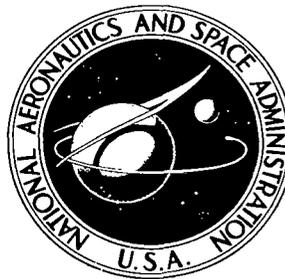


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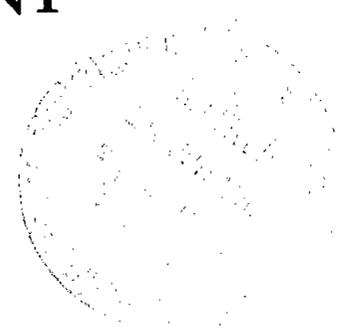
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MANNED OPERATIONS FOR THE APOLLO LUNAR MODULE IN A SIMULATED SPACE ENVIRONMENT

by O. L. Pearson and P. R. Gauthier

Manned Spacecraft Center

Houston, Texas 77058





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16. ABSTRACT A series of tests was conducted in a simulated space environment to confirm the satisfactory performance of the Apollo lunar module in a thermal-vacuum environment and to verify crew operating procedures in a thermal-vacuum environment. Because of mission simulation requirements, the spacecraft was manned only during specific time periods of the test. The crewmen were required to perform ingress/egress while in thermal-vacuum conditions. The ingress/egress sequences were based on sequential transfer of the test crewmen from the chamber manlock to the chamber and then into the spacecraft by a stairway which was 13.5 feet high and at an angle of 63° with the horizontal. To perform the ingress/egress sequences safely, the following systems and equipment were developed and qualified: specialized gas-connector assemblies, restraint assemblies, gas and electrical umbilicals, and an open-loop environmental control system. The lunar module test article program presented the first large-scale test of the practical application of the extensive safety practices that were adopted by the National Aeronautics and Space Administration. The tests were successfully completed without compromising safety or delaying the planned Apollo launch schedule.		13. REPORT TYPE AND PERIOD COVERED Technical Note	
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MANNED OPERATIONS FOR THE APOLLO LUNAR MODULE IN A SIMULATED SPACE ENVIRONMENT

By O. L. Pearson and P. R. Gauthier*
Manned Spacecraft Center

SUMMARY

To simulate the flight conditions during ground thermal-vacuum testing of the Apollo lunar module, the crewmen were required to enter and leave the lunar module while the vehicle was in vacuum conditions. These ingress/egress sequences represented the first time that men in space suits transferred from one set of umbilicals to another set while in vacuum conditions. The ease with which these critical transfers were made was achieved only through rigorous equipment qualification, extensive training exercises, and detailed test procedures. The planning, preparation, review, and specialized techniques which were required to meet the objectives of this test program are described in this report.

INTRODUCTION

The objective of the NASA Apollo Program is to land men on the lunar surface and to return them safely to earth. The lunar-landing spacecraft must operate satisfactorily, with a crew of two astronauts, in space and on the lunar surface. Because extreme thermal conditions are encountered on such a mission, it was necessary to ascertain whether the lunar module (LM) would perform adequately during the thermal extremes. To confirm spacecraft performance in the thermal-vacuum (TV) environment and to verify the man/machine relationship and crew operating procedures, a series of tests was conducted by the Space Environment Test Division (SETD) at the NASA Manned Spacecraft Center (MSC) in Houston, Texas.

Each LM was not tested in the TV environment, but design-verification tests were conducted on a representative spacecraft which was manufactured and checked in the same manner as the flight spacecraft. To simulate the mission time lines, it was necessary to follow the planned flight time lines and to establish a thermal similarity. The two crewmen were introduced when these prerequisites were met. The test crewmen entered the spacecraft cabin under TV conditions and activated the vehicle systems in much the same manner as was planned for flight. After approximately 12 hours, the

*The Boeing Company, Houston, Texas.

crewmembers deenergized the vehicle and egressed the chamber while the spacecraft was maintained at TV conditions. This ingress/egress (I/E) was accomplished several times during various simulated mission conditions.

A special test vehicle, designated LM test article 8 (LTA-8), was constructed by the spacecraft prime contractor. This vehicle was configured according to the first manned-flight LM, except that special safety items, supplemental instrumentation, and hardware required to simulate varying thermal loads were added. The tests were conducted in the MSC Space Environment Simulation Laboratory (SESL) chamber B.

These tests satisfied the requirements for the LTA-8 and were the first tests of their kind in the following three categories:

1. First crew transfer from one set of umbilicals to another set while at TV conditions
2. First TV test of a complete, manned LM
3. First test at the MSC of a manned spacecraft in the TV environment, subsequent to the revised NASA safety criteria

The magnitude of the activities that are described in this report is demonstrated by the participation of more than 600 personnel of several major MSC and contractor organizations. The purpose of this report is to convey a discussion of the planning, preparation, review, and specialized techniques which were required to meet the objectives of the TV test program. Primary emphasis is placed on hardware, procedures, and training that affect crew safety. The tests are discussed only in terms that are related to manned activity and technical details of vehicle performance are not included.

A list of the acronyms used in this document is given in appendix A.

FACILITY DESCRIPTION

Chamber B is a 35-foot-diameter stainless steel vessel that has an overall height of 43 feet. The chamber can accommodate a vehicle that has a maximum diameter of 13 feet and a maximum length of 27 feet. Access to the chamber for large test articles is by a removable top head. Two rolling bridge cranes, each of which has a capacity of 50 tons, are available to remove the chamber head and to insert test articles into the chamber.

Chamber B supports a spacecraft weight of 75 000 pounds on a fixed lunar-plane (chamber floor) 20 feet in diameter. The lunar-plane temperature may be varied between 100° and 400° K. The test volume is shielded from the chamber walls by liquid-nitrogen panels.

