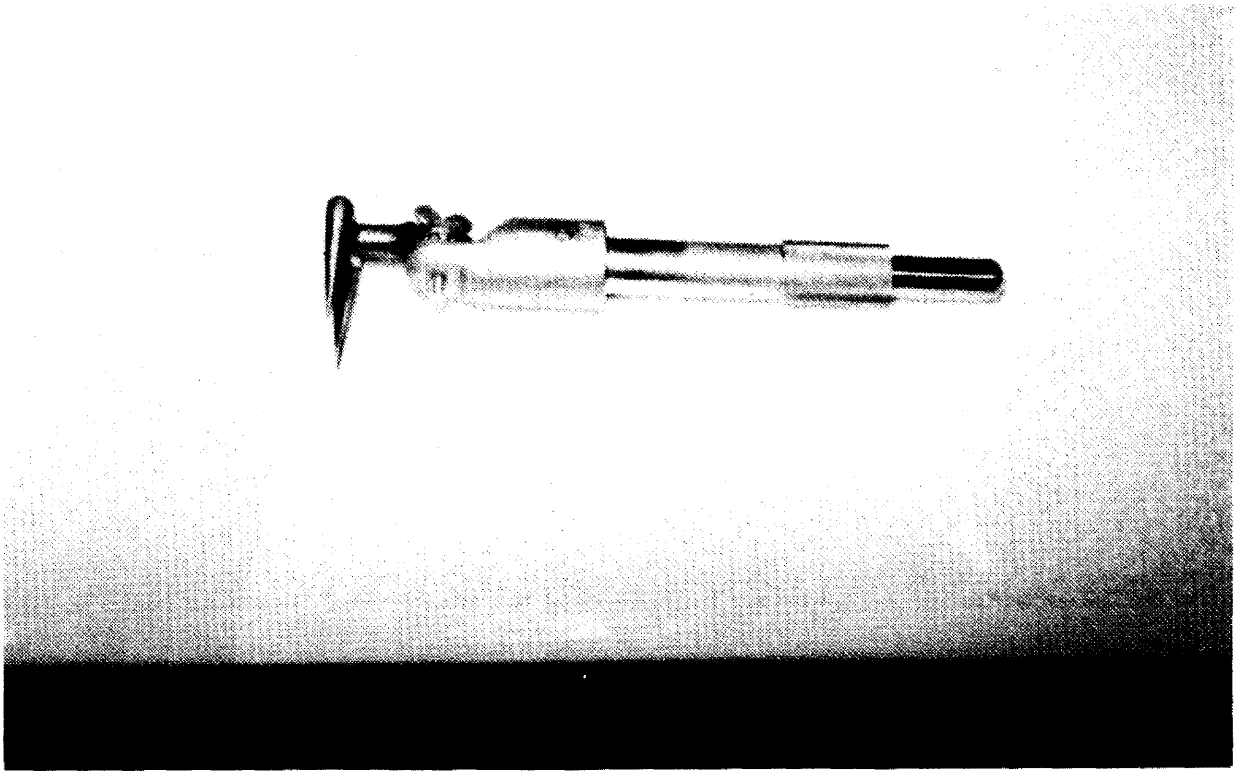


FIGURE 5-20 MUSHROOM (UPPER) AND
TWO-PRONG UNIVERSAL TOOL (LOWER)

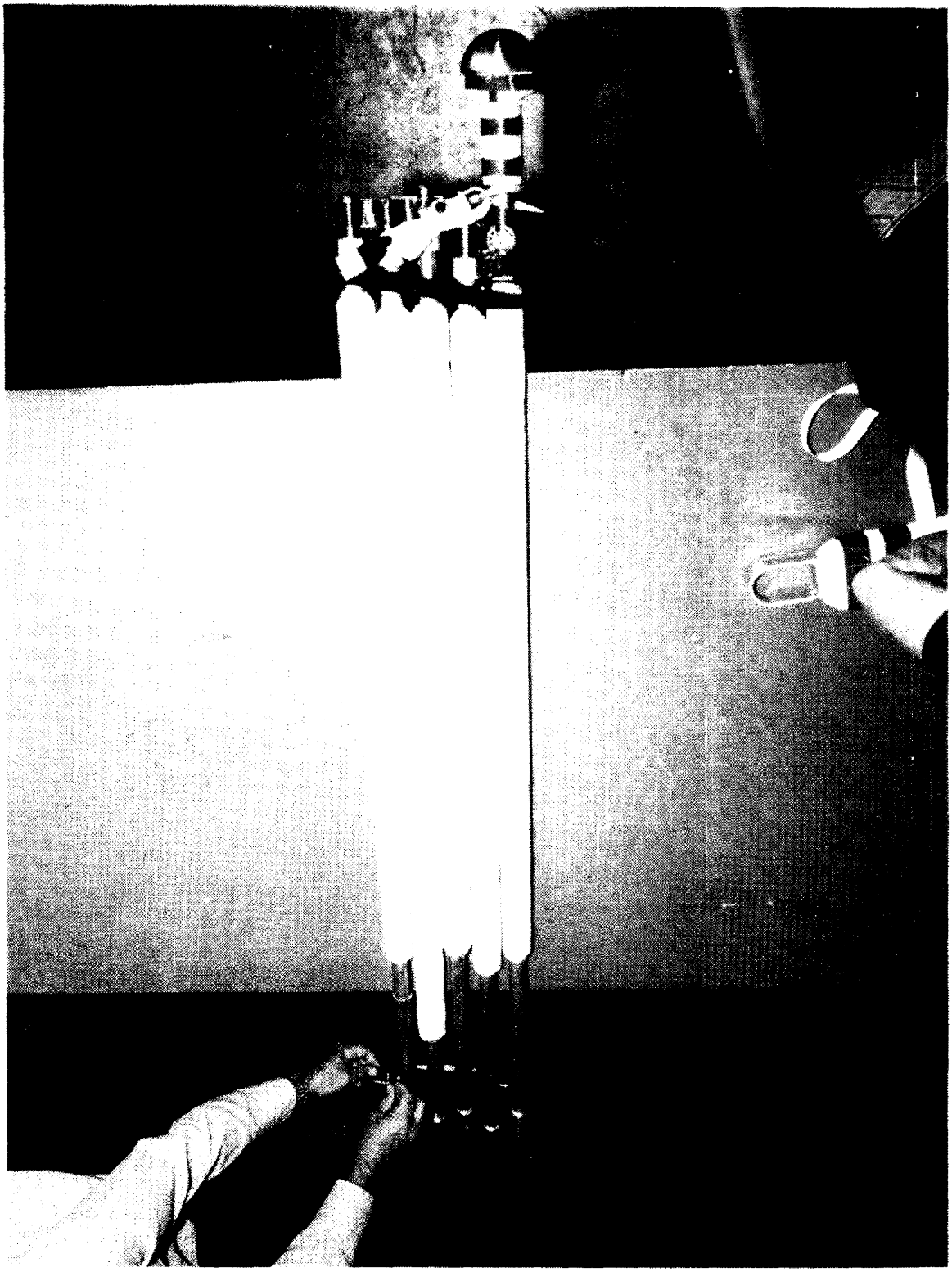


FIGURE 5–21 MSFC SAIL POLES (5) WITH MUSHROOM HEAD

This meant an unprecedented deviation in the crew prelaunch quarantine requirements. To accomplish this task as safely as possible, numerous medical precautions were taken, (all personnel were screened, sanitation masks were worn, etc., as shown in Figure 5-22).

The twin-pole sail deployment training exercise, with Astronauts C. Conrad and J. Kerwin, started approximately at 10:00 A.M. (Figure 5-23) after a NB hardware bench review. The training exercise, using flight procedures developed during the previous tests, was nearly flawless. Dr. Petrone, Mr. Schneider, Mr. Low and Mr. Myers monitored the SL-2 crew training. Total EVA time was 1 hour and 35 minutes with no modifications recommended.

The NB SEVA training, with Astronaut P. Weitz, did not go well due to difficult tool alignment with SAS and surrounding debris. During the evening the flight sail was folded and packed for shipment to KSC by NBS personnel.

23 May 1973 was spent preparing the facilities and hardware for additional verification exercises.

On 24 May 1973, a hardware verification exercise was conducted in the NBS with S&E-PE-MS Engineer C. Cooper as the test subject. This exercise was made to insure hardware compatibility interface. No changes resulted from this exercise.

On 26 May 1973, the SL-2 crew successfully deployed the JSC parasol and the OWS internal temperatures immediately began to drop. On 6 Aug.

FIGURE 5-22 TWIN-POLE SAIL HARDWARE REVIEW

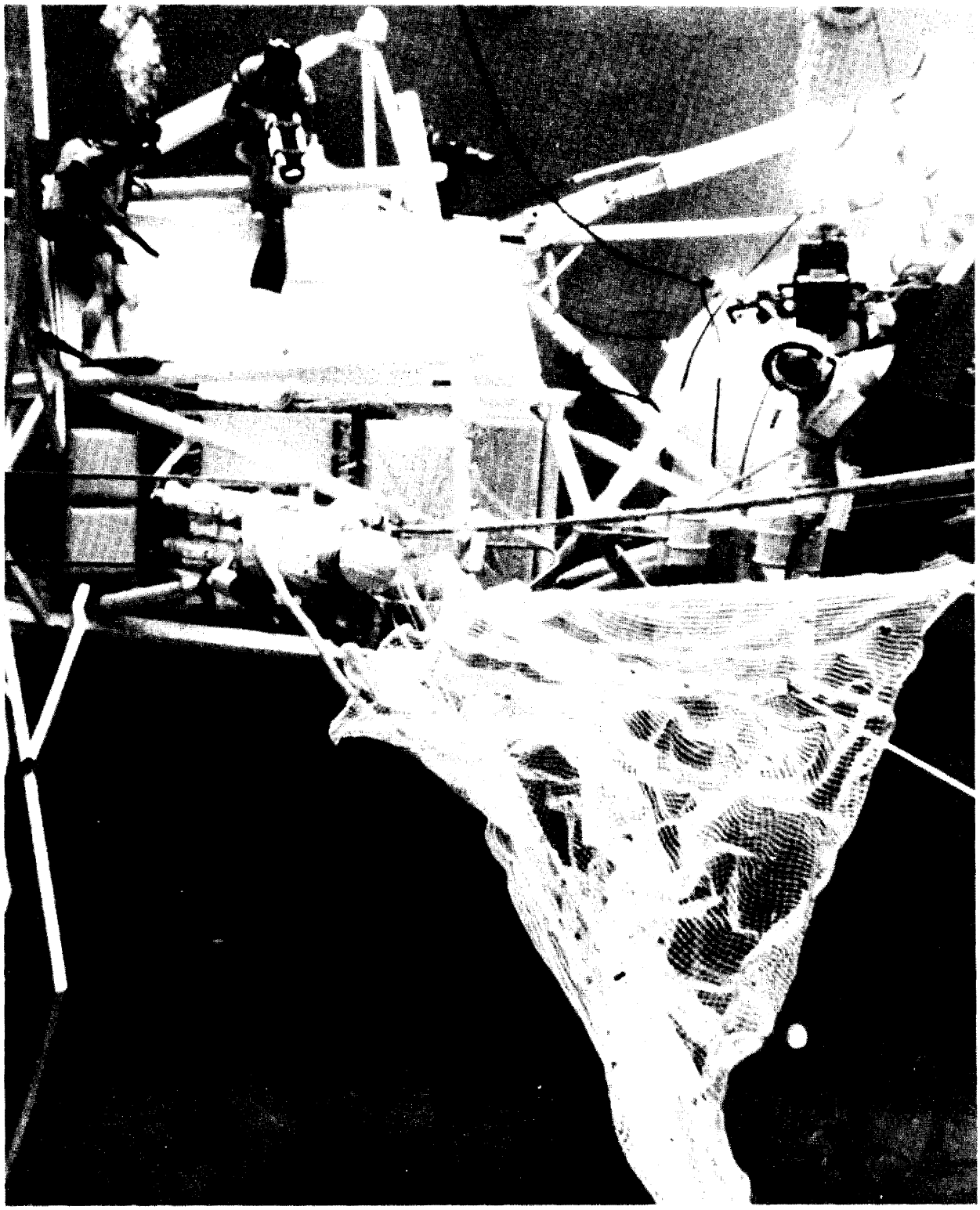


FIGURE 5–23 TWIN-POLE SAIL DEPLOYMENT TRAINING EXERCISE

1973, the SL-3 crew successfully deployed the MSFC twin-pole sail over the parasol which provided adequate OWS thermal protection for the duration of Skylab.

5.2.2 Solar Array System (SAS) Deployment

During the NBS Thermal Sail activities, a parallel effort was initiated to investigate feasible methods for deploying the #1 SAS wing assembly.

Several concepts for deployment of the SAS wing were studied, one of which was the Standup EVA (SEVA) described in section 5.2.1.

On 25 May 1973, SL-2 was launched and the decision was made, prior to launch, that the SAS deployment would be attempted by CM SEVA if the CDR deemed it feasible.

Personnel at the NBS were on "Ready Status" to simulate in real time, the SEVA flight activities to be performed by Astronaut P. Weitz. C. Cooper was pressure suited and the NBS was fully manned for immediate action if requested to resolve unsuspected flight problems.

