NASA SP-149

SUMMARY OF GEMINI EXTRAVEHICULAR ACTIVITY

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1.0 SUMMARY

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1.0 SUMMARY

The Gemini Program extravehicular operations have been summarized in this report. The actual systems employed, the testing and qualifications of these systems, the preparation of the flight crews, and the operational and medical aspects were described from a developmental viewpoint.

During the Gemini Program, the basic feasibility of extravehicular activity was established. Other significant results were:

(a) Demonstration of retrieval of equipment from within the spacecraft adapter and from another satellite

(b) Establishment of requirements for handholds, foot restraints, and body restraints

(c) Evaluation of the dynamics of motion on a short tether

(d) Preliminary evaluation of a hand held maneuvering device

(e) Demonstration that the extravehicular workload could be maintained within the limits of the life support system and the capabilities of the pilot

(f) Demonstration that underwater zero-g simulation was valid in solving body restraint problems and in assessing workloads

While most of the extravehicular operations were successful, several limitations were identified. The most significant limitations were the inability to perform extravehicular tasks without the proper body restraints, the mobility restrictions imposed by the design of the space suit, and the limited cooling capacity of life support systems using gaseous cooling.

Recommendations are made for development of future extravehicular operations.

2.0 INTRODUCTION

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2.0 INTRODUCTION

The Gemini Program provided the first experience in extravehicular activity (EVA) in the United States manned space effort. The original objectives included the following:

(a) Develop the capability for EVA in free space

(b) Use EVA to increase the basic capability of the Gemini spacecraft

(c) Develop operational techniques and evaluate advanced equipment in support of EVA for future programs

In general, these objectives were met. Because of problems encountered during the equipment evaluation, emphasis was shifted from maneuvering equipment to body restraint devices.

In the initial Gemini design guidelines, missions were contemplated that had 30 to 60 minutes of EVA with very low workloads and metabolic heat rates of approximately 500 Btu/hr. The needs for longer periods of EVA and greater heat dissipation capabilities were subsequently indicated from various ground simulations. The design criteria for the extravehicular life support equipment were ultimately set at a mission length of 140 minutes with a normal metabolic rate of 1400 Btu/hr and a peak rate of 2000 Btu/hr. The flight results indicated that in several instances these criteria were unintentionally exceeded. In the final mission, Gemini XII, the equipment and procedures were demonstrated by which the workload and the metabolic rates could be maintained within the desired limits.

One of the most difficult aspects of developing an extravehicular capability was simulating the extravehicular environment. The combination of weightlessness and high vacuum was unattainable on earth. Zero-g aircraft simulations were valuable, but the results of the simulations were occasionally misleading. Underwater neutral buoyancy simulations ultimately proved to be the most realistic duplication of the weightless environment for body positioning and restraint problems. The novel characteristics of the extravehicular environment and the lack of comparable prior experience made intuition and normal design approaches occasionally inadequate. From the accumulation of flight experience, an understanding of the environment and of the techniques for practical operations was gradually obtained. This report documents the facts and examines the factors associated with the development of extravehicular capability during the Gemini Program.

3.0 GEMINI EXTRAVEHICULAR ACTIVITIES

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3.0 GEMINI EXTRAVEHICULAR ACTIVITIES

Extravehicular activity (EVA) was accomplished on 5 of the 10 manned Gemini missions. A total of 6 hours and 1 minute was accumulated in five extravehicular excursions on an umbilical (table 3.0-I). An additional 6 hours and 24 minutes of hatch-open time was accumulated in six periods of standup EVA including two periods for jettisoning equipment. The total extravehicular time for the Gemini Program was 12 hours and 25 minutes.

TABLE 3.0-I.- SUMMARY OF GEMINI EXTRAVEHICULAR ACTIVITY STATISTICS

Mission	Life support system	Umbilical length, ft	Maneuvering device	Umbilical EVA time,[a] hr:min	Standup EVA time,[a,b] hr:min	Total EVA time,[a] hr:min
Gemini IV	VCM[c]	25	HHMU[d]	0:36	--	0:36
Gemini VIII	ELSS[e] - ESP[f]	25	HHMU	--	--	--
Gemini IX-A	ELSS - AMU[g]	25	AMU	2:07	--	2:07
Gemini X	ELSS	50	HHMU	0:39	0:50	1:29
Gemini XI	ELSS	30	HHMU	0:33	2:10	2:43
Gemini XII	ELSS	25	--	2:06	3:24	5:30
EVA totals				6:01	6:24	12:25

[a]Time from hatch opening to hatch closure.

[b]Includes mission equipment jettison time.

[c]Ventilation Control Module.

[d]Hand Held Maneuvering Unit.

[e]Extravehicular Life Support System.

[f]Extravehicular Support Package.

[g]Astronaut Maneuvering Unit.

3.1 GEMINI IV

Two of the objectives of the Gemini IV mission were to establish the initial feasibility of EVA and to evaluate a simple maneuvering device. The life support system was a small chestpack called the Ventilation Control Module (VCM), with oxygen supplied through a 25-foot umbilical hose assembly (fig. 3.1-1). The Hand Held Maneuvering Unit (HHMU) was a self-contained, cold-gas propulsion unit which utilized two 1-pound tractor jets and one 2-pound pusher jet. The G4C space suit was worn with an extravehicular coverlayer for micrometeorite and thermal protection. While outside the spacecraft, the pilot also wore a special sun visor designed for visual protection.

The hatch was opened at 4 hours 18 minutes ground elapsed time (g.e.t.). The pilot was outside the spacecraft for 20 minutes and followed the time line shown in figure 3.1-2. The results established the feasibility of simple EVA without disorientation. The utility of the HHMU for self-propulsion without artificial stabilization was tentatively indicated, although the total available thrust of 20 seconds was too brief for a detailed evaluation of stability and control. The extravehicular pilot evaluated the dynamics of a 25-foot tether, and was able to push out from the surface of the spacecraft under gross control. The umbilical tether caused the pilot to move back in the general direction of the spacecraft. The tether provided no means of body positioning control other than as a distance limiting device. Ingress to the cockpit and hatch closure were substantially more difficult than anticipated because of the high forces required to pull the hatch fully closed. The hatch-locking mechanism malfunctioned, which further complicated the task of ingress. In coping with the hatch-closing problems, the metabolic heat output of the extravehicular pilot exceeded the cooling capacity of the VCM. The pilot was greatly overheated and experienced slight visor fogging at the completion of ingress, although he had been cool while outside the spacecraft. Several hours were required for the pilot to cool off after completion of the extravehicular period; however, no continuing aftereffects were noted. Because of the hatch-closing problems, the hatch was not opened for jettisoning the extravehicular equipment.

The inflight experience showed that substantially more time and effort were required to prepare for the EVA than had been anticipated. The increased hazards of EVA dictated meticulous care in the inflight checkout before the spacecraft was depressurized. The flight crew found the use of detailed checklists a necessary part of the preparations for EVA. In summary, the Gemini IV mission proved that EVA was feasible and indicated several areas where equipment performance needed improvement.

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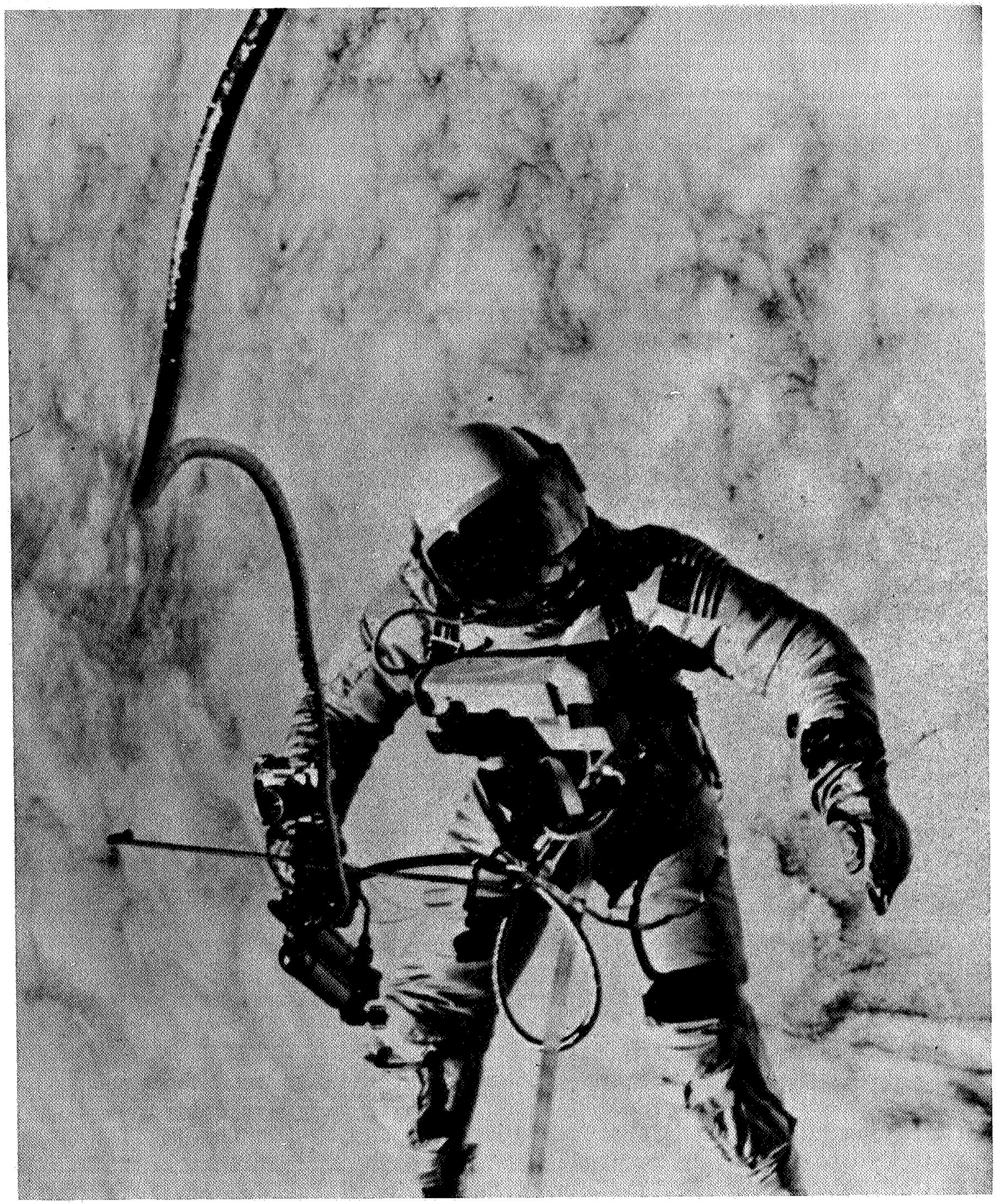

Figure 3.1-1. - Gemini IV EVA equipment.

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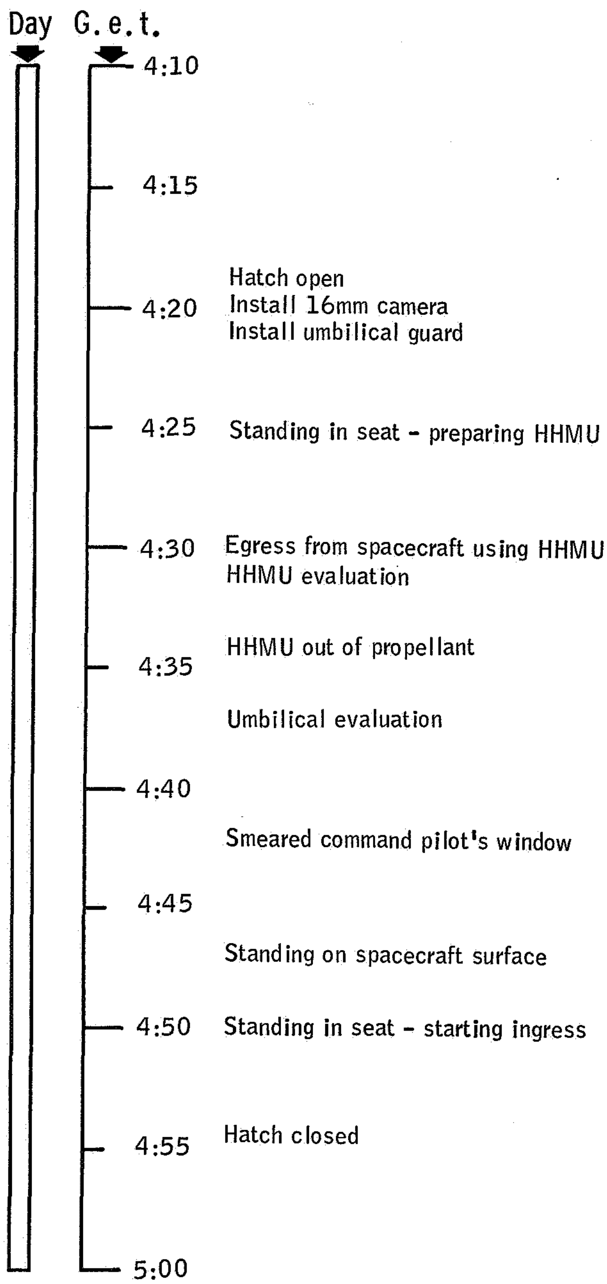

Figure 3.1-2. - Gemini IV EVA time line.

3.2 GEMINI VIII

The primary objectives for EVA during the Gemini VIII mission were evaluation of the Extravehicular Life Support System (ELSS), the HHMU and the Extravehicular Support Package (ESP). The ELSS was a chestpack unit with an increased reserve oxygen supply and a substantially greater thermal capacity than the VCM used during Gemini IV. The ESP consisted of a backpack unit containing an independent oxygen supply for life support, a larger propellant supply for the HHMU, and an ultrahigh frequency radio package for independent voice communications. A detailed evaluation was planned of the HHMU with the pilot on a 75-foot lightweight tether. The equipment for the EVA is shown in figure 3.2-1. The Gemini VIII mission was terminated before the end of the first day because of a spacecraft control system malfunction; therefore, no EVA was accomplished.

Equipment design proved to be quite complex, with a substantial number of late modifications, during preparation for the Gemini VIII mission primarily because the chestpack had to interface with (1) the 25-foot ELSS umbilical, (2) the 75-foot electrical tether, and (3) an ESP line for oxygen. Acceptable designs and procedures were established; however, the handling procedures were more difficult than was desired. Although the equipment provided for the Gemini VIII EVA was not used in orbit, its use in training and in preparation for flight provided initial insight into the problems of complicated equipment connections.

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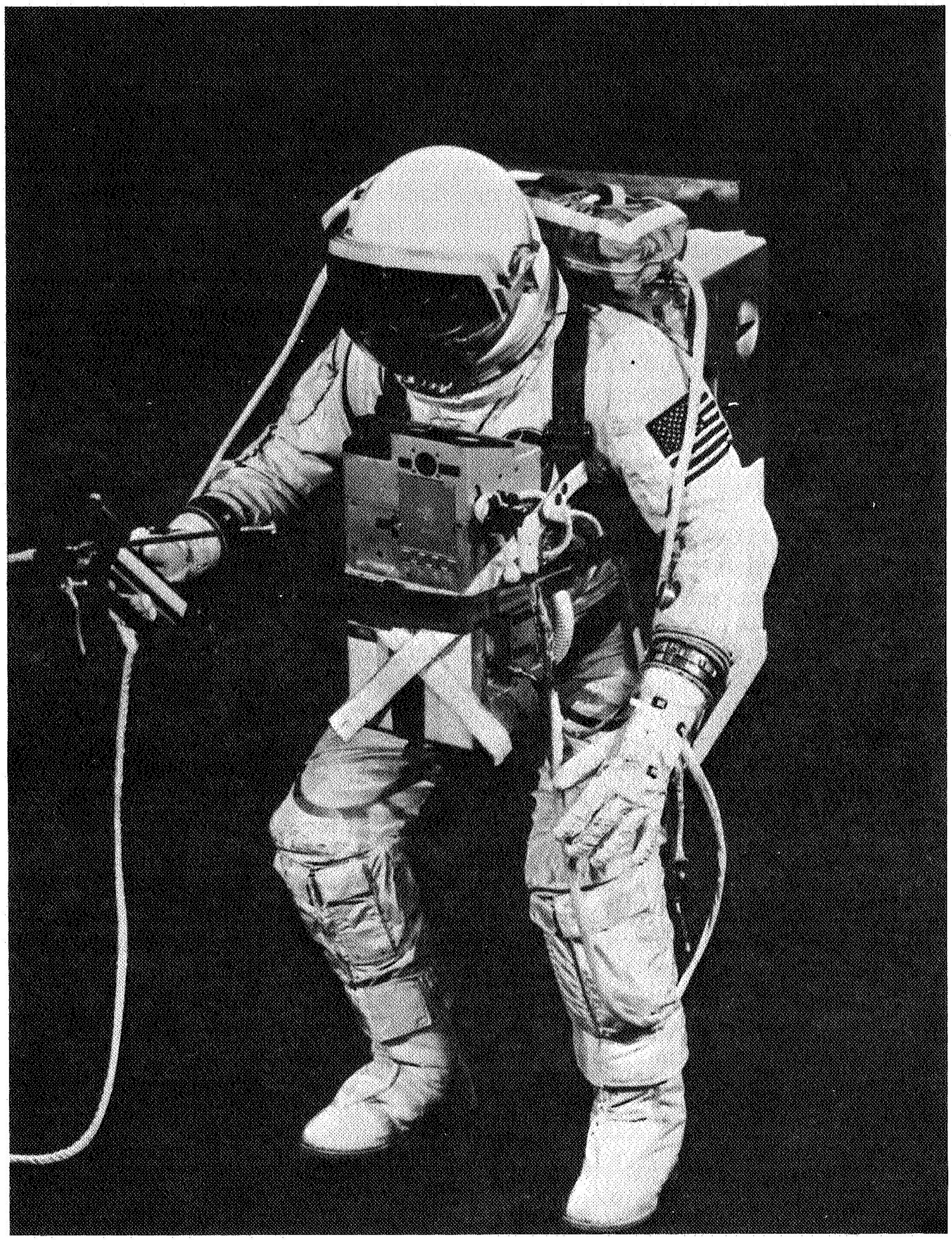

Figure 3.2-1. - Gemini VIII EVA equipment.

3.3 GEMINI IX-A

The prime objective of the Gemini IX-A EVA was to evaluate the ELSS and the Air Force Astronaut Maneuvering Unit (AMU). The AMU was a backpack which included a stabilization and control system, a hydrogen peroxide propulsion system, a life support oxygen supply, and an ultrahigh frequency radio package for voice communications. The mission profile planned for the EVA was very similar to the profile intended for Gemini VIII. The hatch was to be opened at sunrise of a daylight period when good communications could be established with the tracking stations in the continental United States. The first daylight period was to be devoted to familiarization with the environment and to conducting simple evaluations and experiments. The following night period was to be spent in the adapter equipment section of the spacecraft checking out and donning the AMU. The second daylight period was to be spent evaluating the AMU. Then, the pilot was to return to the cockpit, discard the AMU, perform a simple scientific photographic experiment, and ingress. The equipment for EVA during Gemini IX-A is shown in figure 3.3-1.

The Gemini IX-A EVA proceeded essentially as planned for the first daylight period and is indicated in the time line of figure 3.3-2. Higher forces than expected were required to move the hatch in the partially open position, but this condition did not cause immediate difficulty. While outside the spacecraft, the pilot discovered that the familiarization tasks and evaluations required more time and effort than the ground simulations. Minor difficulty was also experienced in controlling body position. Before the end of the first daylight period, the pilot proceeded to the spacecraft adapter and began the preparations for donning the AMU. The tasks of preparing the AMU required much more work than had been expected, principally because of the difficulty in maintaining body position relative to the foot bar and hand bars. At approximately 10 minutes after sunset, the visor on the helmet began to fog. The fogging increased in coverage and severity until the crew were forced to discontinue the activities with the AMU. After sunrise, the fogging decreased slightly, but increased again when the extravehicular pilot expended appreciable effort. Although the AMU was donned, it was not evaluated. The EVA was terminated early because of the visor fogging. The pilot experienced more difficulties in moving the hatch when it was in the intermediate position; however, the forces required to close and lock the hatch were normal.

Postflight evaluation indicated that the ELSS was functioning normally. The task of preparing the AMU and the lack of adequate body restraints resulted in workloads which exceeded the design limits of the ELSS. Visor fogging was attributed to the pilot's high respiration rate and to the resulting high humidity in the helmet. The pilot reported that he was not excessively hot until the time of ingress. The performance of the ELSS heat exchanger may have degraded at this time because of depletion of the evaporator water supply.

Several corrective measures were initiated for the problems encountered during the Gemini IX-A EVA. To minimize visor fogging, an antifog solution was to be applied to the space suit helmet visors immediately before EVA on future missions. Each extravehicular task planned for the succeeding missions was analyzed in greater detail concerning the type of body restraints required and the magnitude of the forces involved. An overshoe type of positive foot restraint was installed in the spacecraft adapter section to be used for Gemini XI and XII. Also, underwater simulation was initiated in an attempt to simulate the weightless environment more accurately than zero-g aircraft simulations. Prior to the Gemini X and XI missions, the underwater simulations were used only for procedure validation, but not for training or development of time lines. For the Gemini XII mission, underwater simulations were used for crew training and time line development.

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Figure 3.3-1. - Gemini IX-A EVA equipment.

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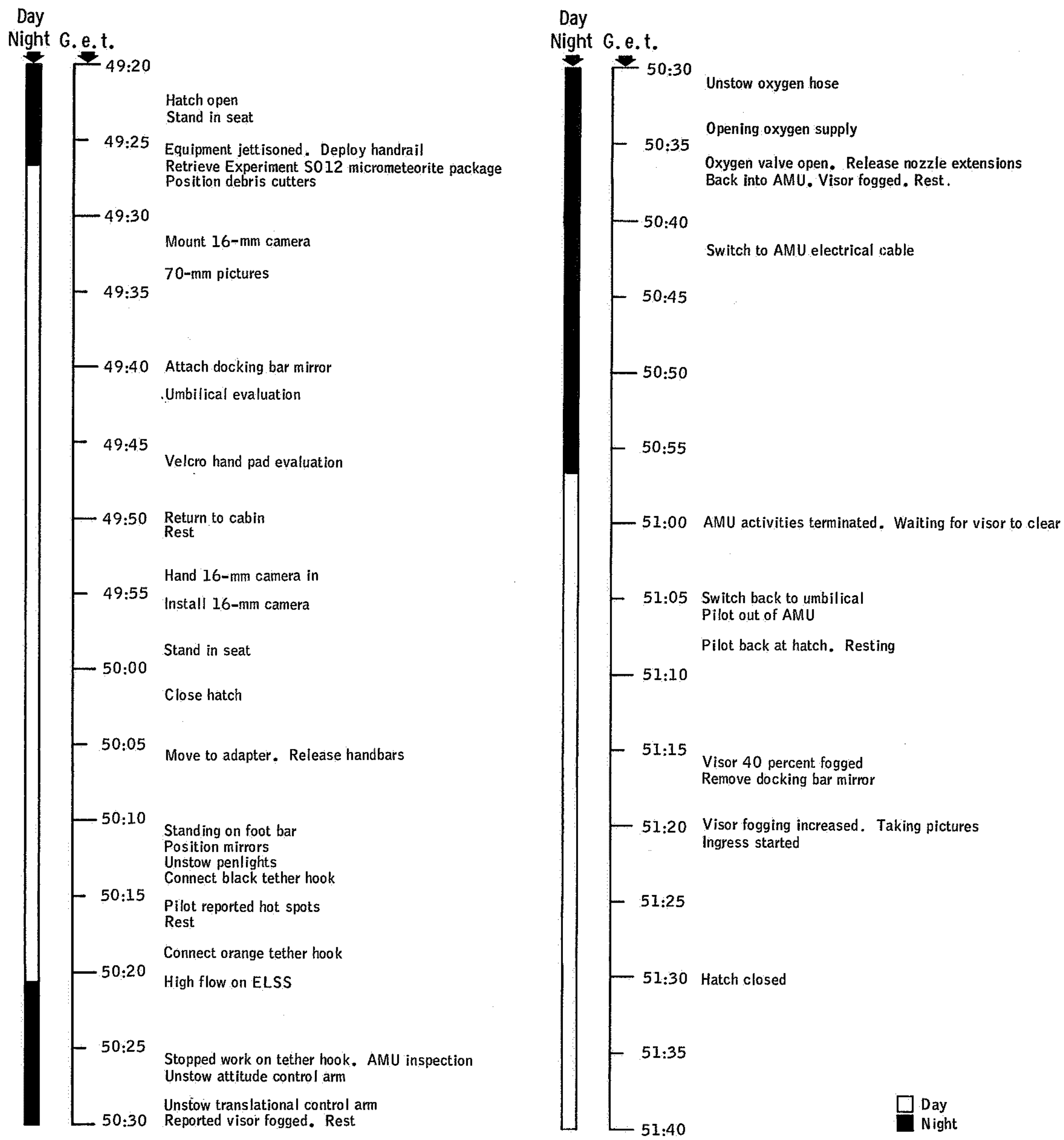

Figure 3.3-2. - Gemini IX-A EVA time line.

3.4 GEMINI X

The prime objective of the Gemini X EVA was to retrieve the Experiment S010 Micrometeorite Collection package from the target vehicle that had been launched 4 months earlier as part of the Gemini VIII mission. The package was to be retrieved immediately after rendezvous with the Gemini VIII target vehicle, and the umbilical EVA was to last approximately one daylight period. Also planned were the evaluation of the HHMU, the installation of a new S010 experiment package on the target vehicle, the retrieval of the Experiment S012 Gemini Micrometeorite Collection package from the spacecraft adapter section, and the performance of several photographic experiments. Photography was scheduled for 1-1/2 orbits during a period of standup EVA.

The EVA equipment included the ELSS, an improved HHMU, and the new 50-foot dual umbilical. One hose in the umbilical carried the spacecraft oxygen to the ELSS. The other hose carried nitrogen to the HHMU. The umbilical was designed so that the HHMU and all oxygen fittings could be connected before the hatch was opened; however, the nitrogen hose for the HHMU had to be connected while outside the spacecraft cabin. The configuration and operation of this umbilical were simpler than those of the Gemini VIII and IX-A equipment, but the 50-foot umbilical required a substantial increase in stowage volume. The equipment for the umbilical EVA for Gemini X is shown in figure 3.4-1. For the standup EVA, short extension hoses were connected to the spacecraft Environmental Control System (ECS) to permit the pilot to remain on the spacecraft closed-loop system while standing. The pilot also used a fabric strap standup tether to hold himself in the cockpit, thereby avoiding any loads on the extension hoses.

The standup activity began just after sunset at an elapsed flight time of 23 hours 24 minutes and proceeded normally for the first 30 minutes (fig. 3.4-2). The pilot was satisfactorily restrained by the standup tether, and since there were no unusual problems with body positioning, ultraviolet photographs of various star fields were taken. Immediately after sunrise, both crewmembers experienced eye irritation and tear formation which interfered with their vision. The crew elected to terminate the standup EVA at this time.

The eye irritation subsided gradually after ingress and hatch closure. The cause of the eye irritation was not known, but was believed to have been related to the simultaneous use of both compressors in the spacecraft oxygen-supply loop to the space suits. Prior to the umbilical EVA, an additional cabin depressurization was conducted to verify that there was no significant eye irritation when only one suit compressor was used and the cabin was decompressed.

The Gemini X umbilical EVA was initiated at an elapsed time of 48 hours 42 minutes, immediately after rendezvous with the Gemini VIII target vehicle. The target vehicle was completely passive with no electrical power available because of the long staytime in orbit. The sequence of events is indicated in figure 3.4-3. The pilot retrieved the Experiment S012 Gemini Micrometeorite Collection package from the exterior of the spacecraft adapter, moved outside to connect the nitrogen umbilical supply line for the HHMU, and then returned to the cockpit. Meanwhile, the command pilot was flying the spacecraft in close formation with the target vehicle (fig. 3.4-4). With the docking cone of the target vehicle approximately 5 feet away, the pilot pushed off from the spacecraft and grasped the outer lip of the docking cone. In moving around the target vehicle to the location of the Experiment S010 Agena Micrometeorite Collection package, the pilot lost his hold on the smooth lip of the docking cone and drifted away from the target vehicle. He used the HHMU to translate approximately 15 feet back to the spacecraft. The pilot then used the HHMU to translate to the target vehicle. On his second attempt to move around the docking cone, he used the wire bundles and struts behind the cone as handholds, and was able to maintain satisfactory control of his body position. Retrieval of the Experiment S010 Agena Micrometeorite Collection package was accomplished without difficulty; however, the pilot elected at this time to discard the replacement S010 package rather than risk losing the one he had just retrieved. The pilot, carrying the package, used the umbilical to pull himself back to the cockpit. At this time, the spacecraft propellant had reached the lower limit allotted for the EVA and station keeping operation. The EVA was terminated. During ingress, the pilot became entangled in the 50-foot umbilical. Several minutes of effort by both crewmembers were required to free the pilot from the umbilical so that he could continue to ingress. The hatch was then closed normally.

Fifty minutes later, the crew opened the right hatch and jettisoned the ELSS chestpack, the umbilical, and other equipment not required for the remainder of the mission.

During the umbilical EVA, the pilot reported the loss of the 70-mm still camera used during the EVA. The camera had been fastened to the ELSS with a lanyard, but the attaching screw came loose. Also, it was discovered that the Experiment S012 Gemini Micrometeorite Collection package was missing. The package had been stowed in a pouch with an elastic top, but appeared to have been knocked free while the 50-foot umbilical was being untangled.

The principal lessons learned from the EVA phase of this mission were:

(a) Preparation for EVA was an important task and the full time attention of both crewmem[illegible] was desirable. Performing a rendezvous with a passive target vehicle and simultaneous EVA preparation caused the crew to be rushed and did not allow the command pilot time to give the pilot as much assistance as had been planned.

(b) The tasks of crew transfer and equipment retrieval from another satellite were accomplished in a deliberate fashion without an excessive workload.

(c) Formation flying with another satellite during EVA was accomplished by coordination of thruster operation between the command pilot and the extravehicular pilot.

(d) Equipment which was not securely tied down was susceptible to drifting away during EVA, even when precautions were being taken.

(e) The bulk of the 50-foot umbilical was a greater inconvenience than had been anticipated. The stowage during normal flight and the handling during ingress made this length undesirable.

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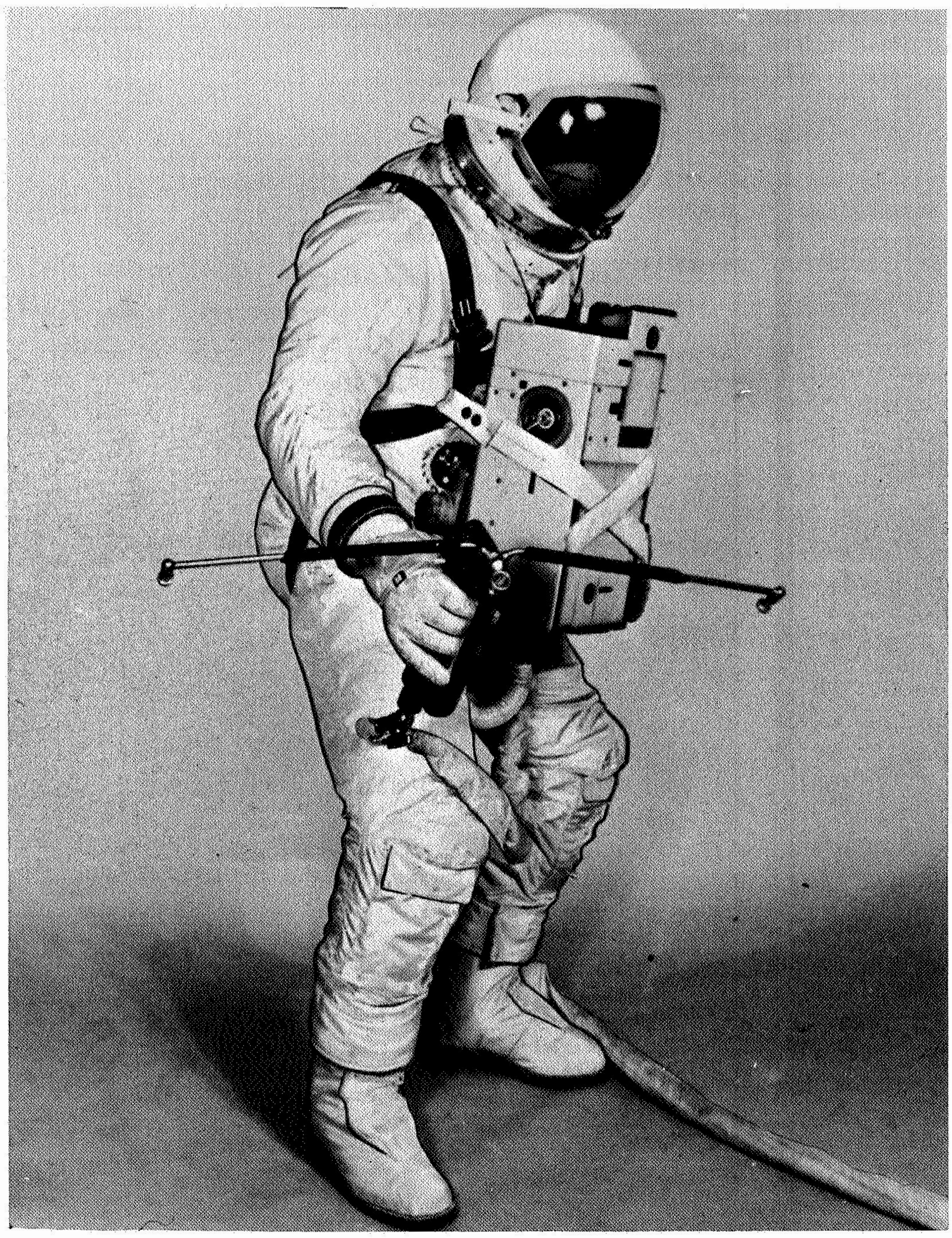

Figure 3.4-1. - Gemini X umbilical EVA equipment.

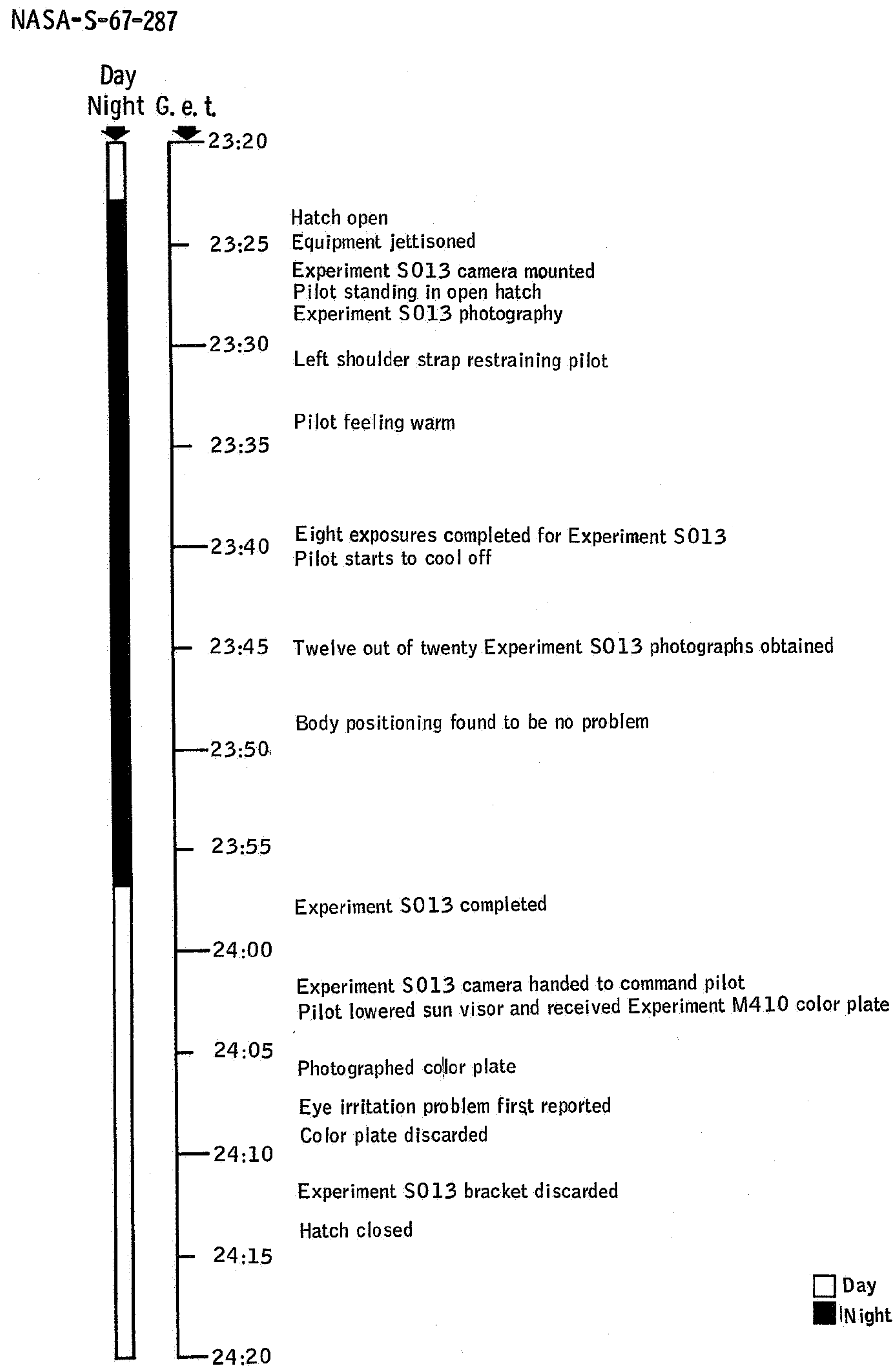

Figure 3.4-2. - Gemini X standup EVA time line.

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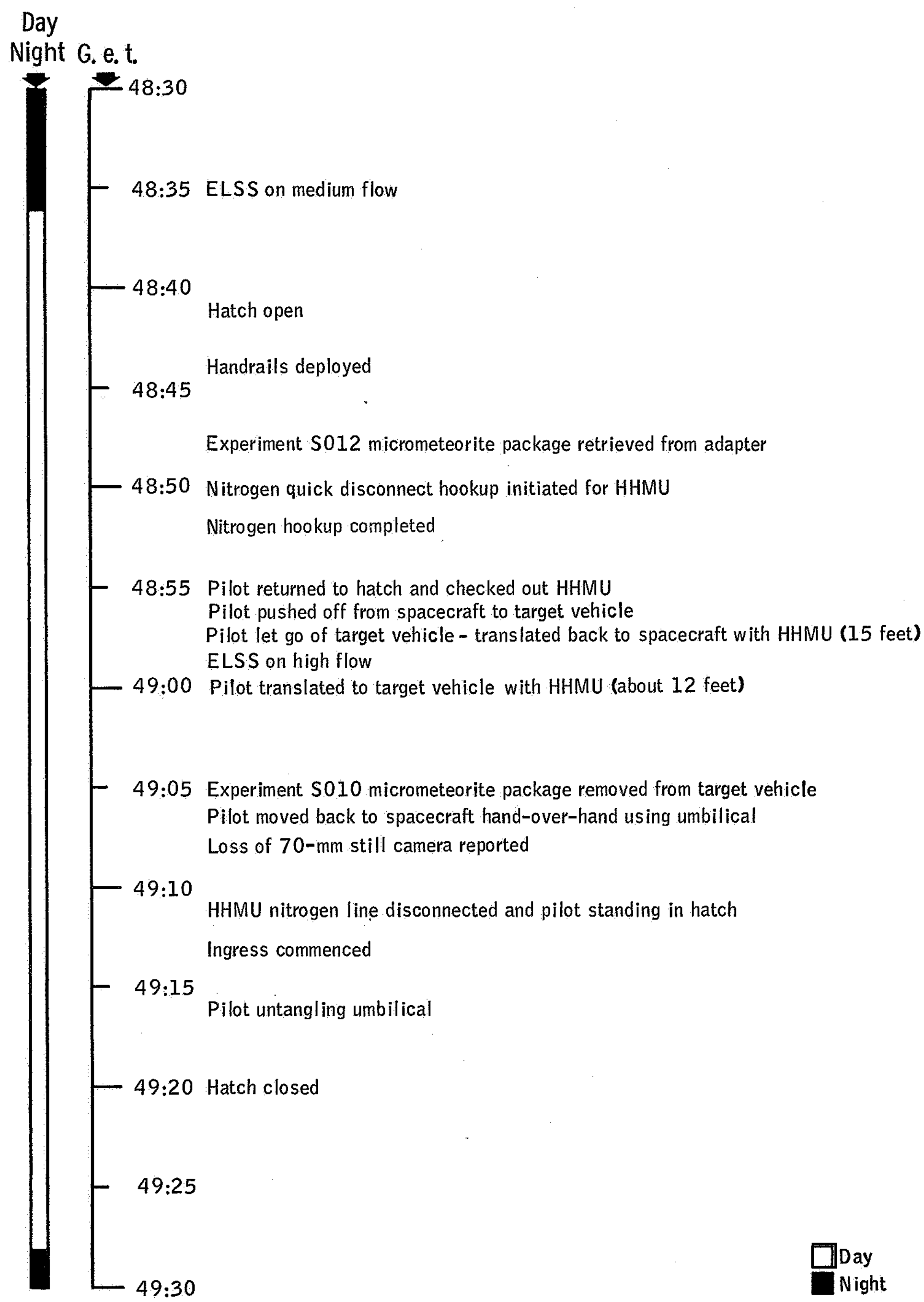

Figure 3.4-3. - Gemini X umbilical EVA time line.

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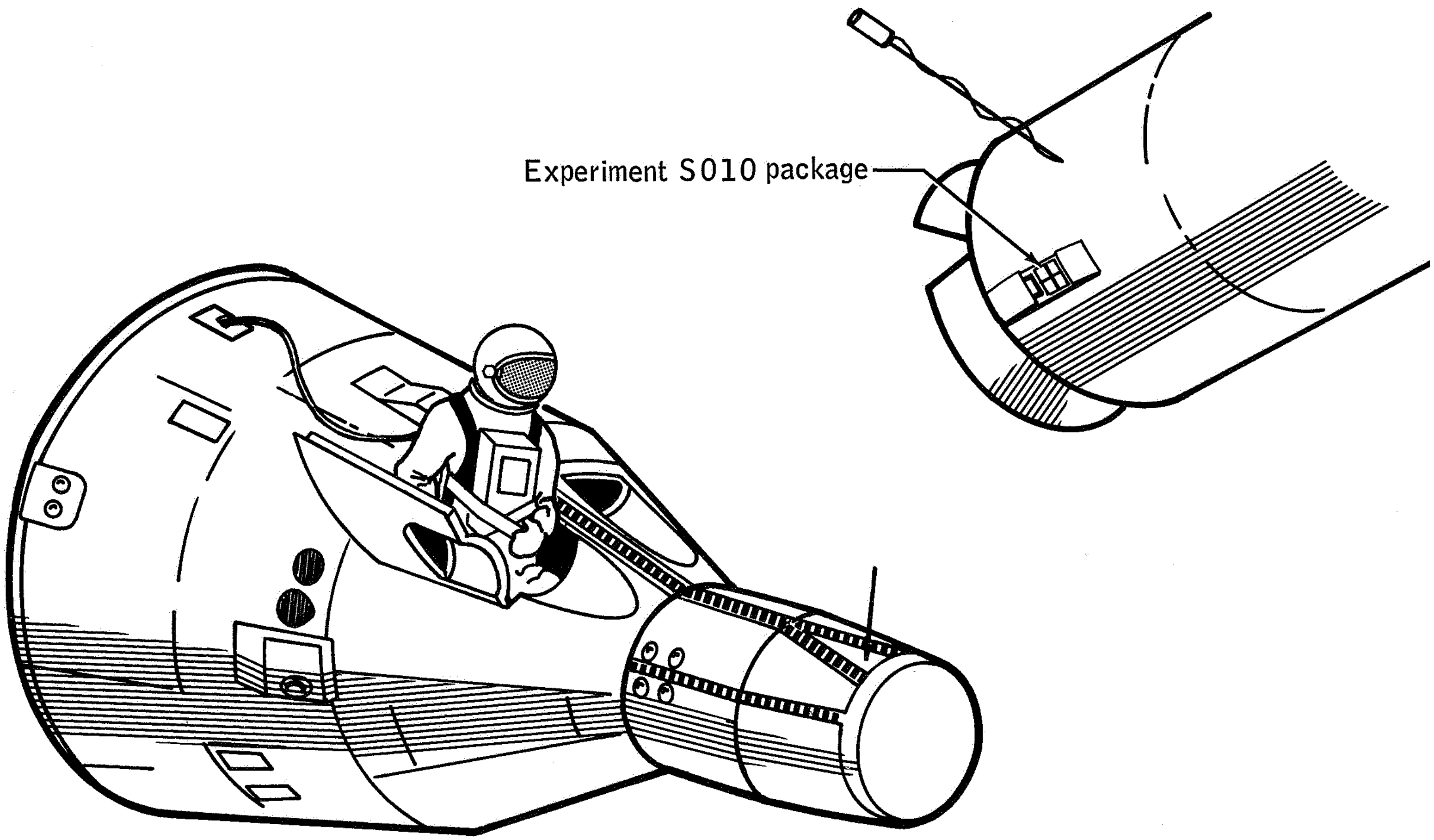

Figure 3.4-4. - Beginning of the Gemini X EVA transfer.

3.5 GEMINI XI

The prime objectives of the Gemini XI EVA were to attach a 100-foot tether between the spacecraft and the target vehicle and to provide a more extensive evaluation of the HHMU. In addition, several experiments, including ultraviolet photography, were scheduled for the standup EVA. The umbilical EVA was scheduled for the morning of the second day so that the spacecraft/target vehicle tether evaluation could be accomplished later that day.

The equipment (fig. 3.5-1) for the Gemini XI EVA was the same as for the Gemini X mission, except that the dual umbilical was shortened from 50 to 30 feet to reduce the stowage and handling problems. An Apollo sump-tank module, which was mounted in the spacecraft adapter section, incorporated two sequence cameras that were to be retrieved during EVA. The HHMU was also stowed in the adapter section. A molded overshoe type of foot restraint (fig. 3.5-2) was provided for body restraint when performing tasks in the adapter equipment section.

The Gemini XI umbilical EVA began at an elapsed flight time of 24 hours 2 minutes; almost immediately, there were indications of difficulty. The first significant task after egress was to position and secure the external sequence camera. After the camera was secured, the pilot indicated that he was fatigued and out of breath. The pilot then moved to the front of the spacecraft and assumed a straddle position on the rendezvous and recovery section in preparation for attaching the spacecraft/target vehicle tether. While maintaining position and attaching the tether, the pilot expended a high level of effort for several minutes. After returning to the cockpit to rest, the pilot continued to breathe very heavily and was apparently fatigued. In view of the unknown amount of effort required for the remaining tasks, the crew elected to terminate the EVA prior to the end of the first daylight period. Ingress and hatch closure were readily accomplished. The time line for the umbilical EVA is shown in figure 3.5-3.

The Gemini XI standup EVA was initiated at an elapsed time of 46 hours 6 minutes, just before sunset. The crew began the ultraviolet stellar photography as soon as practical after sunset; the photography of star patterns was readily accomplished. The extravehicular pilot operated at a very low work level because he was well restrained by the standup tether. As in the Gemini X standup EVA, the crew had little difficulty with the standup tasks. After completing the planned activities (fig. 3.5-4), the pilot ingressed and closed the hatch without any difficulty.

Discussions with the crew and analysis of the onboard films revealed that several factors contributed to the high rate of exertion during the umbilical activity and the subsequent exhaustion of the pilot.

(a) A high rate of physical effort was required to maintain the desired position on the rendezvous and recovery section of the spacecraft because of the lack of body restraints.

(b) The zero-g aircraft simulations had not sufficiently duplicated the extravehicular environment to demonstrate the difficulties of the initial extravehicular tasks.

(c) The pilot had experienced difficulty in donning the extravehicular visor on his helmet with the space suit pressurized. As a result, he had become partially fatigued and overheated prior to opening the hatch.

(d) The requirement to perform a mission-critical task immediately following egress did not allow the pilot time to become accustomed to the environment. This factor probably caused the pilot to work faster than was desired.

(e) The high workloads may have resulted in a concentration of carbon dioxide in the space suit helmet high enough to cause the increased respiration and the apparent exhaustion. Although no measurement of carbon dioxide concentration was made during the mission, an increase had been shown during testing of the ELSS at high workloads. For workloads which exceed design limits, the carbon dioxide concentration may reach values that cause physiological symptoms, including high respiration rates, and decreased work tolerance.

The Gemini XI umbilical EVA results failed to substantiate the confidence generated by the relatively successful Gemini X umbilical EVA. In order to provide a better understanding of the basic techniques for performing EVA tasks, the umbilical EVA planned for Gemini XII was redirected from an evaluation of the AMU to further evaluations of body restraints and workloads.

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Figure 3.5-1. - Gemini XI umbilical EVA equipment.

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Figure 3.5-2. - EVA foot restraints used on Gemini XI and XII.

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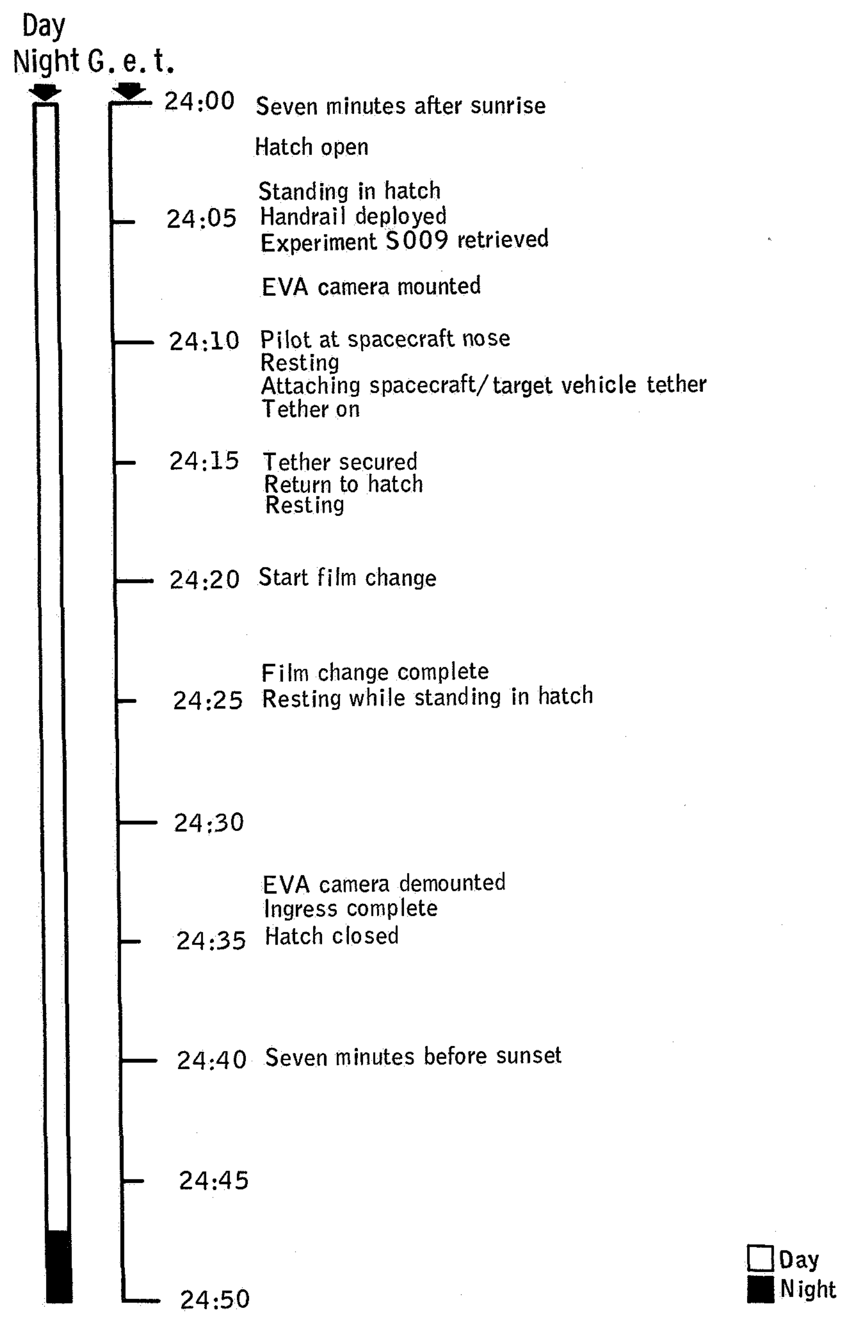

Figure 3.5-3. - Gemini XI umbilical EVA time line.

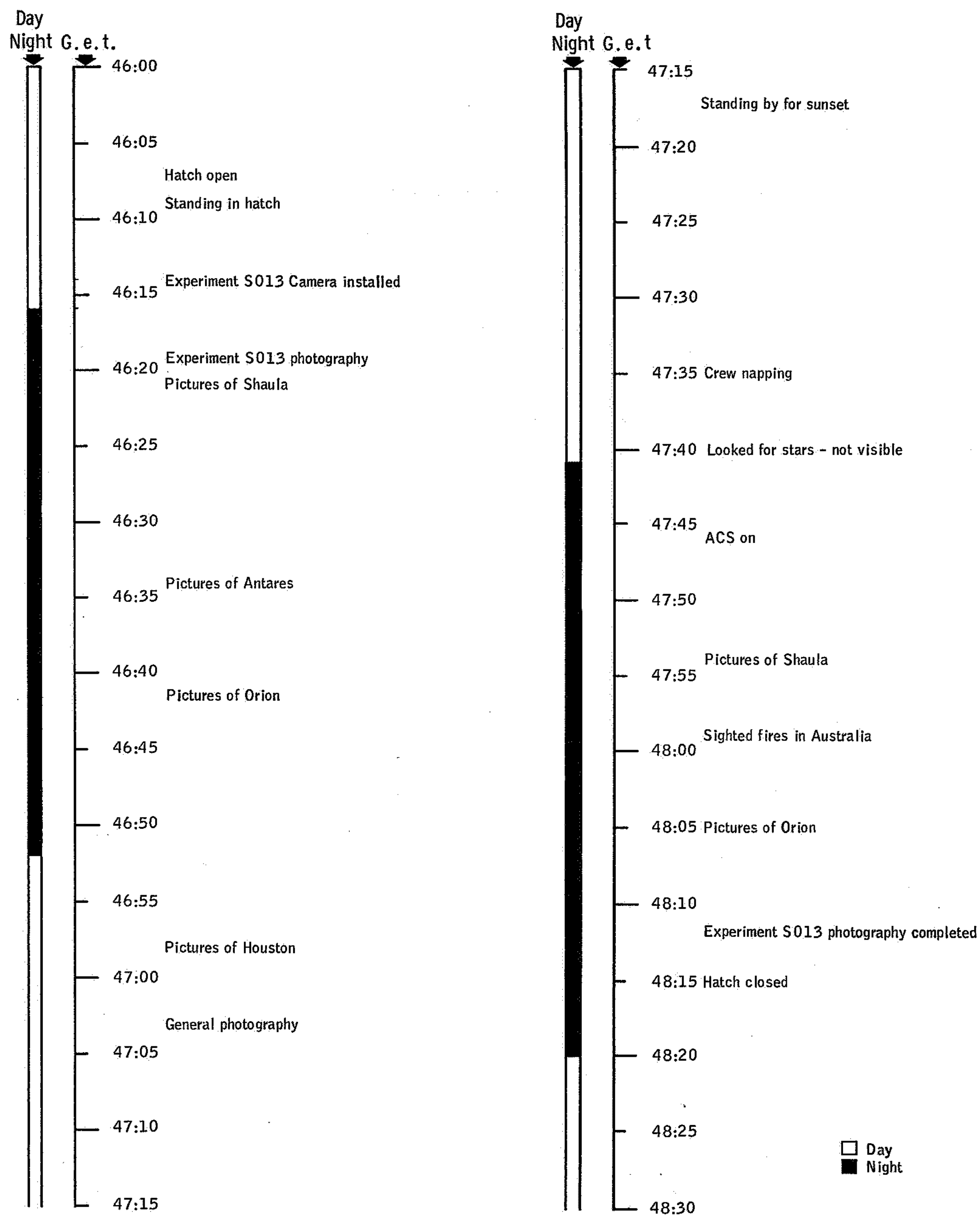

Figure 3.5-4. - Gemini XI standup EVA time line.

3.6 GEMINI XII

The prime objective of the Gemini XII EVA was to evaluate the type of body restraints and the associated workload required for a series of representative tasks. Other objectives were attachment of the spacecraft/target vehicle tether and ultraviolet stellar photography. The extravehicular equipment for the Gemini XII mission included a new work station in the adapter equipment section (fig. 3.6-1), a new work station on the Target Docking Adapter (TDA) (fig. 3.6-2), and several added body restraints and handholds. The pilot's extravehicular equipment (fig. 3.6-3) was essentially identical to that of Gemini IX-A.

The flight crew training for the Gemini XII EVA was expanded to include five sessions of intensive underwater simulation training. During these sessions, the pilot followed the planned flight procedures and duplicated the planned umbilical EVA on an end-to-end basis. The procedures and times for each event were established and used to schedule the final inflight task sequence. The underwater training supplemented the extensive ground training and zero-g aircraft simulations.

To increase the margin for success and provide a suitable period of acclimatization before the performance of any critical tasks, the standup EVA was scheduled prior to the umbilical activity. The planned EVA time line was interspersed with 2-minute rest periods. Procedures were established for monitoring the heart rate and respiration rate of the extravehicular pilot; the crewmembers were to be advised of any indications of a high rate of exertion before the condition could become serious. Finally, the pilot was trained to operate at a moderate work rate, and flight and ground personnel were instructed in the importance of workload control.

The first standup EVA was very similar to the previous two missions. As indicated in the time line of figure 3.6-4, the ultraviolet stellar and the synoptic terrain photography experiments were accomplished on a routine basis. During the standup activity, the pilot performed several tasks designed for familiarization with the environment and for comparison of the standup and umbilical EVA's. These tasks included mounting the extravehicular sequence camera and deploying a handrail from the cabin of the spacecraft to the TDA on the target vehicle. The pilot also retrieved the Experiment S010 Micrometeorite Collection package and several contamination sample disks from the adapter section. The standup activity was completed without difficulty.

The umbilical EVA preparations proceeded smoothly. The hatch was opened within 2 minutes of the planned time (fig. 3.6-5). The use of waist tethers during performance of the initial tasks on the TDA enabled the pilot to rest easily, to work without great effort, and to connect the spacecraft/target vehicle tether in an expeditious manner. The pilot activated the Experiment S010 Agena Micrometeorite Collection package on the target vehicle for possible future retrieval. Before the end of the first daylight period, the pilot moved to the spacecraft adapter section where he evaluated the work tasks of torquing bolts, making and breaking electrical and fluid connectors, cutting cables and fluid lines, hooking rings and hooks, and stripping patches of Velcro. The tasks were accomplished using either the foot restraints or the waist tethers. Both systems of restraint proved to be satisfactory.

During the second daylight period of the umbilical activity, the pilot returned to the target vehicle and performed tasks at a small work station on the outside of the docking cone. The tasks were similar to those in the spacecraft adapter section and, in addition, included use of an Apollo torque wrench. The pilot evaluated working with the use of one or two waist tethers and without a waist tether. At the end of the scheduled EVA, the pilot returned to the cabin and ingressed without difficulty.

A second standup EVA was conducted (fig. 3.6-6). Again, this activity was routine. All the objectives were satisfactorily completed.

The results of the Gemini XII EVA showed that all the tasks attempted were feasible when body restraints were used to maintain position. The results also showed that the EVA workload could be controlled within desired limits by the application of proper procedures and indoctrination. Finally, perhaps the most significant result was that the underwater simulation duplicated the actual extravehicular actions and reactions with a high degree of fidelity. It was concluded that any task which could be accomplished readily in underwater simulation would have a high probability of success during the actual EVA.

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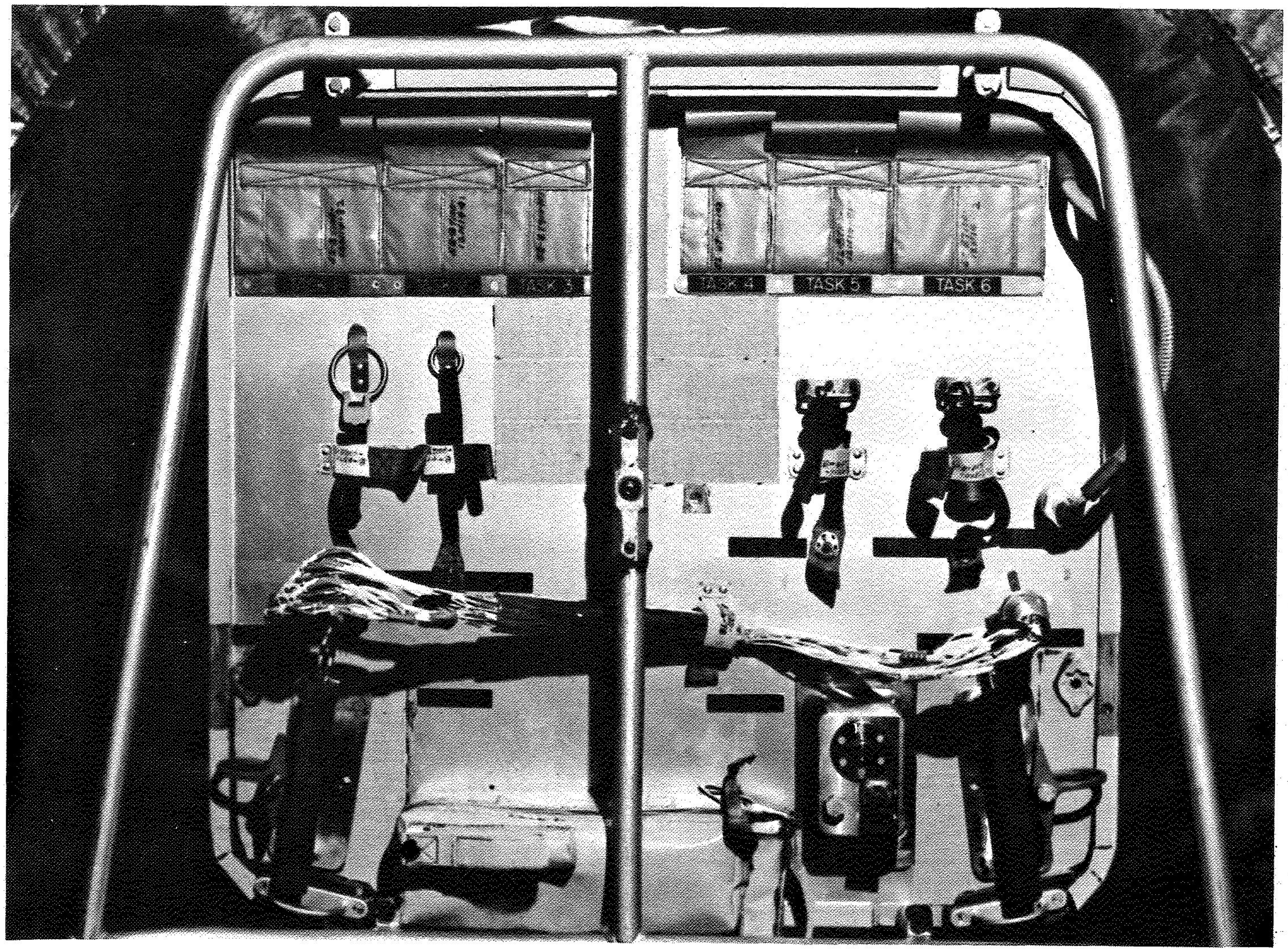

Figure 3.6-1. - Gemini XII EVA work station in adapter equipment section.

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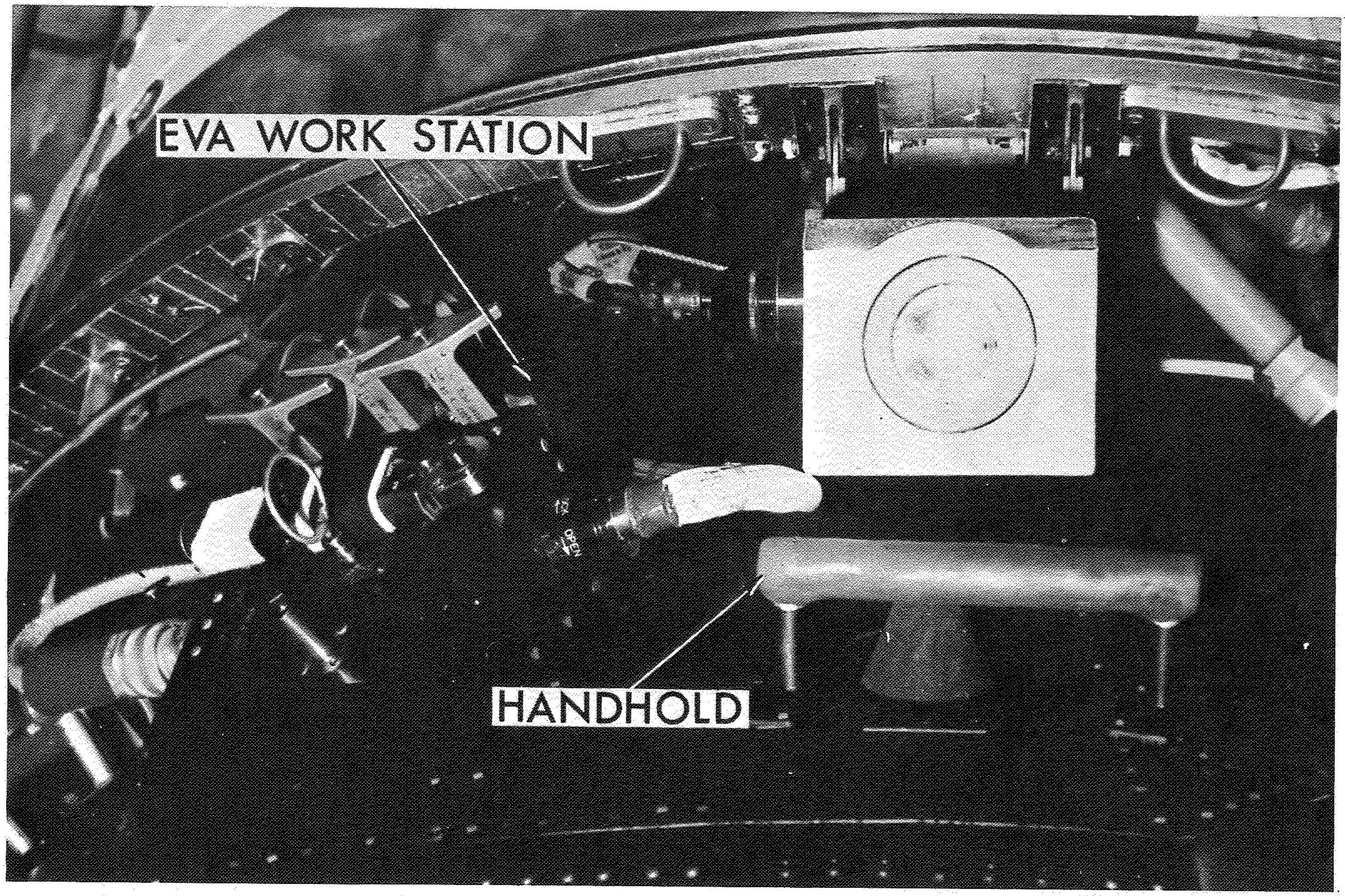

Figure 3.6-2. - Gemini XII TDA work station.

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Figure 3.6-3. - Gemini XII EVA equipment.

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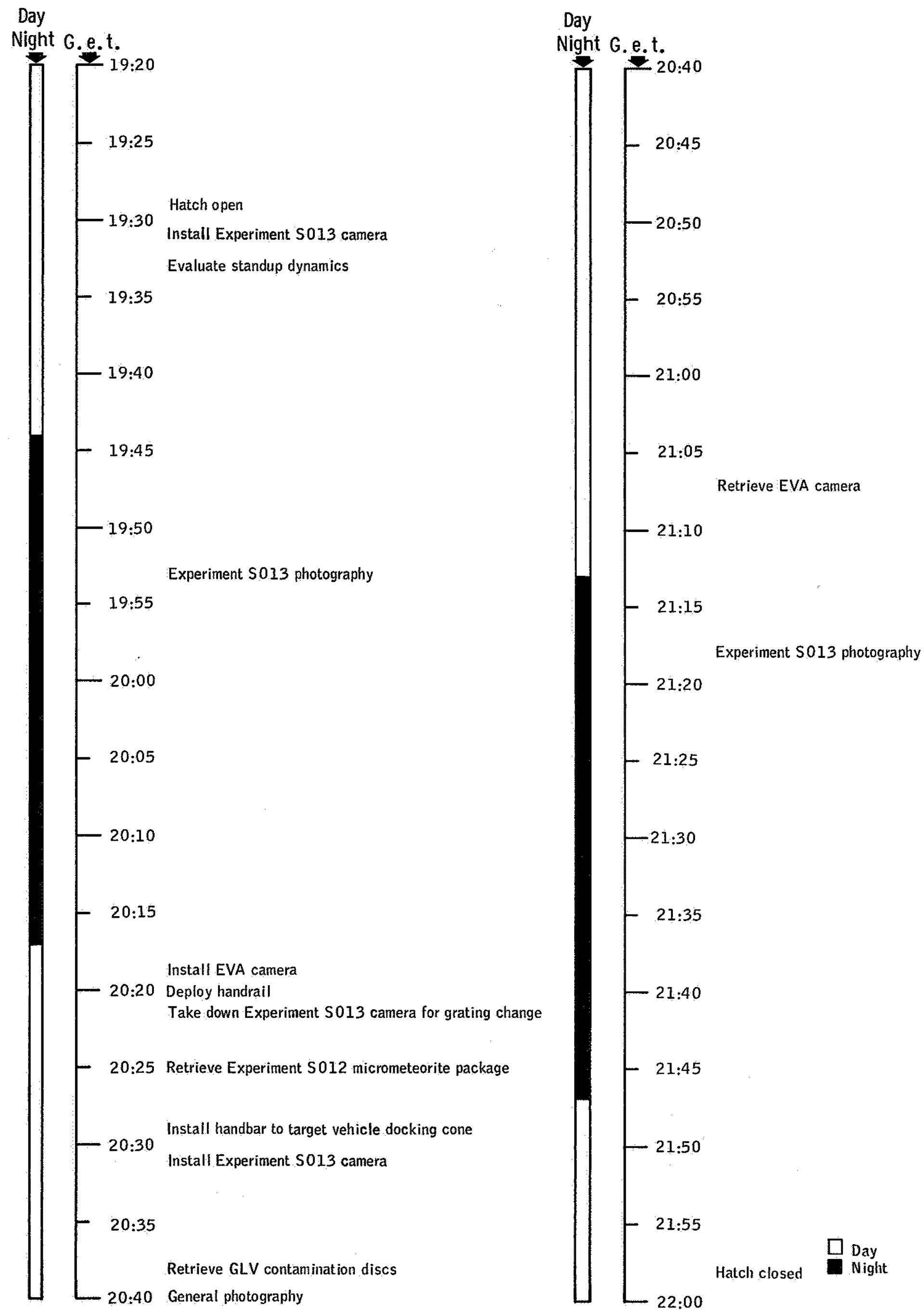

Figure 3.6-4. - Gemini XII first standup EVA time line.

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Figure 3.6-5. - Gemini XII umbilical EVA time line.

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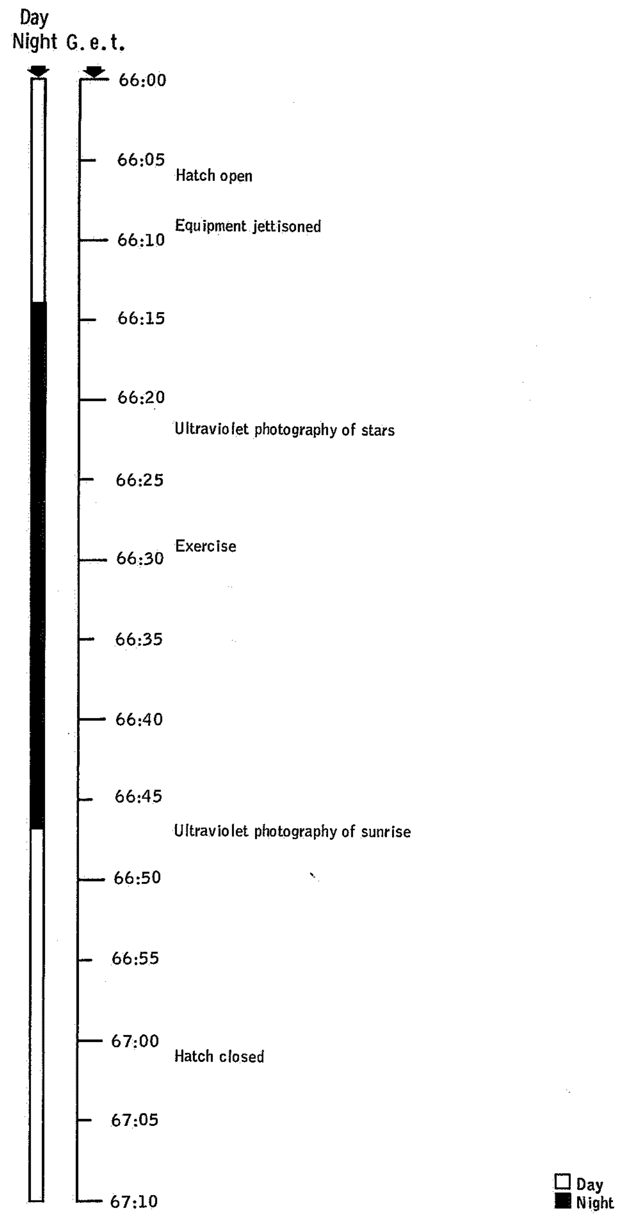

Figure 3.6-6. - Gemini XII second standup EVA time line.

4.0 LIFE SUPPORT SYSTEMS FOR EXTRAVEHICULAR ACTIVITY

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4.0 LIFE SUPPORT SYSTEMS FOR EXTRAVEHICULAR ACTIVITY

4.1 EXTRAVEHICULAR SPACE SUITS

The Gemini space suit, initially designed for intravehicular use, was successfully modified for extravehicular use. During an extravehicular mission the space suit becomes, in effect, a small, close-fitting pressure vessel which can maintain a structurally sound pressure environment and aid in provision of metabolic oxygen and thermal control. Body and joint mobility are necessary to perform the assigned extravehicular tasks.

The Gemini space suit was a multilayer fabric system consisting generally of a comfort liner, a gas bladder, a structural restraint, and an outer protective cover. To facilitate donning and doffing the suit and associated components, quick disconnects were located at the wrists for the glove connections, at the neck for the helmet connection, and at the waist for ventilation gas connections. Entry to the suit was provided through the use of a pressure-sealing zipper closure which extended from the crotch to the back of the neck. A second zipper was incorporated into the closure for structural redundancy. Waste management functions were also accommodated through this closure.

A gas distribution system inside the suit directed oxygen flow to the helmet area for metabolic use and to all areas for thermal control.

Additional equipment which was added to the space suit assembly for extravehicular use included:

(a) Extravehicular coverlayer which provided thermal and micrometeoroid protection

(b) Extravehicular gloves which reduced conductive heat transfer from the spacecraft or equipment surfaces

(c) Low-emittance coating on the exterior surface of the pressure visor which minimized radiant heat loss

(d) Sun visor which attenuated visible, infrared, and ultraviolet energy and provided mechanical protection for the pressure visor.

4.1.1 Gemini IV Suit

4.1.1.1 Design.- The G4C extravehicular space suit is shown in figures 4.1-1 and 4.1-2. The extravehicular coverlayer consisted of an outer protective layer of high-temperature-resistant (HT-1) nylon, a layer of nylon felt for micrometeoroid protection, seven layers of aluminized Mylar and unwoven Dacron superinsulation, and two additional layers of high-temperature nylon for micrometeoroid shock absorption.

The helmet, for this mission only, was equipped with a detachable extravehicular visor assembly consisting of two over visors (fig. 4.1-3). The outer visor, or sun visor, was made from gray-tinted Plexiglas and was coated on the outside with thin gold film to reduce the visible transmittance to 12 percent. The gold film also absorbed the eye-damaging ultraviolet light and reflected much of the solar infrared energy. A high-emittance coating, placed over the gold film, protected the gold from flaking and helped to reduce the surface temperature of the visor when exposed to full sunlight.

The second visor, fabricated from a polycarbonate material, was used to fulfill the following requirements:

(a) Thermal control by means of a low-emittance coating applied to the exterior surface

(b) Visual protection against ultraviolet energy through the use of an ultraviolet inhibitor in the polycarbonate material

(c) Impact protection for the Plexiglas pressure visor

For this mission only, a pair of overgloves was provided for thermal protection. The gloves utilized silastic palm insulation to permit direct palm contact with objects at 250° or -150° F for a period of 2 minutes.

The extravehicular coverlayer was made in two parts - a main part which covered the torso and a removable jacket (fig. 4.1-4) which covered the arms and shoulders. The use of the removable jacket permitted the pilot to free himself of the added encumbrance of the coverlayer in the area of the arms and shoulders after the EVA was completed.

4.1.1.2 Development and qualification testing.- The testing for the G4C space suit consisted of complete qualification of all new components in addition to those which were previously qualified for the G3C space suit before it was modified for extravehicular use.

4.1.1.2.1 Thermal tests: Three phases of tests were conducted on the Gemini thermal coverlayer. For more detailed information, see reference 1.

(a) Selection of prototype thermal coverlayer: Screening tests of materials were conducted by the contractor, and the selected insulating material was fabricated into the prototype space suit (fig. 4.1-2). The insulated coverall garment was exposed to environments that simulated the thermal-vacuum conditions of orbital space flight.

The temperature data obtained indicated that a net heat loss would be observed from the suit under all test conditions. Coverlayer temperatures were within allowable limits and showed a continuous decreasing temperature gradient through the layers. The temperature range outside the first insulation layer was from -200° to 200° F. The temperature of the suit inner layer varied from 58° to 86° F.

(b) Evaluation of the production configuration coverlayer: At the space environment simulator, the contractor tested a thermal dummy in a complete suit assembly. The dummy was capable of providing the sensible heat produced by a man. Environmental conditions simulating an earth orbital mission were obtained using a liquid nitrogen shroud, a bank of mercury xenon lamps, a maximum pressure of 10^{-4} mm Hg, and a reflective aluminum plate coated with a controlled emittance paint and located opposite the solar lamps. A spacecraft surface was simulated by a section of aluminum structure which could be moved into contact with the suited dummy. The surface temperature of the aluminum structure was adjustable. Thermocouples monitored the performance of the insulating layers as well as the performance of the helmet and visor.

Tests were conducted to measure the suit heat leak in steady-state cold and steady-state hot conditions and under earth orbital conditions. Suit outer surface temperature did not exceed 200° F or fall below -200° F. Visor heat loss when facing deep space was 30 to 40 Btu/hr, while visor heat gain under direct solar radiation was 40 to 50 Btu/hr. Contact with the spacecraft surface at 180° F did not produce unacceptable hot spots on the interior surfaces of the suit.

(c) Evaluation of the flight-configured suit assembly: The contractor conducted detailed qualification tests of the flight-configured suit to determine: suit temperature profiles, internal suit temperatures, evidence of heat shorts, net suit heat gain or loss (as a function of the environmental heat load and position), net heat gain or loss through the pressure visor, the effectiveness of the sun visor, the effects of suit contact with spacecraft surfaces, and the feasibility of wearing the intravehicular suit inside the spacecraft with one hatch open. Representative results are shown in table 4.1-I. The net heat loss ranged from 34.2 Btu/hr under maximum solar heating conditions (80.4 Btu/hr with the sun visor down) to 354 Btu/hr during a cold soak with the sun visor up. These data indicated that a comfortable temperature would be maintained in all areas inside the suit during orbital conditions.

4.1.1.2.2 Extravehicular glove thermal testing: The pressure glove and the extravehicular thermal overglove were subjected to manned thermal tests at temperatures of 250° and -150° F for periods up to 2 minutes. The subject was able to maintain his grip for 2 minutes with a thermal rod at temperatures which exceeded the specified extremes.

4.1.1.2.3 Micrometeoroid protection: Micrometeoroid environment testing was based on an anticipated initial extravehicular mission including 10 minutes of exposures to the external space environment. To avoid mission timing constraints, exposure was assumed to occur during the worst shower period.

(a) Micrometeoroid tests of coverlayer: The meteoroid protective coverlayer design used on the Gemini IV mission was proof tested with simulated meteoroids. The Gemini G4C suit configuration was qualified to provide a 0.999 probability of no penetration P_o of the bladder. With the system pressurized to 3.7 psig, samples of 4- by 4-inch swatches of the meteoroid coverlayer on the bladder were impacted with simulated meteoroids. Since these projectiles approximate the meteoroidal energy that is absorbed by the coverlayer, a corresponding P_o for a 10-minute exposure was determined. The exposure was for a near earth orbit and 25 ft^2 of surface area on the space suit. The composition and density of the projectiles are listed in the following table:

Composition	Density, gm/cc	Diameter, μ	Velocity range, km/sec	P_o
Cork and epoxy	0.53	300	24 to 27	0.99988
Pyrex glass	2.2	350	5 to 6.5	.99959
Pyrex glass	2.2	400	5 to 6.5	.99977
Boro silicate	2.4	510	5 to 6.5	.99991

A pyrex glass sphere 274 microns in diameter at a velocity of 6 km/sec approximates the energy necessary to obtain a P_o of 0.999 for a 10-minute exposure. Acceleration of a particle this small is beyond the capability of the light gas gun, and larger projectiles were used. These tests were conducted with the AVCO RAD light gas gun, the Rhodes and Bloxsom exploding foil gun, and the MSC meteoroid technology light gas gun. Based on these studies, the G4C suit was determined to be adequate for the Gemini IV mission.

(b) Micrometeoroid tests of visor material: Samples of lexan and merlon polycarbonate visor material were pressurized to 3.7 psig and impacted with glass spheres accelerated to hypervelocity with the AVCO RAD light gas gun. The projectile impact energy was progressively increased, until the sample was perforated or a leak occurred. An examination of the targets revealed that the 0.098-inch-thick merlon and lexan withstood the impact of a 0.0156-inch glass sphere at a velocity of 6 km/sec without spall or leakage. This projectile energy, when extrapolated to meteoroidal velocity and density, corresponded to a P_o of 0.99993 for 135-minute exposure.

4.1.1.2.4 Rapid decompression: The parameters of suit and cabin pressure were monitored and recorded through a series of six rapid decompression tests. The chamber pressure, when stabilized at 5.5 ± 0.5 psia, was reduced to maximum altitude in 0.25 second. This rapid pressure reduction exerted the maximum dynamic pressure differential across the suit restraint layer and caused a maximum stress condition upon the suit structure. The suit pressure decreased from 5.6 ± 0.1 psia to 3.75 psia (fig. 4.1-5). Suit leak rate checks, performed before and immediately after each decompression, were below the specification leakage limit of 1000 Scc/min.

4.1.1.2.5 Other qualification testing:

(a) Visor tests: The Plexiglas pressure sealing visor, the impact visor, and the sun visor were tested and accepted for solar ultraviolet, infrared, and visible region transmittance characteristics. The impact visor tests were also satisfactorily completed.

(b) Mechanical and pressure cycling tests: Space suit hardware items were qualified for extravehicular missions to specifications for previous Gemini spacecraft testing programs. Qualification requirements for suit component cycling are presented in the following table.

Components	Number of cycles
Neck disconnect	500
Wrist disconnect	500
Helmet visor	2000
Entrance zipper	500
Inlet and outlet ventilations	500
Complete Gemini space suit don and doff	75
Pressure cycle, complete space suit assembly, manned	500
Wrist flexure	500

The G4C configuration gloves were withdrawn from the test because of early failures and because the intravehicular gloves with protective overgloves were used for the Gemini IV mission. There were no malfunctions or failures of the torso, neck disconnects, wrist disconnects, ventilation inlet and exhaust, and pressure-sealing closures. During the cycle testing equivalent to ten 14-day missions, the leakage increased from 200 to 820 Scc/min. A maximum leakage of 1000 Scc/min was allowable during qualification.

Fabrication of the G4C helmet was completed late in the qualification testing program and was tested separately. Helmet leakage was undetectable at 3.7 psig throughout the 2000-cycle test.

4.1.1.3 Mission results.- During the Gemini IV EVA mission, the space suits functioned normally. The mission confirmed the following:

(a) The adequacy of the micrometeoroid and thermal coverlayers

(b) The acceptability of the visible-light attenuation of the sun visor and the need for this visual protection

(c) The adequacy of the visor thermal coating

(d) The adequacy of the structural concepts of the G4C space suit

(e) The acceptability of suit mobility for spacecraft egress and ingress, although a high work level at ingress was required to operate the hatch mechanism

(f) The need for reduced coverlayer bulk to improve unpressurized suit mobility and pilot comfort

4.1.2 Gemini VIII Suit

4.1.2.1 Design.- The G4C space suit assembly used in the Gemini VIII mission was similar to the one used in the Gemini IV mission (fig. 4.1-2). However, the configuration of the micrometeoroid protective layers of the extravehicular coverlayer was modified to utilize two layers of neoprene-coated nylon in lieu of the nylon felt and 6-ounce HT-1 nylon micrometeoroid layers (fig. 4.1-6). Also, the extravehicular pilot used integrated pressure thermal gloves (fig. 4.1-7), in lieu of the pressure gloves and overgloves used for Gemini IV. The gloves were designed to protect the hands from micrometeoroids and to prevent conductive heat transfer through the glove palms caused from touching surfaces with temperatures ranging from 250° to -150° F. Structurally and functionally, the gloves were similar to the standard intravehicular pressure gloves with a pressure bladder, a restraint layer, and a wrist connector. A 1/8-inch-thick, flexible, insulating, silastic material was provided on the palm side of the glove for conduction insulation. Micrometeoroid protection was through additional layers of fabric used in the layup of the glove.

For intravehicular spacecraft operations, the pilot utilized standard intravehicular gloves of the same design as the command pilot's.

4.1.2.2 Development and qualification testing.- The new coverlayer material (fig. 4.1-6) and the integrated pressure thermal gloves (fig. 4.1-7) were tested to the original specifications (see section 4.1.1.2), except a maximum time of 90 seconds was used for thermal exposure testing. These modifications exceeded qualification specifications. The micrometeoroid testing of the new coverlayer material demonstrated a P_o of 0.999 for worst-case conditions.

4.1.2.3 Mission results.- The extravehicular space suit components were not used for EVA because of early termination of the mission.

The reduced coverlayer bulk resulting from the change in micrometeoroid protective materials improved the unpressurized suit mobility for the intravehicular operations.

4.1.3 Gemini IX-A Suit

4.1.3.1 Design.- The addition of the Astronaut Maneuvering Unit (AMU) to the flight plan for Gemini IX-A required extensive modifications to the coverlayer of the G4C space suit. The lower forward-firing and downward-firing AMU thrusters impinged upon the legs of the suit (fig. 4.1-8). Temperatures as high as 1300° F were possible at the AMU thruster impingement areas on the suit surface. Since the HT-1 high-temperature nylon, which is normally used for the coverlayer, is not recommended for continuous use at temperatures above 500° F, new suit materials were required. A stainless steel fabric was incorporated into the legs of the suit coverlayer to protect it from the heat generated by AMU thruster impingement. Analysis and testing also indicated that the temperatures inside the thermal insulation layers of the coverlayer would exceed the melting temperature of the aluminized Mylar. Aluminized H-film was developed and found to be adequate for the temperatures expected and, when separated by layers of fiberglas cloth, worked well as a high-temperature thermal insulation. Eleven layers each of aluminized H-film and fiberglas cloth were incorporated into the legs to provide thermal protection during AMU operations. A standard extravehicular coverlayer layup was utilized for the upper torso and the steel outer cover with aluminized H-film and fiberglas cloth was used as thermal insulation for the legs (fig. 4.1-9).

The pressure-sealing visor for the Gemini IX-A mission was fabricated from polycarbonate material, since it provided approximately 10 times more resistance to impact loading than Plexiglas. The use of the polycarbonate pressure-sealing visor eliminated the need for the impact visor of the sun visor assembly. The protective visor was deleted, and the mounting hardware was redesigned to accommodate a single, gold-coated Plexiglas visor for visible and infrared energy attenuation.

4.1.3.2 Development and qualification testing.-

(a) The test program demonstrated the capability of the space suit coverlayer to adequately protect the suit structural system from damage caused from the high-temperature plume impingement of the AMU thrusters. However, additional positive protection was required in the area of the hands during thruster firings. Hand protection was provided through the use of two plume deflection shields attached to the AMU controller arms. Therefore, pressure thermal gloves similar to those provided for the Gemini VIII mission could be used.

(b) The test program, used to qualify the polycarbonate materials for use in the Gemini IX-A helmet, consisted of toxicology, oxygen and humidity compatibility, mechanical cycling, and impact testing. All qualification specifications were met, including a 25.8 ft/lb impact visor test.

For detailed information concerning extravehicular environment testing of the AMU coverlayer see references 2, 3, and 4.

4.1.3.3 Mission results.- As discussed in section 4.2.2.5.2, the pilot experienced severe fogging of his space suit pressure visor after a period of particularly high workload associated with AMU preparations. As a result of the fogging, the AMU activities were discontinued; the modified coverlayer could not be evaluated because the AMU thrusters were not fired. In a postflight test of the Gemini IX-A pilot's space suit and of ELSS in an altitude chamber, visor fogging occurred at a sustained workload of 2450 Btu/hr. It was concluded that the high inflight workload and the high respiration rate exceeded the combined capabilities of the ELSS and the space suit ventilation system. The results indicated that the dew point in the helmet rose above the visor temperature because of the excessive moisture introduced through perspiration and respiration. The principal corrective actions planned were reduction of workload and provision of antifog solution for use immediately before EVA. The antifog solution had been applied before the Gemini IV mission, and was not applied for the Gemini IX-A mission, because the solution was only effective for about 12 hours.

During the first daylight period of the Gemini IX-A EVA mission, the pilot reported that the sun caused a "hot spot" on his back which subsided after sunset. The postflight review of the coverlayer thermal insulation revealed that it had separated along the attachment to the entrance closure. The areas where the insulation had separated were the same as those described by the pilot as "hot spots" when the back of the suit was oriented toward the sun. The problem was determined to be the result of an improper repair made to the coverlayer after preflight training period and immediately prior to flight.

A review of the other portions of the suit and of associated components indicated that the general performance of the suit during EVA was satisfactory and that the suit was structurally sound.

4.1.4 Gemini X Suit

4.1.4.1 Design.- The Gemini X extravehicular space suit configuration was very similar to that of the Gemini VIII suit. The following changes were made:

(a) The polycarbonate pressure-sealing visor of the Gemini IX-A configuration was used.

(b) The single-lens sun visor was modified to allow attachment of the visor to the helmet using Velcro instead of metal pivots.

(c) The arms and legs of the underwear were removed at the torso seams.

(d) The fingertip lights incorporated on the extravehicular pressure thermal gloves utilized a red-colored lens to avoid damage to photographic film during a dark-side photographic experiment.

(e) Visor antifog kits, consisting of wet wipes saturated with a visor antifog and cleaning solution, were carried for inflight use by both crewmen during EVA preparations.

4.1.4.2 Mission results.- All real-time and postflight data relative to the space suits indicated that both suits were satisfactory.

The extravehicular sun visor provided for the pilot, worn during the launch and EVA preparation phases of the mission, was severely damaged. Approximately 40 percent of the gold coating flaked off. The damage was apparently due to contact of the unprotected visor surface with the spacecraft hatch or with other items inside the spacecraft.

The postflight inspection of the space suit utilized by the pilot indicated the suit was structurally sound; however, two discrepancies were found, either of which would have caused excessive suit leakage at 3.7 psig.

(a) Inspection of the suit relief valve, after excessive suit assembly leakage was noted, revealed that the relief valve was retained in the cracked position with a small piece of elastomer. Upon removal of the contaminant, the valve performed within specification. Source of the contaminant was not confirmed.

The postflight debriefings indicated that the pilot did not notice the valve leaking while in flight. For subsequent missions, prelaunch suit leakage checks were accomplished after the relief valve performance had been checked.

(b) The postflight leakage tests of the suit also revealed excessive leakage through the helmet neck ring. It was noted that the epoxy bond, which attached a Teflon bearing and wiper surface to the neck ring, was opened at the back center of the ring. This condition appeared to be the result of postflight handling damage or of inflight interference with the ejection seat.

4.1.5 Gemini XI Suit

4.1.5.1 Design.- The Gemini XI space suit configuration was the same design as Gemini X, with the following exceptions:

(a) The suit incorporated additional redundant locks on the wrist disconnects, neck ring, and pressure-sealing zipper. The locking tabs on the suit gas connectors were reduced in size, and locking tab guards were provided to minimize the possibility of inadvertent operation.

(b) A desiccant assembly was added to the suit pressure gage to keep it from fogging during EVA.

4.1.5.2 Mission results.- All comments relative to the space suits indicated that both suits were satisfactory during the intravehicular and extravehicular portions of the mission.

The pilot's extravehicular sun visor was cracked at postflight inspection. After the mission, the crew indicated that the pilot had experienced considerable difficulty when installing the sun visor on the helmet with the suit pressurized to 3.7 psig. It is believed that the visor damage occurred during this installation attempt; however, the damage was not noticed by the crew and did not affect pilot vision during EVA.