One double manlock is located at the lunar-plane level. Chamber penetrations for utility servicing of the spacecraft are located at the ground level. Instrumentation penetrations primarily are through the lunar plane. The chamber can be pumped

(while clean, dry, and empty) to a pressure of 5×10^{-7} torr or less in 10 hours. The vacuum level that was achieved with the spacecraft in the chamber for this test series was 1×10^{-5} torr or less. Further details of the facility capabilities are given in references 1 to 3.

LUNAR MODULE TEST ARTICLE 8 DESCRIPTION

The LTA-8 was a production flight-configuration vehicle, but certain modifications were made to accommodate the test. Hypergolic fluids were replaced with trichlorotrifluoroethane solvent, and spent squibs (pyrotechnic initiators) were used instead of live squibs. For added safety during the initial manned tests, an additional television camera was placed in the cabin to monitor crew activities. Lights were added in the LTA-8 cabin to increase visibility during I/E activities. Water hoses for fire suppression inside the cabin were connected to the facility water supply rather than to the flight-configuration water supply. Thus, an unlimited water supply was provided for emergencies. For extended test operations, facility oxygen piping was connected to the LM and the piping could be activated from outside the chamber. Sling seats were added for crew comfort in the one-g environment.

Basically, the subsystems were operable production units to support the specific requirements of the tests. Instrumentation (in addition to the instrumentation used on flight spacecraft) was installed to determine the vehicle responses during TV testing. Because thermal inputs to LTA-8 were required to simulate solar radiation and engine heat, heater ribbons were attached to the vehicle skin, the engine, and the heat shield in the vicinity of the engine.

To decouple the LTA-8 thermally from the chamber, guard heaters were installed at all service lines between the vehicle and the chamber structure. Further details of the vehicle heaters are given in reference 4.

THERMAL-VACUUM INGRESS/EGRESS

To simulate the planned mission as much as possible, it was necessary to devise a method for spacecraft I/E while the chamber containing the spacecraft was maintained at TV conditions. To conform to these conditions, ingress into chamber B was accomplished by the crewmen entering the manlock at ambient pressure, after which the manlock and chamber pressure were equalized in order for the crewmen to enter the chamber. To reach the vehicle hatch for entry into the spacecraft, the crewmen were required to climb a stairway which was 13.5 feet high and was at an angle of 63° with the horizontal. A layout of the LTA-8 test area is shown in figure 1.

The simplest method for accomplishing I/E would have been for each crewman to have a self-contained environmental control system (ECS). In trials on a mockup, the portable life support system (PLSS), which was to be used later on lunar expeditions, proved to be too heavy in a one-g environment for the crewmen to maneuver for vehicle ingress. In addition, the laboratory biomedical monitoring requirements exceeded the

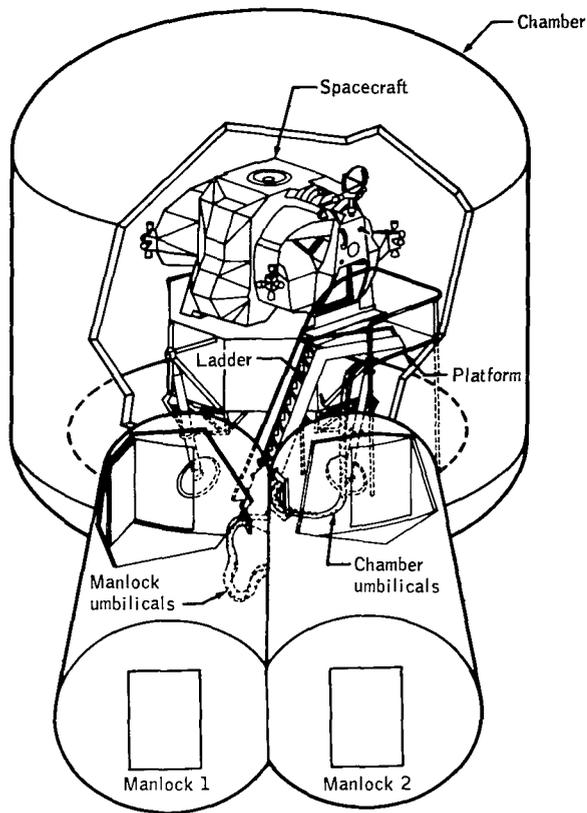


Figure 1. - Layout of test area.

PLSS telemetry transmission capabilities. Development of a special lightweight unit for chamber use did not seem feasible within the time available. Therefore, it was determined that umbilicals would furnish life support and communications for these tests. Three sets of umbilicals were used for each test crewman. One set was used in the manlock; one set was used in the chamber; and one set was used in the spacecraft cabin. Each set was composed of three umbilicals: gas supply, gas return, and electrical.

To close the vehicle hatch upon ingress and to close the manlock door upon egress, a unique problem was presented: how the crewmen could transfer safely from one set of umbilicals to another set at vacuum conditions. A particular hazard considered was that if a suit gas-connector check valve failed to close at umbilical disconnect, the suit would be dumped to vacuum conditions. This potential hazard was avoided by adding an in-line manual valve at each connection (fig. 2). Each suit was equipped with a supply connector and a return-gas umbilical connector on both the right and the left sides.

Another potential hazard was that a crewman might fall while climbing to the top of the platform. This hazard was avoided by the addition of restraint assemblies for each crewman. While standing on the ladder, each crewman was tethered to two cam-operated restraint assemblies. Each restraint assembly was attached to a rod on each side of the ladder. The crewmen were required to lift the handles of the restraint assemblies to slide the assemblies up or down the rods. Should a crewman lose his footing or become incapacitated while standing on the ladder, the toothed cam would engage the rod and prevent the crewman from falling beyond the length of the tethers.