Upon rendezvous with the Skylab cluster, a fly-around inspection of the OWS was conducted with the crew providing real-time TV. The SEVA was attempted but was unsuccessful. From the TV coverage and verbal description from the crew, two assumptions were made: (1) an aluminum angle "strap" was the only debris preventing the SAS wing from being deployed, and (2) on-board tools would be sufficient to cut the strap or pry it loose. This strap was also determined to be approximately 7.6m

(25 ft) below the top of the FAS and .46 (1-1/2 ft) below the first vent module on the SAS wing (Figures 5-24 and 5-25). In addition, studies of the SAS wing hinge joint indicated that the hydraulic deployment actuator would probably be frozen and would require breaking at its weak point, the actuator clevis. McDonnell Douglas Astronautics Company-East suggested using the fulcrum method (Figure 5-26).

From the above information, the NBS #1 SAS wing high-fidelity mock-up was modified (Figure 5-27) and installed on the Skylab NB trainer 27 May 1974.

Two methods of translating to the FAS area above the SAS wing were identified: (1) translation over the ATM Deployment Assembly (DA) trusses and around the top of the FAS to the Discone Antenna Boom, directly forward of the SAS and debris strap; and (2) translation under the DA trusses and over the thermal capacitor using the Molecular Sieve duct for a handrail to the Discone Antenna Boom area. The latter translation route was used. This still left the problem of translating out to the SAS wing since there were no restraints of any kind from the discone antenna area out to the debris strap.

The McDonnell Douglas Astronautics Company-East personnel defined the hi-fidelity requirements of the FAS quadrant from the EVA work area to the +Z axis.

The required hardware installation began in the FAS area on 29 May 1973 to support EVA SAS wing contingency repair training. This consisted of

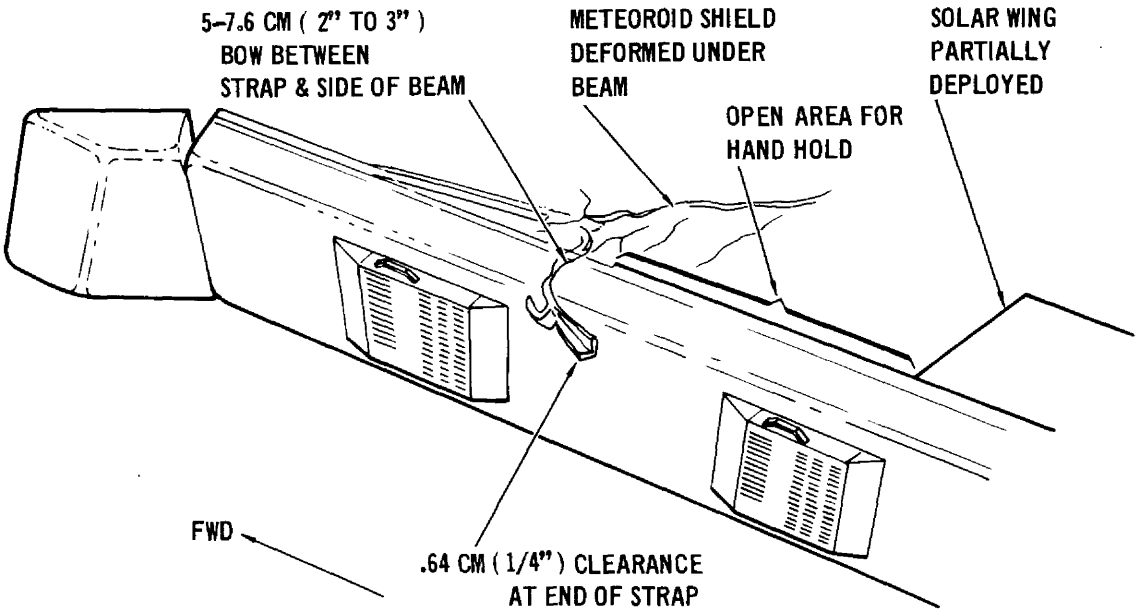


FIGURE 5-24 CONFIGURATION OF SAS WING NO. 1 PER TELECON WITH CREW - CDT 1430 6/1/73

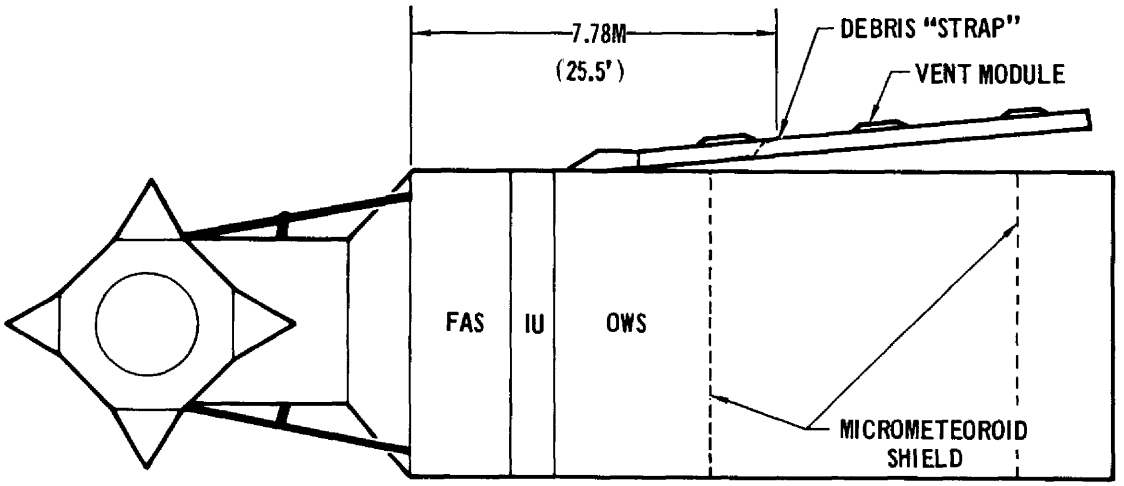


FIGURE 5-25 SAS BEAM DEPLOYMENT AREA

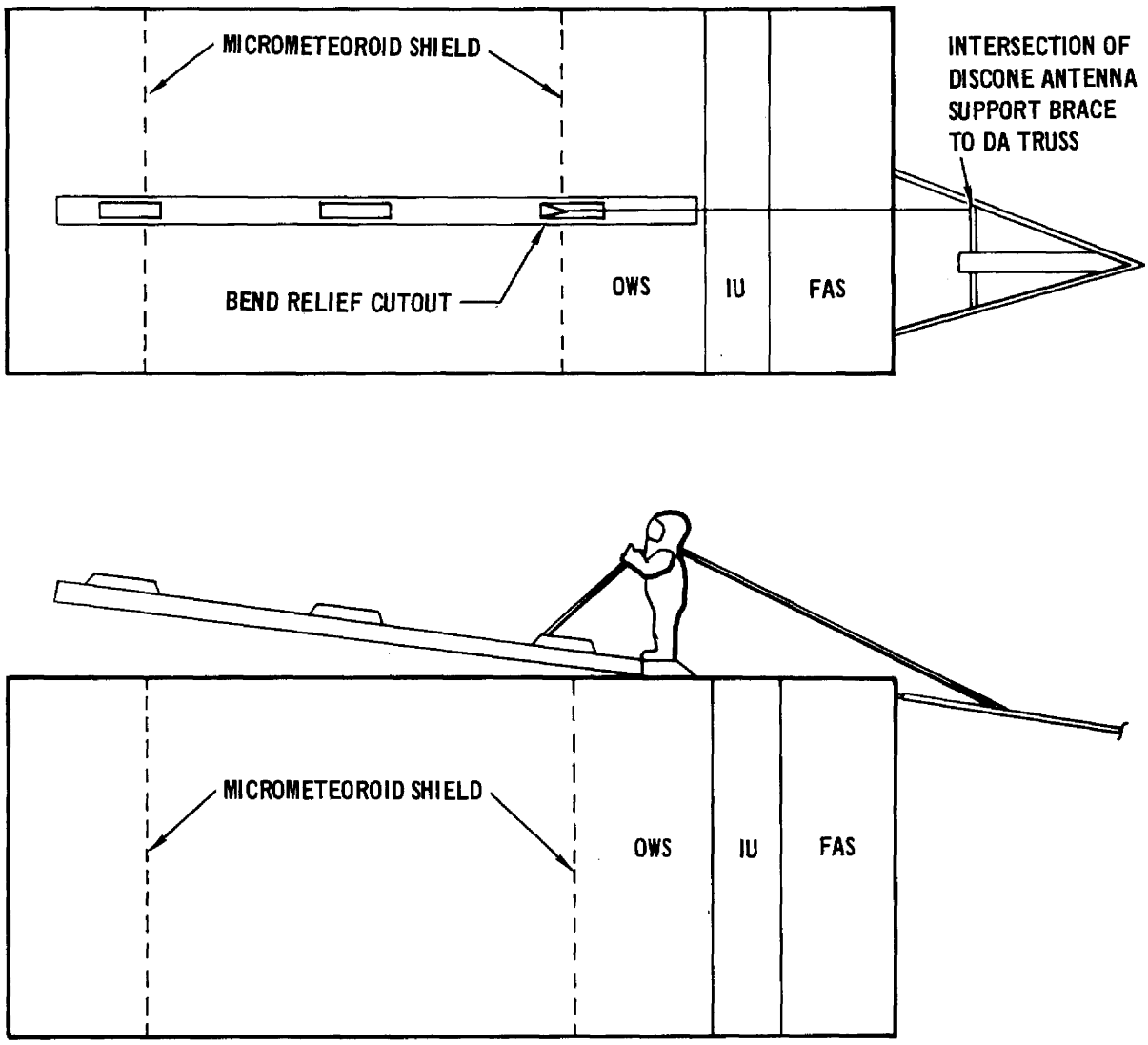


FIGURE 5-26 SAS BEAM DEPLOYMENT CONFIGURATION (FULCRUM METHOD)

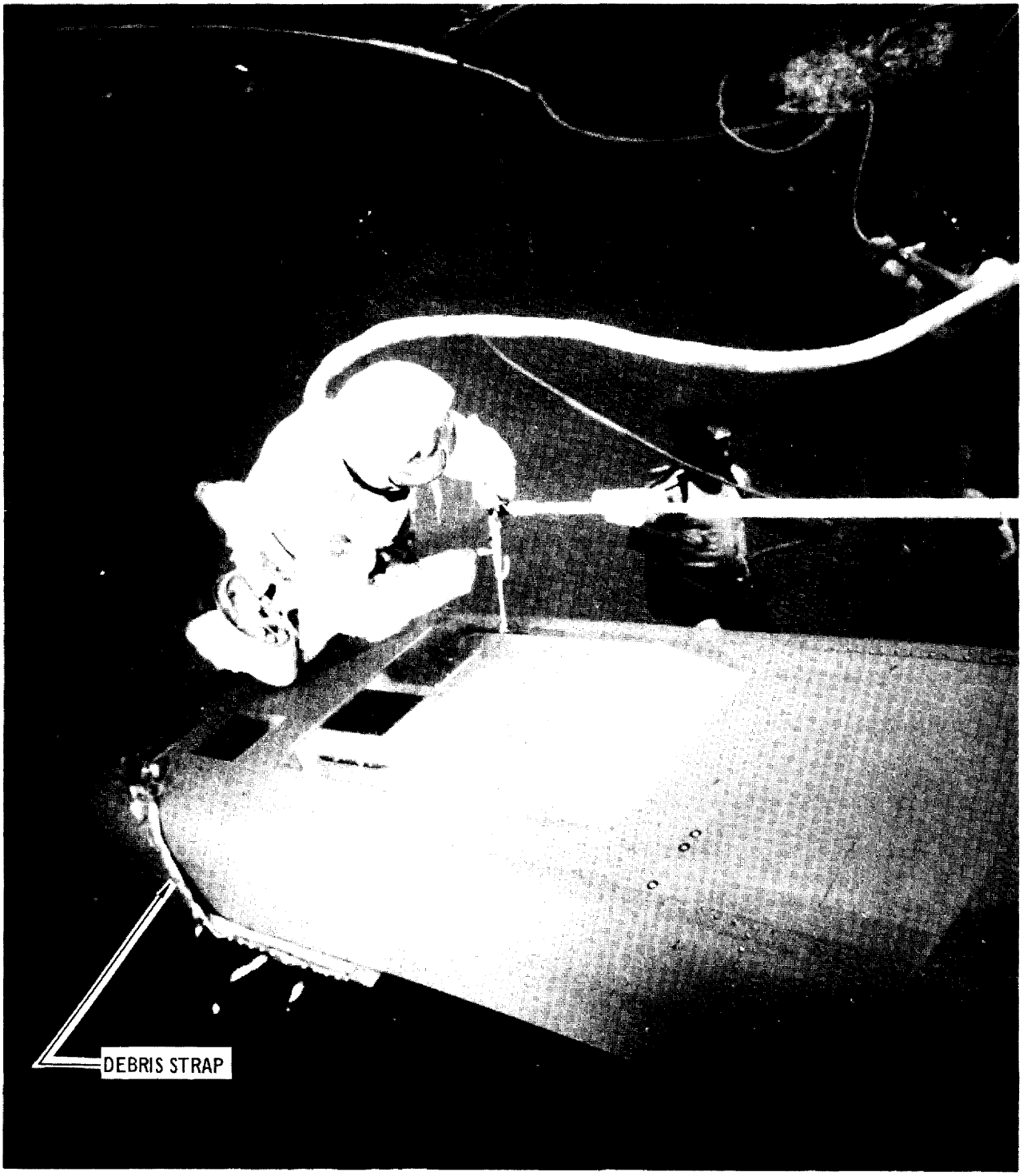


FIGURE 5–27 NBS SAS WING MOCKUP WITH DEBRIS STRAP

adding low fidelity oxygen bottles, a portion of one discone antenna boom with mounting structure, forward FAS ring, one electronic module envelope (+Z truss) and thermal curtains to simulate the flight article in the +Y to +Z quadrant. All the hardware was fabricated on site to minimize time due to the urgency of Skylab's problems. In parallel with this effort, the "parasol" was received from NASA-JSC and installed on the NB trainer to determine the feasibility of deploying the MSFC twin-pole sail over the parasol.