4.1.6 Gemini XII Suit

4.1.6.1 Design.- The Gemini XII space suit used by the pilot was a slightly modified version of the one used for the Gemini IX-A mission. The stainless steel fabric on the legs was replaced with high-temperature nylon, and four layers of the aluminized H-film and fiberglas cloth superinsulation were deleted from the suit legs. The coverlayer thermal layup was quilted to the first layer of micrometeoroid protective material. A rectangular pattern was quilted over the torso area, which strengthened the thermal layer and reduced the possibility of tears or rips in the aluminized H-film and aluminized Mylar layers.

The space suit hose nozzle interconnects utilized a clip-on locking clamp for redundant locking of the interconnect latching tabs.

4.1.6.2 Mission results.- All real-time and postflight reports indicated that both suits functioned satisfactorily during all phases of the mission.

4.1.7 Suit Mobility

4.1.7.1 Limitations.- The restricted mobility of the Gemini space suit was a limiting factor in the accomplishment of extravehicular tasks. The effect of this mobility restriction was not fully appreciated until after the Gemini IX-A mission. The link-net construction of the restraint layer provided a single neutral position of the pressurized suit. Since the ability to control the spacecraft in a pressurized suit was one of the design prerequisites, the neutral point of the suit was in a sitting position. The arms of the suit were positioned for optimum access to the Gemini flight controls. Whenever a crewmember moved within the pressurized suit, he had to overcome the forces tending to return the suit to its neutral position. These forces were particularily large when the arms were raised above the shoulder level. Significant forces were involved in just holding the hands together. Although a well-trained crewman could move about in the suit readily, considerable effort was required which was fatiguing. Fatigue was particularly significant when a position away from the neutral position was held for some time. Therefore, work tasks which could not be accomplished with the suit in the neutral position were formidable. In general, the EVA pilot could not do sustained work below the waist level or above the shoulder level.

4.1.7.2 Arm and leg mobility.- The major suit mobility limitation was in the areas of the arms and the shoulders, particularly when work was attempted with the EVA pilot's arms above the shoulder level. The leg mobility was substantially less than the arm mobility; however, the use of the legs in earth orbit EVA was very limited, and leg mobility was not a significant limitation. For nearly all tasks, the arm mobility restriction was the principal factor in the total workload. When an EVA pilot moved along a handrail, he moved his hands in front of him with a side-to-side motion rather than a hand-over-hand motion, because of the restricted arm mobility.

For the Gemini IX-A mission, the neutral position of the arms on the pilot's space suit was adjusted to be compatible with the location of the AMU controls. This change was readily accomplished, and the effort required to operate the AMU was significantly reduced.

4.1.7.3 Glove mobility.- The extravehicular glove developed for the Gemini VIII and subsequent missions was basically an intravehicular glove with integral thermal and micrometeoroid protection added. The glove mobility was satisfactory for brief periods of pressurized operation; however, for long-term pressurized activity using the gloves, the pilot's hands became very tired. In the Gemini X mission, the EVA pilot used a spring-loaded camera shutter-release cable. His hands were not strong enough to hold the shutter-release cable with one hand for a 2-minute time exposure against the forces of the gloves, and the exposures were made using both hands.

4.1.7.4 Coverlayer effects.- The initial EVA coverlayer for the Gemini IV mission incorporated several layers of HT-1 nylon and a layer of ballistic felt for meteoroid protection. The bulk of this coverlayer restricted pilot mobility, even with the suit unpressurized in the cabin. For Gemini VIII mission, the coverlayer was redesigned to replace the felt layer with a layer of coated nylon. Mobility was definitely improved by the introduction of the new coverlayer.

4.1.7.5 Pressure effects.- The pressure in the suit also affected mobility. An increase in the suit pressure from the nominal 3.7 psia to 4.2 psia, as experienced in Gemini IV EVA, made all movements proportionately more difficult. This factor contributed to the high work level experienced at ingress during the Gemini IV EVA.

4.1.7.6 Suit mobility improvement.- For low workload in future earth orbit EVA, an improvement in mobility in the space suit arms, shoulders, and waist is highly desirable. New concepts of entry closures and waist mobility improvements will be required to provide adequate mobility and freedom of movement. Improved glove mobility, dexterity, and tactility are also highly desirable. Finally, the variation in suit mobility with suit pressure is undesirable and should be eliminated from future designs if possible.

TABLE 4.1-I.- COMPUTED G4C SUIT NET HEAT LEAKAGE RATES

Test system conditions				Heat leakage out of suit, Btu/hr
Thermal condition	Dummy at 98.6° F	Visor	Suit position	
Cold soak	No	Bare	--	243
Cold soak	Yes	Bare	--	354
Simulated orbit	Yes	Bare	--	195
Heat soak	Yes	Bare	Facing solar	34.2
Heat soak	Yes	Bare	Back to solar	91.3
Heat soak	Yes	Insulated	Facing solar	77.2
Heat soak	Yes	Insulated	Back to solar	95.2
Heat soak	Yes	With sun visor	Facing solar	80.4
Simulated orbit	Yes	With sun visor	Suspended	123
Simulated orbit	Yes	With sun visor	Kneeling on cold surface	[a]350
Simulated orbit	Yes	With sun visor	Prone on cold surface	[a]338
Simulated orbit	Yes	With sun visor	Kneeling on hot surface	[a]307
Simulated orbit	Yes	With sun visor	Prone on hot surface	[a]265
Hatch open	Yes	Bare	Facing deep space, intravehicular suit only	[a]403

[a]Test values at 1 hour, systems not stabilized.

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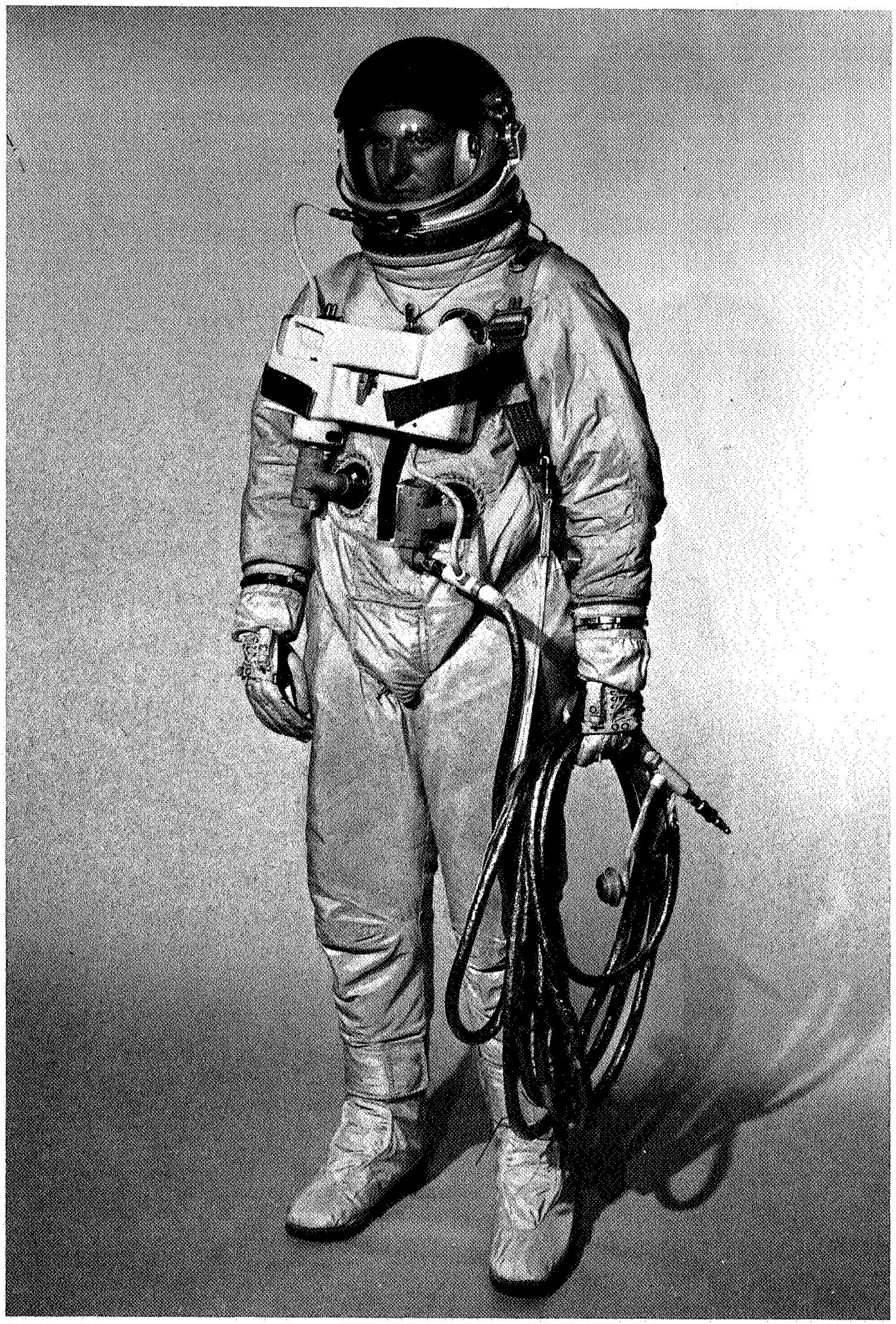

Figure 4.1-1. - Gemini IV extravehicular space suit and life support system.

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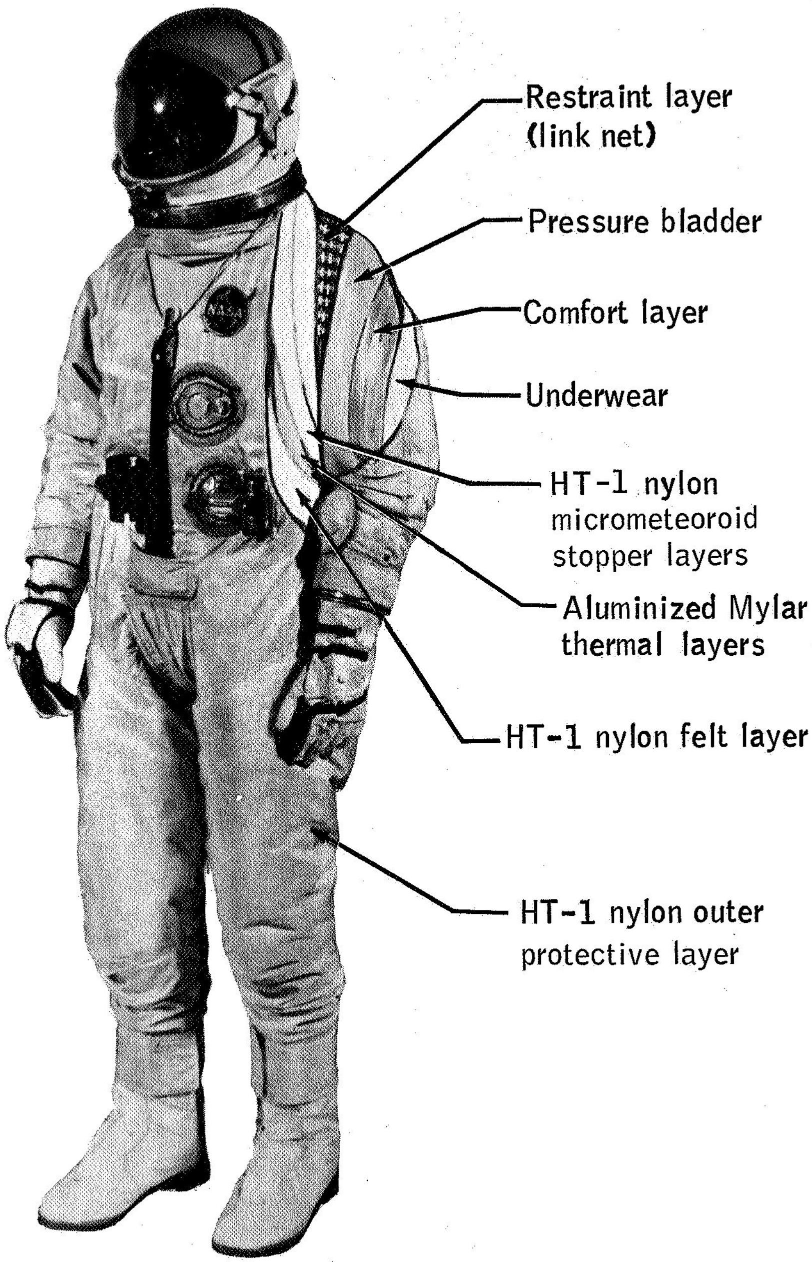

Figure 4.1-2.- Gemini G4C extravehicular space suit.

NASA-S-67-294

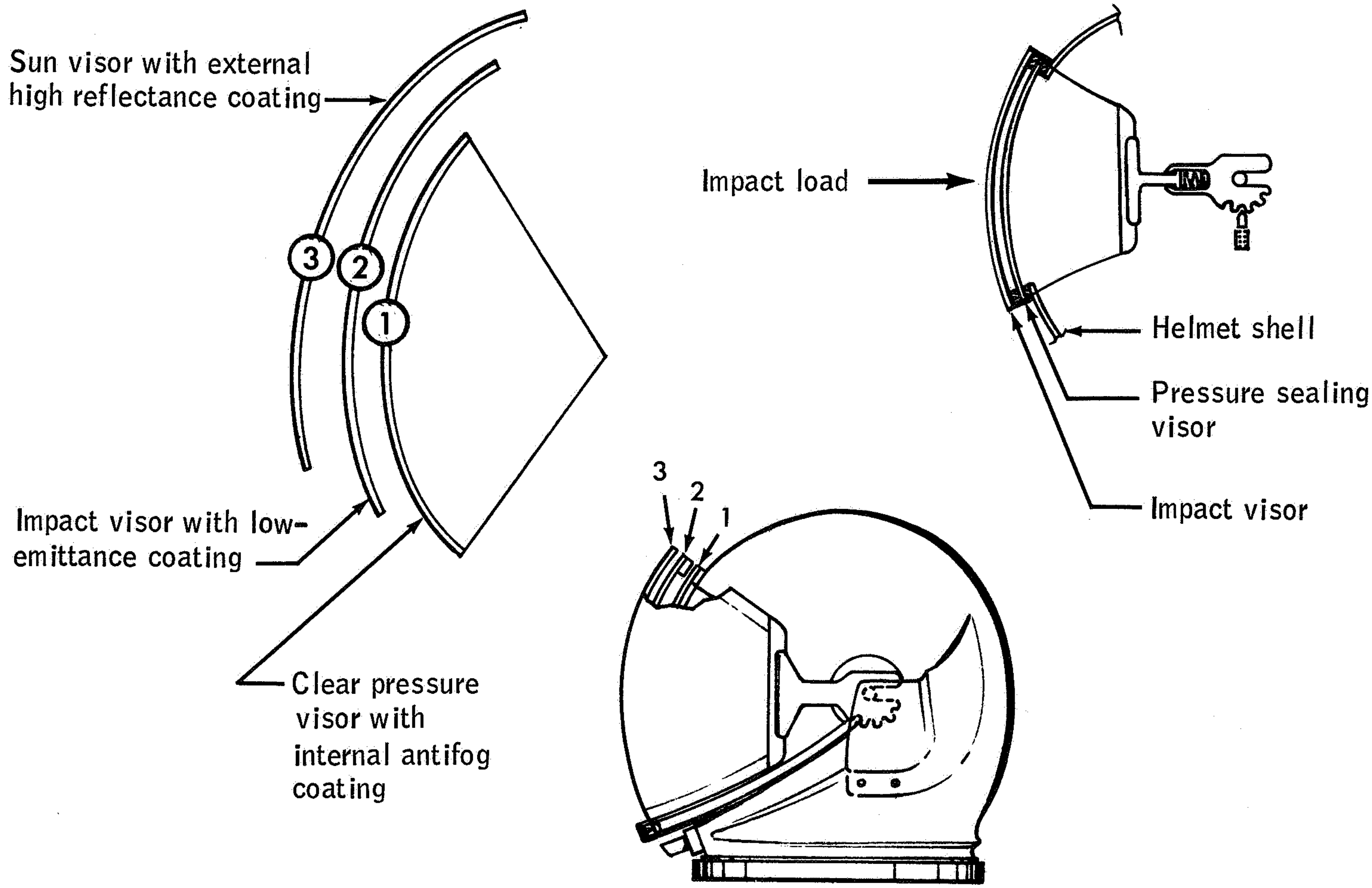

Figure 4.1-3. - Gemini IV extravehicular helmet.

NASA-S-67-297

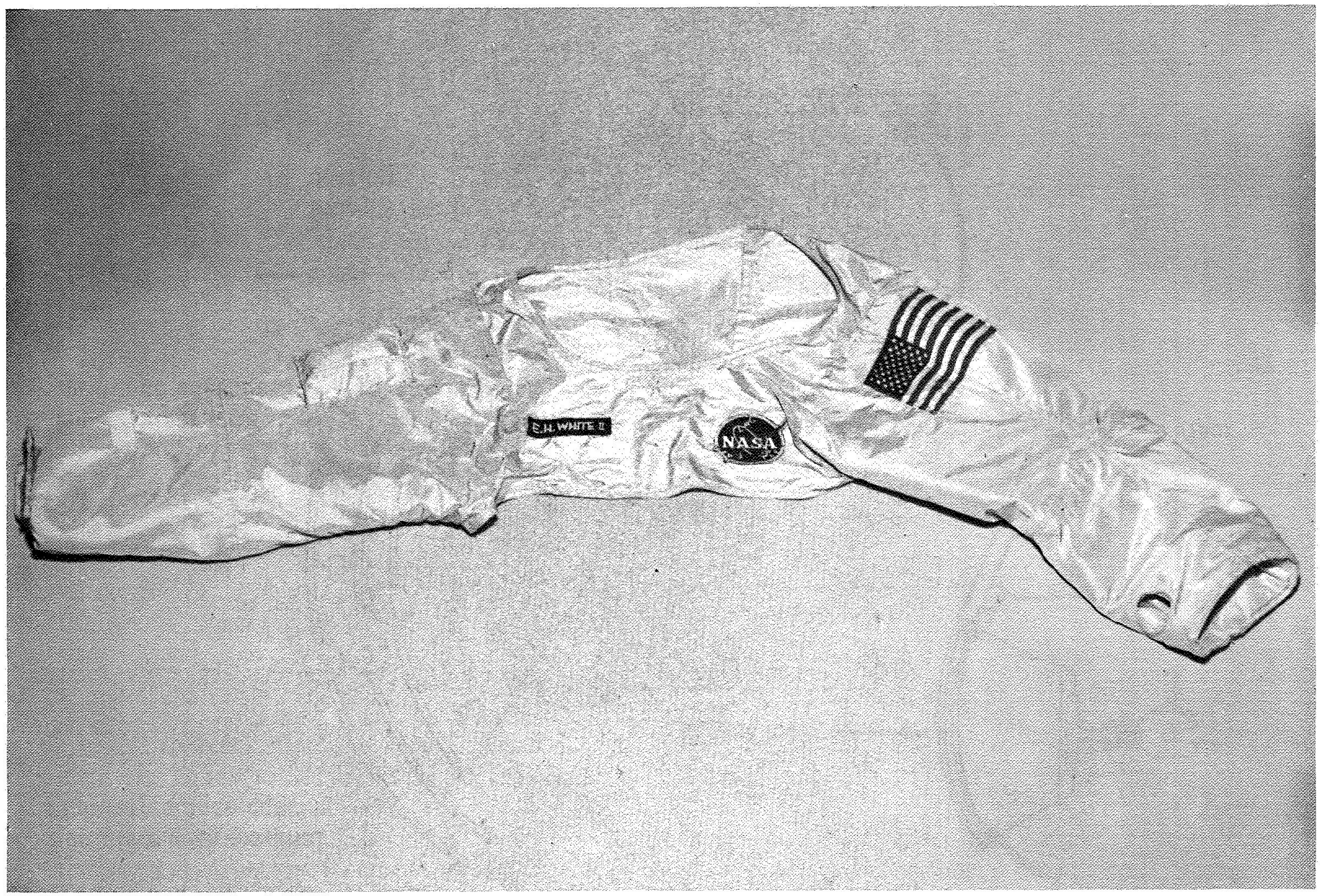

Figure 4.1-4. - EVA protective jacket for pilot.

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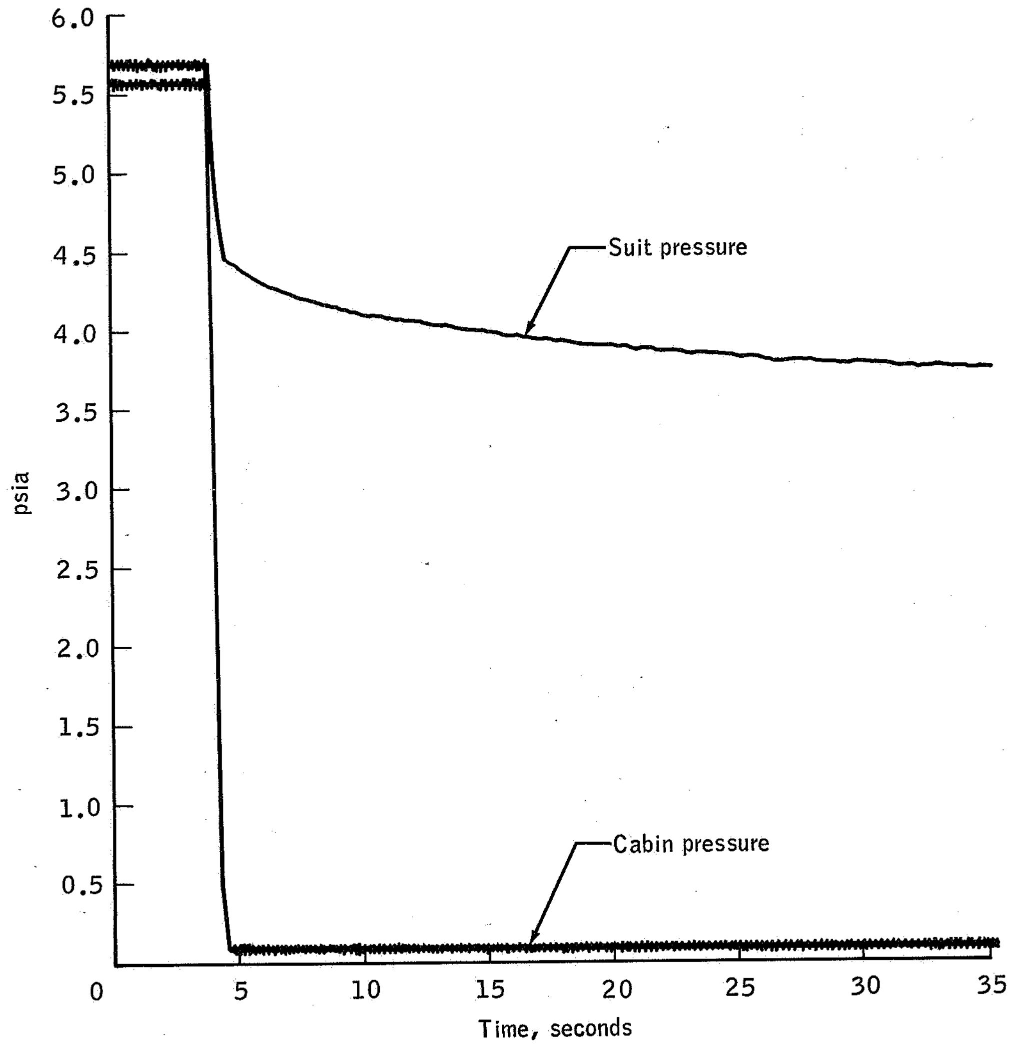

Figure 4.1-5. - Explosive decompression test.

NASA-S-67-842

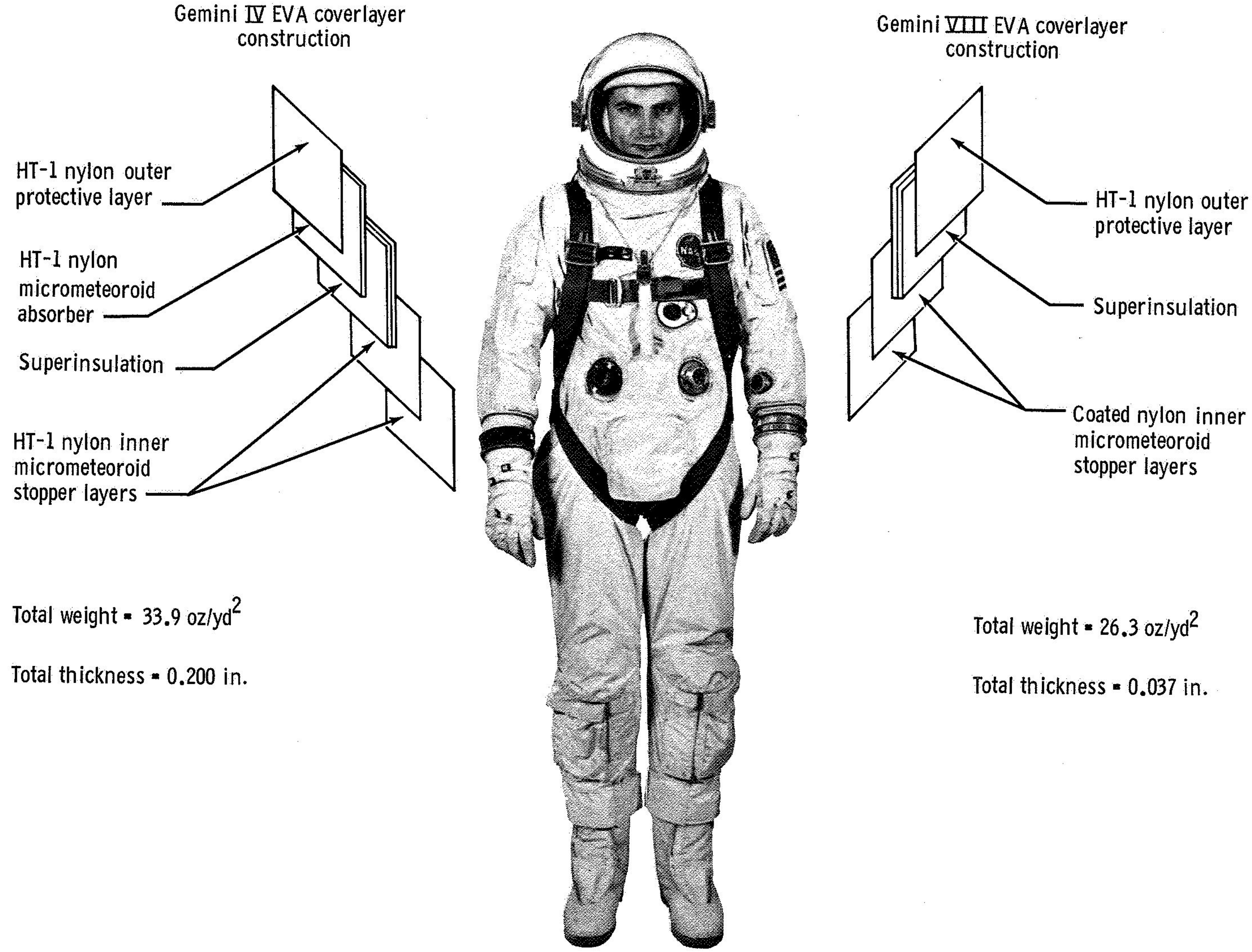

Figure 4.1-6. - Comparison of Gemini IV and Gemini VIII extravehicular coverlayer construction.

NASA-S-67-298

Figure 4.1-7. - Integrated pressure-thermal gloves for EVA.

NASA-S-67-299

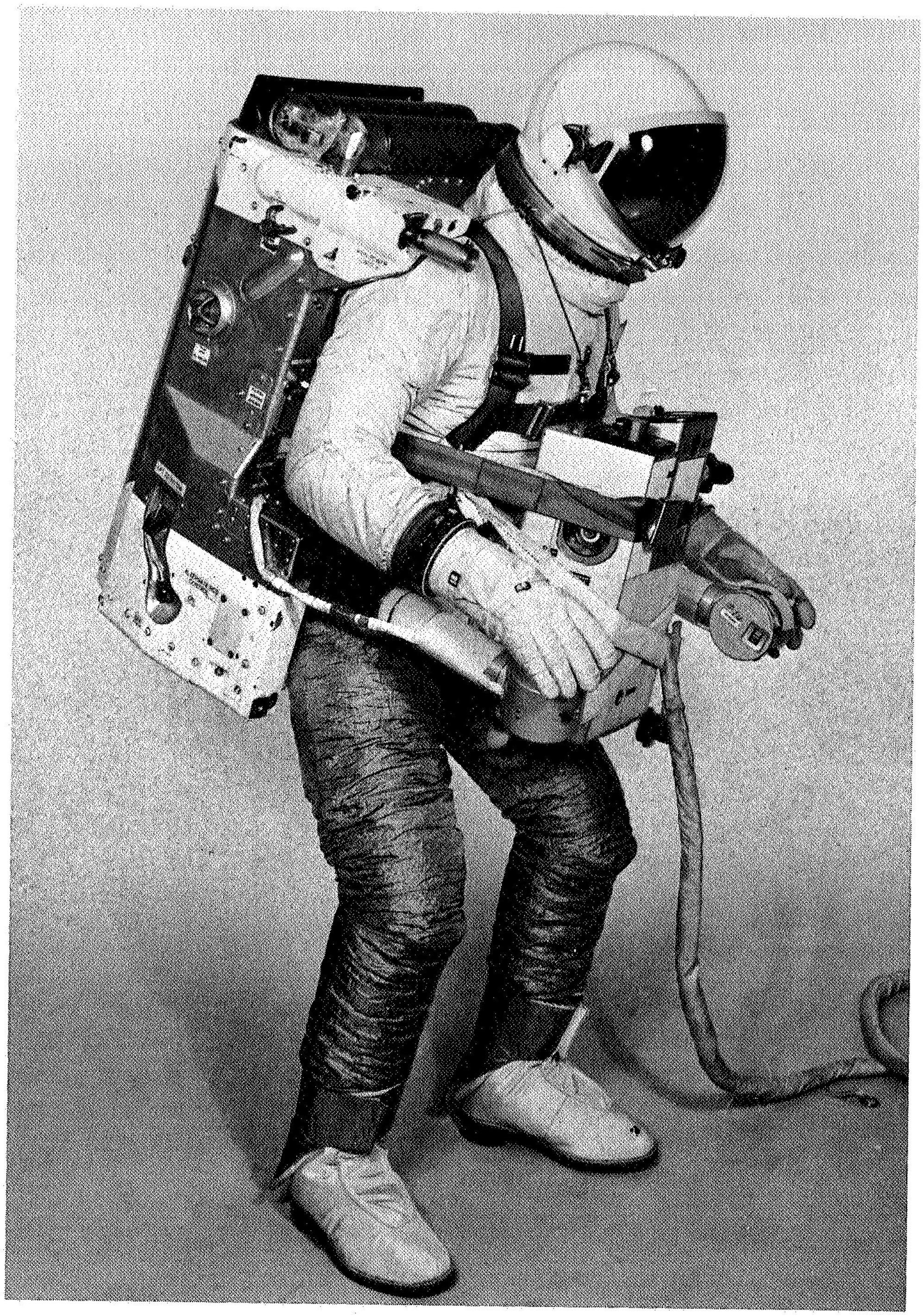

Figure 4.1-8. - Gemini IX-A extravehicular space suit and Astronaut Maneuvering Unit.

NASA-S-67-270

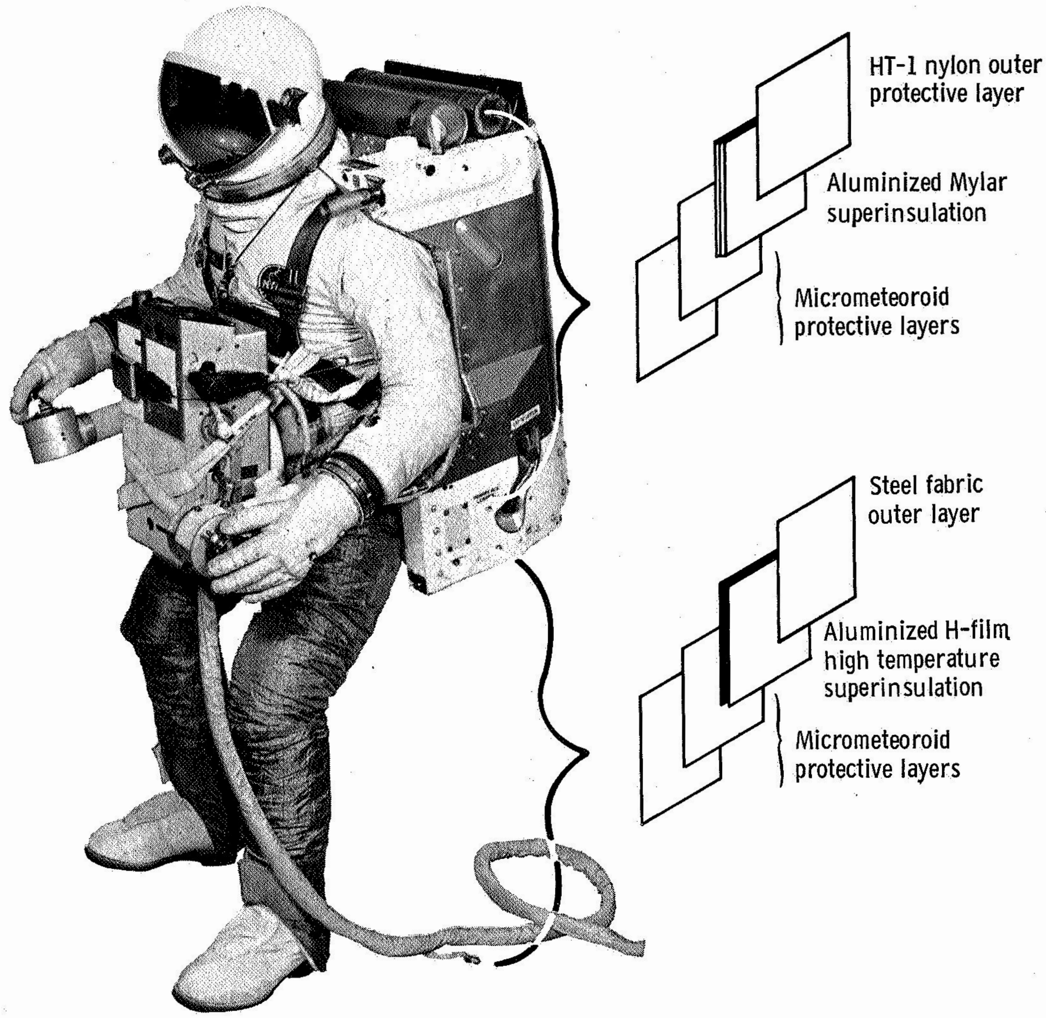

Figure 4.1-9.- Gemini IX-A extravehicular space suit construction.

4.2 LIFE SUPPORT PACKAGES

The life support packages used during the Gemini Program represent the design, development, qualification, and first application of extravehicular life support systems in the United States Space Program. These systems consisted of two basic types of portable environmental control units: the Gemini IV Ventilation Control Module (VCM) system which was an open-loop system, and the semi-open-loop Extravehicular Life Support System (ELSS), which was used on the Gemini IX-A through Gemini XII missions.

The Extravehicular Support Package (ESP) and Astronaut Maneuvering Unit (AMU) were designed to provide the extravehicular crewman with a separate oxygen supply for operation independent of the spacecraft. The ESP contained sufficient oxygen for approximately 82 minutes of operation. The AMU contained an oxygen supply sufficient for 60 minutes of operation. (The information in this section is limited to the VCM, the ELSS, and the ESP. Information pertaining to the AMU is included in section 6.2.)

4.2.1 Ventilation Control Module System

The VCM system included the VCM, a 25-foot umbilical, a pair of multiple gas connectors, and two restraint straps. In this system, oxygen was supplied to the suit inlet fitting by an umbilical from the Gemini spacecraft. This oxygen flow cooled the interior of the space suit and purged carbon dioxide from the helmet area.

Suit pressure was controlled by a back-pressure control located at the suit outlet port. The VCM contained a 9-minute emergency oxygen supply that was ducted directly to the helmet to assure adequate oxygen for the extravehicular crewman in the event of loss of his normal umbilical oxygen supply.

4.2.1.1 Ventilation Control Module.- During normal operation, the VCM controlled the suit pressure with oxygen supplied from the spacecraft. Emergency oxygen was also provided through a probe inserted in the helmet feed port to the oro-nasal area from a self-contained bottle. The emergency oxygen allowed operation independent of the spacecraft by supplying the minimum oxygen flow necessary for emergency operation. The VCM was mounted on the chest of the EVA crewman with connections to the outlet fitting and to the feed port of the suit. Two restraint straps were snapped around the parachute harness and attached by Velcro to the front of the VCM.

An Environmental Control System (ECS) demand regulator and pressure relief valve maintained suit pressure in the relief mode during normal operation. The demand regulator portion maintained suit pressure after the primary oxygen flow was stopped and until emergency oxygen flow to the feed port probe was manually initiated. Suit pressure was maintained at 3.9 ± 0.3 psia with a normal flow of 9.0 lb/hr and an emergency flow of 2.0 lb/hr. The VCM weighed about 7.75 pounds and was 13.4 by 5.75 by 3.25 inches. A schematic of the VCM system and a photograph of the VCM are shown in figures 4.2-1 and 4.2-2.

4.2.1.1.1 Major functional components: All major functional components of the VCM had previously been qualified for use in the Gemini spacecraft ECS.

(a) Demand regulator and pressure relief valve: The demand regulator and pressure relief valve maintained suit pressure at 3.9 ± 0.3 psia. The valve was also designed to provide a limited flow of make-up oxygen in case of loss of the primary oxygen supply from the spacecraft and before manual initiation of emergency flow to the helmet. The flow through the demand portion was limited to a maximum rate of 0.22 lb/min. This component was proven, through additional testing, to be qualified for operation in the relief mode by allowing saturated oxygen to flow with no icing of the relief ports.

(b) Emergency oxygen bottle (early Gemini egress oxygen system): The bottle was uprated to a working pressure of 4000 psig from the design point of 3400 psig and had a capacity of 0.34 pound. All bottles were proof tested to 6400 psig, or 1.6 times operating pressure.

(c) Oxygen pressure regulator (Gemini ECS secondary oxygen system regulator): This component regulated emergency oxygen flow at a nominal 110 psig with a flow capability of 0.35 lb/min.

(d) Oxygen shutoff valve (Gemini ECS secondary oxygen system shutoff valve): This valve was used to initiate VCM emergency oxygen flow to the helmet.

(e) Pressure gage (Gemini egress oxygen system): The gage was used to indicate emergency oxygen pressure of 0 to 4000 psig. The sense line was shortened and bent to a new configuration for use in the VCM.

(f) Emergency oxygen shutoff valve (Gemini ECS primary oxygen system shutoff valve): This valve was used in the VCM to activate the emergency oxygen system during EVA preparations. The valve was modified to remove the detent that locked it in the open position so that emergency oxygen flow could be briefly initiated during inflight checkout procedures.

(g) Umbilical check valve: A Gemini ECS primary oxygen system check valve was used to prevent suit depressurization in the event of umbilical damage or failure.

(h) Emergency oxygen hose: This hose was used to duct emergency oxygen from the VCM to the feed port probe. The construction of the hose was similar to that in the umbilical assembly. Its major qualification was by similarity, although it was subjected to additional flexing tests after cold-soaking at -60° F.

4.2.1.1.2 New components:

(a) Filter: A 17-micron absolute filter was located upstream of the emergency flow control orifice.

(b) Fill valve: An MS-28889 valve rated at 5000 psig was used as the fill valve. The leakage rate was determined to be zero. The seals were changed to oxygen-compatible materials.

(c) Feed port probe: This component was designed and fabricated at the Manned Spacecraft Center.

(d) Structure and connecting lines: These components were also designed and fabricated at the Manned Spacecraft Center.

4.2.1.2 Umbilical assembly.- The umbilical provided the extravehicular crewman with oxygen, a structural tether to the spacecraft, and electrical connections for voice communications and instrumentation. The umbilical supplied a nominal 9.0 lb/hr oxygen flow to the suit inlet at approximately 50° F. An orifice, incorporated in the quick disconnect at the spacecraft end of the umbilical, limited the maximum flow to approximately 10.2 lb/hr. The umbilical-to-suit inlet fitting was provided with a check valve to seal the suit inlet port if the primary oxygen supply pressure decayed below the suit pressure. The structural tether was capable of maintaining mechanical integrity up to a maximum tensile load of 1000 pounds, and all functions would have been maintained at a loading of 373 pounds. The assembly was 25 feet long and was wrapped with a metallic gold finish tape for specific emissive control of thermal radiation. Detailed information pertaining to umbilicals is presented in section 4.3.

4.2.1.3 Development and qualification.-

4.2.1.3.1 Development testing: The initial VCM system was designed to provide normal suit ventilation with emergency oxygen to be supplied automatically to the helmet area if umbilical flow failed. Unmanned development testing of this unit revealed that the suit was maintained at only 3.0 psia during emergency operation, which was undesirable. Further investigation revealed that, in this initial configuration, the pressure drop in the pressure-sensing line from the demand regulator was too great for establishment of the required suit pressure (3.7 ± 0.2 psia). The VCM was modified by changing the pressure-sensing point of the demand regulator from the visor area to the suit outlet ventilation fitting. The VCM demand regulator then provided only suit ventilation relief and pressurization control. The initiation of VCM emergency oxygen flow to the helmet feed port became a manual function. To initiate emergency oxygen flow, the person using the system must be able to detect umbilical flow failure.

The first manned test of this modified unit confirmed the suitability of the manual emergency system. The subject rapidly detected each umbilical flow stoppage and initiated emergency flow within 7 seconds. The suit pressure was maintained at 4.2 and 3.8 psia for the normal and the emergency modes, respectively. Four additional manned vacuum chamber tests were performed with the modified VCM to evaluate the normal and the emergency operational modes. The system met all flight requirements.

4.2.1.3.2 Unmanned qualification testing:

(a) Environmental qualification: The VCM was subjected to the standard tests for random vibration, acceleration, shock, and oxygen atmosphere compatibility required for all Gemini cabin equipment. All environmental qualification requirements were met.

(b) Earth orbit simulation test: This test consisted of 50 minutes of exposure to simulated solar heat flux in a vacuum chamber at 5×10^{-7} mm Hg and at -320° F. A 60-minute cold soak period followed in which the chamber vacuum and the cold-wall temperature were maintained but the solar heat was turned off. Instrumentation showed that the inner case temperatures had reached extremes of 126° and -135° F. The inner structure temperatures reached extremes of 67° and -31° F. These temperatures were acceptable for the VCM thermal design.

4.2.1.3.3 Manned testing:

(a) Mission profile tests: A manned test was conducted with the VCM system to qualify the equipment under end-to-end test conditions simulating the planned EVA mission. This manned test was conducted in the MSC 20-foot altitude chamber. A boilerplate Gemini spacecraft (Boilerplate 2), which incorporated a complete reentry module ECS, was installed in the test chamber. Two crewmen in Boilerplate 2 duplicated the flight crew functions. After the chamber was decompressed to a pressure equivalent to 180 000 feet, the crewmen carried out the sequence of events planned for the Gemini IV EVA mission. All normal and emergency procedures were exercised, including the simulated failure of the umbilical oxygen flow and the procedures for switching back to the spacecraft ECS connections in a decompressed cabin. All mission profile qualification testing requirements were met.

(b) Low temperature test: A manned test was conducted in the 20-foot chamber to qualify the VCM system for extremely low temperature conditions. The test conditions were a chamber pressure equivalent to 180 000 feet, with the liquid nitrogen cold walls cooled below -300° F. The test subject wore the VCM and a Gemini extravehicular space suit and stood in the cold room for 31 minutes. Primary oxygen was supplied through a flight-configuration umbilical at a flow rate of 9 lb/hr. Both the normal and the emergency oxygen systems were tested. Throughout the test, the VCM maintained the suit pressure at 4.5 psia on normal flow and 4.4 psia on emergency oxygen supply. This test satisfied the manned qualification requirements for low temperature vacuum operations.

(c) Flight equipment validation: Subsequently, both the Gemini IV prime and backup EVA pilots underwent the same mission profile test described in paragraph (a) using the actual flight and backup equipment. The complete sequence of normal and emergency procedures was validated by both pilots. These tests served the combined function of crew familiarization and final end-to-end system testing of the extravehicular equipment prior to flight.

4.2.1.4 Mission results.- The VCM system was used successfully during the Gemini IV EVA mission. Space suit pressure was maintained at a nominal 4.2 psia with a primary oxygen flow of 8.2 lb/hr. This open-loop flow was adequate for cooling the pilot throughout the EVA period except when he was mounting the external camera and during ingress. The pilot expended a moderately high effort in mounting the camera, and he became slightly overheated. As soon as he reduced his activity level, he began to cool off and to return to normal. At ingress he expended a very high effort pulling the hatch fully closed and in manipulating the faulty hatch-locking mechanism. During this period of activity he became greatly overheated, and the cooling capability of the VCM system was substantially exceeded. The pilot perspired profusely and experienced slight visor fogging. Because he removed his helmet soon after ingress, his recovery from the overheated condition was rapid and no prolonged aftereffects from this condition were seen. The VCM system was concluded to be adequate for the nominal EVA mission, but the cooling capabilities with the 8.2 lb/hr normal flow or the 2 lb/hr emergency flow were insufficient for the high work levels which could be expected in emergency conditions.

4.2.2 Extravehicular Life Support System

The Extravehicular Life Support System (ELSS) provided substantially greater oxygen reserves and greater capacity for removal of heat and moisture than the VCM system. The ELSS was designed to permit operation independent of the spacecraft, using a backpack for communications and primary oxygen. It was the basic extravehicular system carried on Gemini VIII to Gemini XII. The central component of the Gemini ELSS was the chestpack. Other items of the ELSS included two multiple gas connectors, an electrical jumper cable, two restraint straps, two suit hoses, and an umbilical (fig. 4.2-3). The chestpack was held in position on the extravehicular pilot's chest by nylon web restraint straps, which were attached to his parachute harness by Pull-dot fasteners and to the front surface of the chestpack with Velcro. Electrical connections to the chestpack, suit, and umbilical were made through the electrical jumper cable. Two flexible hoses connected the chestpack oxygen loop to the space suit.

4.2.2.1 ELSS chestpack.- Primary oxygen was supplied to the ELSS chestpack by the umbilical from the spacecraft or other external source at normal rates of 5.1 or 7.8 lb/hr. This flow was introduced to an ejector pump where it was mixed with the secondary (recirculated) ventilation gas and then supplied to the suit for cooling and carbon dioxide washout. Suit pressure was controlled to 3.7 psid by a differential pressure valve located at the suit outlet where gas was exhausted to space at a rate equivalent to the primary flow rate. This outflow was sufficient to wash out carbon dioxide at a rate which maintained an acceptable carbon dioxide partial pressure in the oro-nasal area. This system contained a heat exchanger for cooling and removing moisture from the secondary gas, an emergency oxygen supply with a capability of up to 30 minutes of operation, and an emergency audio and visual warning system.

4.2.2.1.1 Controls, displays, and connections: The chestpack contained the following items.

Controls	Flow selector valve Normal/bypass valve Emergency shutoff valve Evaporant control valve Battery switch Test/dim/bright switch Audio reset switch
Displays	Emergency oxygen pressure gage AMU propellant quantity gage Emergency oxygen warning light Suit pressure warning light Spacecraft power light Four AMU malfunction warning lights
Connections	Two oxygen supply quick disconnects Electrical connection Two suit hose connection fittings

4.2.2.1.2 Pneumatic subsystem operation: The pneumatic portion of the chestpack consisted of a medium-pressure oxygen input subsystem, a low-pressure suit loop, and a high-pressure emergency oxygen supply (fig. 4.2-4). No electrical power was required for the basic operation of the pneumatic system.

(a) Medium-pressure oxygen input subsystem: During normal operation, oxygen at nominal conditions of 70° F and 91 psig was supplied to the oxygen input subsystem from the spacecraft umbilical or from any other external oxygen supply. This oxygen was routed to an ejector, where it entered the suit loop. Ejector primary oxygen flow was controlled manually with the oxygen flow selector valve. The ejector primary oxygen flow rate was selected by rotating the oxygen selector valve from OFF to either the MEDIUM (5.1 lb/hr) or to the HIGH (7.8 lb/hr) position. The manual bypass valve could be actuated to allow additional (7.8 lb/hr) oxygen to enter the suit loop downstream of the ejector. This provided additional dry gas to the suit loop, depressing the dew point of the suit inlet gas and increasing the overall heat rejection capability of the chestpack. In the event of a decrease in suit pressure below 3.3 psig, the chestpack would supply additional oxygen through the suit pressure regulator valve to maintain the suit pressure at 3.3 ± 0.1 psig. If the suit pressure regulator were actuated, the demand flow sensor would sense the flow through the suit pressure regulator valve, illuminate the SUIT PRESS warning lamp (fig. 4.2-5) on the chestpack control panel, and initiate an audio warning tone to the flight crew.

(b) Low-pressure suit loop: The chestpack operated on a semi-open-loop principle in which sufficient fresh oxygen was added and sufficient ventilation gas was dumped overboard during recirculation to maintain the carbon dioxide partial pressure of the circulated gas at an acceptable level. The fresh oxygen entered the suit loop at the ejector where its pressure energy was converted into velocity, thus circulating the ventilation gas around the suit loop. The primary oxygen was mixed with recirculated secondary oxygen, and the mixed gas then flowed to the space suit inlet at a nominal temperature of 55° F. The vent gas exited the suit at a nominal temperature of 85° F and relative humidity of 85 percent and flowed through the suit outlet valve to reenter the chestpack. The suit outflow valve was located near the suit loop entrance to the chestpack, directly upstream of the heat exchanger. The suit outflow valve served two functions: first, to control suit pressure at a nominal 3.7 psi differential to the ambient pressure, and second, to dump gas overboard. The overboard flow was equivalent to primary oxygen flow, and it removed a portion of the carbon dioxide as well as a portion of the moisture and the heat load. The remainder of the secondary gas flowed into the evaporative heat exchanger to be cooled. Cooling was accomplished by transferring heat to the water stored in the integral metal wicks of the heat exchanger. To activate the heat exchanger, the evaporant control valve located on the side of the chestpack was opened manually. The heat exchanger functioned only when exposed to an ambient pressure less than 0.08 psia. A back-pressure control valve maintained a small back pressure to control the boiling point of the liquid. The water received its latent heat of vaporization from the recirculating vent gas, thus cooling the gas flow, and boiled off through the evaporant flow control valve. As the moisture-laden recirculating gas was cooled to 45° F (100-percent relative humidity), the water vapor was condensed on wicking in the condenser side of the heat exchanger. The condensed water was transported by capillary action through this wicking to an area where it was driven through a porous plate by the pressure differential between the suit loop and the external vacuum. The downstream side of the porous plate contained a sponge-storage reservoir and wicking which transported the condensed and stored water to the boiloff area. The condensed water was, therefore, used in a boot-strap operation, which decreased the required amount of cooling water that had to be stored. The cooled secondary gas then passed through the ejector to complete the checkpack suit loop.

(c) High-pressure emergency oxygen supply: In the event the inlet oxygen pressure fell to a nominal 67 psid, the chestpack emergency supply would be automatically initiated. The emergency oxygen was regulated to 67 ± 10 psid; and, if the inlet oxygen pressure dropped below this level, the emergency oxygen regulator would admit regulated oxygen from the supply bottle. An emergency oxygen flow sensor would energize the EMERGENCY O_2 warning lamp (fig. 4.2-5) on the chestpack control panel and would initiate an audio warning tone to the flight crew. Since the emergency oxygen temperature would continually decrease as the stored oxygen expanded to a lower pressure, the emergency oxygen was heated before it entered the low-pressure loop. This was accomplished by a line heater and temperature sensor that automatically controlled the temperature of the regulated emergency oxygen to a nominal 45° F. The duration of the emergency oxygen supply was dependent on the amount of oxygen supplied through the umbilical. With a decreased umbilical supply, the emergency oxygen supply would make up the deficiency. With no umbilical oxygen supply, the emergency system would supply oxygen for up to 20 minutes on high flow or 33 minutes on medium flow. A small decal, located across the lower portion of the H_2O_2 QUANTITY dial (fig. 4.2-5), indicated the mission time remaining as a function of emergency oxygen bottle pressure and the flow selector setting.

4.2.2.1.3 Electrical subsystem operation: The ELSS electrical subsystem consisted of an umbilical cable, the electrical jumper, the chestpack modularized control and monitoring circuit, the sensing circuits, the electrical harness, and a 28-volt-dc wet-cell battery. The major electrical components of the ELSS are depicted in the block diagram in figure 4.2-6.

(a) Chestpack electrical harness assembly - A1: This assembly provided all electrical interconnection among the chestpack subassemblies A2 to A9 and the electrical jumper A10.

(b) Control panel assembly - A2: This assembly, shown in figure 4.2-5, contained:

(1) Control panel background lamps which lighted to indicate that the chestpack was activated and to illuminate the chestpack controls and displays

(2) A test/dim/bright switch which was used to select the illumination level of the background lamps and to check operation of the warning lamps and audio warning circuits

(3) An audio switch that reset the flip-flop circuit in subassembly A8 to stop the audio warning tone generated by the oscillator circuit in subassembly

(4) Six warning lamps, a hydrogen peroxide quantity meter, and an emergency oxygen pressure gage which provided visual indications of chestpack and backpack operating conditions. Four of the warning lamps (H_2O_2, FUEL PRESSURE, O_2 PRESSURE, and RCS) were ground-seeking indicators, and received their inputs from the AMU through subassemblies A1 and electrical jumper A10. The other two warning lamps (SUIT PRESSURE and EMERGENCY O_2) were power-seeking indicators, and received their inputs from subassembly A9 via subassembly A8.

(c) Oxygen temperature sensor - A3: This component sensed the temperature of oxygen from the chestpack emergency oxygen supply tank and provided an input to the temperature control circuit in subassembly A5 to control operation of heater, subassembly A4.

(d) Oxygen heater - A4: This component heated the oxygen from the chestpack emergency oxygen supply tank to a nominal 45° F, as sensed by the temperature sensor subassembly A3 and controlled by subassembly A5.

(e) Oxygen temperature control and oscillator - A5: This module contained two circuits: a temperature control circuit and an oscillator circuit. The temperature control circuit energized the heater subassembly A4, as dictated by the temperature sensor subassembly A3. The oscillator circuit initiated the audio warning tone to the crew when triggered by the flip-flop circuit in subassembly A8.

(f) Pressure transducer - A6: The pressure transducer sensed suit-loop pressure as a differential with respect to ambient pressure and provided a signal to the spacecraft telemetry for ground monitoring. This function was not used after the Gemini IX-A mission.

(g) Battery - A7: The battery was the secondary power source for the chestpack. When the battery switch was placed in the ON position, a nominal 28 volts dc was applied to subassemblies A2, A5, A6, A8, and to the ejector heater. When primary spacecraft power was used, lamp DS1 was illuminated to indicate that the spacecraft power was being used and that relay K1 had disconnected the battery.

(h) Oscillator and light controller voltage regulator - A8. This module contained a three-input OR gate, a flip-flop circuit, and a voltage regulator circuit. The flip-flop circuit generated a voltage to trigger the oscillator circuit in subassembly A5 when an input signal from the OR gate was received. The OR gate supplied an output to the flip-flop circuit if an input was received from either the demand or the emergency flow sensor in subassembly A9 or from the AMU backpack through subassemblies A1 and A10. The voltage regulator controlled the light intensity of the control panel lamps in subassembly A2.

(i) Demand flow sensor and emergency oxygen flow sensor - A9: This module contained the demand flow sensor and the emergency flow sensor. Both flow sensors were of the pressure-differential diaphragm-switch type with a single-pole double-throw contact. The contact closed in the demand flow sensor if oxygen flow was initiated through the suit pressure regulator valve. The contact closed in the emergency flow sensor if emergency oxygen flow was initiated. Either flow sensor contact closure provided an input to the OR gate in subassembly A8, causing the appropriate warning lamp in subassembly A2 to light and the oscillator circuit in subassembly A5 to initiate an audio warning tone.

(j) Spacecraft power status indicator lamp - DS1: This lamp indicated that the chestpack was being supplied with spacecraft power. The lamp was off when the chestpack battery (subassembly A7) was being used.

(k) Relay - K1: This relay disconnected the chestpack battery (subassembly A7) whenever spacecraft power was applied and reconnected the chestpack battery in case of loss of spacecraft power.

(l) Ejector heater: A 20-watt heater which operated continuously was used to prevent ejector icing with possible blockage of the suit ventilation gas flow.

(m) Electrical jumper cable - A10: This assembly provided an electrical interconnection between the chestpack, the space suit, and the umbilical.

(n) Umbilical cable - A11: This assembly provided an electrical interconnection between the spacecraft and the electrical jumper (subassembly A10).

4.2.2.2 ELSS testing.- The ELSS chestpack for flight use during the Gemini extravehicular program was qualified in both unmanned and manned systems testing. To define the environmental extremes necessary for this ELSS qualification, Gemini spacecraft specifications were utilized. Because of the comparatively short time available for system design, development, and qualification, and because many of the system components were similar to previously qualified hardware, chestpack qualification was accomplished on a system basis. Component testing was limited to development testing only, and it was performed on a minimum test basis. In retrospect, if the component development testing had been expanded to include specific tests of major components and extensive tests of all new components, many problems occurring later in the ELSS program might have been discovered and averted in the initial development.

4.2.2.2.1 Unmanned testing: The unmanned testing of the ELSS consisted of thermal and dynamic load testing by the ELSS contractor, system testing at the Manned Spacecraft Center (MSC), and thermal vacuum simulation by a separate thermal study contractor.

(a) Unmanned thermal and dynamic systems testing: The principal unmanned system qualification testing of the ELSS chestpack and its ancillary equipment was performed at the ELSS contractor's test facility. This testing was performed utilizing two chestpack systems, one for thermal environment testing and the other for dynamic loads testing. In addition to the chestpack, each of these systems included an electrical jumper, an umbilical, and a pair of multiple gas connectors. Upon completion of dynamic loads testing, this chestpack and associated hardware were subjected to burst tests. The thermal environment testing included both functional and nonfunctional systems tests, while the dynamic loads testing was nonfunctional. Before qualification testing, each chestpack and the related components were subjected to Performance Record Tests. These tests were performed to the requirements of the ELSS contractor's Acceptance Test Procedures (ATP's). The ATP's had been previously reviewed and approved by NASA and were later utilized as the basis for NASA test documents for system testing conducted at MSC, at the spacecraft contractor's facility, and at the launch site.

(1) Thermal environment testing:

Humidity testing was performed with the chestpack and components nonoperational, using a 24-hour test cycle repeated four times as follows:

Temperature, °F	Humidity, percent	Time, hr
68 to 100	Uncontrolled	Start
100 to 160	Uncontrolled to 95	2
120	95	6
120 to 100	95	16 (minimum)

Temperature testing was performed in a flight-ready standby condition for 9 days, the first 7 days at sea-level pressure and atmosphere, and the last 2 days at 5 psia oxygen. The temperature profile repeated on a 10-hour cycle consisted of 4 hours at 32° F and 4 hours at 120° F, with 1 hour to attain steady-state conditions at the upper or lower temperatures.

Pressure temperature testing was performed with the operating system subjected to three mission profiles typical of the one shown in figure 4.2-7. Each mission was composed of five phases:

Phase 1 - System turned on and cycled in oxygen atmosphere

Phase 2 - Normal chestpack operation with umbilical oxygen supply

Phase 3 - Continuation of normal chestpack operation, but simulation of suit leakage

Phase 4 - Emergency operation with umbilical oxygen turned off

Phase 5 - Continuation of phases 2 and 4, until the ELSS emergency oxygen and heater exchanger, or battery, respectively, were depleted

Explosive decompression testing was performed in a flight-ready, standby condition. The system was exposed to a 7-psi decompression of 0.40-second duration.

(2) Dynamic system testing:

Electromagnetic interference (EMI) testing was performed on the system in accordance with the Class IA requirements of Military Specification MIL-I-26600. The system was operated in emergency and normal modes using battery power where required; otherwise, external laboratory power was used.

Random vibration testing was performed with the system in a flight-serviced, standby condition. The system was subjected to the random vibration test profile shown in figure 4.2-8. The test was performed for 10 minutes along each of the three principal mutually perpendicular axes. This testing was repeated each time there was a major modification to the system, such as installation of ejector heaters or rerouting of the bypass valve.

Acceleration testing was performed with the system in a flight-serviced, standby condition. The system was subjected to the acceleration loads shown in figure 4.2-9. The acceleration loads were applied simultaneously for both the lateral and longitudinal axes of the spacecraft.

Shock testing was performed with the system in a flight-serviced, standby condition, with the exception of the emergency oxygen bottle which was not pressurized. The system was subjected to two half-sine-wave shocks of 11-millisecond duration of 30g and 40g, for a total of four shock tests. Acceptance of shock testing with the emergency oxygen bottle depressurized was based on the assumption that, if the EVA mission were not conducted, the flight crew would vent the high-pressure oxygen from the chestpack. However, during the Gemini VIII mission when it was decided to reenter prior to the scheduled EVA, the emergency oxygen was not vented from the chestpack because a high landing shock was not expected.

Burst testing was performed at the conclusion of the dynamic loads testing, after NASA verification that all objectives of this phase of qualification had been fulfilled. All major components of the ELSS and major pressure loops of the chestpack were subjected to burst pressure tests, except the emergency oxygen bottle. The burst pressure of a specific loop was determined as that pressure at which the first component in that loop failed. Burst pressure of the low pressure loop was 43.3 psig, when a rubber oxygen hose inlet failed at the chestpack. The medium-pressure loop was increased to 960 psig with no failure before the test was terminated. The major components of the high-pressure system were burst individually as follows: pressure gage at 17 800 psig; pressure regulator at 24 400 psig; and emergency oxygen bottle at 18 800 psig.

(b) Unmanned system testing at MSC: Utilizing the 8-foot chamber facility, the ELSS was subjected to the simulated thermal load versus time profiles of three expected mission durations of 35, 65, and 95 minutes. During certain profiles, failures were simulated for loss of umbilical oxygen supply and for penetration of the suit.

During the short and long mission profiles, data were taken on suit inlet temperature and dew point, system flow rate, suit pressure, and gas composition. The data were all within the nominal ranges. On the 65-minute profile, suit pressure was approximately 4.0 psi above chamber pressure, instead of the 3.7 ± 0.2 psi specification. This resulted in replacement of the chestpack outflow valve. During the umbilical failure simulation, the audio warning tone became weak and irregular. However, this problem was due to low voltage caused by an insufficient battery charge cycle before testing.

When the system was subjected to a simulated suit leak which would cause a flow of 13.6 lb/hr at 3.7 psia (based on maximum flow of the outflow valve when failed open or on a 1/4-inch-diameter penetration), the suit pressure decayed almost instantaneously from 3.75 to 3.1 psia; and the suit pressure warning light and audio tone came on. This condition was maintained for 15 minutes with no further pressure decay.

The system was then subjected to a simulated leak which would cause a flow of 27.7 lb/hr at 3.7 psia; and again, decay to 3.1 psia was almost instantaneous. The suit pressure warning light, the emergency oxygen flow warning light, and the audio tone all operated as designed. These conditions were maintained for 15 minutes with no further pressure decay.

Medical opinion indicated that 3.0 psia is the minimum acceptable suit pressure for a 15-minute exposure. Therefore, the ELSS was capable of compensation for the condition of a failed-open outflow valve.

(c) Unmanned thermal vacuum testing: This testing was performed in the Space Environmental Simulator of the thermal study contractor. Two flight configuration chestpacks, one umbilical, one electrical jumper, one pair of multiple gas connectors, and one pair of hoses to connect the chestpack to the space suit comprised the ELSS assembly. These packs were not the same as those used for the ELSS contractor's qualification testing, but were the two packs originally scheduled for use on the Gemini VI mission. For metabolic rate simulation, two Gemini Crewman Simulators (CMS's) were connected in series and used to produce the sensible and latent heat loads for ELSS performance evaluation. Figure 4.2-10 shows the test schematic. Because each CMS was rated at 1150 Btu/hr, the series hookup was required to provide sufficient heat load simulation capability. The test article and the CMS's were suspended in the test chamber from an insulated overhead support. During chamber pumpdown, cold-wall stabilization, and chamber recompression, it was necessary to prevent the ELSS from cold soaking to lower than specification temperatures caused by prolonged exposure to cold-wall temperatures. This was accomplished by use of infrared heaters located around the ELSS which were turned on during these nontest periods. The test environment used to simulate the Gemini day-night orbital conditions was a 55-minute day and 40-minute night cycle, a maximum average cold-wall temperature of -290° F, and a solar flux constant during daylight simulation of 443 Btu/hr-ft^2 (one sun equivalent) at the test article.

Each pack was heavily instrumented on inner and outer surfaces of the component and the case. This instrumentation provided a record of temperature extremes during day and night simulations as well as of the effects on these temperatures of the addition of small patches of Velcro. A total of four systems tests were scheduled, which included varying mission profiles from 65 to 270 minutes at normal operation, plus an additional 15-minute period at the end of each test for emergency simulations. The metabolic rates programmed for these test profiles were 1000, 1400, and 2000 Btu/hr. To maintain the required test environment during ELSS operation, it was necessary to cap the outflow valve and to duct the effluent gas to a vacuum exhaust pump. This gas was removed from the suit loop immediately upstream of the inlet to the chestpack with suit loop pressure and effluent withdrawal rate manually controlled by a valve located outside the test chamber. This test condition shielded the outflow valve poppet from the test environment and prevented evaluation of outflow valve performance and of possible icing conditions.

Because of instrumentation problems and extensive CMS performance and control problems, the first three tests of this series were only partially completed. The mass flowmeters used during this testing presented many problems in that they were quite sensitive to changes in fluid density, fluid moisture content, fluid temperature, and ambient temperature. Therefore, a great deal of the mass flow data was invalid. Since good ELSS inlet-to-outlet-port differential pressure data had been collected, both chestpacks were tested to determine suit loop flow rates as a function of pack differential pressure while the flow selector position and umbilical supply pressure were varied. The resultant data (figs. 4.2-11 and 4.2-12) were used to determine the heat loads imposed upon the ELSS. When the fourth system test was begun, the CMS's had been reworked to the extent that a fair degree of the mission metabolic load could be generated and controlled (fig. 4.2-13). This test was, therefore, extended until heat exchanger dry-out occurred. All normal and emergency sequences originally scheduled for the test series were accomplished during this fourth test period.

From the experience gained during this testing, the need for a reliable, compact, and portable crewman simulator to support in-house and contract life support systems testing was apparent. The lack of a reliable simulation device caused repeated delays and compromised a substantial portion of the test data obtained.

This simulated orbital environment was considered to be more severe than true earth orbital conditions. During testing, surface temperatures of the pack varied within acceptable limits from 165° to -56° F, and component temperatures varied from 20° to 85° F. The maximum oxygen temperature differential through the 25-foot umbilical during exposure to day and night temperature extremes was 35° F. The umbilical surface temperature ranged from 130° to -70° F, which was within specified limits. Although the outflow valve was capped to prevent gas flow through the valve, a significant portion of the valve body adjacent to the valve poppet was exposed to the Space Environmental Simulator test environment. This surface was instrumented for temperatures, and from the data (minimum temperature recorded was 60° F), it was concluded that the valve would not ice during actual operation in an orbital environment. During testing, it was possible to observe the evaporator steam pressure control valve poppet. From these observations, from temperatures recorded for the poppet valve seat, and from the external chamber surface temperatures (minimum temperature recorded was 50° F), there was no evidence of icing or improper evaporator steam pressure control.

The chestpack heat exchanger evaporator controlled the suit inlet dew point and dry-bulb temperatures within specified limits except (1) when an excessively high sensible heat load was delivered to the pack caused by malfunction of the crewman simulator, (2) during and immediately following simulated heat exchanger failure, and (3) after depletion of heat exchanger evaporator water. The test data indicated that the heat exchanger had a total sensible heat rejection capability between 400 to 600 Btu. The balance of the system heat load must be rejected by gas dumped from the suit loop outflow valve and by the latent heat rejected through the evaporator.

This phase of testing completed the unmanned qualification of the ELSS assembly. Five chestpacks were used for this testing and for the subsequent manned test program conducted at MSC.

4.2.2.2.2 Manned qualification test summary:

(a) Tests at ambient temperature with programmed metabolic load: The tests in this program were (1) medium mission profile, failing the heat exchanger for the last 15 minutes; (2) normal long mission profile; (3) long mission profile, failing the umbilical oxygen supply for the last 15 minutes; (4) normal medium mission profile; and (5) medium mission, failing the umbilical oxygen supply for the last 15 minutes.

For all five tests, the test subject was connected to the ELSS at 5.0 psia and began exercising as the chamber was depressurized below 4 mm Hg. Exercise rates and metabolic rate were determined for each test subject. The exercise consisted of stepping up and down using a 9-inch-high step.

During the first test, the subject did not alter the flow mode after closing the heat exchanger shutoff valve, even though the suit inlet dew point and dry-bulb temperatures increased 9° and 14° F, respectively. The subject reported that he did not feel excessively warm or sweaty. In the first three tests, suit outlet pressure varied erratically from 3.85 to 4.10 psid. The fault was traced to the outflow valve. A modified valve was incorporated in the test item before the final tests. In the last two tests, suit outlet pressures were maintained at 4.0 and 3.9 psid, respectively, with little or no variation during the test. No other problems were encountered.

(b) Tests in Gemini Boilerplate 2: To demonstrate compatibility between the ELSS and the Gemini Environmental Control System (ECS), and to verify that the ELSS could be donned in the confines of the spacecraft, two tests were conducted in Gemini Boilerplate 2.

During the first test, the right-hand crewman donned the ELSS with the Boilerplate 2 cabin pressure at 5.0 psia and with pressure in the 20-foot chamber at less than 4 mm Hg. Both crewmen were initially connected to the ECS. The cabin was depressurized to 3.0 psia to check suit, ELSS, and ECS integrity, and then was fully depressurized. No undue difficulties were encountered in this procedure. The right-hand crewman placed the ELSS in various flow modes and then reconnected to the ECS while the cabin was still depressurized. During this procedure, limited suit mobility and restricted visibility made the reconnection more difficult than had been anticipated. However, the reconnection was accomplished, and the test was completed successfully.

The second test was terminated before any significant results were obtained. The cause was a test equipment malfunction which was unrelated to the ELSS operation. No further tests were run with Boilerplate 2 since analysis of the test data showed that all of the primary qualification test requirements had been met in the first test run.

(c) Tests at orbital night temperature: Three tests were completed out of four attempts. The unsuccessful test was caused by a facility malfunction which was not related to the ELSS. Orbital night temperature tests were run at a pressure of less than 4 mm Hg in an enclosure which had liquid nitrogen circulating through the roof and three walls. The tests were: (1) medium mission profile, failing the umbilical for the last 15 minutes; (2) normal medium mission profile plus an extra 100 minutes at 1000 Btu/hr; (3) long mission profile, switching from the spacecraft umbilical to a simulated AMU umbilical and back to the spacecraft umbilical; and (4) 120 minutes at 1000-Btu/hr metabolic rate with the oxygen flow selector on HIGH, then connecting to the ESP oxygen supply and running for 20 minutes. The last portion of the test was a development test for the ESP and was not required for qualifying the ELSS.

During the second test, suit inlet temperature dropped to 30° F. Subsequent analysis of the test data indicated that the entire test setup had been biased by exposure of the umbilical hose assembly and the ELSS suit hoses to the cold walls. In addition, excessive moisture had condensed on all exposed surfaces in the test chambers when the cold walls were activated before the proper vacuum conditions were reached. Consequently, the temperature data obtained in this test were invalid.

In the third test, 20 minutes operating from the ESP oxygen supply was planned. However, 5 minutes after connecting to the ESP, a tear in the left glove restraint layer was found, and the test ended. Analysis of the test data showed that the ELSS performance had been within the required limits. The glove failure resulted from excessive wear on equipment which had been used for testing as well as for training. Since this anomaly did not reflect on the ELSS performance, the test was considered acceptable. This completed the ELSS qualification test program.

In spite of the numerous problems, the ELSS qualification program demonstrated the basic adequacy of the system. Subsequent mission changes and component failures showed that initial qualification requirements were not extensive or stringent enough to uncover all of the underlying weaknesses in the system components. The split responsibility in the qualification program, in which the contractor performed only the unmanned dynamic tests and MSC performed the manned systems tests, compounded the problem. This arrangement hindered the feedback of performance results to the contractor, and it tended to relieve the contractor of the responsibility for detailed analysis, except when major failures occurred.

A more effective qualification program would have resulted if all qualification test responsibilities had been placed on the contractor including the manned testing and detailed analysis of the results. Use of government test facilities with MSC coordination of external interfaces would have facilitated such an operation. In summary, project responsibility for the ELSS qualification program should have been centered with the ELSS contractor.

(d) Testing with the Gemini spacecraft: Integrated testing of the ELSS with the Gemini spacecraft was performed at the spacecraft contractor's plant and at the launch site. The testing at the spacecraft contractor's plant was intended to verify the compatibility of operation with the ELSS prior to delivery of the spacecraft. The testing at the launch site was the normal prelaunch verification of all systems on an end-to-end basis.

(1) Testing at the spacecraft contractor's plant: In preparation for the integrated tests with the spacecraft, the ELSS and all associated components were subjected to detailed Pre-Installation Acceptance (PIA) tests. These acceptance tests repeated all the essential portions of the Pre-Delivery Acceptance tests, and verified that the ELSS was ready to be tested with the spacecraft. For the PIA testing, a complete set of ELSS ground support equipment was provided and maintained at the spacecraft contractor's plant. Also, full-time support was required from experienced test and service technicians in the ELSS contractor's organization. Because of the critical nature of disassembly and reassembly of the ELSS resulting from its high package density, all work inside the chestpack was performed by ELSS contractor technicians. Initially, all PIA testing was performed by MSC engineers and by

ELSS contractor technicians; subsequently, the spacecraft contractor was assigned the responsibility. MSC engineering support and ELSS contractor support were continued on a near-full-time basis to insure uniformity of testing among the various ELSS test locations. System disassembly, repair, and reassembly remained a function of ELSS contractor personnel. Under normal work schedules the PIA testing of the prime and backup flight ELSS's required about 5 days per unit.

Following PIA testing, the ELSS was tested with the spacecraft in several major systems tests. The first of these was the ECS Validation. This test was a sea-level test of the spacecraft ECS and served to test the compatibility between the spacecraft oxygen supply system and the ELSS.

The second major test was a Simulated Flight Test which served to test the compatibility of the electrical, communication, and instrumentation systems of the spacecraft and the ELSS. The flight crews participated in the Simulated Flight Tests and verified the compatibility of the ELSS and of the space suit communication and bioinstrumentation systems.

The final major test was the Altitude Chamber Test. This test was an overall validation of the spacecraft systems under vacuum conditions and was the final end-to-end systems verification before spacecraft delivery. The test was conducted in five parts: one unmanned run at a simulated altitude of 150 000 feet; two sea-level practice runs in which the prime and backup flight crews checked out all cockpit equipment and procedures; and two manned altitude runs with the prime and backup crews, respectively. The manned altitude runs included a simulation of the planned EVA mission for each spacecraft. The ELSS was checked out and donned, the cabin was depressurized, and the hatch was opened under vacuum conditions; however, safety considerations precluded actual egress during these runs. As a result, these test verified the vacuum compatibility between the spacecraft and the ELSS, but they did not test the ELSS under critical thermal or metabolic conditions. Upon completion of the Altitude Chamber Test, the ELSS was shipped to the launch site with the spacecraft.

(2) Testing at the launch site: The ELSS was tested with the spacecraft for all major prelaunch tests which involved ELSS compatibility. The first of these was the Spacecraft/Gemini Agena Target Vehicle (GATV) Radio-Frequency and Functional Compatibility Test, which was designated the Plan X Test. Since EVA was planned to be conducted in the vicinity of the target vehicle for all missions starting with Gemini VIII, the ELSS radio-frequency compatibility with both the spacecraft and the target vehicle was verified. The tests were conducted on a 50-foot timber tower at the Kennedy Space Center, and the ELSS electrical and electronic systems were checked in both the docked and the undocked configuration.

The second major test was the Systems Assurance Test, which reverified the ELSS compatibility with the spacecraft systems on the launch pad. The third major test was the Simulated Flight Test which was similar to the test conducted prior to delivery and reverified the electrical and electronic systems compatibility.

The final major ELSS tests were a detailed shakedown inspection and a final PIA test. Every time the chestpack was used in a manned test, the low-pressure loop was exposed to perspiration, and salt deposits resulted. A detailed flushing and cleaning procedure was required, and the chestpacks were subjected to a substantial amount of servicing and handling for each manned test. Also, the ELSS was exposed to a much more varied environment than most spacecraft systems because it was portable. For these reasons and because modifications were made before the early EVA missions, the detailed shakedown inspection of the internal chestpack assemblies and of the complete PIA were conducted on each ELSS. These tests constituted the final inspections and ELSS systems verifications before launch. The results of these tests provided the high confidence in reliable system operation necessary for final flight readiness.

(e) Preflight altitude chamber tests: To provide a final end-to-end system test of the extravehicular equipment in a vacuum environment, altitude chamber tests were conducted with the actual flight equipment during the last few weeks before launch. These tests were conducted with the prime and backup pilots wearing their flight space suits. Also, these tests provided the necessary flight crew familiarization with the equipment under operating conditions which simulated the orbital environment. For the Gemini VIII, IX-A, and X missions, the final altitude chamber tests served to validate the chestpack and related equipment for vacuum operation after completion of significant modifications.

The tests prior to the Gemini VIII mission were conducted at the MSC 20-foot altitude chamber using liquid nitrogen cold walls to simulate the orbital thermal conditions. The planned EVA mission sequence was followed closely, including the connection and use of the ESP. Several ELSS problems were found. Corrective modifications were made and further vacuum tests were conducted. These problems and the subsequent solutions are described in detail in paragraphs 4.2.2.3.2 and 4.2.2.3.3. After incorporation of the modifications, both the flight and the backup ELSS were tested again in the altitude chamber, following a simulated mission profile. These final tests were successful, and validated the flight equipment under vacuum conditions.

The tests prior to the Gemini IX-A mission were also conducted in the 20-foot altitude chamber. The prime pilot used the flight ELSS and a flight-configuration Astronaut Maneuvering Unit (AMU) to follow the planned Gemini IX-A EVA sequence. The backup ELSS was also tested. ELSS operation was satisfactory.

As part of the early preparations for the Gemini X mission, both the prime and backup flight crews participated in altitude training runs in the 20-foot chamber using the Boilerplate 2 test vehicle for spacecraft familiarization. The crews practiced the entire sequence of ELSS operating procedures in vacuum conditions before the spacecraft altitude chamber tests at the spacecraft contractor's plant. Subsequently, two thermal-vacuum simulation tests were conducted in Chamber B of the Space Environmental Simulation Laboratory at the MSC. The prime and backup pilots used the flight and backup ELSS, respectively. These tests were conducted at a pressure below 1×10^{-4} mm Hg, and solar simulation was used during the daylight period of the simulated mission. Liquid nitrogen cold walls were used throughout the tests. This test facility provided a more authentic thermal environment then had been obtainable in the 20-foot chamber. In addition, the pilots exercised at measured rates similar to the work rates anticipated during the Gemini X mission. The ELSS performed satisfactorily in both tests and the thermal performance of the ELSS system with the 50-foot dual umbilical was validated. Representative results from the test in MSC chamber with the Gemini XI pilot are shown in figure 4.2-14.

In preparation for the Gemini XI mission, a thermal-vacuum simulation in Chamber B was conducted with the prime pilot and the flight ELSS. The results of this test were satisfactory and were similar to those conducted for Gemini X. The backup ELSS was validated by the backup pilot in an altitude test in the 20-foot chamber. By this time, sufficient confidence had been gained in the ELSS operation, particularly from the standpoint of thermal performance, that emphasis on complete thermal simulation was reduced. At the same time, other high priority testing in Chamber B precluded continued use of this facility for Gemini preflight validation tests. The test results obtained in the 20-foot chamber were normal.

In preparation for the Gemini XII mission, the flight ELSS was used by the prime pilot for an altitude test in the 20-foot chamber. A qualification unit of the AMU was also used in this test, although the AMU was subsequently deleted from the Gemini XII mission. The ELSS operation was satisfactory in all flow modes. Altitude testing of the backup ELSS was not repeated since it had been tested for the previous mission.

The general consensus concerning altitude testing of the extravehicular flight equipment with the flight crews was that it was a necessary part of the flight preparation activities. In a sense, these tests were the only end-to-end verification of that system which included the extravehicular pilot and his life support devices. The value of this type of testing was particularly important when little flight experience was available on the equipment. The testing was also important for thermal effects, since the ELSS heat exchanger and much of the system insulation did not function except under vacuum conditions. Another significant benefit was the detailed crew familiarization with their flight equipment. The firsthand familiarity with vacuum operation of the flight equipment gave the extravehicular pilots an understanding and a confidence level which could not be duplicated by any other means.

4.2.2.3 System design problems and modifications.- During the ELSS program, several problem areas were encountered which resulted in significant modifications to the system design and hardware. Many of these problems were discovered during manned testing, which took place near the end of, or subsequent to, the planned qualification test program. Therefore, the development and qualification phase of the program was completed only a short time before the first flight. Some problems were not fully understood or recognized until after the initial flight experience was obtained. The solutions to all the known problems were achieved prior to the Gemini XII mission. The significant problems and modifications follow:

4.2.2.3.1 Chestpack battery: The first ELSS battery consisted of 18 silver oxide/zinc cells in a series arrangement. This battery failed to provide the energy storage capacity necessary to fulfill the 38.8-watt-hour power requirements predicted for a typical ELSS EVA mission.

In the second battery design, the ELSS contractor attempted to provide the maximum energy storage in the available space without giving adequate consideration to battery life, service and handling, materials compatibility, and manufacturing techniques. Although the same basic battery was utilized through the remainder of the Gemini ELSS program, its reliability was poor, loss of units during servicing was high, much time was spent nursing batteries through activation for each flight, and many minor changes to the battery were required. This battery contained twenty-four 1.5-ampere-hour silver oxide/zinc cells in a series-parallel arrangement with 14 cells in series with 2 parallel groups of 5 cells each. The problems encountered with this battery included complex and lengthy activation and service procedures, electrolyte spillage from fill ports of the cells, inadequate battery-servicing procedures and equipment, electrolyte leakage through individual cell seams, poor adhesion of potting to the cells, and the use of materials incompatible with cells and cell cements. The principal design objective was to provide maximum energy by use of the maximum number of cells in the space alloted. Tests indicated that a battery in good condition would produce 65 to 70 watt-hours.

4.2.2.3.2 Outflow valve: During the manned ELSS testing before the Gemini VIII mission, suit pressures varied in several instances well above the normal limits of 3.7 ± 0.2 psia. These fluctuations characteristically followed operation at low temperature with the heat exchanger shut off, or followed several successive chestpack operations without intervening cleaning and flushing. The low temperature problems indicated icing, and the problems after successive operations indicated perspiration salt deposits. Detailed analysis of the ELSS test history indicated that the outflow valve was susceptible to hanging up, particularly under the conditions described. A modified outflow valve was designed to correct this malfunction. In addition, operation of the ELSS with the heat exchanger shut off was prohibited, and more elaborate flushing and cleaning procedures were established for use after each manned operation. After installation of the new outflow valves and implementation of these procedures, no further space suit pressure anomalies were encountered.

4.2.2.3.3 Ejector icing: The results of the manned low-temperature altitude chamber tests conducted in preparation for Gemini VIII indicated that the chestpack ejector was susceptible to icing under conditions of low temperature and excessive water.

A series of ejector icing tests was conducted by the ELSS contractor with an ejector that had been modified to allow observation and to provide instrumentation for detection of icing. The results of this testing indicated that ice formation on the ejector primary injection nozzle and on the inner walls of the diffuser tube would occur with a primary oxygen supply temperature of -20° F with secondary gas dry-bulb and dew point temperatures varying from 46° to 56° F, and 41° to 48° F, respectively. Based on these data, a minimum allowable oxygen supply temperature of 0° F was established. In addition, electrical heaters were added to the ELSS ejector subassembly and to the oxygen supply line to the ejector. Power for the ejector heater installation was provided from the spacecraft through the umbilical. The ELSS battery was only required then for independent operation with a backpack or in the event that external power was lost. The wires in the 25-foot umbilical previously allocated for suit inlet gas temperature measurement were reallocated for ELSS external power. This modification required minor wiring changes in the spacecraft, rewiring of the chestpacks, and replacement of the electrical jumper cables.

The need for the ejector heater modifications was identified less than a month before the Gemini VIII mission. To expedite the ELSS wiring modifications, the task was assigned to the spacecraft contractor. This method of modification permitted a rapid response to the immediate problem, but it tended to remove the ELSS contractor from active participation in the ELSS design analysis and verification at a time when other problems were being discovered. As a result of detailed coordination efforts between MSC and the two contractors, a prototype and two flight ELSS units were configured and tested in time to support the Gemini VIII mission. The modification of the ELSS units for Gemini IX and subsequent missions was assigned to the ELSS contractor. This arrangement consolidated ELSS modification activities at the same location, and facilitated the overall design analysis and verification by the ELSS contractor.

4.2.2.3.4 Ejector bypass modification: The concern over ejector icing and possible blockage led to a relocation of the bypass line downstream from the ejector. In the original design, the bypass inlet to the suit loop was located upstream of the ejector assembly as an integral portion of a complex valve group housing. The reason for this location was concern that the nominal bypass flow rate of 7.4 lb/hr into the ejector diffuser duct would cause a buffeting condition that would reduce the ejector pumping efficiency severely. Subsequent testing conducted with the developmental ELSS unit indicated that this buffeting was not as severe as had been anticipated and that it had no noticeable effect on ejector performance. The bypass modification was accomplished by plugging the original bypass port in the valve group housing, drilling a new port into the bypass valve subassembly, and installing a tube from this port to the lower extreme of the ejector diffuser tube. After requalifying a modified chestpack for random vibration, this modification was incorporated in all chestpacks for Gemini IX and subsequent missions.

4.2.2.3.5 High-pressure-oxygen fill-port check-valve modification: The chestpack emergency oxygen bottles had been serviced with oxygen to 7500 psig numerous times during qualification testing, Pre-Delivery Acceptance testing, PIA testing, preparation for manned altitude chamber runs, and flight servicing for Gemini VIII. During oxygen servicing of the chestpacks for the Gemini X altitude chamber runs, however, a fill check valve began leaking when the inlet pressure was relieved. The check valve was removed, photographed under magnification, and sent to a chemical analysis laboratory. Review of the photographs indicated combustion of the check valve, and the laboratory analysis reported carbon and RTV silicon rubber present on the burned areas. The Viton-A poppet seat was completely burned away. A literature survey on Viton-A categorized it as a compound that should not be used in high-pressure oxygen systems. The Viton-A used on the poppet seat was produced by the ELSS contractor using a company formula. Each batch of the material so produced was thoroughly tested for suitability in high-pressure oxygen systems. Material tests conducted at the MSC showed that Loctite-C, which was used as a check valve thread sealant, was impact-sensitive in liquid oxygen. The tests also showed that the Dow Corning-510 lubricant used on the outer surface of the O-rings was fairly insensitive to similar tests. Although these problems were related only to servicing operations, Loctite-C was immediately eliminated from all parts of the oxygen system in the chestpack.

A few weeks later, while the problem was still being analyzed, a similar failure occurred on a Gemini IX chestpack during preflight testing at the Kennedy Space Center. The check valve was removed and sent to the Malfunction Analysis Laboratory at the Kennedy Space Center for failure analysis. This analysis included visual inspection, photography, X-ray, disassembly, sectioning of parts of the check valve, and a detailed chemical analysis of all contaminants removed from the parts. The contaminants were confirmed to be decomposed Viton-A seat and corrosion/erosion products of the stainless steel components. It was concluded that a contained explosion had occurred within the valve body. High-pressure oxygen flow with concurrent heating resulting from this explosion disintegrated and partially consumed the Viton-A on the poppet. It also attacked and eroded the poppet, the poppet drive pin (mounted through the poppet stem, holding it to the valve body), and the valve housing. The exact cause of the explosion ignition was not determined, but a combination of possibilities existed that was formulated into a general conclusion. It was fairly certain that some sort of contamination was present in the check valve body. To prevent this type of failure, all high-pressure oxygen-servicing systems used for the chestpack were sampled for contamination. Cleaning and contamination control procedures were reviewed for adequacy, Loctite-C was eliminated, Dow Corning-510 lubricant was used sparingly on the O-rings, the allowable fill rate was lowered to a maximum of 250 psi/min, and the check valve was redesigned to eliminate the drive pin and replace the Viton-A seat with a ball-type, metal-to-metal seat. The valve design and the redesign concepts are shown in figure 4.2-15. The first few check valves fabricated to the new design did not seat properly and allowed leakage. A burnishing technique was utilized to produce a precision seat which eliminated the problem by using a positive metal-to-metal seal of the ball and seat. The redesigned check valves performed without failure during the remainder of the Gemini Program.

4.2.2.3.6 Heat exchanger water fill: During the chestpack qualification testing, the heat exchanger water fill loads were normally between 0.6 and 0.7 pound. After a chestpack had been operated frequently with a man in the loop, however, the heat exchanger water capacity began to decrease. This was first observed when only 0.55 pound of water could be loaded in the Gemini VIII chestpack for flight. Before the Gemini IX-A launch, the maximum water loading of the chestpack heat exchanger was 0.596 pound. The Gemini IX-A EVA mission profile was lengthy, and moderately high metabolic loads were anticipated. This situation emphasized the need for an adequate heat exchanger fill, preferably a minimum of 0.722 pound.

At the Gemini IX-A Flight Readiness Review, it was decided that a manned altitude chamber test should be performed to operate the chestpack until the heat exchanger dried out and to observe the cooling capability and the effect on the subject for a period after the heat exchanger had dried out. With an itital water loading of 0.47 pound, the heat exchanger began to dry out after 42 minutes of the test, and reduced heat rejection resulted. The heat exchanger continued rejecting some heat until the end of the test (60 minutes after the heat exchanger dried out). At the completion of the test, the subject was exercising with a metabolic heat load of approximately 1200 Btu/hr, and he indicated that he could have continued at that activity level without difficulty. It was, therefore, concluded that the EVA pilot would not be in danger if the heat exchanger dried out.

The ELSS contractor also investigated the problem of inadequate heat exchanger water capacity. A series of servicing tests was performed by the contractor, and a vacuum fill procedure with de-aerated water was recommended. Prior to Gemini X mission, the vacuum fill procedure was used with de-aerated water, and the heat exchanger fill loads improved significantly. Subsequently, it was established that a new or refurbished heat exchanger could be filled with up to 0.8 pound of water using normal service techniques. This fact indicated that the heat exchanger capacity was decreasing with use, presumably because of the deposits from perspiration which accumulated in the heat exchanger. The contractor developed a method for disassembling and refurbishing the heat exchangers. The refurbishing technique was utilized on the Gemini XI and the Gemini XII chestpacks. As a result, the heat exchanger water loads were approximately 0.8 pound. The heat exchanger refurbishing technique and the vacuum fill technique effectively eliminated the problem with heat exchanger water capacity.

4.2.2.4 Minor design problems.- In the course of flight crew evaluations and training activities for the EVA missions, many minor problems were discovered in the equipment design. Many of these problems were recognized only after an increased understanding of the operating requirements for extravehicular equipment had been obtained through crew training exercises and actual flight experience. During the preparations for the initial EVA missions, an almost continual series of minor equipment changes occurred as these minor problems were discovered. This change activity diminished substantially with the preparations for the later EVA missions. These small problems and the resulting corrective actions represented the growing pains of the first attempts to operate in a new environment with little previous experience. A few examples of these problems follow.

4.2.2.4.1 Electrical connector design: The electrical connector selected for operation with the pressurized space suit was chosen because it could be connected without damage to the pins, even if it were not visible to the pilot. Initial experience with this connector indicated that the barrel of the connector was too small in diameter to be gripped readily with a pressurized glove. Also the connector was relatively fragile, and the rough treatment it received from crewmen operating in pressurized space suits caused several different types of failures. The corrective measures were to add large cloverleaf grip-rings to the connectors to facilitate handling and to modify the connectors, as required, to eliminate the several possible failure modes. After these changes, the electrical connectors were durable and readily operable with a pressurized space suit. No inflight failure of these connectors was experienced.

4.2.2.4.2 Guard plates for the oxygen connections: The ELSS had two oxygen connections on the left side for primary oxygen supply. One connection was for the umbilical, and the other was for the backpack oxygen hose. In the Gemini VIII training exercises, connecting these oxygen connectors was very difficult in the pressurized space suit, but releasing them was so easy as to be hazardous. A guard plate was finally designed which protected against inadvertent release of these connections. The guard plate had a recessed guide in the outer surface to assist the EVA pilot in locating the mating connector. Thereafter, the operation of the oxygen connections was routine.

4.2.2.4.3 Oxygen quantity scale: An oxygen quantity and duration scale was added to the display panel of the ELSS chestpack. This scale indicated the usable duration of emergency oxygen versus the remaining oxygen pressure. This information would have been needed in case a requirement ever developed to ingress on emergency oxygen.

4.2.2.4.4 Test/dim/bright switch guard: A guard was added to the switch on the chestpack display panel because the crews found they were hitting and damaging the switch with the helmet neck ring during normal operation.

4.2.2.4.5 Addition of Velcro: Velcro hook was added to the sides and top of the chestpack for attachment of restraint straps and for retention of miscellaneous equipment during EVA. Velcro pile was added to nearly every small item which might be attached (such as multiple connectors, the jumper cable, and umbilical connectors) for zero-g stowage purposes. The amount of Velcro used was increased with each mission, and every usable surface of the Gemini XII chestpack was covered.

4.2.2.5 Mission results and equipment performance.-

4.2.2.5.1 Gemini VIII: Because of problems encountered in the spacecraft control system, this mission was terminated prematurely, and the EVA equipment was not used. However, the ELSS and its related components were recovered from the spacecraft. Following postflight inspection and retest, the components were returned to the spacecraft contractor for reuse on a later spacecraft.