Because both crewmen ingress and egress together, it was easier for one crewman to perform the actions necessary to transfer the umbilicals of the other crewman. The following is a summary of the ingress sequence of events.

1. The crewmen enter the manlock and are connected to the umbilicals while at ambient pressure.
2. The air in the manlock is evacuated and the manlock pressure is equalized with the chamber pressure.

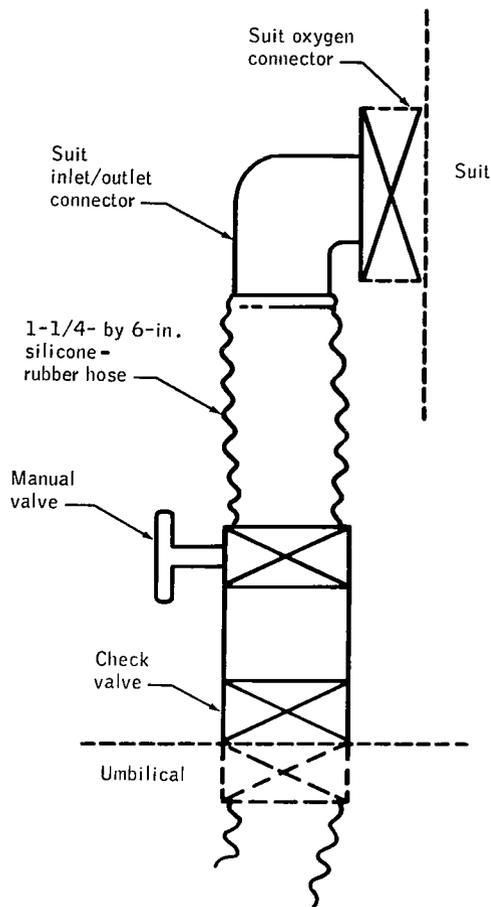


Figure 2. - Ventilation umbilical connector system.

3. The manlock door is opened to the chamber.
4. The crewmen transfer to chamber umbilicals.
5. The crewmen attach the restraint assemblies and climb the ladder to the platform.
6. The crewmen detach the restraint assemblies and pull the slack in the umbilicals up on the platform.
7. The crewmen enter the spacecraft.
8. The crewmen transfer to the spacecraft umbilicals.
9. The crewmen stow the chamber umbilicals on the platform and close the cabin hatch.

The time that was required for the crew ingress sequence, the ECS and manlock operations, and the crew rest periods was 1-1/2 to 2 hours. Egress was performed in reverse sequence and required approximately half the time (because the manlock could be repressurized much faster than it could be pumped down).

THE MSC SAFETY MANUAL

Minimum safety criteria for manned ground testing either at total oxygen pressures less than 14.7 psia or at partial oxygen pressures greater than 3.1 psia were incorporated into the MSC Safety Manual in May 1967. The chamber in which the LTA-8 tests were conducted conformed to all requirements of the safety manual. These requirements are summarized in appendix B.

DETAILED TEST PROCEDURES

All test operations in the laboratory were conducted according to detailed step-by-step procedures. Critical system procedures were accomplished under

quality-control surveillance. Provisions were made to revise the procedures if necessary. The detailed step-by-step actions to be taken in the event of credible emergencies were preplanned, approved, verified, and practiced during simulated emergencies.

A specific document was prepared which contained test rules for each series of tests. The purpose of the test rules was to provide preplanned actions to be accomplished in the event of off-normal conditions arising during the tests. The order of priority upon which the rules were based was (1) personnel safety and (2) prevention of damage to equipment.

The test procedures were subjected to a comprehensive review and approval cycle as specified in the MSC Safety Manual. All test procedures were distributed to test-team personnel at least 5 days before the test, unless specifically waived by MSC management.

In addition to the normal supervisory review and approval cycle, investigative and review groups monitored the test activities prior to vehicle arrival at the MSC through post-test operations. These review groups are described in appendix C.

SAFETY SYSTEMS

The chamber emergency repressurization (ER) system allowed chamber B to be pressurized with dry stored gas (approximately 22 percent oxygen and 78 percent nitrogen) to 6 psia in 30 seconds. Then, the chamber could be repressurized to a 14.7-psia environment in an additional 60 seconds (or longer, if desired) by using the dry stored gas again. Ambient air was not used because moisture would condense upon contact with the cold walls and would seriously impair visibility. The system could be activated manually either by the test director or the medical officer. If suit pressure should drop to 2 ± 0.1 psia, the system would be activated automatically.

A manually operated water fire-suppression system was installed. The system consisted of four zones: the chamber test volume, the portion of the chamber below the test volume, manlock 1, and manlock 2. Each zone could be operated independently. A diagram of the fire-suppression system is shown in figure 3. The system could deliver 450 gal/min on the spacecraft or 30 gal/min in either manlock. The piping was heated and kept dry so that the water would not freeze if the fire-suppression system were activated. The plan was to activate the system only at 6 psia or greater. During TV tests, the test director was responsible for activation of the system. During ambient periods, the spacecraft contractor was responsible for system activation.