An NBS exercise was made on 30 May 1973 with C. Cooper, S&E-PT-MSE, and R. Heckman, S&E-ASTN-SMD, as suited subjects. This exercise was made using preliminary procedures to determine potential ways/techniques of restraining a crewman and freeing the SAS from the debris strap using the various tools and equipment flown up on SL-2 (SEVA hook, mushroom head, cable cutters, universal tool, twin-pole segments, onboard tethers, etc.).

C. Cooper made an additional suited test exercise to verify that the twin-pole sail could be deployed over the JSC "parasol", which had been deployed on Skylab by the SL-2 crew through the OWS Scientific Air Lock on 26 May 1973. This simulation exercise proved that it could be accomplished with no problems since it was learned that the parasol rods would deflect far enough under the twin-pole sail to allow the sail to rest against the aft OWS skin.

By 31 May 1973, SAS deployment feasibility studies had been accelerated. The following schedule activities were planned for that day:

8:00 A.M.	Debriefing of the 30 May suited exercise and suggested hardware usage
11:00 A.M.	Bench review of the NB on-board type hardware and equipment available for SAS deployment
11:30 A.M.	SCUBA exercise, Astronaut R. Schweickart
4:30 P.M.	Suited exercise using NB tool hardware and preliminary procedures

Five sail pole segments, for a total length of 7.6m (25 ft), with the universal tool on one end held by the crewman, with aid of a waist tether, were selected as prime equipment for the 4:30 P.M. suited exercise.

Astronaut Schweickart suggested the dental kit bone saw for cutting the debris strap. He also suggested the N_2 purge duct, located on the FAS ring in the EVA bay, as an alternate work station for translating to the debris strap using the SEVA hook taped or clamped to the sail pole (five segments), as shown in Figure 5-28.

The NBS exercise with Astronaut Schweickart and C. Cooper, S&E-PT-MSE as suited subjects was very informative. The N_2 purge duct work station with SEVA hook and sail pole was determined dangerous because the crewman's umbilical would be over the SAS wing when debris strap was cut. When the crewman was at the SAS debris strap area, it was noted that restraints were needed to secure him in a working position. The Discone Antenna work station went much smoother but lack of restraints at the debris work area hampered the work efforts.

On 1 June 1973, Astronaut Schweickart made an evaluation exercise, in SCUBA gear, of the hardware [tool pole with cable cutters, bone saw, pry

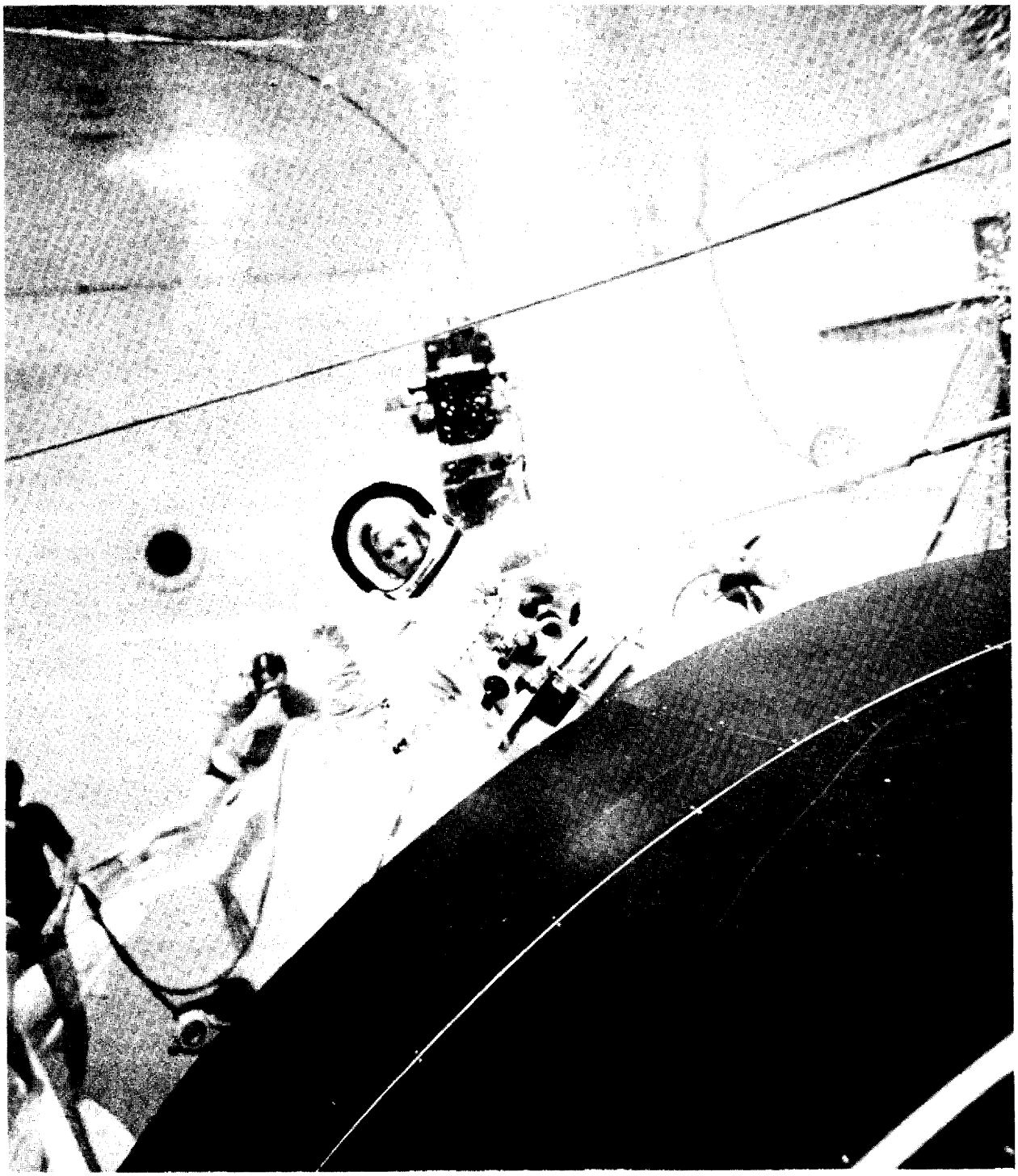


FIGURE 5–28 ASTRONAUT SCHWEICKART AT THE FAS N_2 PURGE DUCT ASSEMBLING FIVE SAIL POLE SEGMENTS

bar, wrist and waist tethers, and the 9.5m (31 ft) long adjustable tether], work stations, and methods of restraining a crewman at the SAS debris strap. In addition, he evaluated the "fulcrum method" for breaking the frozen actuator clevis.

The next morning, 2 June 1973, a bench review was held at the NBS of the selected flight-type NB hardware to be evaluated for the SAS deployment. An EVA "Prep" was conducted after the bench review for the NBS exercise that afternoon in which Astronaut Schweickart verbally went over all the hardware describing the function, nomenclature, tethering methods and procedures.

The exercise that afternoon started at 3:00 P.M. and was completed at 5:30 P.M. Astronauts R. Schweickart and E. Gibson were the suited subjects. This exercise was an end-to-end evaluation, starting and finishing at the FAS EVA work station. Equipment transfer in the FAS area, sail pole assembly, and equipment transfer in the Discone Antenna area are shown in Figures 5-29, 5-30, and 5-31. Restraining methods at the Discone Antenna Area (Figure 5-32), crewman tranlation to the SAS debris strap (Figure 5-33), and various methods of restraint in a working position and cutting the debris strap were evaluated; including simulation of the breaking of the actuator clevis using the fulcrum method (Figure 5-34). Some of the NB hardware was "negative" i.e., not neutral, which made several tasks more difficult. Results of this exercise were; equipment and hardware need to be neutral, restraining methods need to be improved, and the EVA "Prep" needed further development.