4.2.2.5.2 Gemini IX-A: An EVA period of 167 minutes was scheduled in the flight plan. Because of the EVA pilot's visor fogging, the EVA was terminated after 128 minutes without evaluating the AMU. The ELSS performed normally during the EVA preparation period, and continued to perform normally in the medium flow rate from the time of hatch opening until after the end of the first daylight period. The pressure in the space suit remained steady at 3.7 psia, and the pilot reported being comfortable. At 63 minutes after hatch opening, the pilot's visor began to fog. This time was about 8 minutes after local sunset, and the fogging followed a period of particularly high work load resulting from the pilot's attempts to connect the AMU tether hooks and lower the AMU controller arms. Throughout the remainder of the night period, the ELSS was operated on high flow in an attempt to clear the visor. Because of the visor fogging, the crew elected to terminate the AMU evaluation soon after the beginning of the second daylight period.

The pilot reported that he was neither cool nor hot and that his only problem was visor fogging. After resting, the visor fogging began to clear gradually during the second daylight period. After returning to the cockpit, the pilot reported that his visor was 60 percent clear. At this time, he retrieved the docking bar mirror, and the added work load caused the visor fogging to increase. Ingress to the cabin produced heavy fogging. When the hatch was closed, the pilot's visor was completely fogged over again. After locking the hatch and repressurizing the cabin, the pilot was perspiring profusely and was noticeably overheated. The interior of his space suit was soaking wet, and portions of the ELSS suit loop had become saturated with water.

Two EVA anomalies directly involved the ELSS and resulted in the early termination of the Gemini IX-A EVA: visor fogging and apparent heat exchanger dry-out. Higher work loads than expected were evident throughout the EVA. The heat exchanger was designed for a nominal metabolic rate of 1400 Btu/hr and maximum of 2000 Btu/hr for periods of short duration. The heart rate data recorded by the bioinstrumentation indicate that these rates may have been exceeded, which, in effect, would overpower the capabilities of the ELSS heat exchanger.

The cooling capability was adequate, even on medium flow, but at excessive metabolic rates, the heat exchanger was not able to keep up with the high latent thermal load and maintain the suit environment at a low enough humidity to preclude fogging. During the high work loads, fogging was probably intensified by the high respiration rates observed during the EVA. This respiration rate would humidify 55 to 75 percent of the total oxygen flow to the helmet, raising the dew point around the visor sufficiently to cause fogging at normal visor operating temperatures, and also to inhibit clearing of the visor. The high work load and respiration rate apparently exceeded the combined capabilities of the ELSS and the space suit ventilation system.

After the mission an attempt was made to repeat the observed fogging phenomenon in an altitude chamber test with the Gemini IX-A flight ELSS and space suit equipment. The test was successful in duplicating the observed results, and fogging occurred over about 80 percent of the visor at a calibrated metabolic rate of about 2450 Btu/hr. Anti-fog solution applied to a small section of the visor kept that section free of fog. Visor clearing occurred when the subject stopped exercising, and this result was in fair agreement with the fact that some clearing of the visor had occurred during the periods when the Gemini IX-A pilot was resting.

The flight and test results indicated that the basic ELSS design capabilities of 1000 Btu/hr for 71 minutes, 1400 Btu/hr for 86 minutes, and 2000 Btu/hr for 10 minutes were substantially exceeded by the activity levels encountered during the Gemini IX-A EVA. For future EVA missions with the ELSS, it was apparent that the EVA work load would have to be reduced to be within the system capabilities. (See section 5.1 for a discussion of work load and body restraints.) As a further precaution against visor fogging, provision was made for future crews to carry anti-fog solution to be applied immediately before EVA.

The ELSS heat exchanger contained 0.596 pound of water at lift-off. The residual amount of water after flight was 0.246 pound. The pilot stated that during ingress, he became uncomfortably warm. Heat exchanger performance was beginning to decrease because it was drying out near the time of ingress. Depletion of the heat exchanger water was attributed to the higher-than-anticipated metabolic load.

4.2.2.5.3 Gemini X: The Gemini X ELSS chestpack performed satisfactorily and without incident during the 38-minute umbilical EVA. Wet wiping pads soaked in a visor anti-fog solution were used during EVA preparation. Although work loads experienced may have been higher than design specification, no visor fogging occurred.

The pilot had difficulty removing the ELSS from the center stowage frame. Initially, some resistance was experienced in attempting to slide the ELSS forward. The forces exerted by the pilot caused the ELSS to slide forward rapidly in the storage frame and strike the center cabin light. The remainder of ELSS donning was accomplished without incident.

No free water was observed in the chestpack ports at any time, indicating that the initial ELSS heat exchanger charge of 0.626 pound of water was held in the storage wicks.

The ELSS emergency oxygen supply pressure was 6300 psig at egress, since some oxygen depletion occurred during and after checkout of the ELSS. The largest depletion occurred when the pilot opened his space suit visor briefly while waiting for the designated time for cabin depressurization.

At the time of hatch opening and egress the ELSS was set on medium flow. After moderate sustained exertion in conjunction with the extravehicular transfer to the Gemini VIII GATV, the pilot noticed that he was warm and selected ELSS high flow, which restored his comfort. Because of a shortage of spacecraft propellant, the Gemini X EVA was terminated early. The ELSS cooling was adequate during ingress, and although the pilot's work load was moderate to high, he reported that he was cooler than he had been during ground simulations in the vacuum chamber. The pilot reported that, after advancing to high flow, he felt neither hot nor cold until ingress, at which time he was warm, though not overheated.

A qualitative assessment of the heat load to the ELSS indicated that the pilot's heat output before ingress was significantly less than that experienced during Gemini IX-A. Total time on the ELSS in the vacuum environment was about 40 minutes. The ELSS chestpack, hoses, and restraint straps were jettisoned during the next revolution after ingress.

4.2.2.5.4 Gemini XI: EVA preparations were initiated 4 hours prior to scheduled cabin depressurization. Because the crew was considerably ahead of schedule after nearly 1 hour of work, EVA preparations were temporarily stopped, and the crew rested for nearly one revolution.

The EVA preparations continued to proceed more rapidly than anticipated; consequently, the ELSS donning and checkout were completed more than 2 hours before the scheduled hatch opening. The pilot remained on the ELSS for approximately 10 minutes and then returned to the spacecraft ECS because of the lack of cooling and because of the higher rate of spacecraft oxygen consumption when on the ELSS. During this period, the cabin was at 5 psia, and the ELSS heat exchanger was not providing cooling, since a vacuum environment was required for water evaporation. After the mission, the pilot reported that he was becoming uncomfortably warm during this 10-minute period of operation on the ELSS.

ELSS operation was resumed approximately 30 minutes before the scheduled hatch opening. The pilot began to get warm again, and this heat condition was aggravated by difficulty in installing the sun visor on his helmet. It is apparent from his description that the pilot became quite warm and perspired significantly during this period.

The cabin was depressurized to less than 0.2 psia 5 minutes before the hatch was opened, and the ELSS heat exchanger began normal operation at this time. At the time of hatch opening, the ELSS flow control was set on the medium position, and the pilot subsequently reported that the ELSS cooling was satisfactory with the medium flow.

Attaching the spacecraft/GATV tether involved an unusually high expenditure of energy, and the pilot became very fatigued and began breathing very heavily. As a result, the EVA was terminated early after the hatch had been open only 33 minutes. Ingress was normal, and hatch closure presented no problems. The air-to-ground transmissions immediately after EVA termination indicated that the pilot's vision was impaired by heavy perspiration. More detailed discussions, after the mission, revealed that the pilot's fatigue and the concern for his ability to complete additional high-effort tasks were the principal factors in the decision to terminate the EVA. The pilot reported that he had used high flow on the ELSS during the attachment of the GATV tether and that the cooling was adequate for comfort and was comparable to ground simulations. He also reported that his face was wet with perspiration and that perspiration in his left eye had caused irritation, but it had been tolerable. Although the EVA termination may not have been caused by vision impairment from perspiration, the results of this EVA emphasized the limitations of a gaseous-flow cooling system. At high work levels, heavy perspiration ensued, and the gaseous flow did not evaporate all the moisture that was produced. Results from ground testing indicated that satisfactory cooling and moisture control could be maintained when the work levels and the metabolic rates were less than 2000 Btu/hr. The overheat condition encountered before hatch opening and the high energy expenditure in the early part of the Gemini XI EVA apparently exceeded the system capacity for moisture removal.

4.2.2.5.5 Gemini XII: The ELSS performed normally during the EVA preparations. The pilot used medium flow on the ELSS during the period before hatch opening. At that time, he selected high flow, which was continued for the duration of ELSS operation. The ELSS maintained a comfortable suit environment for the entire 126-minute EVA period.

The pilot reported that he was cool and that his feet were cold. After the mission, the pilot commented that his feet had been cold, but not to the extent of any discomfort. This is in contrast with pilot reports on Gemini IX-A, X, and XI, after which the pilots reported that they were neither warm nor cool during EVA.

The oxygen allotment for umbilical EVA was 25 pounds, with 2.9 pounds scheduled for egress preparation and 22.1 pounds for a projected 2-hour and 10-minute EVA time line. From the experience of the Gemini XI pilot at the Target Docking Adapter (TDA) of the GATV, the use of the medium-plus-bypass flow mode was planned for all TDA work. This mode increased dry makeup oxygen flow to the ELSS chestpack and increased the capability of the ventilation gas to remove latent heat and to purge carbon dioxide from the helmet. If work loads exceeded the design limits, medium-plus-bypass flow would provide greater protection against visor fogging than that obtained in the normal high flow mode. The pilot elected to remain in the high flow mode for the entire hatch-open period because of the satisfactory cooling and the absence of visor fogging. The pilot stated that he felt that his work rate had not taxed the capability of the system in the high flow mode and that he could have worked somewhat harder without discomfort.

Total ELSS oxygen usage for the 126-minute EVA period was 18.9 pounds, which indicated a usage rate of 8.9 lb/hr, as compared to the measured value of 8.5 lb/hr obtained during preflight testing.

The EVA pilot performed several tasks intended to evaluate any forces acting on him from either thrust or pressure forces from the ELSS outflow. He reported that he was unable to detect any forces which might be attributable to the ELSS. There was no noticeable float-out or float-up tendency when he was standing in the cockpit with the hatch open.

Ingress was accomplished on time and without incident. The hatch was closed, and repressurization of the cabin was performed using the ELSS self-contained emergency oxygen supply. High-plus-bypass flow was selected to increase the rate of cabin pressurization, and flow from this source was verified by the ELSS emergency alarm tone, which was actuated by flow through the emergency oxygen supply line.

4.2.2.6 Assessment of chestpack capability.-

4.2.2.6.1 Pilot encumbrance: As previously stated, the ELSS was chest mounted. In order that the EVA pilot could see all of the displays and warning lights over the lower lip of the Gemini suit helmet, the chestpack had to be carried as high as possible under the helmet neck ring and close to the body. This pack location restricted two-hand task performance in the most natural work area and caused some complication to the pilot when he worked close to a fixed object.

4.2.2.6.2 Metabolic heat rejection: Although the system was designed to operate with average metabolic loads of 1400 Btu/hr and with peaks of 2000 Btu/hr for fairly short durations, the average sustained inflight heat loads appeared to have exceeded the peak operating capability of the ELSS in the Gemini IX-A and Gemini XI missions. The EVA pilots indicated that they were never uncomfortably hot, but that they generally became quite damp from the perspiration. The latent metabolic heat load had exceeded the heat rejection capability of the ELSS; the heat exchanger was continuing to reject heat and provide some cooling to the pilot.

4.2.2.6.3 Carbon dioxide removal: The generally accepted standard for maximum carbon dioxide partial pressure is 7.6 mm Hg (1 percent) for indefinite operation and for short-time or emergency operation not more than 15 mm Hg. From test data gathered during manned qualification test and crew training runs with the chestpack, the partial pressure of the carbon dioxide in the inspired gas ranged from 7 to 13 mm Hg for work rates up to approximately 2400 Btu/hr. This range was, of course, subject to considerable variation, depending on the ELSS flow mode (medium, high, medium-plus-bypass, or high-plus-bypass) and the associated work levels. Although carbon dioxide control was accomplished by dumping gas from the suit loop, its washout was dependent upon the amount of gas being dumped; that is, if the primary gas flow rate was increased, the ventilation flow rate would increase proportionally, and the overboard flow would increase by the same amount as the primary. Carbon dioxide control was also dependent upon flow rate of fresh gas to the helmet oro-nasal area, or upon the suit ventilation efficiency. Modifications in one or both of these areas would have been required to reduce the level of inspired carbon dioxide, but since normal design workloads did not produce critical concentrations of carbon dioxide, these modifications were apparently not needed. At workloads well beyond the design limits, carbon dioxide concentrations may be objectionably high. A high carbon dioxide concentration may have contributed to the sudden fatigue and heavy respiration of the pilot during the Gemini XI umbilical EVA.

4.2.2.6.4 Mechanical and electrical operation: Despite the problems discussed herein and many other minor problems, the overall operation of the ELSS electrical and mechanical subsystems during extravehicular use as compared to design requirements must be considered excellent, and in most instances, in excess of anticipated capability.

4.2.3 Extravehicular Support Package

The ESP backpack was furnished for the Gemini VIII mission and was designed to provide primary oxygen to the ELSS and Freon-14 propellant to the HHMU so that an extravehicular crewman might maneuver in space without spacecraft supplies. The only tie to the spacecraft while operating with the ESP was to be a 75-foot tether. The ESP configuration was the same as that of the AMU and its mounting provisions were like the AMU to facilitate integration with the spacecraft.

4.2.3.1 ESP backpack.- The ESP backpack (fig. 4.2-17) supplied oxygen to the ELSS chestpack at 97 ± 10 psig for pressurization, ventilation, and metabolic use. The ESP oxygen flow to the ELSS was 5.1 or 7.8 lb/hr for normal modes of operation and up to 16.2 lb/hr under emergency conditions or if bypass-plus-high flow were selected. However, if bypass flow were initiated, flow sharing between the ESP and ELSS emergency supply might occur because of the increased pressure drop across the ESP oxygen pressure regulator under the high-flow conditions.

Freon-14 propellant was supplied to the HHMU at 100 ± 15 psig. The obtainable thrust was 2 ± 0.25 pounds over a time span of about 200 seconds, with a total velocity increment of 72.5 ± 2.5 ft/sec.

As seen in figure 4.2-16, the life support oxygen and Freon-14 for propulsion were stored in a gaseous state in two pressure vessels at 5000 psig. Gemini ECS secondary oxygen pressure vessels were used to minimize development and qualification testing requirements. The ESP oxygen supply system supporting the ELSS chestpack was a complete Gemini ECS secondary oxygen subsystem, with the pressure setting modified from 75 ± 10 psig to 97 ± 10 psig to assure compatibility with the ELSS chestpack. The Freon-14 subsystem included a Project Mercury oxygen regulator for a larger flow capability for the HHMU.

The ESP had a self-contained power supply, an ELSS-type battery. The power requirement of the ESP was 28 watts at 28 ± 4 V dc. The battery supplied power for the UHF transceiver, the pressure transducers, the voltage regulator/signal conditioner, and the oxygen line heater. The voltage regulator/signal conditioner provided regulated 12 V dc power to the oxygen and Freon-14 subassembly pressure transducers. The pressure-transducer outputs were conditioned by the signal conditioner before going to the ELSS chestpack hydrogen peroxide quantity gage for display of either oxygen or Freon-14 quantity remaining. A switch located on the lower left-hand side of the ESP enabled the pilot to select either oxygen or Freon-14 quantity for display. Figure 4.2-17 shows the operational time available on the ESP in terms of the quantity of oxygen remaining and the chestpack flow mode.

The ESP had two modes of voice communication between the EVA pilot and the command pilot in the spacecraft. One mode utilized the UHF voice transceiver developed for the Air Force AMU, and the other was hard-line by means of the 75-foot tether. The hard-line mode provided the EVA pilot direct communication with the spacecraft. However, in the RF (transceiver) mode, the pilot had a push-to-talk control to key the transceiver. He could select the desired mode of communication by a switch located on the lower right-hand side of the ESP.

A 20-watt resistance heater was wrapped around the ESP outlet oxygen line to maintain the outlet oxygen temperature above 0° F to be compatible with ELSS chestpack inlet requirements. The heater was manually actuated by the EVA pilot with a switch located below the communication switch on the lower right side of the ESP. The heater operating cycle during ESP operation was dependent upon mission length and upon chestpack flow mode.

4.2.3.2 Seventy-five-foot tether.- The 75-foot tether was developed to provide mechanical and electrical attachment between the EVA pilot and the spacecraft, when utilizing the ESP backpack. In use, the 75-foot tether was connected between the 25-foot ELSS umbilical and the pilot to allow a total of 100 feet for translation from the spacecraft. The 75-foot tether provided the following electrical connections to the spacecraft:

Parameter	Number of shielded wires
Power	3
Electrocardiogram	2
Impedance pneumograph	2
Microphones	2
Earphones	3
Total	12

The restraint portion of the tether consisted of rolled HT-1 nylon with an ultimate breaking strength greater than 1000 pounds.

4.2.3.3 Mechanical interface requirements.- The mechanical interface between the spacecraft and ESP included ESP stowage and operational provisions required for EVA support. The ESP was stowed in the adapter equipment section of the spacecraft. The ESP overall dimensions, mating spacecraft hardpoints, and their locating dimensions were the same as those defined for the AMU flown on Gemini IX-A.

4.2.3.4 Development and qualification.-

4.2.3.4.1 Development testing: One manned development test was performed with the development ESP. This test was performed in conjunction with the last manned vacuum qualification test of the ELSS. The ESP was cold soaked in a cold room with three walls and the ceiling maintained at the temperature of liquid nitrogen (-320° F) for approximately one hour. The ESP functioned to specification for 5 minutes when the test was terminated because of a torn glove. The design of the ESP subsystems was considered acceptable and qualification hardware was fabricated for the tests described in the following paragraphs.

4.2.3.4.2 Qualification testing:

(a) Manned altitude qualification test summary: Three manned tests were conducted in the MSC 20-foot altitude chamber to determine high propellant usage by the HHMU and high oxygen usage by the ELSS. To qualify the ESP for flight as an oxygen source for the ELSS and a propellant source for the HHMU, three walls and the ceiling of the cold room were maintained at liquid nitrogen temperatures for simulation of orbital night.

During the tests, the ESP oxygen system provided sufficient flow and pressure for nominal chestpack operation. The temperature of oxygen supplied from the ESP declined to -52°, -70°, and -48° F in Tests 1, 2, and 3, respectively.

(1) Manned high propellant usage (Test 1): Utilizing Boilerplate 2 as a spacecraft oxygen supply to the ELSS, the chamber pressure was reduced to 4 mm Hg, the oxygen line from the ESP was connected to the ELSS, and the 25-foot umbilical was disconnected. The ELSS was operated on medium flow for 45 minutes with the subject working at a nominal rate of 1000 Btu/hr. Following this operation with the chestpack, cyclic operation of the HHMU was initiated with a duty cycle of 30 seconds on and 30 seconds off, to simulate a high usage rate, until the supply of Freon-14 was depleted. The only difficulty with this sequence was the failure of the HHMU propellant valves to close quickly after each duty cycle. Operation was continued using the ESP oxygen system until depletion, and ELSS emergency oxygen was initiated. The ELSS was then reconnected to the 25-foot umbilical and the chamber was returned to sea-level pressure.

(2) Manned high oxygen usage (Test 2): The test subject used the ELSS with a simulated spacecraft oxygen supply in the 20-foot chamber, which was decompressed to a pressure of 4 mm Hg. The oxygen line from the ESP was connected and the ELSS operated at high flow. However, the run was unsuccessful because of the failure of an aluminum line that was used to lengthen the ESP oxygen hose in the test setup. The failure

resulted in loss of the remaining ESP oxygen and in actuation of the ELSS emergency oxygen and warning systems. The ELSS functioned normally when the primary oxygen supply from the ESP stopped.

(3) Manned high-oxygen usage (Test 3): The run described in the preceding paragraph was repeated. The chestpack was operated on high flow until, after 55 minutes, the ESP oxygen supply was depleted, and the ELSS emergency flow began. The subject worked at a nominal 1400-Btu/hr rate during the test. Upon depletion of the ESP oxygen supply, the 25-foot umbilical was reconnected, and the HHMU was cycled 30 seconds on and 30 seconds off for 5 bursts; then 5 seconds on and 15 seconds off. To verify operation of the disconnect, the HHMU was disconnected from the supply line after every 5 bursts. The HHMU disconnect was hard to disconnect and it leaked. The propellant valves failed to seal properly, as in Test 1. Therefore, the disconnect was changed to a threaded connector, and two shutoff valves were added to the Freon line (one adjacent to the HHMU and one on the bottom of the ESP). To rectify the propellant valves sticking open, the O-ring material was changed to Teflon. Also, the Freon-14 servicing procedures were changed to verify less than 10 ppm moisture content. The HHMU qualification was completed by separate test, as described in paragraph 6.1.2.

(b) Vibration tests:

(1) Normal vibration: The ESP was placed in a Gemini spacecraft adapter at the spacecraft contractor's plant, mounted against the spacecraft blast shield in the launch-mounting configuration. The oxygen subsystem was pressurized to 5000 psig nitrogen and the Freon subsystem to 5000 psig Freon-14. The adapter was subjected to a random vibration spectrum along the longitudinal axis comparable to the launch environment. Upon completion of the test, all systems functioned normally.

(2) Overstress vibration: Later, at the Manned Spacecraft Center, the ESP with subsystems unpressurized was mounted on a shaker in the launch attitude, and an overstress random vibration test was performed. After this test, the ESP functioned correctly.

(c) Acceleration tests: The ESP was subjected to two separate acceleration profiles during qualification. The ESP oxygen and Freon subsystems were each pressurized with 5000 psig nitrogen and Freon-14. The first profile consisted of an increasing acceleration along the longitudinal spacecraft axis from 1g to 7.25g linearly over a period of 165 seconds. This profile was performed twice in the MSC Acceleration Laboratory centrifuge. The second profile (shock) was a 4-g load for 0.25 second along the spacecraft longitudinal axis and along each of the mutually perpendicular axes. Visual inspection revealed that one of bulkheads supporting the bottles was slightly warped. However, the structural integrity was not compromised, the ESP was subjected to functional testing, and the ESP was considered qualified for the anticipated acceleration loading.

(d) Acoustic noise: The ESP with the oxygen and Freon subsystems serviced with 5000 psig oxygen and Freon-14 was subjected to the launch environment acoustic noise spectrum which was applied to the three most sensitive, mutually perpendicular axes with a duration of 10 minutes in each axis (fig. 4.2-18). The ESP successfully completed functional tests after being subjected to this environment.

(e) Explosive atmosphere: With pad pressure in the oxygen and Freon-14 subsystems of the ESP, explosive atmosphere testing was conducted as follows. The ESP was placed in an atmosphere of butane gas and air and operated with power to all electrical components without causing an explosion.

(f) Humidity test: The ESP structural and pneumatic components were considered qualified by previous test for this environment. The wiring harness and voltage regulator/signal conditioner were subjected to a 97.5 ± 2.5 percent relative humidity environment while temperature was cycled at 120° F for 8 hours, and from 68° to 100° F for 16 hours. This was repeated for five cycles, or for a total of 120 hours. The harness and voltage regulator/signal conditioner were operationally checked, and no degradation in performance was detected.

(g) Oxygen and Freon supply-hose cold-bearing tests: The oxygen supply hose was subjected to 25 cycles of 90-degree bending in all directions about the same point of flexure while in an ambient temperature of -60° F. The hose was pressurized to 110 psig and exhibited no structural degradation or leakage at the end of the test.

(h) Thermal test: The ESP and extension umbilical were subjected to the expected thermal environment for the Gemini VIII EVA in a thermal vacuum testing facility. The environmental test conditions included:

(1) The test chamber pressure was less than 5×10^{-4} mm Hg.

(2) The chamber cyrogenic wall temperature average was less than -290° F.

(3) A simulated solar flux of one solar constant was provided at the test plane.

The ESP, serviced to 5000 psig oxygen in the oxygen subsystem, and with nitrogen and Freon-14 in the propellent subsystem, was attached to a thermal dummy wearing a Gemini extravehicular suit with the AMU thermal coverall for more complete simulation of actual conditions. The suited dummy, the 75-foot tether, and the ESP were suspended from a rotation mechanism in the Space Environment Simulator and operated through two simulated EVA missions. Each mission simulated egress 5 minutes before sunrise and lasted to a minimum of 40 minutes after sundown. The second test sequence was limited because of a leak which developed at the Freon regulator inlet (refer to paragraph 4.2.3.5.4). The only equipment malfunction during the tests was the aforementioned leak.

Temperature variations were monitored during each test in critical areas: battery, transceiver, ELSS oxygen supply system, HHMU Freon supply system, and ESP structure. The important variations were as follows.

(1) The temperature of the dormant battery ranged between 33° and 75° F with the lower temperature experienced after 79 minutes of simulated night orbit.

(2) The transceiver temperature varied between 62° and 108° F.

(3) The low point of the delivered gas temperature measured during blowdown of the propellent supply subsystem was -13° F when serviced with nitrogen, and -110° F when serviced with Freon-14.

(4) The low point of the delivered gas temperature of the oxygen supply subsystem was -21° F after depletion at a flow rate of 6.8 lbs/hr for 30 minutes and 12.7 lbs/hr for 17 minutes.

A visual inspection of the ESP and extension umbilical after completion of testing revealed no evidence of damage or deterioration.

(i) Radio-frequency interference (RFI): The RFI compatibility testing of the ESP assembly was checked with the Gemini VIII spacecraft during a radio-frequency compatibility and communication test at the launch site. As a result, a push-to-talk switch was installed in the ESP electrical system, and the transceiver VOX circuitry was disabled. This modification proved satisfactory during Joint Combined Systems Test and Final Systems Test with the ESP and the spacecraft at Launch Complex 19 prior to flight.

(j) Seventy-five-foot tether: The 75-foot tether was qualified with the ESP in all tests except humidity and explosive atmosphere. In addition, the umbilical was tested separately for humidity.

4.2.3.5 Significant problem areas.-

4.2.3.5.1 Transceiver VOX: The transceiver was designed as a voice-operated system, that is, each time the EVA pilot spoke, the transceiver was automatically keyed to the transmit mode. At any other time, the system was in the receiving mode.

During preliminary compatibility tests, the VOX system stayed keyed continuously (transmit mode). This problem was corrected by modifying the ESP wire harness to eliminate a cross-talk condition between the headset and the microphone leads. This corrective action appeared to be satisfactory during subsequent communications checks; however, during the electrical verification test for Gemini VIII, the transceiver was keyed repeatedly by the noise level of the ventilation gas flow through the EVA pilot's suit helmet. Consequently, a push-to-talk switch was incorporated into the ESP electrical system, and the VOX control was disabled. This switch was located on the right front of the ESP.

4.2.3.5.2 Alarm system limitations: While the transceiver was in use, a limitation was imposed on the chestpack alarm system. With hard-line communication, the alarm tone emanating from the chestpack was transmitted simultaneously to the pilot and the command pilot. When the transceiver was in use, however, and the alarm signal (audio tone) was activated, this signal was transmitted via hard-line only to the command pilot who, in turn, alerted the pilot of the emergency condition via RF transmission. The pilot would verify the condition by observing the chestpack control panel lights. When this limitation was discovered, it was not rectified. To redesign and modify the system was deemed impractical at the time because the transceiver was being carried as a backup system.

4.2.3.5.3 ESP oxygen quick disconnect: During the final manned ESP qualification test, the test subject experienced difficulty attaching the ESP oxygen quick disconnect (QD) to the mating QD on the ELSS. Cyclic connect-disconnect tests were satisfactorily performed at temperature extremes of -30° to 250° F. Testing performed by MSC personnel and the QD manufacturer showed, that at temperatures below -30° F, the QD's were hard to mate and did not shut off rapidly when disconnected. The problem was attributed to improper QD cleaning and drying procedures.

4.2.3.5.4 High-pressure Freon leak: Leakage from the storage bottle into the Freon regulator occurred twice in the propellant subsystem at the high-pressure fitting. Failure analysis revealed two contributing factors:

(a) Inadequate clearance between the O-ring seal and the first thread of the fitting

(b) The Teflon backup disc to the O-ring in the fitting was cold flowing to an initial set after torque was applied to the nut, thus reducing the actual torque on the fitting

The corrective action taken was to increase the assembly torque to 300 inch-pounds to obtain a metal-to-metal contact and maximum cold flow of the Teflon. Also each fitting was X-rayed to insure proper clearance after assembly.

4.2.3.5.5 Chestpack oxygen supply temperature: During initial manned chamber testing, it was found that the oxygen delivery temperature from the ESP to the chestpack might drop to a value as low as -70° F, depending upon the ELSS flow mode and duration of ESP operation. A 20-watt resistance heater was installed on the ESP outlet oxygen line to prevent the chestpack inlet temperature from falling below 0° F during ESP operation.

4.2.3.6 Mission results.- The ESP was flown on the Gemini VIII mission; however, because of a malfunction of the spacecraft Orbital Attitude and Maneuver System, the flight was terminated early, and the ESP was not utilized. Figures 4.2-19 and 4.2-20 show some parts of the ESP.

NASA-S-67-254

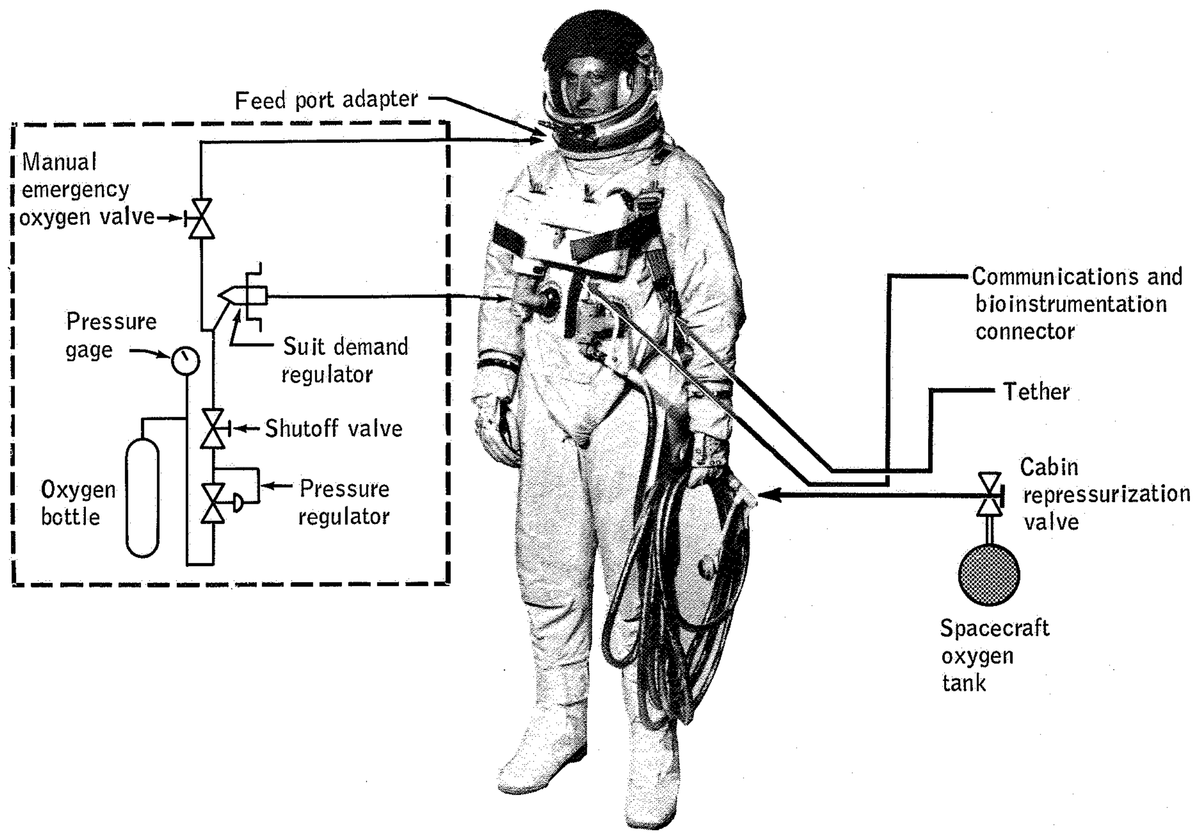

Figure 4.2-1. - Ventilation Control Module system.

NASA-S-67-227

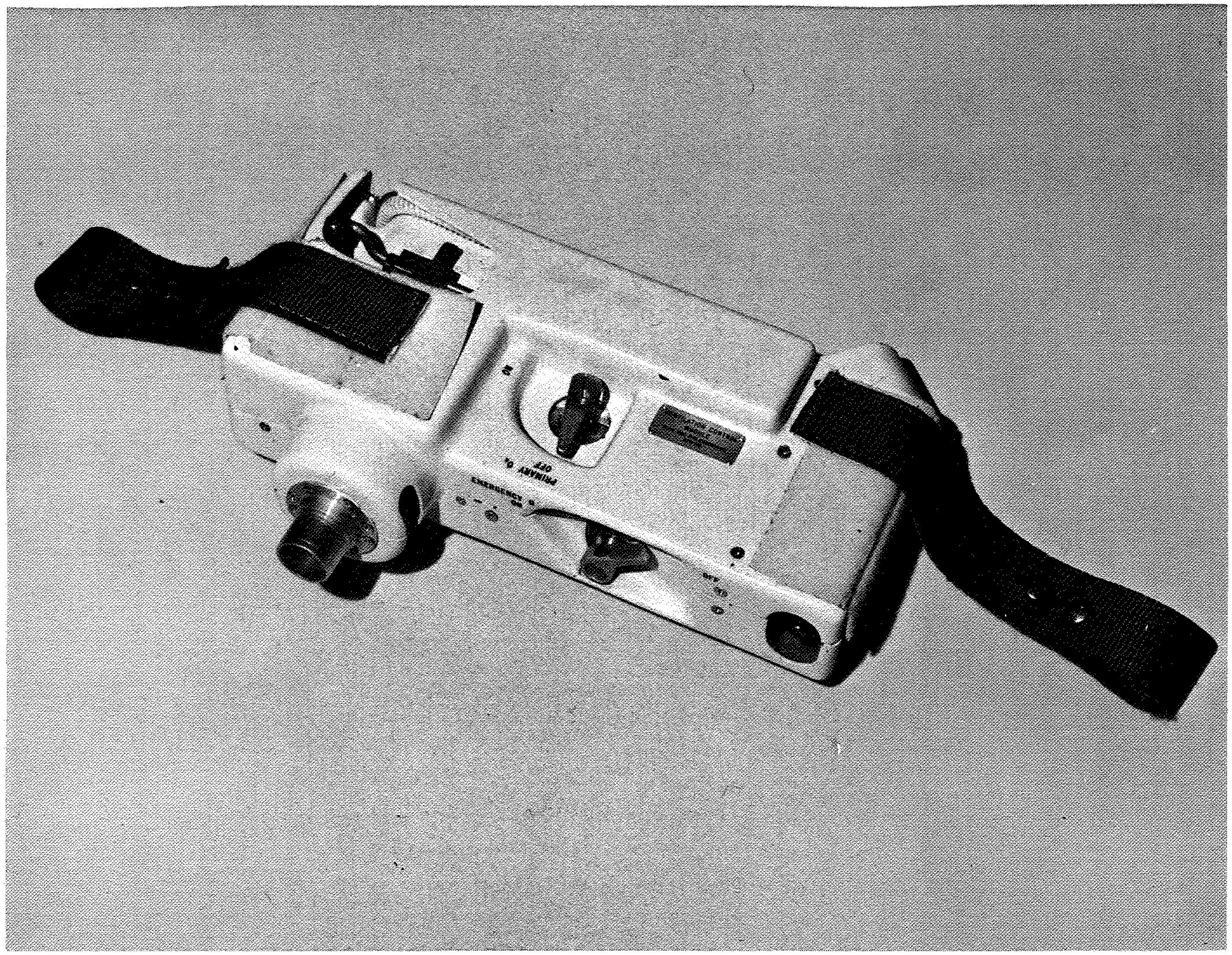

Figure 4.2-2. - Ventilation Control Module.

NASA-S-67-233

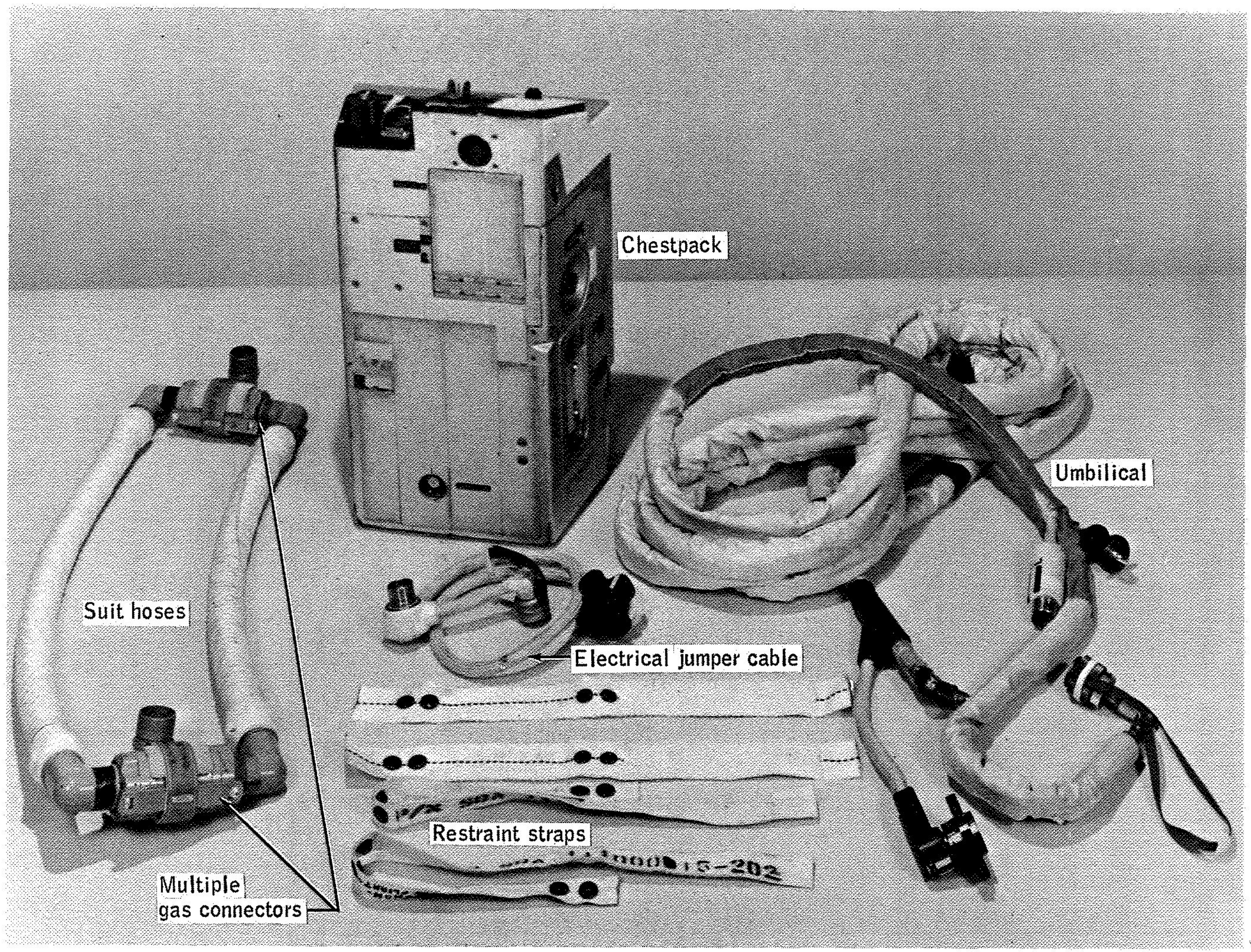

Figure 4.2-3. - ELSS components.

NASA-S-67-242

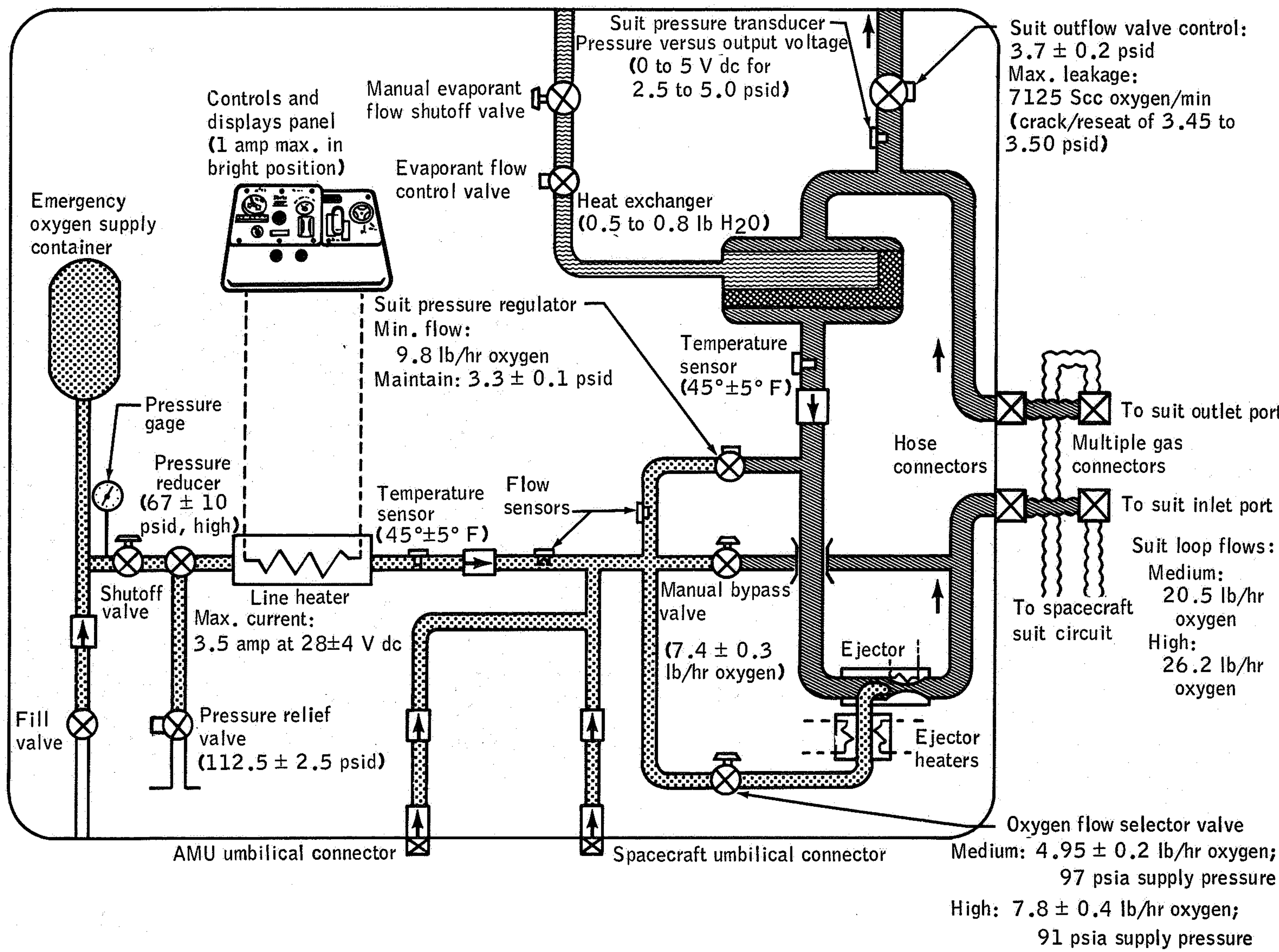

Figure 4.2-4. - ELSS chestpack pneumatic subsystem with nominal component performance values.

NASA-S-67-229

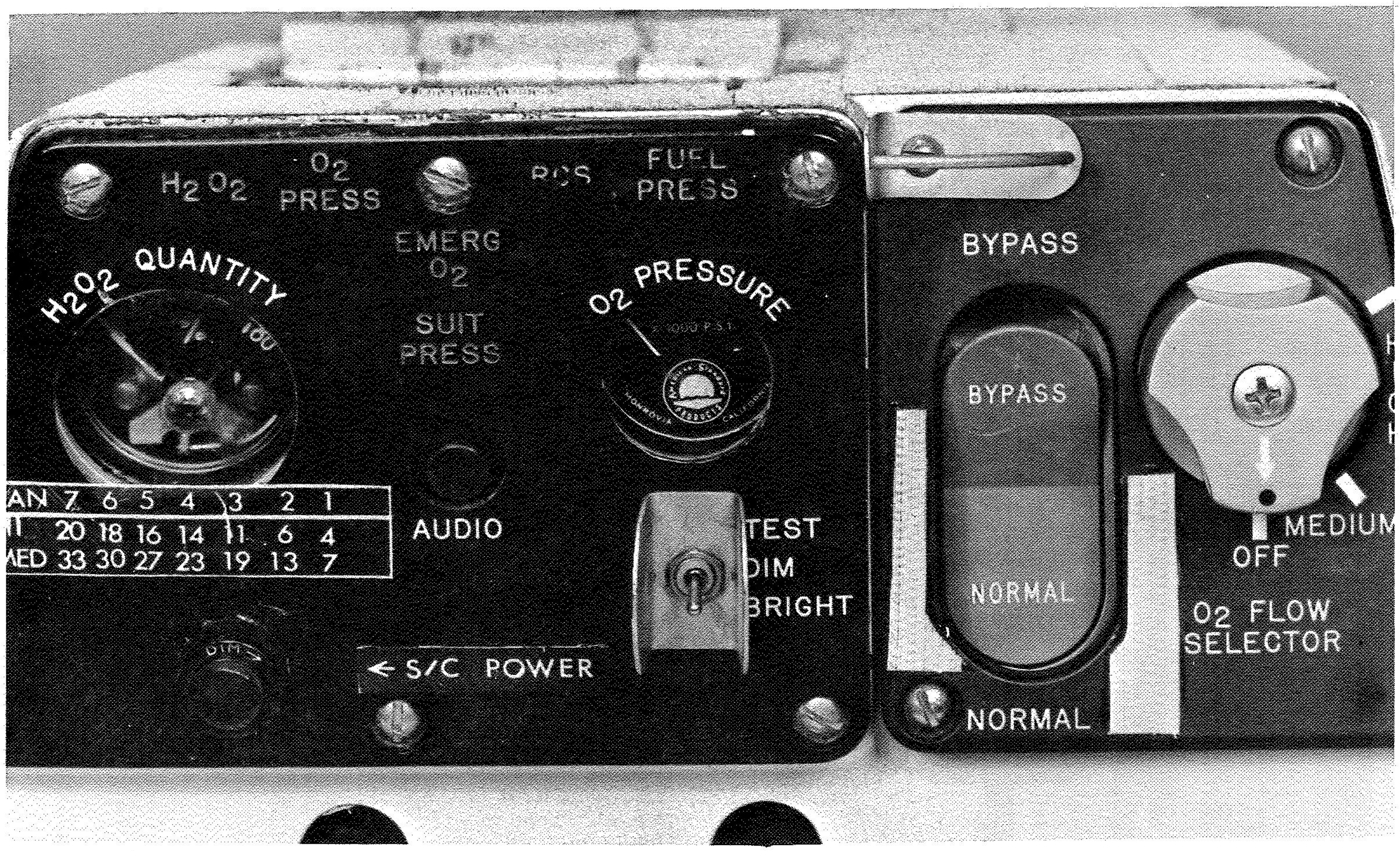

Figure 4.2-5. - ELSS chestpack controls and displays panel with AMU emergency displays.

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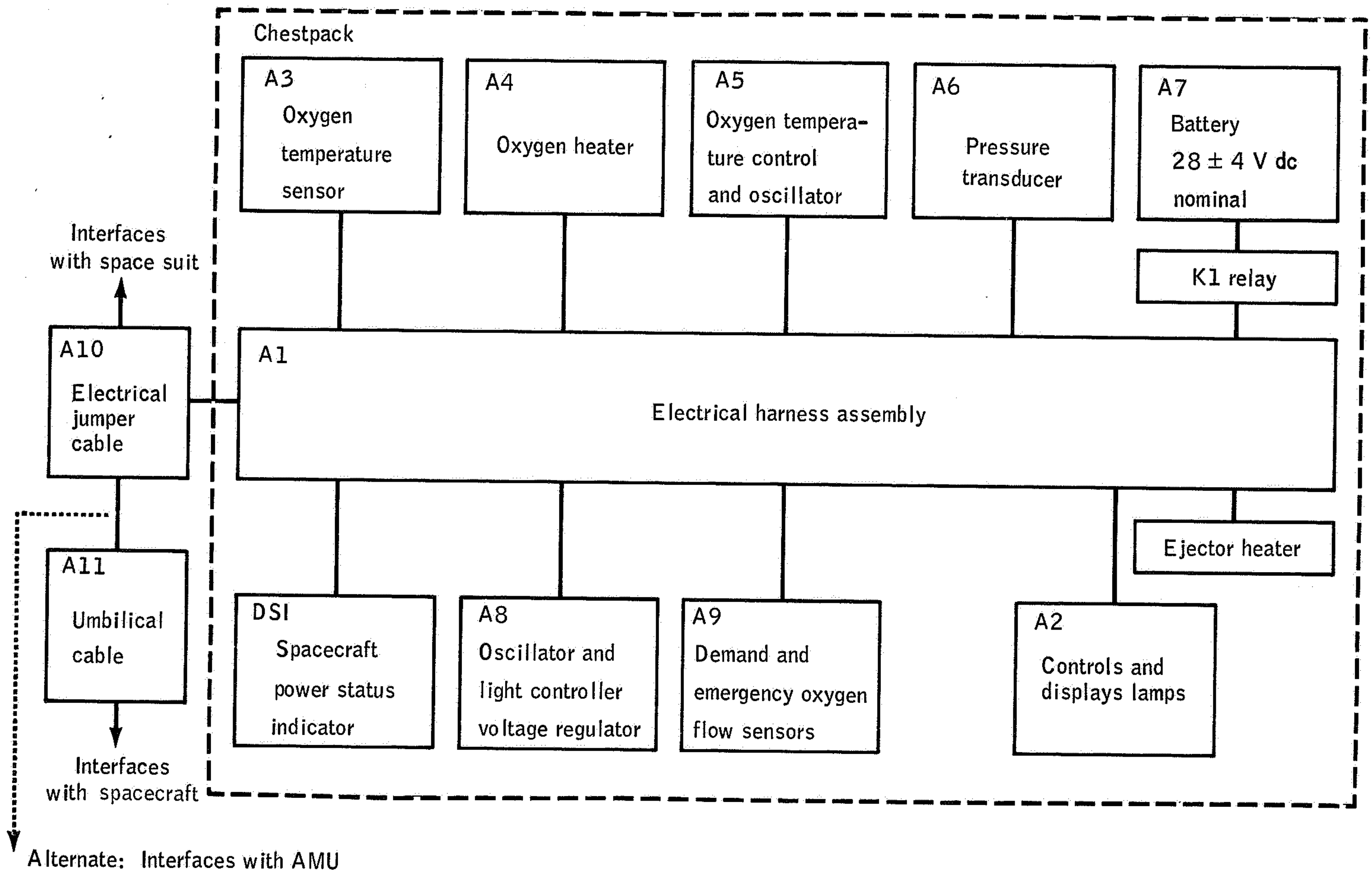

Figure 4.2-6. - ELSS electrical system block diagram.

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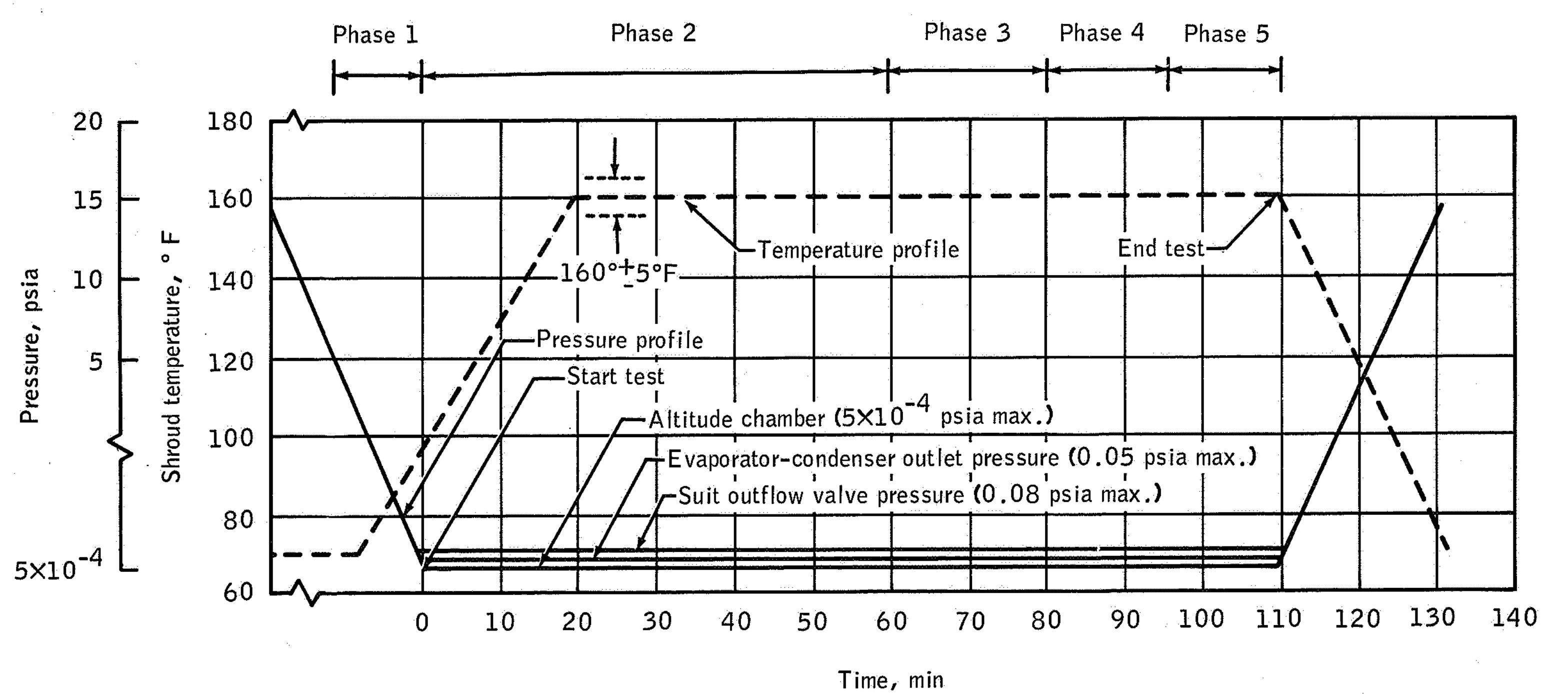

Figure 4.2-7. - ELSS pressure/temperature qualification test profile.

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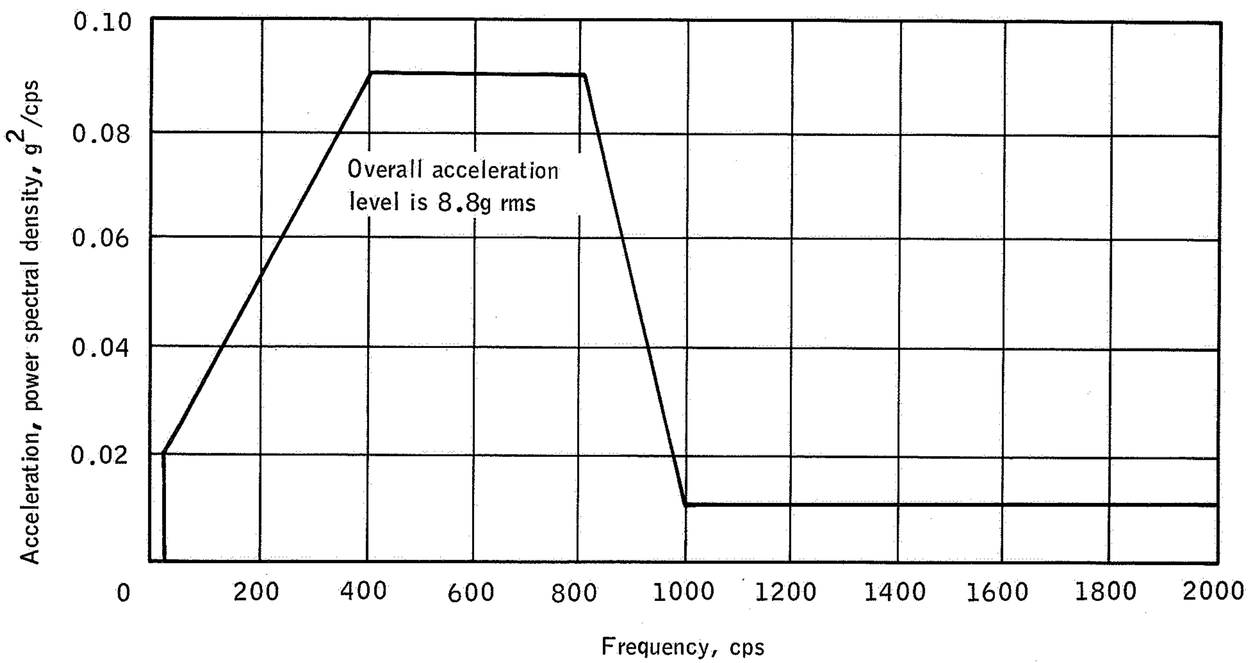

Figure 4.2-8. - ELSS random vibration qualification test profile.

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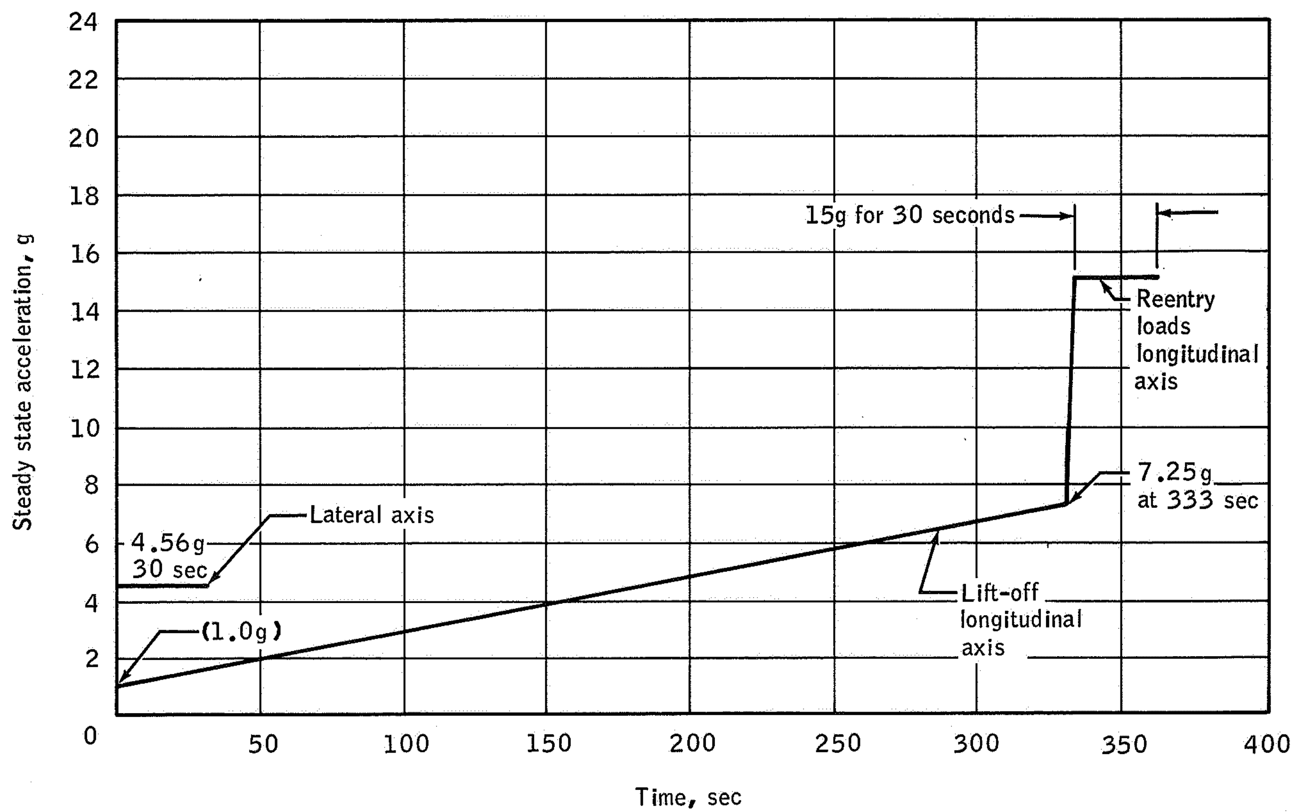

Figure 4.2-9. - ELSS acceleration qualification test profile.

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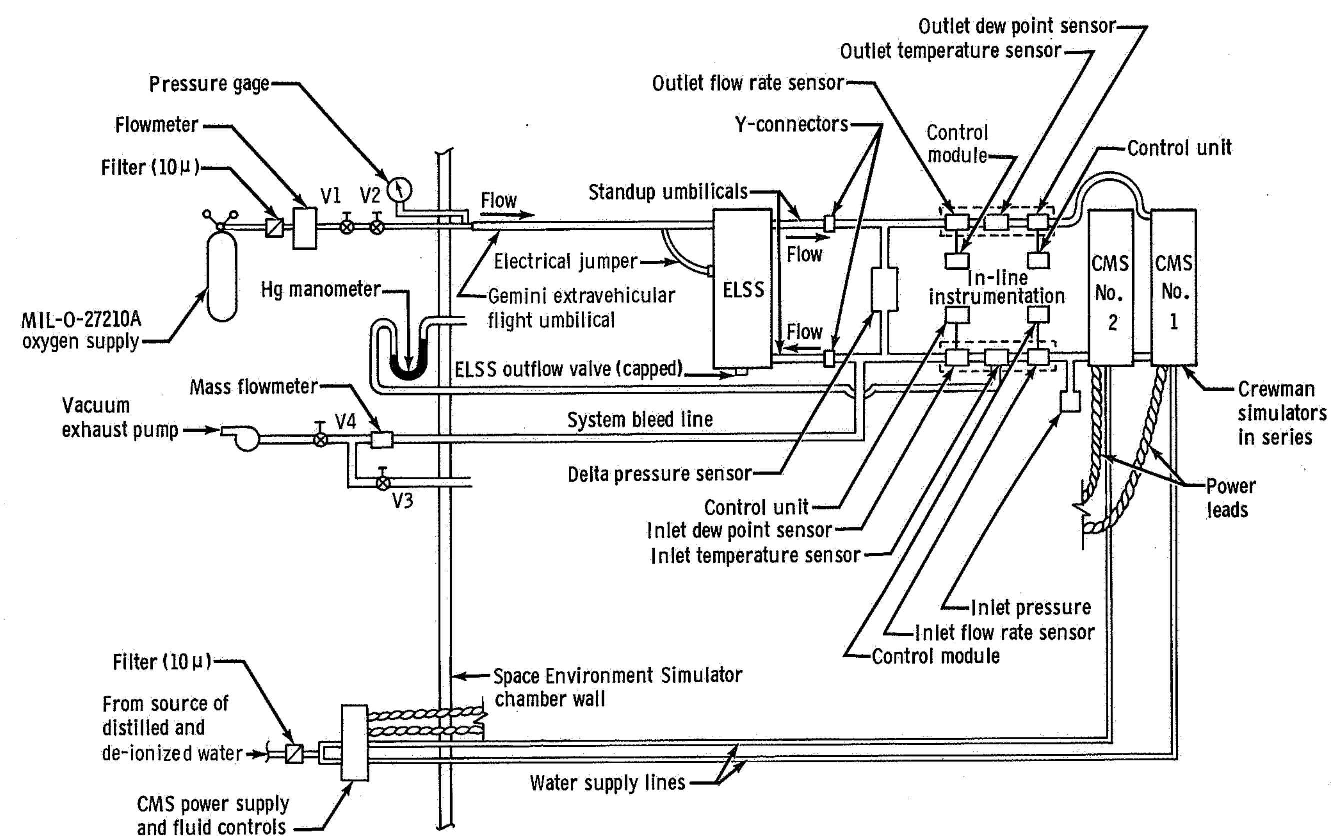

Notes: (1) Standup umbilicals looped over back of ELSS and 10 layers of superinsulation applied (not shown) over back of ELSS

(2) Actuators for remote control of ELSS flow selector, bypass, evaporator, and battery switch (not shown)

(3) Cylindrical infrared lamp array, (not shown) installed to encircle ELSS/CMS

Figure 4.2-10. - Test schematic for contractor qualification testing of ELSS in Space Environment Simulator.

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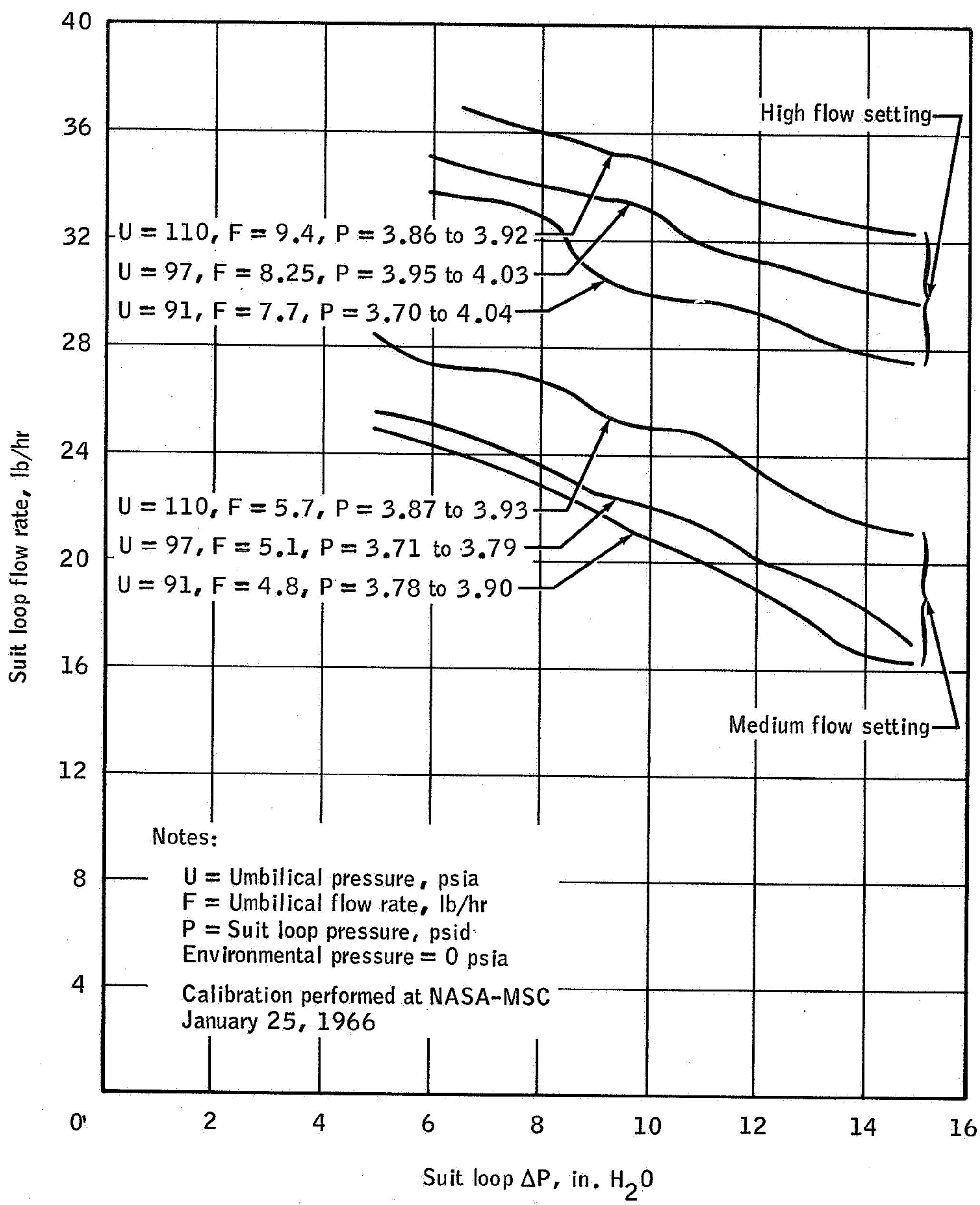

Figure 4.2-11. - Gas flow rate calibration for ELSS chestpack 105.

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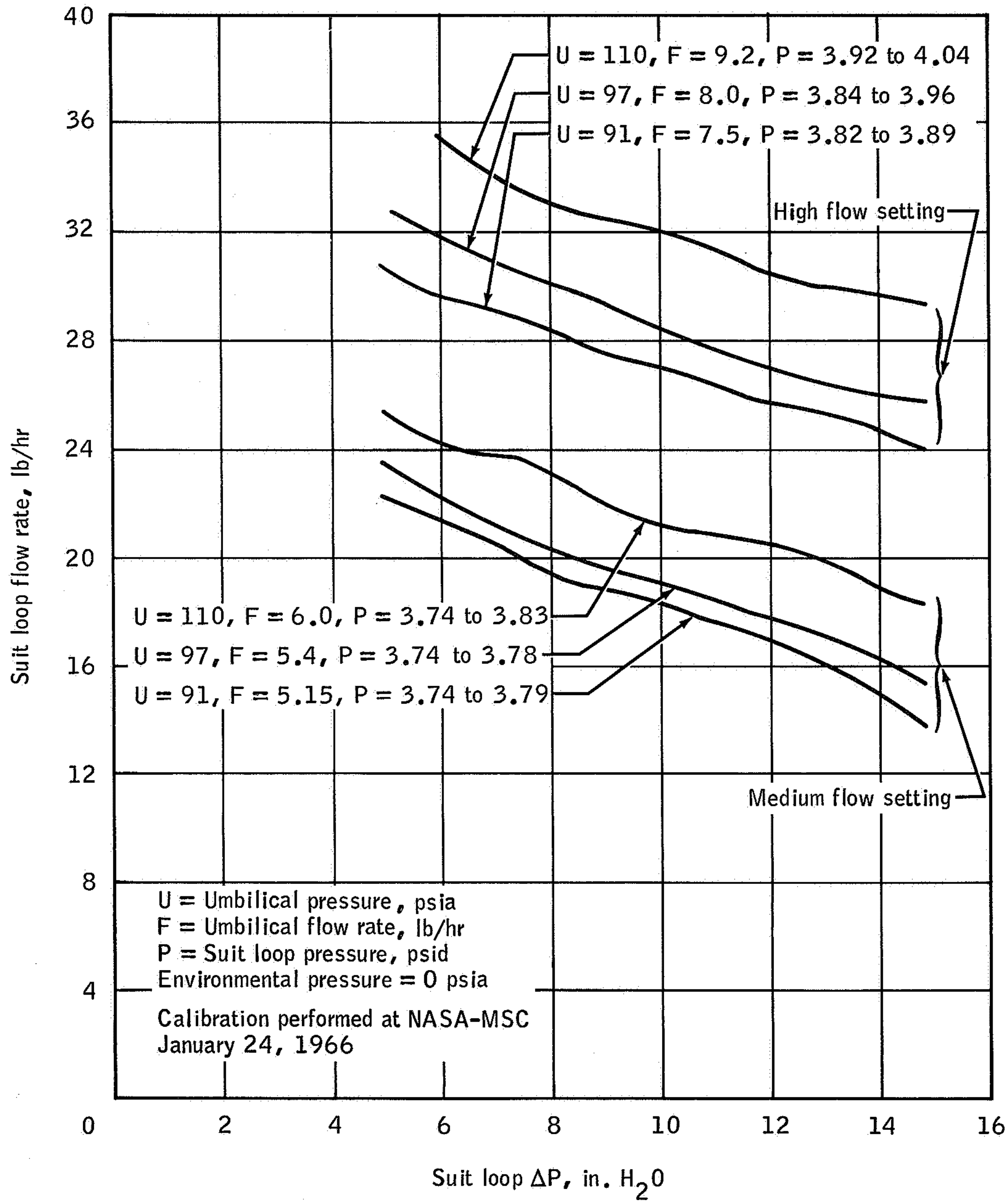

Figure 4.2-12. - Gas flow rate calibration for ELSS chestpack 107.

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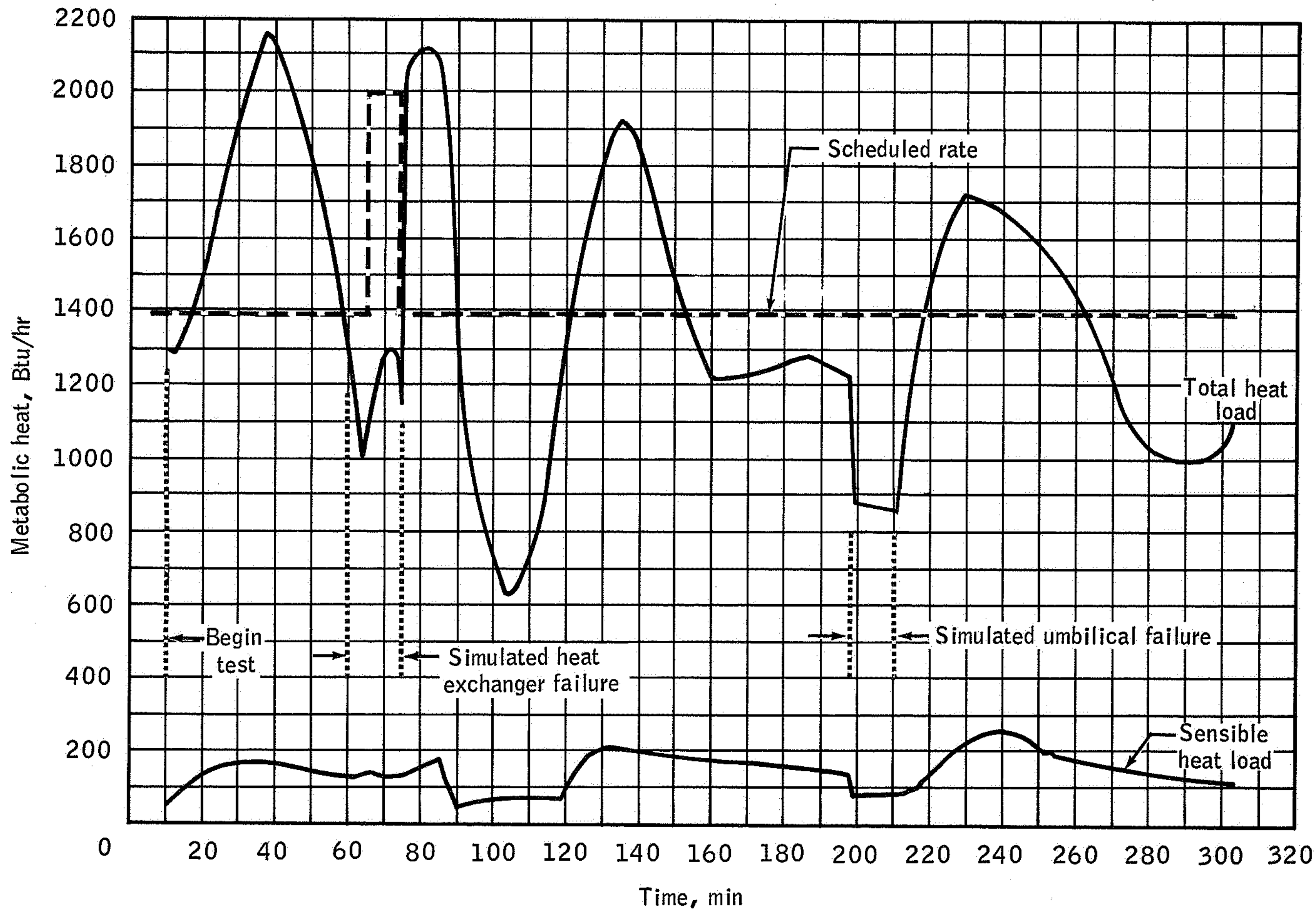

Figure 4.2-13. - Simulated metabolic heat profile - final test of ELSS in contractor Space Environment Simulator.

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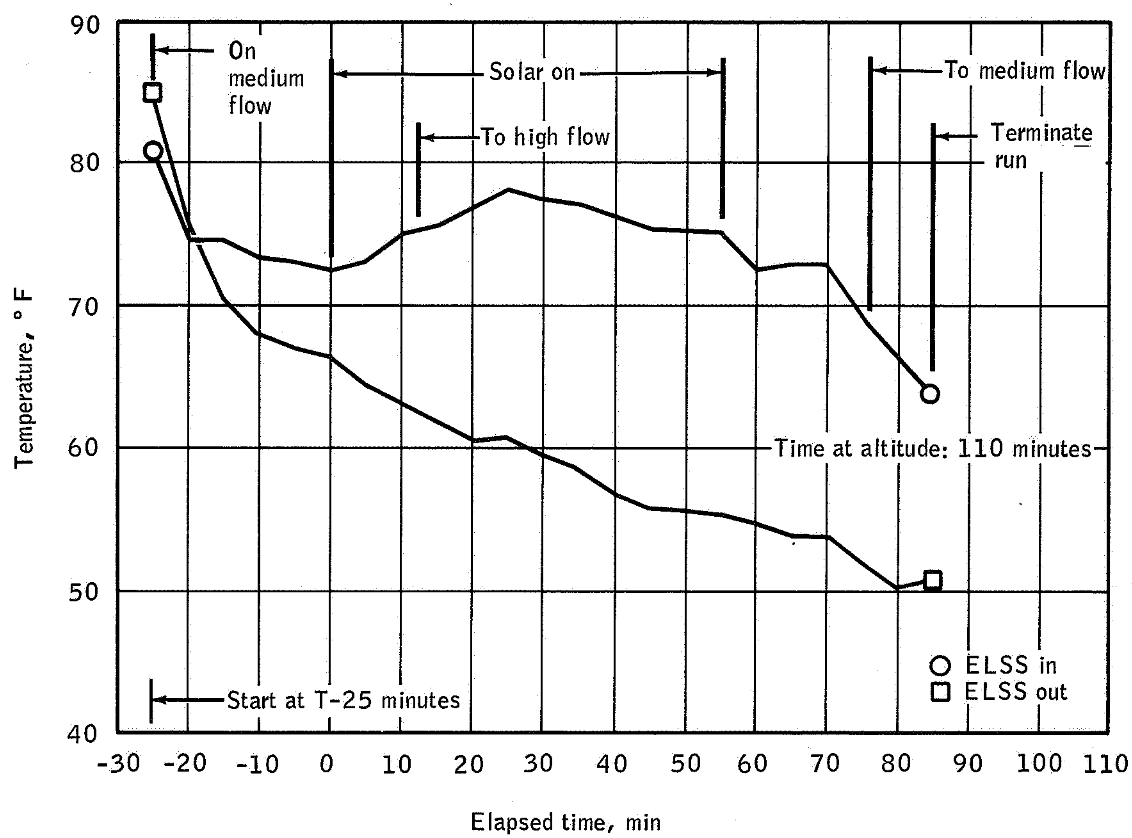

Chestpack 113.

Figure 4.2-14. - ELSS chestpack performance during Gemini XI pilot test in MSC Chamber B.

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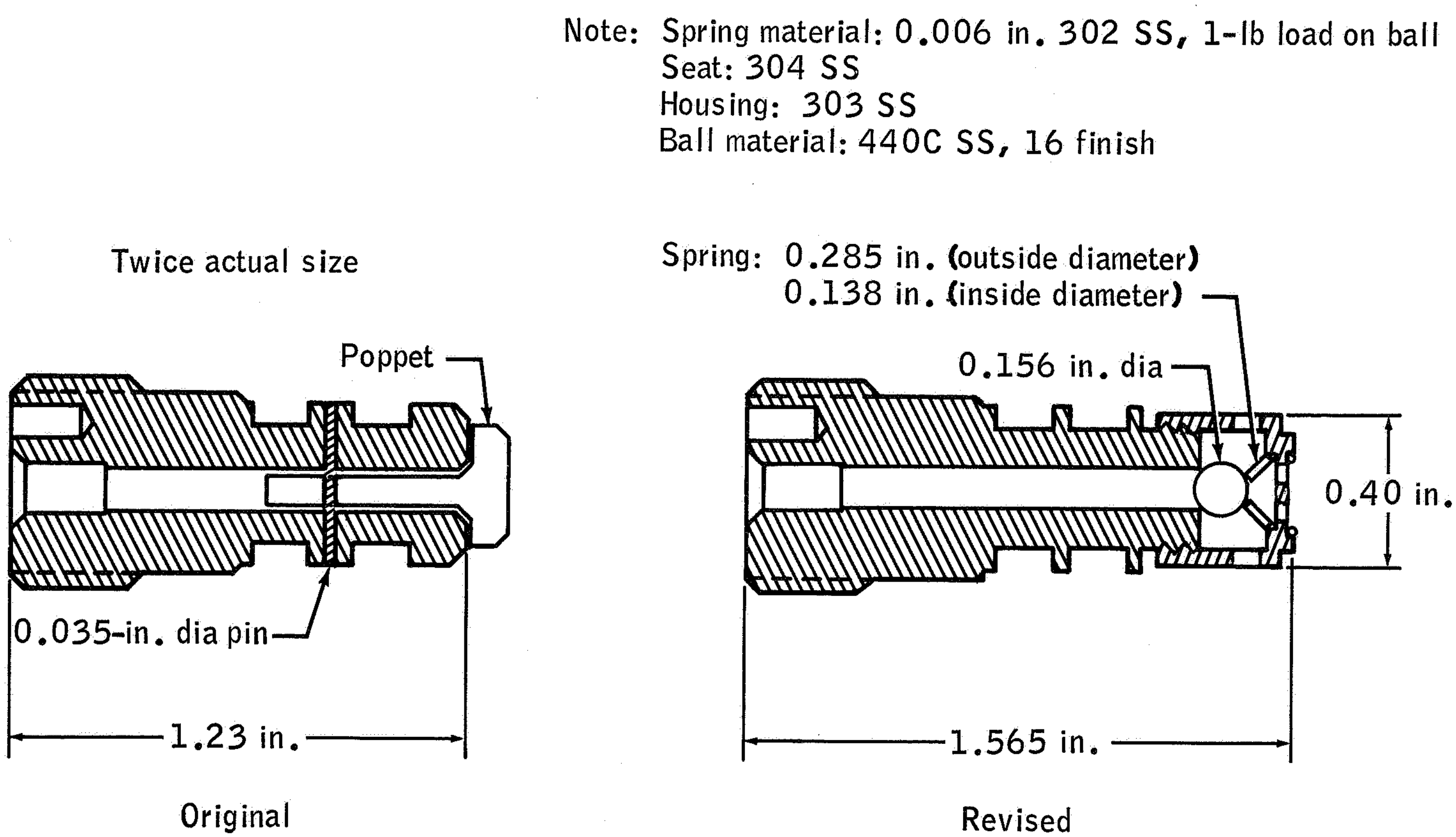

Figure 4.2-15. - Comparison of ELSS chestpack fill port check valves.

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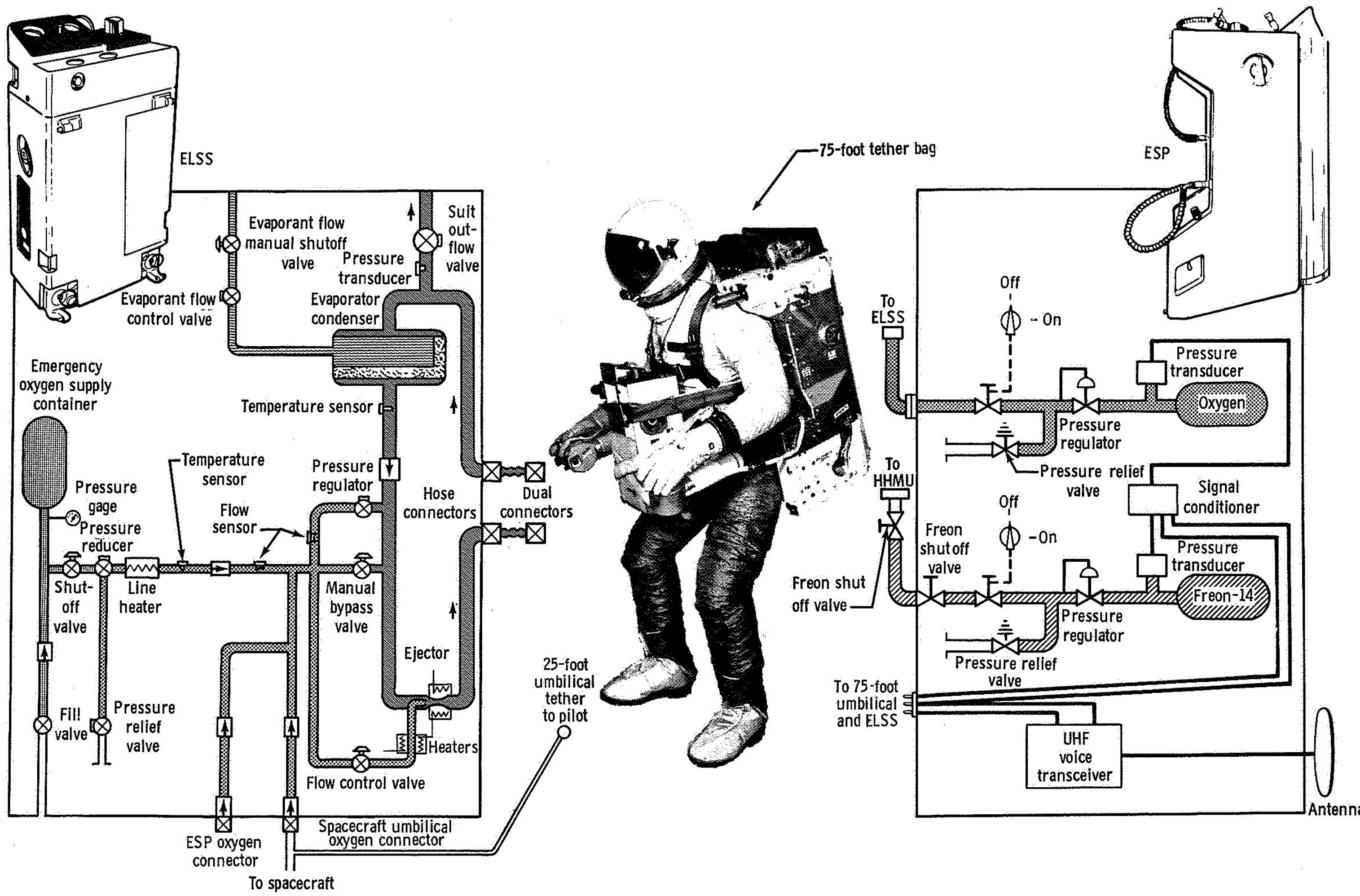

Figure 4.2-16 - Gemini VIII extravehicular system - ELSS / ESP.

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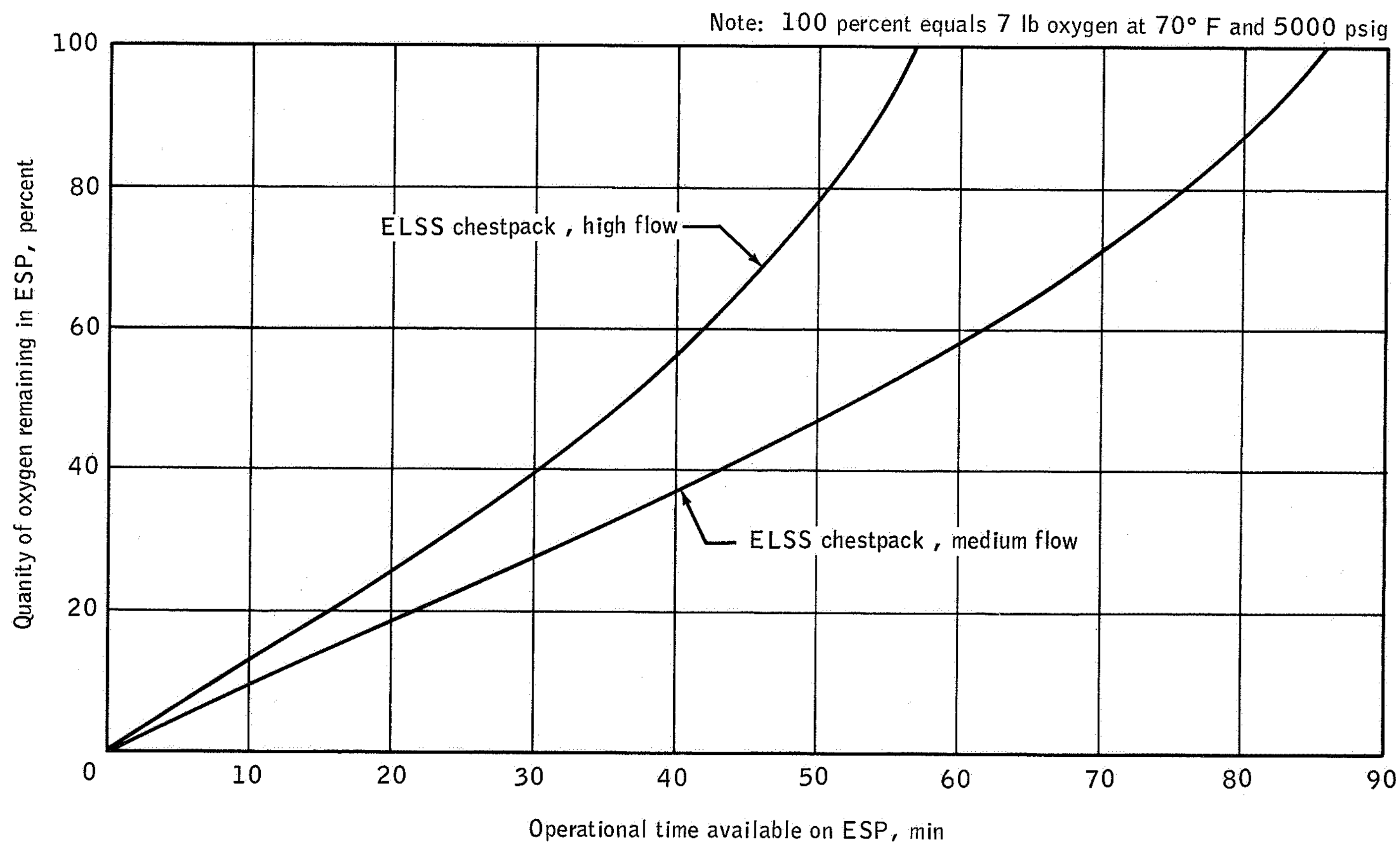

Figure 4.2-17. - ELSS operating time versus remaining ESP oxygen.

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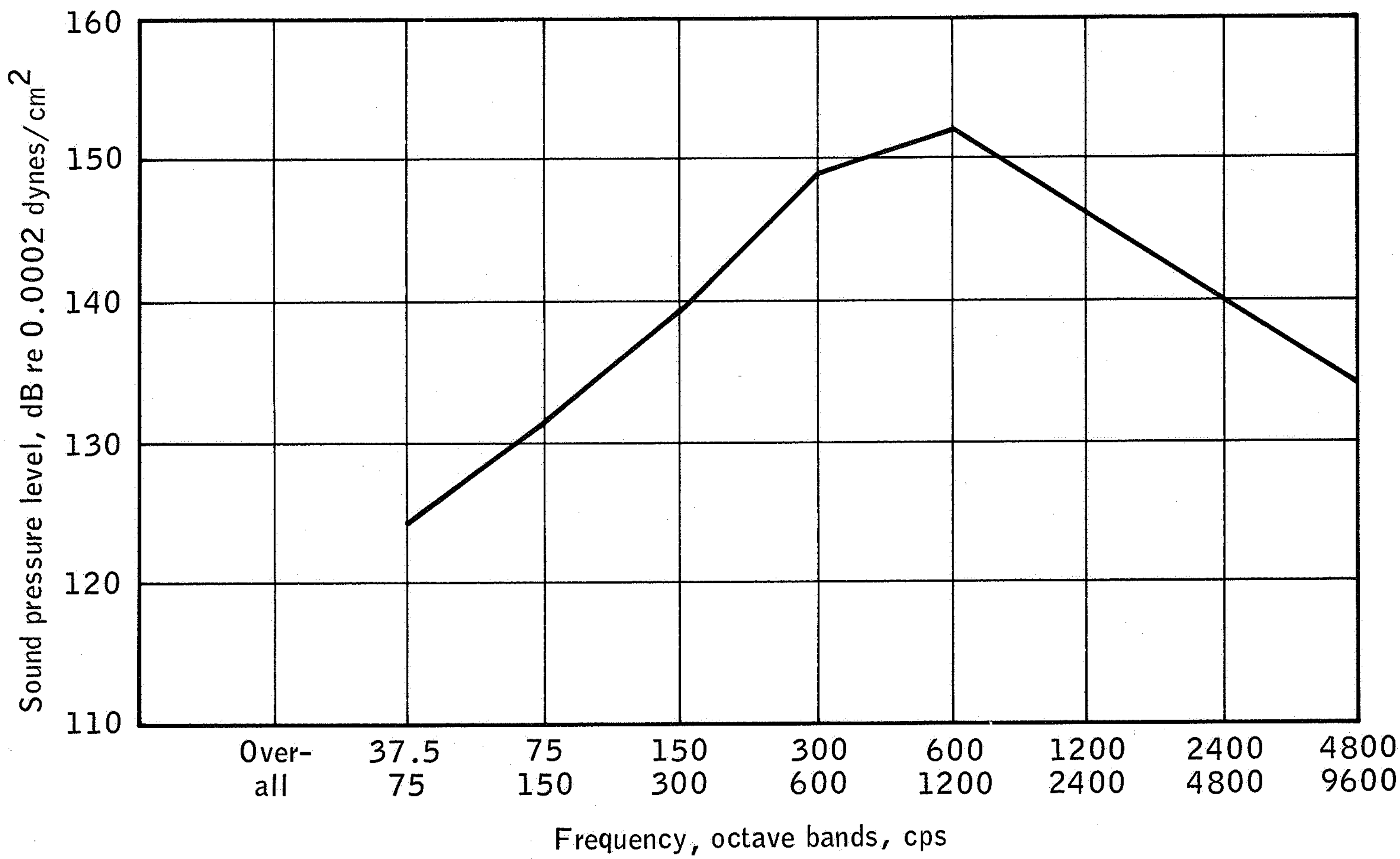

Figure 4.2-18. - ESP acoustic noise qualification spectrum.