An interlock system was installed to interlock the operation of safety-critical power sources if an emergency occurred. The interlock is operated in one of three emergency modes: the fire mode, the ER mode, or the power failure mode. The test director activates the fire mode by operating the interlock switch or the fire-suppression switch. Initiation of the ER system automatically activates the proper

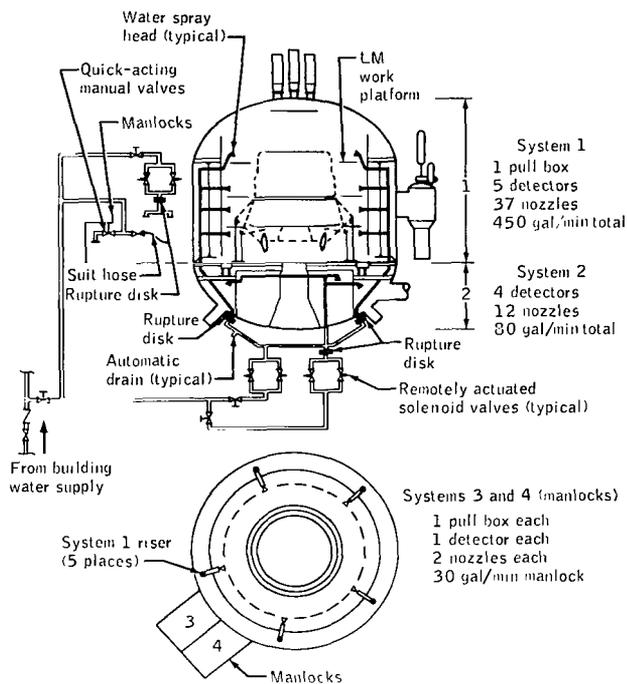


Figure 3. - Fire-suppression system.

sequences of the ER mode of the interlock system. The power-failure mode is activated automatically by the loss of prime laboratory power. Table I shows the capability of the interlock system.

In the event of facility power-supply failure, an emergency power system automatically supplies electrical power to equipment and lighting that are essential for personnel safety. The system consists of an emergency power generator driven by a natural-gas engine which is equipped with a battery-powered starter and with an automatic load transfer device. During facility operation, the emergency power system runs unloaded at idling speed. Within 3 seconds after power failure, the emergency power system accelerates and picks up the emergency power load to which the system has been connected by an automatic transfer switch. The emergency load consists of the medical officer console, the ECS, the chamber and manlock lighting, and general area

TABLE I. - INTERLOCK SYSTEM

Power	Mode and action taken by interlock		
	Fire mode	ER mode	Laboratory-power-failure mode
Vehicle skin heater power	Deactivated	Deactivated	Interlocks power off when facility power restored
Vehicle ground power	Deactivated	No action	Interlocks power off when facility power restored
Vehicle battery power	Deactivated	No action	Provides capability to remove battery power manually from outside the chamber
Vehicle supplemental instrumentation stimuli power	Deactivated	No action	No action
Airborne instrumentation ground power	Deactivated	On emergency power; remains on	On emergency power; remains on
Ground-support-equipment cabin-light power	Activated from emergency power	Activated from emergency power	Activated from emergency power
Facility ECS-to-spacecraft valve power	Both crewmen are switched to flow from facility ECS	Both crewmen are switched to flow from facility ECS	Both crewmen are switched to flow from facility ECS

lighting. Frequency is regulated by an adjustable governor on the engine. The governor maintains a frequency constant of 60 ± 0.5 hertz for any constant load between one-fourth and full generator rating.

ENVIRONMENTAL CONTROL SYSTEM

Because the mission requirements necessitated hard-vacuum crew I/E, a facility ECS was installed to support the crewmen as they progressed from the manlock to the chamber and from the chamber to the spacecraft. Primarily, the system consisted of three modules and a flow distribution panel. The overall requirements for the ECS are summarized as follows.

1. To provide 0 to 1.25 lb/min of oxygen to each suited crewman at suit pressures of 3.7 to 18.4 psia while a suit gas-inlet temperature of $50^{\circ} \pm 5^{\circ}$ F is maintained
2. To provide oxygen flow-distribution control for umbilical transfer sequences
3. To provide redundant life-support capabilities in the event of facility or spacecraft ECS malfunctions
4. To provide safety features to prevent overpressure or underpressure of the space suit during all normal and emergency operating modes
5. To provide warm-gas flow to unused gas umbilicals while the umbilicals are exposed to TV conditions
6. To provide a means for pressurizing the suit to 18.4 psia with air for crew-training exercises

The manner by which these objectives were incorporated into the ECS design is discussed in the following sections.

Environmental Control System Module

Three identical open-loop ECS modules (one for each crewman, plus a backup unit) were fabricated and installed. The ECS module and ECS schematics are shown in figures 4 and 5, respectively. One ECS module is illustrated in figure 6. The ECS module is supplied with 100 psig oxygen from the facility oxygen tube trailer. The oxygen is filtered to a 10-micron level and then is reduced to a 35-psig level at the suit-supply flowmeter. Suit pressure can be maintained in one of the three following ways.

1. Differential pressure control, 0 to 1 psia greater than manlock, chamber, or spacecraft pressure
2. Absolute pressure control, 0 to 15 psia
3. Manual control as desired, normally up to 18.4 psia