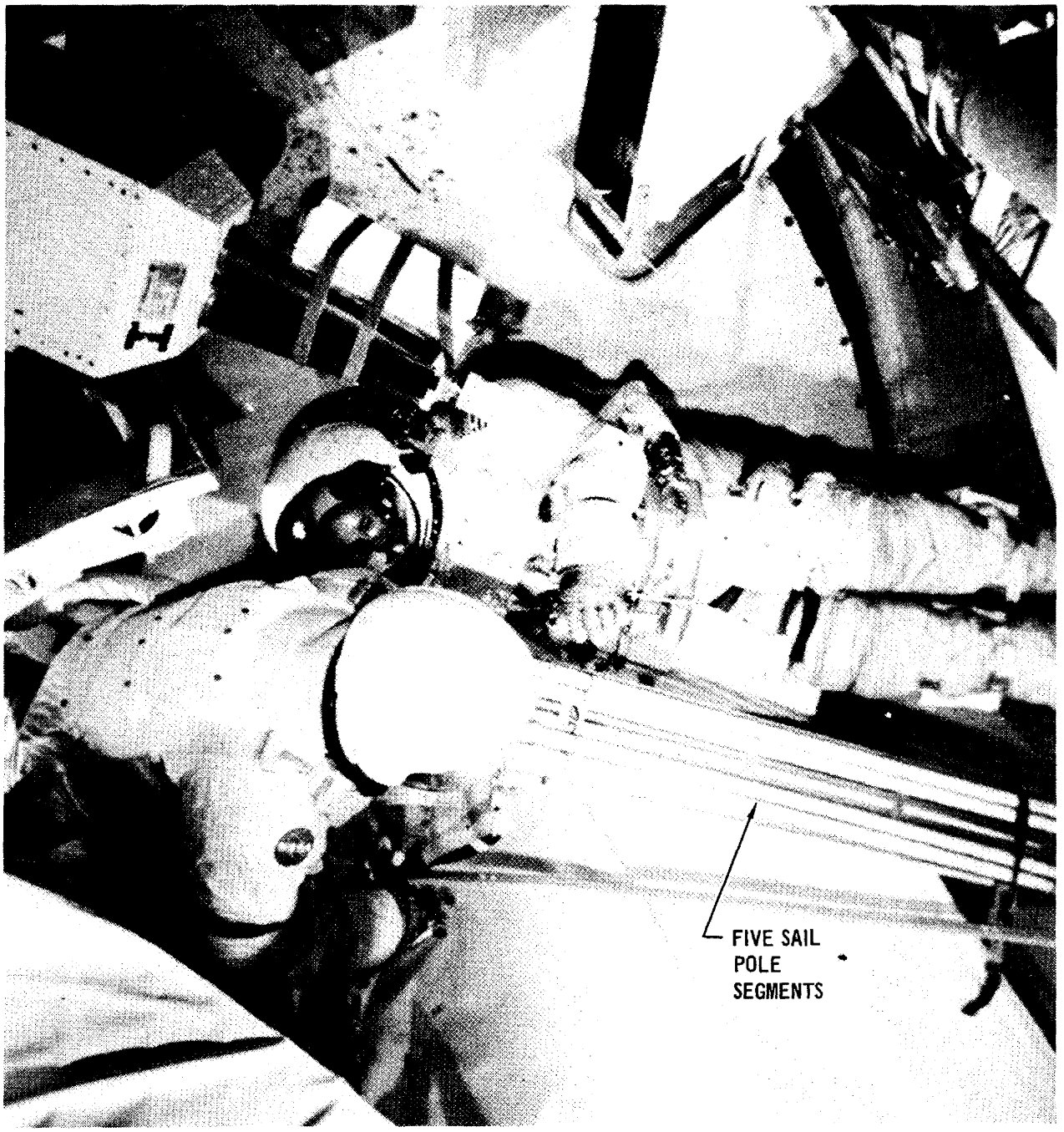


FIGURE 5-29 NBS EXERCISE IN EQUIPMENT TRANSFER FOR SAS WING DEPLOYMENT

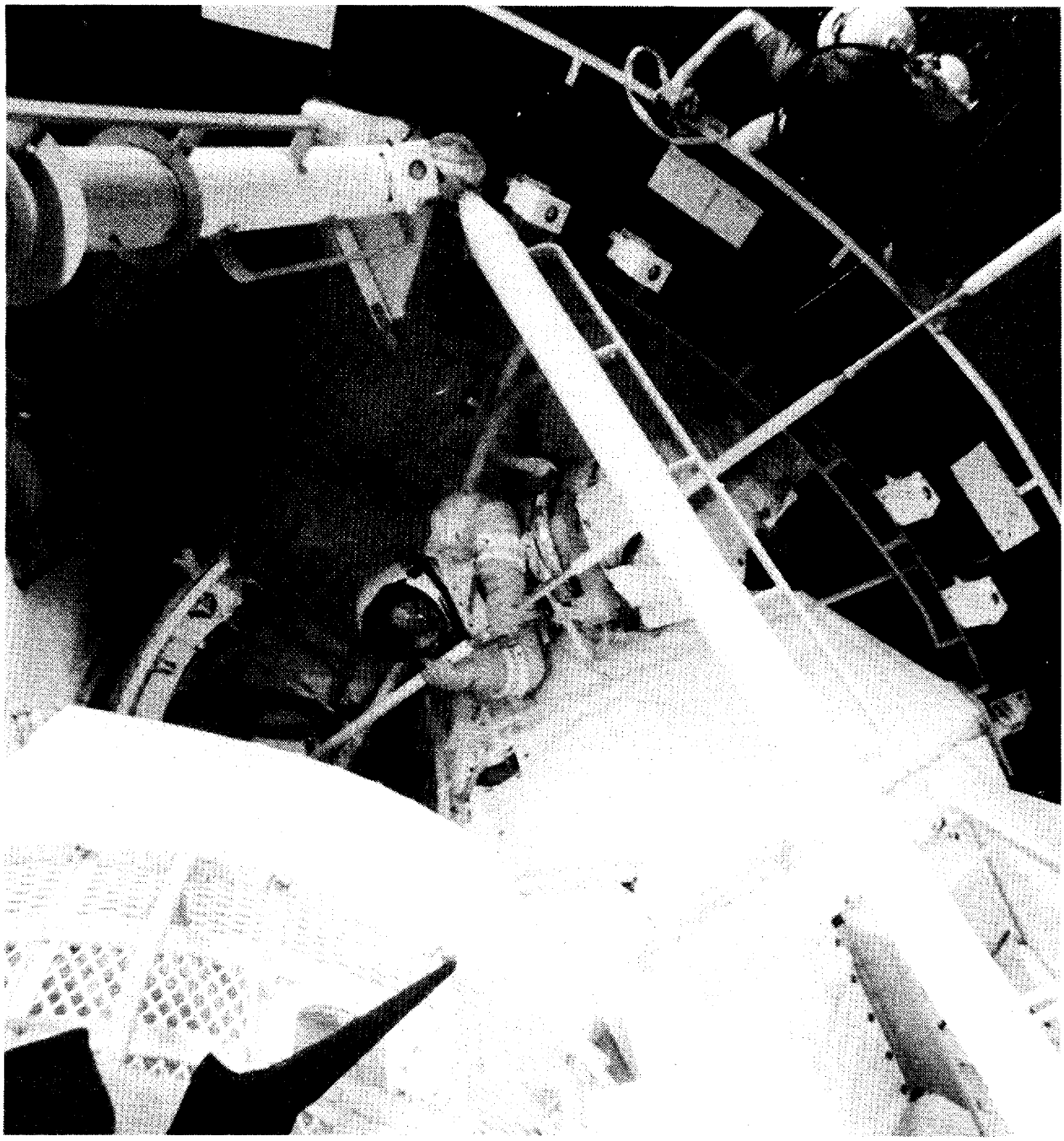


FIGURE 5–30 ASTRONAUT ASSEMBLING FIVE SAIL POLE SEGMENTS AT THE VF

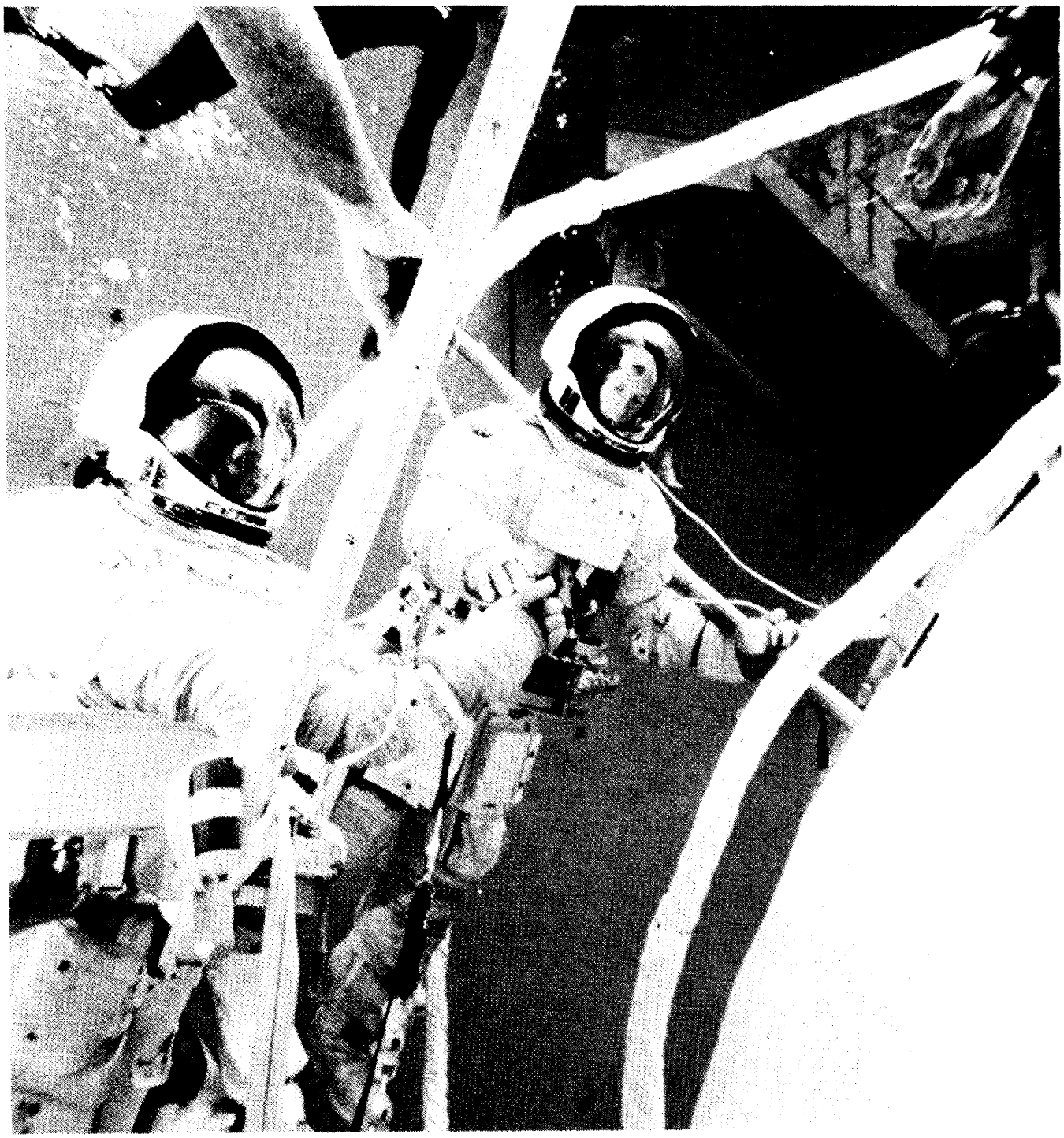


FIGURE 5–31 EQUIPMENT TRANSFER EXERCISE AT THE DISCONE ANTENNA AREA

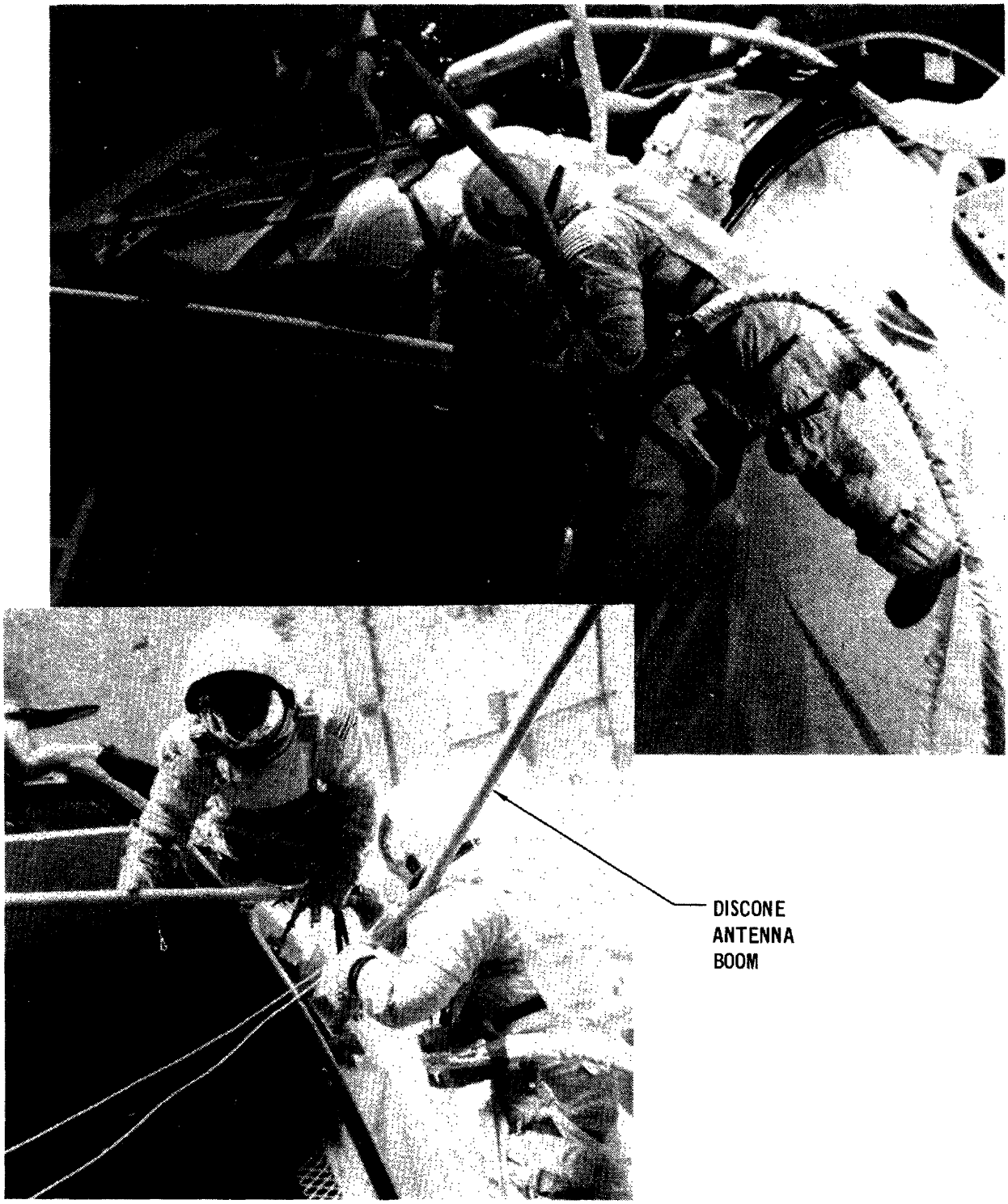


FIGURE 5-32 NBS EXERCISE EVALUATING RESTRAINING METHODS AT THE DISCONE ANTENNA AREA

FIGURE 5–33 ASTRONAUTS TRANSLATING OUT TO THE SAS WING USING FIVE SAIL POLE SEGMENTS WITH CABLE CUTTER CLAMPED TO DEBRIS STRAP

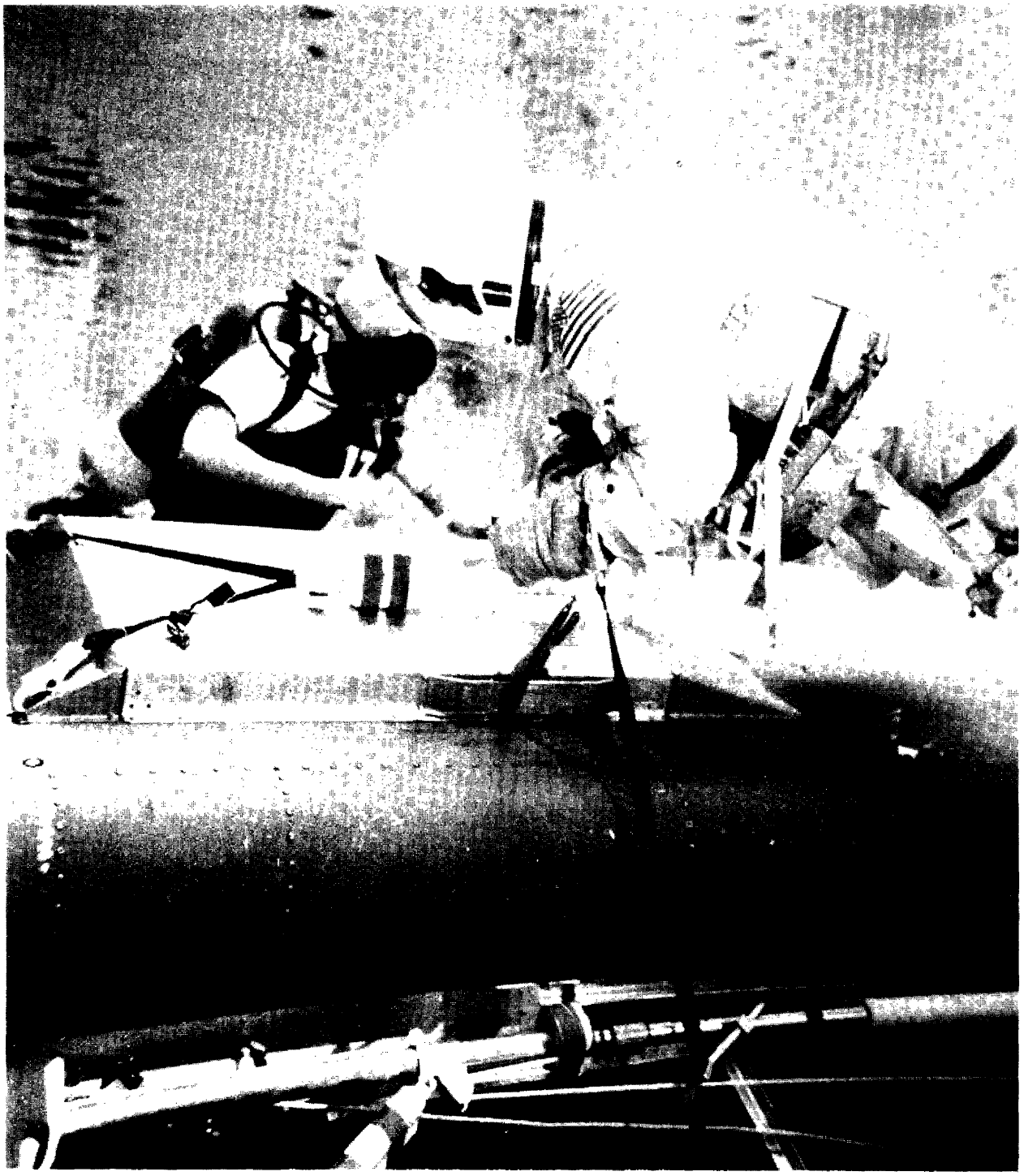


FIGURE 5–34 ASTRONAUT ATTACHING THE ADJUSTABLE TETHER TO THE SAS WING VENT MODULE FOR BREAKING THE ACTUATOR CLEVIS BY THE FULCRUM METHOD

The method for freeing the debris strap from the SAS wing was determined to be at the option of the EVA crewman: (1) cut with cable cutters (Figure 5-35); (2) pry loose using the pry bar (Figure 5-36), or (3) saw with the dental bone saw (Figure 5-37).