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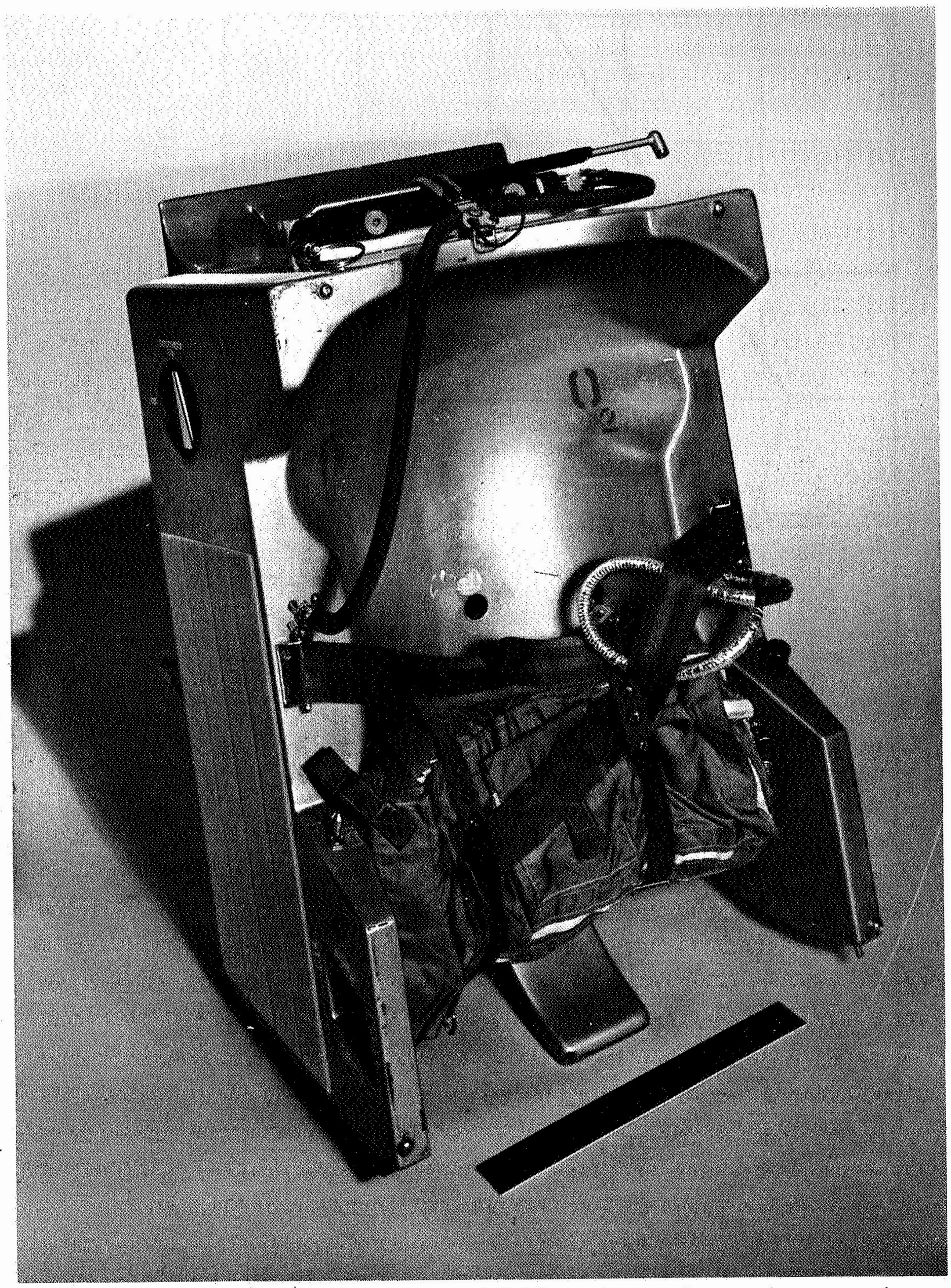

Figure 4.2-19. - Front view of ESP with 75-foot tether stored.

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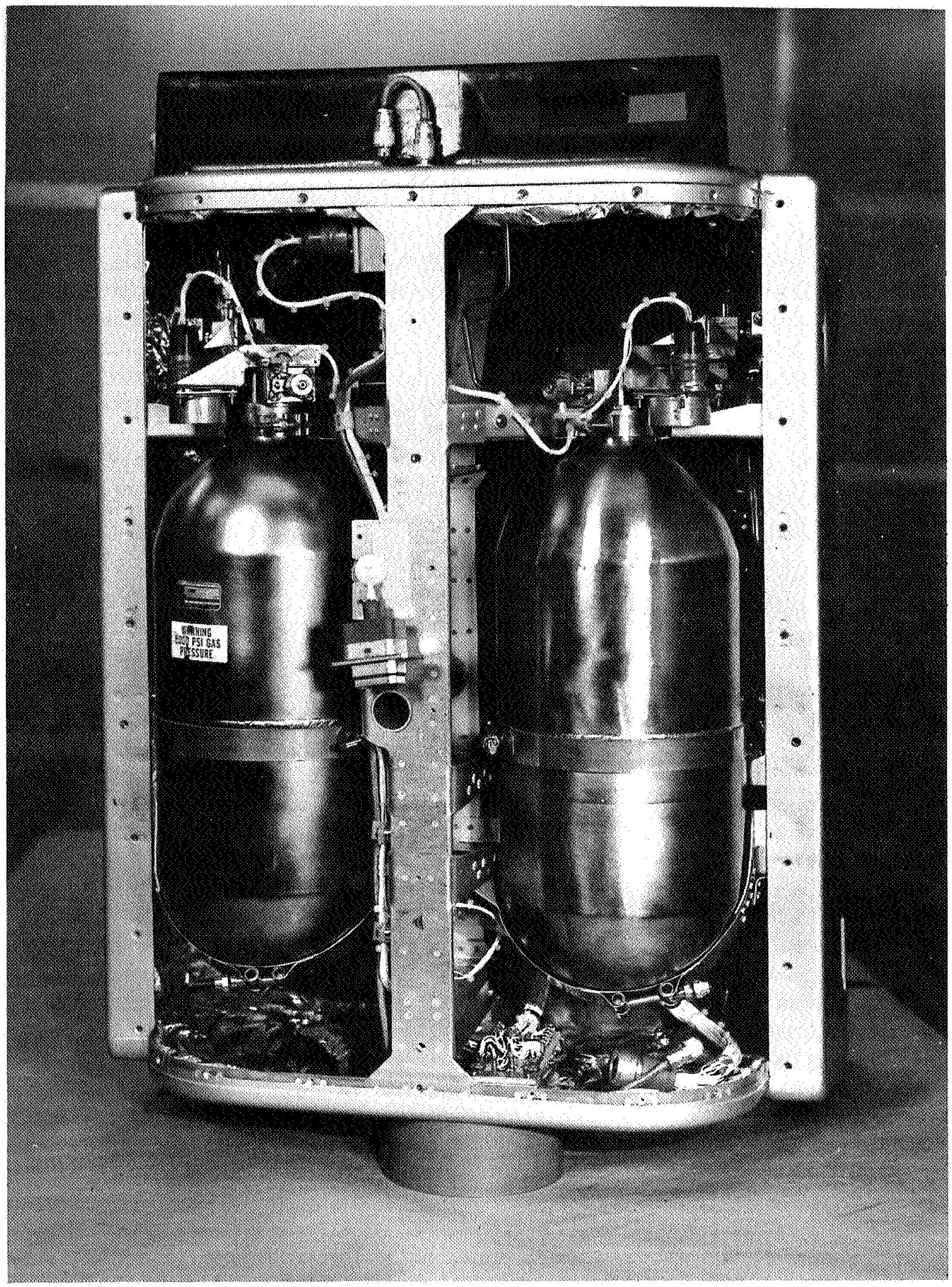

Figure 4.2-20. - ESP internal components.

4.3 UMBILICAL AND TETHER COMBINATIONS

Several types of umbilical and tether combinations were designed, fabricated, and used in accomplishing the extravehicular activities of the Gemini Program to provide structural, fluid, and electrical linkage with the spacecraft and to limit the distance between the extravehicular crewman and the spacecraft. Body positioning tethers are discussed in section 5.0 of this report.

The basic function of the umbilicals was to provide a structural attachment, electrical leads for voice communications and biomedical data, and an oxygen supply line. In one case, the 75-foot tether for the Extravehicular Support Package (ESP) supplied only a structural member and electrical leads. And, the 50-foot and 30-foot umbilicals flown on Gemini X and Gemini XI, respectively, included a nitrogen supply line for the HHMU. A 25-foot umbilical was flown on Gemini IV, VIII, IX-A, and XII. The 50-foot and 30-foot umbilicals were flown on Gemini X and XI, respectively. The 75-foot tether was to have been used during the ESP evaluation planned for Gemini VIII.

4.3.1 Umbilical Development

The 25-foot umbilical was the original umbilical designed for Gemini EVA. Development of the 30-foot and 50-foot umbilicals was based, in a large part, on work accomplished on the 25-foot umbilical.

4.3.1.1 Twenty-five-foot umbilical.- The initial umbilical configuration was an integral coaxial assembly which incorporated a gold-plated outer sheath that enclosed the hose, tether, and electrical leads. The configuration is shown in cross section in figure 4.3-1. The oxygen hose was used as a core with the electrical conductors spiral wrapped around the outside. A tubular nylon braid was selected as the load-carrying tether. The nylon braid was pressed as a flat strap and was placed between the conductors and the outer sheath. The overall flexibility was almost the same as that of the 3/16-inch (inside diameter) oxygen hose alone.

The electrical wiring consisted of four shielded twisted pairs, two twisted shielded triads, one single shielded conductor, and one single wire conductor. All wire was number 22 gage, 19-strand, nickel-plated copper wire per MIL-W-16878, Type ET, insulated with double-wrapped TFE Teflon.

The tether strap was standard tubular nylon webbing, one-half inch wide (when flattened), fabricated to MIL-W-5625D, and with a minimum tensile strength of 1000 pounds. The tether was designed shorter than the oxygen and electrical portion of the umbilical to allow for elongation under load. The unstressed length was designed so that a 240-pound man (including man, suit, and ELSS) with an initial velocity of 10 ft/sec could be damped without applying a load on the oxygen line or electrical leads. A 24-foot tether stretched to 27 feet with a 375-pound pull. Oxygen and electrical lines were 27 feet long, based on this design load.

The insulation material initially applied to the outer sheath was Armalon 97-001G. The material consisted of a 0.005-inch FEP film laminated to Teflon fabric and metalized with gold. The material had a nominal thickness of 0.001 inch and an emissivity of 0.1.

A method was later developed to provide a more flexible and durable gold coating. The process involved a transfer of 24-carat gold from an acetate film directly onto the nylon outer sheath by use of a thermoplastic adhesive system. This eliminated the gold-plated Teflon tape.

Thermal analysis of the coaxial umbilical design resulted in the performance envelope shown in figure 4.3-2. Temperature extremes of the oxygen delivered to the chestpack (cooling in Case I and heating in Case III) were obtained at the end of the proposed 45-minute EVA. A conservative value of 0.2 was assumed for the emissivity of the gold-plated outer covering.

Performance and qualification tests were conducted with flight-configuration umbilical systems. The insulation resistance was found to be insufficient between some of the wires and shields. This failure was due to wires protruding through insulation at kinked areas of the conductor. The kinks were caused during the temperature curing cycle of the umbilical assembly gold coating at 320° F. Short sections of nylon cord used as spacers of the wire around the umbilical assembly shrank because the nylon had not been temperature stabilized. Subsequent units were fabricated using temperature stabilized nylon cord.

As a result of insulation failures noted during qualification testing, the wire type in the umbilical was changed from MIL-W-16878D, Type ET, to MIL-W-16878D, Type E. The difference between the two types is the insulation wall thickness. Type ET has a nominal insulation wall thickness of 0.006 inch, whereas Type E has a nominal insulation wall thickness of 0.010 inch.

Production problems were encountered in applying the gold coating. Also ground thermal tests at MSC indicated that the gold coating was not as effective during nightside operations as had first been expected.

After the Gemini IV mission, several layers of aluminized Mylar superinsulation under a Nomex (HT nylon) sheath were used instead of the gold coating to provide thermal control during both dayside and darkside operation. The superinsulation was made of layers of 0.25-mil aluminized Mylar with 3.2-mil layers of Dacron scrim spacer.

Evaluations of stowage and attachment were conducted. The outlet to the spacecraft cabin repressurization valve was modified to include a quick disconnect half to mate with the umbilical. The controls for this valve were already located on the center console in the cockpit. In this location, the oxygen line attachment point was easily accessible to either crewman. The existing shut-off valve, with minor modifications, was utilized, thereby avoiding significant spacecraft modifications.

On the Gemini IV mission, the inboard elbow restraint of the right-hand seat was used as the tether attach point. In the raised position, the restraint formed an easily accessible and structurally sound point of attachment. For Gemini VIII and subsequent missions, an eyebolt-type attachment point was provided at the pilot's egress handle. This location eliminated the need for hoses and cables in the center of the cabin.

The umbilical was first coiled in a bag and then the bag stowed in the aft food box. The coil configuration was in the form of a figure 8 as shown in figure 4.3-3. Figure 4.3-4 shows the umbilical within the bag in the stowed configuration.

4.3.1.2 Seventy-five-foot electrical tether.- A 75-foot electrical tether assembly was developed for use during the ESP evaluation planned for Gemini VIII. No oxygen supply line was required because the ESP carried its own supply. Therefore, a structural member and electrical leads were the only requirements. The 75-foot tether consisted of communications and bioinstrumentation leads encased in nylon cloth, together with a rolled high-temperature nylon strength member. The leads and the structural member were encased in a tubular, high-temperature nylon sheath for abrasion protection.

4.3.1.3 Fifty-foot and thirty-foot umbilicals.- A 50-foot umbilical was developed for Gemini X which provided an oxygen supply line, communication and biomedical leads, a tether, and a propulsion gas supply line. The inclusion of a propulsion gas line in the umbilical enabled the extravehicular crewman to evaluate the HHMU without the encumberance of a backpack, such as the ESP, and eliminated the complex donning requirements of a back-mounted system. This concept also permitted attachment of all oxygen connections within the cabin before opening the hatch. The design and interface requirements with the ELSS and spacecraft were established as shown in figure 4.3-5.

The 50-foot umbilical design was patterned after the existing 25-foot umbilical design. One major difference, in addition to the propulsion gas hose, was the elimination of the ELSS electrical jumper cable. The 50-foot umbilical connected directly to the ELSS chestpack and to the suit (fig. 4.3-6).

The 30-foot umbilical, which was flown on Gemini XI, was identical to the 50-foot umbilical, except that the length was reduced to ease stowage and handling problems.

4.3.2 Umbilical Testing

The umbilical assemblies were subjected to the same level of development, prototype, and qualification testing as had been accomplished on the other components of the ELSS. The qualification program of the 25-foot umbilical assembly was accelerated to meet the Gemini IV flight schedule. The 50-foot and 30-foot umbilicals were qualified, in large part, by similarity to the 25-foot umbilicals. In addition to the development, prototype, and qualification tests noted above, various special tests were performed to verify certain umbilical functions. The umbilicals were subjected to a system-level qualification program rather than to a component-level program.

4.3.2.1 Twenty-five-foot umbilical.- The 25-foot umbilical, as a component of the ELSS, was subjected to the unmanned and manned test program described in section 4.2.2.2. The only problem encountered during the qualification of the 25-foot umbilical was the electrical insulation failure noted in section 4.3.1.1.

For Gemini VIII and later missions the gold thermal insulation was replaced by an aluminized Mylar superinsulation. Better thermal control and more flexibility was attained with Mylar than with a gold coating.

Thermal-vacuum performance tests were conducted on an umbilical wrapped with 10 to 12 layers of aluminized Mylar at pressures approaching 10^{-5} mm Hg and in a cold environment (less than -280° F). The umbilical was exposed to the cold walls for the duration of each test, while solar simulation was employed on an earth orbital time cycle of 50 minutes dayside and 40 minutes darkside. Figure 4.3-7 presents data from this test. Note that after 100 minutes elapsed time, the umbilical outlet gas temperature was approximately 13° F colder than the inlet gas and that this gas differential temperature ΔT remained relatively constant, even though umbilical skin temperatures dropped as low as -210° F.

A production 25-foot umbilical, with 12 layers of Mylar insulation, was subjected to the unmanned thermal-vacuum qualification tests conducted on the ELSS equipment, as presented in section 4.2.2.2.1, paragraph (c). These tests were performed in a space environment simulator chamber under conditions of 5×10^{-4} mm Hg maximum, 1 solar constant, and approximately -300° F. Umbilical gas supply pressure was maintained at 92 ± 10 psia throughout the test. The operational qualification criteria for the umbilical were umbilical gas ΔT (inlet to outlet) less than 40° F and umbilical skin temperatures within the range of -200° to 160° F. Umbilical surface temperatures were measured in each quadrant around the periphery at a point where the umbilical was normal to the sun's rays. Representative data from these tests are shown in figure 4.3-8. The maximum umbilical surface temperature during the tests was 130° F on areas directly facing the simulated solar radiation. The maximum umbilical surface temperatures measured were higher than actual orbital values because the absorptivity of synthetic fabrics, such as the nylon cover, was typically lower in the spectrum of the extraterrestrial sun. Lowest umbilical surface temperatures occurred during the night portions of simulated orbits. The lowest temperature measured was -170° F. The cold test conditions were also somewhat lower than actual orbital values, since the earth heat emission during dark portions of an orbit was not simulated. Gas temperatures at the umbilical exit are lower than at the inlet because a gas temperature drop occurred, even when the umbilical was exposed to the sun and because the average temperature around the umbilical was always lower than the gas temperature.

The umbilical gas inlet and outlet temperature data showed that the maximum gas ΔT was approximately 35° F during cold (darkside) test conditions (fig. 4.3-9). Typical umbilical gas ΔT during conditions of exposure to solar radiation was 15° F. During simulated umbilical failures, when the umbilical flow was stopped, the outlet gas thermocouple showed sudden increasing temperature, and the inlet gas thermocouple showed a decrease in temperature. The increase in outlet temperature during no-flow was believed to be due to heat soakback from the ELSS connection to the measurement point. The decrease in inlet temperature showed the sudden loss of thermal energy transport by the umbilical gas flow. The inlet measurement was at a point that received no solar energy. Recovery to normal flow temperatures occurred about 10 minutes after umbilical flow was restored.

The spacecraft umbilical met qualification criteria temperature requirements.

4.3.2.2 <u>Fifty-foot and thirty-foot umbilicals</u>.- The nitrogen quick disconnect, the nitrogen umbilical hose, and the oxygen umbilical hose were qualified by similarity to equipment furnished by the same vendor for other Gemini applications. The oxygen umbilical quick disconnects, the HHMU coupling valve, and the tether hook were qualified by their use for other Gemini applications.

The umbilical assembly was subjected to a thermal qualification test to insure that the umbilical would deliver oxygen at a temperature compatible with the ELSS. A differential temperature qualification test was performed in the MSC Chamber E facility. The test setup is shown in figure 4.3-10. This test was conducted at a pressure of less than 1×10^{-4} mm Hg with cold walls at -260° F and with intermittent solar simulation.

The umbilical thermal qualification requirement was that the oxygen umbilical hose outlet gas temperature must not drop below 0° F during a 55-minute simulated day cycle with the following initial and operating conditions:

(a) 125 ± 5 psia nitrogen hose inlet pressure

(b) 96 ± 5 lb/hr intermittent nitrogen flow through nitrogen hose

(c) 25° ± 5° F nitrogen hose inlet temperature

(d) 110 ± 10 psia oxygen hose inlet pressure

(e) 4.78 ± 0.38 lb/hr nitrogen flow through oxygen hose

(f) 55° ± 5° F oxygen hose inlet temperature

The oxygen umbilical hose outlet gas temperature must not drop below 0° F at the specified flow rate during a 30-minute night cycle. Initial conditions for the night cycle were those existing at the termination of the 55-minute day cycle, except that solar simulation and flow through the nitrogen umbilical were terminated.

The first two attempts were terminated prematurely because of an increase in chamber pressure at 40 and 45 minutes into the day cycle. Leakage tests were subsequently performed at low temperature conditions. After a cold soak of about 30 minutes, the umbilical end fitting leaked. The leaks were not detectable at ambient conditions or before the cold soak, which pointed out the importance of low-temperature leakage tests.

In the Chamber E test, an umbilical outlet oxygen temperature of -11° F was recorded at the end of the 30-minute night cycle. In subsequent performance testing, temperatures between 0° and 5° F could be expected after the 55-minute day cycle and between 0° and -15° F after a 30-minute night cycle. Because the test conditions were more severe than actual conditions, and because the umbilical was shortened to 30 feet for the Gemini XI mission, it was determined that the 30-foot umbilical would supply oxygen to the ELSS at acceptable temperatures. This result was borne out in a comparison of the data shown in figure 4.3-11. This is a composite plot of Chamber E data and of data taken during a crew training run conducted in the Chamber B facility.

An ultimate load test was accomplished on a 50-foot umbilical tether sample to insure a minimum breaking strength of 1000 pounds. Failure occurred at the tether hook at 1970 pounds. A dynamic loading test verified that the umbilical assembly was capable of withstanding any dynamic loads induced by use of the HHMU.

4.3.2.3 Seventy-five-foot electrical tether.- The components of the 75-foot tether were qualified by similarity to the previously qualified components of the 25-foot umbilical. The complete assembly, as a component of the ESP, was subjected to the test series covered in section 4.2.3.4.2 and to the following additional tests.

4.3.2.3.1 Mechanical strength test: A load was applied to the tether in 100-pound increments up to 1000 pounds. Electrical continuity was maintained at a 400-pound load, and the tether mechanical integrity was maintained at a 1000-pound load.

4.3.2.3.2 Cold bending test: A segment of the umbilical assembly was subjected to an environment of -60° ± 10° F for 90 minutes. The segment was flexed through an angle of 80° ± 5° around a 2-inch-diameter mandrel 100 times. Electrical continuity was maintained throughout the test.

4.3.2.3.3 Flexibility test: Two test points on the umbilical were located at 6 inches from the end of the ELSS and at the approximate midpoint. Each test point was flexed 50 times around a 1.5-inch-diameter rod through an angle of 180°. Electrical continuity was maintained throughout the testing.

4.3.2.3.4 Potting reliability test: A torque of 50 inch-ounces was applied clockwise and counterclockwise 25 times each to the back of the potting about the axis of each connector. The force was applied in a plane perpendicular to the pins in the connector. The potting retained mechanical integrity throughout the test and showed no signs of separation from the wires, sheath, or connector.

4.3.2.4 One-hundred-twenty-five-foot AMU tether.- The components of the 125-foot AMU tether were qualified by similarity to the webbing and hooks of the tether assembly of the 25-foot umbilical. The tether assembly was subjected to a static load test and a dynamic load test to complete the qualification. Both tests were performed on a 25-foot tether and on a 125-foot tether. The tests were designed to verify adequacy of the tether design for the following conditions:

(a) Limit load: 200 lb (maximum)

(b) Proof load: 400 lb (minimum)

(c) Ultimate load (complete assembly): 800 lb (minimum)

(d) Ultimate load (webbing material): 1000 lb (minimum)

(e) Connection and splices: 800 lb (minimum)

(f) Tether assembly capable of withstanding dynamic loads at a rate 1.5 times the maximum anticipated AMU velocity

The tether assembly successfully completed the static load testing except for the ultimate load test. The 125-foot assembly broke at 604.8 pounds (required 800-pound minimum). Inspection of the tether revealed that stitching at one of the hooks was incorrectly accomplished; one row of stitching had not secured the two layers of tether material. The tether was resewn according to the design requirements and met the 800-pound test requirement.

The dynamic load testing was successfully completed on both the 25-foot and 125-foot tethers. Velocities of 3 and 4 ft/sec resulted in tensile loads of 150 to 201 pounds to the 25-foot tether. Velocities of 4 and 6 ft/sec resulted in the tensile loads of 80 to 110 pounds to the 125-foot tether. Maximum elongation and rebound velocities were within the established limits.

4.3.3 Flight Equipment Design

4.3.3.1 Twenty-five-foot umbilical.- As noted previously, the 25-foot umbilical was carried on the Gemini IV, VIII, IX-A, and XII missions.

4.3.3.1.1 Gemini IV umbilical assembly: The Gemini IV umbilical assembly is shown in figure 4.3-12. An electrical schematic is shown in figure 4.3-13. A hose nozzle was installed at the suit end of the umbilical assembly and provided for umbilical connection to the dual connector installed in the suit inlet fitting. A quick disconnect was installed on the spacecraft end of the umbilical and connected to a mating quick disconnect installed on the cabin repressurization valve (fig. 4.3-14). The quick disconnect incorporated a flow-limiting Venturi, which limited the oxygen flow from the spacecraft.

(a) Normal flow: 7.15 lb/hr oxygen at 60° F, with an inlet pressure of 94 psia and an outlet pressure of 81 psia

(b) Maximum flow: 10.2 lb/hr oxygen at 40° F with an inlet pressure of 111 psia and an outlet pressure of 40 psia

4.3.3.1.2 Gemini VIII umbilical assembly: A 25-foot umbilical and a 75-foot tether were planned for the Gemini VIII EVA. The Gemini VIII 25-foot umbilical assembly is shown in figure 4.3-15. Mylar superinsulation was used instead of gold sheath. The electrical pigtails and tether breakouts were configured for more appropriate connecting and interface with the spacecraft, chestpack, and crewman. In addition, a slip ring (with hook) was provided to permit attachment of the umbilical to an eyebolt installed at the nose of the spacecraft. The electrical schematic for Gemini VIII, IX-A, and XII umbilicals is shown in figure 4.3-16.

4.3.3.1.3 Gemini IX-A umbilical assembly: The 25-foot umbilical utilized on Gemini IX-A was similar to the one provided for Gemini VIII except that metal-sheath insulation was incorporated for protection against AMU thruster impingement (fig. 4.3-17).

4.3.3.1.4 Gemini XII umbilical assembly: The 25-foot umbilical shown in figure 4.3-18, was identical to the Gemini IX-A umbilical except for the following:

(a) The tether was shortened, and the short tether jumper was removed.

(b) The tether breakout point on the suit end of the umbilical was relocated to a point approximately 17 inches nearer the end of the umbilical.

(c) The tether hook for attachment to the D-ring of the parachute harness was replaced with a larger flanged hook. This hook was more readily manipulated in a pressurized glove.

(d) The tether hook at the spacecraft end of the umbilical was replaced with a flanged hook similar to the one used on the other end.

4.3.3.2 Gemini VIII 75-foot tether.- The 75-foot tether, shown in figure 4.3-19, was to be used during the ESP evaluation. The electrical schematic is shown in figure 4.3-20.

4.3.3.3 Gemini X 50-foot umbilical assembly.- The Gemini X umbilical assembly is shown in figure 4.3-21. To minimize the entanglement of various end connections, the tether of the 50-foot umbilical was attached at the "X" formed by the parachute harness at the pilot's left hip rather than at the D-ring. An electrical schematic of the 50-foot umbilical is shown in figure 4.3-22.

4.3.3.4 Gemini XI 30-foot umbilical assembly.- The 30-foot umbilical assembly, shown in figure 4.3-23, was similar to the 50-foot umbilical assembly of Gemini X, except in length and in the nitrogen valve and quick disconnect assembly which mated with the HHMU. The nitrogen valve and quick disconnect assembly was an improved design which permitted the pilot to connect and disconnect the HHMU more readily with a pressurized glove.

4.3.4 Results and Discussion

The feasibility of using umbilicals for EVA in the vicinity of the spacecraft was established. The umbilicals produced no unfavorable torques or forces on the EVA pilots. However, some difficulty was experienced during ingress with the bulk of the 50-foot umbilical used for the Gemini X EVA. The donning of the umbilicals was easy, and a complete system checkout could be made before opening the hatch. The incorporation of a supply line for the propulsion system of the HHMU proved satisfactory, and this concept has possible future application for power tools as well as for maneuvering units.

The umbilical concept was particularly applicable to near-vehicle operations, or operations in close quarters where the bulk of a life support pack would have been undesirable.

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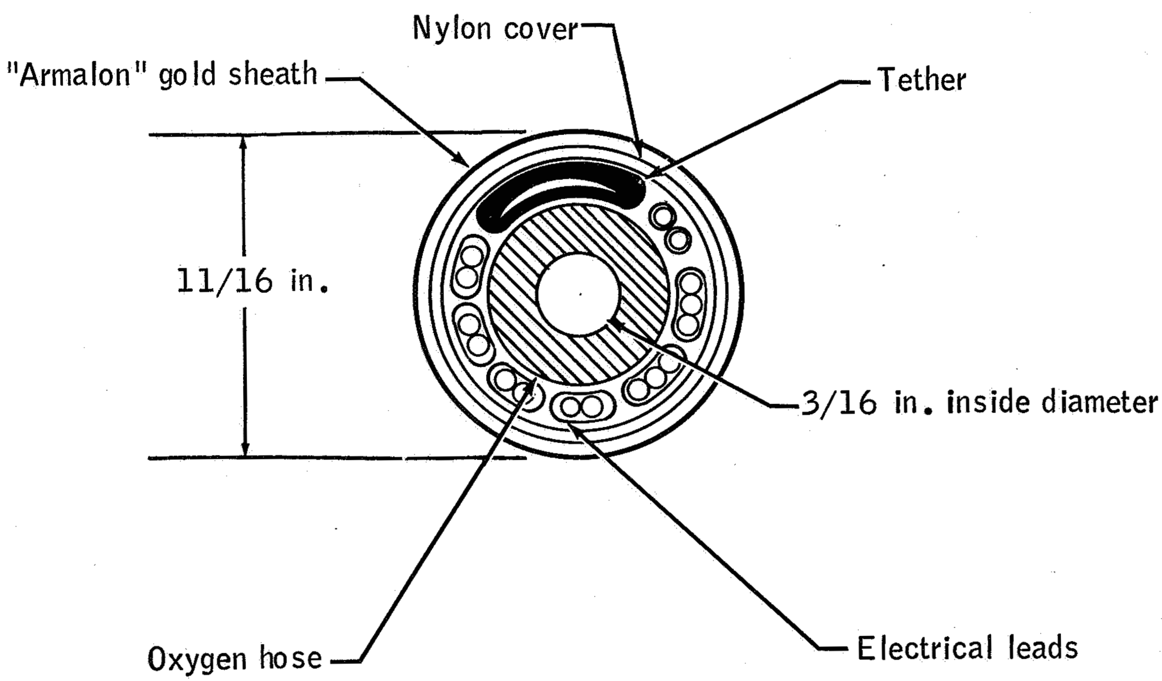

Figure 4.3-1. - Cross section of integral coaxial umbilical.

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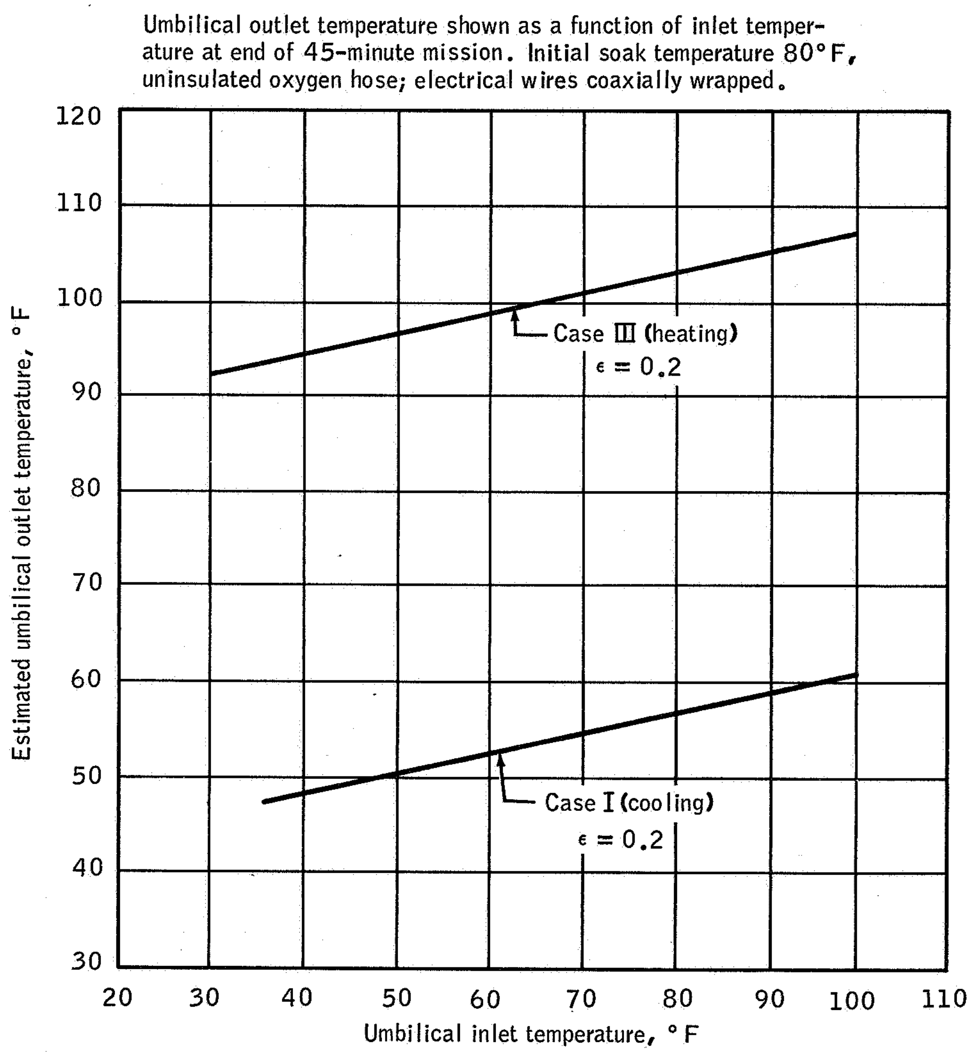

Figure 4.3-2. - Temperature performance envelope of coaxial umbilical with gold outer sheath.

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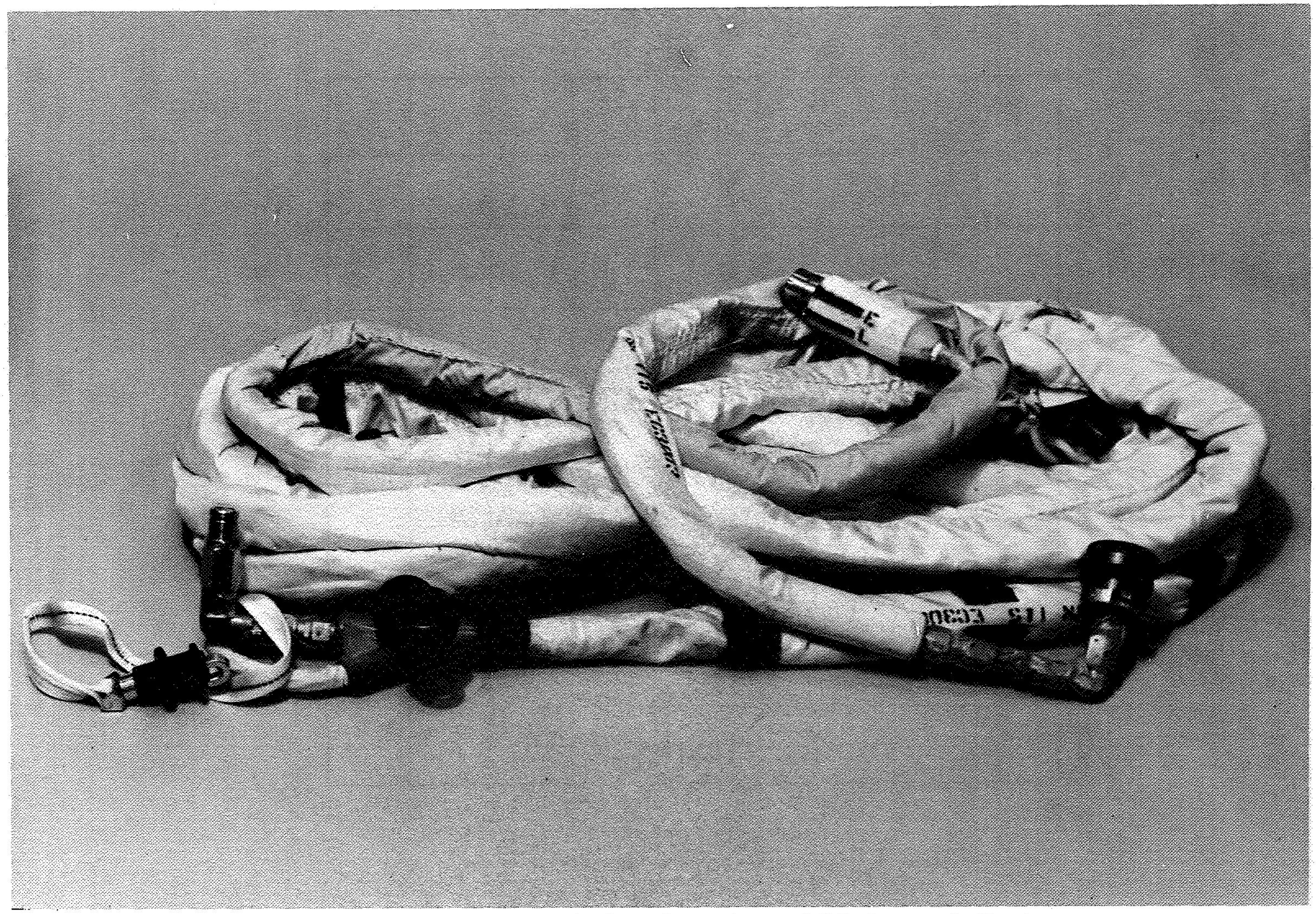

Figure 4.3-3. - Coiled configuration of 25-foot umbilical.

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Figure 4.3-4. - Twenty-five-foot umbilical stowed in bag.

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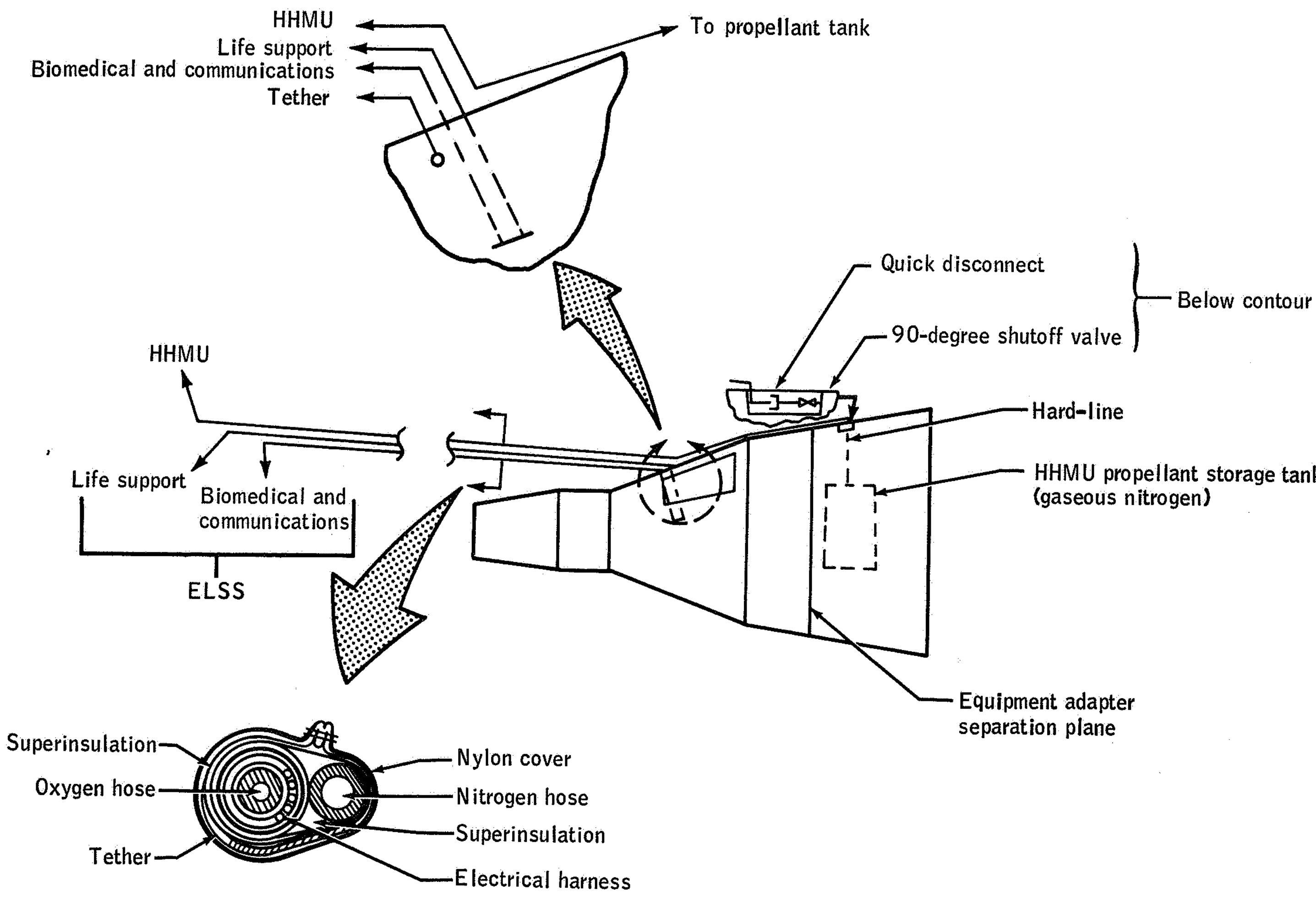

Cross section of 50-foot umbilical

Figure 4.3-5. - Design and interface requirements of the 50-foot umbilical.

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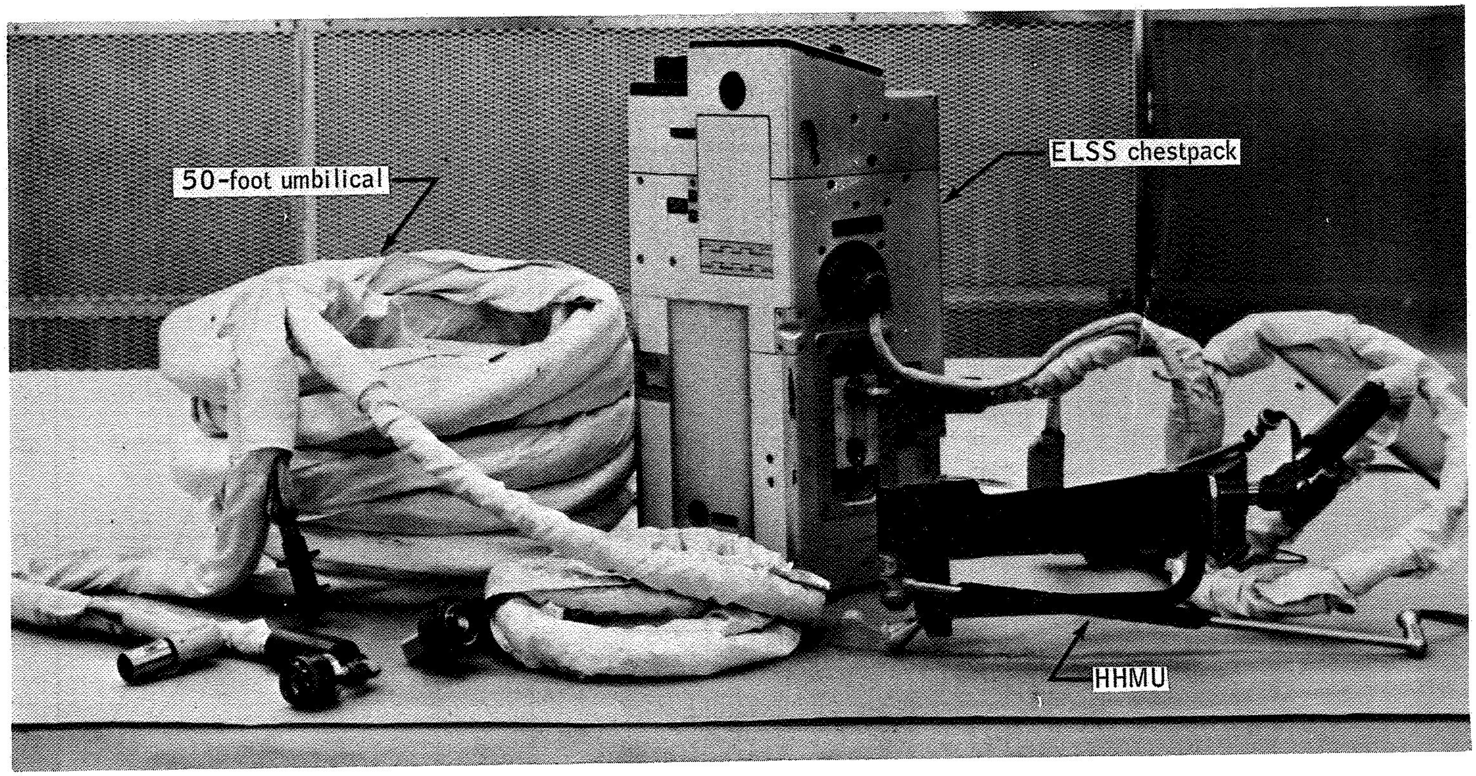

Figure 4.3-6. - Gemini X extravehicular equipment.

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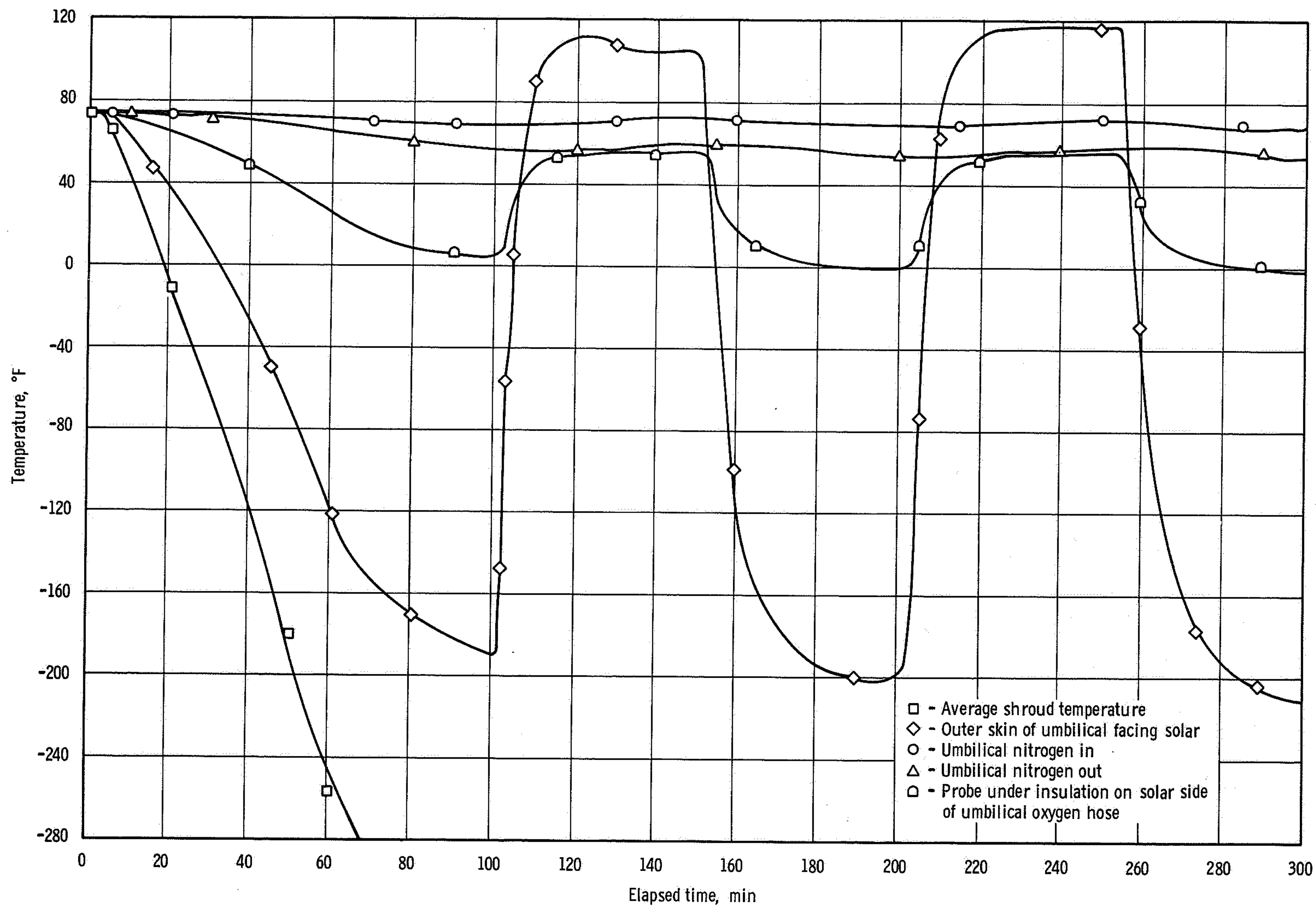

Figure 4.3-7. - Umbilical thermal test, June 14, 1965.

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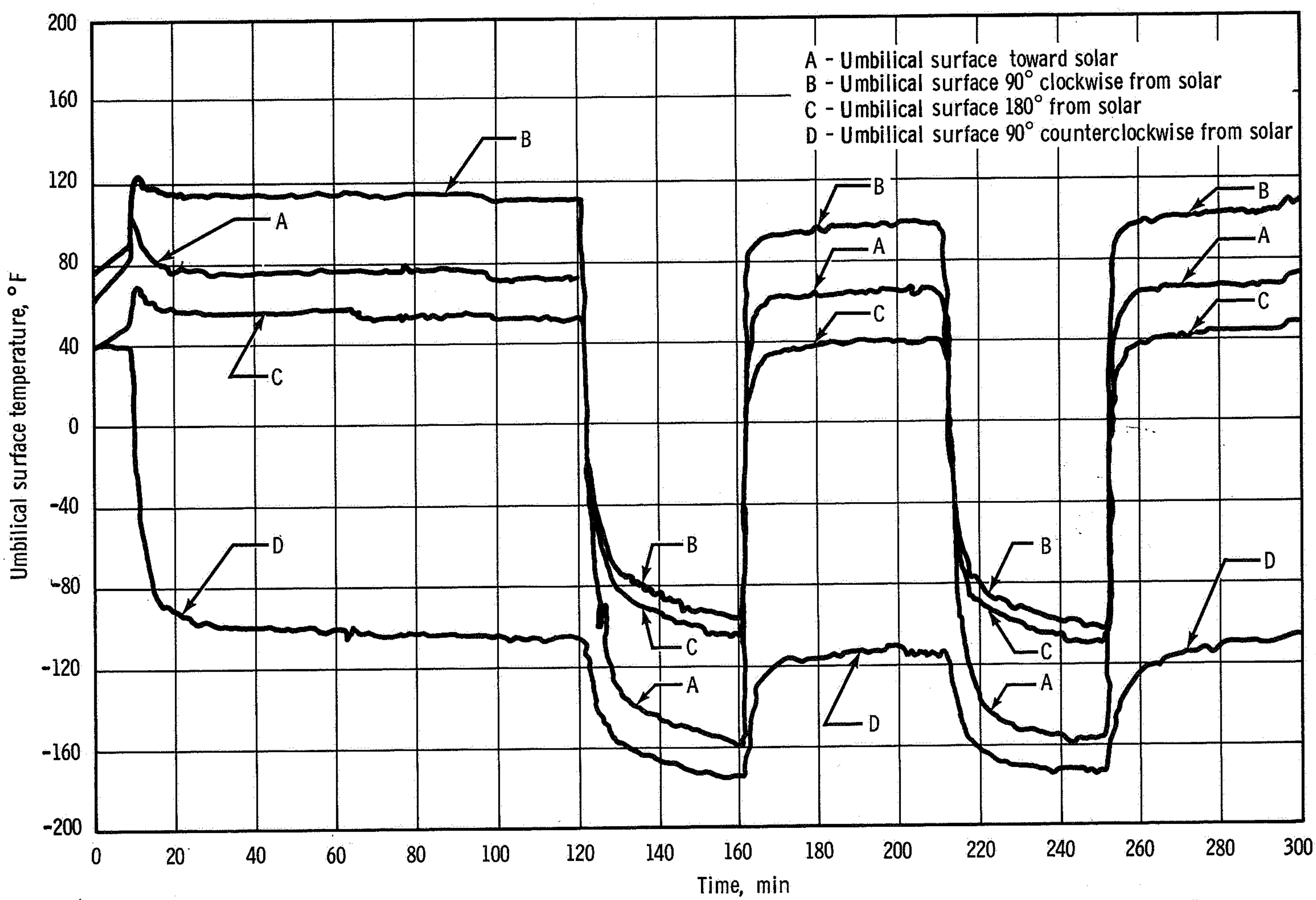

Figure 4.3-8. - Gemini ELSS environmental operation qualification test, umbilical surface temperature, test day 4.

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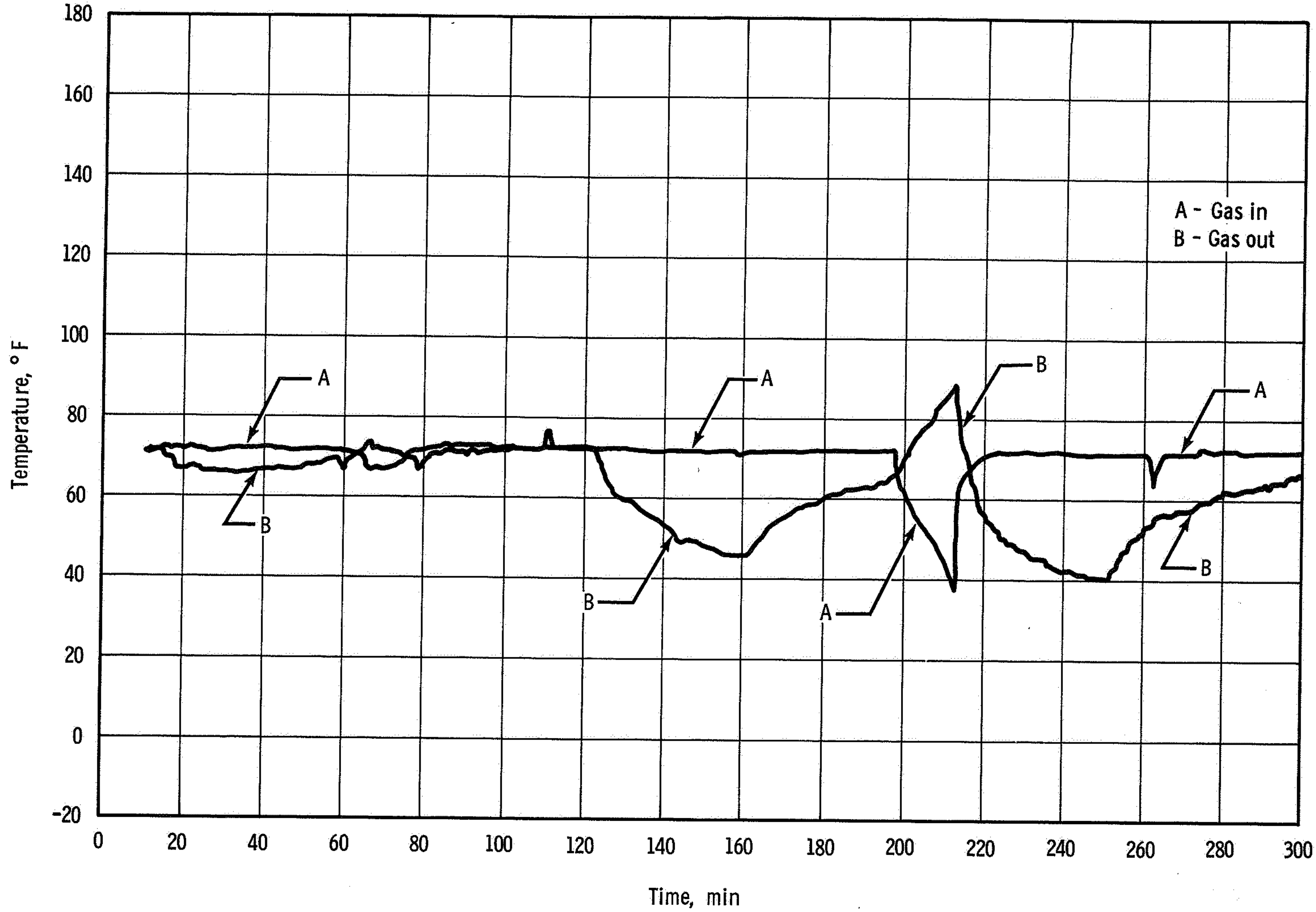

Figure 4.3-9. - Gemini ELSS environmental operation qualification test, umbilical gas temperature, test day 4.

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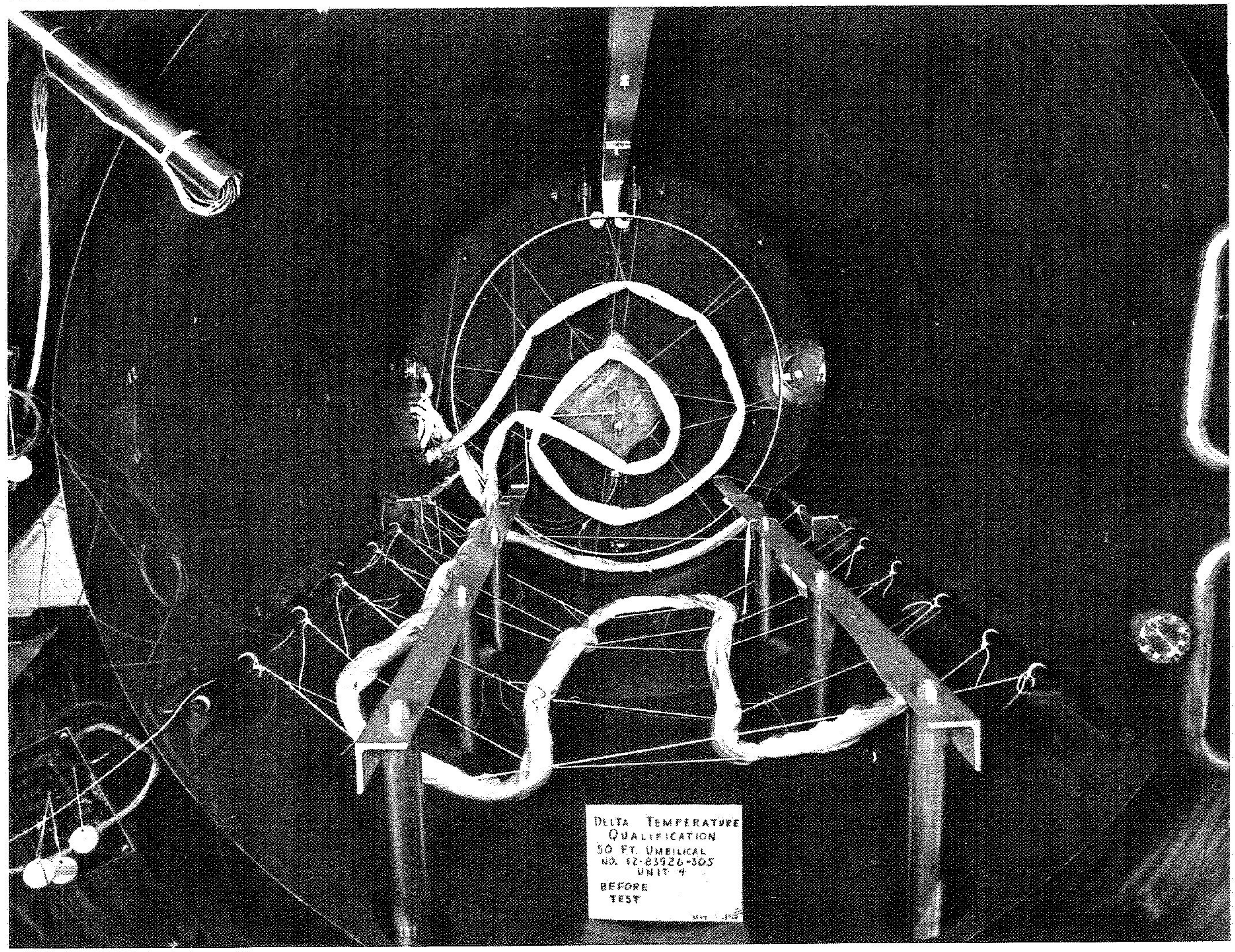

Figure 4.3-10. - Fifty-foot umbilical qualification test setup in Chamber E facility.

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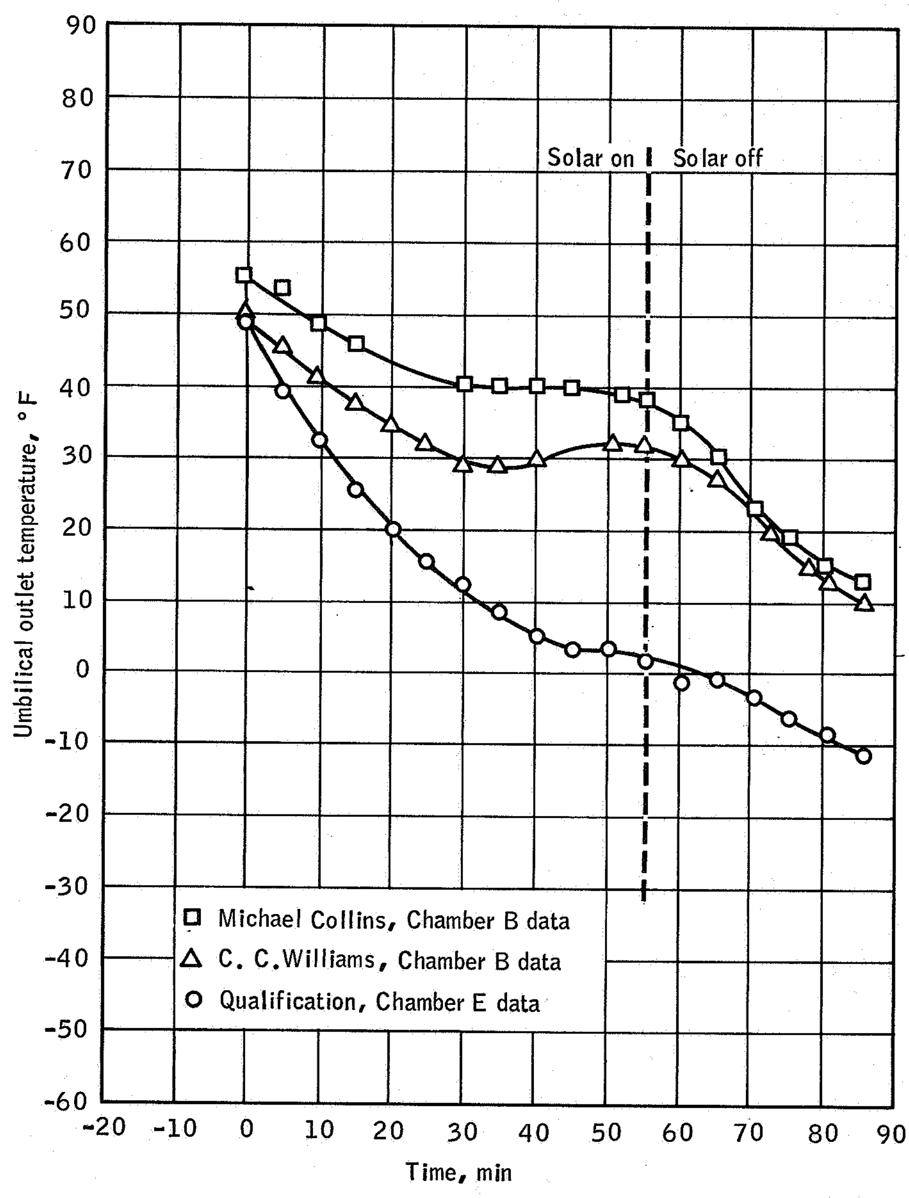

Figure 4.3-11. - Fifty-foot umbilical test.

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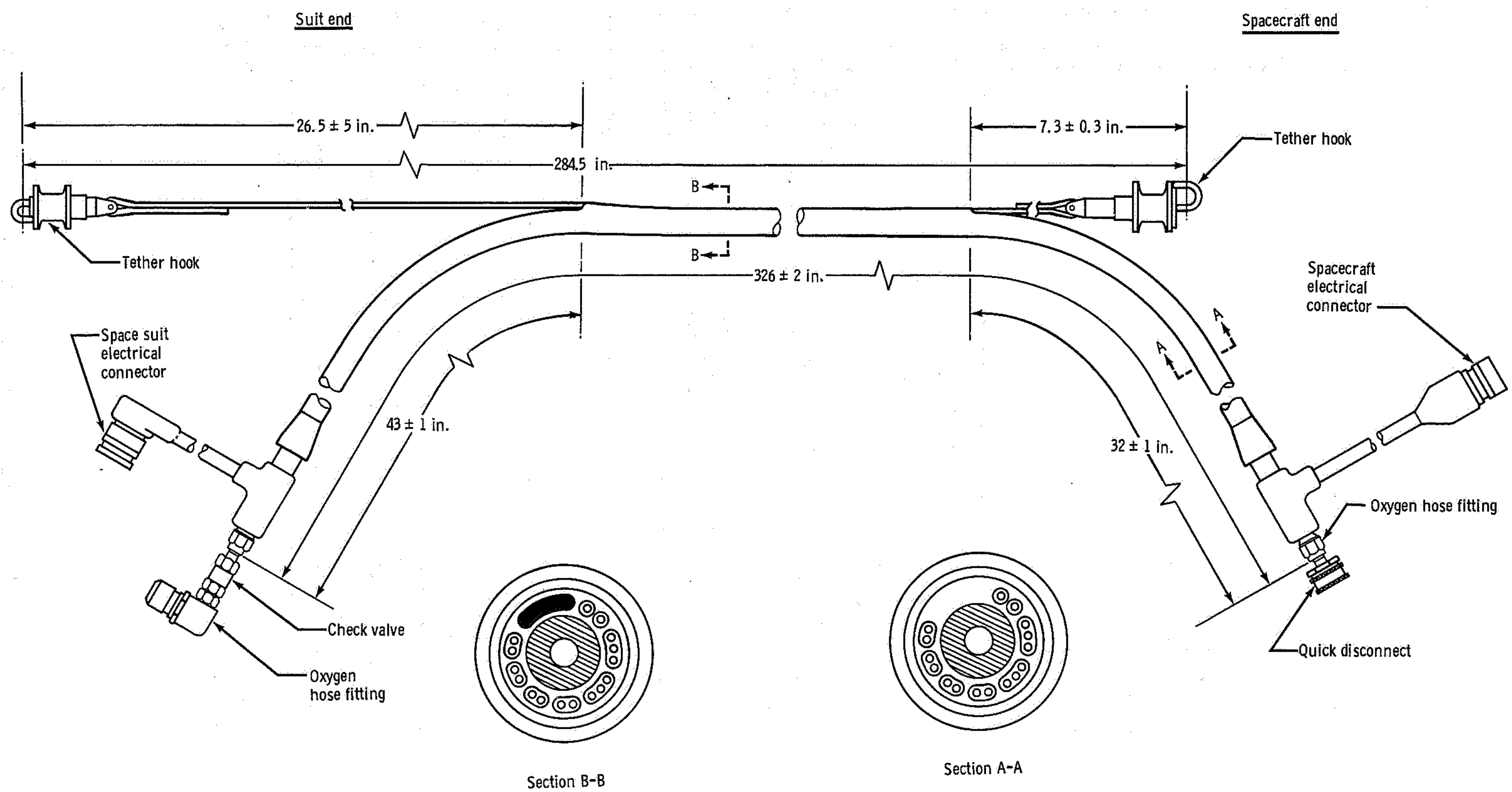

Figure 4.3-12. - Gemini IV umbilical assembly.

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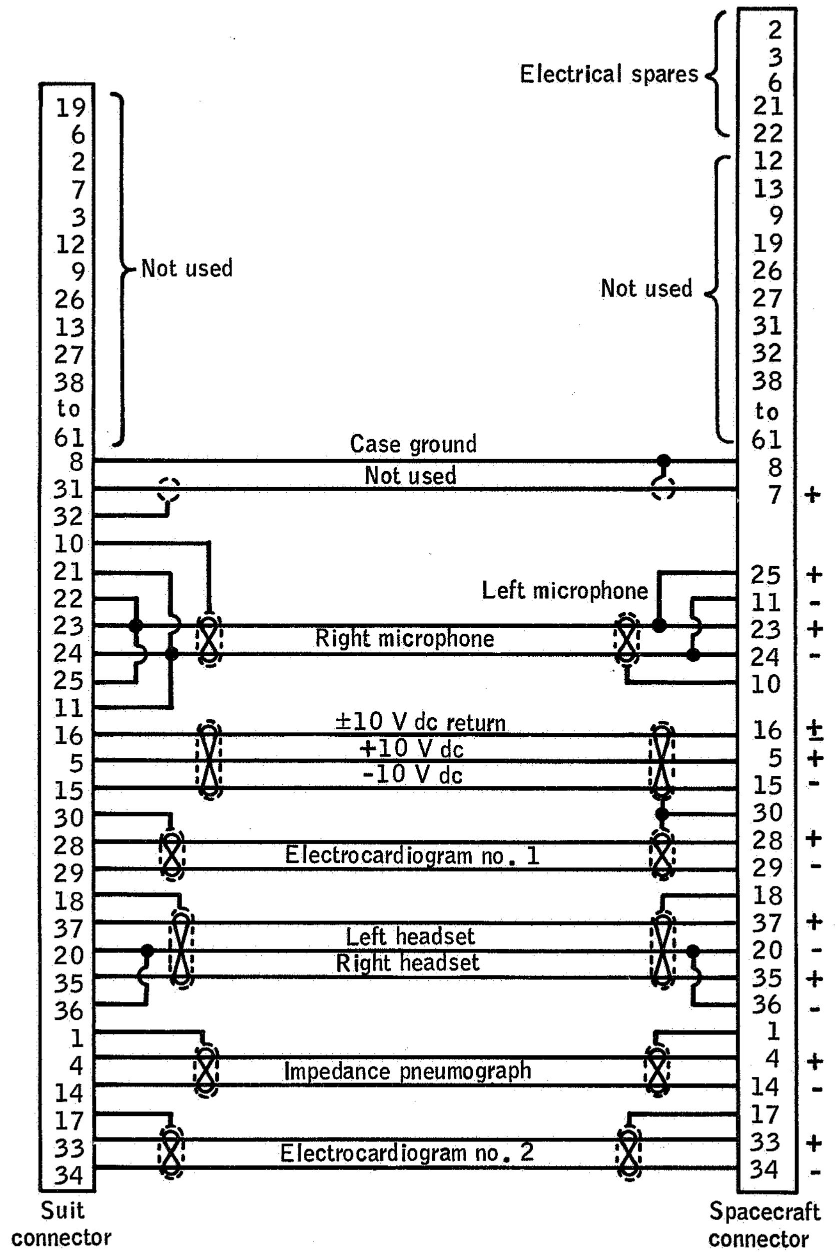

Figure 4.3-13. - Electrical schematic of Gemini IV umbilical.

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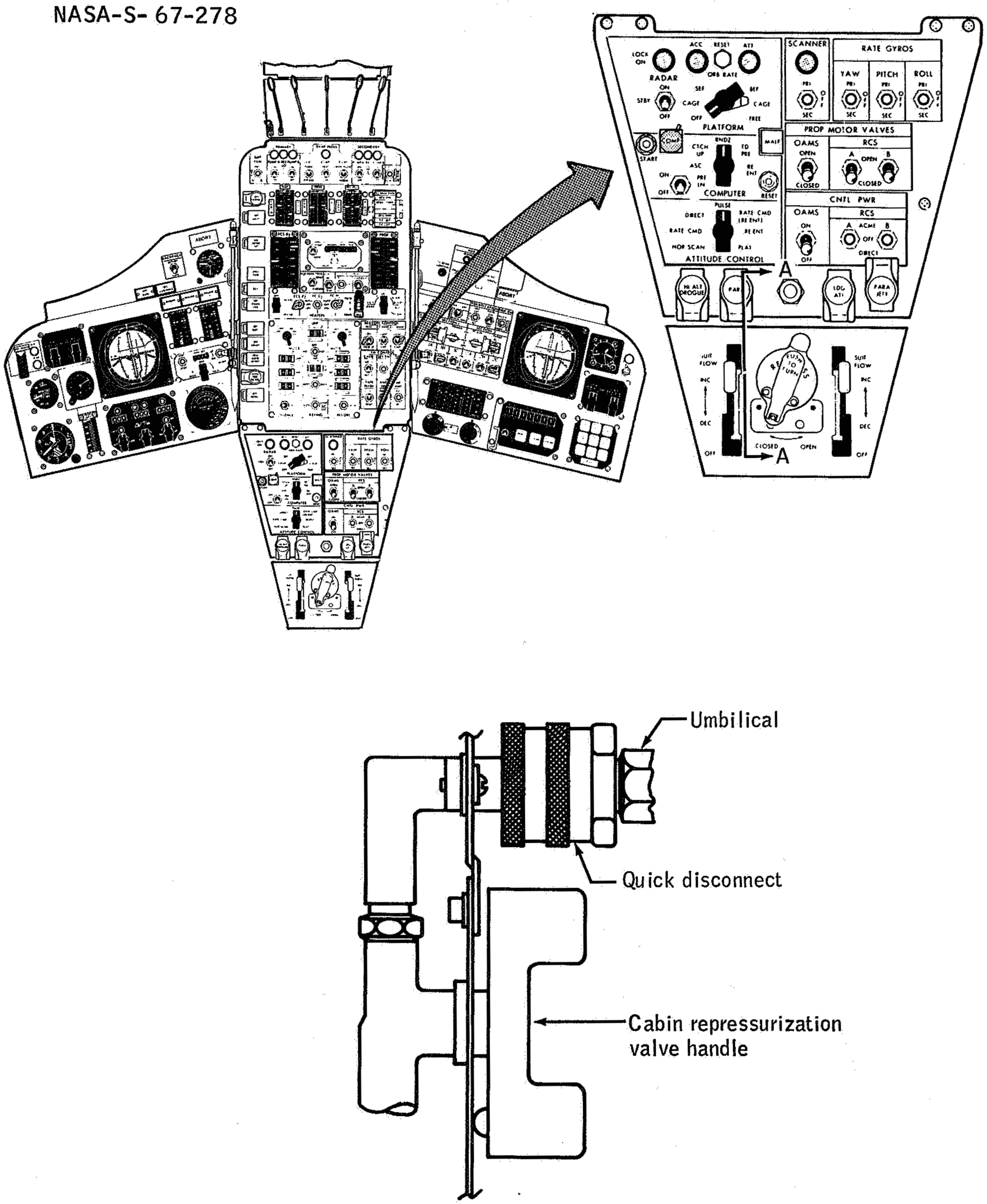

View A-A
(With umbilical quick disconnect attached)

Figure 4.3-14. - ELSS umbilical-spacecraft oxygen attachment point.

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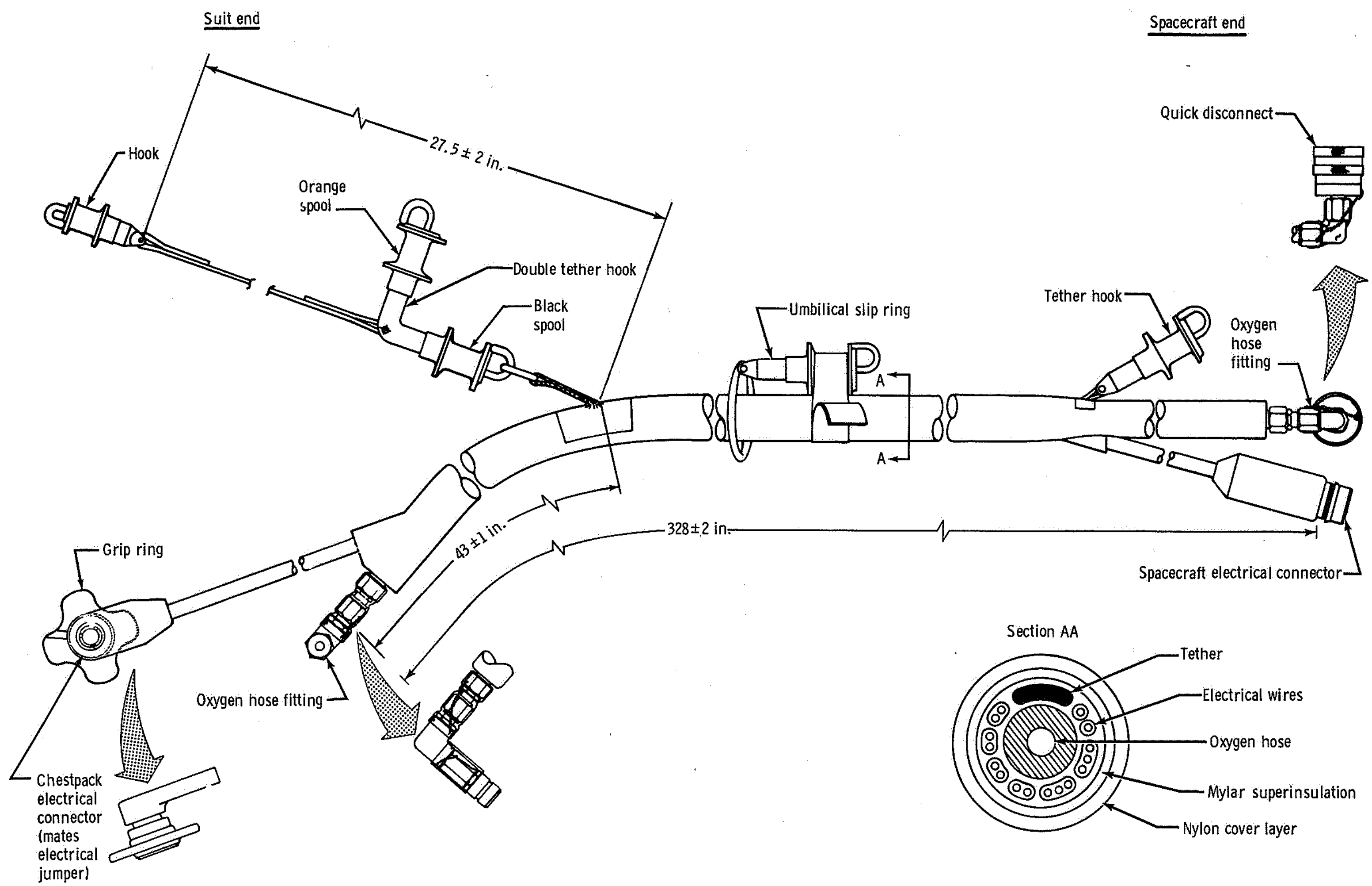

Figure 4.3-15. - ELSS 25-foot umbilical used for Gemini VIII.

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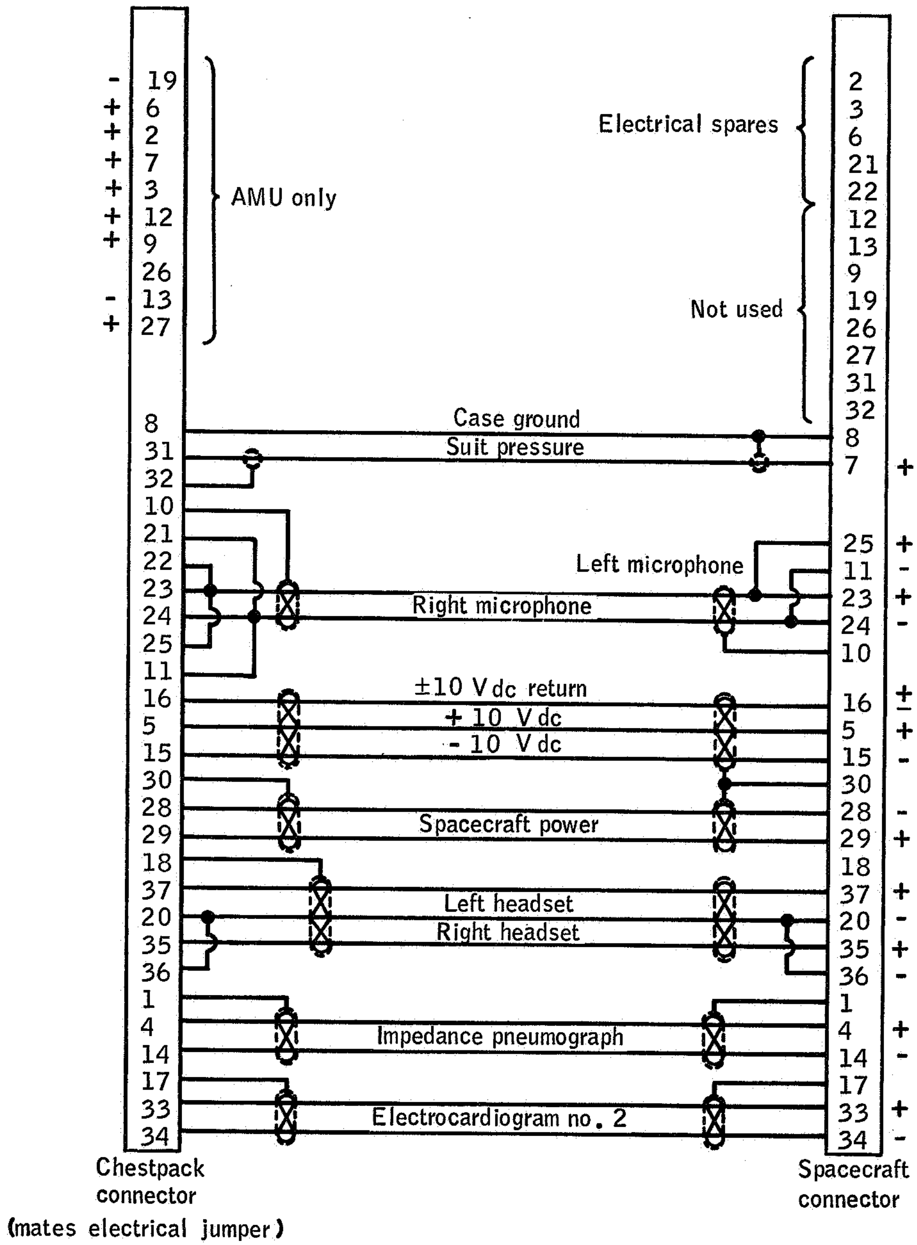

Figure 4.3-16. - Electrical schematic for Gemini VIII, IX-A, and XII umbilicals.

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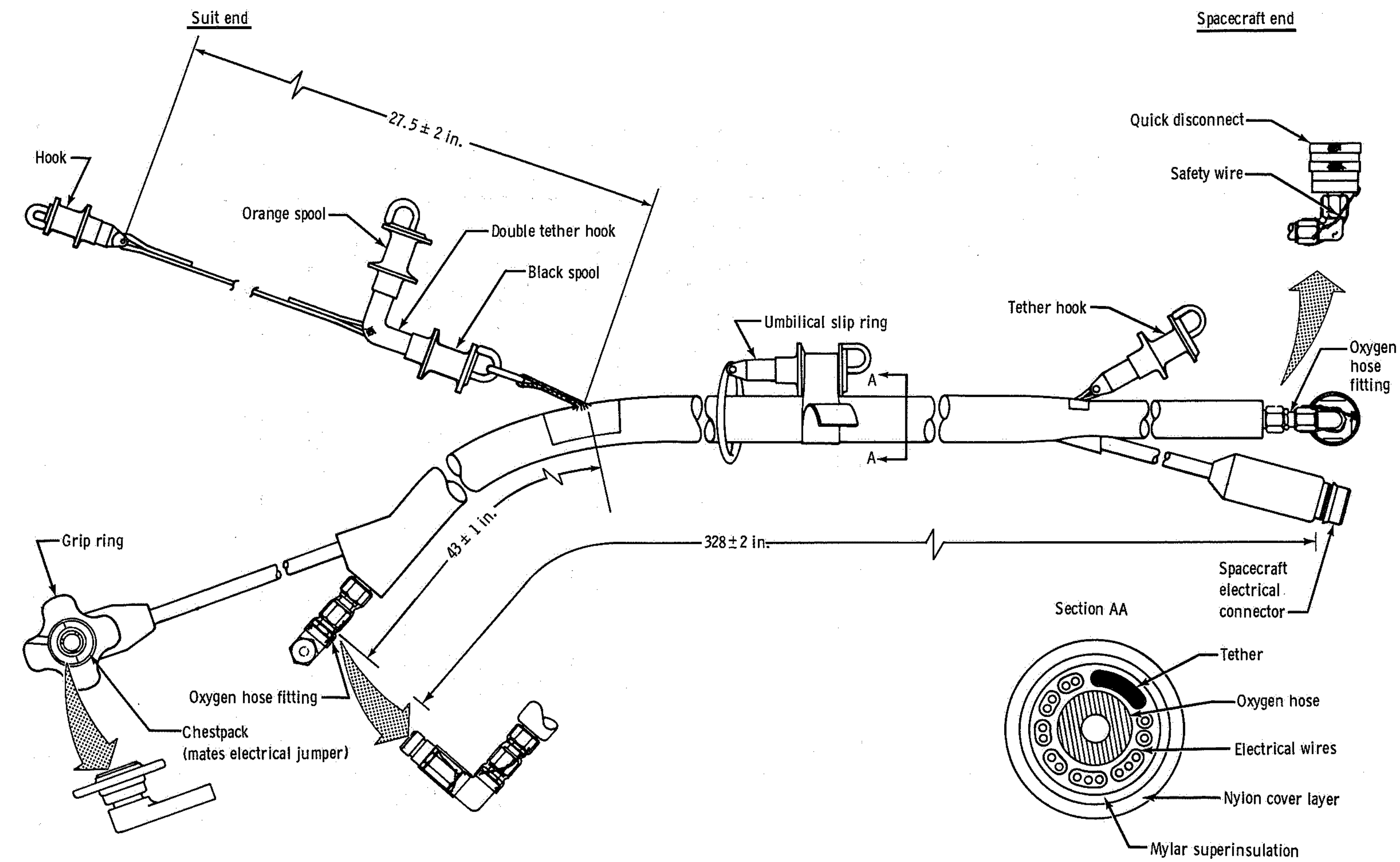

Figure 4.3-17. - ELSS-25 foot umbilical used for Gemini IX-A.

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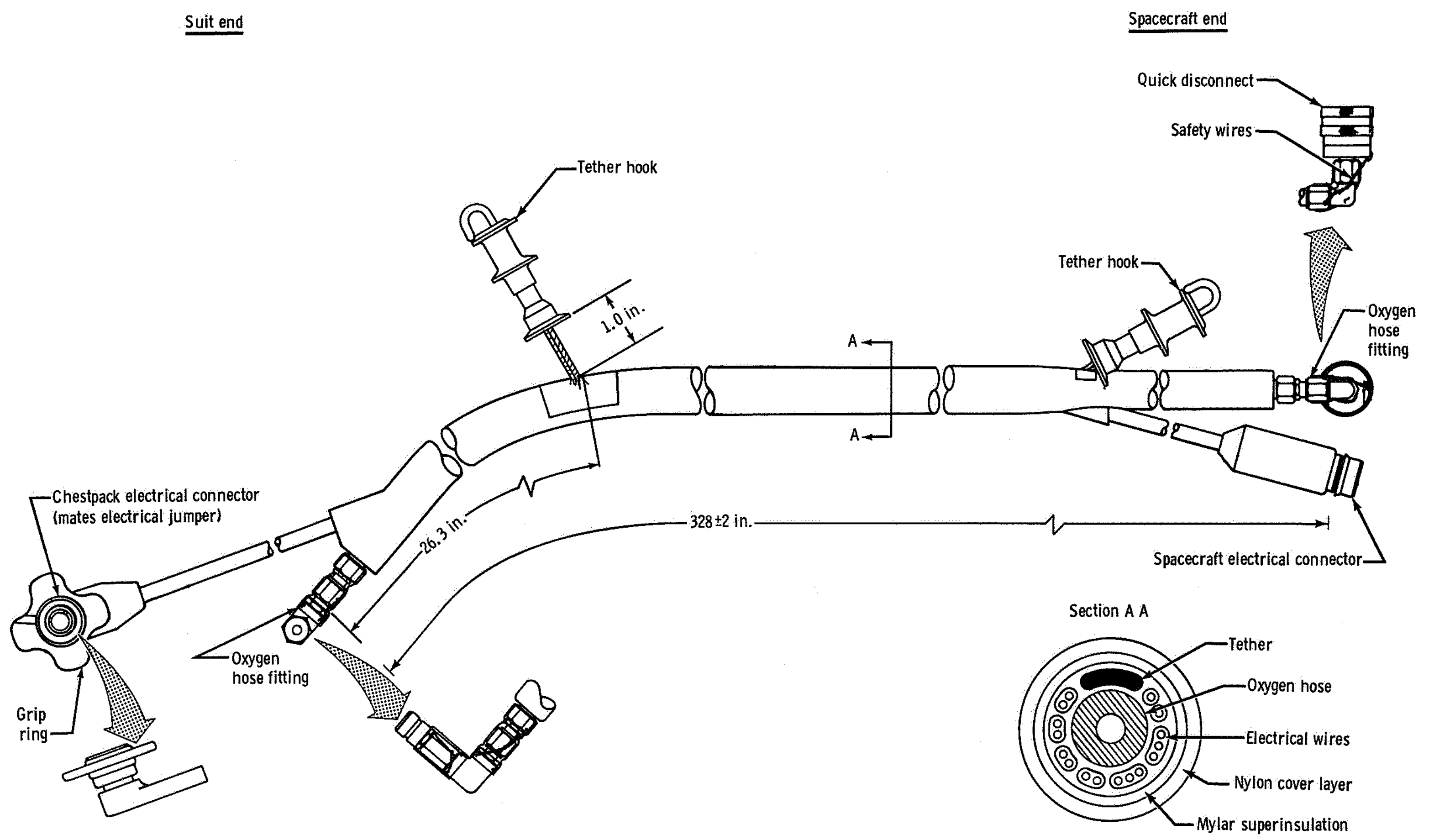

Figure 4.3-18. - ELSS 25-foot umbilical used for Gemini XII.

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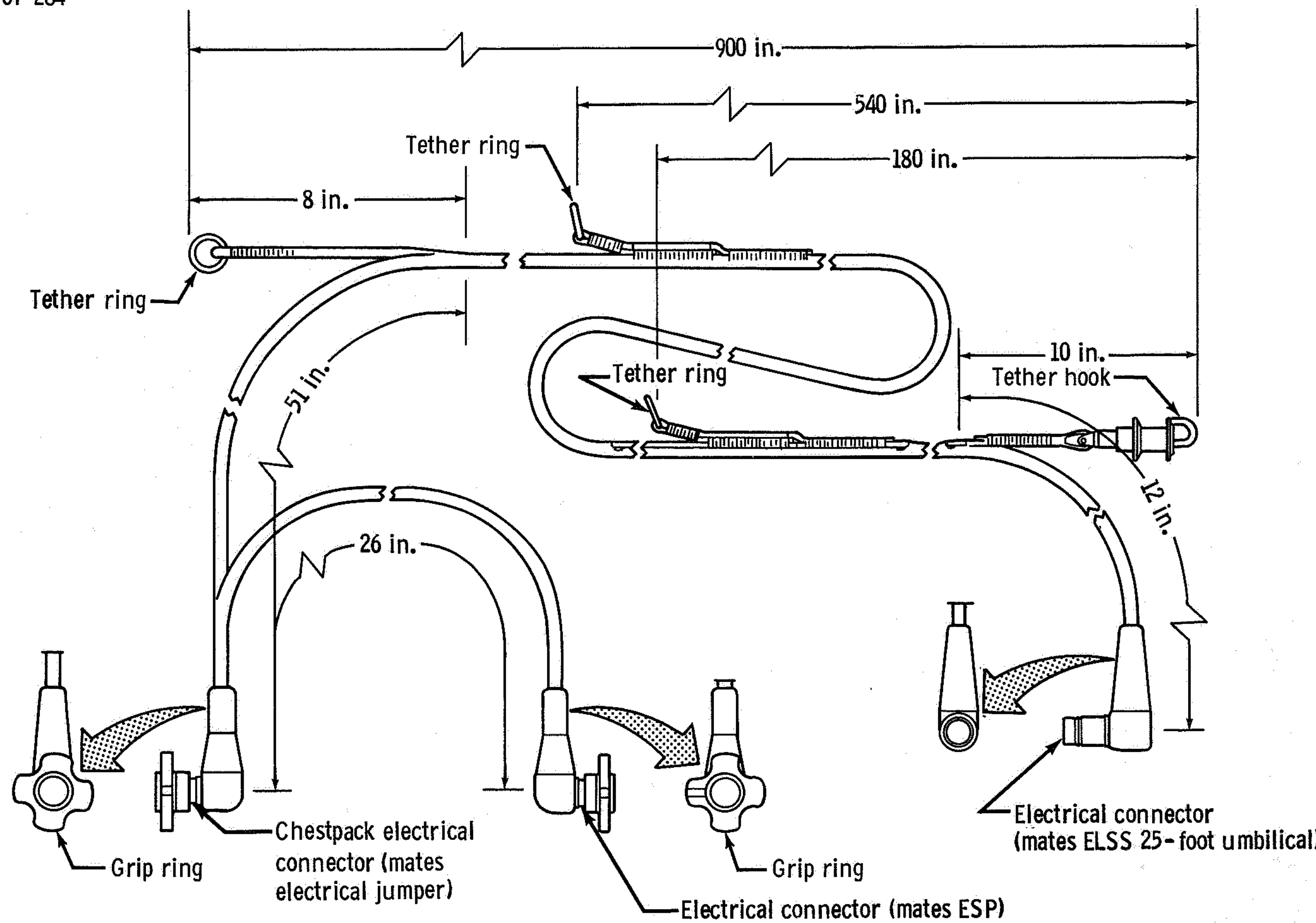

Figure 4.3-19.- Seventy-five-foot electrical tether.