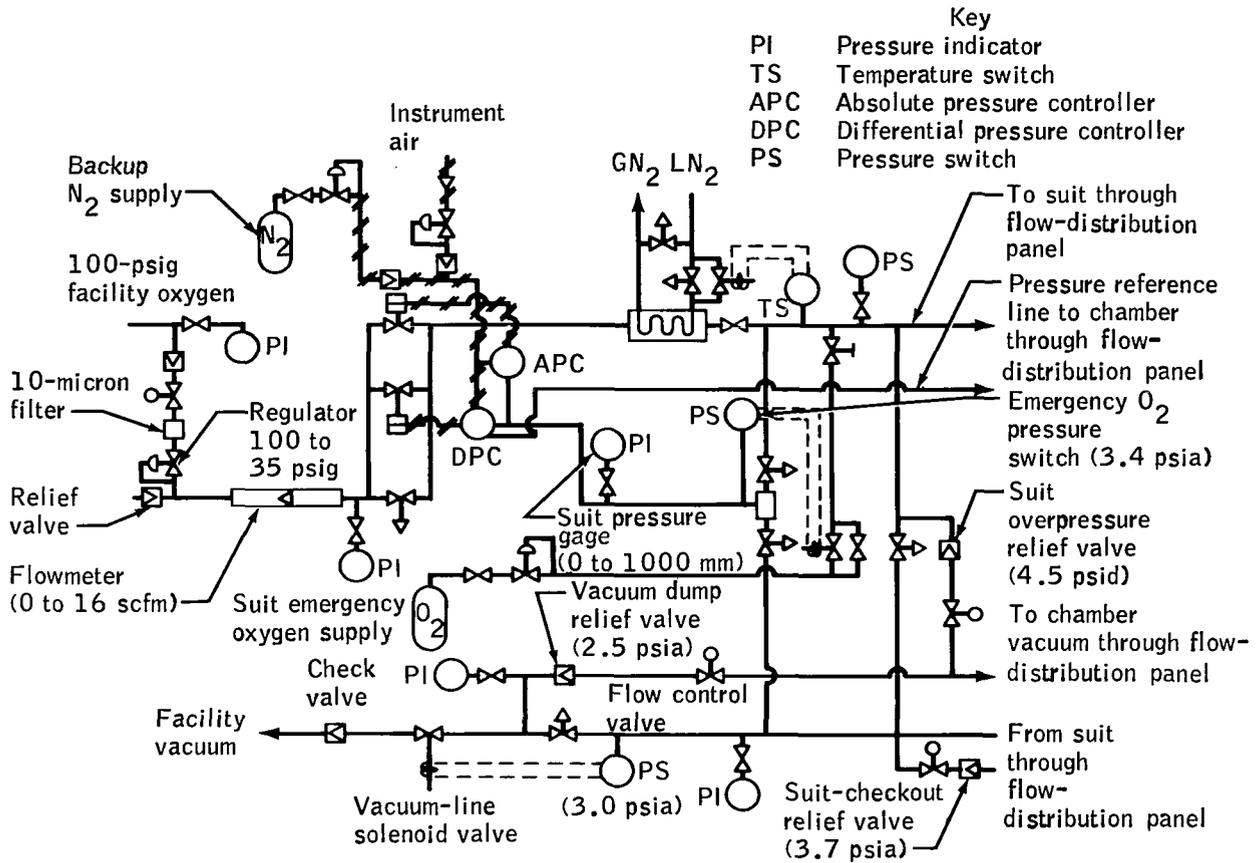


Figure 4. - A schematic of the environmental control system module.

The controllers are basically referenced to an equivalent suit pressure generated by adjusting two small needle valves on the supply-and-return-line pressure taps so that the suit pressure remains within ± 0.04 psia of the controller settings under all normal operating conditions. These valves were calibrated during unmanned tests and were locked in position after the unmanned tests.

The oxygen (or air for crew training) travels through the flow-distribution system to and from the suit. Flow control is maintained by a globe valve on the return line, and the oxygen is discharged to the facility ECS vacuum-pumping system.

The ECS module includes the following additional components.

1. The suit overpressure relief valve, set at 4.5 psid
2. The suit emergency oxygen supply, 0.62 lb/min, which is initiated at a suit pressure of 3.4 psia