The 9.5m (31 ft) adjustable tether was replaced with parts from the JSC SEVA sail concept and tether hooks, called the Boom Erection Tether (BET), which had been flown up on SL-2 (Figure 5-38). The BET had greater tensile strength than the adjustable tether, which provided a greater safety margin when using the fulcrum erection method.

Another hardware bench review was held in the NBS Building on 3 June 1973. Afterwards Astronauts R. Schweickart and E. Gibson did their EVA "Prep" for the 10:30 A.M. NB suited exercise.

The end-to-end suited exercise using the refined EVA procedures went very smoothly. Equipment transfer from the FAS EVA work station to the Discone Antenna work area went well. The sail pole with the cable cutters clamped securely to the debris strap worked well as a translation rail while the second crewman secured the other end of the pole at the discone antenna area. Once the crewman was at the SAS debris strap he could tether himself to the sail pole or to the SAS vent module.

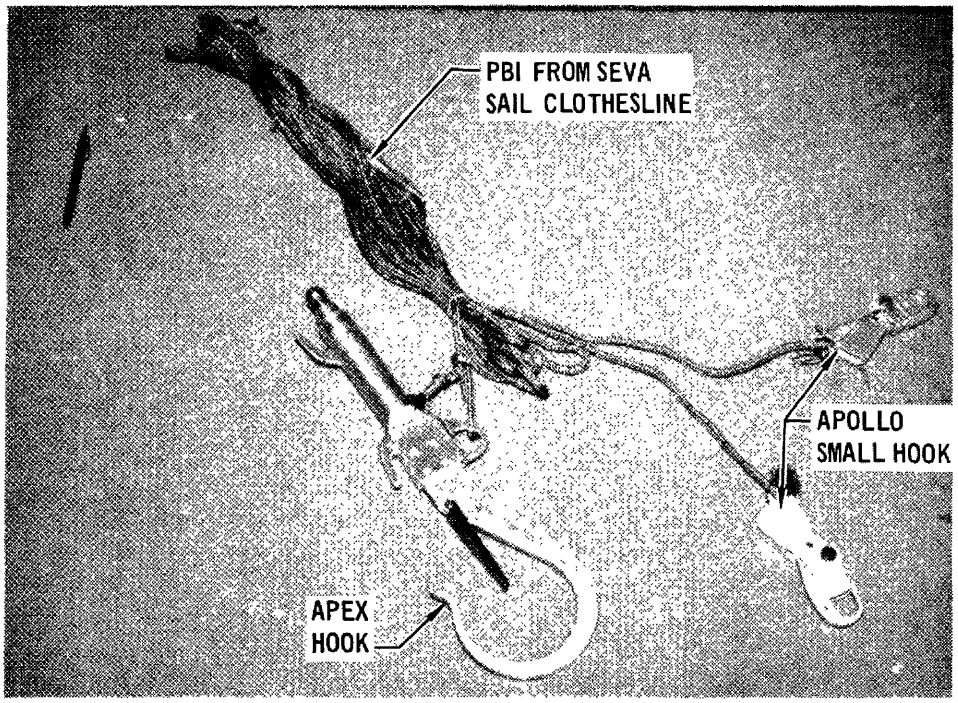
On 4 June 1973, NASA Management gave the approval for the Skylab contingency EVA to complete SAS deployment.

Most of the day on 6 June was spent preparing the facilities and "trimming out" the hardware for real-time simulation the next day, 7 June 1973.

FIGURE 5-35 CUTTING DEBRIS STRAP WITH CABLE CUTTERS

FIGURE 5-36 ASTRONAUT USING PRY BAR TO REMOVE SAS WING DEBRIS STRAP

FIGURE 5-37 ASTRONAUT CUTTING DEBRIS STRAP WITH DENTAL BONE SAW



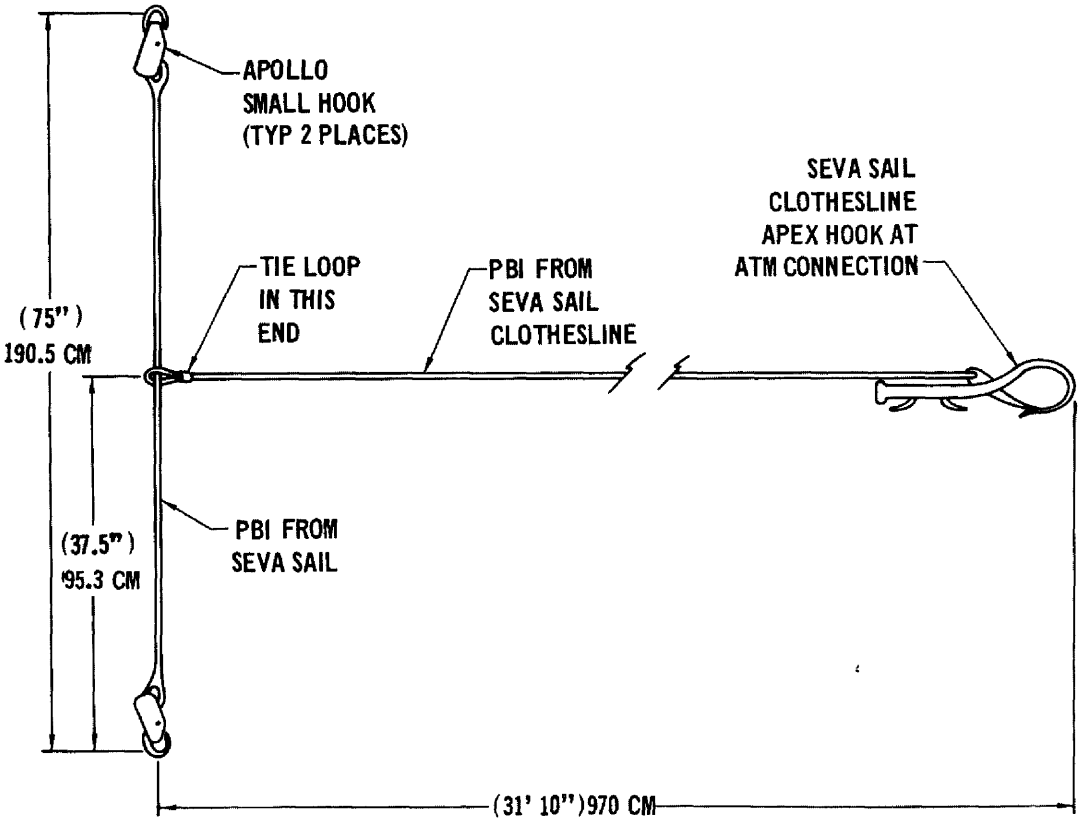


FIGURE 5-38 BOOM ERECTION TETHER (BET)

R. Schweickart communicated with the SL-2 crew briefing them on all the EVA hardware, tethers, restraining and translation methods, etc., and answered any questions they had on the EVA procedures sent to them the night before via the teleprinter.

The next day, 7 June 1973, SL-2 Crewmen C. Conrad and J. Kerwin successfully deployed the #1 SAS wing assembly. The debris strap was cut using the cable cutters (Figure 5-39) and the actuator clevis was broken using the "BET" (Figure 5-40). During the contingency EVA, the NBS was on standby ready for real-time simulation.

5.2.3 Supplemental Solar Array System (SSAS)

An alternate method of restoring sufficient electrical power to Skylab was studied, although the confidence of deploying the #1 SAS Wing Assembly by EVA was very high. This method was to deploy a folded SSAS by EVA on the SL-3 Mission. The mechanical attachment would be at the Airlock FAS ring, with an electrical cabling connection at the umbilical plate located at the IU/OWS interface.

The Skylab NBS again was utilized to evaluate methods of attachment and means of connecting the electrical cabling. To perform these evaluations, the NBS forward ring was up-dated to flight configuration and a flight type IU/OWS umbilical plate was installed.

On 6 June 1974, MDAC-E Neutral Buoyancy support personnel provided the engineering coordination and drawings for fabrication of the required NBS modification hardware and fidelity.

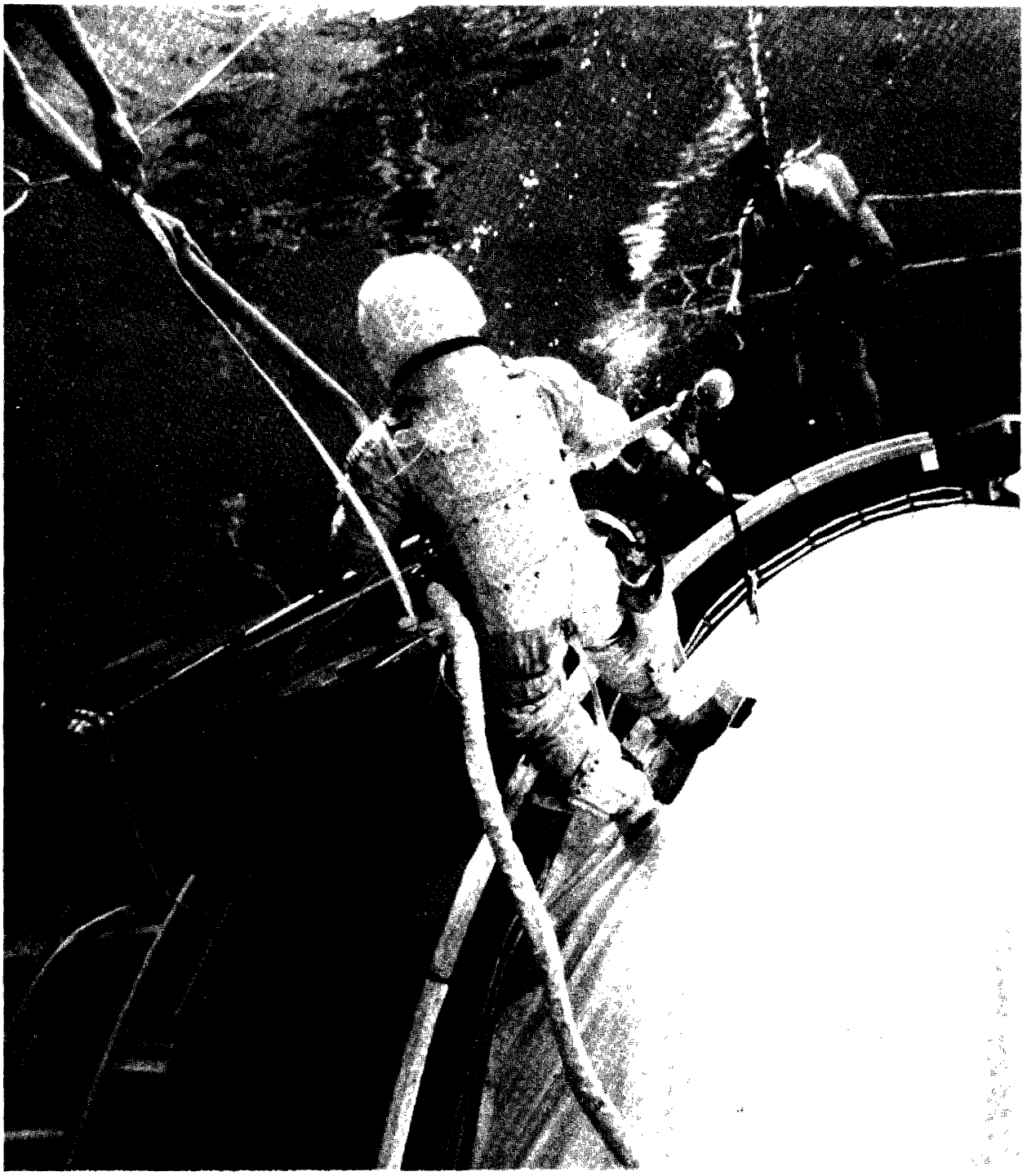


FIGURE 5–39 ASTRONAUT TETHERED AT DISCONE ANTENNA BOOM USING FIVE SAIL POLE SEGMENTS WITH CABLE CUTTERS ATTACHED TO CUT DEBRIS STRAP