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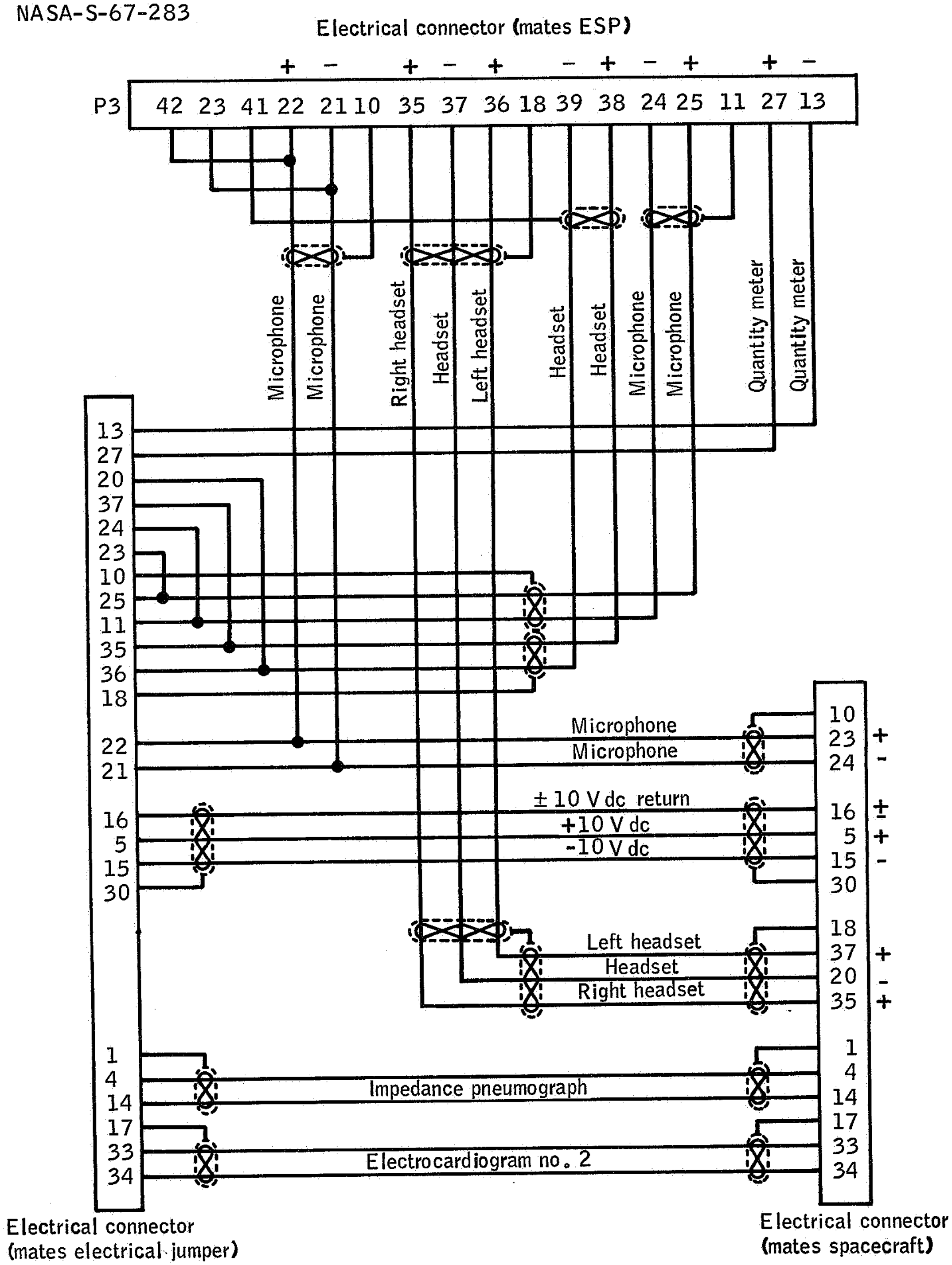

Figure 4.3-20. - Electrical schematic of 75-foot electrical tether.

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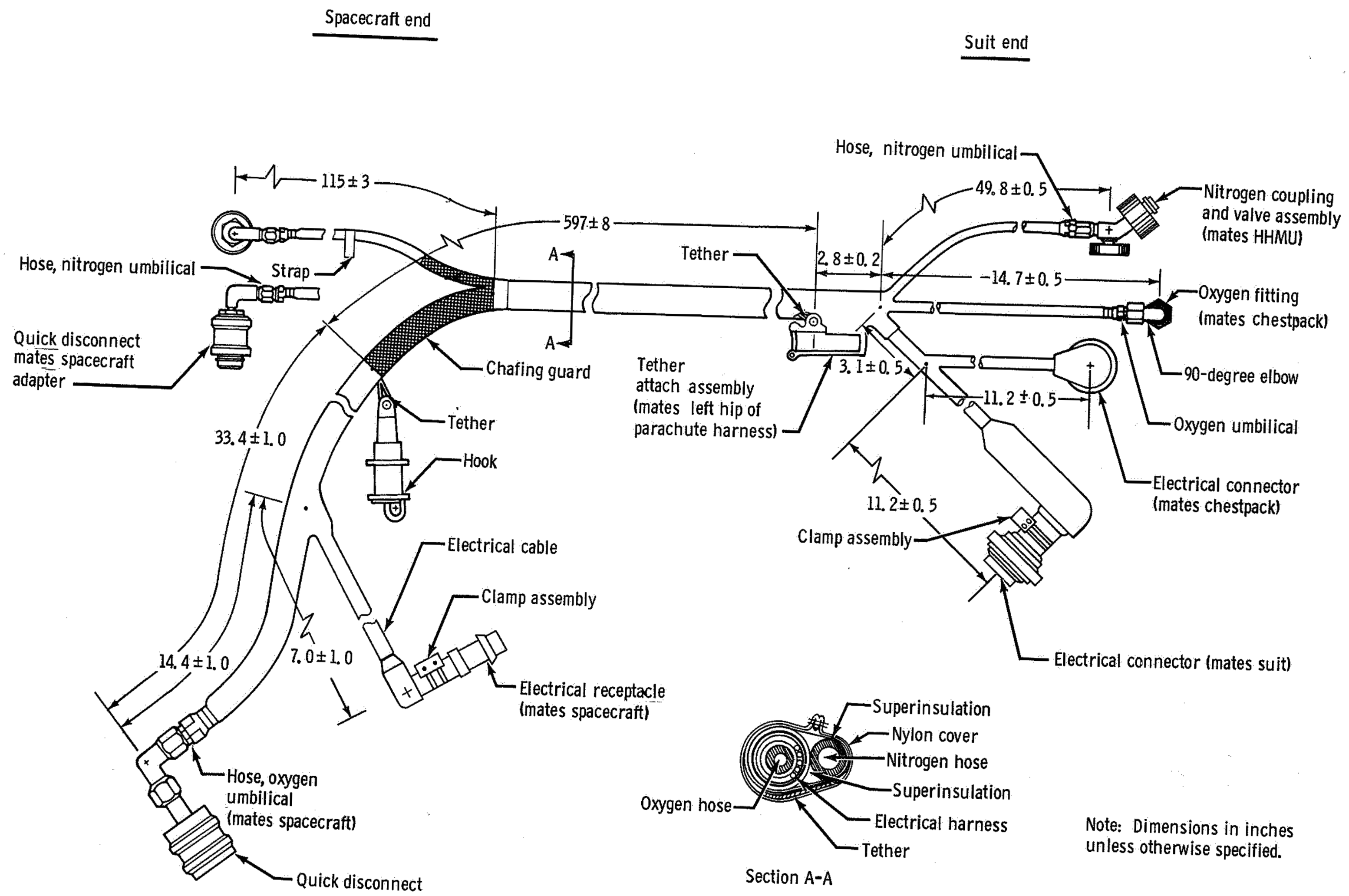

Figure 4.3-21. - ELSS 50-foot umbilical.

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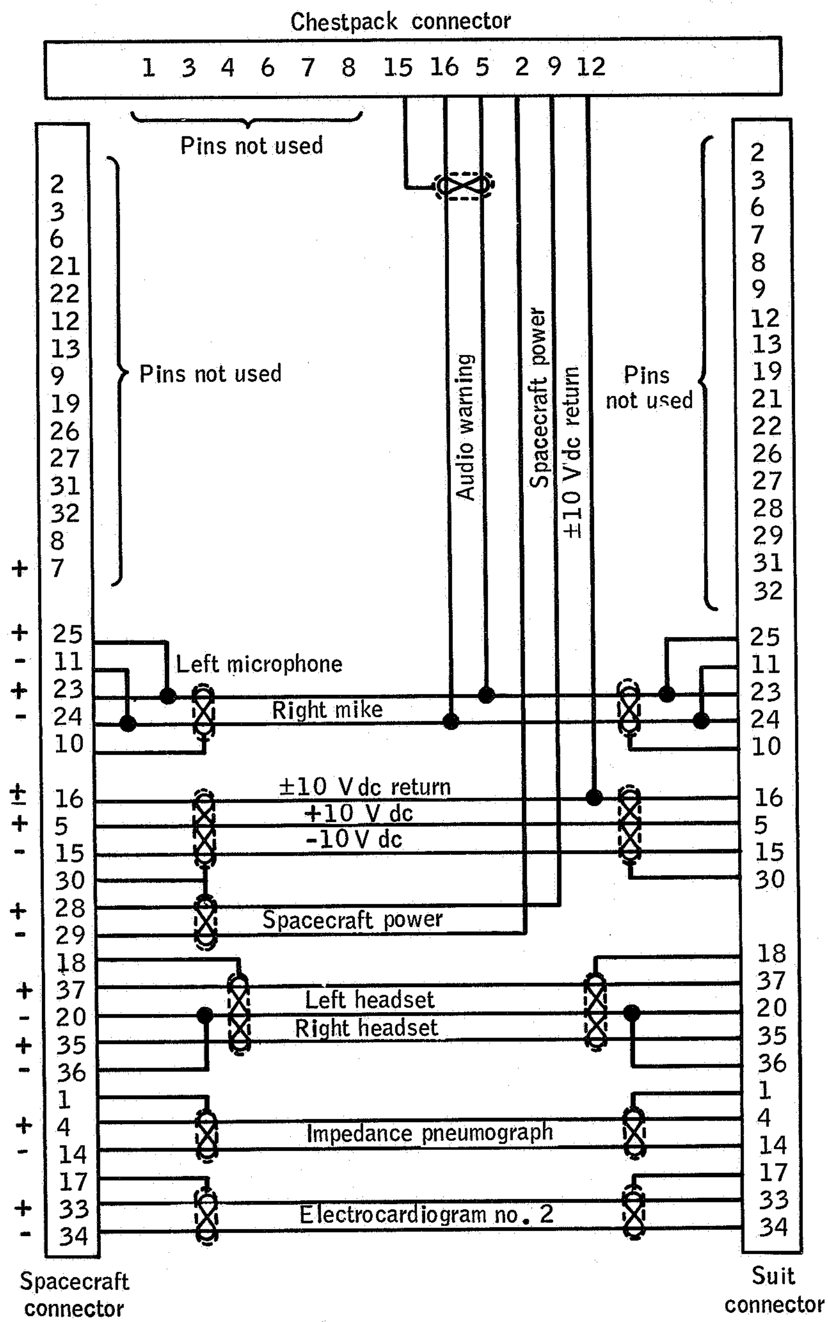

Figure 4.3-22. - Electrical schematic for Gemini X and XI umbilicals.

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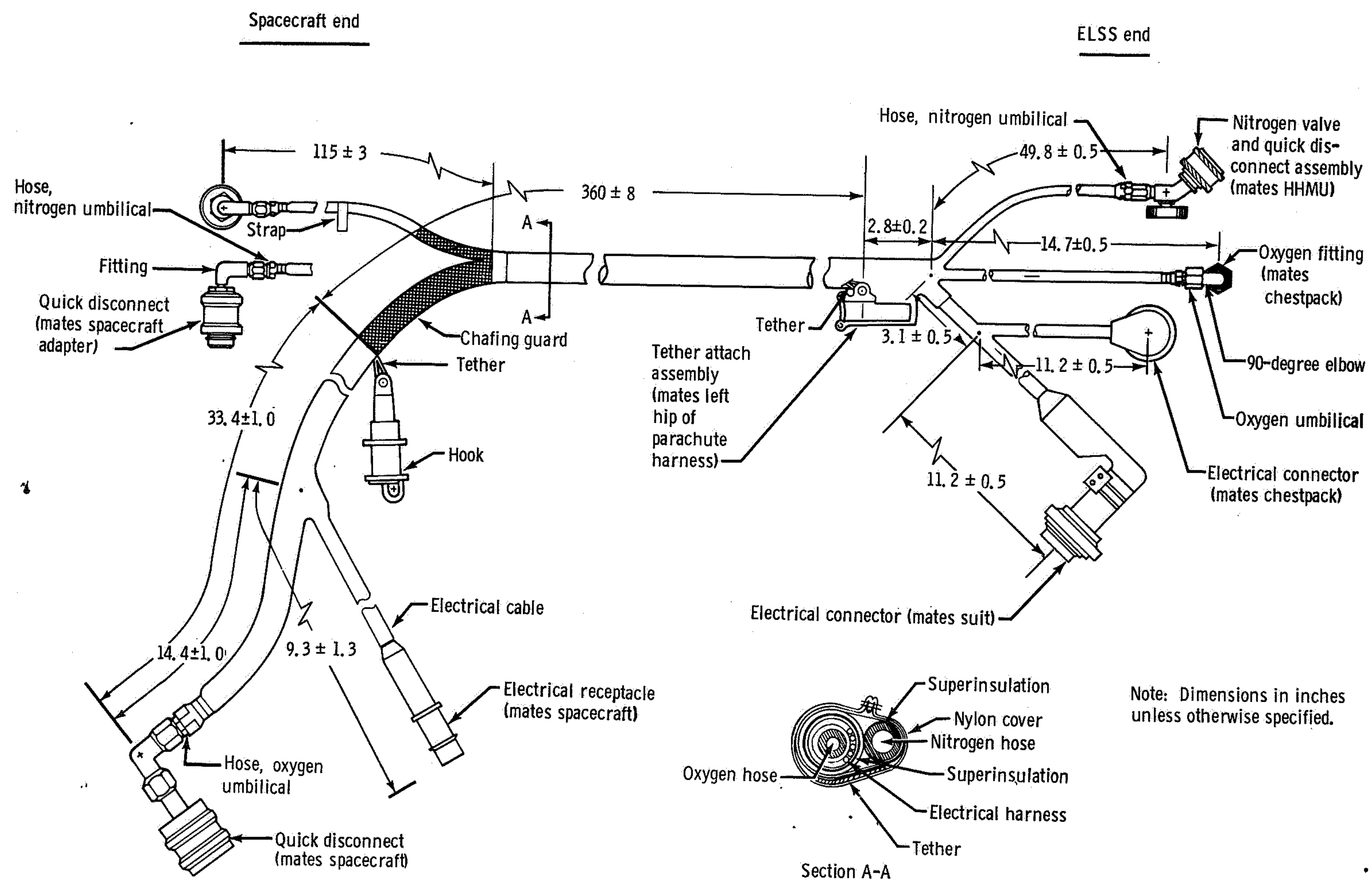

Figure 4.3-23. - ELSS 30-foot umbilical.

5.0 BODY POSITIONING AND RESTRAINTS

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5.0 BODY POSITIONING AND RESTRAINTS

The requirement for body restraints during extravehicular activity (EVA) was indicated on Gemini IV. After depletion of the propellant in the Hand Held Maneuvering Unit (HHMU), the pilot evaluated the umbilical as an aid for body positioning and for moving through space. It was concluded that the umbilical was usable only as an aid in moving to its origin, and that handholds would be required for other movements on the outside of the spacecraft. The significance of the requirement was emphasized when body restraint problems contributed to the premature termination of the Gemini IX-A and Gemini XI EVA missions. During the Gemini XII mission, with adequate restraint provisions, a great variety of EVA tasks were performed. For the Gemini XII EVA, 44 pieces of equipment were provided for extravehicular body restraint in contrast to the 9 pieces provided for Gemini IX-A EVA.

5.1 CONTROL OF BODY POSITION

5.1.1 Foot Restraints

The first major EVA work task attempted during the Gemini Program was the checkout and donning of the Astronaut Maneuvering Unit (AMU) on Gemini IX-A. The original restraint provisions for this task were two handbars and a horizontal footbar. Velcro pile on the footbar was intended to mate with Velcro hook on the pilot's boots; however, before the mission, the need for additional body restraint for this task was demonstrated during tests in the zero-g aircraft (fig. 5.1-1). A pair of foot stirrups was added to the horizontal footbar, and on subsequent tests in the zero-g aircraft (fig. 5.1-2), the checkout of the AMU was easily accomplished. The pilot forced his feet into the stirrups. The frictional force restrained his feet and allowed both hands to be free for working.

During the Gemini IX-A EVA, the pilot was unable to maintain body position using only the foot stirrups. The tasks that required the use of both hands, such as tether connections, were exceedingly difficult because the pilot had to stop working every few seconds and use his hands to regain proper body position. The foot stirrups were unsatisfactory when the pilot was unstowing the AMU controller arms. When he bent forward and applied a downward force to the controller arm, he created a moment which caused his feet to come out of the stirrups. In addition to the work involved in performing the tasks, the inadequacy of the foot restraints caused the pilot to exert a continuously high workload to maintain control of his body position. Heat and perspiration were produced at a rate that exceeded the removal capability of the life support system, and fog began to form on the space suit visor. This fogging increased until the pilot's vision was severely restricted, forcing him to discontinue his attempts to don and use the AMU.

As a result, new requirements for foot restraints were developed, and the investigation of underwater simulation of zero g was initiated. Equipment modifications were also incorporated to simplify the EVA tasks on subsequent missions.

Analysis of the Gemini IX-A body-restraint problem resulted in the following criteria for design of new foot restraints: motion must be restrained in all six degrees of freedom; the foot restraints must position the EVA crewman for convenient access to the intended work task; and release of the feet must not depend on the action of any moving mechanism. Molded fiberglas foot restraints incorporating these features were designed for the Gemini XI and XII spacecraft. These restraints were custom-fitted to the pilot for each flight and were mounted on a platform attached to the inside surface of the spacecraft adapter equipment section (fig. 3.5-2). During the zero-g aircraft training, the Gemini XI and XII flight crews evaluated the foot restraints and found them to be satisfactory for all applicable tasks. The Gemini XII flight crew also evaluated the restraints in underwater zero-g simulation tests with the same results.

5.1.2 Underwater Zero-G Simulation

The initial evaluation of the underwater zero-g simulation was conducted by the Gemini IX-A pilot shortly after the mission. The underwater mockup equipment was similar to the Gemini IX-A spacecraft, and the pilot completed the AMU donning procedures previously attempted in flight. The pilot concluded that the underwater zero-g simulation very nearly duplicated the actual weightless condition and the accompanying problems experienced in the actual flight. The extravehicular tasks planned for Gemini X, XI, and XII were performed in the underwater zero-g simulation, and recommendations were made concerning the required restraints and the feasibility of proposed tasks. The simulations for Gemini X and XI were performed using contractor test subjects. For Gemini XII, the prime and backup pilots both participated in underwater simulations for procedures development and training. Underwater simulation of zero g was particularly applicable to the problems of body positioning and restraints.

5.1.3 Handholds and Tether Devices

Minor restraint problems were encountered during the Gemini X EVA, but performance of the planned tasks was not seriously affected. The pilot had difficulty controlling his body position while using the outer edge of the target vehicle docking cone as a handrail. Attachment of the umbilical nitrogen fitting also involved minor difficulty because one of the adapter section handrails had not fully deployed. The tasks were accomplished with one hand, while the other hand was used for restraint.

For the Gemini XI mission, the tether for the spacecraft/Gemini Agena Target Vehicle (GATV) tether evaluation was assembled and stowed so that the pilot could attach the tether to the spacecraft docking bar with one hand. With the other hand, he could use one of three handholds on the back surface of the docking cone to maintain position. However, the pilot had been trained to have both hands free, and he had been able to wrap his legs around the spacecraft nose and to wedge his legs into the docking cone. The pilot was able to place himself in the position by arm force using the handholds provided. In the zero-g aircraft simulations, the pilot was able to move from the hatch, to force himself into the restrained position, and to make the complete tether hookup in about 30 seconds. In orbit, however, this positioning technique proved extremely difficult, and the pilot expended a great deal of energy during the 6 minutes that were required to move from the hatch and to make the tether hookup. The resulting fatigue was the major factor in his inability to continue the flight plan for the EVA. Similar to the Gemini IX-A pilot, the principal expenditure of energy by the Gemini XI pilot was the effort required to overcome the forces of the space suit to maintain the desired body position. The frictional forces induced by the pilot in wedging his legs into the docking cone were not sufficient to overcome the tendency of the pressurized suit to straighten itself out and push him out of the docking cone.

As a result of this experience, the extravehicular objective for Gemini XII was redirected from an evaluation of the AMU to an evaluation of body restraints required for representative extravehicular tasks. Also, underwater zero-g simulation was included as part of the flight crew training program for the Gemini XII mission.

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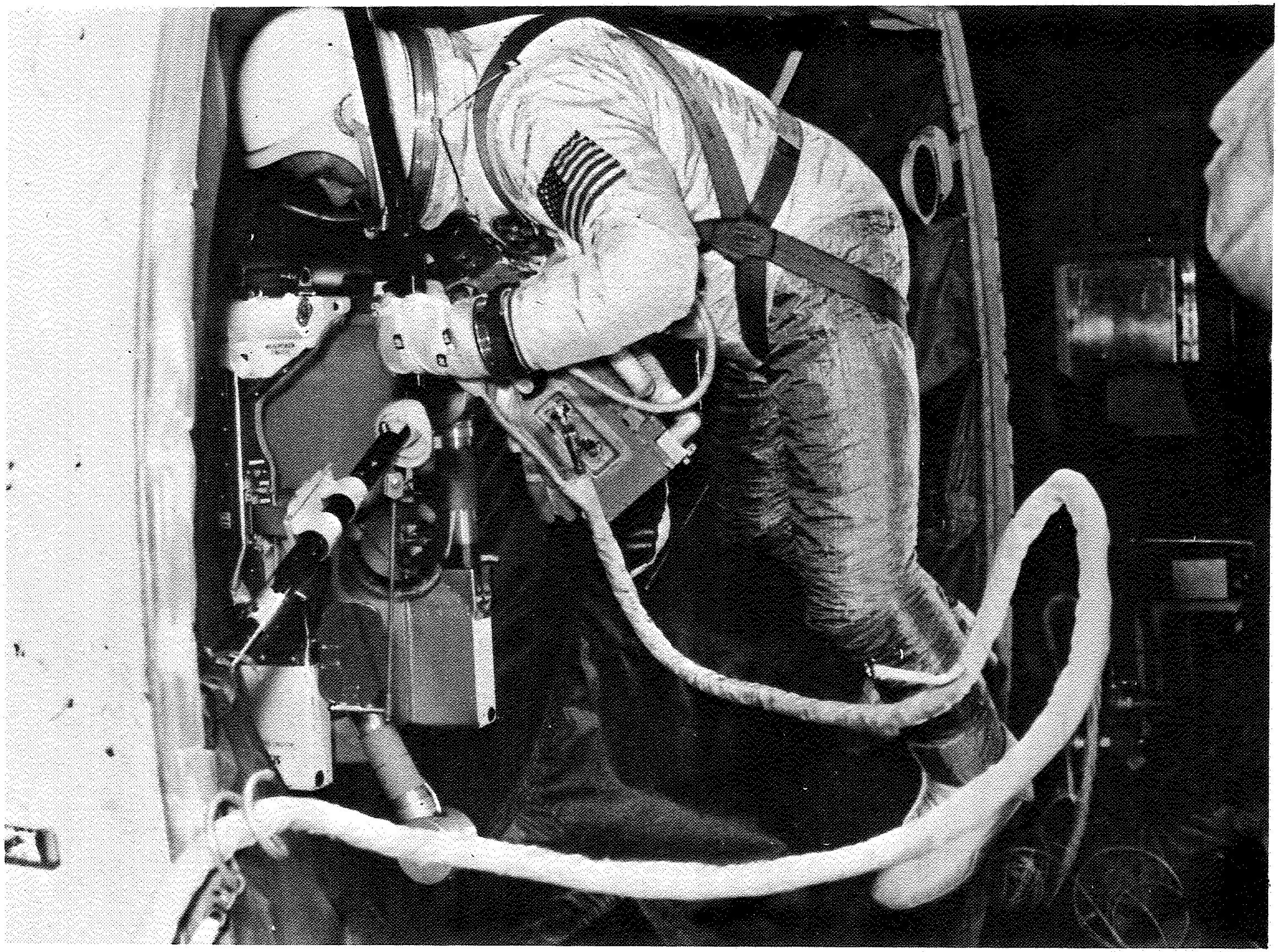

Figure 5.1-1. - AMU donning without foot retraints in zero-g aircraft.

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Figure 5.1-2. - AMU donning with foot stirrups in zero-g aircraft.

5.2 RESTRAINT EQUIPMENT

The use of restraint devices for EVA in the Gemini Program is summarized in table 5.2-I. Descriptions of these devices and the results of their use follow.

5.2.1 Rectangular Handrails

Two handrails (fig. 5.2-1) were installed along the spacecraft adapter to assist the pilot in moving from the cockpit to the adapter equipment section where various tasks, such as donning the AMU, were to be performed. The painted metal handrails were 0.55 by 1.25 inches in cross section. The forward handrail was 21 inches long and was mounted on the retrograde section of the adapter. The aft handrail was 46 inches long and was mounted on the adapter equipment section. There was a 9-inch gap between the two sections. Both handrails were flush with the spacecraft surface at launch, but were 1.5 inches above the spacecraft surface when deployed. The aft handrail was deployed automatically when the spacecraft separated from the launch vehicle. Improper rigging resulted in failure of this handrail to deploy fully on the Gemini X mission; however, it deployed properly on Gemini IX-A, XI, and XII. The forward handrail was deployed manually by the extravehicular pilot, and it functioned properly on all missions.

The Gemini IX-A and XII pilots used the handrails to traverse the 8 feet from the cockpit to the aft end of the spacecraft. Limited suit mobility and interference of the Extravehicular Life Support System (ELSS) chestpack required the pilots to move their hands one after the other in a sideways motion along the handrail, rather than hand-over-hand. The Gemini X pilot used the handrail for transit and for a handhold while making and breaking the nitrogen connection on the 50-foot umbilical. Comments by the pilots indicated that this handrail was a satisfactory device for transit between two points on the spacecraft surface. A rectangular, rather than a cylindrical, cross section was preferred by the pilots because the rectangular shape offered more resistance to rotation for a given hand force and allowed better control of body attitude. In a pressurized Gemini suit, the width of the rectangular handrail (1.25 inches) was a good size for gripping.

5.2.2 Large Cylindrical Handbars

A pair of large, cylindrical, painted metal handbars was installed in the adapter equipment section (fig. 5.2-2) to permit the pilot to move from the rectangular handrails to the work area and to provide restraint while positioning his feet in foot restraints or while working. The two handbars were located symmetrically on each side of the work station. The handbars were retracted at launch so that they would clear the launch vehicle tank dome. After separation of the spacecraft from the launch vehicle second stage, the handbars were pyrotechnically deployed on command from the crew. The deployment procedure was satisfactory on each mission. The method of travel, when using the large cylindrical handbars, was also to the side. Although the pilots indicated a preference for rectangular cross section, they were able to introduce the significant body torques required to position their feet in the foot restraints with these cylindrical handbars. The 1.38-inch diameter of the cylindrical handbars was the most favorable size.

5.2.3 Small Cylindrical Handrails

Small cylindrical handrails were mounted on the right and left sides of the Gemini XII GATV (figs. 5.2-3 and 5.2-4). They were made of unpainted metal 0.317 inch in diameter, and the two segments were 10.5 and 31.5 inches in length. The handrails were small enough to be used as waist tether attach points and as handholds.

5.2.4 Telescoping Cylindrical Handrail

The Gemini IX-A and XI pilots used the Reentry Control System thrusters as handholds for transit from the spacecraft hatch to the spacecraft nose, but these handholds were inadequate. When the Gemini XI pilot attempted to move from the hatch to the nose area, he missed the docking bar and drifted at the end of the umbilical in a curved path until he made contact with the spacecraft adapter section behind the hatch. On a second attempt, the pilot managed to push from the hatch to the docking bar.

The telescoping handrail (figs. 5.2-5 and 5.2-6) was installed to facilitate transit from the spacecraft hatch to the spacecraft nose on the Gemini XII EVA. The telescoping handrail was stowed in the compressed condition above the pilot's right shoulder and near the hinge of the right hatch. In the stowed configuration, the handrail was 37 inches long and 1-3/8 inches in diameter and was constructed of anodized aluminum. After the cabin was decompressed and the hatch was opened for the standup EVA, the pilot unstowed and manually extended the four-section handrail to a maximum length of 99 inches. The pilot then installed the small end (0.625-inch diameter) of the handrail in a special receptacle in the docking cone and the large end on a mounting bolt located in the spacecraft center beam between the hatches. During the umbilical EVA, the pilot used this handrail for transit between the spacecraft hatch and the spacecraft nose and as a handhold for several changes in body attitude. The flexibility of the handrail was reported by the pilot to be undesirable. When the handrail flexed, the pilot had less control of his body position and attitude. The pilot also attached a waist tether into the ring on the telescoping handrail. At the conclusion of the Gemini XII umbilical EVA, the pilot jettisoned the handrail.

5.2.5 Fixed Handholds

Three fixed handholds were provided on the back of the docking cone on the Gemini XI GATV to provide restraint during the spacecraft/GATV tether attachment. Two similar handholds (fig. 3.6-2) were provided on the back of the docking cone on the Gemini XII GATV. The handholds were 6.5 inches in length and 1 inch in diameter, with a 1.5-inch clearance from the surface. These handholds were coated with a resilient friction material which was helpful. The handholds proved very useful in flight; however, the pilot favored a metal handhold of rectangular cross section rather than the coated cylinder.

5.2.6 Flexible Velcro-Backed Portable Handholds

Flexible Velcro-backed portable handholds (fig. 5.2-7) were evaluated as restraints and as maneuvering aids during the Gemini IX-A mission. Two fabric-backed nylon Velcro-pile pads were carried in the spacecraft. The pilot attached the pads to his gloves with an elastic strap wrapped around the palms of his hands. There were 80 patches of nylon Velcro hook on the surface of the spacecraft to engage the pile handholds. The significant results were:

(a) The elastic attachment was inadequate, and one of the handholds was pulled off the pilot's hand.

(b) The contact forces were insufficient to accommodate controlled maneuvering or body attitude, but were adequate for holding a stationary position.

(c) The unprotected nylon Velcro hook on the spacecraft nose was damaged by launch heating.

5.2.7 Rigid Velcro-Backed Portable Handholds

For Gemini XII, four trowel-shaped, rigid, Velcro-backed, portable handholds (fig. 5.2-8) were installed in the EVA work areas. The handholds were 6.5 inches in length and 1 inch in diameter, and they were coated with resilient material. Each handhold also had a tether attachment ring (1.5 inches in diameter) at one end of the handle. Two of the handholds had about 9 square inches of nylon Velcro pile, and the other two had about 16 square inches of polyester Velcro pile. The handholds were stowed for launch on surfaces of nylon Velcro hook and secured by pip-pin devices. Polyester Velcro hook was located on built-up flat surfaces in four places on the target vehicle to engage the Velcro pile on the handholds.

Detailed evaluation of the rigid handholds was not included in the flight plan for the Gemini XII EVA because of the limited time available for EVA. Analyses and simulations indicated a number of limitations to the usefulness of the devices. For example, best utilization of the devices required that the Velcro be used in shear rather than in tension, and this complicated the usage. Also, to serve as restraints, the retention force should be significantly greater than the application force. Polyester Velcro had a higher retention force than the nylon Velcro, but it had not been evaluated as thoroughly. The use of steel Velcro appeared to make the use of these devices feasible; but because of the potential hazard to the space suit gloves, steel Velcro could not be used under these conditions. The consensus was that fixed handholds were superior to portable devices and that the portable handholds should be used only when fixed handrails or handholds could not be provided.

5.2.8 Waist Tethers

The Gemini XII waist tethers (fig. 5.2-9) were made of stiff nylon webbing with a length adjustment buckle and a large hook for attachment to the various tether attachment rings. The waist tethers were looped around the pilot's parachute harness and were fastened together with two large snaps. A large fabric tab was provided to facilitate opening the snaps in a pressurized suit. A D-shaped ring was provided for making length adjustments, and it was used several times by the pilot. The adjustment buckle, a conventional single-loop buckle, allowed length adjustment approximately from 21 to 32 inches. The large flange hooks, used for most extravehicular applications after Gemini IX-A, were used on the waist tethers.

The waist tethers were installed on the parachute harness by the pilot during preparation for the umbilical EVA. The locations of the tether attachments at points slightly below waist level were optimum. A thin metal plate with a ring on each end was provided to hold the waist tether hooks when they were not being used by the EVA pilot. The device was slightly longer than the front width of the ELSS chestpack and was attached with Velcro. The pilot used a variety of devices for attaching the tethers in the spacecraft adapter section and on the target vehicle.

Once, because of the lack of body attitude control, the pilot experienced a slight difficulty in moving a tether to a new attachment point. With one hand occupied in making a waist tether attachment, the pilot had to use the other hand to control his body attitude. Therefore, a pair of handholds, or other restraint, near each pair of tether attachment points would be desirable. Also, it was determined that the waist tether attachment points should be as far apart as possible (42 to 48 inches), consistent with the pilot's reach in the pressurized suit. The attachments were easier to make if the attachment points were located at the pilot's sides rather than directly in front of him; and torques were minimized with the widespread tether attachment points. The pilot observed that few adjustments to the tether length were required; consequently, provisions for adjustments could be eliminated from future body tethers.

In the spacecraft adapter section and with only the waist tethers for restraint, the pilot was able to install and tighten a bolt to about 250 inch-pounds, using a conventional dial-indicator torque wrench. The wrench handle was 9 inches long; hence, the force applied was approximately 28 pounds. Also, with only the waist tethers for restraint, the pilot was able to pull nylon Velcro pile strips 4 inches long and 5 inches wide from both nylon and steel Velcro hooks and to disconnect and reconnect three electrical connectors. The pilot made a variety of hook and ring connections, including the use of hooks and rings of the same sizes which had proved impossible for the Gemini IX-A pilot.

The waist tethers, when attached to the tether attachment points on the target vehicle, provided the required restraint for the Gemini XII pilot to attach the spacecraft/GATV tether, to activate the Experiment S010 (Agena Micrometeorite Collection) package, and to disconnect and connect a fluid connector and an electrical connector. The pilot also used the 5-inch Apollo torque wrench (fig. 5.2-10) and was able to exert greater than 100 inch-pounds of torque. He reported that his work capability was not taxed at these torque levels, and he concluded that his work efforts in performing these tasks were similar to underwater zero-g simulations. The pilot was able to perform these tasks with one waist tether attached and with one hand on a handhold and to repeat the tasks without using waist tethers. He strongly recommended, however, that body tethers be included in the restraint systems for future EVA involving torquing tasks. Body tethers provided a greater capability for applying torque, minimized the effort required in controlling body position, and eliminated the possibility of drifting away if a tool slipped.

One of the best features of body tethers was the elimination of the constant problem of drifting while working or while resting. The waist tethers permitted the Gemini XII pilot to relax during the designated rest periods or at any other time. During previous umbilical EVA's, this was not possible because the pilots had to hold on to the spacecraft with one or both hands during rest periods. Of course, work required to control body position eliminated the possibility of complete rest.

The Gemini XII pilot jettisoned the waist tethers near the end of the umbilical EVA. He detached by shortening the tethers, by pulling up against the surface of the target vehicle, and by opening the snaps which fastened the tethers to the parachute harness. By pushing against the target vehicle with his arms, he forced the waist tethers out from under the parachute harness; then, the pilot detached the waist tethers from the target vehicle and jettisoned them.

5.2.9 Pip-Pin Handhold/Tether Attachment Devices

Seven pip-pin handhold/tether attachment devices (fig. 5.2-11) were used on Gemini XII. These anodized aluminum devices used a conventional pip-pin mechanism with ball detents for attachment to the spacecraft. A spring-loaded pushbutton actuator was depressed to retract the balls before the device could be installed or removed. The T-shaped pip-pins were 3 inches wide to facilitate their use as handholds; a loop with an inside diameter of 1.75 inches was installed for tether attachment. The pilot used these devices as handholds during changes in body position and as waist tether attachment points during some of the work tasks on the target vehicle.

The T-shaped pip-pins were a convenient shape and size for hand gripping. When the rotational freedom of the devices was removed, they were excellent handholds, helped to control body attitude, and were useful as waist tether attachment points because waist tether attachment was simplified.

5.2.10 Pip-Pin Antirotation Devices

Pip-pin antirotation devices were installed over 11 of the pip-pin attachment holes (fig. 5.2-12). Without the antirotation devices, the pip-pins were free to rotate and would do so when any small torque was applied. Experience during Gemini XII simulations showed that the antirotation devices were valuable when the pilot was applying torque to the pip-pins. However, with the antirotation devices in place, the pip-pins had to be in one of eight specific orientations, and this requirement complicated the installation. Therefore, if pip-pin devices are used, antirotation devices are desirable; but the requirement for such precise alignment is undesirable.

5.2.11 U-Bolt Handhold/Tether Attachment Devices

Nine U-bolt handhold/tether attachment devices were installed in the EVA work areas on Gemini XII (figs. 3.6-2 and 5.2-10). The devices were bare metal, 0.250 inch in cross-sectional diameter, and 1.5 and 2 inches in inside diameter. These dimensions provided ease of hook attachment and a convenient handhold. The pilot used two of the U-bolts installed in the spacecraft adapter as waist tether attachment points during the work without foot restraints, but the close proximity to the bolt platform (about 4 inches) caused some inconvenience during the bolt torquing. The pilot found the U-bolts on the target vehicle useful for waist tether attachment and as handholds during work tasks and position changes.

5.2.12 Foot Restraints

The Gemini IX-A foot stirrups were inadequate for body restraint, even in the absence of external forces. The molded foot restraints used on the Gemini XI and XII spacecraft were far superior to all other restraint devices evaluated. With his feet in these restraints, the pilot was able to duplicate very nearly his one-g proficiency in performing tasks. He applied forces in excess of 25 pounds and performed electrical connector alignment tasks and cutting tasks. In addition to performing the work tasks, the Gemini XII pilot evaluated the body attitude constraints imposed by the foot restraints. The pilot was able to lean backward (pitch up) about 90 degrees, although a significant effort was required to maintain that position. He was also able to roll about ±45 degrees and his yaw capability was almost ±90 degrees. The volume of the pair of foot restraints used for Gemini XII was 21 by 13 by 4 inches.

5.2.13 Standup Tether

To prevent stressing the pilot's oxygen and electrical connections with the spacecraft, a short tether (fig. 5.2-13) was used during the standup EVA on Gemini X, XI, and XII. The standup tether was attached to the pilot's parachute harness and to the left side of the pilot's seat. The tether was made of thin nylon webbing and had a conventional single-loop adjustment buckle. A short tab on the adjustment buckle was incorporated in the Gemini XII standup tether to facilitate use in a pressurized space suit. The command pilot held the free end of the tether and usually did the required adjusting, although the Gemini XII pilot also made adjustments.

5.2.14 Strap on Space Suit Leg

For Gemini XI, a strap about 9 inches in length was sewed on the left leg of the pilot's space suit (fig. 5.2-14). When not in use, the strap was folded up inside a Velcro pocket on the space suit. During umbilical EVA, with the pilot standing in the seat, the command pilot opened the Velcro pocket and pulled out the strap. The strap was provided as a handhold for the command pilot to keep the pilot from floating out of the cockpit.

On the Gemini XII mission, identical straps were sewed on both legs of the pilot's space suit. However, the straps were not used because the command pilot found it easier to hold the pilot's foot.

TABLE 5.2-I.- RESTRAINT DEVICES USED DURING GEMINI EXTRAVEHICULAR ACTIVITIES

Configuration of restraint device	Gemini mission			
	IX-A	X	XI	XII
Rectangular handrail	X	X	X	X
Large cylindrical handbars (1.38-in. diameter)	X			X
Small cylindrical handrails (0.317-in. diameter)				X
Telescoping cylindrical handrail				X
Fixed handhold			X	X
Flexible Velcro-backed portable handhold	X			
Rigid Velcro-backed portable handhold				X
Waist tethers				X
Pip-pin handhold/tether attachment device				X
Pip-pin antirotation device				X
U-bolt handhold/tether attach device				X
Foot stirrups	X			
Foot restraints				X
Standup tether		X	X	X
Straps on space suit leg			X	X

NASA-S-67-837

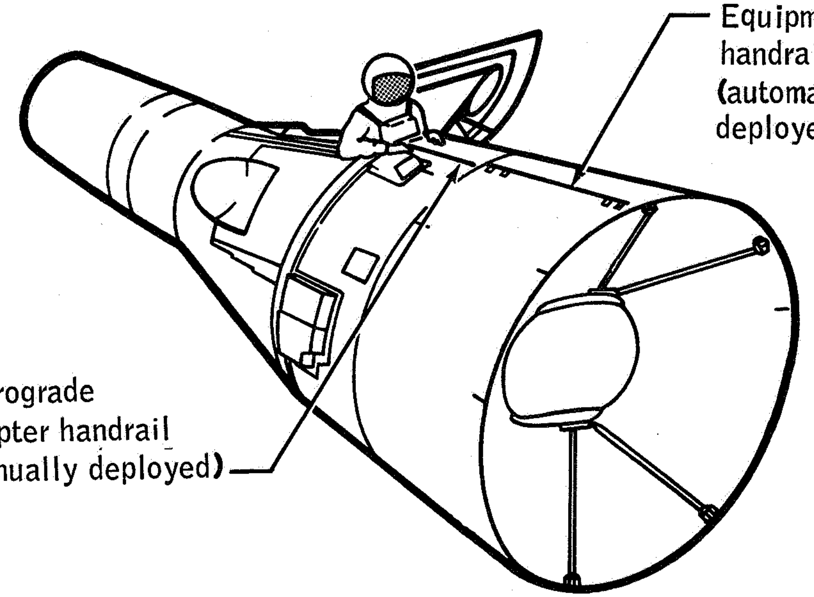

Figure 5.2-1. - Extendible handrails on spacecraft adapter.

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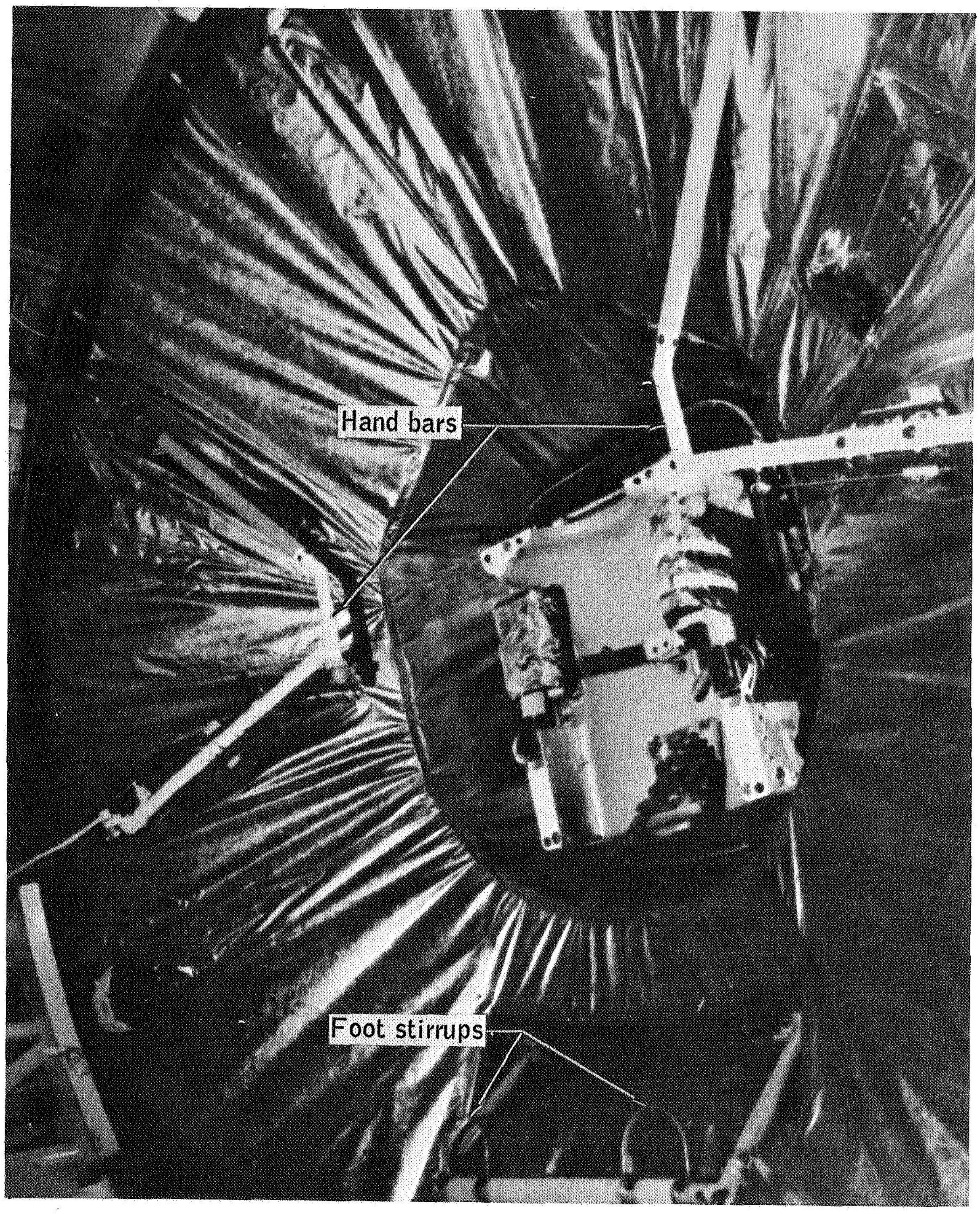

Figure 5.2-2. - Gemini IX-A adapter provisions for EVA.

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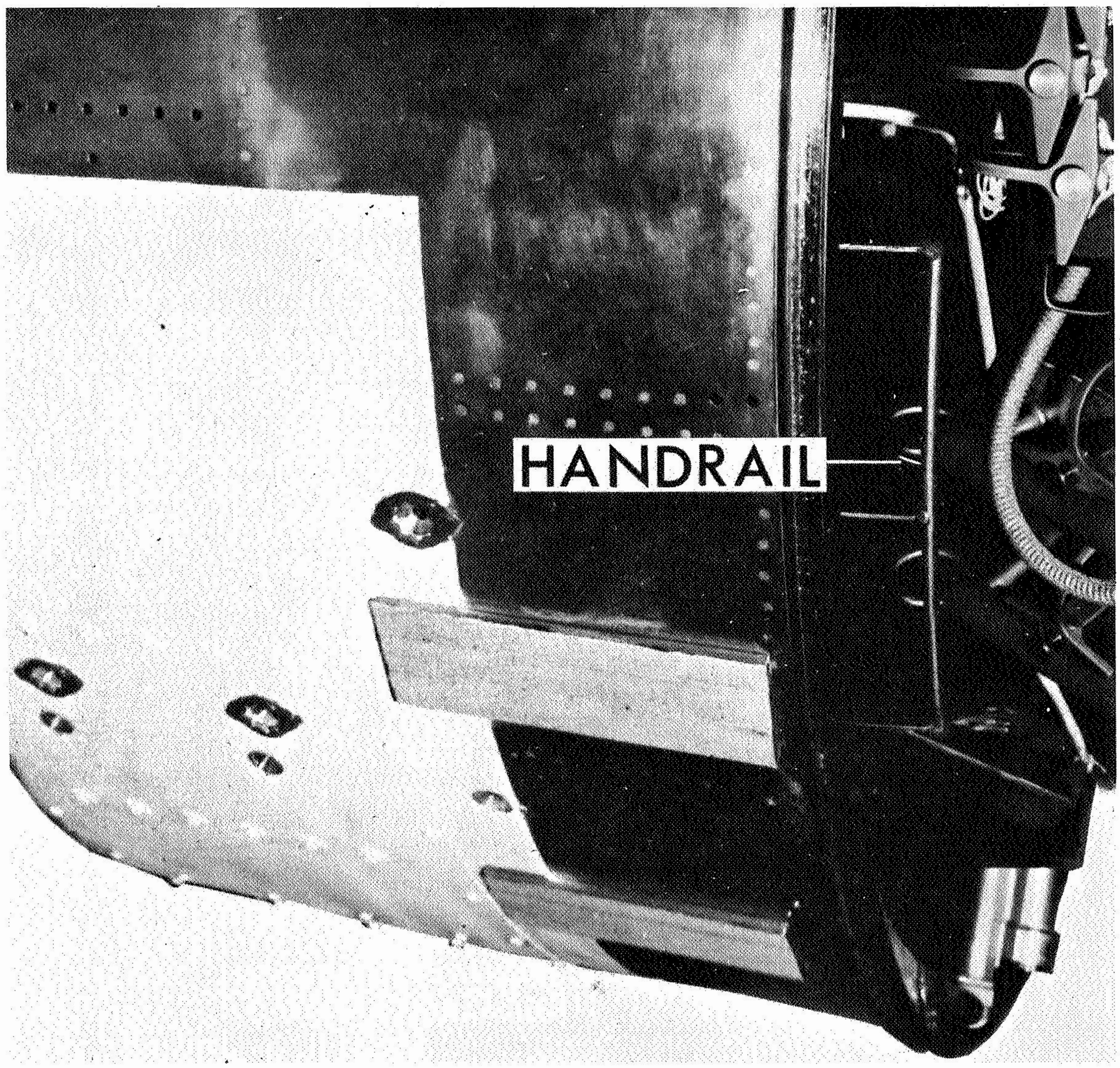

Figure 5.2-4. - Handrail on Gemini XII GATV - left side.

NASA-S-67-803

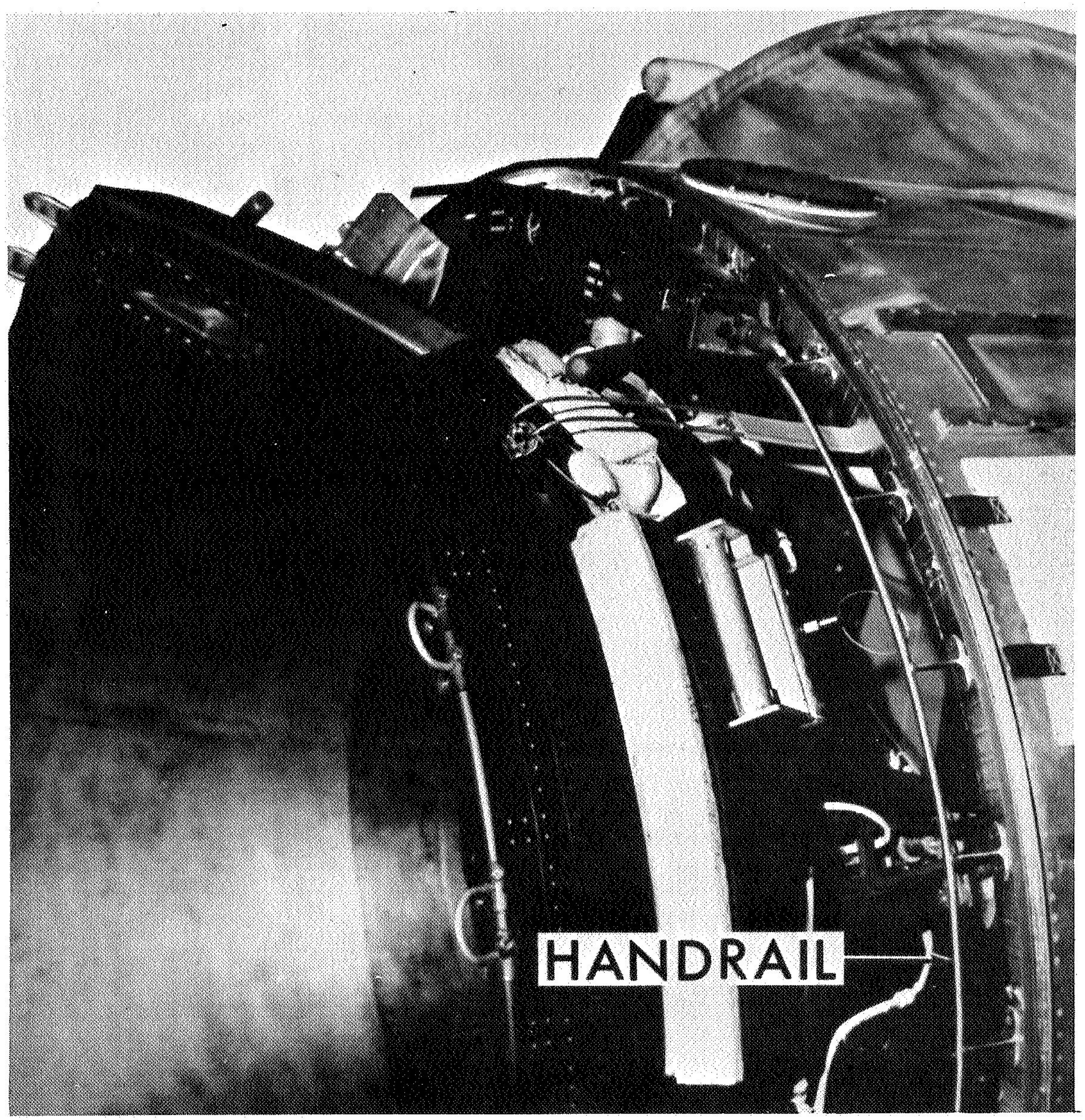

Figure 5.2-3. - Handrail on Gemini XII GATV - right side.

NASA-S-67-805

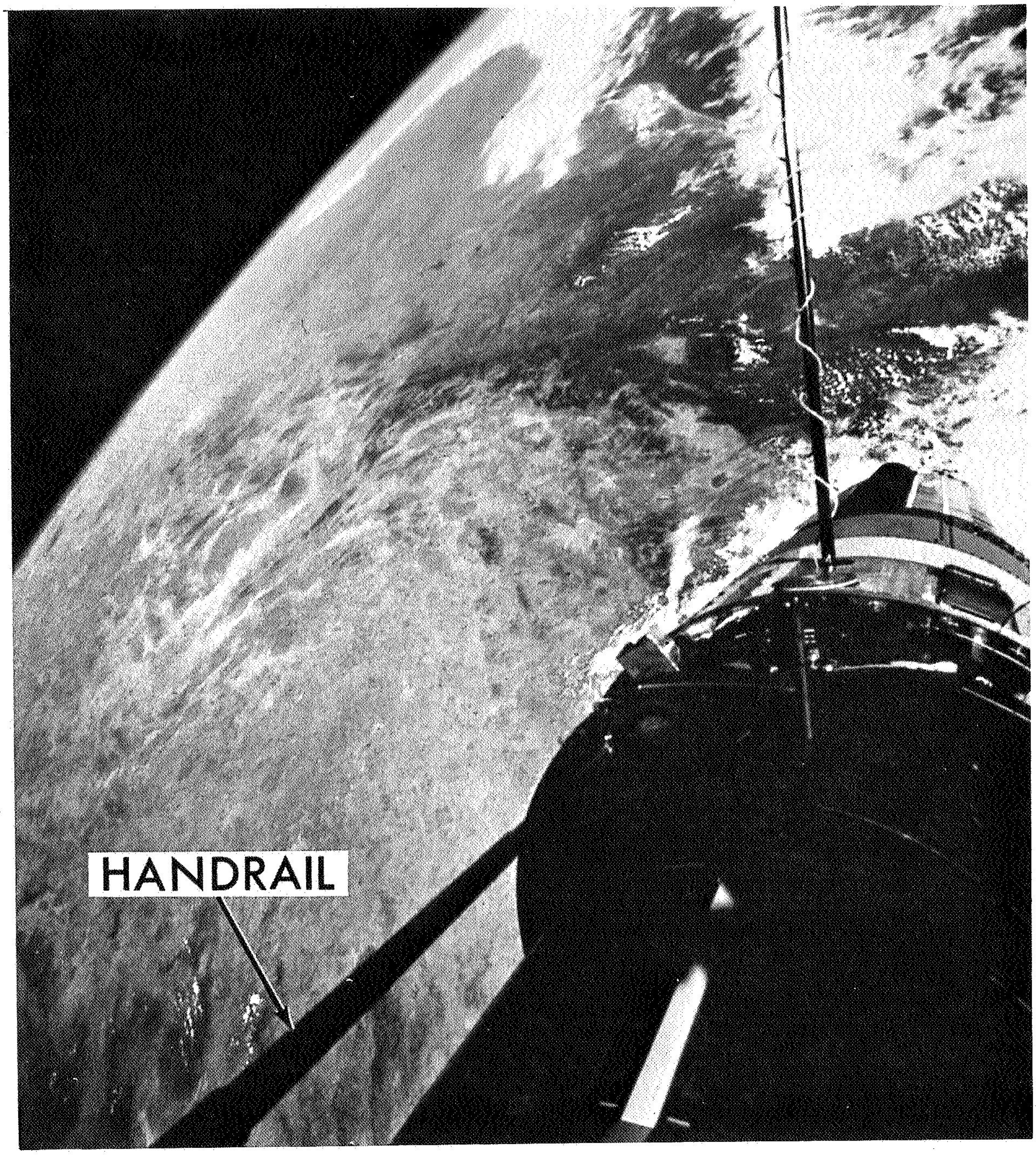

Figure 5.2-5. - Telescoping handrail used on Gemini XII.

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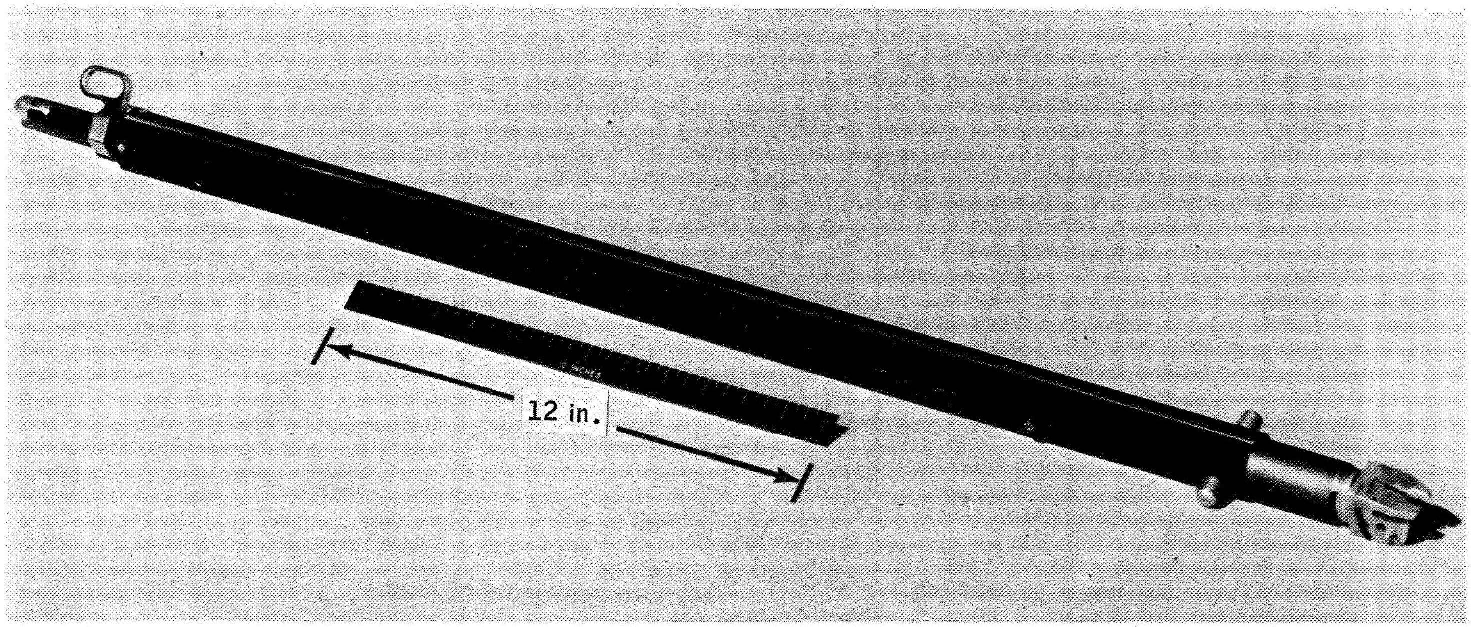

Figure 5.2-6. - Telescoping handrail - compressed.

NASA-S-67-808

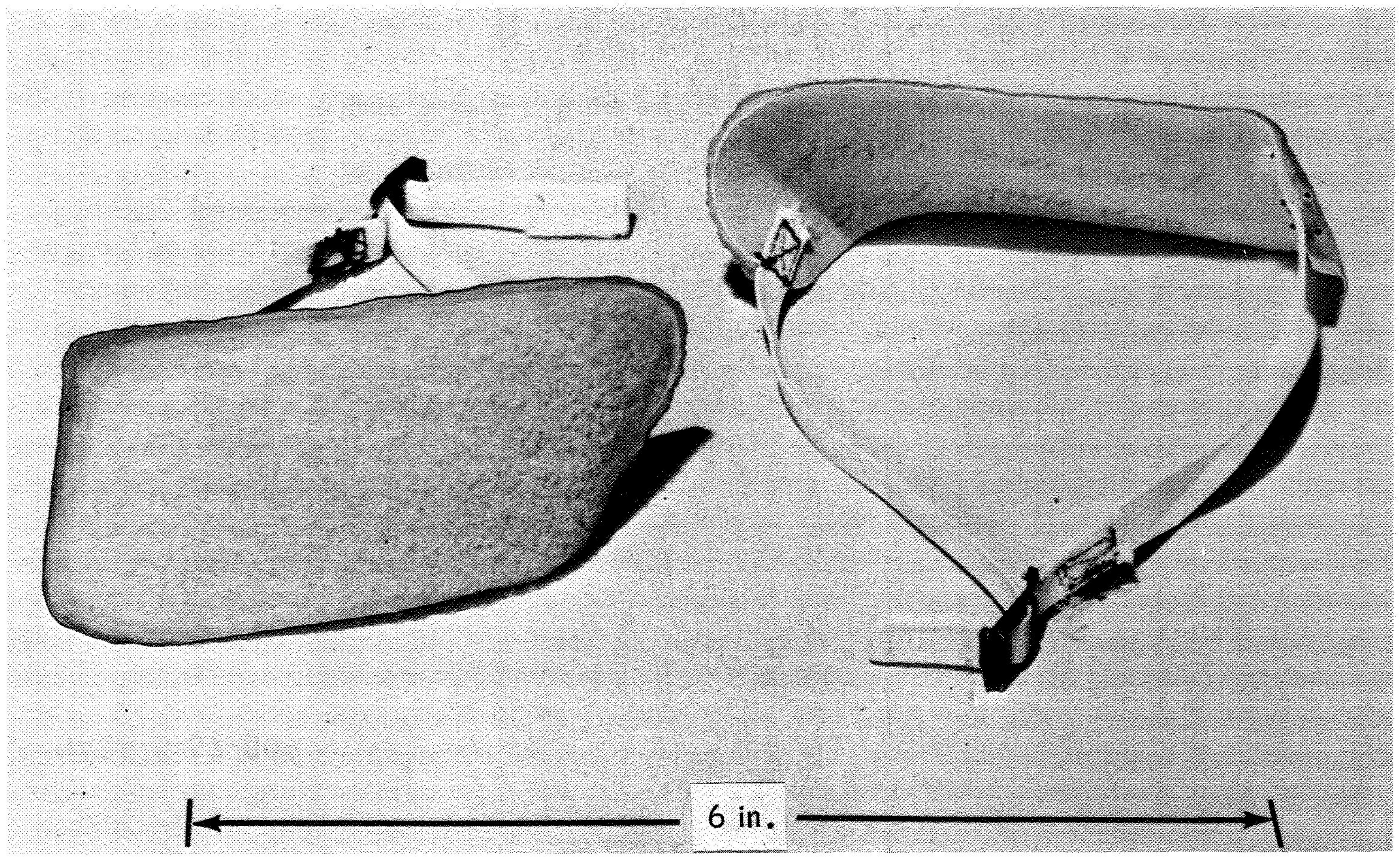

Figure 5.2-7. - Flexible Velcro-backed portable handholds.

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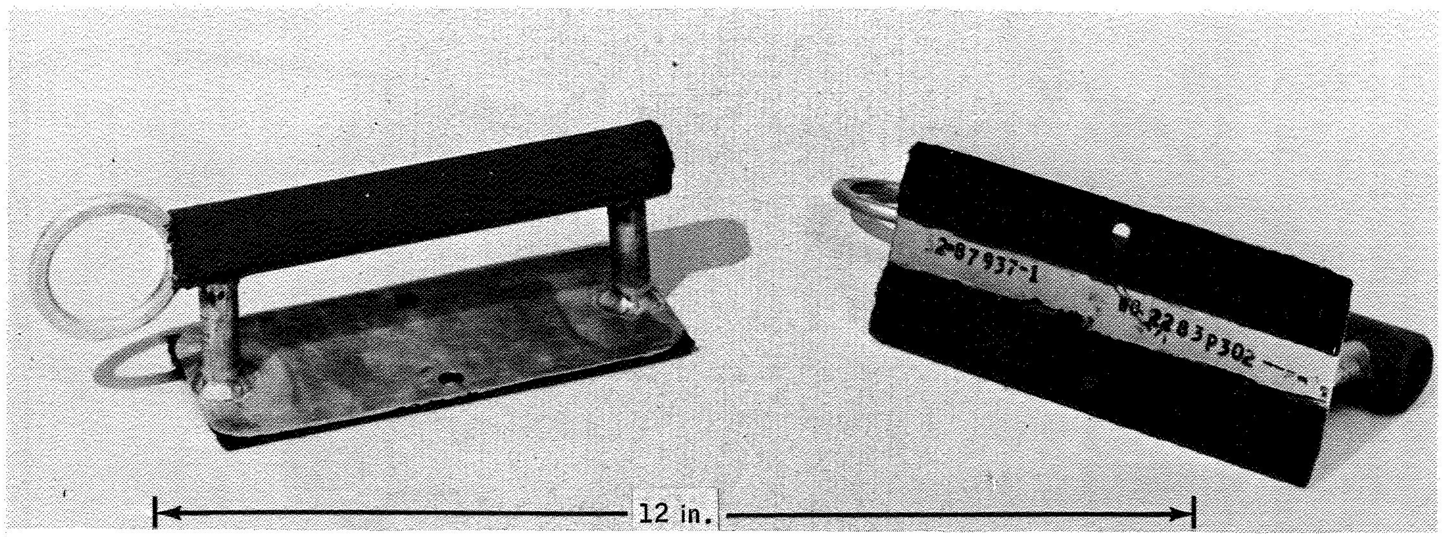

Figure 5.2-8. - Rigid Velcro-backed portable handholds.

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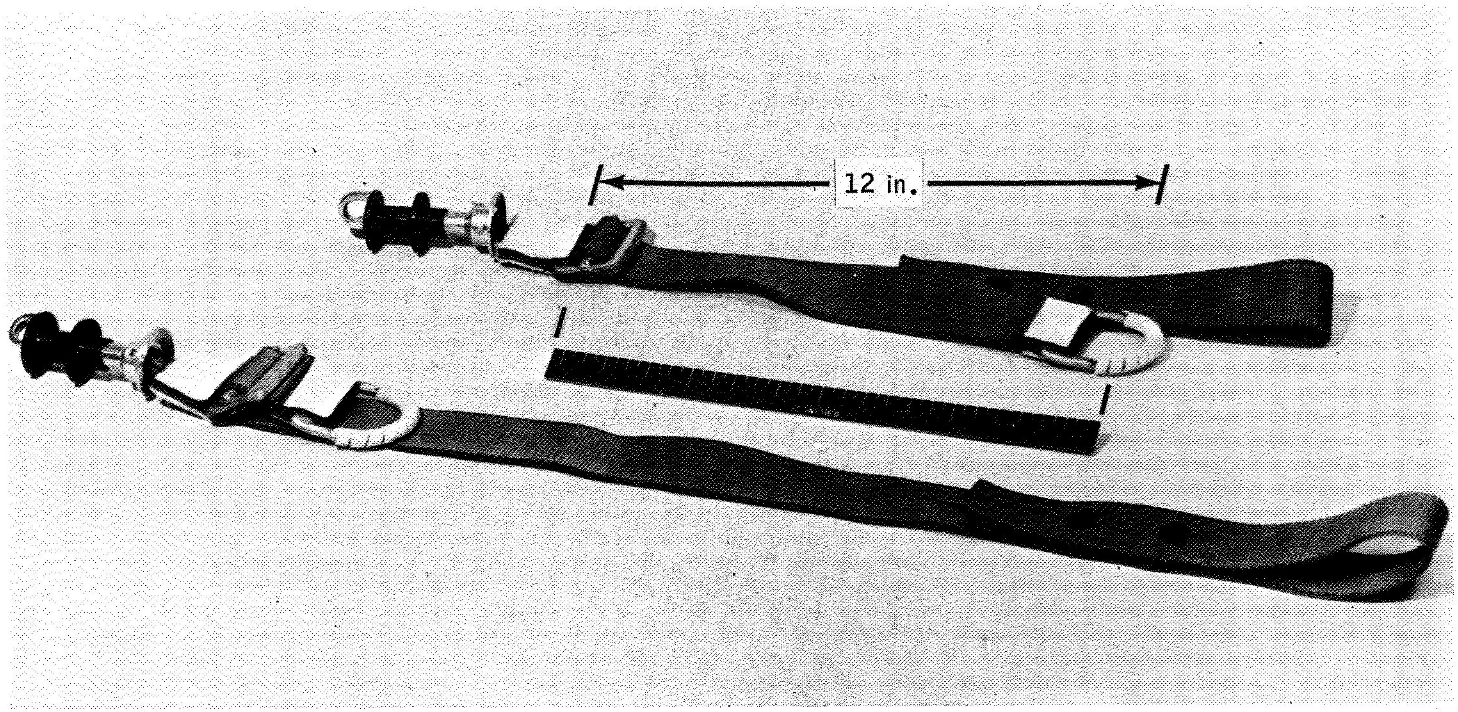

Figure 5.2-9. - Waist tethers.

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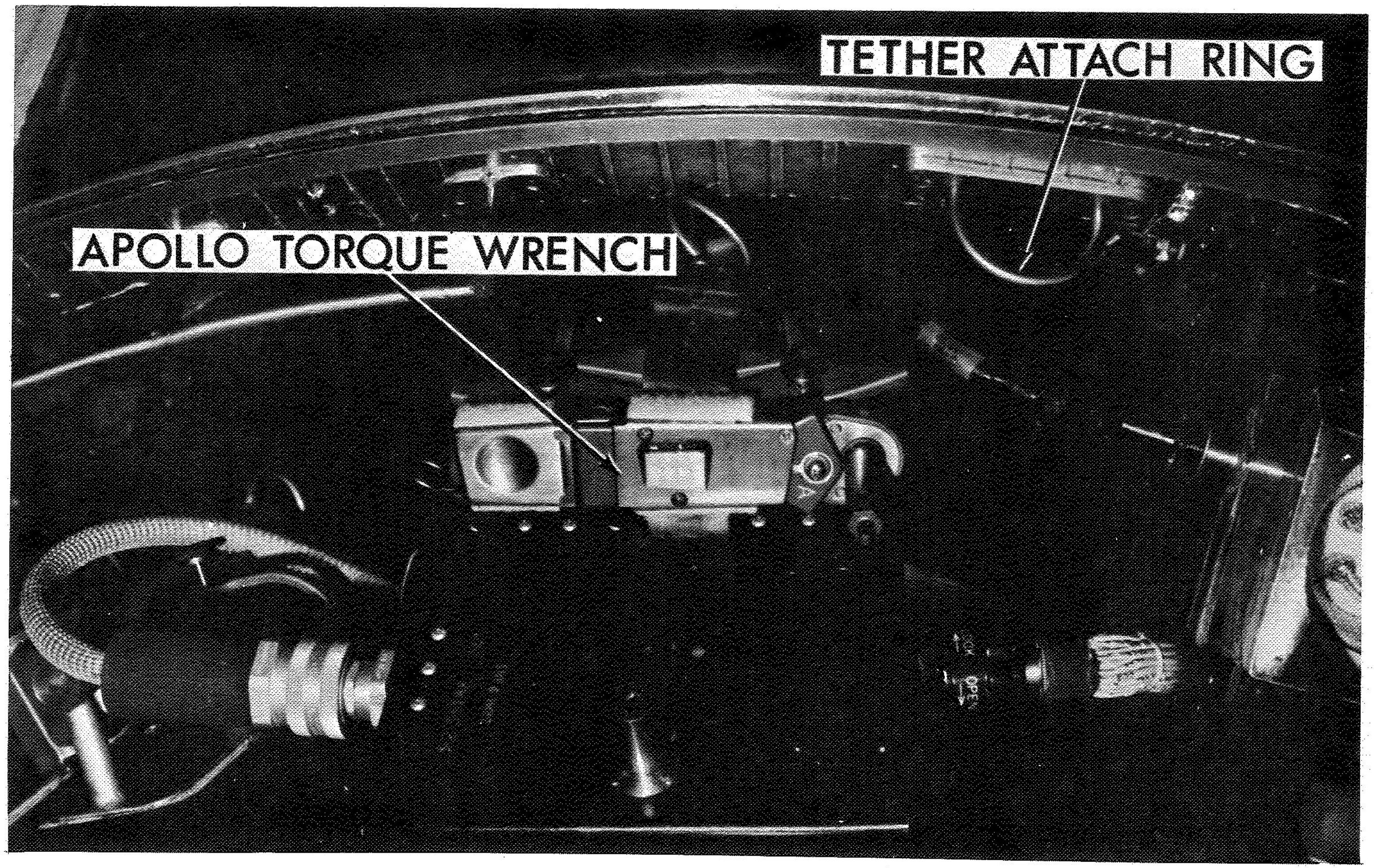

Figure 5.2-10. - EVA provisions on Gemini XII GATV docking cone.

NASA-S-67-811

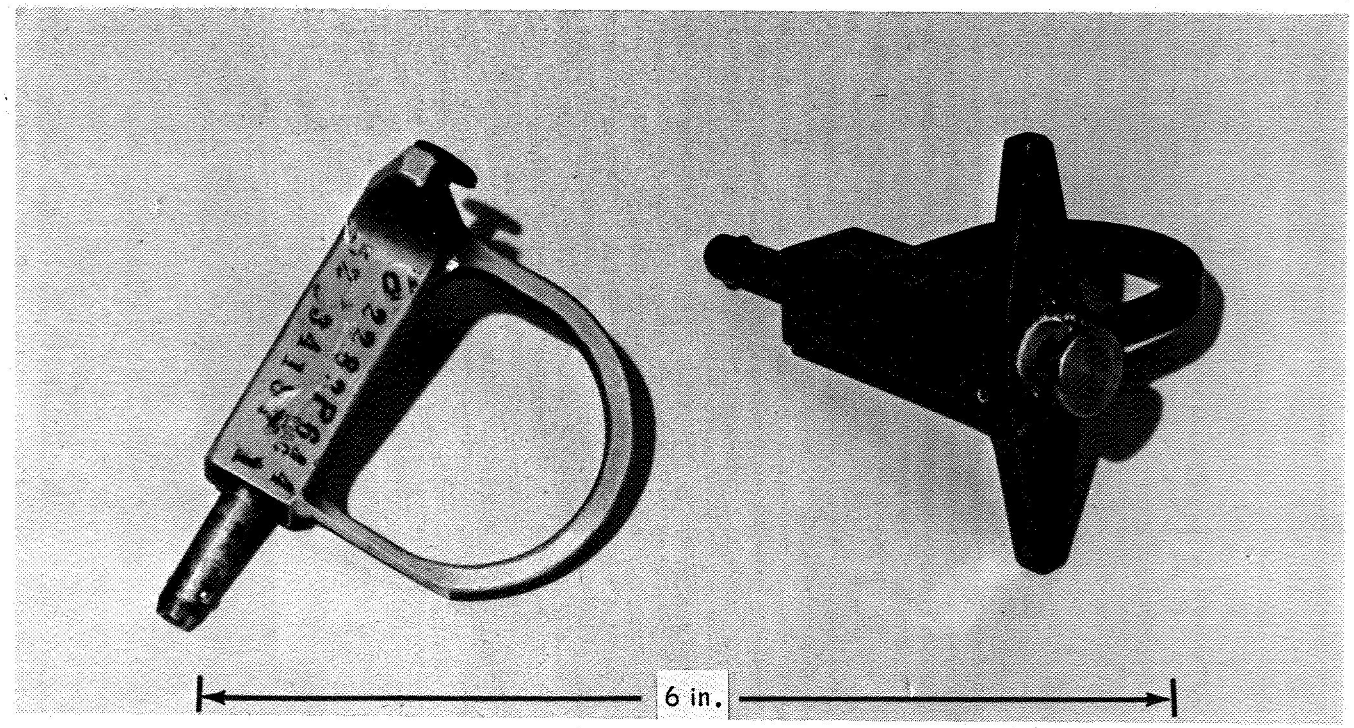

Figure 5.2-11. - Pip-pin handhold/tether attachment devices.

NASA-S-67-812

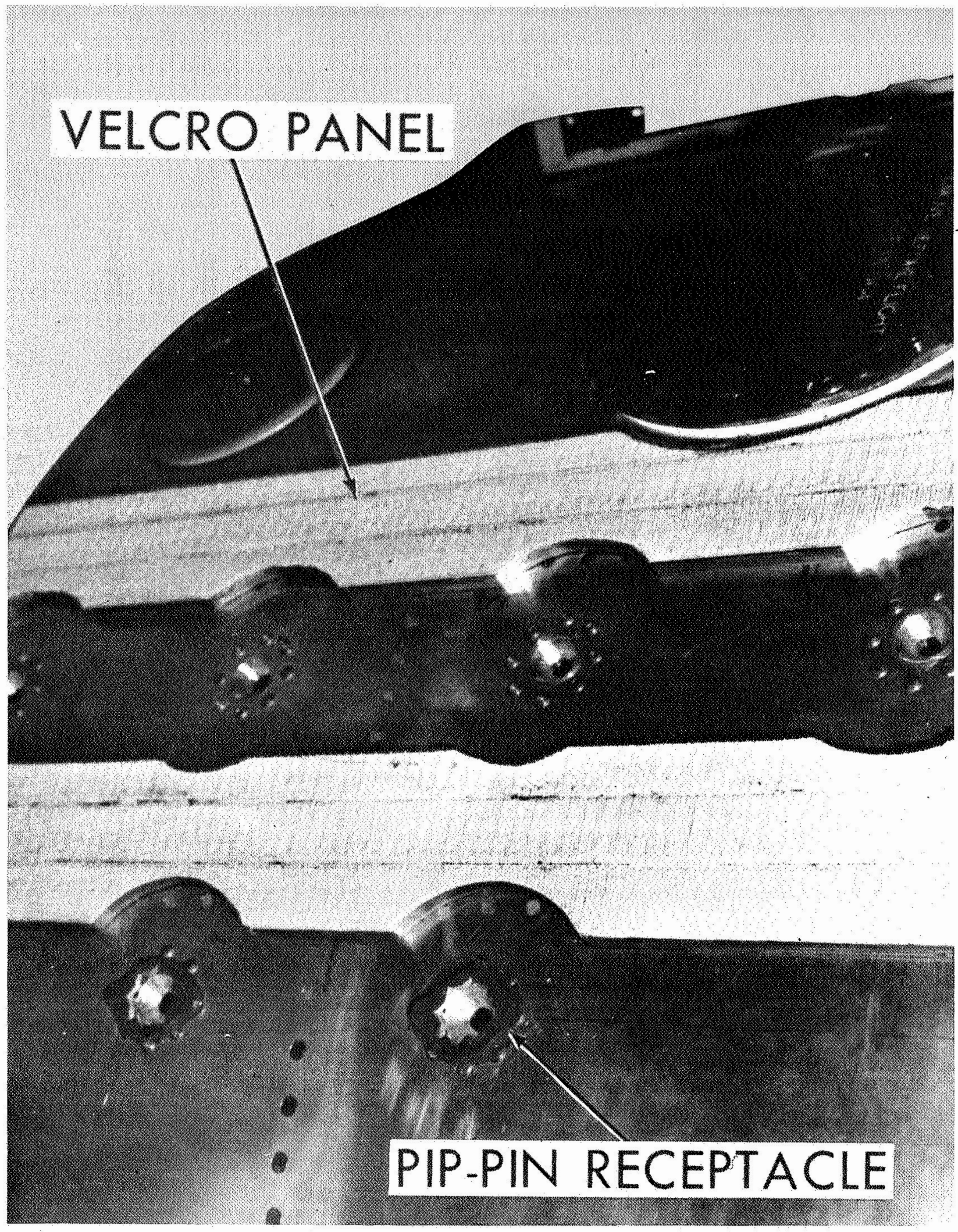

Figure 5.2-12. - EVA restraint provisions on Gemini XII GATV.

NASA-S-67-815

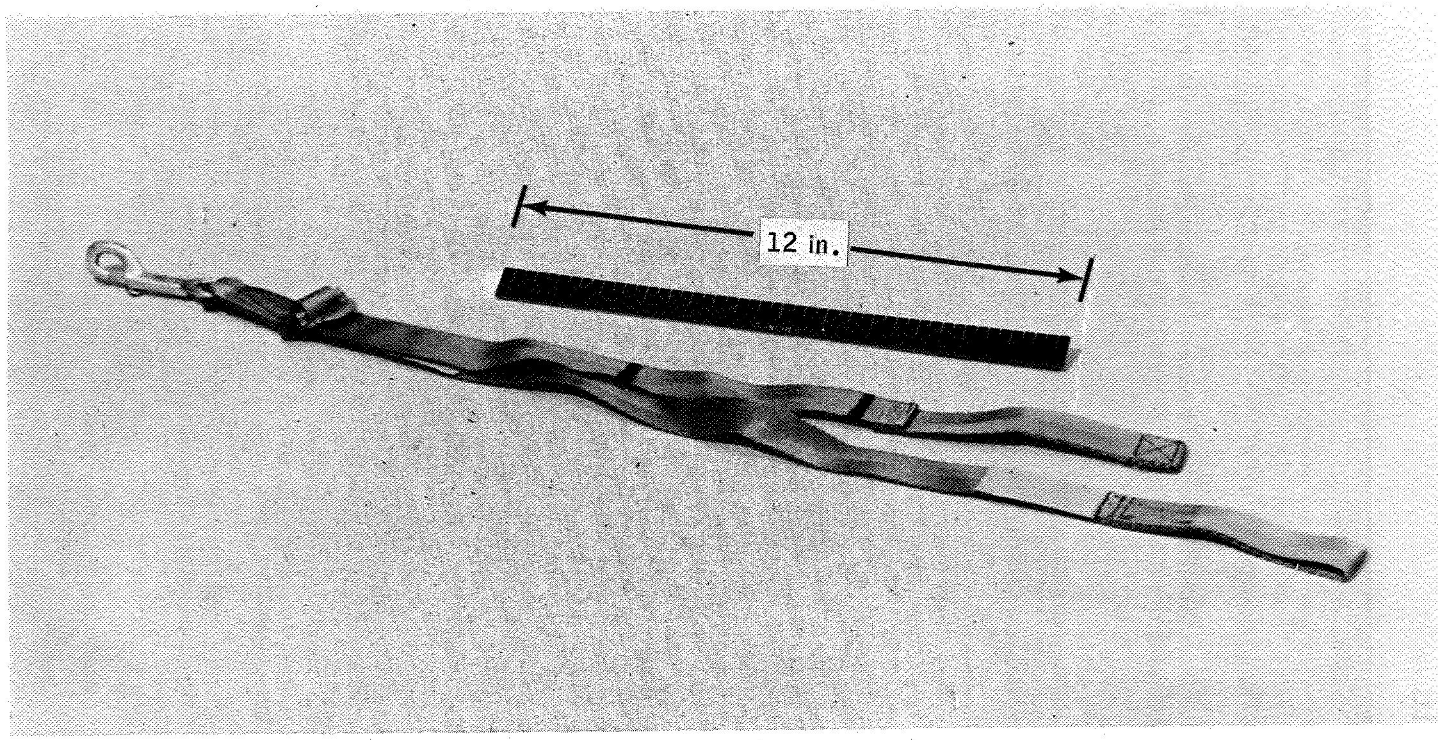

Figure 5.2-13. - Standup tether.

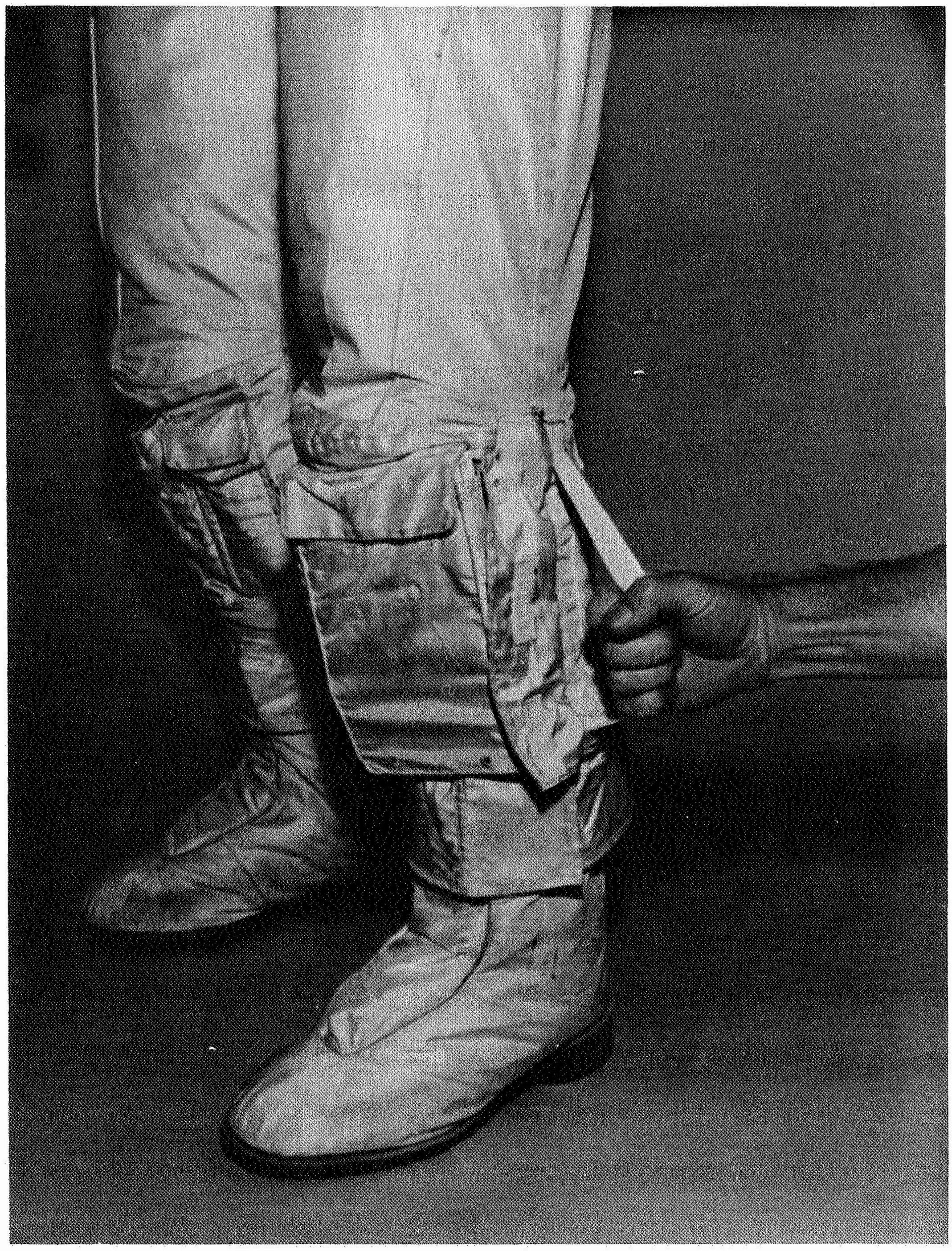

Figure 5.2-14. - Strap on space suit leg.

5.3 CONCLUDING REMARKS

The use of proper body restraints is necessary to assure the success of an EVA mission. The extravehicular experience accumulated in the Gemini Program indicated that thorough analysis and accurate simulation for EVA must be conducted and that body restraint requirements indicated by the analysis and the simulations must be satisfied. During EVA, restraints must be provided both for rest and for work tasks.

The following restraints were found to be most satisfactory in the Gemini Program:

(a) Foot restraints as used on Gemini XII for rest and localized work

(b) Waist tethers as used on Gemini XII for rest and localized work (slightly greater freedom of movement was possible with waist tethers than with foot restraints)

(c) Rectangular handrail for transit across a spacecraft surface

(d) Pip-pin devices for combination tether attachment points and handholds where flush-surface installations were required

(e) U-bolts for simple attachment points where flush-surface installations were not required

6.0 MANEUVERING EQUIPMENT

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6.0 MANEUVERING EQUIPMENT

The original plan for the use of the extravehicular maneuvering equipment was to evaluate the Hand Held Maneuvering Unit (HHMU) during the Gemini IV, VIII, X, and XI missions, and the Air Force Astronaut Maneuvering Unit (AMU) during the Gemini IX-A and XII missions. The HHMU was the only maneuvering device actually evaluated in orbit.

The evaluations of maneuvering equipment planned for Gemini VIII, X, and XI were not completed because of problems with other systems. The AMU was not carried on Gemini XII because of the increased emphasis on the evaluation of body restraints.

6.1 HAND HELD MANEUVERING SYSTEMS DEVELOPED FOR GEMINI

Prior to the development of the HHMU utilized on the Gemini IV mission, several experimental hand-held gas-expulsion devices were evaluated at the air-bearing facility of the MSC. The following conclusions were derived from early investigations.

(a) For translation, the tractor mode was inherently stable and easiest to control.

(b) Parallel tractor nozzles placed far apart produced much lower thrust losses from gas-impingement than nozzles placed side by side and canted outward.

(c) Because of the lack of finger dexerity in pressurized space suit gloves, the trigger which operated the pusher and tractor valves should be controlled by gross movements of the hand.

(d) Because arm and hand movements were constrained by the pressurized space suit, the handle of the HHMU was placed on top.

(e) Because of the necessity to easily align the thrust with the center of gravity of the operator, the thrusters were oriented at specific angles to insure easy aiming.

(f) Attitude control was improved by utilizing a proportional thrust system, rather than an off-on system, for controlling thrust level.

6.1.1 Gemini IV Self-Contained HHMU

The configuration of the Gemini IV HHMU (figs. 6.1-1 and 6.1-2) evolved from early concepts, mission requirements, and available qualified components. The 4000-psi storage tanks were the same as the emergency oxygen bottles used in the early Gemini ejection seats. The pressure regulator was used in the Project Mercury Environmental Control System. A summary of the operating characteristics of the Gemini IV HHMU is provided in the following table.

GEMINI IV HAND HELD MANEUVERING UNIT CHARACTERISTICS	
Thrust, tractor or pusher, lb	0 to 2
Total impulse, lb-sec	40
Total available velocity increment, ft/sec	6
Trigger preload, lb	15
Trigger force at maximum thrust, lb	20
Storage tank pressure, psi	4000
Regulated pressure, psi	120
Nozzle area ratio	50:1
Empty weight, lb	6.8
Oxygen weight, lb	0.7
HHMU weight, lb	7.5

Mission requirements dictated that the HHMU be stowed inside the spacecraft cabin. This in turn required a propellant gas which would not be hazardous if leakage occurred; gaseous oxygen was chosen. Since storage space was very limited, the HHMU was stowed in two sections; the hand assembly section and the high pressure section. The two assemblies were joined by connecting a coupling at the regulator and inserting a pin adjacent to the pusher nozzle (fig. 6.1-1).

Operation of the HHMU resulted from gas flow through the system. After gaseous oxygen left the 4000-psi storage tanks (fig. 6.1-2), it passed through a manifold to a shutoff and fill valve. When this valve was opened, the oxygen entered a pressure regulator which reduced the pressure to 120 psi. The low pressure oxygen entered the handle of the HHMU and passed through a filter to two valves. The valve located at the rear of the handle permitted the gas to flow through the trigger guard to the pusher nozzle. The valve located at the forward end of the unit ported gas through a swivel joint to two arms and to the tractor nozzles. The arms of the tractor nozzles could be folded back for compact storage. The pusher and tractor valves were actuated by the trigger.

The amount of force applied to the pusher or tractor valve determined the thrust level. A force of 15 pounds applied to the valve poppet initiated gas flow to the nozzle; as the force was increased to 20 pounds, the thrust level increased proportionately from 0 to 2 pounds.

The gas storage tanks held 0.7 pound of oxygen. This provided a total impulse of 40 lb-sec, or a velocity increment of 6 ft/sec.

6.1.2 Gemini VIII Backpack-Supplied HHMU

In the Gemini VIII HHMU system, the total impulse was increased to 600 lb-sec. A summary of the Gemini VIII maneuvering system characteristics is given in the following table.