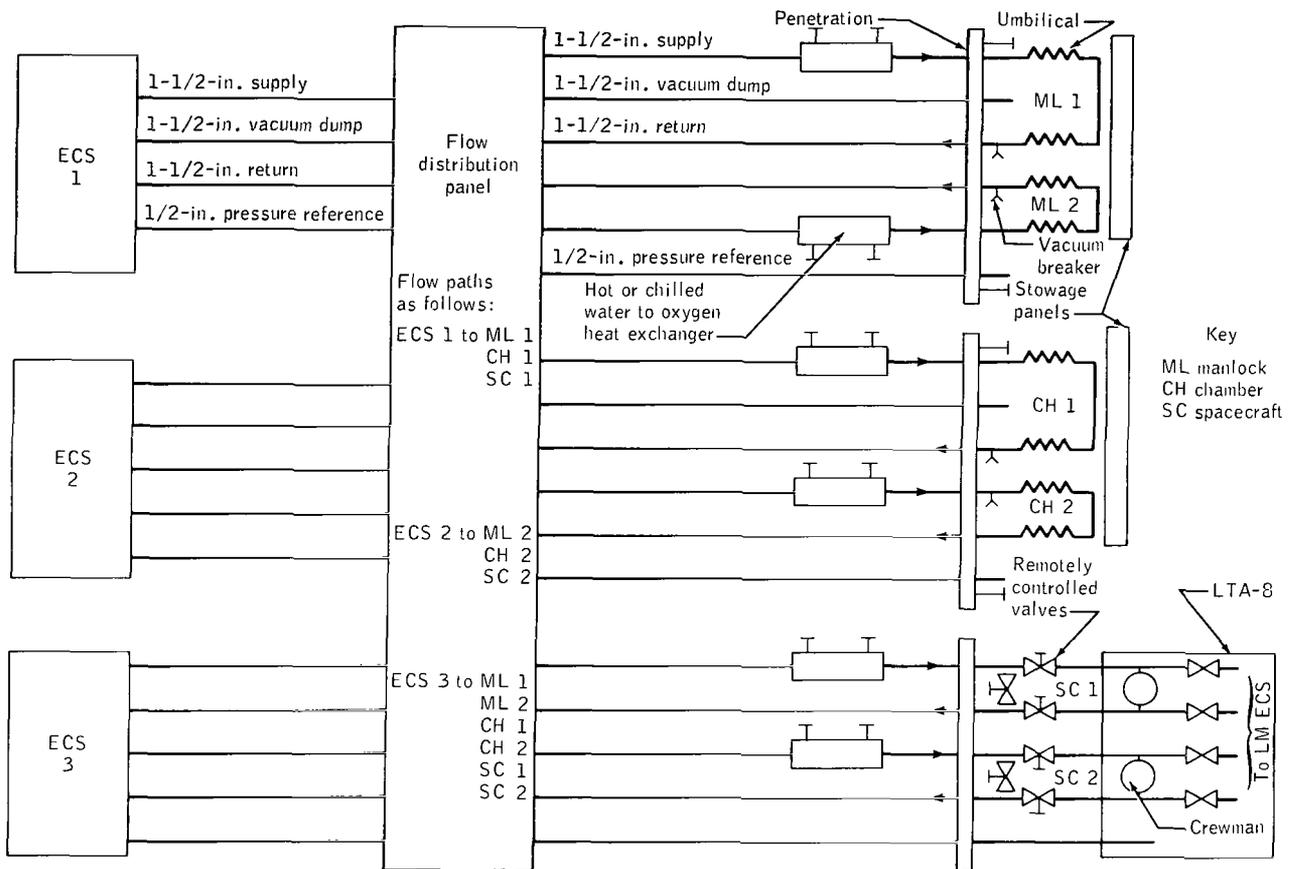


Figure 5. - A schematic of the environmental control system.

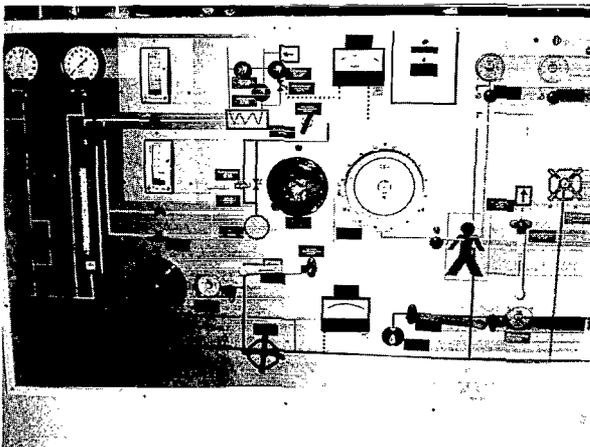


Figure 6. - The environmental control system module.

3. The vacuum-line solenoid valve, set to prevent the suit pressure from becoming less than 3.0 psia
4. The vacuum dump relief valve, set to maintain 2.5 psid downstream of the flow control valve (used only if the vacuum-pumping system failed)
5. The suit-checkout relief valve, used to exhaust air to the atmosphere during 18.4-psia suit-pressure mode (crew training)
6. The oxygen manual pressure-control valve which provides a means of controlling suit pressure in case of controller open failure

7. The backup nitrogen supply for the pressure controllers
8. Electrical power from the facility emergency power bus

All components of the ECS module are fail-safe; that is, the position of a component after a failure will not endanger the crewman. The seals and O-rings that were used in the construction of each component were certified to be oxygen-compatible. Cleanliness of the modules was maintained to a high oxygen-compatibility level during fabrication.

Environmental Control System Qualification

The qualification of the open-loop ECS to support the LTA-8 program was performed in three separate phases. Initially, a thorough shakedown was done and an informal test period was held to identify and solve any operational problem encountered with the system prior to starting the formal qualification program. Nitrogen gas was used in the system during this initial phase of testing.

The formal oxygen-qualification program was based on a detailed test procedure that exercised the ECS modules and flow-distribution system in all normal, emergency, and failure modes. Once the ECS had been qualified in an unmanned configuration, two manlock tests were done to verify both umbilical and backup-module transfer procedures and to demonstrate that the ECS was man-rated. Because this test was manned, the safety and procedural considerations required for the LTA-8 tests were also required for the manlock tests. The manlock tests were successful in verifying that the addition of a suited man to the system did not require operational changes from the unmanned configuration.

Thermal Qualification

After completion of the manlock tests, one major category of qualification was not verified until the start of spacecraft testing. This category was the capability of the system to provide the required temperature control for space-suit-inlet temperatures and to maintain the chamber umbilicals in a relatively warm condition. The umbilical configuration is shown in figure 7. During the unmanned part of the LTA-8 man-rating test, a detailed test of the ECS thermal capabilities was conducted. Various combinations of system pressures and inlet temperatures were set while gas-stream and umbilical-surface temperatures were measured. The results of the tests are given as follows.

1. The effectiveness and control of gas-stream and umbilical-surface temperatures were more dependent on ECS total pressure and flow rate than on gas-inlet temperature. At an operating pressure of 5.4 psia, temperature could be controlled easily; but at 3.7 psia, the ECS operated at the low-temperature limit (50° F).

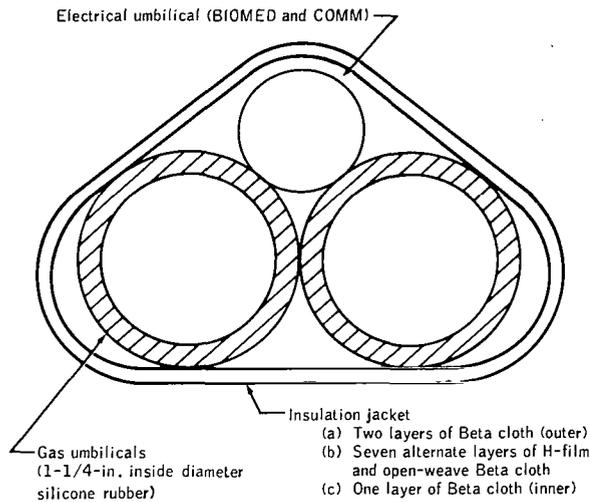


Figure 7. - The umbilical configuration.