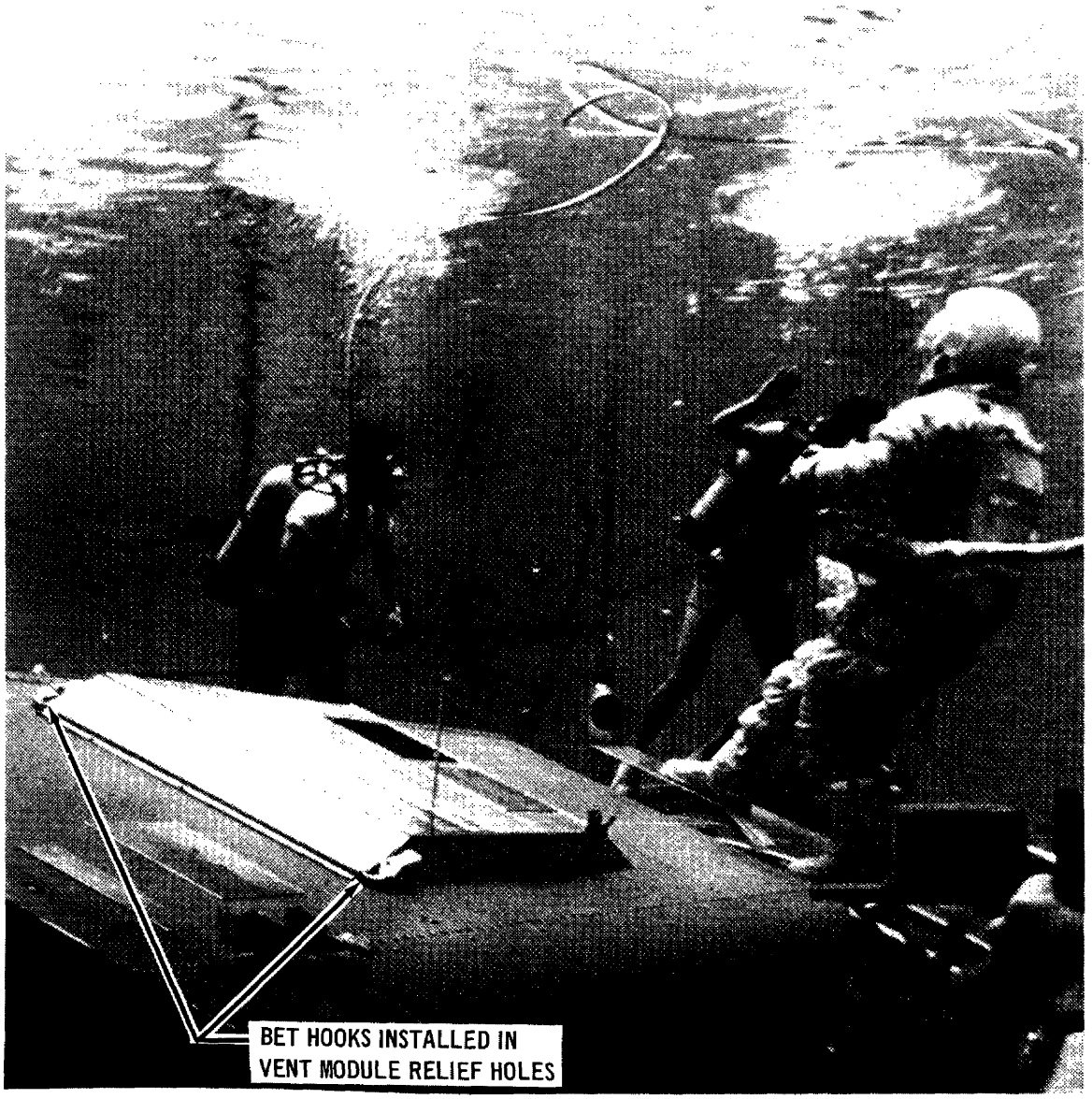


FIGURE 5-40 ASTRONAUT USING BET TO DEPLOY SAS WING

The word from NASA Management was "Press On" for SSAS PDR to be held at MSFC 11 June 1974.

Several NB exercises were made to evaluate concepts of translating from the FAS EVA workstation to the IU/OWS umbilical plate and methods of restraining the crewman.

A management council meeting was held 13 June 1974 and, based on successful SAS deployment and Airlock Electrical Power System (EPS) activation, the decision was made to stop all efforts on the SSAS.

5.2.4 Charger-Battery-Regulator Module (CBRM) and Rate Gyro Repair

The Charger-Battery-Regulator Module (CBRM) No. 3 and No. 15, and the orbital attitude rate gyros malfunctioned early in the SL-2 mission. An evaluation of the telemetry measurements indicated the CBRM's problem was probably caused by a relay contact being stuck in the open position. The attitude rate gyros indicated faulty, erratic data. The methods chosen for repair attempts were replacement of CBRM No. 3, use of a jumper cable on CBRM No. 15, and installation of a special Rate Gyro Package (RGP) or "Six Pack". In order to evaluate these repair methods, the Skylab NBS was used for developing techniques, formulating procedures, and crew training.

A meeting was held 13 June to define these repair techniques and the NB hardware required for the evaluation and training. The NB cabling and connector hardware was prepared by the S&E-ASTR Laboratory, which worked closely with the NB personnel in fabricating the hardware for underwater use (Figures 5-41 and 5-42).

FIGURE 5-41 NBS ELECTRICAL CONNECTOR PANEL AT UPPER DA FOR RATE GYRO REPAIR

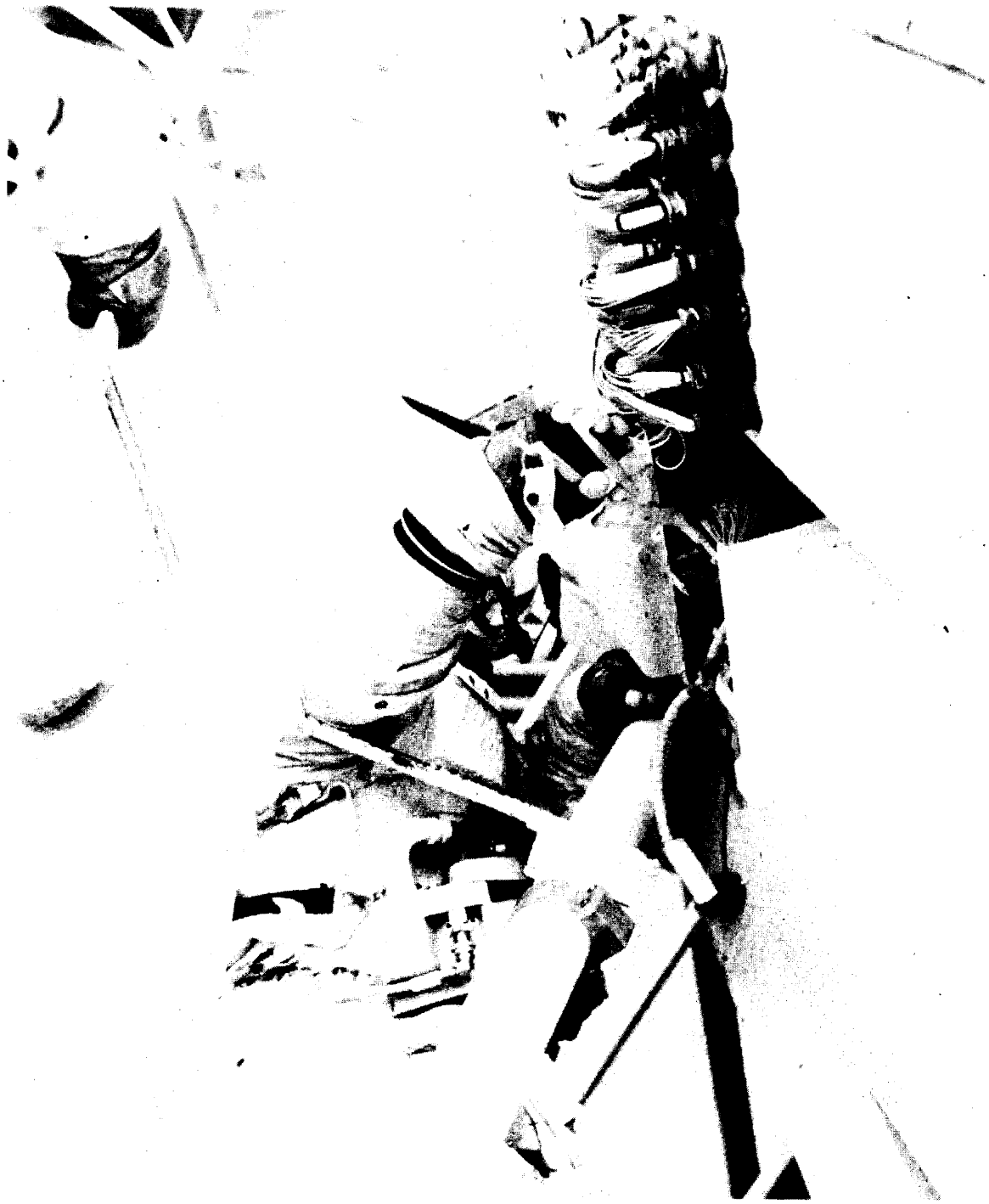


FIGURE 5–42 NBS ELECTRICAL CONNECTORS AT ATM FOR RATE GYRO REPAIR

On 15 June, a NB pressure suited exercise was performed by C. Cooper. This exercise was made for familiarization of cable connectors, EVA routes, restraining techniques, and to evaluate the length of cabling required.

After several NB exercises the replacement of a CBRM was determined not feasible and jumpering the stuck relay appeared more likely to succeed; however, the EVA crewman would have to remove and replace cable connectors in tight access areas.

During the first EVA on the SL-2 mission the S&E-ASTR Laboratory wanted to try the procedure of an EVA crewman striking the CBRM No. 15 cover near the relay with a hammer (or other appropriate tool) in the hope that the shock would free the relay.

On the first EVA of SL-2 the above procedure was successfully completed. The RGP rate gyro problem remained. Special cable connectors with extended backshells and a set of connector pliers were developed for the SL-3 mission. During this phase, the required areas of the Skylab NBS were brought to flight configuration. The DA trunnion interconnect box and the ATM Workshop Computer Interface Unit (WCIU) were modified to provide the same working envelope and "flight feel" ("C" fidelity). During the EVA, connectors at both the DA trunnion interconnect box and the WCIU would be disconnected and the new cable connected. The "Six Pack" would then be mounted inside the MDA.

On 22 June, Astronauts O. Garriott and J. Lousma performed a suited NB exercise. This exercise included an end-to-end CBRM and "Six Pack" procedure run through. The next day, 23 June, Astronaut A. Bean and C. Cooper, S&E-PE-MS performed the same suited exercise (Figure 5-43). After these NB exercises, the contingency EVA procedures were finalized.

On the second EVA of SL-3, the "Six Pack" was successfully installed and the system began to work satisfactorily.

5.2.5 S193 Antenna Repair

The S193 Microwave Radiometer/Scatterometer utilized a gimballed antenna which developed scanning malfunctions during the second manned mission. Troubleshooting and repair required an EVA operation and the NBS was used for development of the equipment and techniques.

The antenna was a 1.13m (44.5 inch) diameter dish mounted on an electronics package, installed between DA struts below the STS. This was on the side opposite to the ATM, i.e., on the "bottom" of the vehicle. No EVA operations had been planned for in this area. Thus, several problems had to be solved: (1) EVA lights, handrails, and workstation foot restraints were not available; (2) the electronics package was very inaccessible behind the antenna dish; (3) the exact nature of the malfunction and the required corrective action were not yet established.

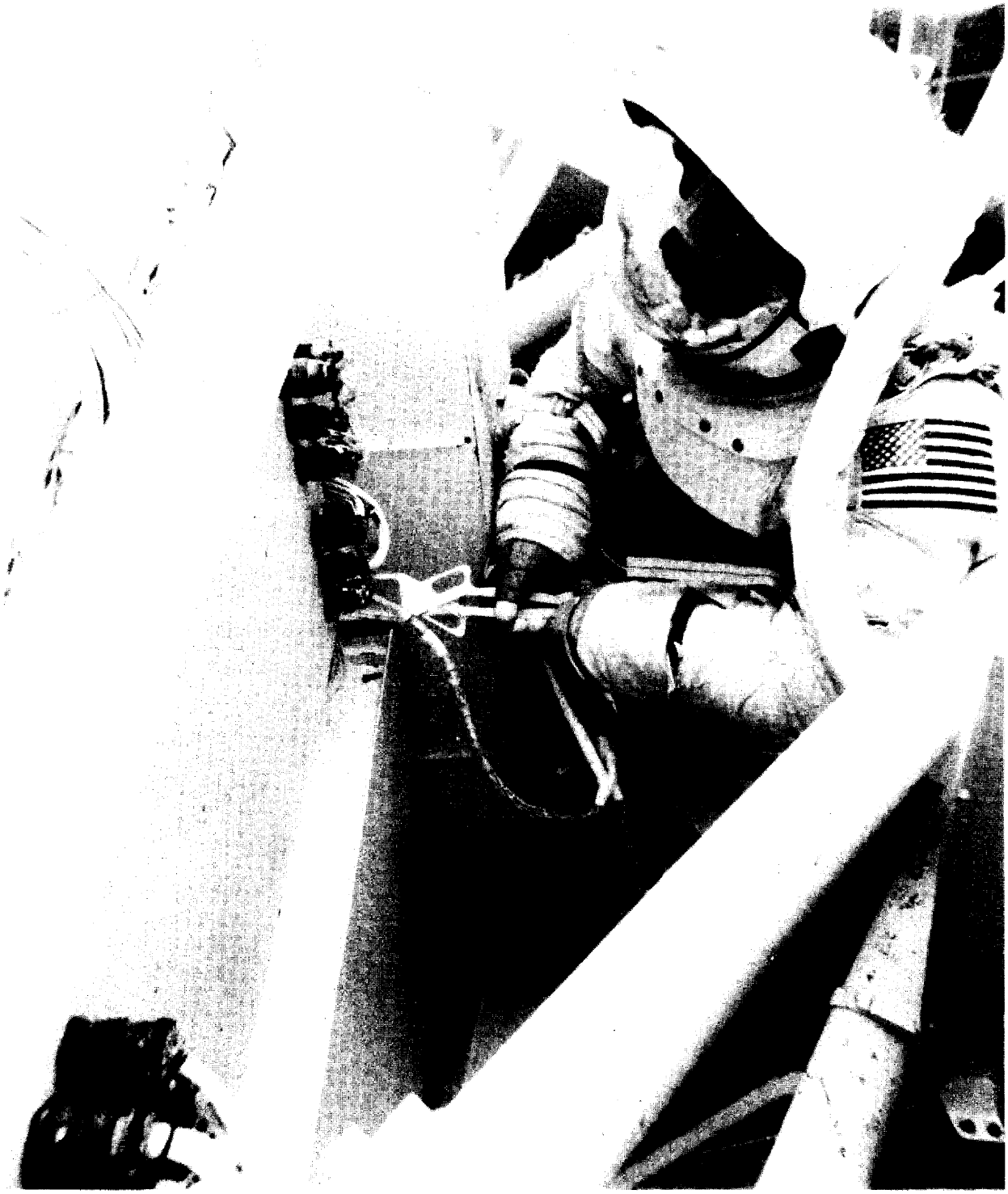


FIGURE 5-43 ASTRONAUT USING EVA CONNECTOR PLIERS IN RATE GYRO REPAIR

Initial NBS exercises to evaluate repair techniques (shown in Figure 5-44) emphasized the need for better fidelity of S193 equipment, work station foot restraints, and a device for holding tools in an accessible position.