GEMINI VIII HAND HELD MANEUVERING UNIT CHARACTERISTICS	
Propellant, gas	Freon-14
Thrust, tractor or pusher, lb	0 to 2
Specific impulse (calculated), sec	33.4
Total impulse, lb-sec	600
Total available velocity increment, ft/sec	54
Trigger preload, lb	15
Trigger force at maximum thrust, lb	20
Storage tank pressure, psi	5000
Regulated pressure, psi	110 ± 15
Nozzle area ratio	51:1
Weight of propellant, lb	18
HHMU weight, lb	3

The Freon-14 propellant was stored at 5000 psi in a 439-cubic-inch tank. The tank was mounted in the Extravehicular Support Package (fig 3.2-1) which also housed a second tank filled with 7 pounds of life support oxygen. Freon-14 was chosen as a propellant because, even though its specific impulse (33.4 seconds) was lower than oxygen (59 seconds) or nitrogen (63 seconds), its density was almost three times as great; therefore, the total impulse was increased substantially with only an 11-pound increase in total mass. The total impulse was calculated as follows:

(a) Oxygen: 7 lb × 59 lb-sec/lb = 413 lb-sec

(b) Freon-14: 18 lb × 33.4 lb-sec/lb = 600 lb-sec

The calculations indicate a 45-percent increase in total impulse for Freon-14 over oxygen at the same maximum tank pressure (5000 psi).

The expansion of the Freon-14 from 5000 psi to 110 psi resulted in temperatures of approximately -150° F in the HHMU handle assembly. With the initial unit design, the poppet valves stuck open at this temperature when actuated. To make the valves operable at -150° F, Teflon cryogenic seals were incorporated in place of the elastomer seals. Although qualification testing demonstrated that the redesigned valves operated satisfactorily at low temperatures, two shutoff valves were incorporated in the system (fig. 6.1-3). One of the valves was located immediately upstream of the coupling and was designed to shut off the gas flow if the poppet valves failed to close. The other shutoff valve was located in the backpack upstream of the flexible feedline, and was designed to shut off gas flow in the event of a leak in the flexible hose. These extra precautions were taken to preclude the possibility of uncontrolled thrusting of the system which might cause tumbling and loss of control during EVA. The handle of the HHMU was also modified to provide the pilot with a better grip.

6.1.3 Gemini X Umbilical-Supplied HHMU

For the Gemini X mission, the HHMU (fig. 6.1-4) was modified by sloping the handle to provide easier movement of the pilot's hand from pusher to tractor actuation. Grooves were cut in the handle to accommodate the contour of the palm of the space suit glove. The single rocking trigger was replaced with two shorter triggers pivoted at the end. An inverted view of the HHMU (fig. 6.1-5) shows the dual trigger configuration. This modification reduced the trigger-actuation forces from between 15 and 20 pounds to between 5 and 8 pounds, and also reduced the distance required for movement of the hand between the pusher and the tractor positions.

On the Gemini X mission, the propellant was stored in two 439-cubic-inch tanks in the spacecraft adapter section and was fed to the HHMU through the 50-foot dual umbilical (fig. 4.3-5). One hose in the umbilical provided life support oxygen and the other hose provided nitrogen gas to the HHMU. Nitrogen was selected as a propellant because the lower temperatures resulting from the use of Freon-14 would have required further development of the spacecraft components, which were already qualified for oxygen and nitrogen. A list of Gemini X HHMU characteristics is provided in the following table.

GEMINI X HAND HELD MANEUVERING UNIT CHARACTERISTICS	
Propellant, gas	Nitrogen
Thrust, tractor or pusher, lb	0 to 2
Specific impulse, sec	63
Total impulse, lb-sec	677
Total available velocity increment, ft/sec	84
Trigger preload, lb	5
Trigger force at maximum thrust, lb	8
Storage tank pressure, psi	5000
Regulated pressure, psi	125 ± 5
Nozzle area ratio	51:1
Weight of usable propellant, lb	10.75
HHMU weight, lb	3
Gross weight of extravehicular pilot, lb	260

The nitrogen was routed through the aluminum tubing from the tank installation in the spacecraft adapter section to a recessed panel behind the hatch. The tubing was clamped to the spacecraft at numerous points to provide heat shorts for warming the cooled gas (due to adiabatic expansion during use). A quick disconnect connector and a shutoff valve were provided on the recessed panel for connecting the nitrogen line in the umbilical to the nitrogen supply.

6.1.4 Gemini XI Umbilical-Supplied HHMU

For the Gemini XI mission, the HHMU was stowed in the spacecraft adapter section rather than in the cabin. The screw-on coupling was changed to a quick disconnect coupling (fig. 6.1-5) to simplify connecting the HHMU to the umbilical, since this action was to be accomplished with one hand in a limited access area and in a pressurized space suit.

The propellant gas storage-tank installation for Gemini XI was identical to the Gemini X configuration and provided the same operational characteristics, except a 30-foot dual umbilical was used instead of the 50-foot dual umbilical.

6.1.5 Ground Training for HHMU Maneuvering

6.1.5.1 Control logic for maneuvering with the HHMU.- A number of different procedures could be used successfully to move from one point to another in space with an HHMU. Figure 6.1-6 illustrates the procedures selected for use with the Gemini systems. The figure illustrates tractor thrusting for either forward or backward translation, as well as pusher thrusting, and applies to any of the three possible rotational control axes: yaw, pitch, or roll. For example, assume that the figure refers to the yaw axis so that our view of the man is from directly above; that is, the label Man would refer to the end of a line running from head to foot. The HHMU is held in front of the center of gravity of the operator at the position of the label FORCE. In this case, the force is pointed forward and considered to be the tractor mode. Assume that a disturbance occurs and causes a rotation to the right, indicated on the figure by the curved velocity arrow labeled $+\omega$. To eliminate this disturbance, the HHMU must be moved laterally toward the right side of the figure, but the thrust line of the HHMU must be pointed directly at the target. By pointing directly at the target at all times the operator (1) insures that he will eventually arrive exactly at the target, (2) maximizes the desired control moment, and (3) minimizes the amount of fuel required for attitude control. The control motions should lead the disturbances if the rotational motions are to be damped out completely. If the control motions remain exactly in phase with the rotational motions, the result is a constant-amplitude snaking oscillation as the operator translates toward or away from the target.

The procedures may appear complicated and overly sophisticated. However, the pilot never consciously thought of procedures while using the HHMU. Application of the procedure can be compared to the automatic actions and reactions required to ride a bicycle. The skilled operator of the HHMU can look directly at the target he wants to approach and take the necessary corrective actions through coordination of muscular commands without consciously seeing the HHMU. The control system of the HHMU is an adaptive control system. The accuracy of this system in space, with all 6 degrees of freedom active is not yet known, since the planned Gemini flight evaluation was incomplete. In any one of the three rotational axes and two translation axes on the 3-degree-of-freedom air bearing, a skilled operator can be within less than 1 inch of his intended target from distances of approximately 25 feet. At longer ranges, the same degree of accuracy could be maintained because control is a terminal guidance type of logic. The operator's axis does not have to be aligned with the direction of translation while using the HHMU. The operator must be physically capable of seeing the target and pointing at the target while maintaining the thrust force through his center of gravity. The HHMU has been designed so that when held in the operator's right hand with the thrust line along the operator's X-axis, the space suit is essentially in the neutral position.

6.1.5.2 Air-bearing training equipment.- The most important requirement for an air-bearing facility, and the most difficult to achieve and maintain, is a flat, hard, smooth floor. The floor of the MSC air-bearing training facility consists of 21 cast-steel machinist's layout tables each 3 feet wide by 8 feet long. Each table weighs about 2200 pounds and is flat to within approximately 0.0002 inch. An area, seven tables wide and three tables long, provides a total floor area of 21 by 24 feet. After leveling, the joints between adjacent tables are accurate to 0.0004 inch, and the overall floor is estimated to be flat within 0.002 inch. The leveling procedure must be repeated every 6 months because of settling of the building foundation. This degree of floor accuracy is highly desirable because it allows free movement of simulators with air cushions approximately 0.001 inch thick. Such low-thickness air cushions are desirable because the required airflow is quite low, and the attendant possible turbine-blade effect resulting from uneven exhaust of the air from the air bearings is negligible. The turbine-blade effect is extremely undesirable because it confuses the results produced by low-thrust jets such as those of the HHMU.

Air-bearing simulators utilized for training during the Gemini Program are shown in figures 6.1-7 to 6.1-10. Figure 6.1-7 shows the Gemini X pilot on a yaw-training simulator. Compressed air for the HHMU, for the pressurized suit, and for floating the air-bearing equipment flowed from a 130-psi service air supply through a dual umbilical identical to the one used in the Gemini X mission. A skilled technician was employed to minimize umbilical interference during training.

Figure 6.1-8 shows the Gemini VIII pilot during a yaw-training session prior to the mission. The Extravehicular Support Package (ESP) was supported by metal legs; three supporting air pads were utilized for the necessary added stability because of the large combined mass and volume of both the ESP and the ELSS. In the simulator, compressed air for floating the platform was carried in a surplus oxygen bottle mounted on the platform, and compressed air for the HHMU was carried in a high pressure bottle located inside the ESP training unit. No umbilical or tether was utilized. This simulator was also used in training for the AMU.

Figure 6.1-9 shows the Gemini X pilot in pitch-axis training on a different type of simulator. The cot on which he lay was made of lightweight aluminum tubing which did not appreciably change his inertia in pitch. Three pads are used to provide satisfactory tipping stability. The compressed air needed to power the HHMU, to pressurize the suit, and to float the air-bearing equipment was furnished by the service air supply through the 3/8-inch-inside-diameter umbilical. The umbilical contained small coffee-can air-bearing supporters which allowed more accurate simulation of the in-space effect of a similar umbilical.

Figure 6.1-10 shows the Gemini X pilot on the same simulator, in roll-axis training. Roll-axis training was practiced by looking at the target while translating to the target, and by looking at the ceiling while translating to the side. The latter case was important because in normal use, the HHMU rolling velocity should be zero while translating forward.

6.1.5.3 Representative training runs.- The following is a representative list of the types of training runs made on the air-bearing equipment in preparation for EVA maneuvering. The runs were made in the yaw and pitch modes, and most runs were also made in the roll mode. Points A and B are any two specific points in the training area.

(a) Familiarization with air bearing

(b) Use of muscle power to control attitude

(c) Control attitude while being towed to target with HHMU in hand

(d) Translate from point A to a collision with point B with hip-kit compressed-air bottle and no umbilical

(e) Repeat preceding step, but stop completely 1 foot in front of point B

(f) With initial rotational velocity at point A, stop rotation, proceed to point B, and stop completely 1 foot in front of point B

(g) With both initial random rotation and translation in vicinity of point A, stop both initial rotation and translation, proceed to point B, and stop completely 1 foot in front of point B

(h) Starting from rest at point A, intercept a target moving at constant velocity at right angles to the line of sight

(i) Make precision attitude changes of 45 to 90 degrees, stopping any translation existing at end of run

(j) Without HHMU, practice pushing off from simulated spacecraft and stopping completely by gently snubbing the umbilical

(k) Practice hand walking the umbilical back to the simulated spacecraft, being careful not to generate excessive translational velocity

(l) Investigate elasticity and wrap-up tendencies of umbilical by translating to the end of umbilical with various initial translational and rotational velocities

The training time on the air-bearing table varied between 12 and 20 hours for the pilots scheduled to evaluate the HHMU in orbit.

6.1.5.4 Inertia coupling training-aid model.- In connection with the extravehicular training for Gemini VIII, the question arose as to whether controlled rotations about one axis of an extravehicular pilot might lead to uncontrolled rotations about the other two axes due to inertia coupling or product-of-inertia effects. To gain a qualitative idea of the severity of these effects, a 1:4.5-scale model of the Gemini VIII pilot was constructed and mounted in a set of very light gimbals. The model (fig. 6.1-11) was carved from wood and was based upon three-view scale photographs of a pressurized space suit. The scale weight and center-of-gravity position of the pilot, the ESP, and the ELSS were closely duplicated in the model, although no attempt was made to measure and duplicate the moments of inertia of these items. The gimbal arrangement is shown in figure 6.1-12. The yaw axis is at the top; the half-pitch gimbal is next, followed by the roll gimbal, which consisted of two ball bearings inside the body of the model. The yaw and pitch gimbals were also mounted on ball bearings. The gimbal weight was approximately 0.2 percent of the model weight.

Investigations of inertia coupling effects were conducted by rotating the model about one of its major axes while holding the other two axes fixed, and then releasing the two fixed gimbals. The observed results follow:

(a) Following a pure yaw rotational input, if the pitch and roll gimbals were released first, slow up-and-down changes in pitch attitude resulted. As the motion slowed from gimbal bearing friction, the model rotated 90 degrees in roll so that the original yawing motion became a pure pitching motion. This attitude was stable because no coupling was noted if the model was again spun up about the original axis of rotation.

(b) Following a pure pitch rotational input, the model merely slowed to zero rotational velocity (because of gimbal bearing friction) without exhibiting inertia coupling tendencies of any kind.

(c) Release of the pitch and yaw gimbals after a pure roll rotational input immediately resulted in a confused pitching, yawing, and rolling tumbling motion.

The behavior of the model correlated with the observed shape of the model. For example, the mass distribution of the model, and also of an EVA pilot, was almost symmetrical about the X-Z plane; therefore, practically no rolling or yawing moments were generated when the model was rotated in pitch. However, the model with backpack and chestpack was asymmetrical about the Y-Z plane, and large pitching and yawing moments resulted from rotations in roll.

The tests with the model resulted in the following simple maneuvering rules for the EVA pilot. The rules are designed to eliminate or reduce greatly the chance of encountering inertia coupling effects:

(a) Never roll intentionally. Always establish the attitude toward the target by yawing, then pitching. Avoid roll motions while translating.

(b) If inertia coupling effects are encountered, always stop the rolling velocity first, the yawing velocity second, and the pitching velocity last.

6.1.6 HHMU Flight Maneuvering Performance

6.1.6.1 Gemini IV.- The Gemini IV pilot accomplished the first propulsive EVA maneuvering in history. Figure 3.1-1 is one of the many pictures the command pilot took during the EVA. In this particular picture, the pilot exhibits the perfect posture for maneuvering with an HHMU. In the postflight debriefing, the pilot described his experiences with the HHMU and with the umbilical as follows:

> "I left (the spacecraft) entirely under the influence of the gun (the HHMU), and it carried me right straight out, a little higher than I wanted to go. I wanted to maneuver over to your (command pilot's) side, but I maneuvered out of the spacecraft and forward and perhaps a little higher than I wanted to be. When I got out to what I estimate as probably one-half or two-thirds the way out on the tether, I was out past the nose of the spacecraft. I started a yaw to the left with the gun and that's when I reported that the gun really worked quite well. I believed that I stopped that yaw, and I started translating back toward the spacecraft. It was either on this translation or the one following this that I got into a bit of combination of pitch, roll and yaw together. I felt that I could have corrected it, but I knew that it would have taken more fuel than I had wanted to expend with the gun, so I gave a little tug on the tether and came back in. This is the first experience I had with tether dynamics and it brough me right back to where I did not want to be. It brought me right back on top of the spacecraft, by the adapter section.
>
> "This is the first time it had happened. I said (to the command pilot), 'All right, I'm coming back out (to front of spacecraft) again.' This is one of the most impressive uses of the gun that I had. I started back out with that gun, and I decided that I would fire a pretty good burst too. I started back out with the gun, and I literally

flew with the gun right down along the edge of the spacecraft, right out to the front of the nose, and out past the end of the nose. I then actually stopped myself with the gun. That was easier than I thought. I must have been fairly fortunate, because I must have fired it right through my c.g. I stopped out there and, if my memory serves me right, this is where I tried a couple of yaw maneuvers. I tried a couple of yaw and a couple of pitch maneuvers, and then I started firing the gun to come back in (to the spacecraft). I think this was the time that the gun ran out. And I was actually able to stop myself with it out there that second time too. The longest firing time that I put on the gun was the one that I used to start over the doors up by the adapter section. I started back out then. I probably fired it for a 1-second burst or something like that. I used small bursts all the time. You could put a little burst in and the response was tremendous. You could start a slow yaw or a slow pitch. It seemed to be a rather efficient way to operate. I would have liked to have had a 3-foot bottle out there—the bigger the better. It was quite easy to control.

"The technique that I used with the gun was the technique that we developed on the air-bearing platform. I kept my left hand out to the side (fig. 3.1-1) and the gun as close to my center of gravity as I could. I think that the training I had on the air-bearing tables was very representative, especially in yaw and pitch. I felt quite confident with the gun in yaw and pitch, but I felt a little less confident in roll. I felt that I would have to use too much of my fuel. I felt that it would be a little more difficult to control and I didn't want to use my fuel to take out my roll combination with the yaw.

"As soon as my gun ran out (of fuel) I wasn't able to control myself the way I could with the gun. With that gun, I could decide to go to a part of a spacecraft and very confidently go."

6.1.6.2 Gemini X.- The Gemini X pilot was to perform an extensive evaluation of the HHMU, including precise angular attitude changes and translations. However, the flight plan for the EVA required that a number of other activities be accomplished before this evaluation. One of these planned activities was to transfer to the target vehicle at very short range and to retrieve the Experiment S010 Agena Micrometeorite

Package attached near the docking cone. During this activity, the pilot used the HHMU which he described during the postflight debriefing as follows:

"Okay, we're in this EVA. I got back and stood up in the hatch and checked out the gun and made sure it was squirting nitrogen. That's the only gun checkout I did. In the meantime, ...(the command pilot) maneuvered the spacecraft over toward the end of the TDA, just as we had planned. He got in such a position that my head was 4 to 5 feet from the docking cone. It was upward at about a 45-degree angle, just as we planned. I believe at one time there you said you had trouble seeing it, and I gave you (the command pilot) some instructions about 'forward', 'forward', 'stop, stop.' So I actually sort of talked...(him) into position. (See fig. 3.4-4.)

"I translated over by pushing off from the spacecraft. I floated forward and upward fairly slowly and contacted the Agena. I grabbed hold of the docking cone, as near as I can recall, at about the 2 o'clock position. If you call the location of the notch in it, the 12 o'clock, I was to the right of that - at about the 2 o'clock position and I started crawling around. No, I must have been more about the 4 o'clock position because I started crawling around at the docking cone counterclockwise, and the docking cone itself, the leading edge of the docking cone, which is very blunt, makes a very poor handhold in those pressure gloves. I had great difficulty in holding on to the...thing. And, as a matter of fact, when I got over by the S010 package and tried to stop my motion, my inertia, (the inertia of) my lower body kept me right on moving and my hand slipped and I fell off the Agena.

"At any rate, when I fell off, I figured I had either one of two things to do. I could either pull in on the umbilical and get back to the spacecraft, or I could use the gun (the HHMU). And I chose to use the gun. It was floating free at this time. It had come loose from the chestpack. So I reached down to my left hip and found the nitrogen line and started pulling in on it and found the gun, and unfolded the arms of the gun and started looking around. I picked up the spacecraft in view. I was pointed roughly toward the spacecraft. The spacecraft was forward and below me on my left. The Agena was just about over my left shoulder and below me, or down on my left side and below me. I used the gun to translate back to the cockpit area. Now, I was trying to thrust in a straight line from where I was back to the cockpit, but in leaving the Agena I had developed some tangential velocity, which was bringing me out around the side and the rear of the Gemini. So what happened was, it was almost as if I was in an airplane on downwind for a landing, and in making a left-hand pattern I flew around and made a 180-degree left descending turn, and flew right into the cockpit. It was a combination of just luck, I think, being able to use the gun. At any rate, I did return to the cockpit in that manner, and the command pilot again maneuvered the spacecraft. When I got to the cockpit, I stood up in the hatch and held on to the hatch. The command pilot maneuvered the spacecraft again up next to the Agena. This time we were, I think, slightly farther away because I felt that rather than trying to just push off I would use the gun and translate over. And I did, in fact, squirt the gun up, depart the cockpit and translate over to the docking cone using the gun as a control device. The gun got me there. It wasn't extremely accurate. What happened was, as I was going over, I guess in leaving the cockpit, I somehow developed an inadvertent pitch-down moment, and when I corrected this out with the gun, I developed an upward translation as well as an upward pitching moment. So I did damp out the pitch. I converted that downward pitch moment into an upward pitching moment, and then I was able to stop my pitch entirely. But in the process of doing that, I developed an inadvertent up translation, which nearly caused me to miss the Agena. As a matter of fact, I came very close to passing over the top of the Agena, and I was just barely able to pitch down with the gun and snag a hold of the docking cone as I went by the second time."

During further technical debriefings, the Gemini X pilot made several other comments. Concerning the response characteristics of the HHMU, the pilot stated that thrust levels from 0 to 2 pounds were satisfactory. These levels provided adequate translational and rotational control without an overly sensitive response. The Gemini IV pilot had made the same comment.

With respect to ability to transfer the control skills acquired on the 3-degrees-of-freedom air-bearing simulators to the 6-degrees-of-freedom that actually existed in space, the Gemini X pilot stated that the transfer was made easily and naturally. This pilot was, perhaps, a little surprised to find that the pitch control was more difficult than yaw control. Because of the very low body inertia about the yaw axis, yawing motions could be generated more rapidly with the HHMU than either pitch or roll motions.

The Gemini X pilot stated that during his brief periods of maneuvering with the HHMU no rolling motions had been experienced. This was significant because: (1) based upon indications of the inertia coupling model, and upon the experience obtained during the Gemini IV EVA, the pilot had trained specifically to avoid rolling motions, and to stop them immediately if they should occur, and (2) in the absence of rolling motions, control with the HHMU was reduced to a simpler problem involving yawing rotations, pitching rotations, and linear translations.

NASA-S-67-300

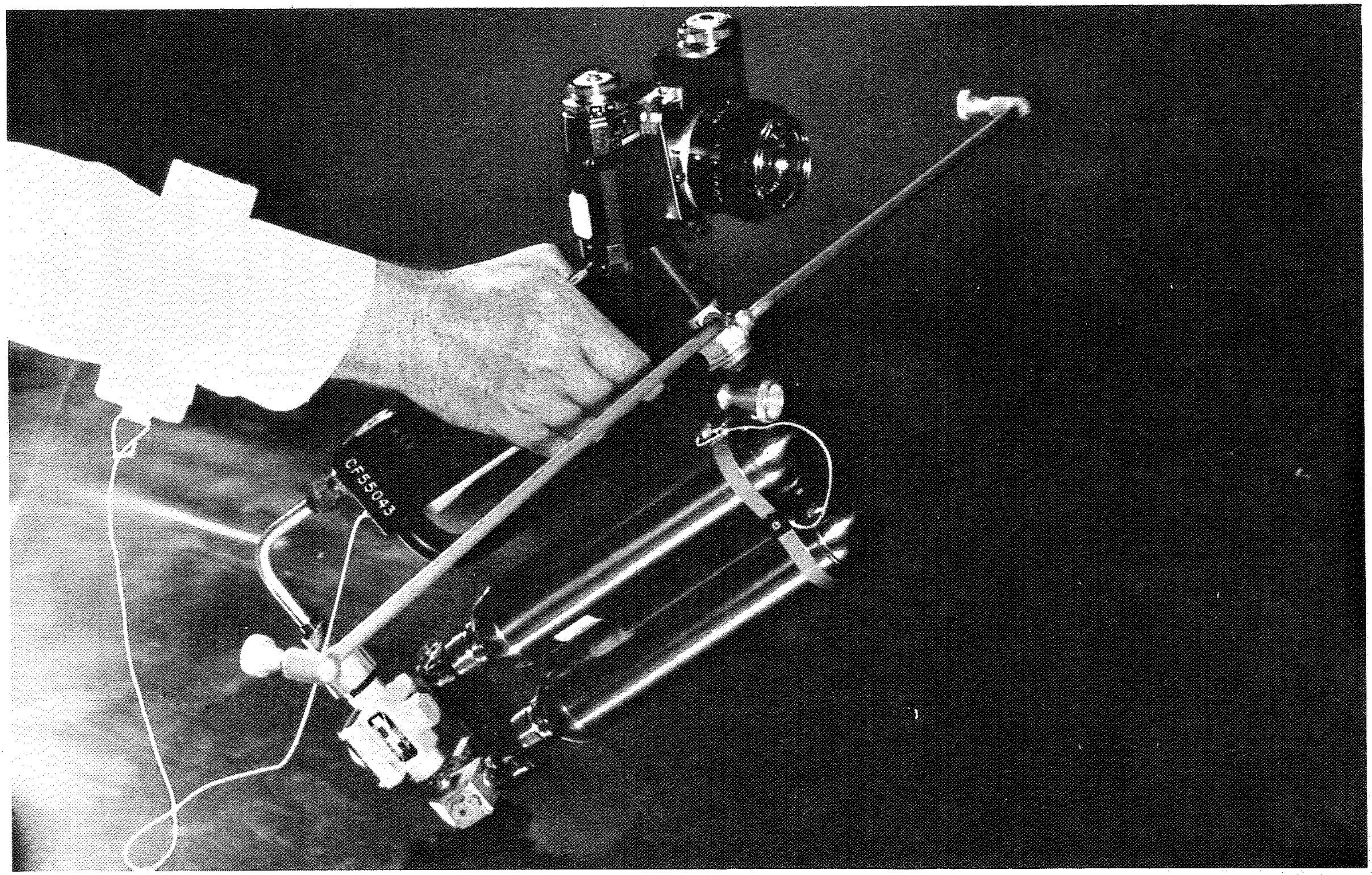


Figure 6.1-1.- Gemini IV Hand Held Maneuvering Unit.

NASA-S-67-787

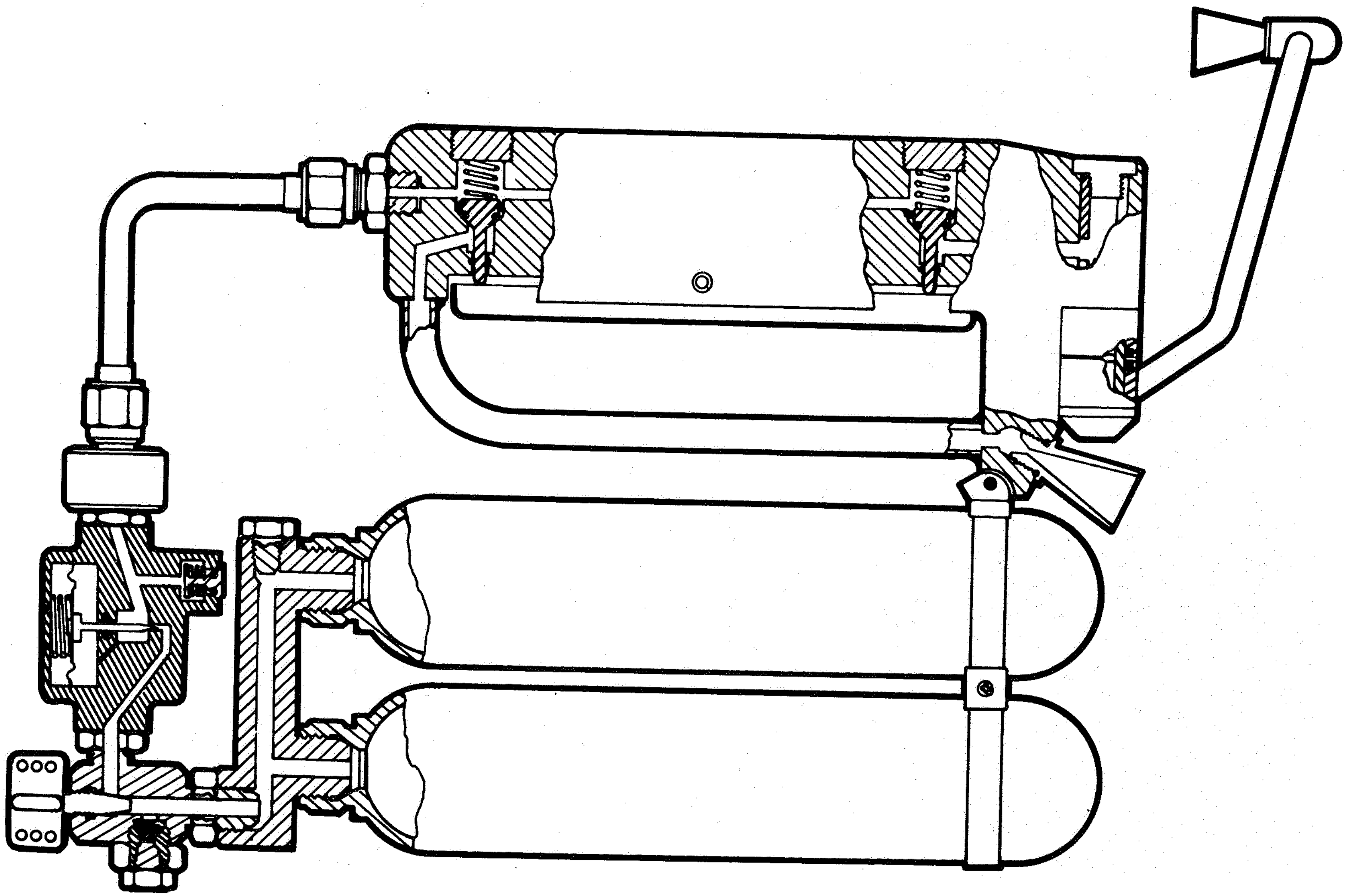


Figure 6.1-2. - Cutaway of Gemini IV Hand Held Maneuvering Unit.

NASA-S-67-789

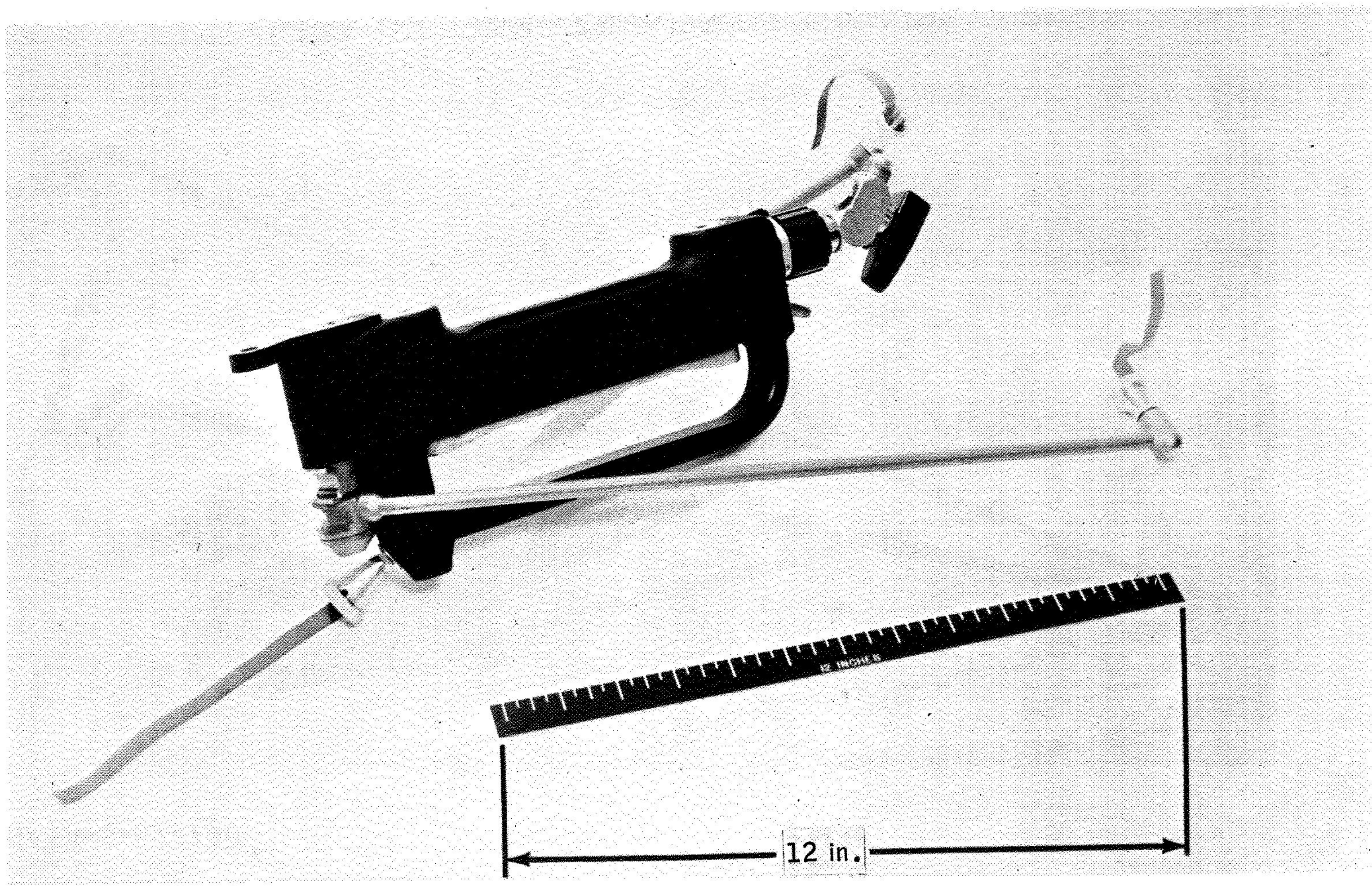


Figure 6.1-3. - Gemini VIII Hand Held Maneuvering Unit.

NASA-S-67-790

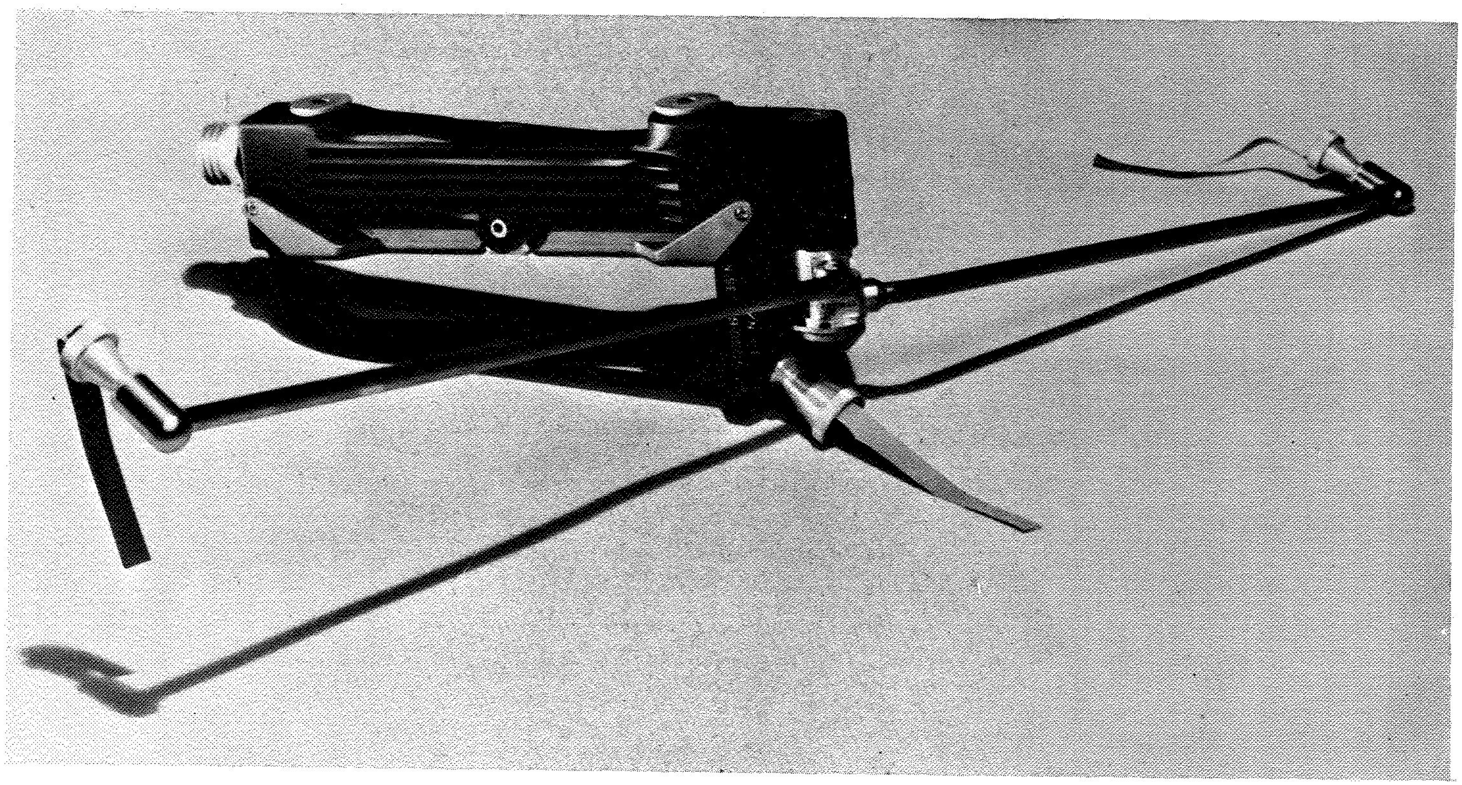


Figure 6.1-4. - Gemini X Hand Held Maneuvering Unit.

NASA-S-67-792

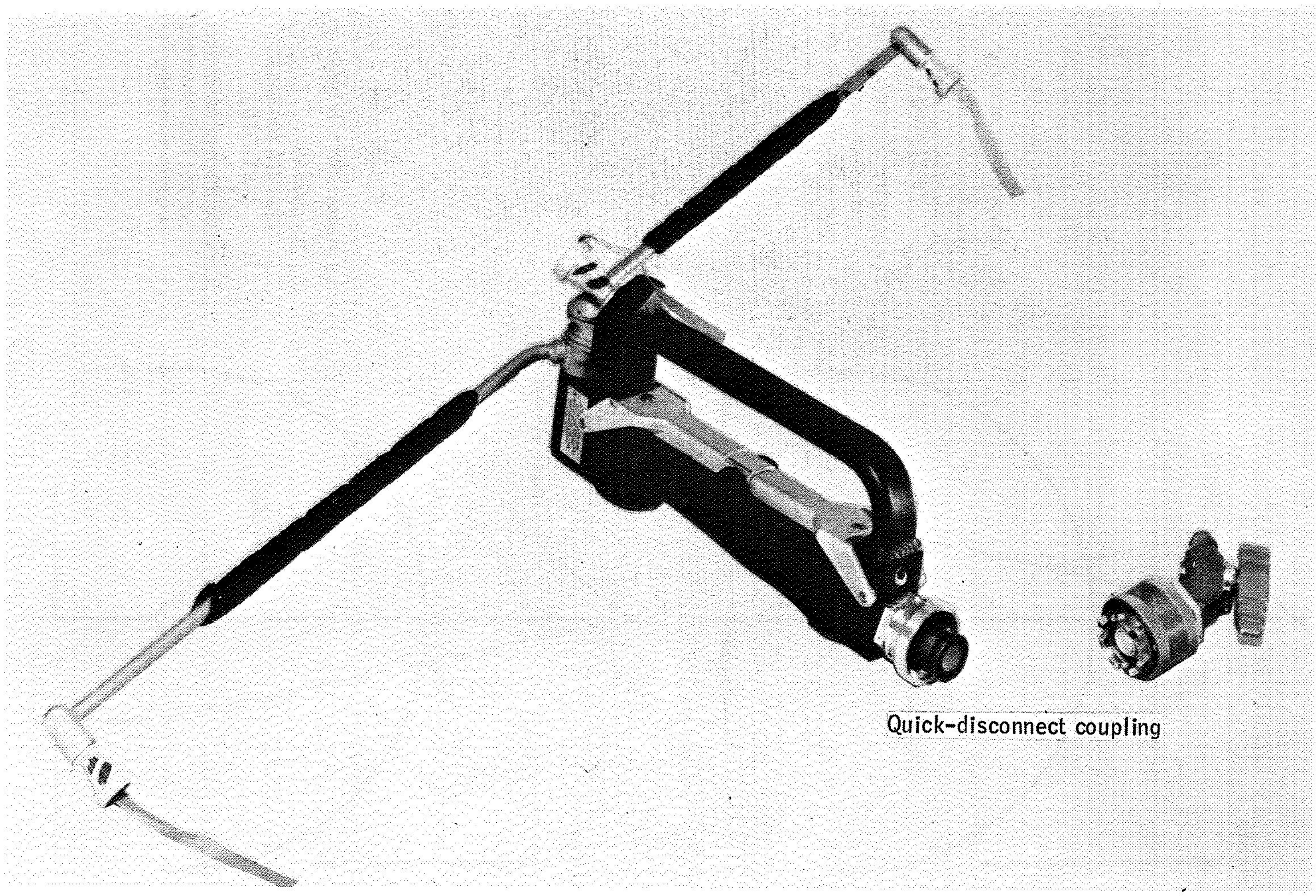
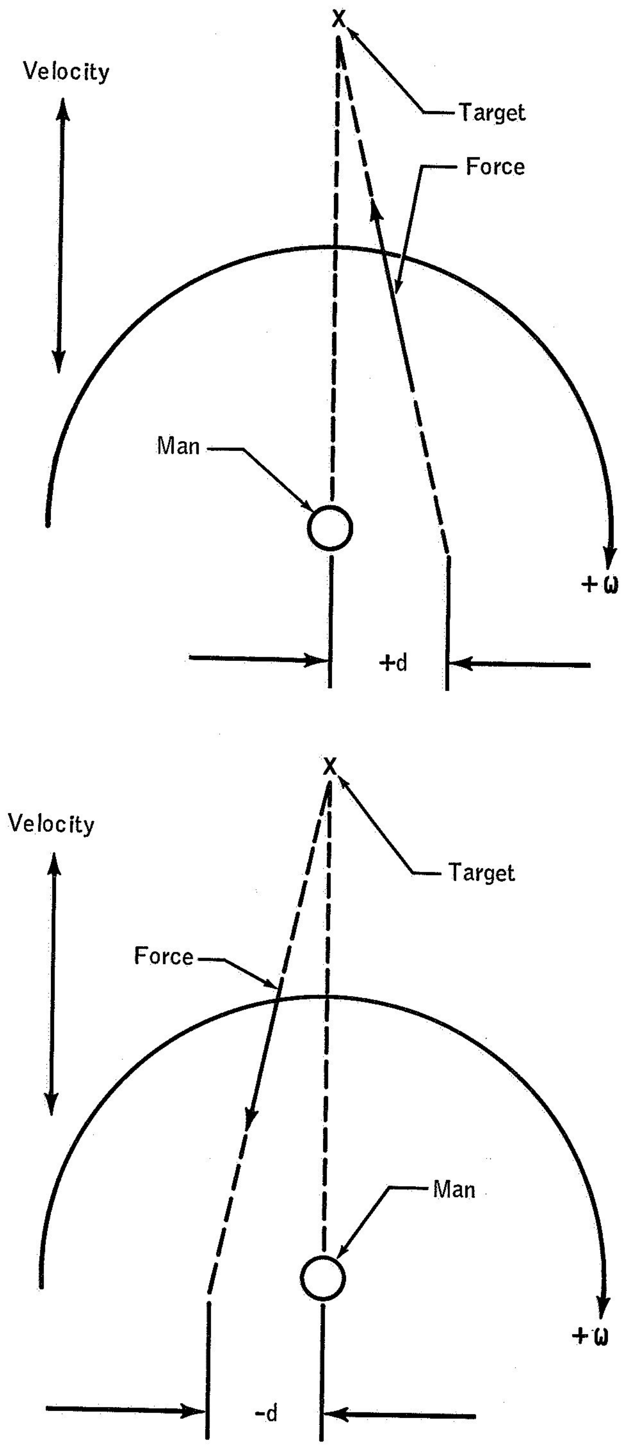


Figure 6.1-5. - Gemini XI Hand Held Maneuvering Unit.

NASA-S-67-841



Tractor mode

1. Always point at target
2. Displace device in same direction as rotation (+d for +ω)
3. Lead the rotations by the control displacements in order to eliminate the rotations

Pusher mode

1. Always point at target
2. Displace device in opposite direction as rotation (-d for +ω)
3. Lead the rotation by the control displacements in order to eliminate the rotations

Figure 6.1-6. - Rules for attitude control using HHMU during straight-line travel.

NASA-S-67-793

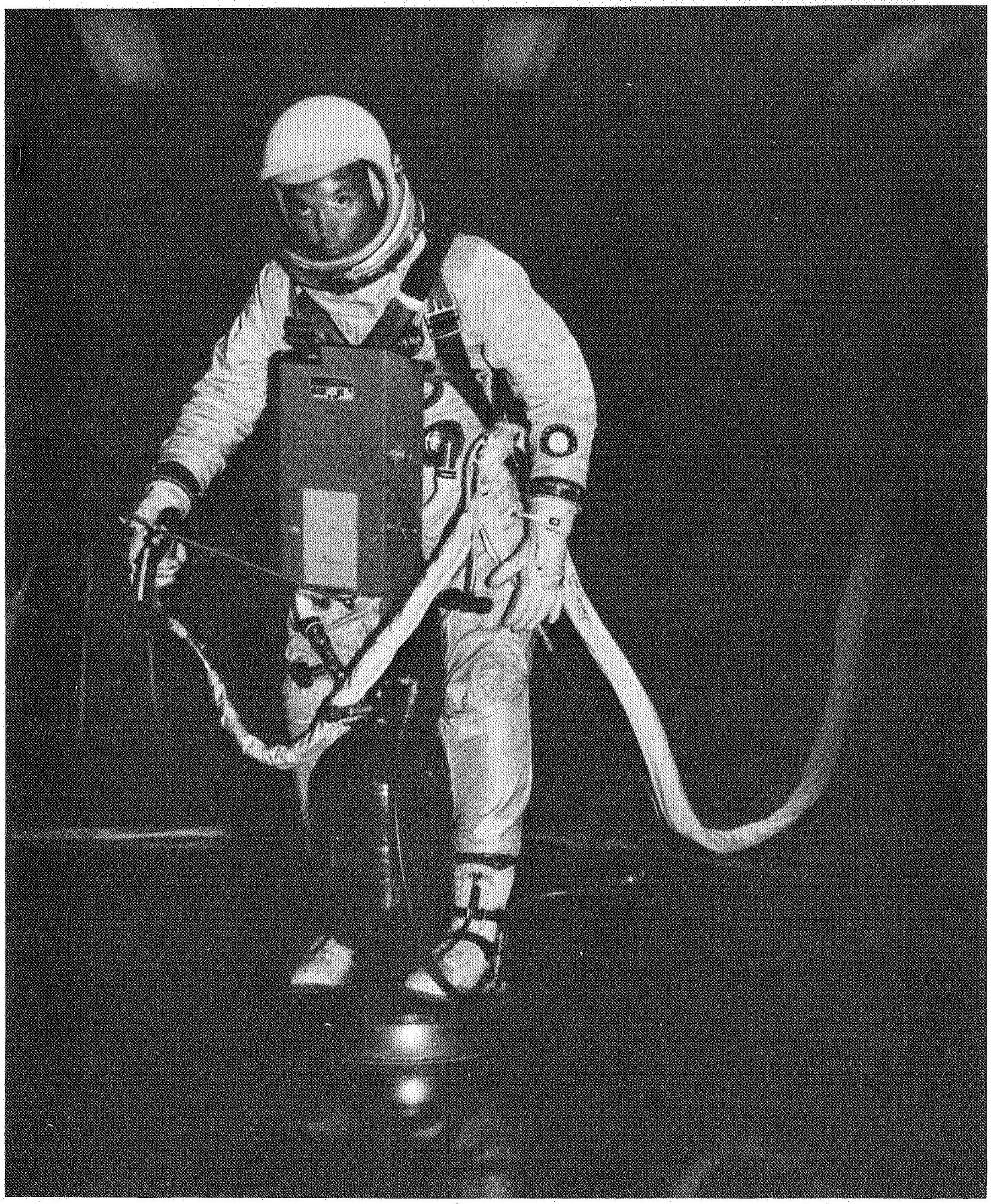


Figure 6.1-7. - HHMU air-bearing simulation (yaw-axis training).

NASA-S-67-794

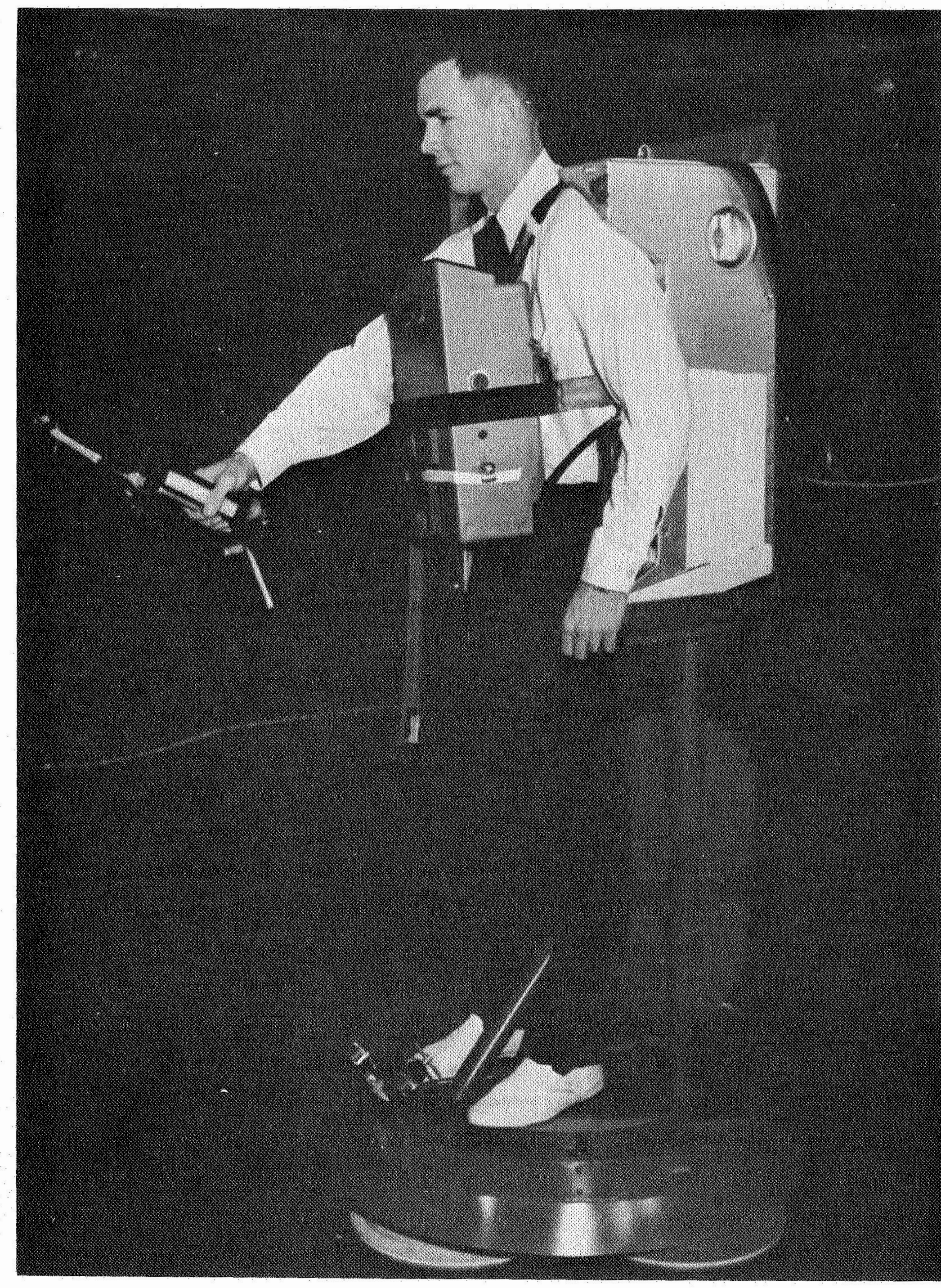


Figure 6.1-8. - HHMU/ESP air-bearing simulation (yaw-axis training).

NASA-S-67-795

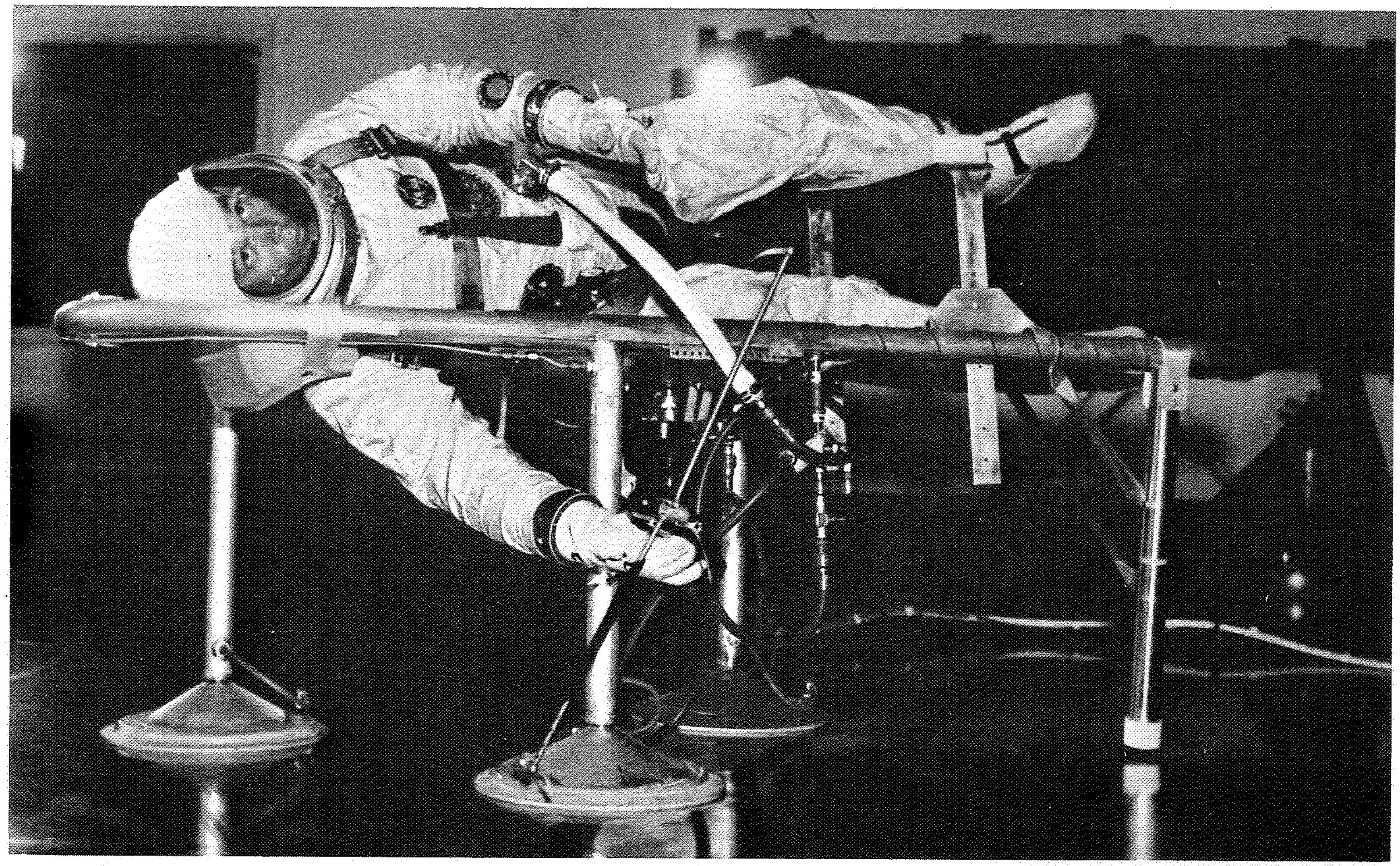


Figure 6.1-9. - HHMU air-bearing simulation (pitch-axis training).

NASA-S-67-796

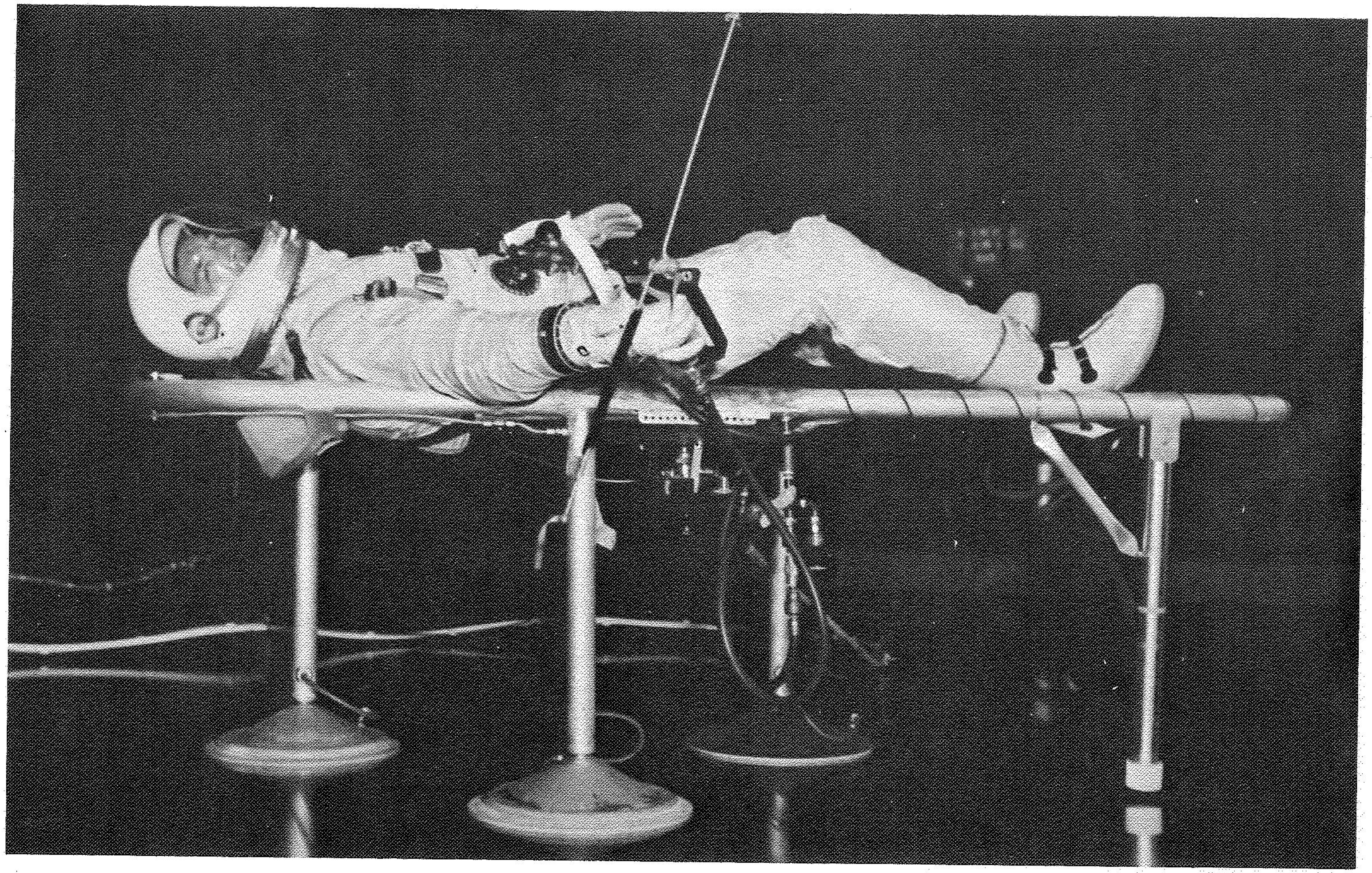


Figure 6.1-10. - HHMU air-bearing simulation (roll-axis training).

NASA-S-67-797

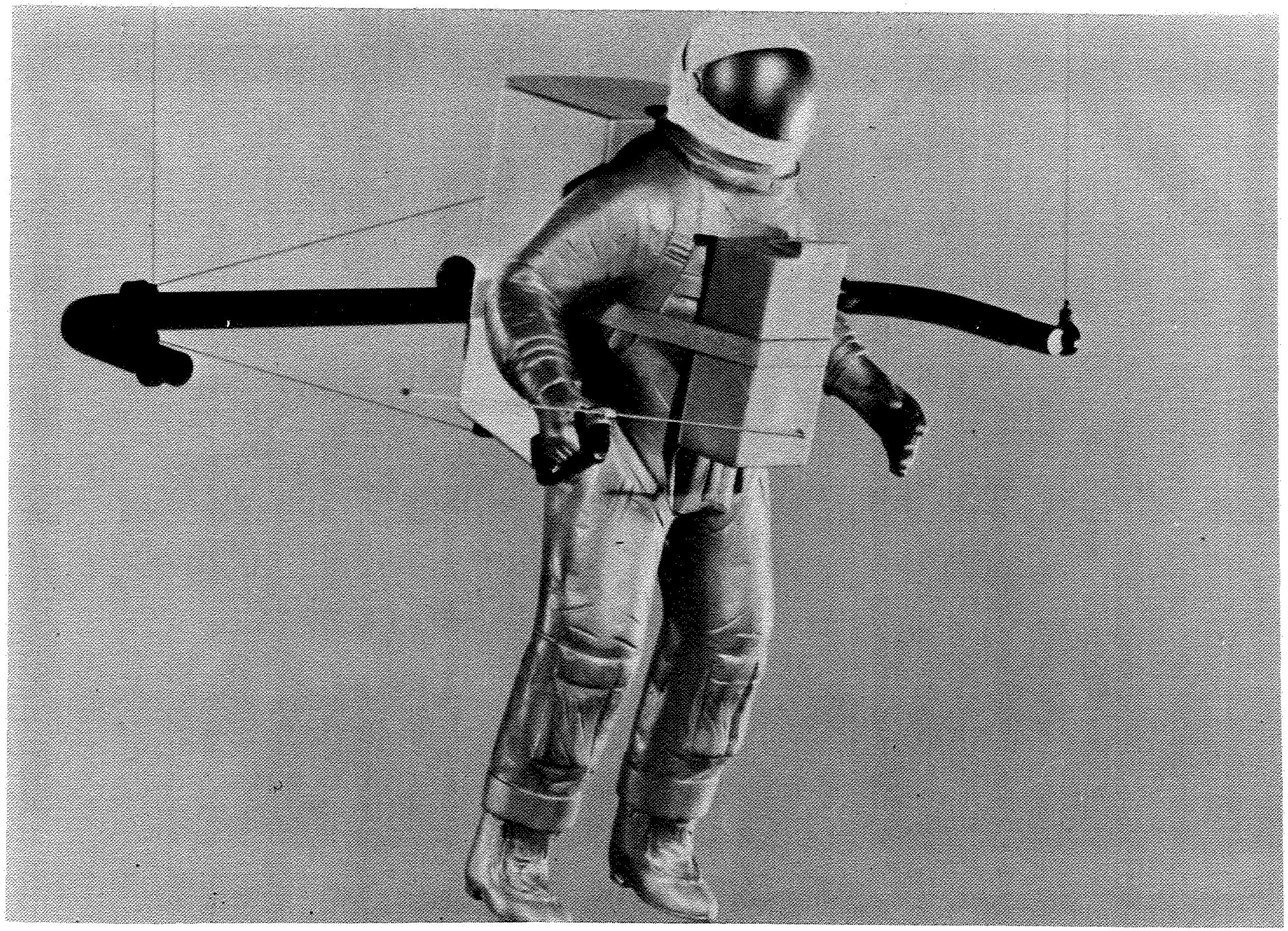


Figure 6.1-11. - Inertia coupling training-aid model.

NASA-S-67-798

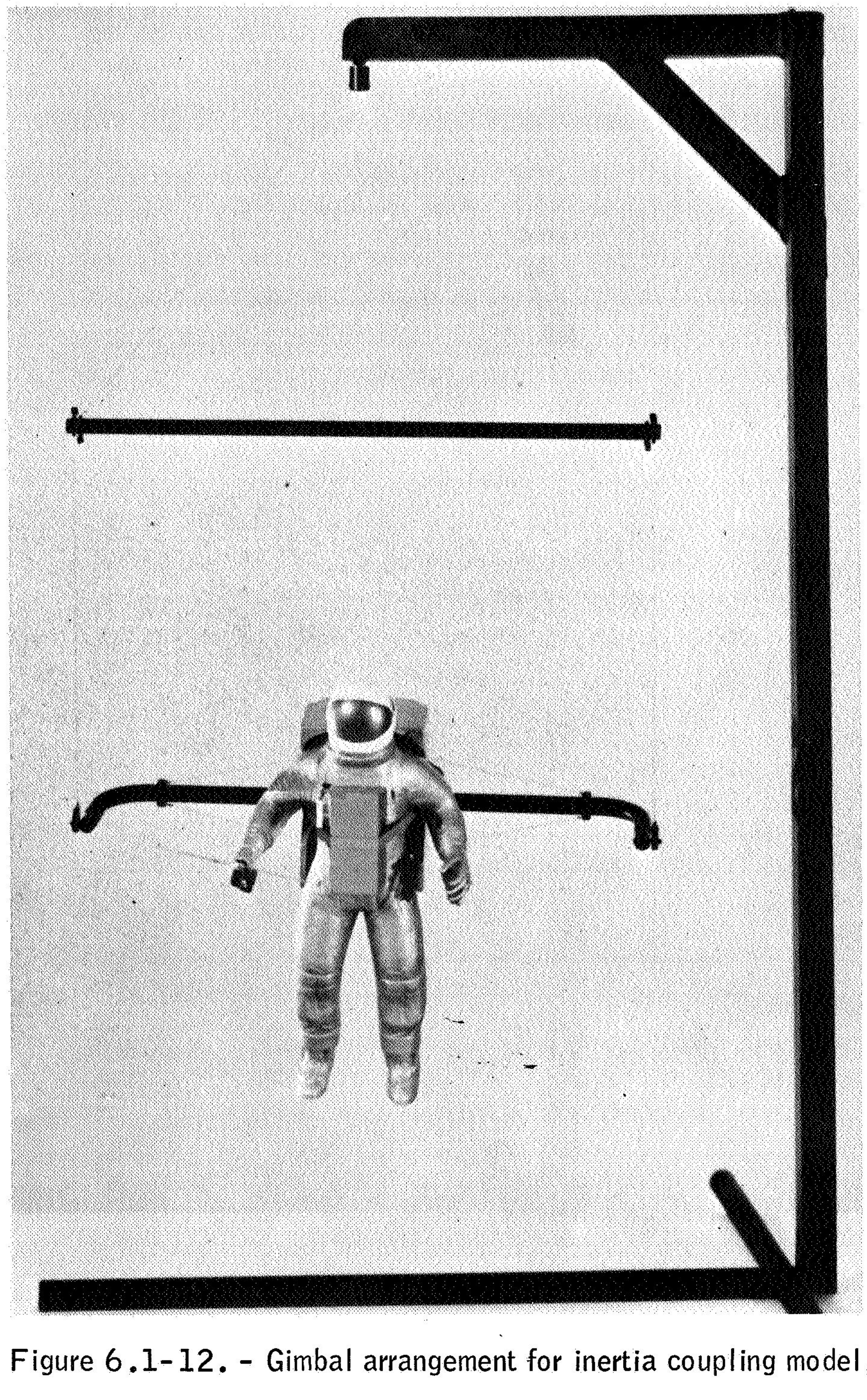


Figure 6.1-12. - Gimbal arrangement for inertia coupling model.

6.2 ASTRONAUT MANEUVERING UNIT

The Astronaut Maneuvering Unit (AMU) was a backpack device which contained the necessary systems to permit an extravehicular crewman to maneuver in space independent of spacecraft systems. The AMU was carried on Gemini IX-A under Air Force Experiment D012 and was originally planned to be carried on Gemini XII. However, the Gemini XII flight plan was subsequently revised, and the AMU was not included. Although a maneuvering evaluation was not accomplished in orbit, a large effort was expended in preparing for the evaluation. The planning for the AMU dominated the EVA flight plan for Gemini IX-A.

6.2.1 Equipment Description

The AMU was a compact unit consisting of a basic structure and six major systems: propulsion, flight control, oxygen supply, power supply, alarm, and communications. A weight breakdown follows:

System	Weight, lb
Structure	34.4
Propulsion	62.6
Flight control	12.7
Oxygen supply	26.9
Power supply	21.9
Alarm	0.7
Communications	9.7
Total	168.3

6.2.1.1 Structure.- The structure consisted of the backpack shell, two folding sidearm controllers, and folding nozzle extensions. The shell was a box-like structure consisting of three main beams and supporting shelves on which the components were mounted. The size of the backpack was determined by the hydrogen peroxide, oxygen, and nitrogen tanks. The thrusters were located in the corners of the structure to provide controlling forces and moments about the center of gravity of the entire AMU. The remainder of the components were located in available spaces inside the pack. The total volume and shape were constrained by the stowage location in the Gemini equipment adapter section, which required the folding features of the nozzle extensions and flight-controller arms. A removable thermal curtain covered the stowage cavity to provide passive temperature control for the backpack. As part of the donning exercise, the extravehicular pilot unfolded the nozzle extensions and controller arms into position. The control handles by which the pilot could introduce translation and attitude commands were in a readily accessible position on the front of the controller arms. The nozzle extensions directed the exhaust plumes from the upper forward-firing thrusters away from the helmet and shoulders of the suit.

6.2.1.2 Propulsion system.- The propulsion system was the heaviest, largest, and most complex system in the AMU. About 24 pounds of hydrogen peroxide were provided to supply a total impulse of 3000 to 3500 lb/sec. Positive expulsion of the hydrogen peroxide was provided, with the nitrogen stored at 3500 psi. The nitrogen tank supplied high-pressure gaseous nitrogen to a regulator when the nitrogen shutoff valve was opened manually. Nitrogen regulated to 455 psi was then supplied to the hydrogen peroxide tank. A bladder in the hydrogen peroxide tank separated the propellant from the nitrogen. The flow of propellant from the tank to the thrust chamber assemblies was controlled with the manual valves, which also controlled the application of electrical power to the individual thruster valves. Two manual valves were provided, one for the primary control system and one for the alternate system. There were 12 thrust chambers of nominal 2.3-pound thrust and 16 solenoid-actuated control valves. Each control system utilized eight thrusters; two forward, two aft, two up, and two down. The forward-firing and aft-firing thrusters were operated as balanced pairs for translation forward and aft and for pitch and yaw control. The up-firing and down-firing thrusters were used for translation vertically and for roll control. The alternate system used entirely separate forward-firing and aft-firing thrusters but used the same thrust chambers for up and down thrusting. However, separate control valves were used in the alternate system for the up, down, and roll commands. Safety features were provided in the relief valves located in both the nitrogen and hydrogen peroxide lines. The valves vented into thrust-neutralizing overboard vents.

6.2.1.3 Flight control system.- The flight control system provided manual and automatic three-axis attitude control and stabilization and manual translation in two axes. Two redundant systems were available. Control commands were made manually through the control handles located on the controller arms. The left-hand controller provided translation commands; the right-hand controller provided attitude control. Also, on the left-hand controller assembly were the mode selection switch, a voice communication volume control, and a VOX disable switch. The mode selection switch was used to select either automatic or manual attitude control and stabilization. The volume control permitted the pilot to control the headset volume. The VOX disable switch prevented keying of the voice-operated switches. Also, on each controller arm there was a thermal shield for protection of the pilot's gloves from the thruster plume heat. These shields were added before the flight of Gemini IX-A when an analysis showed the need for additional protection. The bulk of the pressure-thermal gloves was greater than desired, so the addition of insulation to the gloves was not an acceptable solution to the problem. Therefore, the thermal shields were incorporated as part of the AMU.

In the manual control mode, translational inputs resulted in accelerations of about 0.35 ft/sec^2 for the duration of the input. However, pure translation would not result because of the offset of the center of mass from the center of thrust and because of the tolerance in thrust values. In the automatic (stabilized) mode, pure translations could be obtained from translational inputs, but the acceleration level was approximately halved due to attitude control requirements on the thrusters. A priority was incorporated in the jet-select logic for the forward-firing and aft-firing thrusters which gave yaw first priority, pitch second, and translation third. Pulse width modulation was utilized, with thruster-on time directly proportional to the input signal.

Rotational inputs in the manual mode resulted in angular accelerations of 11, 13, and 25 deg/sec^2 in roll, pitch, and yaw, respectively, for the duration of the input. Pure rotation would not result for the same reasons that pure translation could not be attained in the manual mode. Pure single-axis rotations could be attained by use of the automatic mode. Acceleration would occur on command at the levels already specified, until an angular rate of about 18 deg/sec in pitch or yaw, or 26 deg/sec in roll was present. Angular acceleration would then stop, and a continued input to the attitude controller would result in this rate being maintained. If the pilot released the controller head, it would return to the neutral position, and deceleration would begin. When the rotation had been stopped, the control system would go into an attitude-hold mode, maintaining attitude within about ± 2.4 degrees in each axis. In the absence of external torques, the period of limit-cycle operation within this dead band was greater than 20 seconds.

6.2.1.4 Oxygen supply system.- The oxygen supply system supplied expendable oxygen to the ELSS chestpack at closely regulated values of temperature and pressure. A total of 7.3 pounds of gaseous oxygen was stored in the supply tank at a pressure of 7500 psi. When the oxygen manual shutoff valve was opened, the high-pressure oxygen flowed through a heat exchanger for initial heating, then to a pressure regulator and to a thermostatically controlled heater. A minimum of 5.1 pounds of oxygen was available for delivery to the ELSS at 97 ± 10 psi and

65° ± 10° F, at a design flow rate of 5.0 ± 0.2 lb/hr and a peak of 8.4 lb/hr. The thermostatic heater switch was replaced with a manual switch for the Gemini XII unit.

6.2.1.5 Power supply system.- The power supply system provided electrical power to the other AMU systems for the mission duration with a 100-percent reserve capacity. The electrical power was from batteries of silver-zinc cells enclosed in a sealed metal can. Two of the cans were mounted on the backpack for system redundancy. Each can contained two separate batteries, a +28.5-volt battery and a ±16.5-volt battery. The ±16.5-volt battery was composed of 22 1.5-volt silver-zinc cells, each with 1.38-ampere-hour capacity. One set of taps on these cells provided ±16.5 volts to the control system electronics, telemetry signal conditioners, and thruster valves. Another set of taps provided ±15 volts for powering the gyros. The distribution systems for the ±16.5-volt battery in each can were completely independent.

The 28.5-volt battery was composed of 19 1.5-volt silver-zinc cells, each with 2.48-ampere-hour capacity. This battery supplied power to the voice and telemetry transmitters, telemetry multiplexer encoder, telemetry signal conditioner, warning lights, tone generator, oxygen heater, and position lights. The 28-volt power supplies in each can fed to a common bus, but were electrically isolated by diodes to prevent a short circuit of one battery from draining the other. The battery cans were installed as one of the last operations prior to mating the spacecraft adapter to the launch vehicle second stage, since access after that time was impossible without demating the spacecraft. The batteries were isolated from the AMU systems by the main power switch, which the pilot closed as part of the predonning procedure.

6.2.1.6 Alarm system.- The alarm system gave both crewmembers an audible warning when certain critical out-of-tolerance conditions were present. The warning was given both as a beeping 1700-cps tone in the headset and a warning light on the ELSS chestpack display panel. Four individual alarm lights located on the chestpack display panel identified which system was out of tolerance. The four warning lights and the conditions which triggered them were the following:

Warning light	Triggering conditions
O_2 PRESS	(1) Depletion of oxygen supply pressure to 800 psi (indicated when a 10-minute oxygen supply remained) (2) Reduction in temperature of oxygen supply line below 5° ± 5° F (indicated failure of the oxygen heater)[a]
H_2O_2	Propulsion system nitrogen tank pressure biased with temperature (indicated 30 percent of hydrogen peroxide remained)
FUEL PRESS	Depletion of propulsion system nitrogen tank pressure to 650 psi, or hydrogen peroxide tank pressure to 395 psi (indicated leakage of nitrogen or hydrogen peroxide)
RCS	(1) Excessive duty cycle (7.5 percent) on any thruster while operating in the automatic mode (indicated runaway jet) (2) Decrease of any 16.5-volt supply below 14 volts (indicated imminent loss of control authority)

[a]Would have applied to the Gemini XII mission only.

6.2.1.7 Communications system.- The communications system included a telemetry system and a voice system. The telemetry system transmitted certain backpack parameters and biomedical parameters to the spacecraft on 433.0 Mc. On the Gemini spacecraft, the information was to have been stored on the B track of the basic Gemini data acquisition system recorder. There were 23 analog channels, of which 21 were used, and 48 bilevel channels, of which 25 were used. The data were available for postflight analysis only. The voice communications transceiver was a

UHF transmitter-receiver which was controlled by redundant voice-operated switches. Transmissions were at 296.8 Mc. The transceiver was designed to be compatible with the basic Gemini system and utilized the microphone and earphones in the space suit. The signals from both the telemetry transmitter and the transceiver were diplexed, and they utilized a common folded monopole antenna mounted on top of the backpack. While the AMU was stored in the Gemini adapter section, certain parameters were transmitted to the ground by the spacecraft telemetry system, and the hydrogen peroxide pressure and temperature were displayed on a panel in the spacecraft cabin.

6.2.1.8 AMU tether.- The AMU tether consisted of a 125-foot length of 3/8-inch nylon webbing, two hooks, a single ring, and a bag for stowage. At one end, a hook was provided for attachment to the structural member of the ELSS umbilical. This hook permitted travel out to a distance of 125 feet from the umbilical. The second hook was located 100 feet from the first hook. When it was attached to the umbilical tether, it limited the AMU tether length to 25 feet. A ring on the opposite end of the tether attached to a hook on the space suit harness.

6.2.2 AMU Interfaces

6.2.2.1 Gemini spacecraft.- The AMU backpack was installed in the Gemini equipment adapter section before mating the spacecraft to the launch vehicle (figs. 6.2-1 and 6.2-2). Mechanical mating to the spacecraft was accomplished by mounting a four-legged structure or claw assembly to the backpack and by using a tension bolt to pull the claw down firmly against a sheet metal structure (torque box assembly). The torque box was then mounted on the blast shield door. The bolt was to have been severed by an electrically detonated, pyrotechnically operated guillotine actuated from the cabin after the AMU had been donned during the extravehicular mission. A pull-away electrical connector provided instrumentation and power leads for cabin monitoring and for ground servicing and testing.

6.2.2.1.1 Servicing provisions: To permit servicing of the AMU with hydrogen peroxide after mating the spacecraft to the launch vehicle, a service line was installed from the external surface of the adapter assembly to the AMU hydrogen peroxide fill port. A second parallel line to the AMU-regulated nitrogen port allowed reservicing of the system in the event that reservicing had been required. If, for some reason, the hydrogen peroxide had become unstable and the pressure of the system had risen above 575 psia, the AMU relief valve would have opened and vented the hydrogen peroxide through a third line to the adapter skin. The fill and reservicing lines would have been severed by the same guillotine provided to release the AMU. The vent line was routed through a spring-loaded pull-off housing that would have separated when the AMU was released.

6.2.2.1.2 Thermal interface: Because of the temperature limitations of 40° to 100° F for various AMU components, a thermal cover assembly was placed over the AMU in the adapter section to provide passive thermal control under orbital conditions. The cover rested against attachment points on the front of the AMU and was jettisoned by manual operation of a cockpit switch (fig. 6.2-3).

6.2.2.1.3 Donning hardware: Equipment was provided in the adapter section to assist the EVA pilot in donning the AMU. The hardware included a footrail, two handbars, an umbilical guide, and two floodlights for darkside operation. The equipment was deployed and positioned for AMU donning at the same time the thermal cover was released.

6.2.2.1.4 Instrumentation and communications: To obtain AMU performance data, a telemetry receiver was installed on the electronics module in the spacecraft adapter. This receiver was capable of accepting the diphase pulse code modulation (PCM) format transmitted from the AMU. It demodulated the 433-Mc received signal and provided a 5120-bits-per-second diphase signal to the spacecraft PCM recorder. The data were to have been recorded and stored for postflight analysis.

Two whip antennas were mounted on the adapter surface to receive the AMU telemetry transmissions. Only one antenna would have been utilized at any time. The proper antenna would have been selected by coaxial switching from a signal provided by the telemetry receiver. The receiver would have provided automatic control of the coaxial switch to change antennas when the RF signal on the antenna in use dropped below the preset level.

Although propellant status was monitored in the cockpit, the same pressures and temperatures were also monitored on the ground through spacecraft telemetry. A 0-to-715-psia transducer and a thermistor in the AMU propellant tank were powered by the spacecraft for telemetry channel RA01 (hydrogen peroxide pressure) and for channel RA02 (hydrogen peroxide temperature). Readings of hydrogen peroxide pressure were available until the AMU telemetry switch was placed in the BACKPACK position during the donning phase of the extravehicular mission. Temperatures of hydrogen peroxide were read until AMU separation from the spacecraft.

6.2.2.1.5 Crew station displays: Spacecraft crew station displays and controls were as follows:

(a) The propellant temperature and pressure indicator gage indicated pressure and temperature of the hydrogen peroxide propellant stowed in the AMU.

(b) The warning light for hydrogen peroxide pressure would have illuminated if the pressure had reached 575 ± 20 psia.

(c) The BUS ARM switch, located on the Agena control panel, was placed in the EXP position to energize experiment squib circuits before AMU cover release, footrail extension, telemetry antenna deployment, and AMU release.

(d) The MMU switch provided several functions. With the switch in the spring-loaded DEPLOY position, the AMU would have been released by guillotine cutting of the hollow retention bolt and servicing lines. In the telemetry switch ON position, the telemetry receiver and its associated antenna coaxial switch were powered, and the tape recorder was activated.

(e) The INDEX EXT/EVA BARS EXT switch, when placed in the EVA BARS EXT position, released the AMU thermal cover, the footrail, and the handbars and deployed the AMU telemetry antennas.

6.2.2.2 Extravehicular Life Support System.- The ELSS provided electrical, mechanical, and life support connections between the extravehicular pilot and the AMU. A quick disconnect on the umbilical was attached to a mating connector on the ELSS. The AMU oxygen supply system interface is discussed in paragraph 6.2.1.4. Other AMU/ELSS interfaces are presented in the following paragraphs.

6.2.2.2.1 AMU restraint harness interface: A restraint harness was provided as part of the backpack to secure the backpack in place.

6.2.2.2.2 Malfunction detection system interface: A switch was provided on the ELSS to test the operation of the alarm lights and of portions of the backpack alarm system. The test signal to the backpack was provided through the electrical umbilical. The ELSS supplied a 1700-cycles-per-second audio tone signal to the backpack radio receiver-transmitter upon receipt of a signal from the AMU alarm system through the electrical umbilical. The signal to the backpack continued until the reset switch, located on the top of the ELSS, was actuated. This action generated a signal to the backpack, via the electrical umbilical, to reset the alarm trigger in the backpack.

6.2.2.2.3 Telemetry interface: The backpack telemetered the following parameters received from the space suit and ELSS through the AMU electrical umbilical:

(a) Electrocardiogram

(b) Respiration rate

(c) Space suit pressure (Gemini IX-A only)

6.2.2.2.4 Hydrogen peroxide quantity indication interface: A meter was provided on the ELSS display panel to indicate the quantity of hydrogen peroxide remaining in the backpack. Signals were supplied to the meter from the backpack through the AMU electrical umbilical.

6.2.2.3 Gemini suit.- An exhaust-plume heating analysis indicated that the Gemini thermal coverall materials would be heated beyond acceptable limits during an AMU mission. As a result, extensions were added to the upper forward-firing thrusters, and the leg portions of the basic Gemini space suit coverlayer were modified. Eleven layers of superinsulation (a woven fabric, a superinsulation spacer material of fiberglas, and an aluminized reflective material) were used. The nozzle extensions were evaluated to determine their effect on performance systems design and predonning activities. Performance tests on extension configurations indicated that the extensions did not markedly affect thruster performance. Thermal analysis of the selected design verified this solution of the heating problem associated with the upper forward-firing thrusters.

Protective thermal shields were installed on the AMU controllers. The shields utilized the same materials and layup as the modified extravehicular coverlayer. The shields are visible in figure 6.2-4, which shows the AMU installed for launch on Gemini IX-A.

6.2.3 Training

The AMU experience on Gemini IX-A indicated that the training requirements for a flight of this type of device were quite extensive. The Gemini IX-A EVA pilot spent 140 hours in the various AMU training activities. Training for the AMU flight started with introductory briefings about 7 months before the scheduled flight of Gemini IX-A.

Proficiency in the AMU donning techniques was achieved by numerous repetitions of the donning, using a flight-configured training AMU. A variety of structures were used to represent the Gemini adapter so that interfaces could be studied and restraint systems analyzed. The zero-g aircraft was employed for early study of AMU donning, and requests for several spacecraft modifications followed. The donning was repeated frequently in one g, where time was available to work out procedural difficulties discovered in zero g.

Donning was performed several times in one g with the Gemini IX-A flight article (Serial Number 17) and with another flight-type AMU

(Serial Number 15). The Gemini IX-A pilot performed a donning followed by hot-firings of the propulsion system on the Serial Number 15 unit at sea-level ambient conditions. He also performed a donning of the Serial Number 15 unit at altitude conditions in Chamber B of the MSC Space Environmental Simulation Laboratory. This chamber test was part of the AMU/ELSS integration testing and was intended to include breathing from the AMU oxygen supply and firing the AMU thrusters. However, the test was terminated after the AMU electrical connector malfunctioned. He again donned AMU Serial Number 15 at altitude conditions in the MSC 20-foot altitude chamber. AMU communications and propulsion systems were not exercised in this test. However, actual Gemini IX-A life support equipment was used, and the pilot became thoroughly familiar with the operation of these items at altitude conditions, including all ELSS flow modes and verification of the low pressure warning from the AMU oxygen supply.

AMU training also resulted from spacecraft systems tests at the spacecraft contractor's plant. AMU communications and telemetry were checked in conjunction with simulated flight, and the oxygen supply system was checked during spacecraft altitude chamber testing. AMU donning was performed, and closed-loop AMU/ELSS operation was achieved during the sea-level ambient tests. During the altitude tests, electrical and oxygen connections from the AMU to the ELSS were made, utilizing extension umbilicals from the AMU to the spacecraft hatch area, and closed-loop operation was achieved. Crew participation was also included in the RF and Functional Compatibility Test between the spacecraft and target vehicle, Final Systems Tests, Joint Combined Systems Tests, and Simulated Flight at the launch site, which provided some AMU training in conjunction with the primary objective of integrated testing.

AMU flight simulations were a major part of crew training for AMU flight. Three-degree-of-freedom flight simulations were conducted on the MSC air-bearing facility using a special AMU. This unit had most of the characteristics of the flight articles, but had a cold-gas propulsion system with nitrogen instead of the hydrogen peroxide system of the flight AMU. Six-degree-of-freedom AMU flight simulations were conducted at Edwards Air Force Base and at the AMU contractor's plant. Fixed-base simulations were conducted in the T-27 Flight Simulator at Edwards Air Force Base. This simulator utilized a Farrand optical system, which presented an image of a scale-model target vehicle in the T-27 cockpit. A pair of AMU controller knobs were located in approximately their correct location relative to the seat, and a breadboard AMU control system was used. A night sky with or without starfield was available for background, with the horizon provided by an occultation disk. The simulator provided a high-quality visual presentation, but it had a much narrower field of view than the suited extravehicular pilot, which presented a severe limitation in the usefulness of the simulation.

Moving-base simulations were conducted at the AMU contractor's facility (fig. 6.2-5). An AMU structure was used to duplicate the pilot/AMU interface, especially in the areas of body contour and hand-controller location. An AMU control electronics package was used, and the thrust values for the Gemini IX-A flight article (Serial Number 17) were duplicated. The crew station in the simulator was in the middle of a 20-foot sphere, the inside of which was used as a projection surface for the visual presentation. This offered the advantage of a wide field of view, but the target projection was unrealistic. The target was represented by two circles of different colors, with the circles representing the ends of target. The size of the circles and the included angle changed to indicate changes in AMU-to-target range and attitude. Background presentations available were a black earth with a random starfield, and a featureless lighted earth without a starfield. Since AMU flight was planned for orbital day, the latter was used exclusively.

A significant result of the simulations was the development of an AMU flight technique by the NASA flight crew which differed greatly from the flight technique devised by the contractor. The technique developed by the contractor for a rendezvous followed these lines:

(a) Facing the target, introduce a closing velocity with the aft-firing thrusters

(b) When line-of-sight drift is observed against the background, roll until the vertical thrusters are aligned with the direction of drift and fire the up-firing or down-firing thrusters as required to stop the drift

(c) Repeat as required until close to the target

(d) Take out the closing velocity and contact the target

The technique developed by the flight crew was as follows:

(a) Facing the target, introduce a closing velocity with the aft-firing thrusters

(b) After the closing velocity is established, yaw right or left up to 90 degrees. When line-of-sight drift is detected, correct by firing forward, aft, up, or down thrusters as required to stop the drift

(c) Repeat as required until rendezvous is imminent

(d) Yaw back to a facing-the-spacecraft attitude, take out the closing velocity, and contact the target

In simulations, this "over-the-shoulder" rendezvous technique provided faster response for less fuel and was much easier to learn than the earlier method of roll and vertical firing. In some cases, the technique also permitted the pilot to see the target and the starting point without special maneuvers.

The crew demonstrated the ability to perform basic maneuvers of the type which were planned for Gemini IX during the simulations. The maneuvers were primarily rendezvous with a stabilized target vehicle, utilizing the target vehicle for all reference. The horizon was a secondary cue, required to determine relative altitude, but not an essential reference for rendezvous. Rendezvous maneuvers were simpler in the stabilized mode of AMU flight. However, this mode used propellant at a much greater rate than the unstabilized mode because of continuous limit cycling. The crew was able to perform the maneuvers in the unstabilized mode with much less fuel expended, but with the required burden of continuous control.

The optimum control mode utilization was a combination of stabilized and unstabilized modes. The stabilization feature was utilized during periods of thrust input, and coasting was done unstabilized. This method provided the best combination of control, pilot work load, and fuel consumption. The moving base simulations provided the most realistic pilot control training for AMU flight, and the AMU flight plan was based on the results obtained in these simulation exercises.

The simulations also provided training in the detection and correction of AMU malfunctions. All thruster and gyro failures were simulated, both in the off and the on condition. The failed-off conditions were readily detected and corrected in both the stabilized and the unstabilized modes. All failed-on conditions were also detected, but complete correction was not always possible within the limits of the tethered regime. In the case of a failed-on thruster while in the stabilized mode, the attitude-hold feature of the AMU caused thruster firings to occur such that significant translational velocities (up to 2.5 ft/sec) could build up before the failure was detected. Before this velocity could be detected and canceled out, translation beyond the end of the tether (125 feet) would have occurred. This would have resulted in a bounce off the end of the tether, which was a problem of undefined significance.

It was also discovered during the failure simulations that certain failed-on forward-firing or aft-firing thrusters could cause attitude divergence, even in the stabilized mode of operation. A failed-on thruster in the fore and aft axis generated pitch, yaw, and translation. When the pitch and yaw orientations exceeded the dead bands (2.4°), opposing thrusters began firing in pairs to damp these movements. Since one thruster would be part of both the yaw and pitch correcting thruster pairs, the demand on this thruster could exceed 100-percent duty cycle. When this happened, pitch control was lost because control of yaw was given higher priority by the jet selection logic.

The Gemini IX-A EVA pilot trained for 32 hours in AMU flight simulations for the mission.

6.2.4 Mission Results

The AMU was serviced for flight prior to the scheduled launch date of May 17, 1966. Monitoring of the propellant status (hydrogen peroxide) after launch cancellation indicated a stable pressure rise of 0.2 psia per hour due to normal active-oxygen loss, which was well below the allowable of 0.6 psia per hour. The propellant was not reserviced.

The oxygen and nitrogen systems, which were monitored through ground support equipment, showed no leakage. Fresh batteries were installed in the flight unit on May 21, 1966. A subsequent telemetry check of the AMU indicated that all systems were operating normally.

At launch on June 3, 1966, the hydrogen peroxide pressure had increased to approximately 87 psia, which was satisfactory for launch. Immediately after launch, the propellant tank pressure increased to 90.7 psia, where it remained until donning checkout. The propellant temperatures were normal at 72° to 77° F.

When the EVA pilot entered the spacecraft adapter section, the left handbar and the umbilical guide were not fully extended, and the AMU adapter thermal cover was not completely released. Also, the left adapter EVA light was inoperative. When the pilot pulled on the handbar, the handbar moved to the fully deployed position and released the thermal cover and the umbilical guide. Donning activities and AMU inspection were completed through the point of connecting the AMU electrical umbilical. These activities included attaching portable penlights, opening the nitrogen and oxygen shutoff valves, readout of oxygen and nitrogen pressures, positioning the sidearm controllers, positioning the umbilicals and the AMU restraint harness, attaching the AMU tether, turning on the AMU electrical power, and changeover to the AMU electrical umbilical. The oxygen pressure was a normal 7500 psia, and nitrogen pressure after nitrogen-valve opening was 2800 psia (normal for AMU operation). Because of the difficulty in maintaining position in the adapter, donning activities required a much longer time to complete than expected. The pilot tended to drift away from the work area in the adapter. Position could not be maintained, because both hands were required to extend the sidearm controllers and to attach the AMU tether. AMU communications to the command pilot were garbled, but were usable by both pilots.

Because of the severe visor fogging which occurred during the AMU preparation activities, the crew discontinued the AMU experiment. At sunrise, the EVA pilot disconnected the AMU electrical connection, connected the ELSS umbilical, and returned to the cabin, leaving the AMU power on. The AMU remained in the adapter with the systems activated for flight until retrofire.

Termination of the EVA precluded an evaluation of most of the AMU performance capabilities. However, the backpack successfully withstood a Gemini launch and a 2-day exposure to the space environment. Most of the functions of checkout and donning were performed prior to the termination of AMU activities. Although the AMU was transmitting telemetry data following power-up during the predonning activity, failure of the Gemini data recorder precluded the recovery of quantitative analysis of AMU data performance. Analysis of the AMU systems, therefore, was based primarily on the debriefing comments by the flight crew.