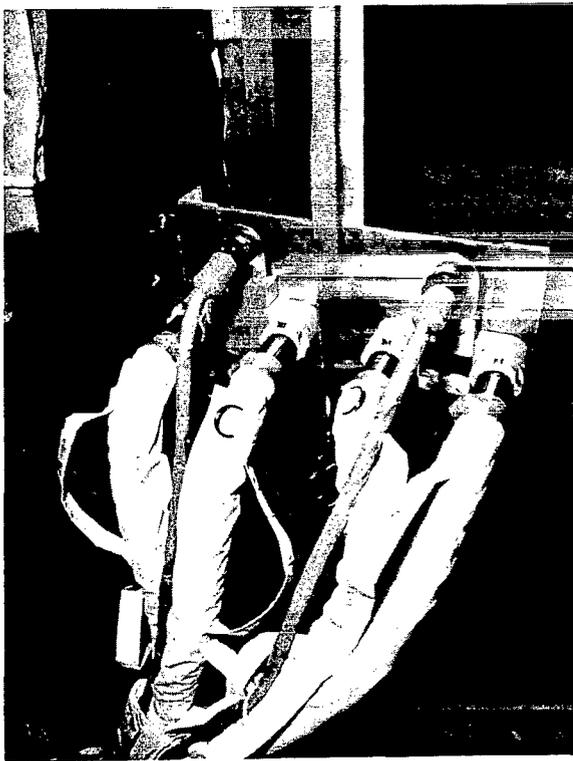


Figure 8. - The chamber umbilical-stowage panel with ECS interconnects.

2. Heaters were required on the interconnects on the chamber umbilical-stowage panel to prevent the interconnect temperature from dropping to less than 30° F. This panel is shown in figure 8.

3. Loss of flow to an insulated silicone-rubber umbilical resulted in a rapid temperature drop (40° to 50° F/hr), which emphasized the need for maintaining warm-gas flow in the umbilicals at all times.

4. The stainless steel facility ECS oxygen lines to the spacecraft were much less sensitive to changes in pressure, flow, and inlet temperature than were the insulated silicone-rubber umbilicals.

The test of the ECS thermal capabilities was successful in verifying that the facility ECS was capable of maintaining the chamber and spacecraft oxygen lines within the desired operating range of 50° to 90° F. The test data also identified the required settings for pressure, flow, the heat exchanger, and the stowage panel heater for each operational mode. These data were then used to define the procedural steps required to establish the proper ECS configurations. In general, gas-inlet temperatures (measured at the chamber penetration) were in the range of 80° to 115° F so that a 50° F suit-inlet temperature was achieved during chamber TV conditions.

Environmental Control System Operation

The umbilical transfer sequences required a high degree of coordination between test crewmen and ECS operators because of the extensive valve sequencing required to ensure that the transfer was made with little change in suit pressure or flow. Detailed procedures verified by several I/E training runs were the means by which these sequences were perfected. During the manned tests, all transfers were made smoothly and safely.

SPECIAL CREW-EQUIPMENT QUALIFICATION TESTS

Ventilation Umbilical Connector System and ECS Interconnect

The environmental control system interconnect (ECSIN) and the ventilation umbilical connector system (VUCS) are shown in figures 8 and 9, respectively. The following tests were conducted on a representative ECSIN and VUCS.



Figure 9. - A crewman wearing the VUCS.

1. Design-limit cycling, 1000 mission cycles, each at 4 psid

2. Low temperature, cool down to 30° F, followed by one mission cycle-and-leakage test (10 scc/min maximum)

3. High temperature, heat to 220° F (for 30 minutes), followed by one mission cycle-and-leakage test (10 scc/min maximum)

4. Hard vacuum, 1×10^{-5} torr for 2 hours, followed by a production acceptance test

5. Oxygen/humidity, 160° F oxygen, 80 to 100 percent relative humidity at 18.7, 14.7, and 5 psia (25 hours total)

6. Pull test, 200-pound pull, followed by leakage test (10 scc/min maximum)

Experience with the ventilation umbilical connector systems and the ECS interconnects showed that these items had been designed and qualified adequately for the LTA-8 test program.

In one test, a failure of the chamber umbilical-stowage-panel heaters caused the ECSIN on the chamber umbilical-stowage panel to reach a low temperature of approximately -100° F during manned operating periods. The crewmen were able to egress with no difficulty, but extra force was required to connect the umbilicals to the ECSIN.

Ingress/Egress Stand

The stairway and platform that were used to provide access from the manlock door to the LTA-8 forward hatch are shown in figures 1 and 10. The I/E stand consisted of a stairway, handrails, restraint assemblies, a foldable slide assembly (for emergency egress), and the ingress platform. Qualification tests of each subassembly were performed.

Restraint assemblies. - The following qualification tests of the restraint assemblies were performed.

1. Exposure of one restraint assembly to a cold environment of -300° F and to the kinetic energy generated by 125 pounds falling a distance of 6 inches
2. Exposure of one restraint assembly to an ambient-temperature environment and to the kinetic energy generated by 125 pounds falling a distance of 6 inches
3. Exposure of all remaining restraint assemblies to an ambient-temperature environment and to the kinetic energy generated by 125 pounds falling a distance of 6 inches with no visible damage to the cam teeth

Success criteria for the tests of the restraint assembly were as follows.

1. No more than one-fourth inch of travel of the restraint assembly on the rail after the cam had been engaged
2. Self-engagement and holding (within one-fourth inch) of the restraint assembly in a -300° F environment
3. Free movement of the restraint assembly with the cam disengaged

The restraint assembly held within one-sixteenth to one-eighth inch when subjected to the tests.