A high fidelity S193 package was made available by General Electric, prepared for underwater operations, and installed in the NBS in place of the existing unit. During this period of time, more data was collected from Skylab and preliminary repair procedures were developed. The first repair step was to sweep the potentiometers with a spatula type brush to remove debris and check operation via third crewman inside the MDA. If this did not prove successful, the EVA crewmen were to demate electrical connectors and install a special switch box to allow external control of the antenna sweep. The repair procedures required several tools built especially for the S193 repair, and contained in a tool pouch that was developed in the NBS. When at the S193 antenna, the astronaut wrapped the tool pouch around the lower DA strut and secured it with a velcro strap. After the pouch was secured to the strut, all of the special tools were easily accessible, one at a time, in individual pockets. Each crew operation was calculated to minimize EVA effort and assure safety of the astronauts.

On 27 September, Astronaut R. Schweickart and R. Heckman, S&E-ASTN-SMD, made a suited NBS exercise. This exercise was to evaluate methods of translating to the S193 antenna and the use of the portable MSFC

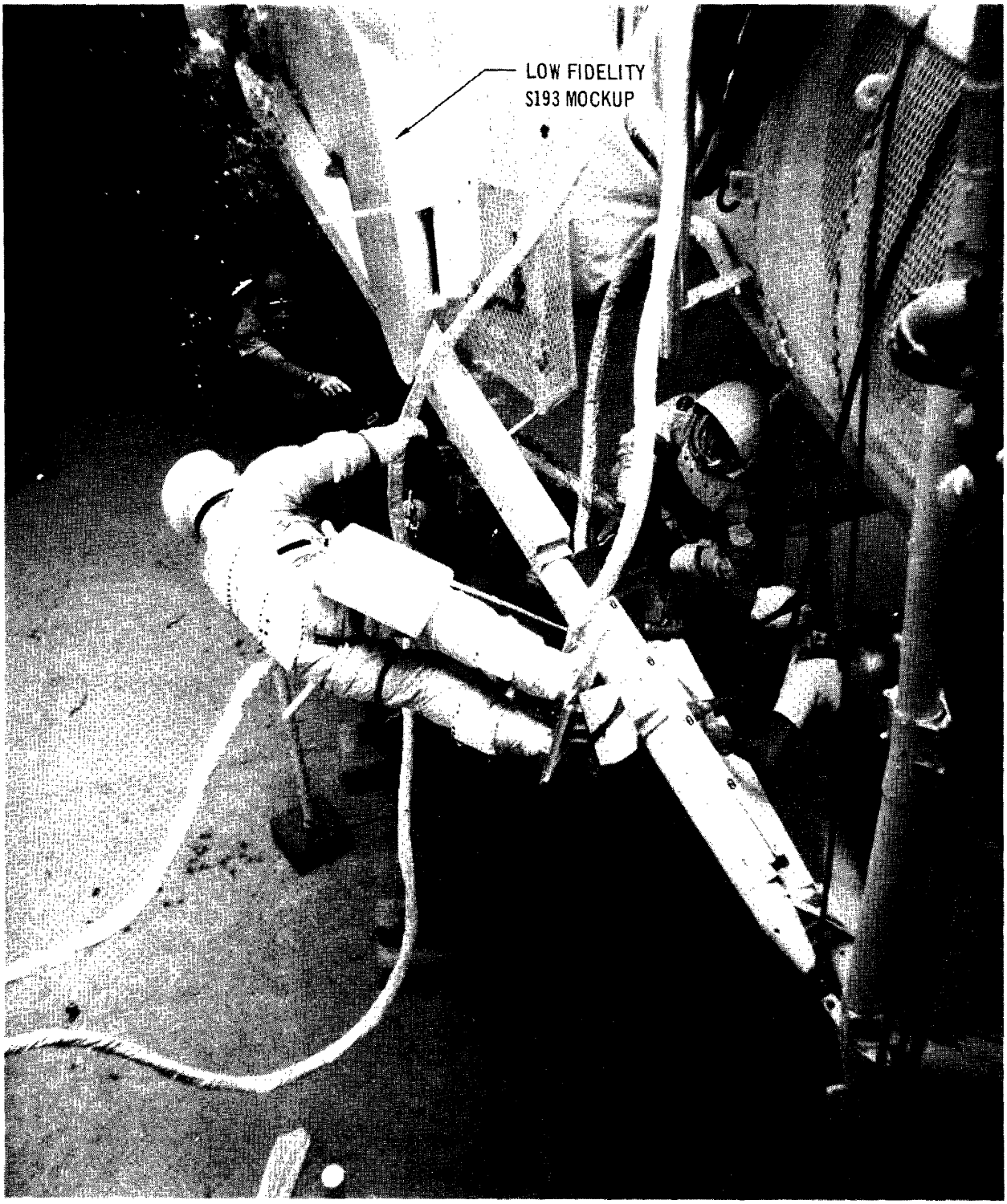


FIGURE 5–44 EARLY NBS S193 REPAIR EVALUATION

universal foot restraints and the JSC restraints. In addition, the test subjects determined possible body positions for repair of the gimbal assembly. The body positions determined the location (on the ATM DA members) for the restraints. The foot restraints were judged for their rigidity and ease of adjustment. As a result of this exercise both the MSFC and JSC universal foot restraints were modified. Due to the critical launch weight, the on board MSFC portable foot restraints were selected with a special NBS developed adapter. The special adapter was installed into an existing lightening hole in the launch support structure of the discone antenna (Figure 5-45). The method of translating to the antenna area was from the FAS workstation using the mole sieve vent duct as a handrail along the exterior of the AM Structure Transition Section (STS).

Another NB exercise was performed on 3 October, with R. Heckman, S&E-ASTN-SMD and C. Cooper, S&E-PE-MSE as suited subjects. This exercise was to develop a preliminary procedure, for the S193 antenna repair, (Figure 5-46). The next day, 4 October, Astronauts W. Lenoir and S. Musgrave performed a suited exercise after a briefing from Astronaut R. Schweickart. This exercise was end-to-end using preliminary procedures (Figure 5-47). The portable foot restraints were evaluated along with the special tools for repair of the S193 antenna and methods of using the waist and wrist tethers.