During the 2-day pre-EVA period, hydrogen peroxide pressure and temperature were monitored by telemetry at least once per orbit. Low activity of both parameters resulted in few cabin readouts. During the pre-EVA period, the predicted active-oxygen loss (AOL) buildup was continuously computed and plotted against the recorded AOL buildup.

Actual AOL pressure buildup was much lower than predicted. (A rise of 8.5 psia had been predicted.) During the 50 hours 37 minutes before the backpack telemetry switch was changed to BACKPACK during AMU donning, the total pressure rise was less than 3 psi. A decrease was predicted in the hydrogen peroxide temperature. During the pre-EVA period, the temperature varied from 69° to 78° F. Readings on the cabin gages during this period were 69° F for temperature and 90 psia for pressure.

6.2.5 Concluding Remarks

All AMU systems exercised during the mission were in an acceptable condition for flight when the AMU evaluation was terminated. Some difficulty was experienced with the reception of the AMU voice signal by the command pilot. Subsequent investigations failed to pinpoint the exact cause of the problem. However, for the expected Gemini XII AMU mission, a third antenna for reception of AMU transmissions was added in the adapter section. Since one of the adapter floodlights did not function on Gemini IX-A, a design change was made to shock-mount the floodlights for Gemini XI and XII. One of the penlights provided for backup failed to operate. A pair of these penlights was subjected to a simulated launch environment mounted on the AMU tether bag as they were on Gemini IX-A. Both functioned properly after the test, and no further action was taken. The preparation and donning of the AMU was a complex procedure involving serial operations. The primary cause of AMU donning problems on Gemini IX-A was the lack of adequate body restraints. This problem is discussed in detail in section 5.0. A new foot restraint system for AMU donning was designed for Gemini XII before the AMU was deleted from the mission. Several changes were made to the AMU after Gemini IX-A to simplify the donning, and changes were made to other EVA equipment to simplify all EVA tasks.

Training for flight of the AMU was very demanding on the crew's time, and this should be considered in planning future EVA maneuvering missions.

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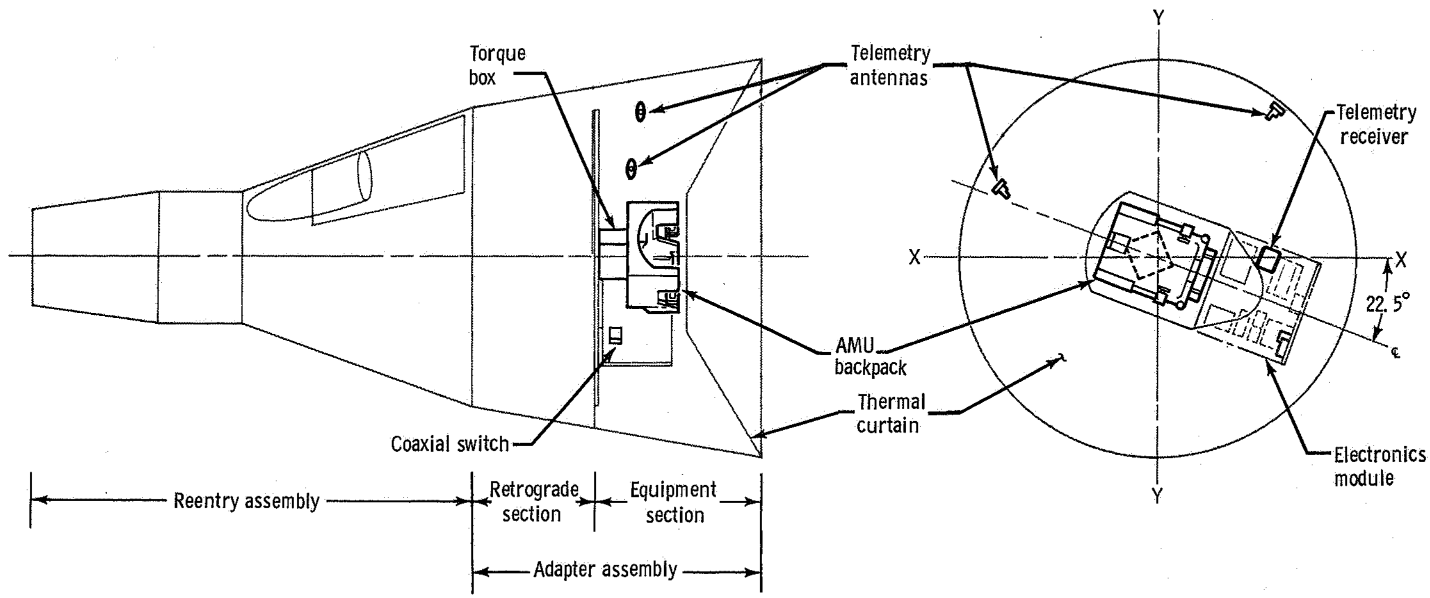

Figure 6.2-1. - Experiment D012 - AMU stowage in adapter assembly.

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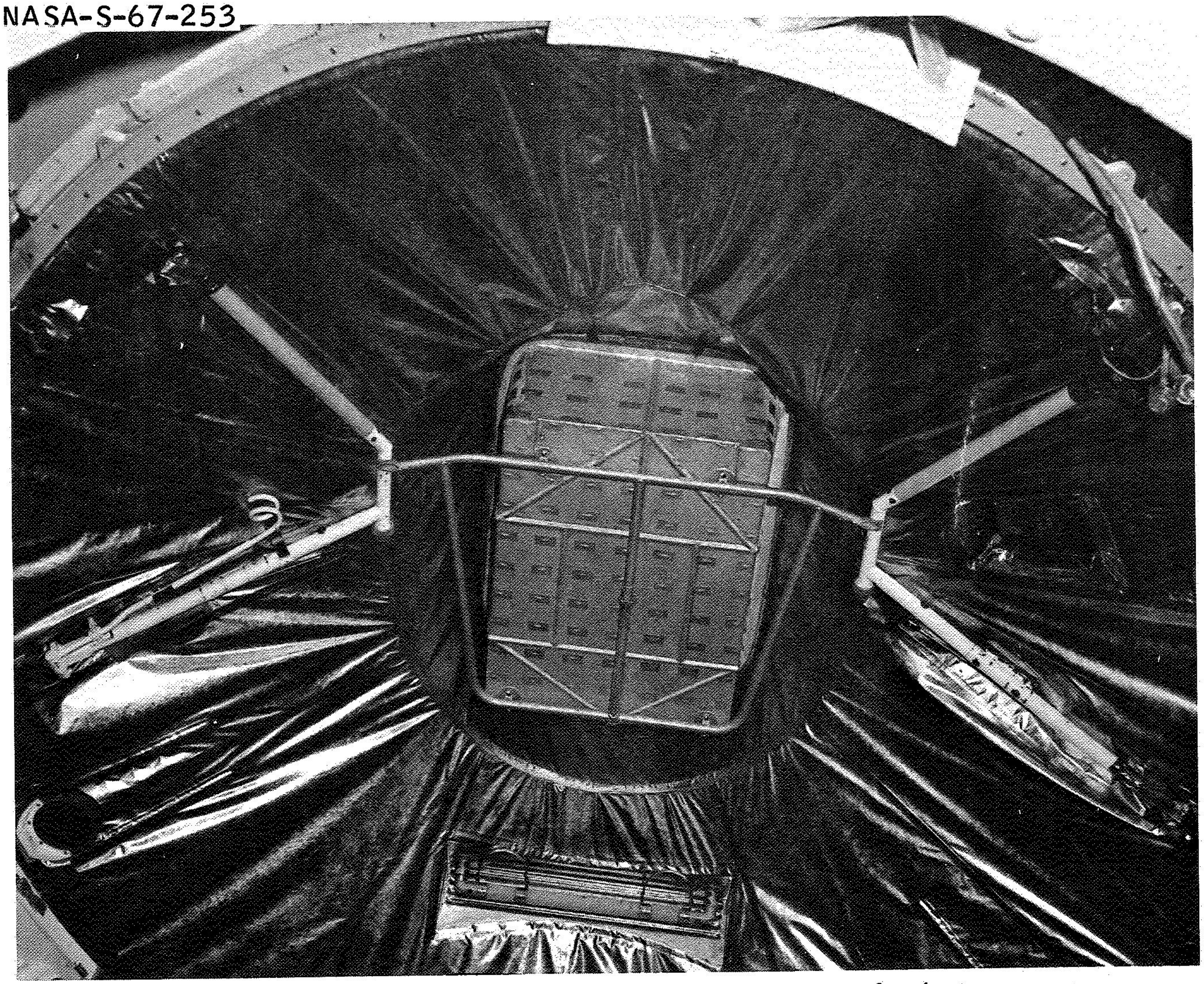

Figure 6.2-2. - AMU installation in spacecraft adapter.

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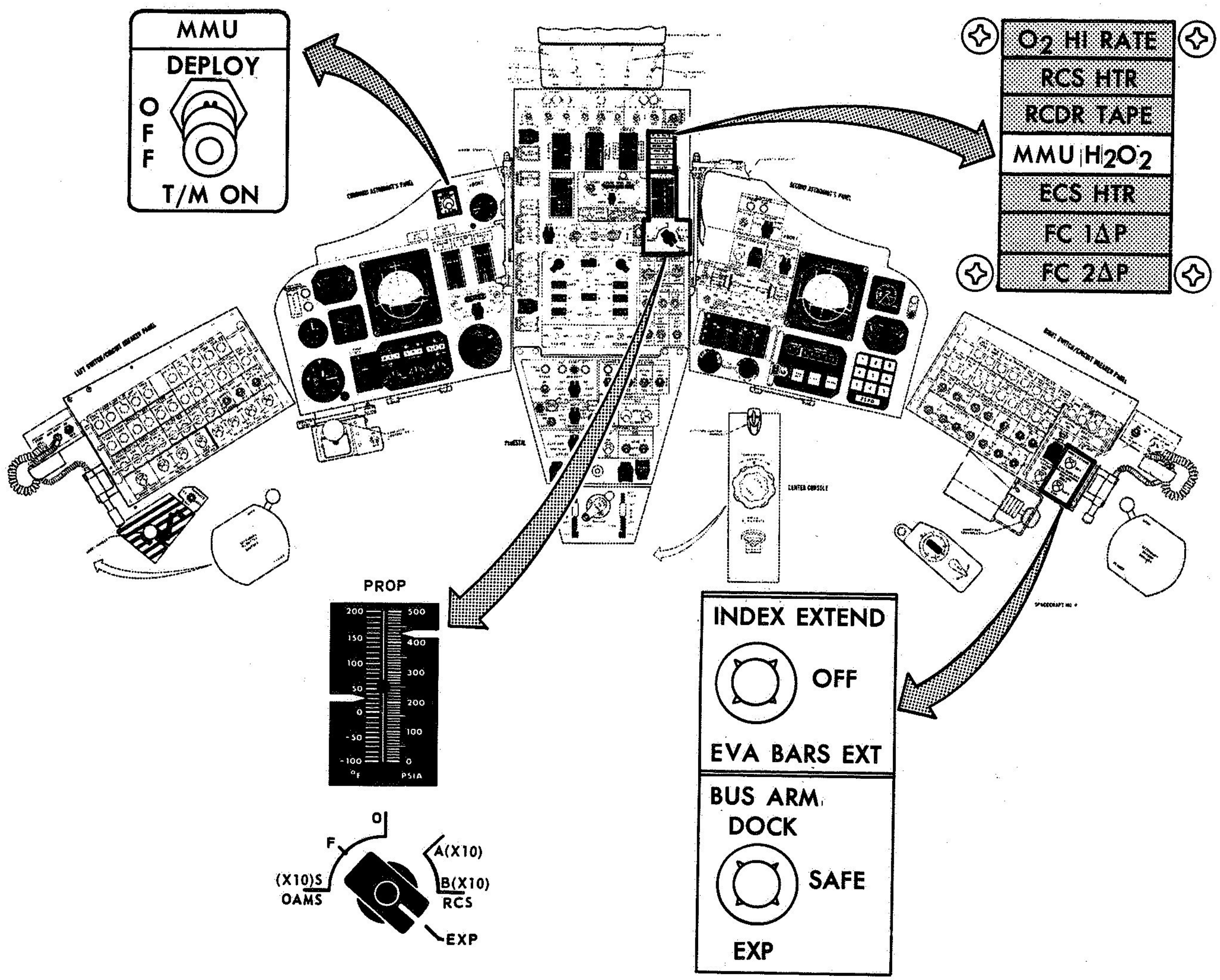

Figure 6.2-3. - Experiment D012- AMU controls and indicators.

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Figure 6.2-4. - AMU with thermal protective cover removed.

NASA-S-67-3058

Figure 6.2-5.- AMU moving-base simulator.

7.0 EXTRAVEHICULAR TRAINING AND SIMULATION

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7.0 EXTRAVEHICULAR TRAINING AND SIMULATION

7.1 ONE-G TRAINING

Some phases of crew training for EVA can be conducted in a one-g environment with little compromise in the value of the training. From the standpoint of available facilities, this training is more convenient than zero-g or underwater simulations. The particular forms of one-g training were dictated by the flight plan requirements and by the facilities available. One-g walk throughs, altitude chamber tests, and air-bearing platform training were the principal forms of one-g EVA training used by the Gemini crews.

7.1.1 Training Objectives

The objectives of all one-g EVA training were to familiarize the flight crews with the procedures, the hardware, and the spacecraft stowage related to EVA and to develop a coordinated work effort between the crewmembers.

7.1.2 Training Methods

7.1.2.1 One-g walk throughs.- The one-g walk through was a training exercise in which a crew walked through a detailed checklist of EVA procedures for practice or training. This form of training was conducted with mockups of the spacecraft reentry module, the Gemini Agena Target Vehicle (GATV), and the spacecraft adapter section. Crew station walk throughs were conducted in a mockup of the crew station which very closely simulated all the detail of the actual Gemini spacecraft and in which was stowed all the planned onboard equipment. The crew, wearing space suits and full flight equipment, would go through a step-by-step sequence of each phase of the EVA portion of the flight plan: preparation for EVA, egress, EVA phase, ingress, and post-EVA activities (fig. 7.1-1). During the crew station walk throughs, the crews became familiar with the procedures for performing the EVA, the related equipment, and the spacecraft stowage.

EVA equipment was carried in the spacecraft adapter section on four missions. Mockups of the spacecraft adapter section were used for adapter walk throughs in which the crews would practice operations with the EVA equipment installed in the adapter (fig. 7.1-2).

Similar walk throughs were held with mockups of the GATV. These consisted of the crew going through the procedures for either the attachment of the GATV tether to the spacecraft docking bar (for Gemini XI and XII), or for the tasks to be performed at the TDA work station for Gemini XII. In each case, the crews became familiar with the hardware involved and the procedure for performing the various tasks.

7.1.2.2 Altitude chamber tests.- Altitude chamber tests provided familiarization and training for the Gemini crews in a simulated space environment. Each crew performed a simulated EVA mission in a vacuum chamber using the actual spacecraft. Altitude chamber training exercises included checkout and donning of the Extravehicular Life Support System (ELSS), the ESP, and the AMU (fig. 7.1-3). These tests familiarized the crews with the EVA systems operation under vacuum conditions and provided increased confidence in the equipment to be used in flight. A more detailed discussion of the altitude chamber testing is presented in section 4.2.2.2.2(e).

7.1.2.3 Air-bearing platform.- Training exercises with the AMU and the Hand Held Maneuvering Unit (HHMU) were conducted on an air-bearing platform (fig. 6.1-7). This simulation of three of the six degrees of freedom experienced in the weightless environment familiarized the crews with the handling characteristics of each unit and with the procedures for operating each unit. However, only one angular degree of freedom could be simulated at one time. (See sections 6.1-5 and 6.2-3 for detailed discussions of the HHMU and AMU training.)

7.1.2.4 Body harnesses.- Slings and body harnesses were used for occasional simulation exercises in which the pilot was suspended above a mockup of the spacecraft adapter for particular task evaluations. This type of simulation introduced the pilot to some of the problems in performing tasks in a weightless condition by simulating four degrees of freedom, but it had very limited use.

7.1.3 Equipment and Procedures Familiarization

7.1.3.1 Spacecraft stowage.- The value of one-g training in spacecraft stowage operations was important because of the stowage problems in the crowded cockpit of the Gemini spacecraft. The numerous experiments and inflight tasks performed on the Gemini missions dictated a detailed and complex stowage plan (fig. 7.1-4 and table 7.1-I). Most equipment was stowed in containers with one piece on top of another. The desired stowage configuration for EVA was with the necessary EVA equipment at the top of the stowage containers or at least readily available. The restowage locations depended on the possibility of its reuse. Some EVA equipment was stowed with other non-EVA equipment which was needed before and/or after the EVA. On the Gemini XII mission, over half of the 207 individual pieces of stowed equipment were handled in one way or another during EVA preparation. Hence, there was a major spacecraft stowage activity during EVA preparation. This stowage activity was recorded in a detailed checklist which gave the crew the step-by-step procedures for the entire task. The crew station walk throughs familiarized the crews with the overall stowage arrangement.

7.1.3.2 Equipment familiarization.- One-g training exercises familiarized the crews with the equipment associated with their particular mission. The walk throughs were also an excellent opportunity for the crew to evaluate the suitability of the EVA equipment for inflight use. The crew handled the equipment in the context of the flight plan, unstowing and using the equipment as it would be used in flight (fig. 7.1-5). In many cases the need for minor modifications was identified in the course of these walk throughs. The resulting modifications were incorporated for subsequent walk throughs for further training and evaluation.

7.1.3.3 Procedures familiarization.- The procedures contained in the EVA checklist were a total sequence of every action necessary to complete the EVA. The checklist was the documentation interface for EVA spacecraft stowage, for hardware, and for the crew. The checklist provided information about equipment location, removal from stowage, operation, and restowage, as well as about the crew function and about other interfaces with the equipment. The checklists were divided into two parts: the soft-suit checklist and the hard-suit checklist. In general, the soft-suit checklist included all those procedures performed in the pressurized spacecraft and the hard-suit checklist included all the procedures performed after spacecraft depressurization.

In preparing the intravehicular procedures, consideration was given to the following factors:

(a) Provide adequate time for EVA preparation

(b) Stow all equipment in one location associated with an EVA or an inflight task

(c) Minimize the number of trips from normal crew positions to equipment stowage areas

(d) Restrict the number of items unstowed in the spacecraft at any one time to only those being used, or to those that could be temporarily stowed so as not to interfere with crew operations

(e) Prevent loose items from floating

(f) Minimize the EVA pilot's work prior to egress

(g) Complete all equipment unstowage and preparation before the crew went to a hard-suit configuration

(h) Complete spacecraft configuration for EVA before going to a hard suit configuration

(i) Prepare the cockpit for the EVA pilot's ingress

(j) Optimize the pilot's entry cross-sectional area relative to the hatch opening area

(k) Determine the equipment restowage requirements

Crew familiarization with intravehicular procedures, EVA preparation, and ingress from EVA was accomplished primarily in crew station walk throughs. The flight crews indicated that the inflight experience was very similar to the crew station walk through. They also indicated that many tasks, such as the handling of heavy equipment, were easier to perform in flight.

The following factors were taken into consideration in preparing the extravehicular procedures:

(a) Detail of procedure commensurate with the complexity of the task to be performed

(b) Programmed rest periods as determined from training

(c) Spacecraft control during the EVA

(d) Significance of reaction forces in the EVA environment

(e) Workload control

(f) Environment familiarization

(g) Pace of the activities

(h) Documentation of the EVA

One-g training provided the basic familiarization with extravehicular procedures as well as the basis for refining and updating the checklist procedures. The crews walked through the procedures at one-g before proceeding to other forms of training. Several walk throughs of the GATV tether attachment were necessary to familiarize the crew with this procedure and the hardware as used in the normal sequence of the flight plan. For more complex tasks, such as the checkout and donning of the AMU (fig. 7.1-2), many more walk throughs were required.

7.1.4 Developing Coordinated Work Effort

A coordinated effort during EVA preparation tended to minimize the effort required of the pilot. This approach was taken to conserve the pilot's energy for the activities outside the spacecraft. While ingress after the EVA was not as complex as the EVA preparation, it also required the cooperative effort of both crewmembers. Crew station walk throughs provided the proper flight plan sequences in which this coordinated work effort could be developed. The command pilot's participation during the EVA phase was somewhat different from that of EVA preparation and ingress. Although he was performing some independent tasks, such as changing film magazines or voice tapes, his principal activity was talking the pilot through the EVA flight plan using the checklist. The command pilot was required to be completely familiar with each task performed by the pilot in order to judge the progress of the EVA flight plan and to assess the work pace. One-g walk throughs in the spacecraft adapter or on the GATV, with the command pilot reading the procedures to the pilot and observing the task being performed, prepared both crewmembers for participation in the EVA (fig. 7.1-2).

7.1.5 Concluding Remarks

One-g training familiarized the crews with EVA hardware, spacecraft stowage, and procedures; provided the basis for developing a coordinated work effort; prepared the crews for other forms of training with greater fidelity of zero-g simulation; and contributed to the preparation of both crewmembers for EVA.

The following factors should be routinely considered in future one-g training:

(a) Any planned modifications to EVA equipment and procedures should be accomplished before training begins.

(b) All EVA equipment involved in the training (mockups of spacecraft, individual EVA hardware items) should have the same configuration as the flight items.

(c) All EVA equipment intended for inflight use should be included in the training exercises.

(d) Detailed procedures should be provided.

(e) The limitations of one-g training techniques must be recognized.

TABLE 7.1-I.- SPACECRAFT 12 LAUNCH STOWAGE

Stowage area[a]	Item	Quantity
(1) Left foreward sidewall pouch	Tissue dispenser Personal hygiene towel Frog egg experiment cover	1 1 1
(2) Left aft sidewall pouch	Flight plan book Hard-suit checklist Soft-suit checklist Systems book Transparent reticle Polaroid shade Reflective shade Eclipse sunshade	1 1 1 1 1 1 1 1
(3) Right foreward sidewall pouch	Tissue dispenser Personal hygiene towel	1 1
(4) Right aft sidewall pouch	Rendezvous book Hard-suit checklist Soft-suit checklist Celestial display - Mercator Orbital path display Polaroid shade Reflective shade	1 1 1 1 1 1 1
(5) Left instrument panel	Optical sight	1
(6) Right instrument panel	Hatch closing devices Experiment S013 bracket Right-hand camera bracket Standup tether Wrist mirror EVA camera bracket	2 1 1 1 1 1
(7) Right hatch	Telescoping handrail	1

[a]Numbers in parentheses refer to figure 7.1-4 for stowage location.

TABLE 7.1-I.- SPACECRAFT 12 LAUNCH STOWAGE - Continued

Stowage area[a]	Item	Quantity
(8) Left circuit breaker panel	Urine collection device clamp Latex cuffs Splash curtain clips Glare shield Tape, 1/2 in. by 10 ft Clothesline	1 4 3 1 1 1
(9) Right circuit breaker panel	Urine collection device clamp Urine receiver, removable cuff Latex cuffs Splash curtain clips Tape, 1/2 in. by 10 ft Rubber bands Screwdriver	1 1 4 3 1 15 1
(10) Left pedestal in footwell	Food, one-man meal	6
(11) Right pedestal in footwell	Experiment T002 sextant bracket	1
(12) Left side box	Personal hygiene towel Waste container Defecation device Voice tape cartridge Velcro pile, 2 by 6 in. Velcro hook, 2 by 6 in. Penlight Plastic zipper bags, 6 by 10 in. Visor anti-fog pads Food, one-man meal Tether stowage ring	1 1 1 5 1 1 1 3 4 2 1
(13) Right side box	Personal hygiene towel Waste container Defecation device	1 1 1

[a]Numbers in parentheses refer to figure 7.1-4 for stowage location.

TABLE 7.1-I.- SPACECRAFT 12 LAUNCH STOWAGE - Continued

Stowage area[a]	Item	Quantity
(13) Right side box - concluded	Voice tape cartridge	5
	Velcro pile, 2 by 6 in.	1
	Velcro hook, 2 by 6 in.	1
	Penlight	1
	Sungoggles	2
	Plastic zipper bags, 6 by 10 in.	3
	Oral hygiene kit	1
	Spot meter and dial	1
	Light bulbs	6
	Glass contamination strips	3
	Plastic zipper bags, 3 by 4 in.	7
(14) Left sidewall pouch	Urine hose and filter	1
	Experiment S012 lanyard	1
(15) Right sidewall pouch	Sextant eyepiece	1
	Sextant battery	1
	25-mm lens (eclipse)	1
	Shutter release cable	1
(16) Left pedestal pouch	Lightweight headset	1
	Velcro straps	3
(17) Right pedestal pouch	Lightweight headset	1
	Velcro straps	3
	Spacer plate	1
(18) Left footwell pouch	Helmet stowage bag	1
(19) Right footwell pouch	Helmet stowage bag	1
	Visor cover	1
	Celestial display - polar	1

[a]Numbers in parentheses refer to figure 7.1-4 for stowage location.

TABLE 7.1-I.- SPACECRAFT 12 LAUNCH STOWAGE - Continued

Stowage area[a]	Item	Quantity
(20) Right hatch sill	Swizzle stick	1
(21) Water management panel	Urine receiver	1
(22) Voice tape recorder	Voice tape recorder cartridge	1
(23) Right sidewall bracket	Inflight medical kit	1
(24) Left sidewall bracket	16-mm sequence camera window bracket	1
(25) Left sidewall	Pilot's preference kit	1
(26) Right sidewall	Pilot's preference kit	1
(27) Left hatch pouch	Food, one-man meal	7
(28) Right hatch pouch	Food, one-man meal	7
(29) Left aft box	ELSS umbilical assembly ELSS hose, short ELSS hose, long Hose nozzle interconnectors Electrical jumper Dual connectors ELSS restraint straps Waist tethers	1 1 1 2 2 2 4 2

[a]Numbers in parentheses refer to figure 7.1-4 for stowage location.

TABLE 7.1-I.- SPACECRAFT 12 LAUNCH STOWAGE - Continued

Stowage area[a]	Item	Quantity
(29) Left aft box -continued	EVA gloves Visor anti-fog pads Food, one-man meal EVA camera bracket Remote camera control cable	1 pr. 6 2 1 2
(30) Right aft box	16-mm sequence camera with magazine and 5-mm lens 16-mm film magazine 70-mm film magazine (Maurer) 70-mm camera body (Maurer) 70-mm film magazine (Hasselblad) Ultraviolet lens, S013 Grating, S013 Objective prism, S013 Filter, green, S011 Filter, yellow, S011 Filter, red, S011 Filter, eclipse Window bracket, S011 Postlanding kit Inflator, manual, blood pressure Defecation device Waste container	1 9 3 1 2 1 1 1 1 1 1 1 1 1 1 6 2
(31) Centerline container door	Experiment T002 sextant	1
(32) Lower centerline container	Mirror mounting bracket 18-mm lens for 16-mm camera 75-mm lens for 16-mm camera 5-mm lens for 16-mm camera 16-mm camera with magazine 16-mm film magazine Ring viewfinder 70-mm Maurer camera with magazine and f/2.8 lens	2 2 1 1 2 8 1 1

[a]Numbers in parentheses refer to figure 7.1-4 for stowage location.

TABLE 7.1-I.- SPACECRAFT 12 LAUNCH STOWAGE - Concluded

Stowage area[a]	Item	Quantity
(32) Lower centerline container -continued	70-mm film magazine	1
	Sighting device, S011	1
	50-mm lens, S011	
	70-mm superwide-angle Hasselblad camera with magazine	1
	Camera handle (Hasselblad)	1
	Lanyard, camera	2
(33) Upper centerline container	ELSS chestpack	1
	Port locking clips	2

[a]Numbers in parentheses refer to figure 7.1-4 for stowage location.

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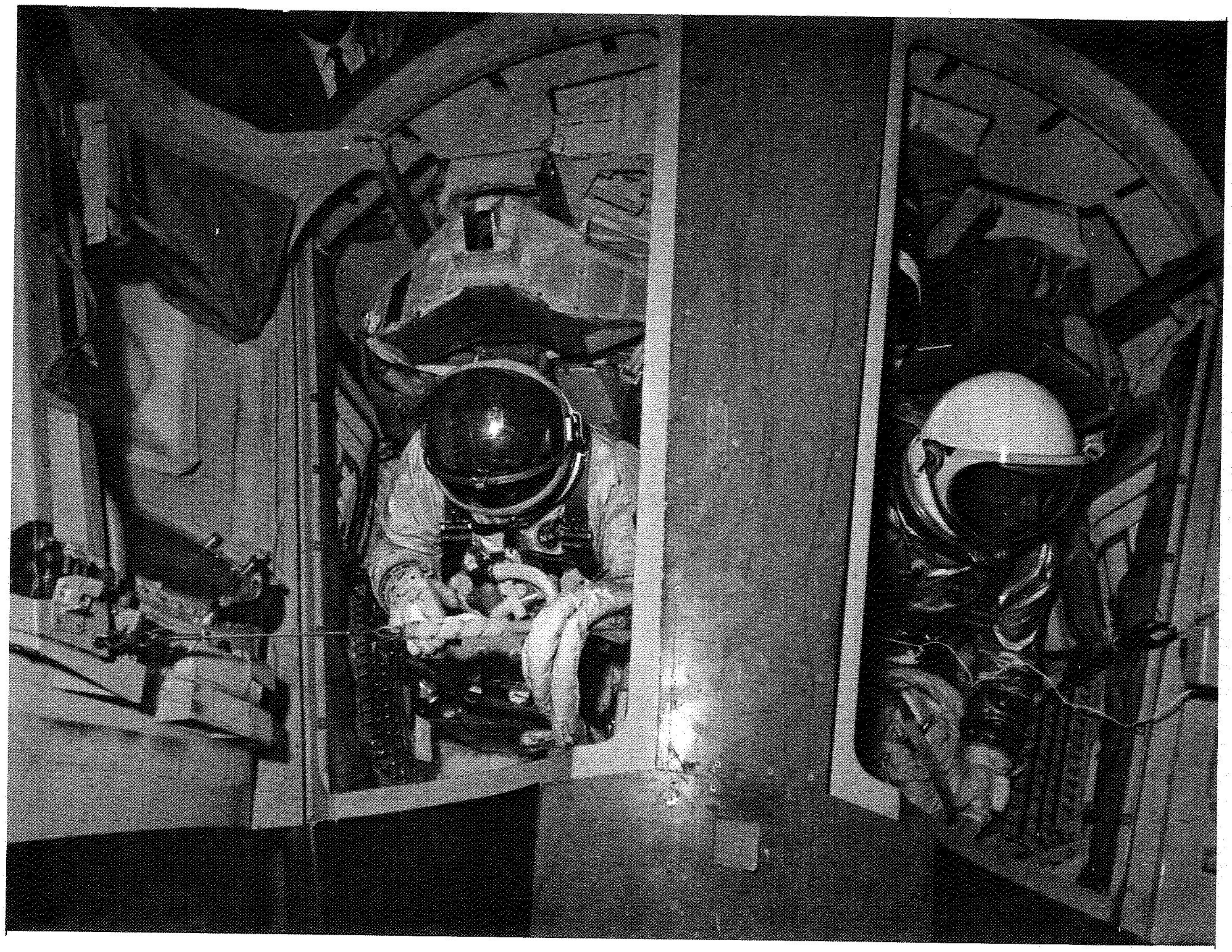

Figure 7.1-1.- EVA procedures training using crew station mockup.

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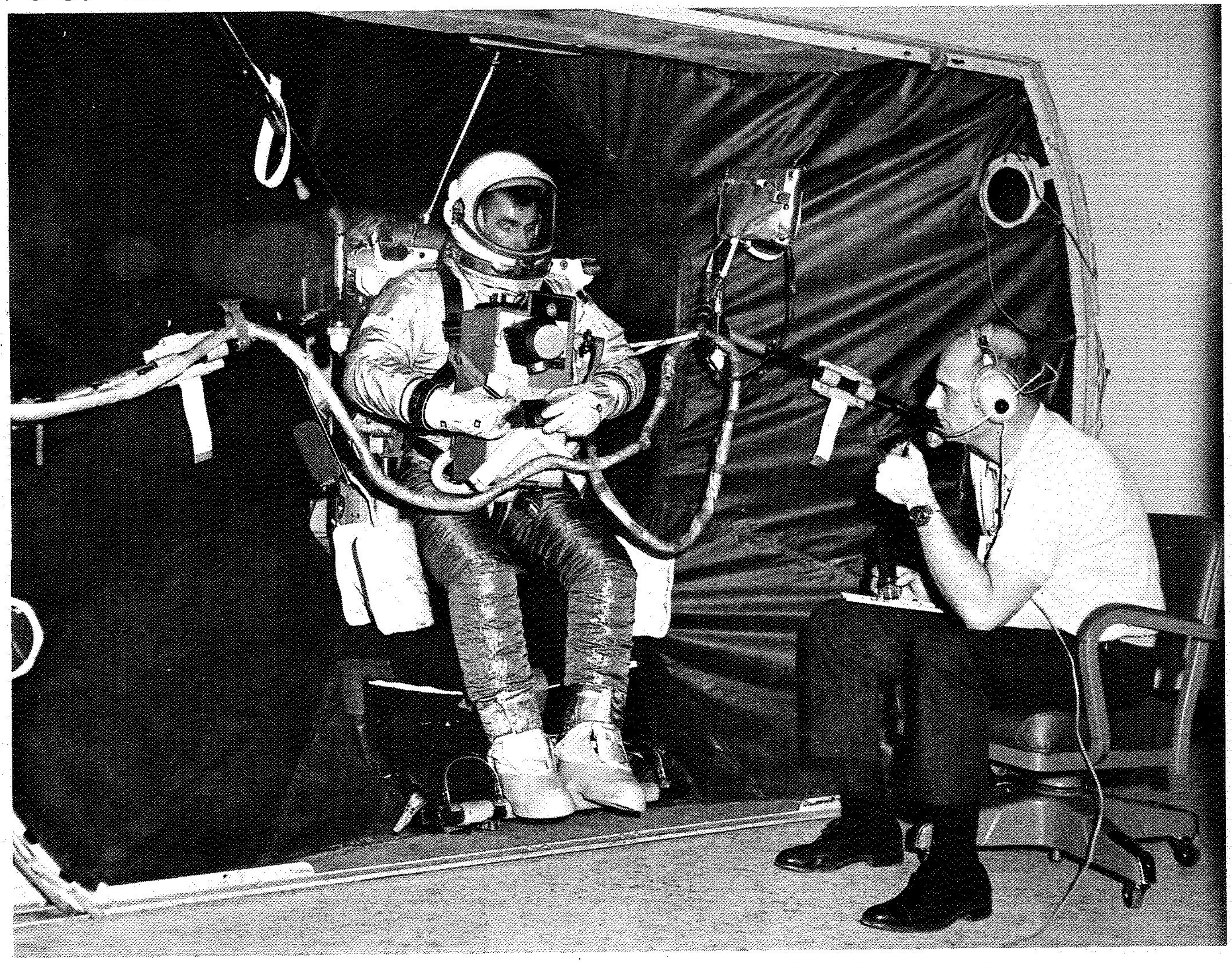

Figure 7.1-2.- EVA procedures training using adapter mockup.

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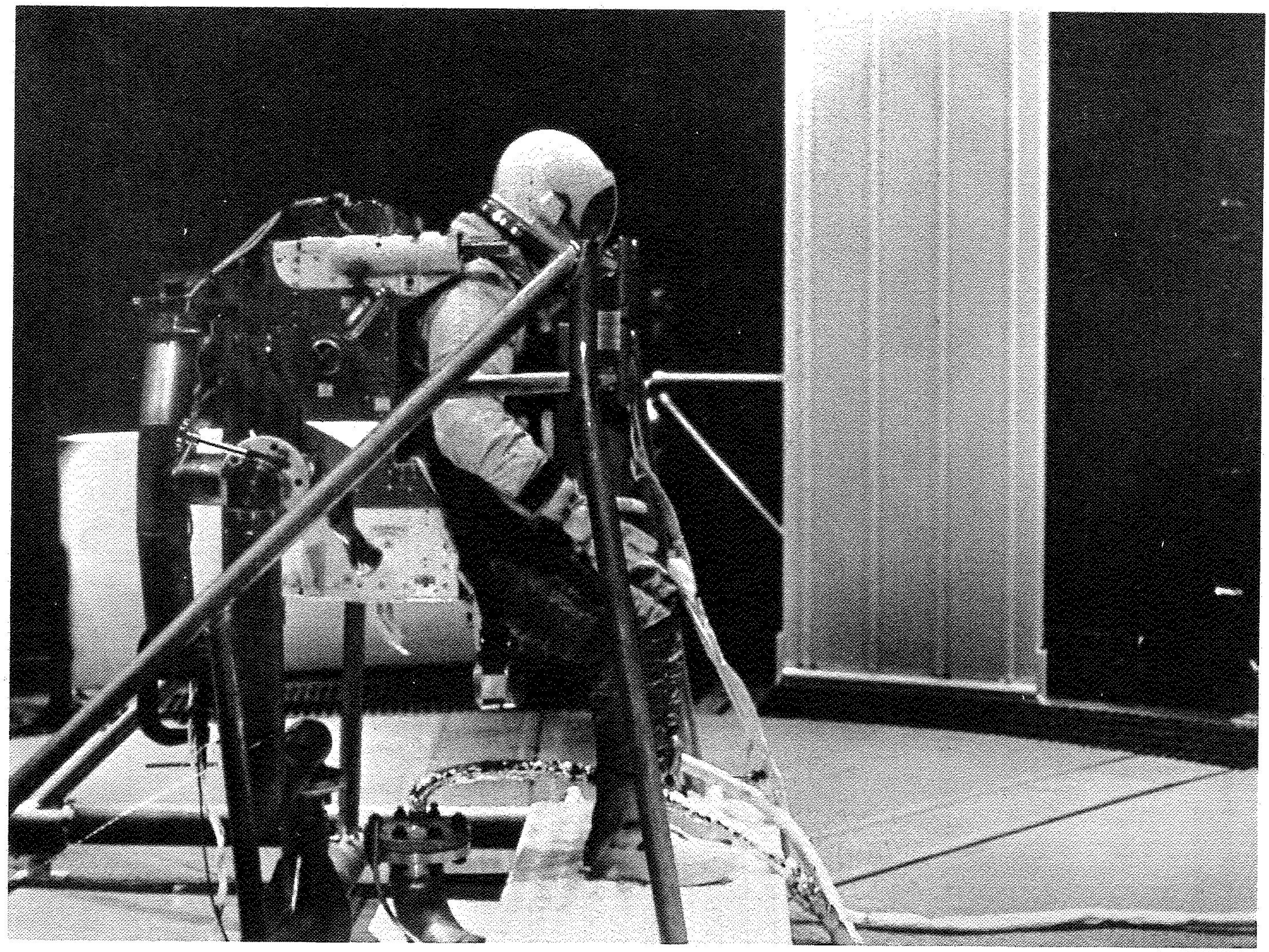

Figure 7.1-3.- Altitude chamber training for AMU.

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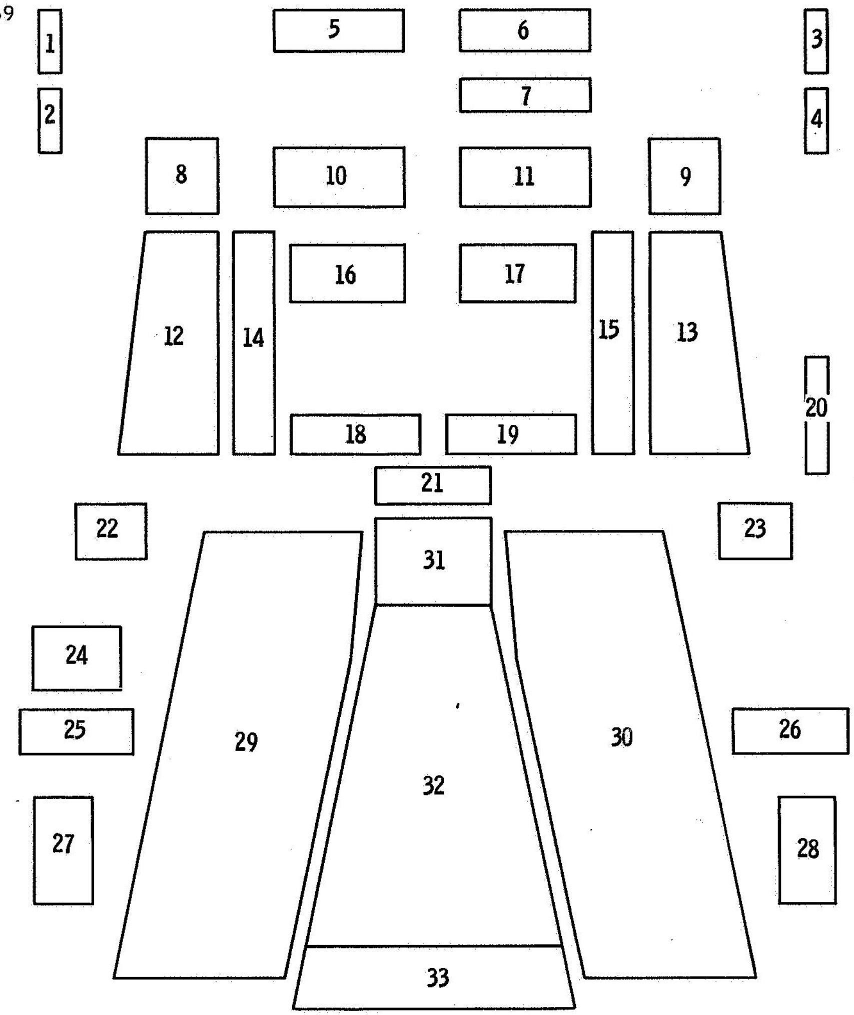

1. Left sidewall pouch (Fwd)
2. Left sidewall pouch (Aft)
3. Right sidewall pouch (Fwd)
4. Right sidewall pouch (Aft)
5. Left instrument panel
6. Right instrument panel
7. Right hatch
8. Left circuit breaker panel
9. Right circuit breaker panel
10. Left pedestal in footwell
11. Right pedestal in footwell
12. Left side box
13. Right side box
14. Left sidewall pouch
15. Right sidewall pouch
16. Left pedestal pouch
17. Right pedestal pouch
18. Left footwell pouch
19. Right footwell pouch
20. Right hatch sill
21. Water management panel
22. Voice tape recorder
23. Right sidewall bracket
24. Left sidewall bracket
25. Left sidewall
26. Right sidewall
27. Left hatch pouch
28. Right hatch pouch
29. Left aft box
30. Right aft box
31. Centerline container door
32. Lower centerline container
33. Upper centerline container

Figure 7.1-4. - Crew station stowage areas.

NASA-S-67-206

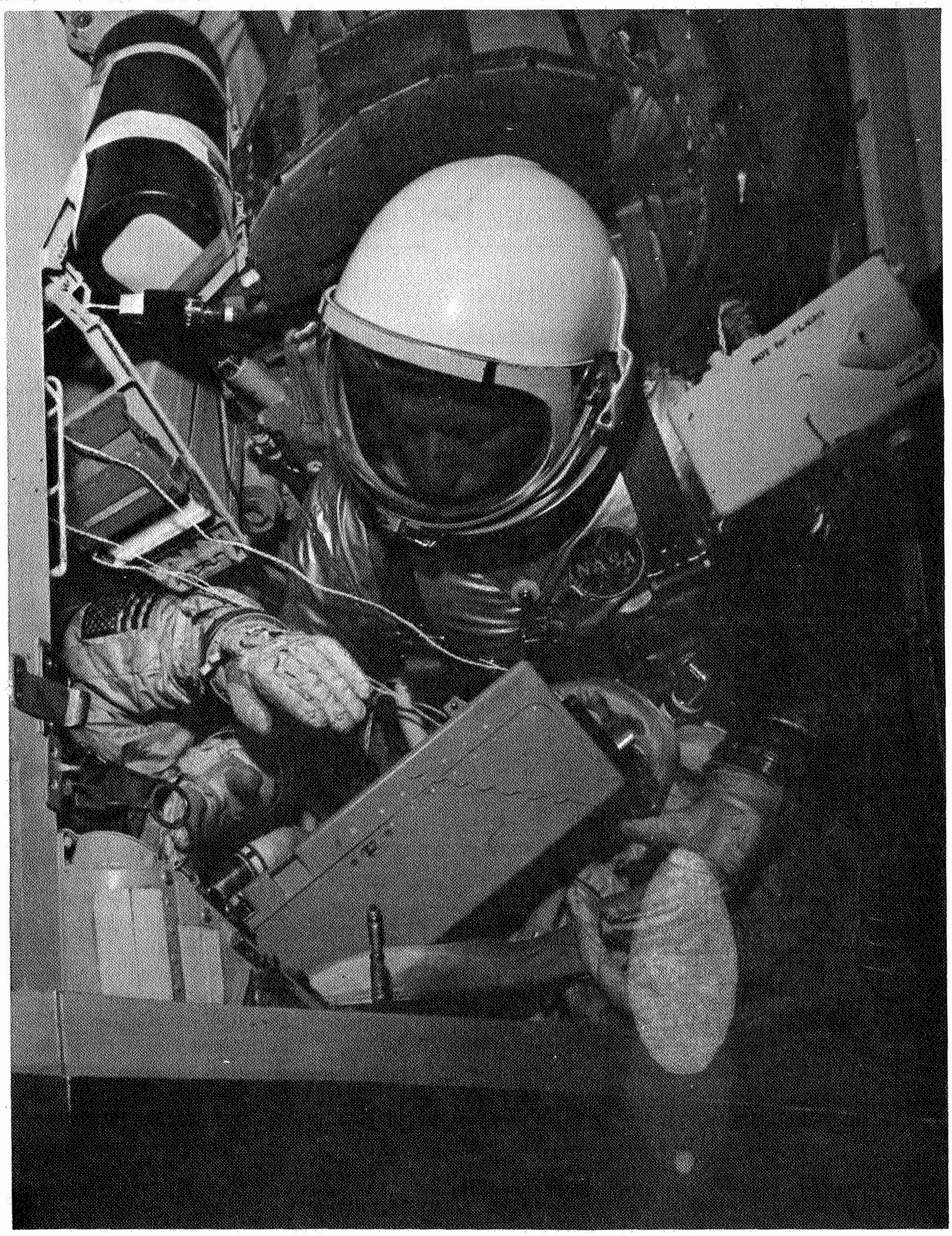

Figure 7.1-5.- Crew station training exercise.

7.2 ZERO-G TRAINING

7.2.1 Training Methods and Objectives

In support of each Gemini extravehicular mission, weightless simulation flights were conducted in an Air Force KC-135 zero-g test aircraft. In these flights, the aircraft followed a ballistic trajectory so that objects inside the aircraft were in a state of free fall, thus being effectively weightless. The period of weightlessness produced was nominally 25 seconds. The degree of accuracy was ±0.01g and depended primarily upon pilot proficiency and prevailing weather conditions.

The interior of the aircraft was modified to provide a working volume of approximately 7 by 10 by 60 feet. Depending upon the mission, the interior configuration of the aircraft included any of the following training mockups:

(a) A reentry module

(b) A partial spacecraft nose section docked with a Target Docking Adapter (TDA)

(c) A quarter section of an adapter section incorporating Experiment D016 (Power Tool Evaluation)

(d) A portion of an adapter section incorporating a nitrogen connection for the 50-foot umbilical

(e) An adapter section incorporating all interior provisions for EVA

The configuration of the mockups and the associated crew equipment was maintained as close to flight configuration as possible to insure a valid and realistic simulation.

The purpose of the zero-g flights was to validate system designs and flight procedures, and to provide crew training for those phases of the extravehicular mission that could be simulated adequately. Typical tasks conducted were egress/ingress, transit, entry into the adapter equipment section, umbilical management, ESP or AMU equipment donning and doffing, attachment of the spacecraft/GATV tether, experiments operation, adapter work station tasks, and TDA work station tasks. Most training sessions were conducted with the crews wearing their training space suits; however, on the final training flights before a mission, the prime pilots usually wore their flight space suits. Proper fit and configuration of the space suits was essential for valid results.

For a typical Gemini mission, the prime and backup crews each participated in five training sessions with an average of 40 parabolas per session. During these sessions, the crews became proficient in the use and operation of equipment in the zero-g environment. In addition to the training benefits, these flights provided an opportunity for evaluation of flight configuration equipment in the zero-g flights. Numerous equipment deficiencies were discovered in these simulations, and corrective modifications were developed and evaluated in the zero-g flights.

7.2.2 Mission Results

7.2.2.1 Gemini IV.- The configuration of the zero-g aircraft for Gemini IV crew training consisted of the reentry module only. Crew training was restricted to removal of Ventilation Control Module (VCM) from the footwell, egress and umbilical guide placement, umbilical management, and ingress and hatch closure. During the initial phase of training, the limited clearance between the hatch and the space suit helmet made ingress and hatch closure difficult. The proper technique for ingress was to force the knees under the instrument panel while keeping the body close to the panel and away from the seat, then push the relatively immobile torso down towards the footwell (figs. 7.2-1 and 7.2-2). Since the clearance for closing the hatch was initially marginal, the following modifications were made prior to the Gemini IV mission:

(a) The egress kit contour thickness was reduced and the ejection seat D-ring housing was lowered to be flush with the egress kit.

(b) A hatch closing lanyard was incorporated to aid in the last 4 to 6 inches of hatch travel. This device was designed for either crewmember to operate in a pressurized space suit (fig. 7.2-1).

(c) The size of the control lever for the hatch actuation mechanism was reduced to prevent damage to the pilot's visor during ingress.

(d) The procedure was established to rotate the VCM 90 degrees downward before operating the hatch handle. This procedure required that the VCM restraint system be removable and that it be operated easily in a pressurized space suit.

The implementation of these design changes made the task of ingress and of locking the hatch suitable for accomplishing in orbit.

7.2.2.2 Gemini VIII.- The configuration of the zero-g aircraft for the Gemini VIII EVA training included the following mockups:

(a) The reentry module

(b) A section of the TDA incorporating the Experiment S010 (Agena Micrometeorite Collection) package

(c) A partial adapter section incorporating Experiment D016 (Power Tool Evaluation)

(d) The adapter section

The crew training included spacecraft egress and ingress, Experiment S010 operation, Experiment D016 operation, transit around the edge of the adapter to the Extravehicular Support Package (ESP) donning station, and ESP checkout and donning.

Although the Gemini IV crew had standardized the ingress operation, hardware differences between the Gemini IV and Gemini VIII missions required the following operational changes:

(a) The Extravehicular Life Support System (ELSS) had to be released and handed to the command pilot in order for the pilot to complete the ingress maneuver (fig. 7.2-3).

(b) Accordingly a quick-release restraint system for the ELSS similar to that used with the Gemini IV VCM was incorporated.

(c) The ELSS could not be stowed in the center stowage location if the space suit was pressurized.

If the spacecraft could not be repressurized after the EVA it was planned that the ELSS would be jettisoned.

Training with Experiment S010 (Agena Micrometeorite Collection) indicated the following problems for which corrective modifications were incorporated:

(a) The fairing cover could not be grasped for removal. A 2-inch-diameter hole was cut in the top portion to allow the extravehicular crewman to insert two fingers to remove the fairing from its holder (fig. 7.2-4).

(b) Several design discrepancies in the Experiment S010 bracket made it impossible to open the mechanism and to position the experiment package in its bracket correctly. The procedure was established to remove the experiment package entirely from its bracket and to attach it to the TDA with a patch of Velcro.

Training with the Experiment D016 (Power Tool Evaluation) was accomplished readily because prior design work and zero-g validation had already been performed. The only change was to reduce the number of operations to the minimum number compatible with the experiment requirements (fig. 7.2-5).

With the ESP, crew training involved some simultaneous developmental activity. The crew training included transit around the edge of the adapter and to the ESP, checkout and preparation of the ESP for donning, donning the ESP, egress from the adapter, and doffing the ESP. Throughout the training sessions, equipment design and procedural changes were made as necessary to obtain an efficient and practical operation. Design criteria were determined for use in the final ESP design. Changes or equipment additions that resulted from the zero-g flights included the following:

(a) An umbilical guide was added at the edge of the spacecraft adapter section to protect the umbilical from chafing.

(b) Mirrors were installed on the handbars in the adapter section to aid in ESP donning.

(c) A Velcro strap was installed on one handbar to hold the umbilical in place.

(d) Electrical and oxygen connectors were properly positioned for ESP donning.

(e) The proper stowage location for the 75-foot tether bag during the ESP evaluation was established to be on the top of the ESP.

(f) Donning procedures were developed for the ESP.

(g) A design was established for the ESP restraint system.

During the preparation for the Gemini IV and Gemini VIII EVA missions, the work performed in the zero-g aircraft could not be separated from that conducted during one-g walk throughs. Both were integral parts of the equipment development and crew training. Close coordination was maintained between equipment development and evaluation activities.

Additional simulation flights led to the establishment of proper procedures for doffing the ESP and its tether and for reconnecting the spacecraft oxygen umbilical. Doffing the ESP was to be performed near the docking bar of the spacecraft, since this location provided the pilot a place to tether himself and provided good visual contact for the command pilot.

7.2.2.3 Gemini IX-A.- The Gemini IX-A zero-g training was oriented toward egress and ingress, transit around the adapter edge and to the AMU, preparation of the AMU, and donning and doffing the AMU. Extensive egress and ingress training was conducted to familiarize the pilots with both normal and emergency situations. Since equipment designs and procedures were well established, training progressed efficiently. Although each crewman had his own learning curve for performing the ingress maneuver, the pilots became proficient within several flights.

Initial training established that the preparation of the AMU for donning required the use of both hands, and because of the lack of proper foot restraints in the adapter section, this task was extremely difficult. A design change was made to provide stirrups on the footbar. Further zero-g flights indicated that this design was adequate; however, the subsequent experience in orbit proved that this design was unsatisfactory and that more positive foot restraints were required.

During the training sessions, the handling of the 125-foot tether bag indicated that it might float away if it became disengaged. Therefore, the bag was modified to permit tethering it to either the AMU or to the pilot at all times.

7.2.2.4 Gemini X.- The configuration of the aircraft for Gemini X training included the reentry module and the TDA section incorporating the Experiment S010 package.

Training for this mission included spacecraft egress and ingress, Experiment S010 retrieval, and nitrogen hookup for the HHMU. Ingress training requirements for the umbilical EVA and the standup EVA periods were quite similar. For the umbilical EVA the pilot removed the ELSS and handed it to the command pilot during ingress. The Environmental Control System (ECS) extension hoses and the electrical extension cable were sized for performing the Experiment S013 (Ultraviolet Astronomical Camera) operation during the standup EVA. The crew also established the proper body position for taking pictures (fig. 7.2-6).

The zero-g aircraft activities in preparation for the Gemini X EVA mission were oriented towards training, since the majority of the design development work had been completed during zero-g preparations for previous missions. During training, only two problem areas developed:

(a) Umbilical management was difficult with the 50-foot umbilical, and entanglement was frequent (fig. 7.2-7).

(b) The hookup of the nitrogen line quick disconnect and the body positioning required to perform this task were occasionally difficult (fig. 7.2-8).

Both of these areas were examined carefully during training to expose the crew to all possible problems that might occur during the mission.

7.2.2.5 Gemini XI.- The Gemini XI EVA equipment was similar to Gemini X equipment; the difference was a reduction of the umbilical length to 30 feet. The number of tasks to be performed, however, was increased and included the following:

(a) Experiment D016 operation

(b) Retrieval of the HHMU and a set of experiment cameras from the adapter section

(c) The spacecraft/GATV tether attachment

The zero-g aircraft contained the reentry module, the section of the adapter incorporating Experiment D016, an updated adapter section, and a section of the spacecraft nose and the TDA for the tether hookup operation.

Training for this flight was concentrated on the adapter section and on the GATV tether attachment because training on the other required activities had been accomplished previously. Refresher training on egress, ingress, and Experiment D016 operation was performed to insure crew proficiency. Work in the adapter section was concentrated on the attachment of the umbilical to the HHMU, and the removal of the HHMU and experiment cameras. Training in this area was emphasized because of the problems encountered by the Gemini IX-A pilot while working in the adapter. The initial training indicated difficulty in getting the feet into the new foot restraints because of visibility problems. Once the feet were in the restraints, the pilot was able to perform all the body and arm movements which were necessary to accomplish the tasks in the adapter section.

Training for the spacecraft/GATV tether hookup required the pilot to move to the nose section of the spacecraft from the hatch, position his body, remove the tether and its clamp from a pouch on the TDA, place the tether and clamp over the docking bar, and then lock the clamp in place. Body stability was maintained by straddling the nose section of the spacecraft and wedging the knees between the conical section of the TDA and the spacecraft. This position allowed the pilot to use both hands in performing the tether hookup operation. The flight crews also practiced an alternate procedure in which the handhold on the TDA was grasped with one hand and the body position was maintained free of the spacecraft. The tether was then attached with the other hand. The crews preferred to straddle the nose section because this method left both hands free; however, the flight results showed that this method was impractical under actual orbit conditions.

7.2.2.6 Gemini XII.- The aircraft configuration for Gemini XII EVA training included a reentry module, an adapter section, and a partial nose section of the spacecraft docked to a TDA. The training sessions included the following:

(a) Egress and ingress for the standup EVA and umbilical EVA

(b) Spacecraft/GATV tether hookup

(c) Adapter work station evaluation with foot restraints and with waist tethers

(d) TDA work station evaluation with and without waist tethers

Throughout the training sessions, the flight crews trained in all phases of the mission, concentrating on the tasks performed on the TDA and in the adapter section. Training in the adapter section was concentrated on transit around the adapter edge and on entry into the foot restraints (fig. 7.2-9). The flight crews practiced extensively on the work station using the foot restraints and waist tethers. Training for the TDA tasks emphasized translation to the TDA from the spacecraft, positioning of the waist tethers for attaching the spacecraft/GATV tether and deploying the Experiment S010, and work station evaluation (fig. 7.2-10). Because of prior EVA problems, body position and handhold placement were evaluated extensively to insure that the pilot was familiar with all possible variations necessary to complete the assigned tasks. As a result of these evaluations, modifications were made to the waist tethers to simplify fastening and unfastening with the pressurized gloves.

7.2.3 Concluding Remarks

The extravehicular crew training conducted in the zero-g aircraft for each Gemini mission was valuable for many of the inflight tasks. The value of the actual training was enhanced by the use of up-to-date flight hardware for which design and procedure validation had already been accomplished. The mission results indicated that for extended tasks, such as AMU donning and spacecraft/target-vehicle tether attachment, data from the short periods of weightlessness were misleading. The rest periods between the weightless parabolas prevented assessment of fatigue as a factor. Also, these rest periods led to the tendency to start each segment of the tasks with more favorable initial conditions than would be experienced in a continuous task. The zero-g aircraft simulation was effective only for short period tasks such as egress and ingress.

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Figure 7.2-1. - Ingress training in zero-g aircraft.

NASA-S-67-209

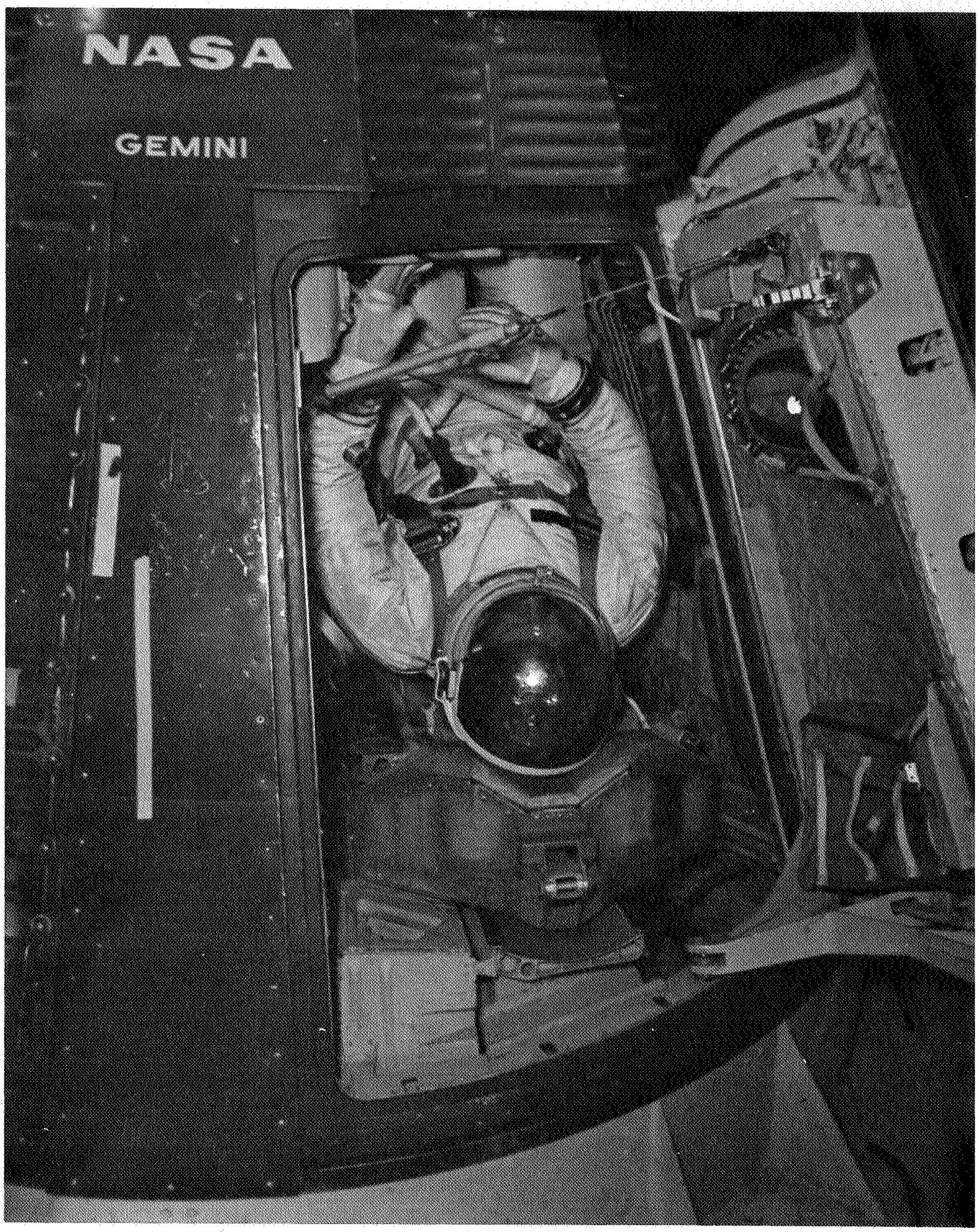

Figure 7.2-2. - Body position for hatch closing.

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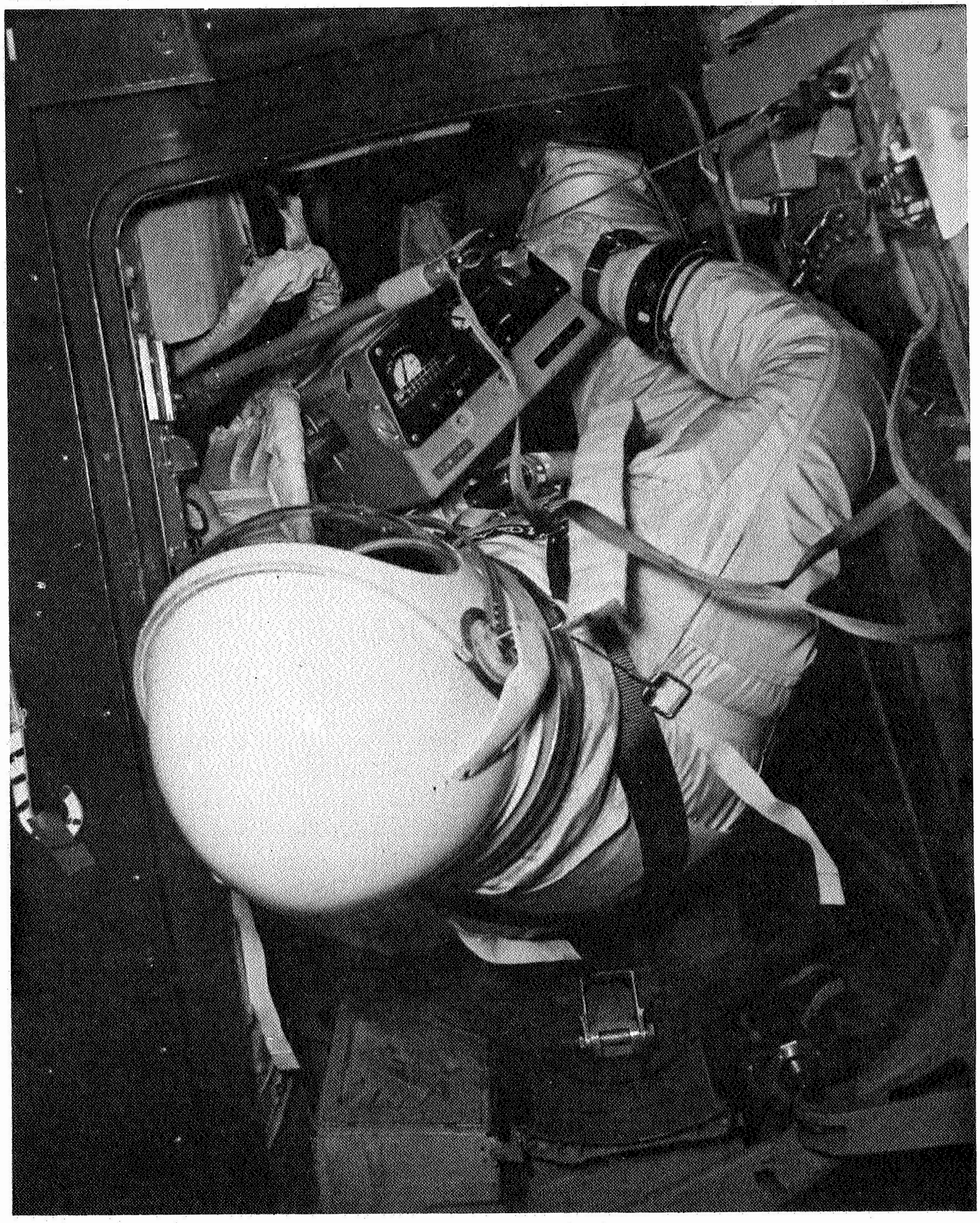

Figure 7.2-3. - Technique for handoff of ELSS during ingress.

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Figure 7.2-4. - Removal of Experiment S010 (Agena Micrometeorite Collection) in zero-g aircraft.

NASA-S-67-213

Figure 7.2-5. - Training for Experiment D016 (Power Tool Evaluation) in zero-g aircraft.

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Figure 7.2-6. - Standup position for Experiment S013 (Ultraviolet Astronomical Camera).

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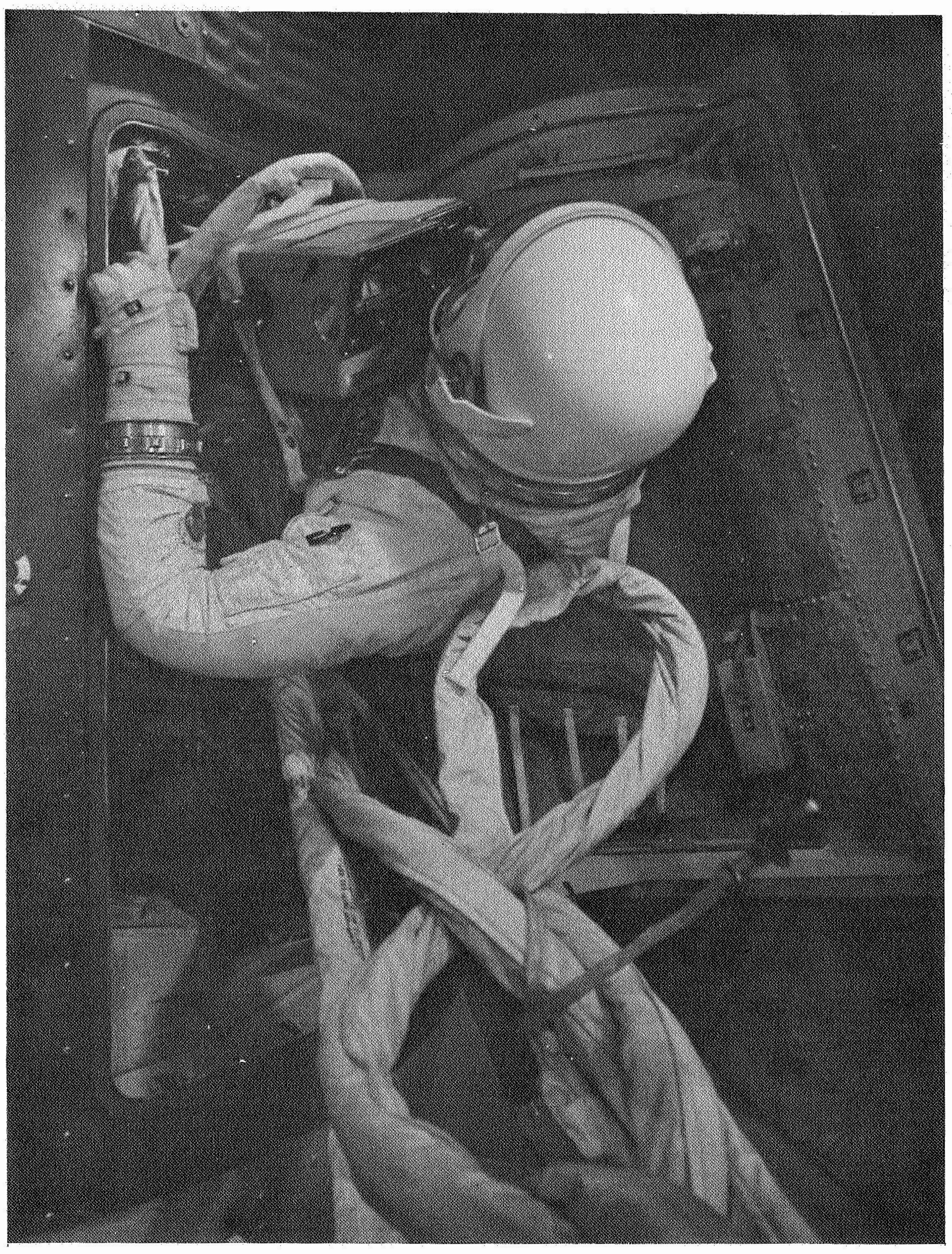

Figure 7.2-7. - Training for ingress with 50-foot umbilical in zero-g aircraft.

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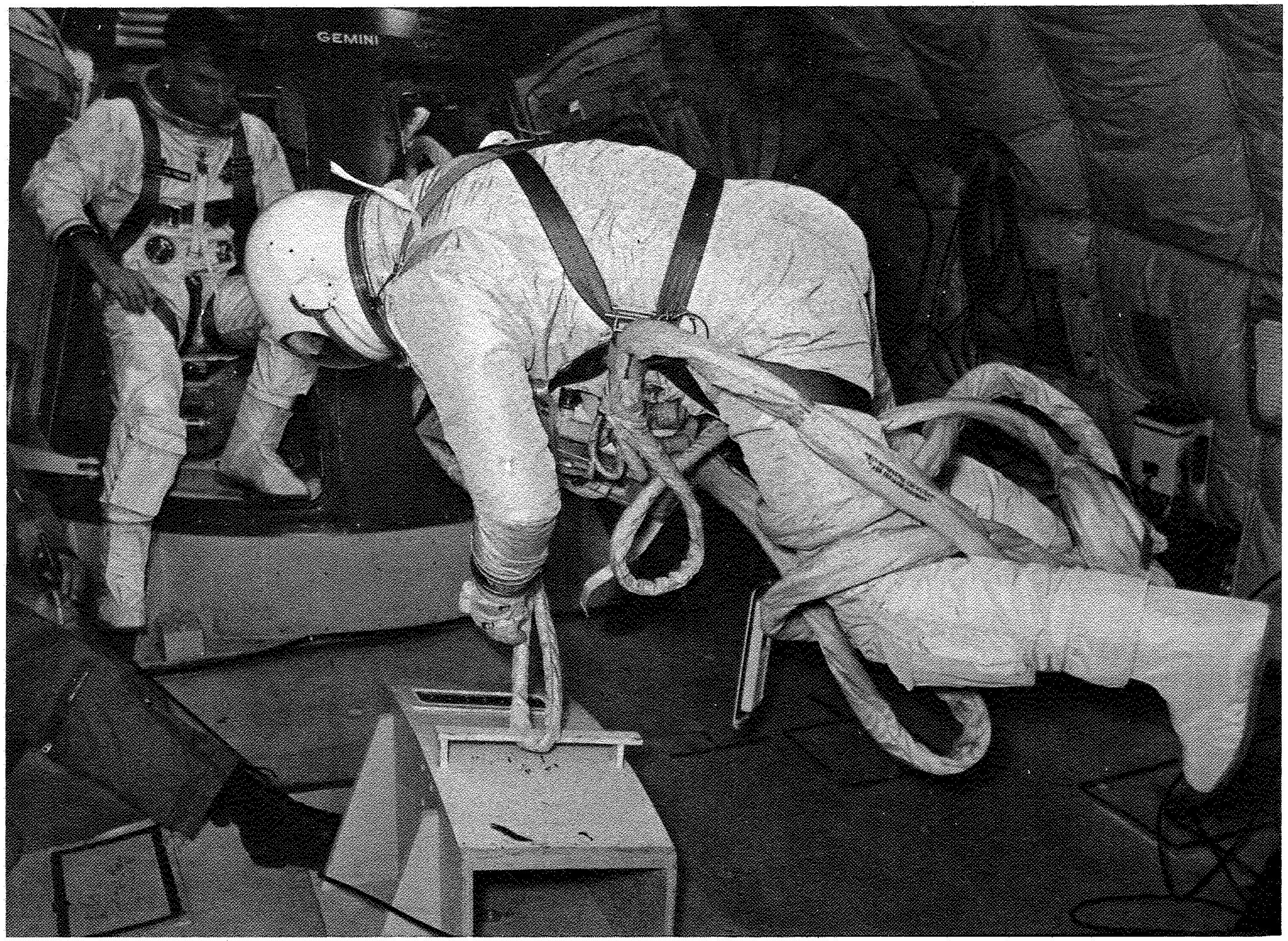

Figure 7.2-8. - Training for 50-foot umbilical nitrogen line hookup in zero-g aircraft.

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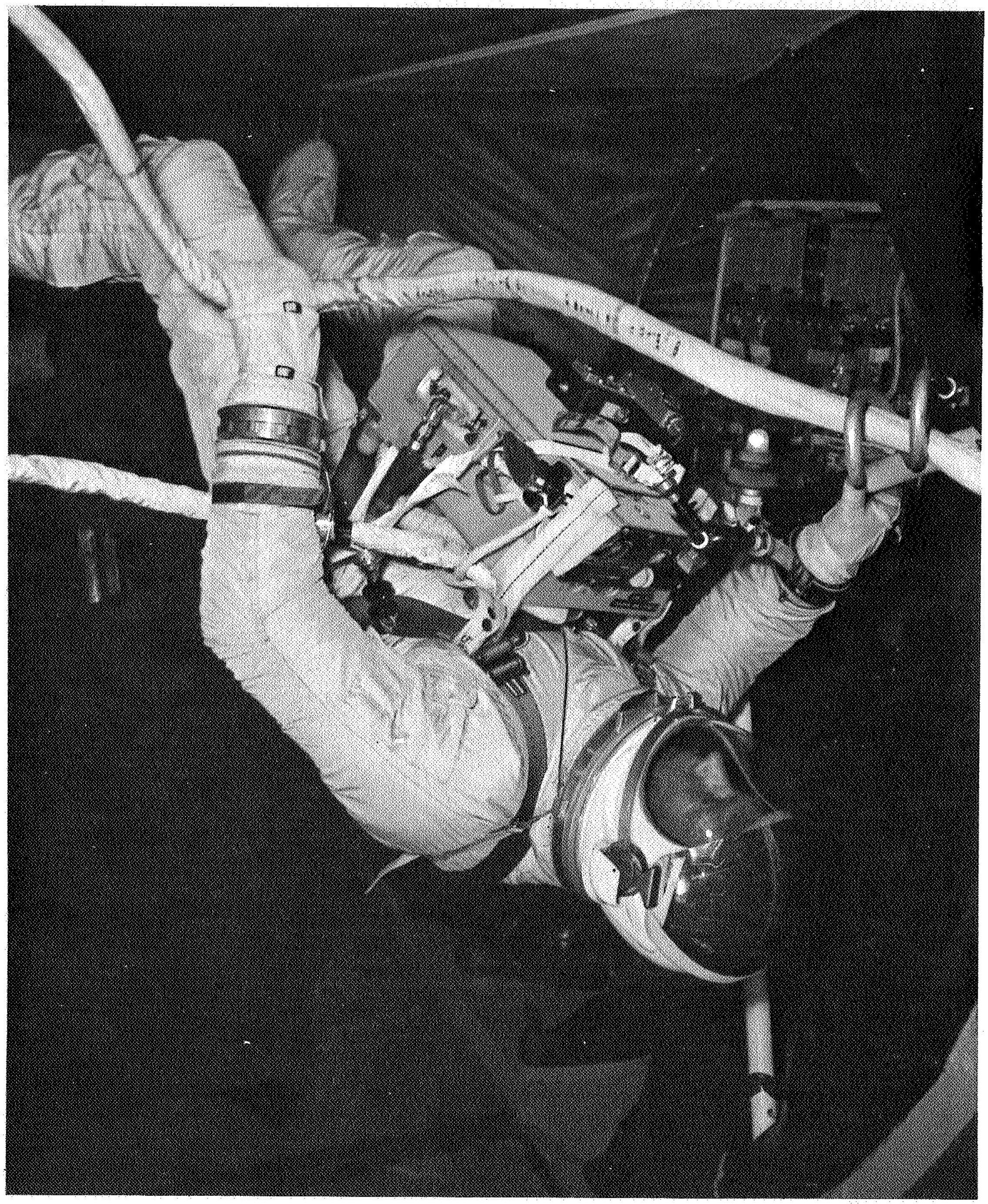

Figure 7.2-9. - Installation of umbilical in adapter umbilical guide.

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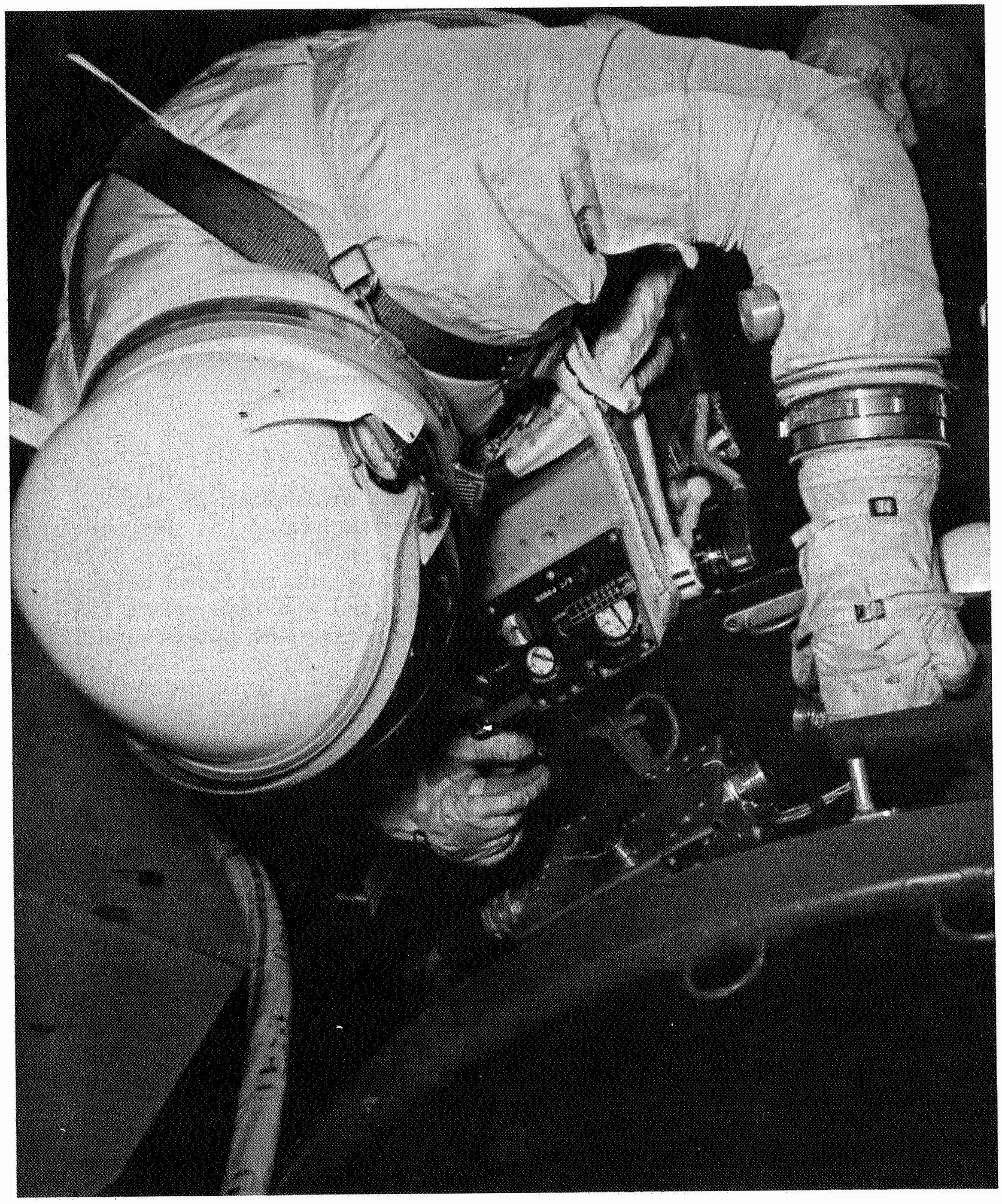

Figure 7.2-10. - TDA work station training in zero-g aircraft.

7.3 UNDERWATER TRAINING

In July 1966, the Langley Research Center sponsored a demonstration of water immersion as an EVA simulation technique. Film clips of the activity were reviewed, and a decision was made to pursue the technique as an equipment and flight plan evaluation aid for Gemini EVA and to investigate its suitability as a crew training aid. The following steps were taken:

(a) Simulation services were contracted.

(b) Gemini mockups were built for underwater use.

(c) Gemini space suits and support equipment were supplied for the simulation.

7.3.1 Simulations

The initial simulation was a partial task evaluation of the Gemini X EVA. As a result of the contractor simulation, it was concluded that the Gemini X tasks were reasonable and feasible. The only difficulties discovered were associated with handling interactions between Experiment S010 (Agena Micrometeorite Collection) and Experiment T017 (Micrometeoroid Erosion) and the EVA still camera. The subsequent flight results confirmed these conclusions.

The second simulation was a reenactment of the Gemini IX-A EVA using the pilot as the subject (fig. 7.3-1). The purpose of this activity was to evaluate the fidelity of the simulation as compared with actual orbital conditions. The conclusions were that the simulation had merit in the area of space suit dynamics and continuity of task. The pilot reported that the body positioning problems and the associated fatigue strongly resembled the conditions he had experienced in orbit.

The third simulation was a contractor evaluation of the Gemini XI EVA procedures and equipment (fig. 7.3-2). The evaluation was analyzed and the results discussed with the flight crew. A primary change was made in the EVA flight plan as a result of the simulation. The EVA still camera and the EVA motion picture camera were deleted from the task in the adapter in order to concentrate on retrieval of the experiment cameras and the HHMU.

The fourth simulation was a contractor evaluation of the original Gemini XII EVA plan using the AMU (fig. 7.3-3). The simulation was used to evaluate EVA equipment, to verify the time line and flight plan, and to train the EVA pilot. The pilot completed these simulations; however, the flight plan for Gemini XII EVA was subsequently modified, and further crew training was required.

The fifth simulation was a preflight evaluation of the revised Gemini XII EVA with the spacecraft adapter and TDA work stations (fig. 7.3-4). The objectives of the simulation were to evaluate the EVA equipment, develop the EVA time line, train the prime and backup EVA pilots, and obtain baseline biomedical data on the prime EVA pilot. The simulation was repeated in seven sessions over a period of 4 weeks preceding the Gemini XII mission. The prime EVA pilot participated in five sessions and the backup EVA pilot participated in two sessions. The command pilot acted as the flight-plan communicator in the final two sessions with the prime EVA pilot. As a result of the simulations, the Gemini XII flight crew concluded that the EVA equipment, flight plan, time line, procedures, and workload were acceptable for flight within the limits of the simulation technique. These conclusions were substantiated by the Gemini XII mission. The Gemini XII pilot made the following comments in the postflight debriefing:

> "The underwater (simulation is)... a medium that has considerable advantage over the zero-g aircraft in that we can timeline things, we can look at the entire flight plan, or whatever the EVA activity might be. It has disadvantages also in that there are buoyancy effects... I think these are minor in looking at the whole underwater situation. I would say that it is an excellent training device and we should attempt to make as much use of it as we can...
>
> "Total timelines are much more valuable to look at in underwater work. Body positioning, I think, is very well simulated in underwater work.
>
> "...the... important thing, I think that we learned... is that the motion that you can get in true zero g in (the) foot restraints and the ability to move around is duplicated to an excellent degree by zero-g flight and also by underwater. So, if we can take any situation and expose it to an underwater environment and make sure that the subject has gotten the right buoyancy and the right kind of suit that reproduces the flight suit that he is going to have, we can check out the operation this way rather than trying to take any measurements from the Gemini adapter and extrapolate from there."

The final simulation was a postflight evaluation of the Gemini XII EVA by the pilot. The purpose was to further evaluate and define the fidelity of the simulation technique. The pilot reported that the fidelity of the simulation was good and that underwater simulation was valuable as a method of establishing flight plans, procedures, and operating techniques for EVA. The biomedical monitors concluded that for the Gemini XII EVA, the preflight and postflight biomedical data obtained from the simulation correlated well with similar data obtained from the Gemini XII pilot as he performed the same tasks during flight.

7.3.2 Concluding Remarks

In summary, underwater neutral buoyancy techniques were adapted to the solution of problems associated with Gemini EVA. The simulation was improved and expanded through Gemini X and XI and fully utilized in evaluating the Gemini XII EVA tasks, equipment, and time line, and in training the Gemini XII prime and backup EVA pilots. Underwater simulation and training contributed materially to the success of the Gemini XII EVA mission. The postmission evaluation showed that there was a very good correlation between the underwater simulation and the actual EVA conditions in orbit. There was strong evidence as to the correlation of task difficulty, and the results indicated that tasks which could be accomplished readily underwater were also accomplished readily in orbit. The use of flight-configuration equipment was essential to the validity of the simulation.

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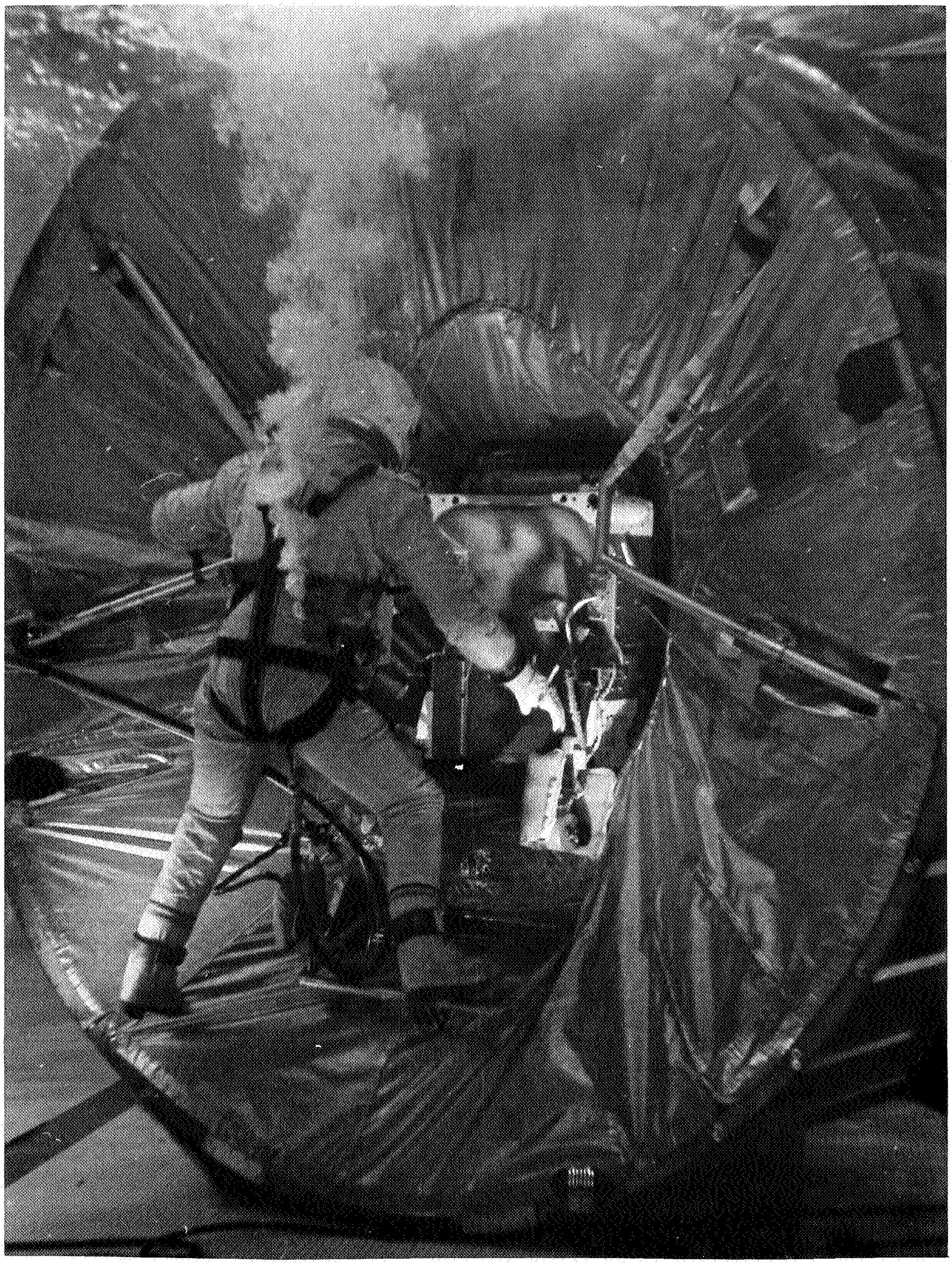

Figure 7.3-1. - Underwater simulation of Gemini IX-A EVA.

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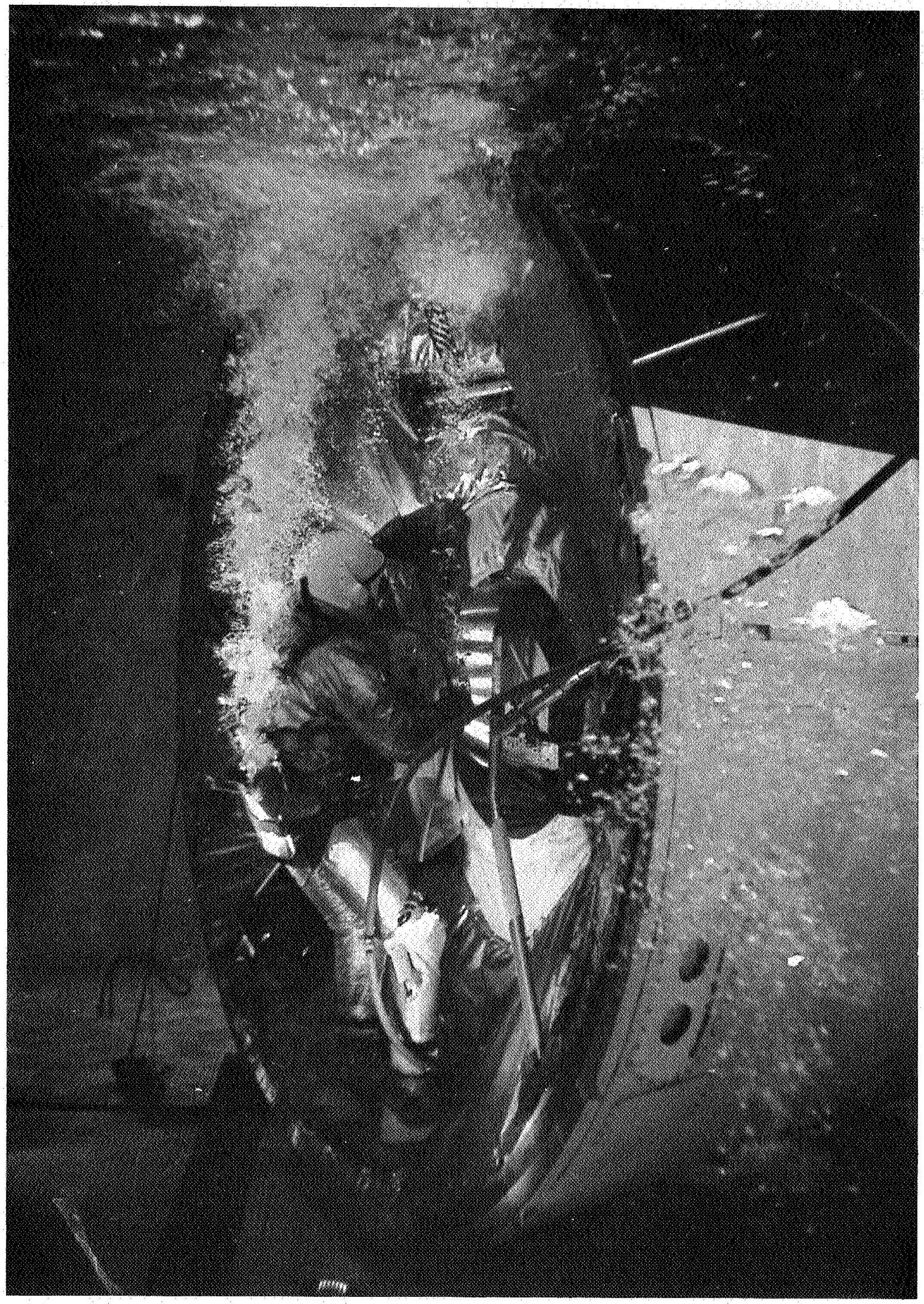

Figure 7.3-2. - Underwater simulation of Gemini XI EVA.

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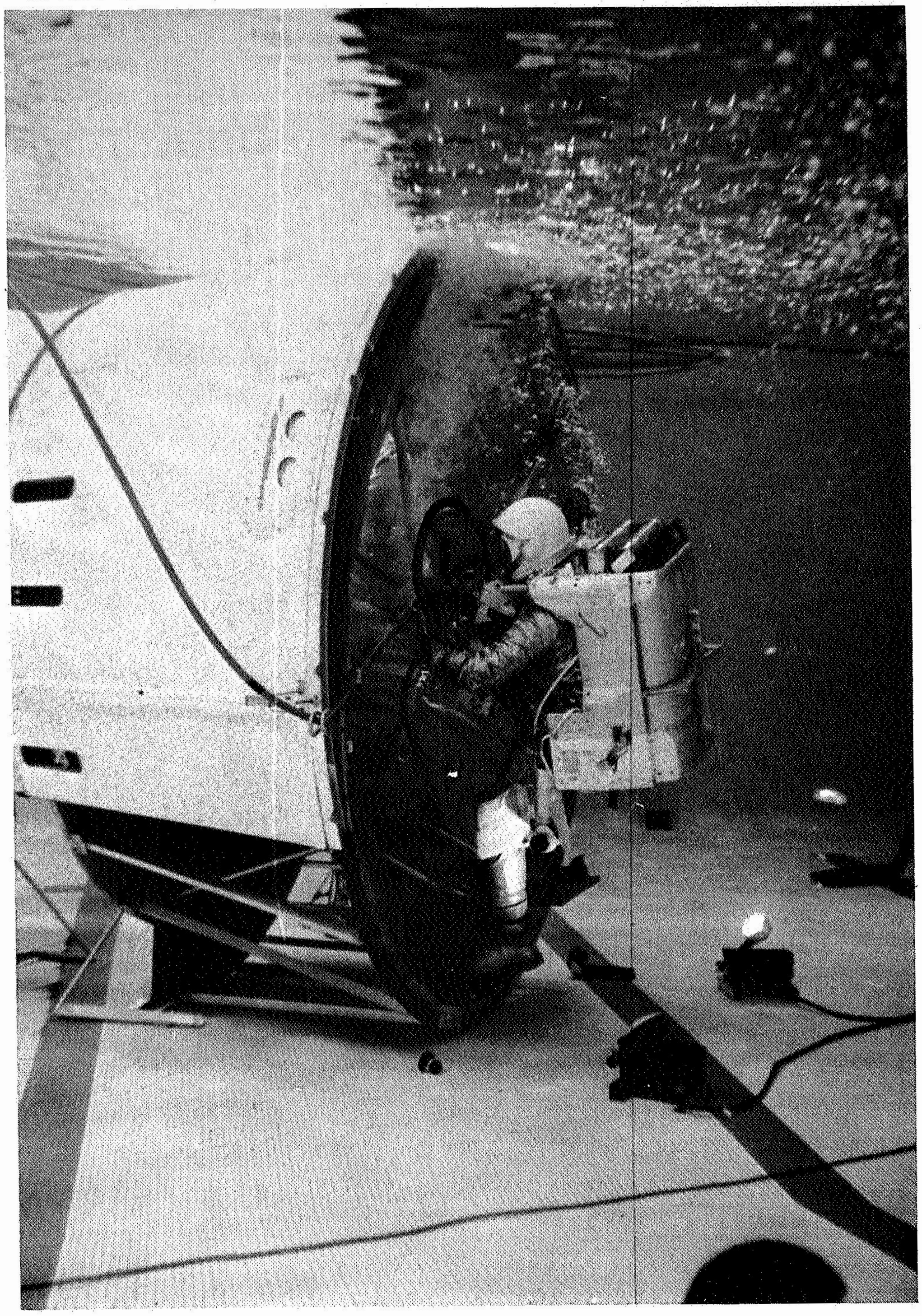

Figure 7.3-3. - Underwater simulation of AMU preparations.

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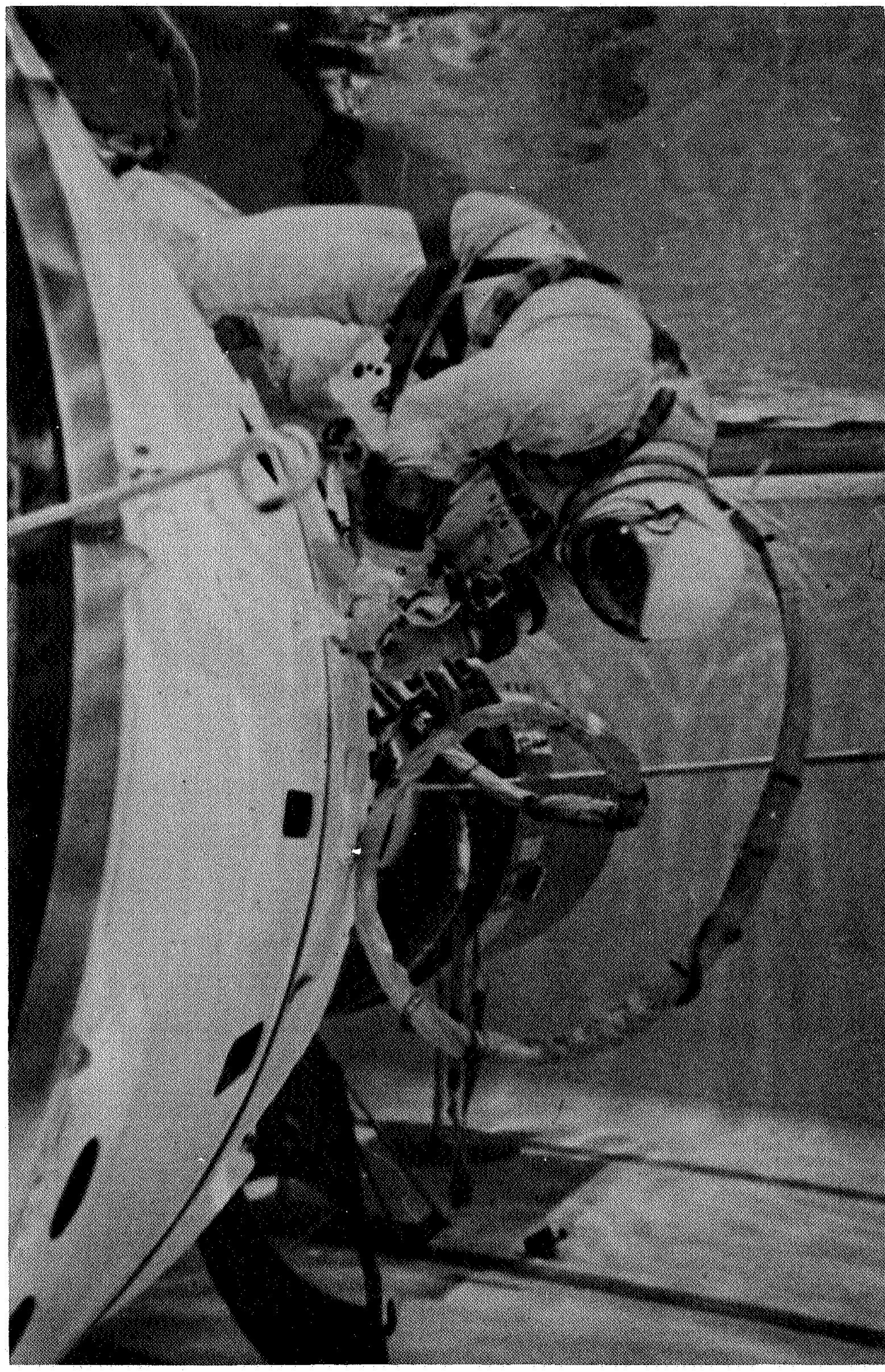

Figure 7.3-4. - Underwater simulation of Gemini XII EVA transit between adapter and TDA work stations.

8.0 OPERATIONAL ASPECTS OF EXTRAVEHICULAR ACTIVITY

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8.0 OPERATIONAL ASPECTS OF EXTRAVEHICULAR ACTIVITY

The operational aspects of Gemini EVA included the factors of planning EVA, the various approaches taken to find solutions to problems, and the knowledge gained from experience in EVA.

8.1 ZERO-G ENVIRONMENT

One of the early discoveries by pilots performing EVA was the dominant effect of small forces in the weightless environment. The lack of a large gravity force made the second-order forces significant, although they had previously been neglected. Each small force exerted on the pilot resulted in a displacement velocity which, in most cases, interfered with the task he was attempting to perform. Also, the pilots seemed to have difficulty in rationalizing the forces and the resulting motions in zero g without adequate simulation and training. It was not until after several hours of extravehicular experience in the space environment had been obtained that a practical appreciation of these second-order forces was achieved. As a result of this knowledge, an increased emphasis was placed on the design and use of body restraint devices. In the Gemini XII mission, the pilot demonstrated methods to perform the assigned EVA tasks more efficiently.

Some of the early experiences in EVA indicated the possible existence of external body forces which caused the pilot to float up, away from the earth. The Gemini IX-A pilot commented as follows in the postflight debriefing:

> "My work load, I felt, was harder than it should be. It was harder than it should be because of position control or maintaining yourself in the stirrups in the adapter. All of our work had been built around the fact that in zero g, you would stay there unless you perturb your body position with some external force or motion. This is not true. It was a continuous work load just to stay put in zero g. I always tended to roll back over to the right and over the top of the spacecraft. So, in addition to these other things, it was a case of position maintenance."

Later Gemini missions included an investigation of external forces during EVA. Objects were placed in a free position inside the spacecraft, with the hatch opened and closed, while the crews watched for any tendencies for movement of the objects. Also, the pilots attempted to position themselves in a stationary position with respect to the spacecraft and to observe the motions caused by any external forces. No preferred direction of motion was observed in any of these evaluations, although some movement invariably ensued. The Gemini XII pilot reported that, if such forces existed, they were much smaller than the magnitude of known small forces such as those associated with the body tether. The results of this investigation also verified that small forces were significant in the motions of the pilot's body or of other objects in the EVA environment. Small forces applied with the fingers or the hand induced body motions and could be used for body positioning at low rates. The following factors, which reflect the knowledge gained from investigations of some of the later Gemini pilots, may have lead to the initial reports of unknown body forces:

(a) Forces were induced by the space suit tending to return to the neutral position.

(b) Body motions resulted from inadvertent application of small forces by the pilot.

(c) Spacecraft outgassing when the hatch was first opened, induced an outward force on all loose items in the cabin, including the pilot.

(d) Small perturbations in spacecraft motion caused primarily by attitude control limit cycling may have induced body motions relative to the spacecraft.

(e) Inability to set up an initial condition of no movement may have led to the impression of external forces.

The effort required to perform assigned EVA tasks was greater than planned on several EVA missions. A major part of the effort was due to the pilot working against the pressurized space suit. The Gemini space suit tended to assume a unique neutral position and to maintain that position. Therefore, if a pilot was unable to perform an assigned task with the suit in the neutral position, he had to work against the space suit to complete the task. While this factor had been anticipated, the magnitude of the effort had not been fully appreciated until the gravity bias force was eliminated. Suit forces of considerable magnitude were encountered when the pilots attempted to change from the neutral suit position, such as moving the arm toward the head area or toward the feet. The magnitude of these forces exerted by the pilot was a function of the displacement from the neutral position of the suit. However, the pilots were able to minimize the suit forces by training for assigned EVA tasks in high-fidelity simulations and by becoming familiar with optimum methods of operating in their own suits.

Experience in EVA indicated that a pilot was in better condition to perform his assigned EVA task successfully if he had had an opportunity to familiarize himself with the EVA environment. The pilots performing the EVA in the Gemini Program had no previous experience in a sustained weightless environment; they approached the tasks without complete knowledge of how to operate in the space suit or to control body positions and attitudes. They were operating in a new environment, and a period of acclimatization improved pilot performance.

8.2 SCHEDULING OF EXTRAVEHICULAR ACTIVITY

Maximum ground tracking coverage during EVA allowed the flight control network to monitor systems performance with maximum communication between the ground and the spacecraft. The Gemini EVA was basically experimental; and, for the overall mission, the EVA could occur at almost any time. EVA was normally scheduled in orbits when the spacecraft was over the United States, since these orbits afforded maximum tracking coverage. Only 4 revolutions of every 15 gave the desired coverage, and this caused a restriction in the flight planning.

An additional restriction was imposed on the flight plan by the extensive preparation and postingress cleanup time required for EVA. A 2-hour umbilical EVA on a typical Gemini mission occupied about 7 hours of flight time. Three and one-half hours were required for EVA preparation, 2 hours for actual EVA, and about 1-1/2 hours for restowage after EVA. Total elapsed time for a standup EVA was less, since standup EVA required only about 2 hours for preparation. In either case, EVA consumed a significant portion of a mission day. Whenever possible, this period was uninterrupted. The many items of hardware unstowed for EVA made continuity highly desirable. Any other activity during EVA preparation complicated both activities because of the loose hardware in the cabin.

Familiarization with the EVA environment also had overall flight plan implications. No pilot encountered any disorientation problems during EVA; however, the desirability of an initial period of familiarization was best satisfied by avoiding mission-critical activities immediately following the initial egress.

8.3 CAPABILITIES OF THE EXTRAVEHICULAR PILOT

Unless the pilot was adequately restrained, his capability for useful work during EVA was severely limited. Pilots were able to perform relatively difficult tasks without adequate restraint, but only with an excessive expenditure of energy. The problem was that the pilot expended a large percentage of his energy in overcoming the space suit forces and in maintaining body position. Two pilots terminated their planned EVA prematurely because the lack of adequate body restraints resulted in high workloads and in high energy expenditures. However, it was also demonstrated that, with proper familiarization, useful work could be continued for long periods of time, if the pilot was provided with adequate body restraints and if the work was paced properly. An ideal sequence included rest periods of 2 to 3 minutes every 5 to 15 minutes depending on the work performed. If the pilot was properly restrained, his normal capabilities were limited principally by the mobility limits of the space suit. Examples of the tasks performed by Gemini pilots are shown in Table 8.3-I.

In addition to the lack of adequate restraints and the lack of space suit mobility, the EVA pilot's capabilities were limited by the design of the EVA hardware. Early experience indicated that performance of EVA tasks was frequently more difficult in orbit than on the ground. In some cases, tasks were more difficult because of minor incompatibilities between the hardware design and the EVA operational environment. The extensive underwater simulation before the Gemini XII mission served to identify this type of hardware problem and to facilitate correction. Hardware designs that were found to be suitable in a valid underwater simulation were also suitable for use in orbit.

The command pilot's capabilities were also limited during EVA. The normal functions of spacecraft control, systems monitor, replacement of voice tape cartridges and film magazines, and general equipment management were complicated by the restrictions of operating in the pressurized space suit. Since the command pilot was responsible for directing the entire EVA operation, he received detailed training in all equipment and procedures. The resulting familiarity enabled effective exercise of the command function. Because of the extensive involvement of the command pilot, a detailed analysis of his tasks and time lines was also needed in the preparation of the EVA flight plan.

TABLE 8.3-I.- SUMMARY OF GEMINI EXTRAVEHICULAR TASKS

EVA tasks	Body restraints used	Forces required	Ease of accomplishment
Removal of 7 in^2 of nylon Velcro strip, Gemini XI	Handholds	Finger, hand, and body	Satisfactory
Translation between two points, Gemini X	None	Establish velocity vector when leaving first point	Satisfactory
GATV tether attachment to spacecraft docking bar, Gemini XI	Handholds	Body control and forces from hands, arms, legs, and torso	Unsatisfactory
Experiment package deployment or retrieval (S009, S010, and S012), Gemini IX-A, X, and XI	Handholds	Body control and forces from fingers, hand, and body	Satisfactory
Unstowage and extension of the AMU controller arm (during AMU checkout), Gemini IX-A	Foot stirrups	Torquing and forces from hands, arms, and body	Unsatisfactory
Unstowage and installation of the telescopic handrail, Gemini XII	Waist tethers	Alignment, body control, and forces from fingers, hands, and body	Satisfactory
GATV tether attachment to the spacecraft docking bar, Gemini XII	Waist tethers	Body control and forces from fingers, hands, and body	Satisfactory
Translation between two points along the surface of the spacecraft on Gemini IX-A, X, and XII	Handrail	Body control and forces from fingers, hands, and body	Satisfactory
Experiment package deployment; bolt-torquing operations, Gemini XII	Waist tethers	Alignment, torque, body control, and forces from finger, hand, and body	Satisfactory
Connector operations, Gemini XII	Waist tethers	Alignment, body control, and push/turn, blind push/turn, and push/push	Satisfactory
Cutting operations, Gemini XII	Foot restraints	Body control, finger, and hand	Satisfactory
Removal of 200 in^2 of nylon Velcro strip, Gemini XII	Foot restraints	Finger, hand, and body	Satisfactory

8.4 DETAILED EXTRAVEHICULAR PROCEDURES

One of the many factors to be considered in EVA flight planning was the writeup of EVA procedures. Detailed checklists were used during Gemini EVA. The Gemini crews consistently used the checklists either as a step-by-step sequence of the tasks to be performed or as a check to see that various tasks had been completed. The detail included was commensurate with the requirements of the tasks to be performed. The checklist included procedures for preparing for the EVA, for performing the EVA, and for ingress. The checklist also provided information concerning equipment location and unstowage, operation, restowage, and concerning the crew function and interface with the equipment. Since the stowed equipment for the later Gemini missions included items for numerous experiments and inflight tasks, the preparation for EVA required substantial handling of loose equipment. A written plan of action was necessary to insure the completion of all the tasks within the time allowed. A typical checklist for standup EVA is shown in figure 8.4-1. Note the Velcro in the photographs which was used to hold the checklist in position.

Early EVA experience indicated the necessity of a detailed checklist for extravehicular tasks. With extravehicular tasks, such as the checkout and donning of the AMU, the procedures were complex and required a specific sequence. Most EVA tasks consisted of individual steps with a specific sequence required for successful completion. Hence, the pilots were confronted with the sequencing of the steps for completing each task, as well as the sequencing of all the tasks to be completed in the EVA flight plan. The efficiency of operation outside the spacecraft was enhanced by reference to a comprehensive set of extravehicular procedures. Besides defining the sequence, the procedures for Gemini XII also provided a realistic time line for EVA which had been developed during underwater zero-g simulations. The Gemini XII experience reflected the benefit of the use of underwater simulations for development of procedures and time lines. An excerpt from the crew checklist for the Gemini XII umbilical EVA is shown in figure 8.4-2.

The EVA checklist was a byproduct of the crew training program. The checklist was the focal point for all items related to EVA, and it was updated because of the following:

(a) Modifications to procedures resulting from crew training and procedures development

(b) Modifications to equipment

(c) Changes to the flight plan or mission because of other factors

Review and validation by the crew during their training was repeated after each revision of the checklist. The flight procedures were in final form when the crew training was completed.

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STANDUP EVA
GT-X 17 JULY 66
PRELIMINARY PREPARATION (21:35)
C · ASSEMBLE MSC-8
P UNSTOW R.H. AFT FOOD BOX.
1. 18" & 24" HOSES
2. URINE SAMPLE BAGS
3. *TETHER & ELECTRICAL EXT. (BIO-MED)
4. *S-13 CAMERA & MAGAZINE
5. PRESSURE THERMAL GLOVES
6. S-10 POUCH
*STOW FOOD - VENTS CLOSED
C ASSEMBLE S-13 (5) DARK SLIDE
MSC - 8 (3) FILM PACK
P HATCH CLOSING DEVICE
COLLECTOR DOOR - LOCK
C INSERT VOICE TAPE
P. REMOVE LIFE VESTS
B PREPARE WASTE JETTISON BAG & SUN BONNET
P MOVE R H CAMERA BRACKET
ATT IND LT C/B-OPEN
FINAL PREPARATION (22:25)
HAW 22:25→22:31
B PLATFORM - BEF (START ALIGNING)
PRIMARY A & SECONDARY B PUMPS - ON; SUIT FANS - 1+2
O_2 PRESSURE - 800 PSI
COMPUTER: PRELAUNCH- OFF
MANEUVER THRUSTER C/B - OPEN
SCANNER - PRI
T/M - R/T & ACQ
EVENT TIMER - ZERO
~~MOVE T-17 EXP TO CMD PILOTS FOOTWELL~~ - "WET WIPE" ON VISOR
LOOSE ITEMS - SECURED
WATCH ON GLOVE-START TIME
B ZIPPER - GLOVES - HELMET - EVA VISOR DONNED & SEALED
B INTEGRITY CHECKS
US 22:38→22:57
C S-13 & MSC - 8 READ[Y]
RECORDER - CONT

P HATCH PAWLS U-U
RECIRC-CLOSED (↓) DW[N]
CABIN LIGHTS - DIMME[D]
C/B'S & SWITCHS IN CORRECT POSITIONS
[EGRE]SS (22:55) CYI 22:54→23:05
C VENT TO 3 PSI TO 0 PSI
B BOTH OPEN HATCH
P PAWLS L-L
OPEN SAWTOOTH

ASC	23:03→KNO 23:13
TAN	23:17→23:28
CRO	23:34→23:45
CTN	23:55→24:03
HAW	24:00→24:11

JETTISON WASTE
RETRIEVE CMD PILOTS WINDOW COVER
INSTALL SUN SHADE ON CMD PILOT'S WINDOW
SET UP S-13 EXP.
C TIMER - START (SUNSET)
S/C - BEF 10 EXP/FIELD MAX
6 AT 10 SEC
1 AT 75 SEC

	YAW	PITCH
00:00-SPICA	120°S	60°U
10:00-β CRUX	100°S	20°U
20:00-SHAULA	130°S	60°U
30:00-γVELORUM	60°S	10°U
40:00-MSC-8EXP F8, F16, F-11, 36"		
45:00-S-5/S-6		

INGRESS US 24:10→24:35
CLOSE HATCH
CABIN VENT - CLOSED (2
~~RAD - BYPASS~~
CABIN REPRESS - OPEN TO 4.5 PSI & SHUT (MAN HTR?)
~~RAD - FLOW; EVAP-NORM~~
CABIN RECIRC - UP 45° (OPEN)
MANEUVER THRUSTERS C/B'S - CLOSED
POWER DOWN S/C
ATT IND LT C/B-CLOSE
REMOVE TETHER
STOW EVA GEAR

Figure 8.4-1. - Standup EVA checklist for Gemini X.

UMBILICAL

S/C DEPRESSURIZATION AND EGRESS

~~(42:35:10 ; SUNRISE -3 MIN)~~

1. INSURE S/C MIRROR IS OUT OF WAY
2. POSITION WASTE POUCH FOR JETTISONING
3. RECORD CONT
4. KEYING - VOX

CMD PILOT:

1. HOLD UMBILICAL IN LAP. (REMOVE BAG)
2. VERIFY CABIN RECIRC VALVE-DWN (CLOSED)
3. CABIN VENT CHECK VALVE-OPEN
4. SLOWLY OPEN CABIN VENT VALVE TO DEPRESSURIZE CABIN TO 3.0 PSIA. VERIFY SYSTEM INTEGRITY WHILE HOLDING CABIN @ 3.0 PSIA.
5. COMPLETE CABIN DEPRESSURIZATION BY OPENING CABIN VENT VALVE ALL THE WAY.

PILOT:

1. VERIFY R/H HATCH CLOSING LANYARD FREE FROM CABIN VENT VALVE HANDLE

CMD PILOT:

1. HOLD HATCH CLOSING DEVICE TO PRECLUDE HATCH EXPLOSIVE OPENING

EGRESS (SUNRISE)
GET ___:___:___

START EVENT TIMER - UP (AT SUNRISE) 00:00

PILOT:

1. UNLATCH SPACECRAFT HATCH
2. OPEN THE HATCH
3. POSITION GAIN AND DRIVE SELECTOR TO THE "L" (LOCK) POSITION
4. STOW HATCH HANDLE

BOTH PILOTS:

1. MAKE FINAL CHECK OF ALL FITTINGS

PILOT:

1. STAND IN SEAT
2. JETTISON WASTE POUCH

CMD PILOT:

1. RESTRAIN PILOT BY USING LEG RESTRAINT

PILOT:

1. REST (2 MIN)

EXTRAVEHICULAR ACTIVITIES

1ST DAY 08:00

PILOT:

1. STANDUP FAMILIARIZATION:
   - A. CHECK FOR ELSS OUT FLOW AND FLOAT OUT TENDENCIES
   - B. EVALUATE STANDUP DYNAMICS IN COMPARISON WITH STANDUP EVA
2. EVALUATE EVA CAMERA INSTALLATION:
   - A. TETHERED IN COCKPIT
   - B. UNTETHERED IN COCKPIT
   - C. FROM OUTSIDE COCKPIT (VERIFY CAMERA SETTING)
3. REST (2 MIN) — *M+P*
4. PULL UMBILICAL OUT OF ~~BAG~~ *S/C* — 15:00
5. MOVE TO NOSE ON HANDRAIL
6. ATTACH WAIST TETHER TO HANDRAIL
7. EVALUATE REST TETHERED TO HANDRAIL
8. HOOK UP AGENA TETHER
9. ATTACH DOCKING BAR CLAMP

9A. EVALUATE WAIST TETHER DYNAMICS

9B. REST (@TDA) — *H*

10. RETURN TO S/C HATCH — 28:00
11. HAND EV 16MM CAMERA TO CP (CHANGE FILM MAG.)
12. RETRIEVE (4) GLV STRIPS & STOW ABOVE R/H SEAT
13. PICK UP & SECURE ADAPTER WORK STATION CAMERA

Figure 8.4-2. - Umbilical EVA checklist for Gemini XII.

PILOT:

13. MOVE TO ADAPTER — 34:00

CMD PILOT:

1. CHANGE VOICE TAPE @ SUNSET

NIGHT PASS:

PILOT:

1. ROUTE UMBILICAL THROUGH UMBILICAL GUIDE
2. POSITION FEET IN FOOT RESTRAINTS (PRIOR TO SUNSET)
   SUNSET @ 55:00 ET OR 43:30:00 G.E.T.
3. INSTALL ADAPTER WORK STATION CAMERA (CONNECT PWR CABLE)

CMD PILOT:

1. EVA CAMERA C/B - CLOSED
2. EVA CAMERA PWR SWITCH - ON

PILOT:

1. START CAMERA (VERIFY CAMERA SETTING)
2. REST
3. PULL UMBILICAL TAUT & INSERT IN CLIP ON HAND BAR
4. UNSTOW AND POSITION MIRROR
5. UNSTOW PEN LIGHTS, ACTUATE & ATTACH LIGHTS TO HAND BARS WITH VELCRO
6. EVALUATE FOOT RESTRAINTS
7. REST
8. PERFORM WORK STATION TASKS — 52:00
   ADAPTER
   A. PERFORM THE FOLLOWING TASKS IN FOOT RESTRAINTS:
      1. OPEN POUCH AND REMOVE WRENCH
      2. PERFORM TORQUEING OPERATION ON FIXED BOLT AT TOP OF BOLT HOUSING
         COMPARE 1/2" HEAD BOLT TO 1/4" HEAD BOLT.
         STOW WRENCH ON VELCRO
      3. DISCONNECT & CONNECT CENTER CONNECTOR
      4. DISCONNECT & CONNECT FLUID QD
      5. REST (2 MIN) — 00:00
      6. REMOVE CUTTERS FROM POUCH
      7. CUT 2 STRANDS OF RIGHT SIDE OF ELECTRICAL CABLE & FLUID QD CABLE
      8. STOW CUTTERS IN POUCH
      9. REMOVE PIP-PINS FROM HAND HOLDS AND STOW
      10. UNSTOW WRENCH FROM VELCRO & REMOVE SATURN BOLT. STOW WRENCH ON VELCRO
      11. ATTACH WAIST TETHERS TO FIXED RINGS ON WORK STATION; REMOVE FEET FROM FOOT RESTRAINTS
      12. REMOVE WRENCH FROM VELCRO & REPLACE SATURN BOLT. (ALLOW ONE MINUTE TO START BOLT) STOW WRENCH ON VELCRO /IN POUCH
      13. EVALUATE HOOK & RING CONNECTIONS
      14. REST (2 MIN) — 20:00
      15. PULL NYLON VELCRO STRIPS & RESTOW (LEFT SIDE)
      16. PULL STEEL VELCRO STRIPS & RESTOW (RIGHT SIDE)
      17. DISCONNECT & CONNECT CENTER CONNECTOR
      18. DISCONNECT & CONNECT L/H (R/H) CONNECTOR
      19. REPOSITION FEET IN FOOT RESTRAINTS
      20. REST (2 MIN) — 25:00
      21. CONNECT WAIST TETHER TO HAND HAND HOLDS & SECURE HAND HOLDS TO CHESTPACK
      22. EVALUATE ONE FOOT RESTRAINT
9. REMOVE UMBILICAL FROM CLIP ON HAND BAR

Figure 8.4-2. - Continued.

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CMD PILOT:

*.2 EVA CAMERA C/B - OPEN
*.1 EVA CAMERA PWR SWITCH - OFF

PILOT:

1. PICK UP & SECURE ADAPTER WORK STATION CAMERA
2. REST UNTIL SUNRISE — M+BP

2ND DAY

PILOT:

1. REMOVE UMBILICAL FROM PIGTAIL
2. MOVE TO S/C HATCH — 30:00
3. HAND ADAPTER WORK STATION CAMERA TO CMD PILOT

CMD PILOT:

1. SECURE THIRD CAMERA TO CLOTHESLINE

PILOT:

1. INSTALL EV 16MM CAMERA (NEW FILM MAG LOADED - VERIFY CAMERA SETTING)
2. MOVE TO S/C NOSE AREA
3. INSTALL 2 PIP-PINS IN TDA & CONNECT WAIST TETHER. MOVE INTO POSITION FOR WORK STATION TASK (REPOSITION PIP-PINS, ADJUST WAIST TETHER AS REQUIRED)
4. REST (2 MIN)
5. PERFORM WORK STATION TASKS TDA — 40:00
   A. PERFORM THE FOLLOWING TASKS ON TWO WAIST TETHERS AT TDA:
      1. DISCONNECT & CONNECT ELECTRICAL CONNECTOR
      2. DISCONNECT & CONNECT FLUID QD
      3. UNSTOW APOLLO TORQUE WRENCH & STOW IN APOLLO BOLT
      4. TORQUE BOLT AT PRESET TORQUE VALUE
      5. ADJUST TORQUE SETTING UP OR DOWN AS REQUIRED
      6. STOW APOLLO TORQUE WRENCH IN APOLLO BOLT
      7. REST (2 MIN)
      8. REMOVE LEFT/RIGHT WAIST TETHER & ATTACH TO ELSS — 46:00

CMD PILOT:

CHANGE VOICE TAPE

PILOT:

   B. PERFORM FOLLOWING TASK WITH ONE WAIST TETHER
      1. DISCONNECT & CONNECT ELECTRICAL CONNECTOR
      2. DISCONNECT & CONNECT FLUID QD
      3. TORQUE BOLT AT SET VALUE
      4. ADJUST TORQUE SETTING UP OR DOWN AS REQUIRED
      5. STOW WRENCH IN APOLLO BOLT
      6. REST (2 MIN)
      7. REMOVE RIGHT/LEFT WAIST TETHER
   C. ATTEMPT STEPS B1 THROUGH B6 WITH NO TETHERS
   D. STOW APOLLO TORQUE WRENCH IN APOLLO BOLT
7. RETURN TO S/C HATCH (WAIST TETHERS JETTISONED) — 60:00

INGRESS

PILOT:

1. STAND IN SEAT (EV VISOR UP) — H
2. RETRIEVE EV 16MM CAMERA. VELCRO CAMERA ABOVE CAMERA BOX
3. REMOVE HANDRAIL & DISCARD

BOTH PILOTS:

1. RETRIEVE UMBILICAL & STOW IN LAP OR FOOTWELL OF CMD PILOT

PILOT:

1. DEPLOY HATCH HOLDING DEVICE (SAW-TOOTH)
2. CHECK HATCH PAWLS TO LOCK (UP)
3. CHECK HATCH SEAL FOR PROPER SEATING AND DEBRIS

CMD PILOT:

1. CLEAR PILOT AREA OF HOSES — 10:00

PILOT:

1. PARTIALLY INGRESS CABIN, RELEASE ELSS RESTRAINTS, AND HAND ELSS TO CMD PILOT (DISPLAY PANEL OF ELSS TOWARD CMD Pilot) Cmd PILOT HELP PILOT AS REQUIRED

Figure 8.4-2. - Continued.

PILOT:

2. COMPLETE INGRESS

BOTH PILOTS:

1. CLOSE HATCH TIGHT BY PULLING ON HATCH CLOSING DEVICE

PILOT:

1. WHEN HATCH FULLY LOCKED, POSITION GAIN SELECTOR AND DRIVE SELECTOR TO THE "N" (NEUTRAL)
2. STOW HANDLE
3. STOW HATCH HOLDING DEVICE

CMD PILOT:

1. CABIN VENT VALVE - CLOSE
2. CABIN VENT CHECK VALVE - CLOSE
3. VERIFY ELSS EMERGENCY O_2 SUPPLY
4. ELSS FLOW SELECTOR VALVE - HIGH
5. ELSS BYPASS VALVE - NORMAL
6. EVAPORATOR - CONDENSER VALVE - OFF

NOTE: OUTFLOW FROM ELSS WILL REPRESS CABIN

BOTH PILOTS:

1. MONITOR CABIN PRESSURE. IF CABIN CANNOT BE REPRESSURIZED USE REPRESSURIZATION FAILURE PROCEDURES
2. IF CABIN IS REPRESSURIZING NORMALLY & ELSS EMERGENCY O_2 HAS NOT BEEN USED, CLOSE CABIN REPRESS VALVE.

NOTE: EMERGENCY O_2 OUTFLOW FROM ELSS WILL REPRESSURIZE CABIN. PILOT MAY SELECT BYPASS AFTER REPRESS VALVE CLOSING TO SPEED BOTTLE DEPLETION

3. WHEN CABIN PRESSURE REACHES 4.5 PSI GRADUALLY OPEN VISOR TO DEPRESSURIZE SUIT. CLOSE CABIN REPRESS VALVE IF NOT ALREADY CLOSED

CMD PILOT:

1. PLACE ELSS C/B - OPEN (S/C PWR LIGHT ON ELSS - OFF)
2. WHEN EMERGENCY O_2 PRESSURE DROPS TO APPROXIMATELY 1000 PSI, ELSS BATTERY SWITCH - OFF

BOTH PILOTS:

1. MONITOR ELSS EMERGENCY O_2 PRESSURE WHEN PRESSURE DROPS TO 100 PSI, THEN SHUT OFF ELSS EMERGENCY O_2 SUPPLY

PILOT:

1. REMOVE GLOVES, HELMET (INSTALL EV VISOR COVER) & STOW HELMET IN FOOTWELL WITH GLOVES & DON [neck & wrist dams] LIGHTWEIGHT HEADSET
2. OPEN RECIRC VALVE & REMOVE INTERCONNECT FROM S/C HOSES & STOW TEMPORARILY
3. DISCONNECT OUTLET "Y" CONNECTOR & CONNECT OUT S/C HOSE TO SUIT
4. DISCONNECT INLET "Y" CONNECTOR & CONNECT INLET S/C HOSE TO SUIT (UNSTOW MIRROR, IF REQUIRED)
5. R/H SUIT FLOW VALVE-FULL INCREASE
6. EXTERNAL LTS - OFF

CMD PILOT:

1. HAND ELSS TO PILOT

PILOT:

1. DISCONNECT ELSS HOSES FROM ELSS & STOW

CMD PILOT:

1. ADJUST LAP & SHOULDER RESTRAINTS AS DESIRED
2. REMOVE HELMET & GLOVES & STOW - [Don]
3. DON LIGHTWEIGHT HEADSET [neck & wrist dams]

PILOT:

1. BIOMED C/B - OPEN
2. DISCONNECT ELECTRICAL JUMPER FROM SUIT & S/C, RECONNECT S/C ELECTRICAL TO SUIT

NOTE: COMMUNICATIONS WILL BE LOST WITH THE PILOT DURING CHANGE OF ELECTRICAL CONNECTORS

Figure 8.4-2. - Continued.

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PILOT:

3. BIOMED C/B - CLOSE
4. VERIFY NORMAL COMMUNICATIONS HAVE BEEN REGAINED

CMD PILOT:

1. DISCONNECT UMBILICAL O_2 AND ELECTRICAL JUMPER FROM ELSS
2. DISCONNECT TETHER FROM PILOT'S HARNESS AND EGRESS BAR
3. DISCONNECT UMBILICAL AT S/C Q.D. AND PLACE UMBILICAL IN BAG
4. UNSTOW CAMERA BOX

PILOT:

1. STOW ELSS
2. VERIFY GAIN & DRIVE SELECTOR IN "N" (NEUTRAL) POSITION

CMD PILOT:

1. STOW 5MM LENS FROM ADAPTER WORK STATION CAMERA IN CAMERA BOX STOW HASSELBLAD, MAURER & USED MAGAZINES IF DESIRED
2. REMOVE L/H 16MM CAMERA GEAR AND STOW
3. STOW CAMERA BOX

PILOT:

1. REMOVE BRACKET & CABLE FROM ADAPTER WORK STATION CAMERA & STOW FOR JETTISONING
2. TEMPORARILY STOW ADAPTER WORK STATION CAMERA ABOVE R/H SEAT

~~3. REMOVE WAIST TETHER & HAND TO CP FOR STOWAGE~~

~~4.~~ 3. REMOVE AND STOW HATCH CLOSING DEVICES

CMD PILOT:

1. RETRIEVE USED 16MM MAGAZINES & PLACE IN L/H FORWARD FOOTWELL POUCH

PILOT:

1. STOW HATCH HOLDING DEVICE

BOTH PILOTS:

1. STOW EV GEAR TO BE JETTISON LATER IN BAG WITH UMBILICAL/WASTE POUCH
2. STOW REMAINING EVA GEAR IN APPROPRIATE ~~PLATE~~ place
3. STOW GLV STRIPS IN GLV STRIP POUCH

END UMBILICAL

Figure 8.4-2. - Concluded.

8.5 DOCUMENTATION OF EXTRAVEHICULAR ACTIVITY

Within the limitations of equipment capabilities, the following documentation was obtained on each EVA mission:

(a) Continuous onboard voice recordings were made of the crew conversations from near-completion of EVA preparation to ingress. These recordings included detailed descriptions from the pilots of the events which took place during the EVA. This method of documenting the EVA also provided the necessary information for generating an actual time line of the EVA for postflight analysis.

(b) Air-to-ground voice recordings provided additional backup documentation of the EVA.

(c) Film coverage provided graphic description for all EVA that occurred within the field of view of the camera. In some missions, this photography added information not provided by the crew. The EVA film was an invaluable aid in postflight evaluation.

8.6 NIGHT OPERATIONS

Night EVA operations were limited to either the standup activity, in which the pilot was restrained in the cockpit, or to activities in the spacecraft adapter section. The EVA pilots carried out these night operations successfully. Adequate lighting was the only constraint identified. A relatively low level of lighting was provided in the adapter section, and this lighting was found adequate in Gemini IX-A and XII. Both the Gemini IX-A and XII pilots indicated that, with appropriate lighting, transit along fixed handrails appeared feasible for night operation.

8.7 SPACECRAFT CONSTRAINTS

Control of spacecraft attitude and position during EVA was complicated by several factors. Tests showed that significant damage to EVA equipment could result if the spacecraft control thrusters were fired when the equipment was within the direct impingement envelope of the thrusters. To avoid such damage, the flight crews coordinated thruster operation and the EVA pilot's movements. The pilot kept track of the position of the umbilical and of his position and notified the command pilot when certain thrusters could be fired safely. This coordination was particularly important during the umbilical EVA on Gemini X when the command pilot was station-keeping with the Gemini VIII GATV. Coordination between the pilots enabled them to accomplish the task without equipment damage.

Another complication to spacecraft attitude control was the significant torques introduced by the EVA pilots. During the umbilical EVA on Gemini IX-A, the pilot may have caused noticeable attitude excursions when he moved about on the external surface of the spacecraft. The control system was off at the time. When he was in the adapter section and the control system was reactivated, there were frequent thruster firings, especially whenever the pilot moved vigorously. The use of an automatic control mode tended to relieve the command pilot of the task of counteracting the disturbances introduced by the EVA pilot.

Although the spacecraft exterior was designed to withstand the extremes of heat inputs from direct solar radiation and of radiation heat losses to deep space, the Gemini spacecraft interior was not so designed. Opening the hatch for EVA exposed the spacecraft interior to these conditions. On Gemini IX-A, there was an overheating problem, and some of the paint on the top of the ejection seat headrest and on the seat pan was blistered. Review of the time line indicated that the seat was only exposed to the sun for approximately 30 minutes. Subsequent analysis showed that in thin metal structures, such as the ejection seat, the surface temperature could reach 200° to 300° F within 20 minutes exposure to direct sunlight. A study of the shadowing using a scaled mockup was made to determine the sun angles which could be tolerated. For Gemini XI and XII, a fixed inertial attitude was maintained during the umbilical EVA, using the GATV attitude control system. The attitude was chosen to avoid direct sunlight on the interior of the cockpit, even with the right hatch open.

9.0 MEDICAL ASPECTS OF EXTRAVEHICULAR ACTIVITY

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9.0 MEDICAL ASPECTS OF EXTRAVEHICULAR ACTIVITY

9.1 DISCUSSION OF MEDICAL FACTORS

During Gemini extravehicular activities, several physiological problems developed which were within the area of medical cognizance. There were indications that excessive workload might be a limiting factor during EVA. A postflight evaluation of data from Gemini IX-A and XI indicated that an excessive thermal load may have been imposed on the extravehicular pilot, and high respiration rates encountered during Gemini XI indicated that a buildup in carbon dioxide level may have been a problem. Since there were no actual data on thermal conditions or carbon dioxide levels and no direct measure of metabolic load, a quantitative evaluation of these possible problem areas could not be made.

Gemini extravehicular bioinstrumentation consisted of the electrocardiogram and the impedance pneumogram. These parameters have been monitored during a great many physiological and psychological tests and under widely varying conditions. The existing pool of information has established the fact that heart rate responds to psychological, physiological, and pathological conditions. There are considerable individual variations in these responses; however, since a quantitative indication of workload actually experienced in flight appeared to be of primary importance, the feasibility of using heart rate as a quantitative indication of workload was investigated. On Gemini IX-A, X, XI, and XII, preflight and postflight exercise tests using the bicycle ergometer were performed on the pilots. During these tests, the subject performed a measured amount of work in increasing increments, while heart rate, blood pressure, and respiration rate were monitored and periodic samples of expired gas were collected for analysis. These data were translated into oxygen utilization curves and Btu plots which are included as figures 9.1-1 and 9.1-2. Timed volumes for expired air $\dot{V}_E$, for oxygen $\dot{V}_{O_2}$, and for carbon dioxide $\dot{V}_{CO_2}$ were corrected to standard temperature and pressure, dry (STPD). Using these plots and the heart rate data obtained during each flight, an approximate workload curve was plotted against the EVA time line (fig. 9.1-3). These derived data were considered inaccurate, because changes in heart rate caused by thermal or environmental problems could not be taken into consideration. The psychological effect of a new and different environment also could have increased the heart rates without a corresponding change in metabolic rate. However, any error introduced by these factors would have increased the observed heart rate for a given workload level. This fact tended to increase the usefulness of such a plot in preflight planning and in inflight monitoring of EVA. When data from previous flights, altitude chamber tests, one-g walk throughs, and underwater zero-g simulations were examined in this manner, a qualitative indication of work expended on various tasks could be derived. This was important in the assessment of the relative physiological cost of various tasks and in the determination of acceptable tasks and realistic time lines during simulations and preflight planning. The heart rate and respiration rate data, when coupled with voice contact and with an understanding of the planned activities, proved to be an extremely important and reliable indication of the medical status of extravehicular crewmen during EVA. An example was seen in the Gemini XI mission.

During the attempts by the pilot of Gemini XI to attach the spacecraft/target-vehicle tether to the docking bar, he expended an unexpectedly high level of energy in attempting to maintain his position. He used the large muscles in his torso and legs to straddle the spacecraft nose section. In doing so, he worked strenuously to force his legs into an unnatural position for the pressurized space suit. The high work subjectively described by the pilot was confirmed by heart rates and respiration rates as seen in figure 9.1-3(d). The high respiration rates seen in this figure also indicated the possibility of an increased carbon dioxide level. The ELSS was not designed to handle workloads of the magnitude indicated by these rates in terms of thermal control or carbon dioxide removal. The thermal and carbon dioxide buildups, along with psychological factors which may have been present, probably contributed to the high heart rates recorded.

In planning for Gemini XII EVA, one of the objectives was to avoid workloads which would overload the ELSS. Previous tests had shown that the ELSS was capable of dissipating 2000 Btu/hr, while maintaining a carbon dioxide level of approximately 6 mm Hg. Figure 9.1-1 shows that during the preflight ergometry studies, the pilot's heart rate was approximately 120 beats per minute when his workload was 2000 Btu/hr. Because of the several factors which were known to cause increased heart rate, the actual heart rates were expected to exceed this level during the planned EVA on Gemini XII. After evaluation of all data from previous EVA missions, altitude chamber tests, and underwater zero-g simulations, it was concluded that if the pilot's heart rate remained under 140 beats per minute for the majority of the EVA, the probability of successfully completing the EVA without exceeding the ELSS capabilities was high. Therefore, the pilot was to be advised to slow down and rest whenever his heart rate exceeded 140 beats per minute. If his heart rate exceeded 160 beats per minute, he would be advised to stop all activities.

Figure 9.1-3(e) is a plot of heart rate related to events during the Gemini XII umbilical EVA. The pilot's heart rate exceeded the expected levels only one time, during a period of unscheduled activities in which psychological factors may have contributed significantly to the heart rate. When the pilot was asked to decrease his activities, his heart rates returned to a resting level in less than 1 minute.

Periods of exercise were included in both of the standup EVA's. These exercises consisted of moving the arms away from the neutral position of the pressurized space suit. Both arms were brought from the neutral position to the sides of the helmet once each second for 60 seconds. An attempt was made to correlate heart rate data during these inflight exercise periods with preflight exercise tests, as shown in figure 9.1-4. When compared in this manner, no significant difference appeared in the response to exercise performed before and during flight. It must be remembered, however, that only qualitative conclusions can be drawn from these data. Valid quantitative conclusions must await the results of more precise inflight medical experimentation in which controlled conditions and additional data collection are feasible.

Several other factors were significant in the medical aspects of Gemini EVA. One of these was the art of conserving energy as demonstrated in Gemini XII. The pilot of Gemini XII was able to condition himself to relax completely within the neutral position of the space suit. He reported that he systematically monitored each muscle group. When a group of muscles was found to be tense while performing no useful work, he was able to relax these muscles consciously. All of his movements were slow and deliberate. When a task could be performed by small movement of the fingers, he would use only those muscles necessary for this small movement. This technique of conserving energy contributed to the low indicated work levels in the Gemini XII umbilical EVA.

Chronic fatigue and physical conditioning may have been a problem during some of the EVA missions. Sleep during the first night of each mission was consistently inadequate, and scheduled activities necessary for EVA preparation tended to be detailed and fatiguing. Furthermore, the pace of preflight activities, the pressure of planning, training, and preparation to meet a flight schedule predisposed the crews to chronic fatigue. During the final weeks of preparation for a flight, each crew found that time for rest, relaxation, and physical conditioning was at a premium and was often reduced. Accordingly, the workload peaks indicated during several of the EVA missions may have been due in part to a fatigued condition.

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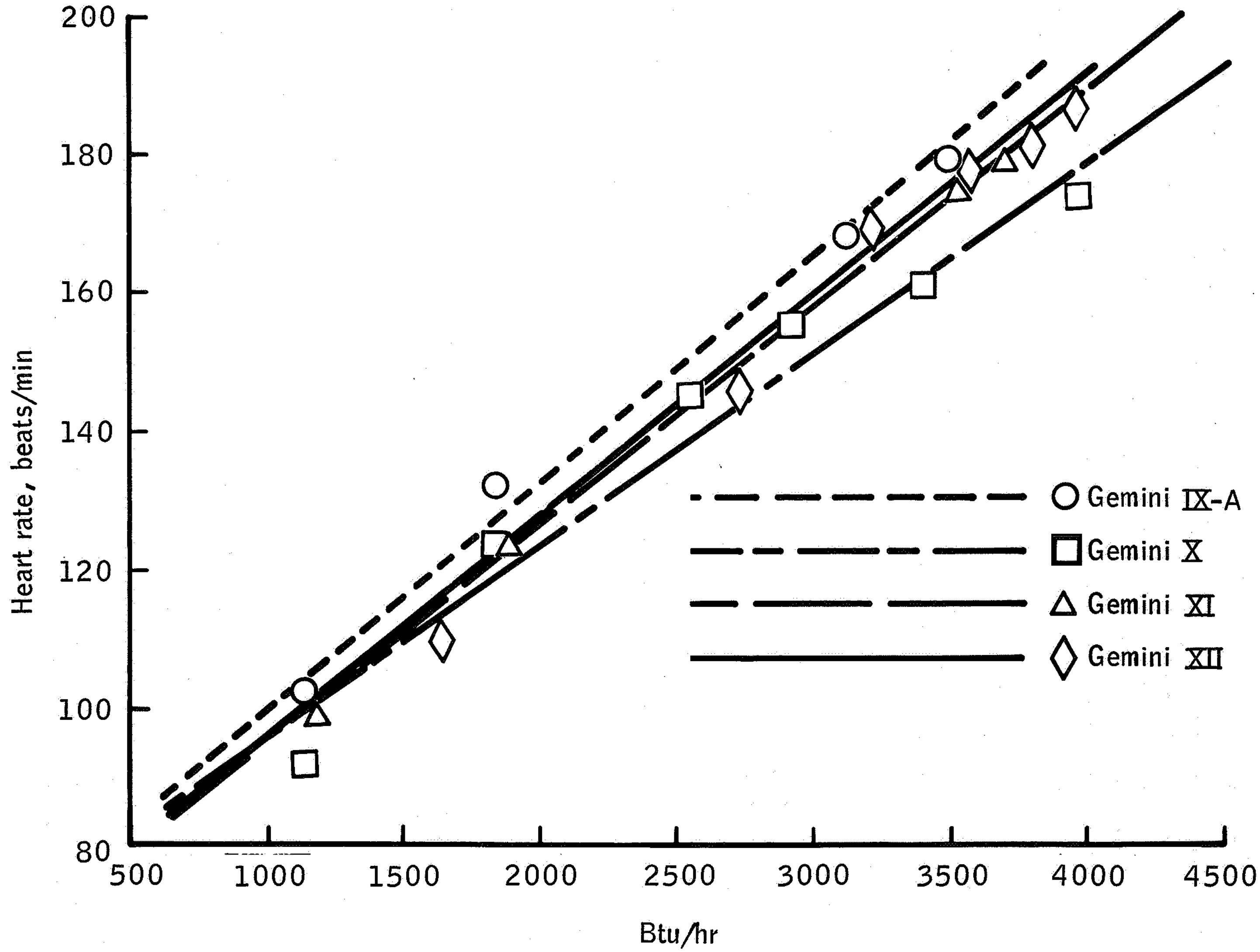
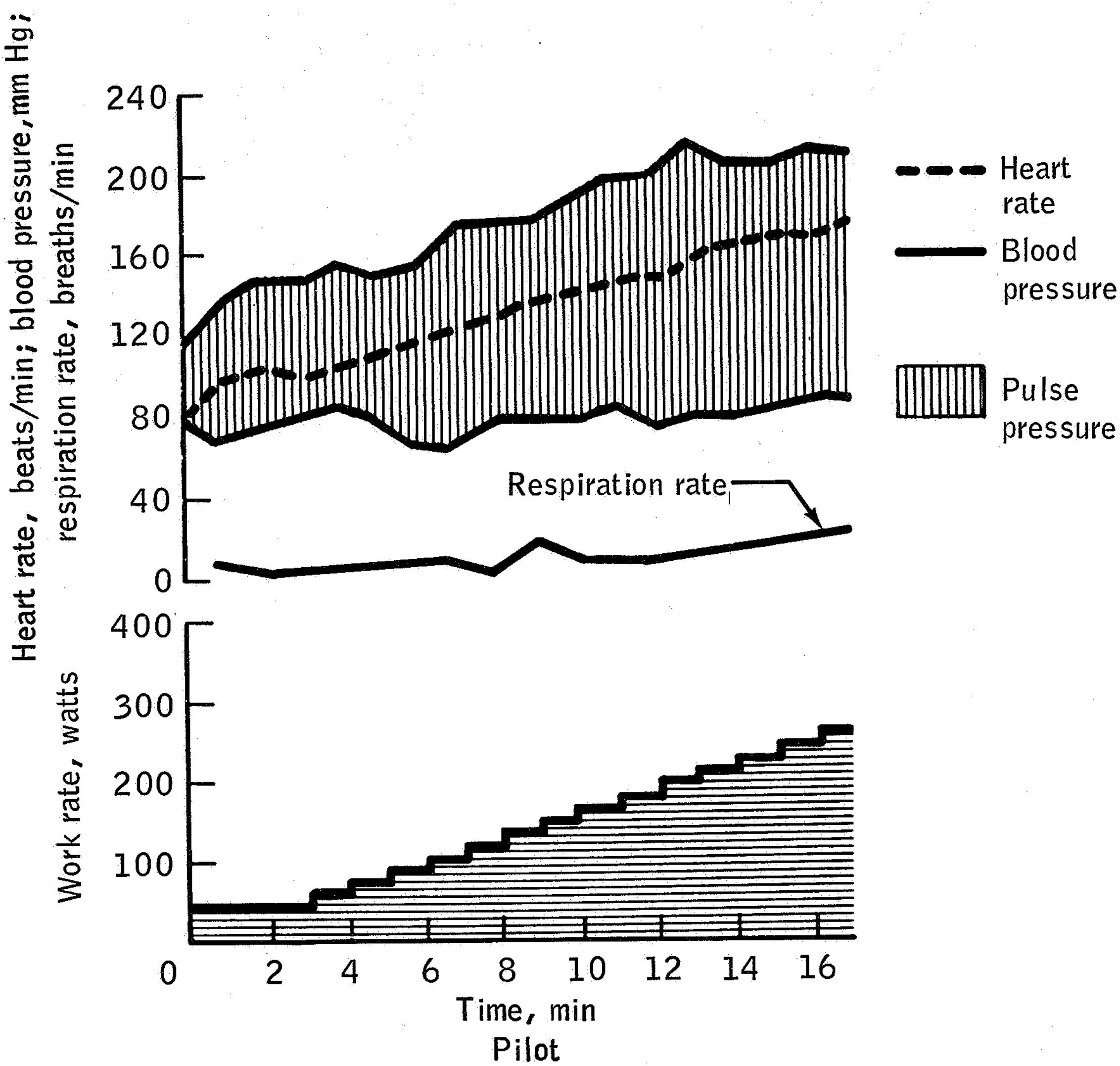


Figure 9.1-1. - Preflight ergometry.



(a) Part I.

Figure 9.1-2. - Exercise capacity test results.

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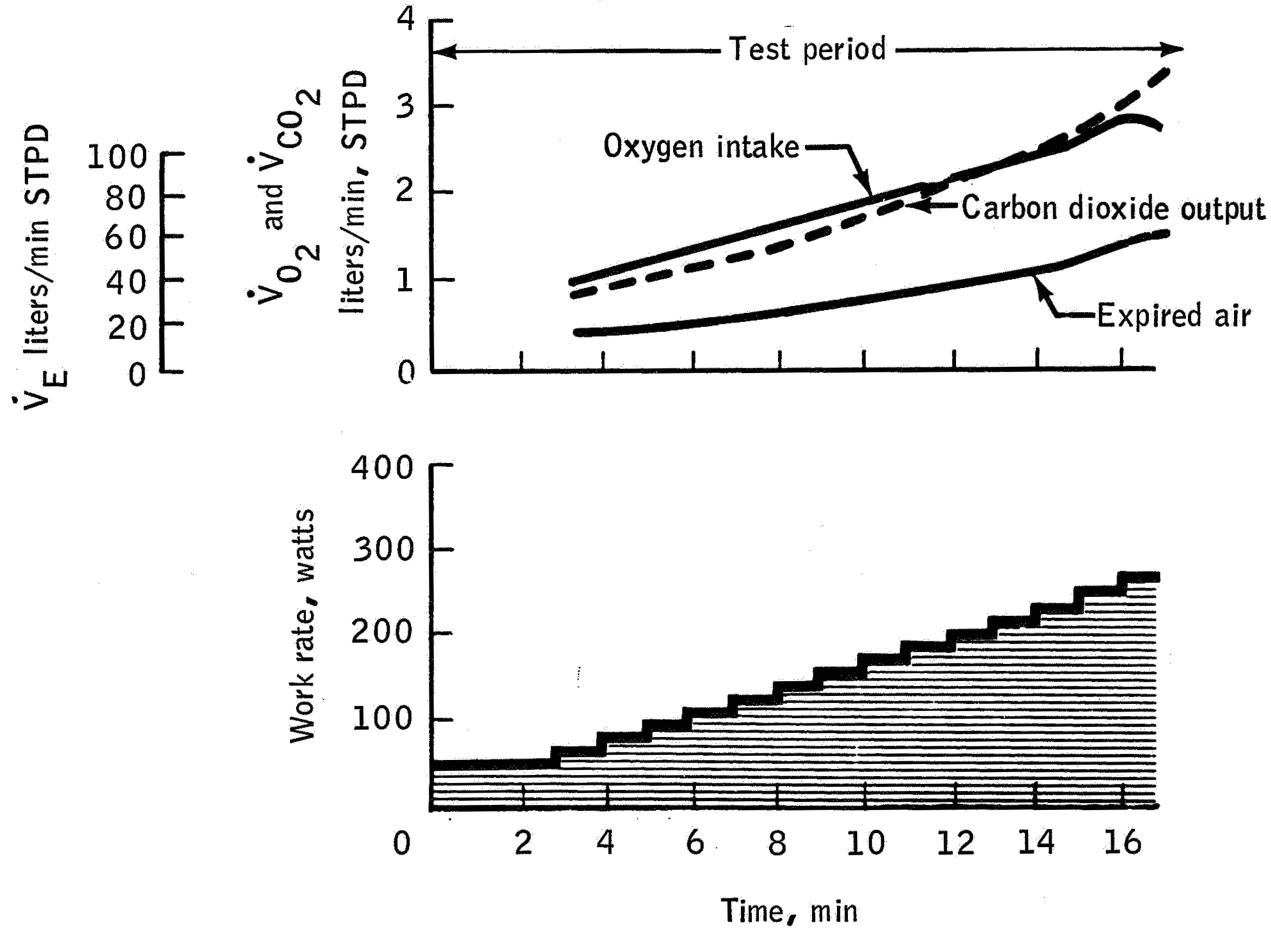

Pilot

(b) Part II.
Figure 9.1-2. - Concluded.

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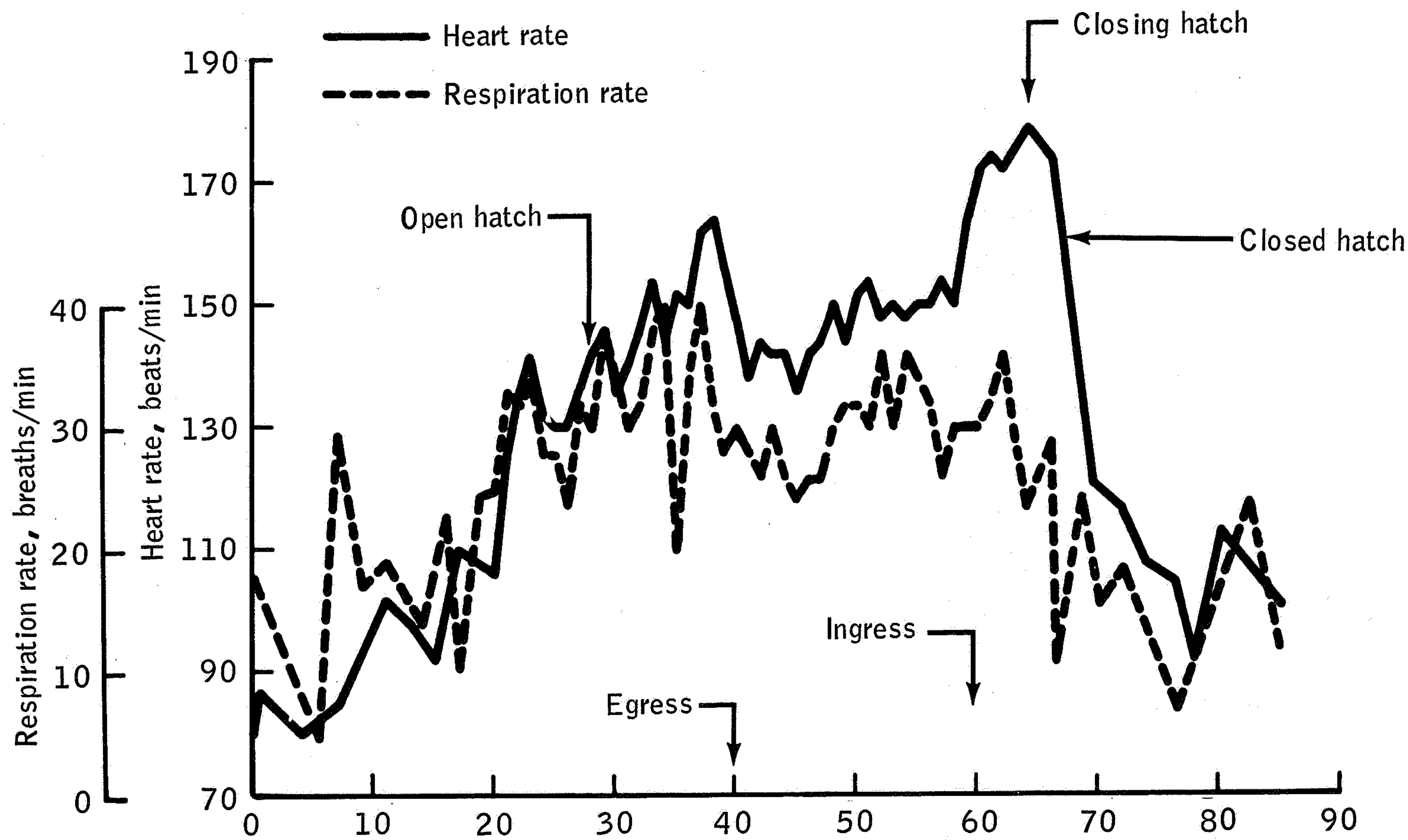

(a) Gemini IV.

Figure 9.1-3. - Umbilical EVA.

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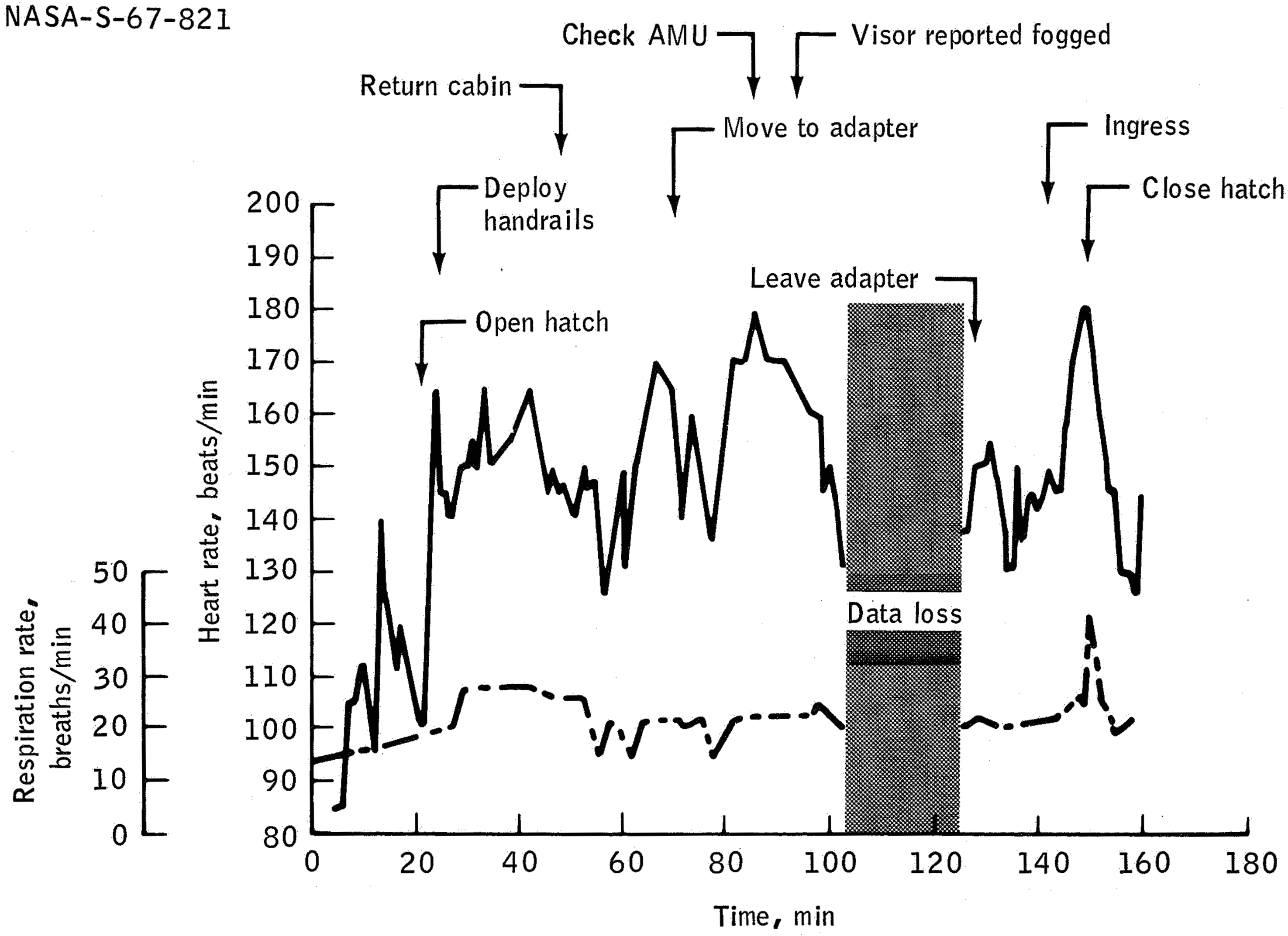

(b) Gemini IX-A.

Figure 9.1-3. - Continued.

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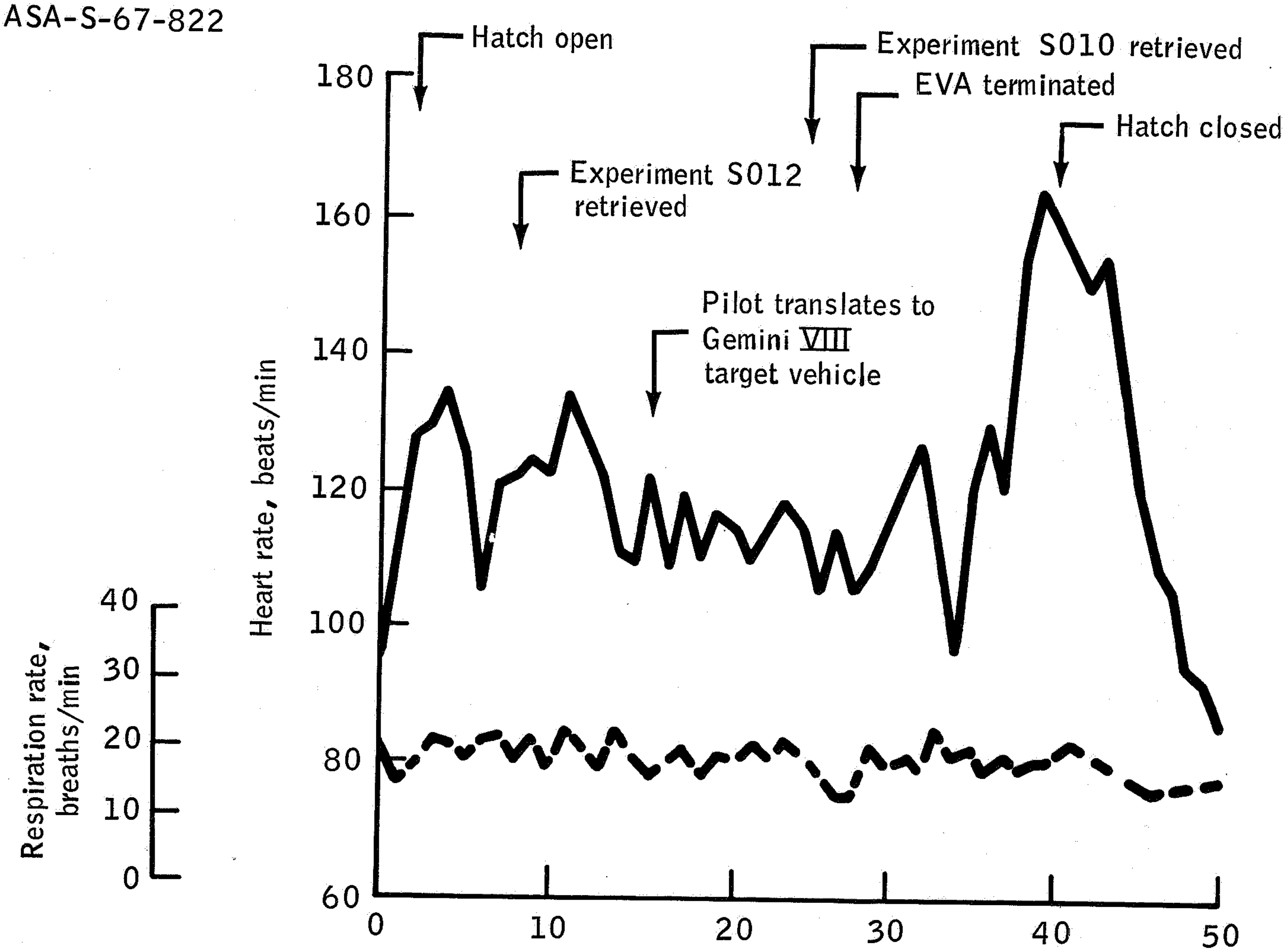

(c) Gemini X.
Figure 9.1-3. - Continued.

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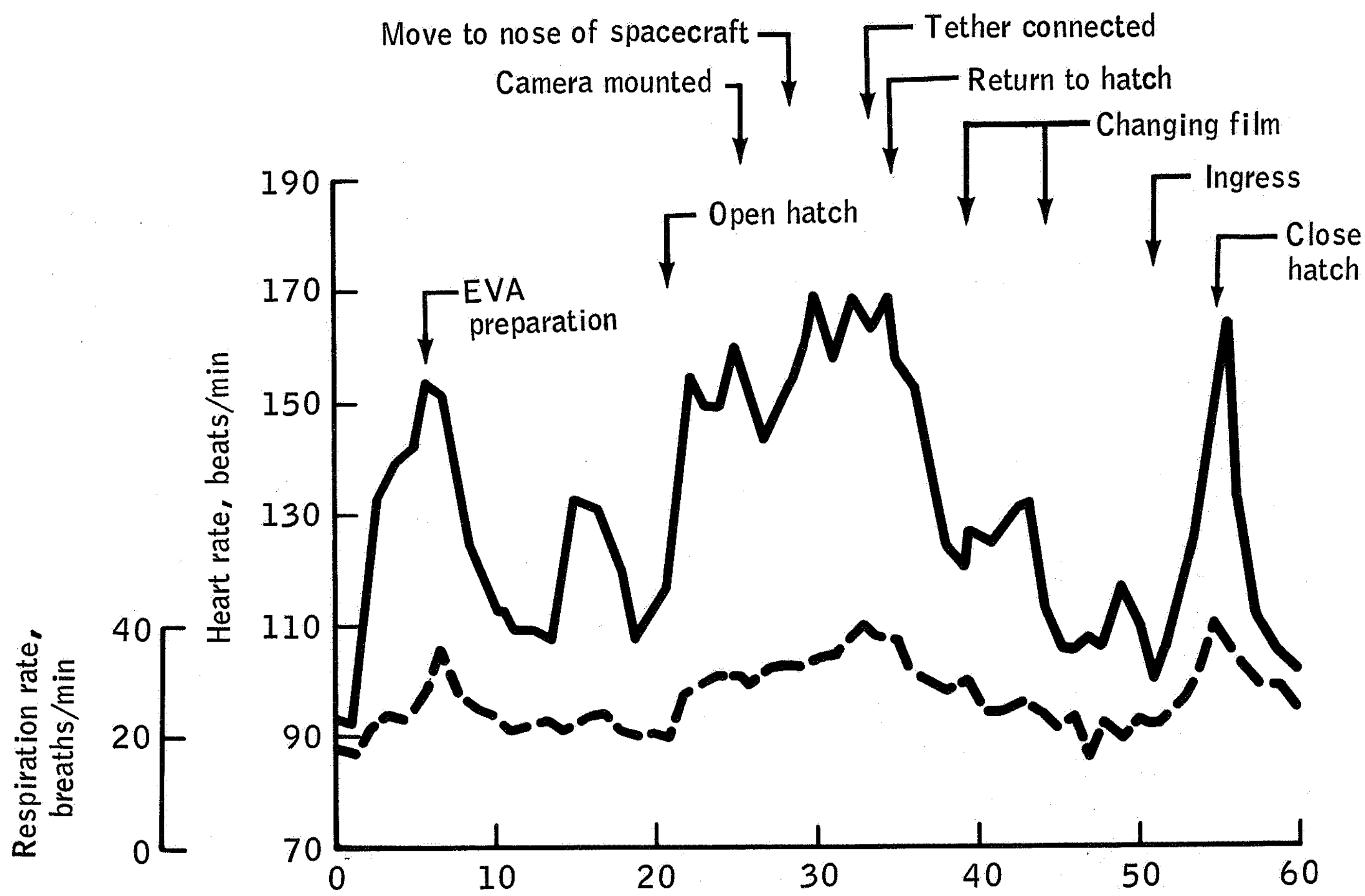

(d) Gemini XI.
Figure 9.1-3. - Continued.

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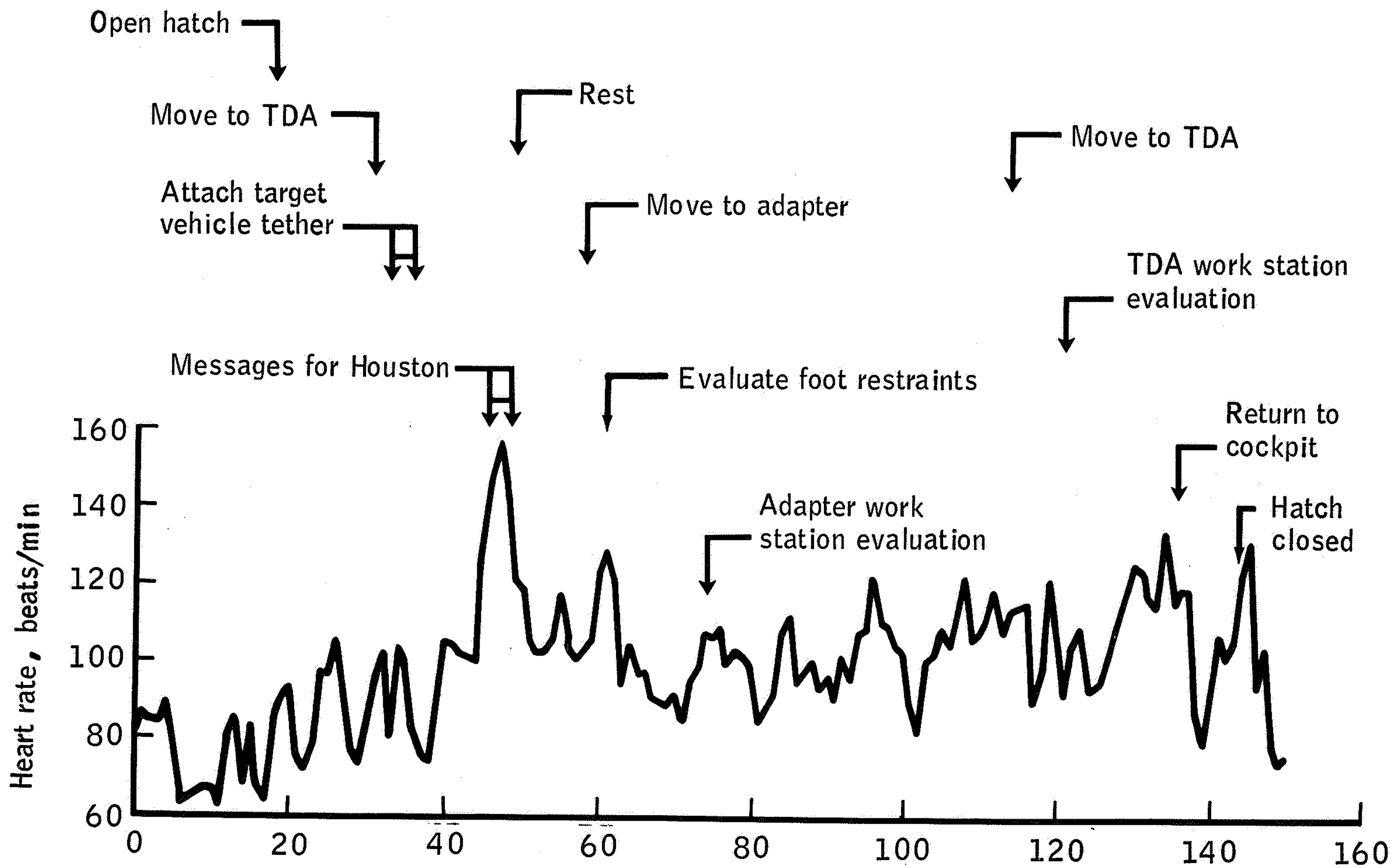

(e) Gemini XII.
Figure 9.1-3. - Concluded.

NASA-S-67-825

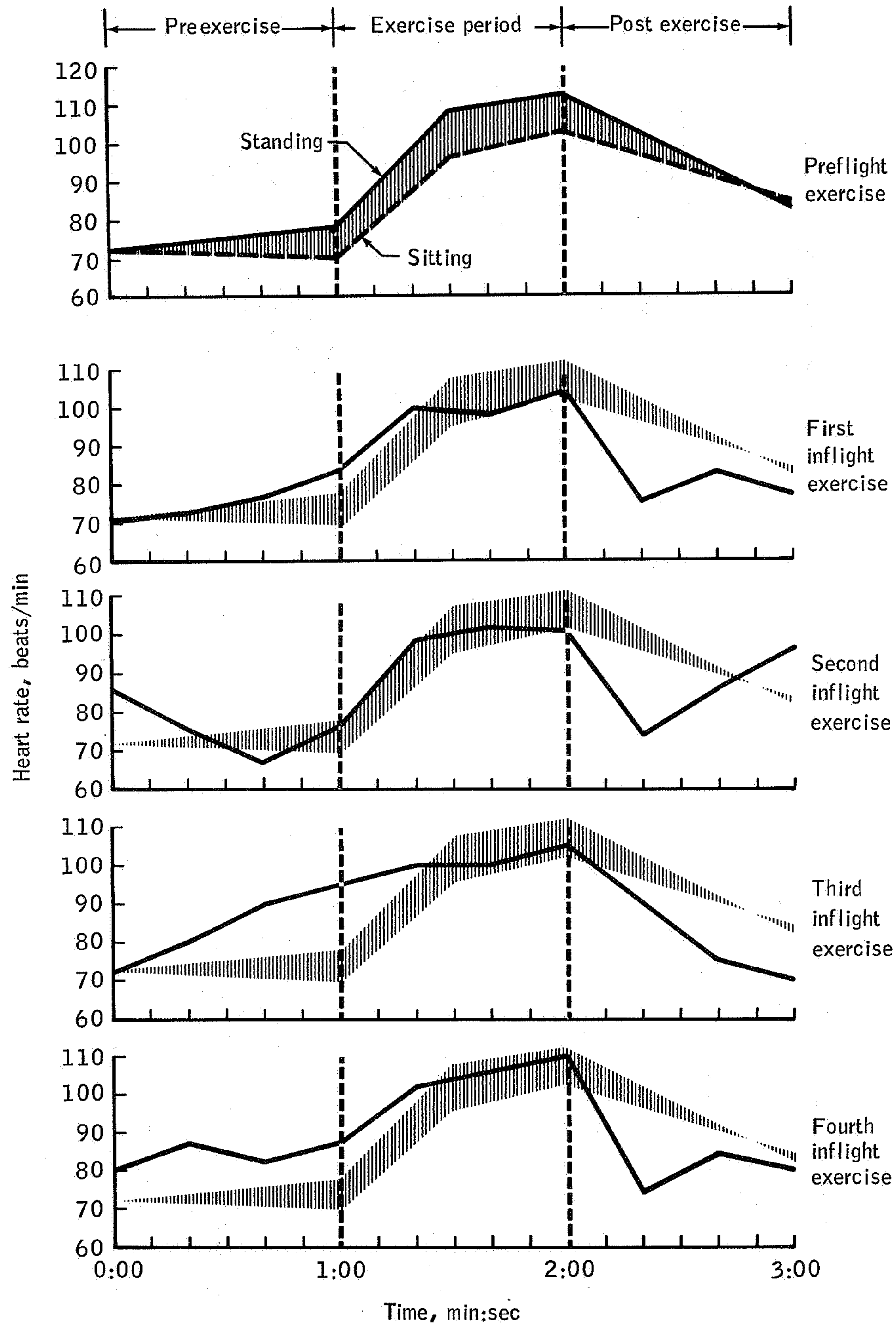

Figure 9.1-4. - Preflight and inflight exercise studies.

9.2 CONCLUDING REMARKS

Medical experience gained as a result of Gemini EVA has provided information which will be valuable in preparing for future EVA missions. There were no indications that the ability of man to do work was significantly altered during EVA. The major factors which produced the highest workload during EVA were engineering design problems which were resolved for Gemini XII. The success of Gemini XII EVA demonstrated that when these factors were understood properly, the medical response to EVA was very close to prediction. Evaluation of physiological factors during EVA in Gemini was limited by the lack of more extensive instrumentation. Much was learned about the physiological responses to EVA from simulations such as sea-level practice exercises and the zero-g underwater simulations. However, without specific knowledge of the thermal and environmental conditions, a complete analysis of the physiological aspects of EVA could not be accomplished. Specific measurements which were lacking were the carbon dioxide concentration, the dew point in the space suit helmet, the space suit inlet and outlet temperatures, and the body temperature. The electrocardiogram and the rate and depth of respiration were useful but only partially effective in assessing total physiological performance during EVA.

The successful completion of the Gemini EVA program indicated that EVA life support system planning had been essentially sound. The success of Gemini XII indicated that within the limitations of our experience, time lines and work levels could be tailored so that flight objectives could be accomplished. There were no medical contraindications to the type of EVA accomplished in the Gemini Program.

10.0 RESULTS AND CONCLUSIONS

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10.0 RESULTS AND CONCLUSIONS

10.1 CAPABILITIES DEMONSTRATED

A number of capabilities were demonstrated during the Gemini missions which met or exceeded the original EVA objectives. The basic feasibility of EVA was established by 11 hatch openings and by more than 12 hours of operation in the environment outside the spacecraft. The Gemini XII mission demonstrated the ability to control the workloads within the limits of the life support system and the capabilities of the EVA pilot. Standup and umbilical extravehicular operations were accomplished during eight separate nighttime periods to confirm the feasibility of night EVA.

The need for handholds for transit over exterior surfaces of the spacecraft was shown, and several types of fixed and portable handholds and handrails were demonstrated to be satisfactory. The capability to perform work tasks of varying complexity was demonstrated. The character of feasible and practical tasks was shown, and some of the factors limiting task complexity and difficulty were identified.

Several methods were demonstrated for crew transfer between two space vehicles: (1) surface transit while docked, (2) free-floating transit between two undocked vehicles in close proximity, (3) self-propulsion between two undocked vehicles, and (4) tether or umbilical pull-in from one undocked vehicle to another. These methods were accomplished with a maximum separation of 15 feet.

The Hand Held Maneuvering Unit (HHMU) was evaluated briefly, but successfully, on two missions. The EVA pilots accomplished maneuvers they attempted with the HHMU without disorientation.

Retrieval of equipment from outside the spacecraft was demonstrated on four missions. In one case, equipment was retrieved from an unstabilized passive target vehicle which had been in orbit for more than 4 months.

During Gemini X, the command pilot was able to maneuver in close proximity to the target vehicle while the pilot was outside the spacecraft. The close formation flying was successfully accomplished by coordinating the thruster firings by the command pilot with the extravehicular maneuvers of the pilot. No damage nor indication of imminent hazard occurred during the operation.

Photography from outside the spacecraft was accomplished on every EVA mission. The most successful photograph activities were the ultraviolet stellar spectral photography, performed during standup EVA on three missions, and the extravehicular sequence photography, taken with the camera mounted outside the spacecraft cabin.

The dynamics of motion on a short tether were evaluated on two missions. The only capability demonstrated with a tether was its use as a distance-limiting device. Return to the spacecraft with the 25-foot umbilical was accomplished on three missions, but in all cases the control was marginal and careful motions were required.

The requirements and the capabilities of foot restraints and waist tethers were demonstrated in considerable detail. The validity of underwater simulation in solving body restraint problems and in assessing workloads was confirmed by inflight results and postflight evaluation.

The basic techniques for productive use of EVA were demonstrated during the Gemini missions. Problem areas were defined to indicate the preferred equipment and procedures for future EVA application.

10.2 PRINCIPAL PROBLEMS AND SOLUTIONS

While most of the Gemini EVA results were successful, several areas of significant limitations were encountered. Space suit mobility restrictions constituted one basic limitation which affected all the mission results. The excellent physical capabilities and condition of the flight crews tended to obscure the fact that moving around in a pressurized space suit was a significant work task. Since the suit design was fixed, the principal solution was to optimize the tasks and the body restraints. For the 2-hour EVA mission, glove mobility restrictions caused hand fatigue in both training and flight situations.

The size and location of the ELSS chestpack was a constant encumbrance to the crews. The design was selected because of space limitations within the spacecraft, and the crews were continually hampered in two-handed operations by the bulk of the chest-mounted system.

The use of gaseous oxygen as the coolant medium in the space suit was a limiting factor both in the rejection of metabolic heat and in pilot comfort. The use of a gaseous system required the evaporation of perspiration as a cooling mechanism. Heavy perspiration and high humidity within the suit occurred on the two missions where the workloads apparently exceeded the planned values. Corrective action involved controlling the workload within the capabilities of the ELSS and the space suit.

Work levels and metabolic rates could not be measured inflight; however, the flight results indicated that the design limits of the ELSS were exceeded. Inflight work levels were controlled by designing tasks so that they could be accomplished readily, by providing additional body restraints, by allowing a generous amount of time for each task, and by establishing planned rest periods between tasks. These steps and the use of underwater simulation techniques enabled the Gemini XII pilot to control his workload within the design limits of the ELSS.

The limitations of the zero-g aircraft simulations and the ground training without weightless simulation were emphasized by the experience of the Gemini XI EVA mission. These media were useful but incomplete in simulating EVA tasks. The use of underwater simulation for both the development of procedures and crew training proved very effective for Gemini XII.

The ease of accomplishing EVA tasks appeared to correlate with the sequence in which they were scheduled. A period of acclimatization to the extravehicular environment appeared desirable. Those pilots who had completed a standup EVA first appeared to be more at ease during the umbilical EVA. It appears that critical EVA tasks should not be scheduled until the pilot has had an opportunity to familiarize himself with the environment.

Equipment retention during EVA was a problem for all items which were not tied down or securely fastened. By the extensive use of equipment lanyards, the loss of equipment was avoided on the last two missions.

Human engineering of foot restraints, handholds, and equipment design caused problems in orbit which were difficult to identify on the ground prior to flight. Extensive one-g simulations, particularly underwater simulations, reduced these problems substantially.

Differences in configuration between the training hardware and the flight hardware caused occasional problems. Although considerable attention was given to maintaining the training hardware in an authentic configuration, the efforts were not always successful. The use of the actual flight hardware in final simulations was the principal method for insuring crew familiarity with the flight configuration.

10.3 CONCLUSIONS

The following conclusions are based on the results of the Gemini EVA:

(1) Extravehicular operation in free space is feasible and can be used for productive tasks, if adequate attention is given to body restraints, task sequence, workload control, realistic simulation, and proper training.

(2) Space suit mobility restrictions constituted a significant limiting factor in the tasks which could be accomplished in Gemini EVA. For future EVA missions in earth orbit, improved mobility in the arms, shoulders, gloves, and waist is highly desirable.

(3) The Hand Held Maneuvering Unit is promising as a transportation device in free space; however, evaluations to date have been too brief to fully define its capabilities or limitations.

(4) The Extravehicular Life Support System for Gemini performed satisfactorily on all missions. The size and the necessity for a chest-mounted location caused some encumbrance to the EVA pilots. The use of gaseous cooling was not optimal for the high workloads which were encountered in some EVA tasks.

(5) Extravehicular umbilicals were useful for EVA in the vicinity of the spacecraft. The use of umbilicals reduced the volume of the life support, communications, and electrical power equipment worn by the EVA pilots. Excess umbilical length was undesirable because of the possibility of entanglement.

(6) Underwater simulation provided a high-fidelity duplication of the EVA environment which was very effective for procedures development and crew training. Strong evidence indicated that tasks which could be readily accomplished in a valid underwater simulation could also be accomplished in orbit.

(7) Undesirable aspects of the Gemini Extravehicular Life Support System qualification test program were the lack of detailed component level tests, the lack of off-nominal manned tests following representative mission profiles and emergency conditions, and the split responsibility between the government and the life support system contractor.

(8) Vacuum chamber tests with the prime and backup EVA pilots using their flight space suits and extravehicular life support equipment contributed significantly to the readiness of the crews to perform EVA in orbit. These tests provided end-to-end verification and increased confidence in the EVA systems.

(9) The environmental qualification of the ELSS with the oxygen tank empty led to operational difficulties when an emergency spacecraft reentry was made with the tank fully serviced. Qualification testing in a nonoperational configuration was undesirable.

(10) The use of flight configuration hardware is essential for effective crew training for EVA. Special effort is required to control the configuration of EVA training hardware.

(11) Loose equipment must be tied down at all times during extravehicular activity to avoid loss.

(12) The type of body restraints used in Gemini XII EVA was suitable for in-orbit use.

(13) The Gemini Program provided a foundation of technical and operational knowledge on which to base the planning for extravehicular activity in subsequent programs.

11.0 RECOMMENDATIONS

NASA Manned Spacecraft Center Staff

11.0 RECOMMENDATIONS

(1) EVA should be considered for future missions where a specific need exists, and where the activity cannot be accomplished by any other practical means. Since EVA involves some increased hazard, it should not be conducted merely for the purpose of doing EVA.

(2) In future EVA missions, consideration should be given to body restraints, proper task sequence, workload control, realistic simulation, and proper training.

(3) Underwater simulation should be used for EVA procedures development and crew training in conjunction with zero-g aircraft simulations and ground simulations.

(4) The Hand Held Maneuvering Unit should be evaluated further in orbital flight with emphasis on stability and control capabilities. Other maneuvering systems which incorporate stabilization systems should be evaluated for comparison.

(5) Priority efforts should be given to improving the mobility of space suits with emphasis on arm, shoulder, and glove mobility.

(6) In future Extravehicular Life Support Systems, consideration should be given to cooling systems with greater heat removal capacity than the gaseous cooling systems used in the Gemini Program. The bulk and encumbrance of sizable chest-mounted units should be avoided. Any life support system should be capable of supporting the anticipated peak workloads.

(7) Qualification test programs for future EVA life support systems should include detailed component testing; should be conducted in a flight-serviced configuration, whenever appropriate; should include manned testing on representative off-nominal mission profiles; and should require that the contractor take the lead in all qualification testing of his equipment.

(8) Vacuum chamber tests should be included in the preparations for future EVA missions. Both the prime and backup crews should participate in these tests using EVA flight hardware.

(9) Detailed EVA flight plans and crew procedures should be established as early in the hardware development cycle as possible, so that the impact of design or procedures changes can be evaluated.

(10) Training programs for further EVA missions should include a configuration control procedure to insure that the training hardware is maintained in representative flight configuration.

(11) Planning for future EVA missions should include consideration of the Gemini EVA experience and results.

12.0 REFERENCES

12.0 REFERENCES

1. Copeland, R. J.; Lipnicky, E. G.; and Goodnight, F. H.: Unmanned Thermal Performance Evaluation of a Gemini Extravehicular Space Suit. Vol. 1 and 2, Report Number 00.683 (NAS 9-3414) submitted by Astronautics Division, LTV Aerospace Corp., July 15, 1965.

2. Baker, M. E.; Goodnight, F. H.; and Jordan, W. D.: An Investigation of Modular Maneuvering Exhaust Plume Heating of the Gemini Extravehicular Suit. Report Number 335.12 (AF04(695)-592) submitted by Astronautics Division, LTV Aerospace Corp., Nov. 25, 1964.

3. Jordan, W. D.; and Rogers, D. C.: Design Studies of Exhaust Plume Heating on the Extravehicular Coverall for the MMU Mission. Report Number 335.44 (AF04(695)-592) submitted by Astronautics Division, LTV Aerospace Corp., Aug. 23, 1965.

4. Jordan, W. D.; and Ward, T. L.: Final Report on Exhaust Plume Heating Qualification Test of the Gemini/MMU Extravehicular Coverall and Upper Forward Nozzle Extension. Report Number 335.52 (AF04(695)-592) submitted by Astronautics Division, LTV Aerospace Corp., Oct. 29, 1965.

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