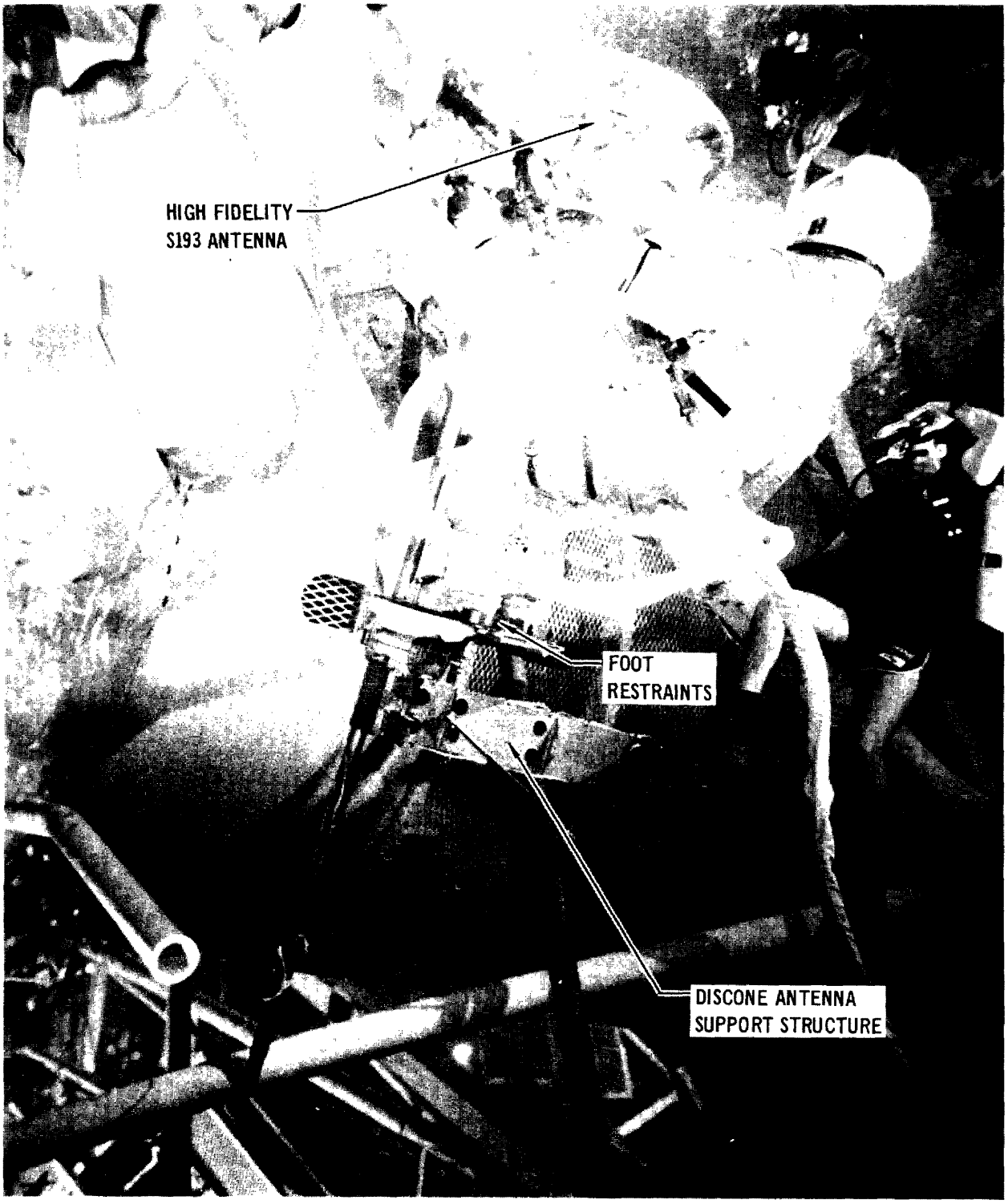


FIGURE 5-45 FOOT RESTRAINT LOCATION FOR S193 REPAIR

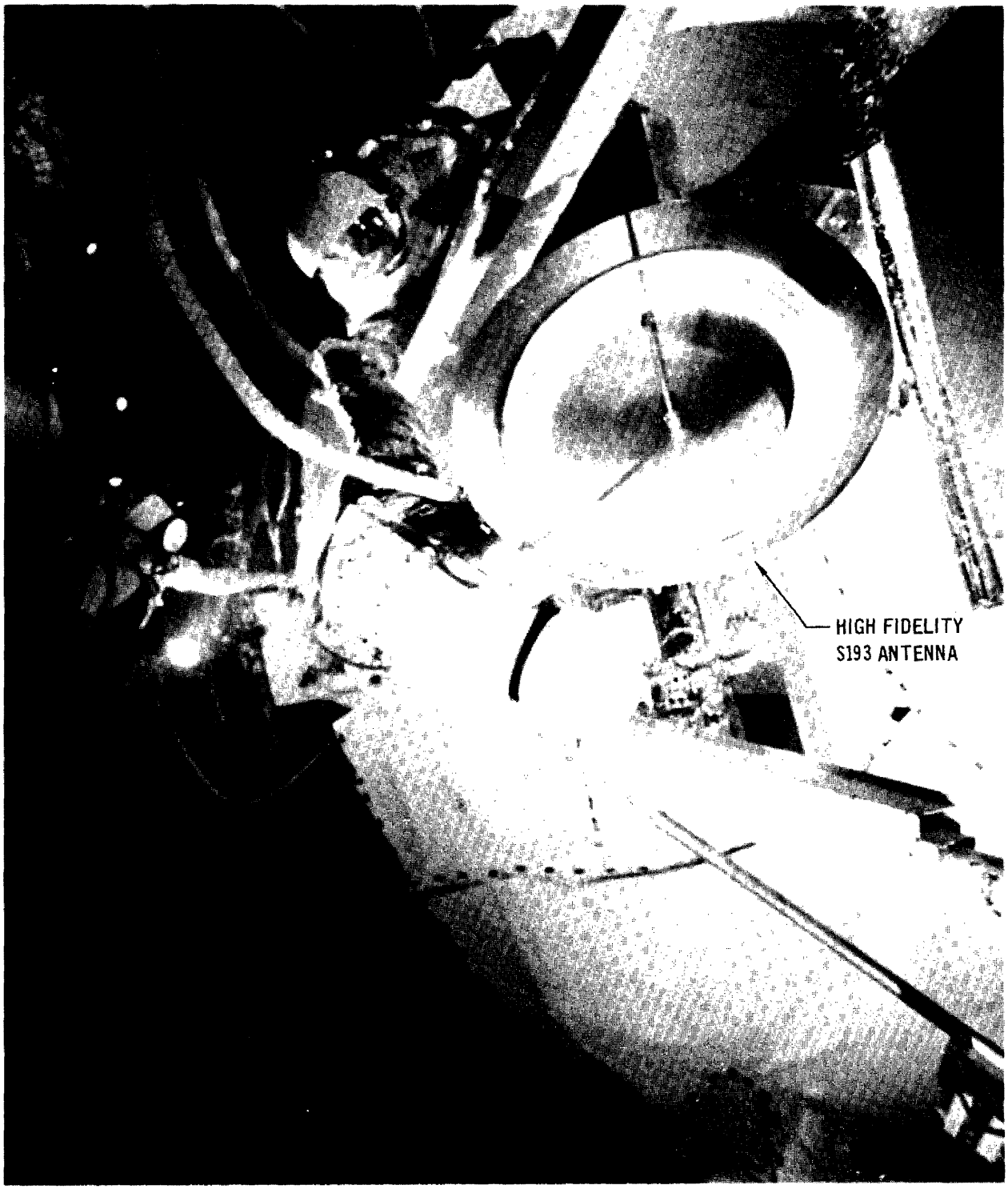


FIGURE 5–46 NBS S193 ANTENNA REPAIR EXERCISE

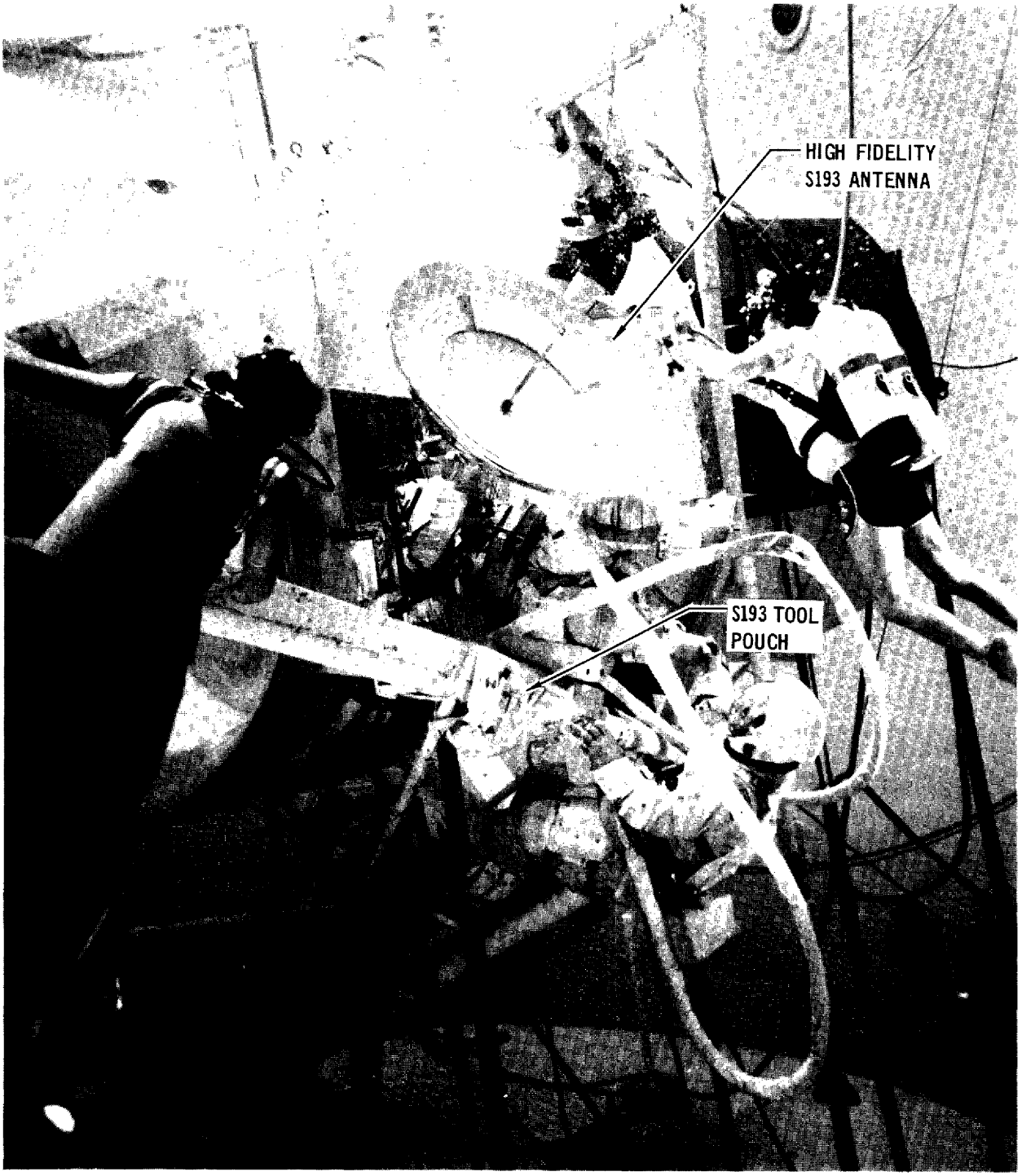


FIGURE 5–47 ASTRONAUTS TRAINING FOR S193 ANTENNA REPAIR

The SL-4 prime crew made an end-to-end NB training exercise on 10 October on the S193 antenna repair. On 11 October, the back-up crew performed the same exercise. The NBS tests verified that the antenna repair could be performed, but because of the antenna's mass and size, and the inaccessibilities of the electronic components, the task would be both long and difficult.

During the first EVA of SL-4, two crewmen successfully performed the inspection repair task and the antenna's pitch and roll gimbal was pinned, and a disable plug and jumper box installed.
During the contingency EVA, the NBS was on standby status to assist in solving any problems with real time simulation.

5.3 Lessons Learned

- The NBS has proven to be a necessary tool in EVA training and its use should be planned into future space programs.
- NBS contingency evaluations and training proved that repair tasks not before thought possible could be accomplished in orbit with proper tools, access, restraints, and procedures.
- Foot restraints are preferred over waist tethers or hand-holds because they give the crewman more flexibility and freedom of movement.
- For NBS training and evaluations to be meaningful high-fidelity equipment is required in the crew interface areas, expecially tether points, protrusions, envelopes, etc.

- Crew training in the NBS gave the astronauts valuable pressure suit familiarization experience in a simulated zero-G environment. Experience showed that at least twenty hours of NBS suited operation is required before a crewman can start to benefit from NBS training.
- Possibly one of the greatest benefits from the NBS was derived by NASA management during the critical repair contingency training exercises. By viewing the actual simulation exercise performed by the crew, and subsequently reviewing video tapes of training exercises, management made their decision to approve the flight plan changes, based on a full understanding of the activities proposed for the crewmen to perform. Thus, the NBS served as a tool to allow evaluation of the risks to life and mission and make critical real-time decisions.
- On future manned space programs, high fidelity hardware such as test articles, qualification units, static articles, etc., should be made available to the NBS for use during the mission. After hardware has served its original purpose (test, qualification, etc.) NBS personnel could adapt it for underwater service so that it could be used immediately to work out repair methods and procedures under simulated zero-G conditions.
- The Skylab missions demonstrated that EVA task time lines could be closely defined by performing end-to-end training exercises. Although some IVA tasks have been accomplished underwater, results have shown more experience must be gained before

meaningful simulations can be accomplished. Future programs may benefit from NBS IVA training for orientation purposes. The three dimensional freedom of training could be a valuable asset for IVA exercises especially for short duration flights.

6.0 CONCLUSIONS

The Neutral Buoyancy Simulator was an extremely useful tool in EVA equipment evaluation, crew training, procedures development and was an essential element in the real time determination of the repair capability that made Skylab a success. This was clearly demonstrated in the nine very successful Skylab EVA's and is bourne out by the following crew comments:

> "If you can do it in the NBS, it works."

> "Trainers, Neutral Buoyancy: I personnally couldn't say enough for that whole effort, both from the standpoint of training and from the standpoint of evaluation and procedures development. Much of that went on during the Skylab mission as we came up with new EVA's. That was where all the action was and it was exceptionally well done. I can't say enough for the people at the tank and their motivation and capabilities. I hope that those people will be used in the future."

> "The other EVA's that came up in Skylab - Pete started off with the wing deployment, the deployment of the twin poles and finally we ended up with S193 and a couple of others. I think all that went well because of the efforts of people in the neutral buoyancy tank. Had that tank not been available, I wouldn't have given you a dime for the efforts of those EVA's ever succeeding . . . . . I can't say enough for those people. I think their contribution to the Skylab program was just outstanding."

"Any EVA activity like rate gyro installation has to be well thought out and trained for in the water tank and have foot restraints where the guy has to work to assure success."

"I hope we don't lose that facility."

"I doubt if Skylab would have succeeded without the tank."

In-flight maintenance and hardware replacement proved to be no more difficult than anticipated from NBS experience. The NBS provided the zero-G environment that was necessary in developing hardware and procedures to successfully perform Skylab EVA repair tasks that were considered impossible before the SL-1 launch. This, in no small way, allowed man to demonstrate almost limitless repair capabilities in orbit.

Based on the success of Skylab, the NBS has a definite place in manned space programs and its use should be a bonafide step in future development plans.

APPENDIX A
ACRONYMS AND ABBREVIATIONS

The following list includes those acronyms and abbreviations considered appropriate to the NBS. Obvious standard abbreviations are not included.

AGE	Aerospace Ground Equipment
ALC	Audio Load Compensator
ALSA	Astronaut Life Support Assembly
AM	Airlock Module
AMS	Airlock Module Station
ATM	Apollo Telescope Mount
BET	Boom Erection Tether
CBRM	Charger-Battery-Regulator Module (ATM)
CCU	Crewman Communication Umbilical
C&D	Control and Display
CDR	Commander
CDR	Critical Design Review
CEI	Contract End Item
CFE	Contractor Furnished Equipment
CM	Command Module
COMM	Communications
CRS	Cluster Requirements Specification
CSM	Command and Service Module
C&W	Caution and Warning
DA	Deployment Assembly

DAC	Data Acquisition Camera
DCR	Design Certification Review
DCS	Digital Command System
DOY	Day Of Year
ECS	Environmental Control System
EJS	Engineering Job Sheet
EKG	Electrocardiagram
EOP	Emergency Oxygen Pack
EPS	Electrical Power System
EREP	Earth Resource Experiment Package
ESE	Electrical Support Equipment
EVA	Extra-Vehicular Activity
FAS	Fixed Airlock Shroud
FTB	Film Transfer Boom
GE	General Electric Company
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
ICD	Interface Control Document
I/F	Interface
IU	Instrumentation Unit
IVA	Intervehicular Activity
JSC	Johnson Space Center
LCCU	Lightweight Crewman Communication Umbilical
LCG	Liquid-Cooled Garment

LSU	Life Support Umbilical
MDA	Multiple Docking Adapter
MDAC-E	McDonnell Douglas Astronautics Company - East
MDAC-W	McDonnell Douglas Astronautics Company - West
MMC	Martin Marietta Corporation
MMS	McDonnell Material Specifications
MOLE	Molecular (Reference to the Molecular Sieve)
MSFC	Marshall Space Flight Center (NASA)
MSG	Mission Support Groups
NBS	Neutral Buoyancy Simulator
NBT	Neutral Buoyancy Trainer
NT	NASA Trainer
OA	Orbital Assembly
ORI	Operational Readiness Inspection
OV	Orbital Vehicle
OWS	Orbital Workshop
PB	Process Bulletin
PCU	Pressure Control Unit
PDR	Preliminary Design Review
PI	Principal Investigator
$PPCO_2$	Partial Pressure Carbon Dioxide
PPM	Parts Per Million
PPO_2	Partial Pressure Oxygen
PS	Payload Shroud

QA	Quality Assurance
QD	Quick Disconnect
RGP	Rate Gyro Package
SAL	Scientific Air Lock
SAR	Spacecraft Acceptance Review
SAS	Solar Array System
SCD	Source (Specification) Control Drawing
SCUBA	Self Contained Underwater Breathing Apparatus
SEVA	Standup EVA
SL	Skylab
SL-1	Skylab 1 (Laboratory)
SL-2	Skylab 2 (Crew Vehicle 1)
SL-3	Skylab 3 (Crew Vehicle 2)
SL-4	Skylab 4 (Crew Vehicle 3)
SM	Service Module
S/O	Shutoff
SOP	Supplemental Oxygen Package
SOS	Supplemental Oxygen System
SPT	Science Pilot
SSAS	Supplemental Solar Array System
STS	Structural Transition Section
SUS	Suit Umbilical System
SV	Space Vehicle

SWS	Saturn Workshop (PS/MDA/ATM/AM/OWS/IU/ATM, Deployment Assembly)
TCS	Thermal Control System
TCV	Temperature Control Valve
TR	Test Request
U-1	Airlock Vehicle Unit 1
U-2	Airlock Vehicle Unit 2
VC	Workstation - Center
VF	Workstation - FAS
VR	Workstation - Replacement
VS	Workstation - Sun End
VT	Workstation - Transfer
WCIU	Workshop Computer Interface Unit

APPROVAL

MSFC SKYLAB NEUTRAL BUOYANCY SIMULATOR

By

Space Simulation Branch

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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