Slide assembly. - The slide assembly was tested to determine deployment capability under the following conditions.

1. Ambient temperature
2. Cold temperatures (-300° F)



Figure 10. - Two crewmen on the I/E stand.

3. Cold temperatures (-300° F) and ice resulting from the use of water spray in the chamber

Four tests incorporating force-measurement devices were made to deploy the slide from an enclosure in which the slide temperature could be controlled with liquid nitrogen. The slide was deployed successfully in all tests, even when a thick coat of ice existed.

Ingress platform and stairway. - A static loading test was conducted in which the stairway was loaded to 500 pounds (distributed over four steps) and the platform was loaded to 1000 pounds (distributed over four areas). At the satisfactory conclusion of the tests, the I/E platform was installed in chamber B.

System verification. - A 250-pound anthropomorphic dummy was placed in a standing position on the stairway and was attached to the restraint assembly and handrails. The dummy was dropped the maximum distance that a crewman might fall if he lost his footing and both handholds. The system performed as designed in that the dummy fell to the length of the tethers and stopped. A crewman attached to the restraint assembly is shown in figure 11. The component parts of the restraint assembly are shown in figure 12. The deployed slide and a rescued subject in position to be lowered are shown in figure 13.

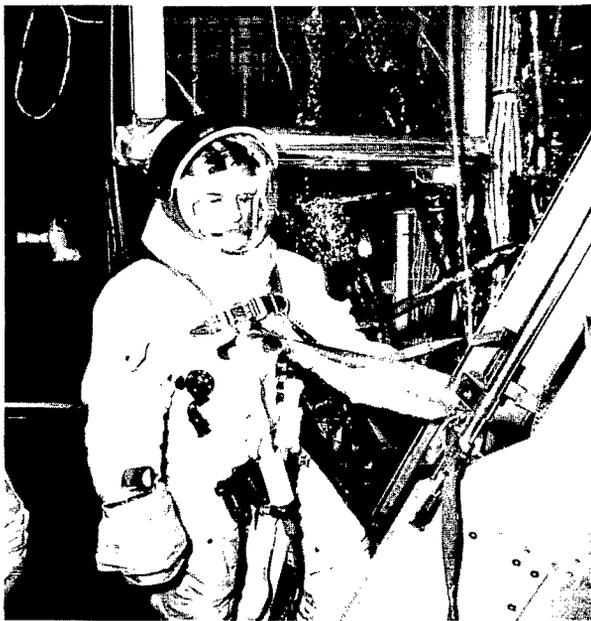


Figure 11. - A crewman attached to the restraint assembly.

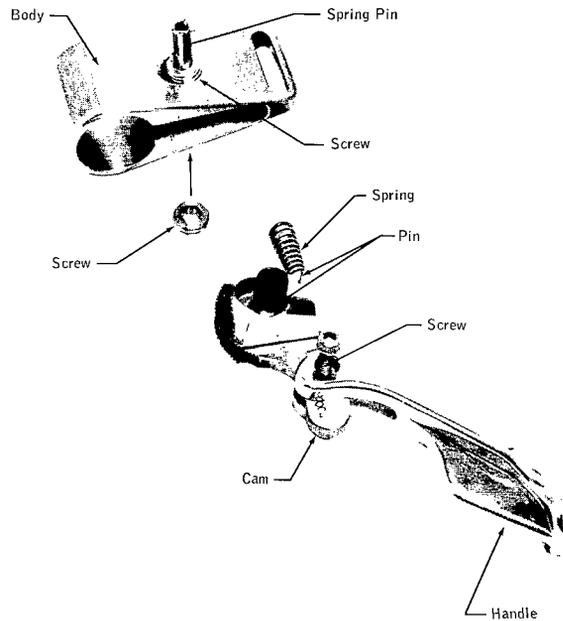


Figure 12. - The component parts of the restraint assembly.

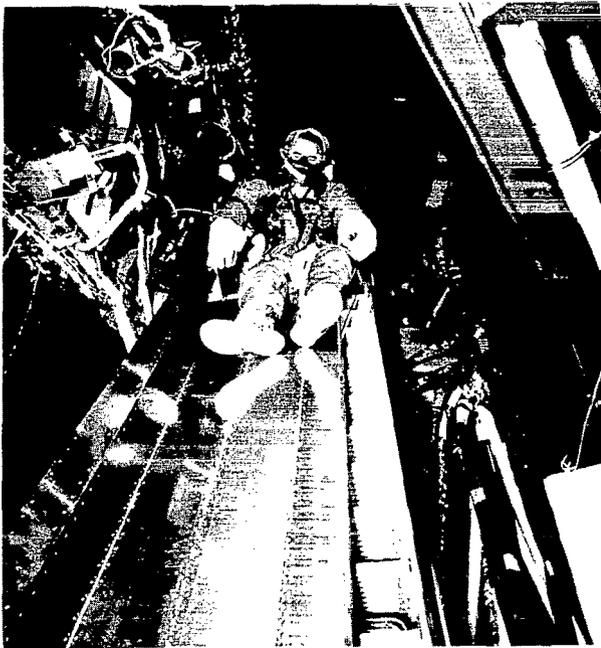


Figure 13.- A rescued subject on the slide.

performed on an open-loop system and in parallel with other suit-room and manlock activities.

Space Suits

The space suits used by the test crewmen were of the Apollo Block II type A6L modified configuration, as shown in figures 9 and 11. Flight verification tests were conducted in the MSC Crew Systems Division test facilities to qualify the suits for altitude use.

MEDICAL CONSIDERATIONS

The test-team members whose actions could directly affect the safety of the test crewmen were required to take periodic medical examinations. All test crewmen and manlock observers were examined by the medical officer prior to each test.

A schedule of prebreathing of 100 percent oxygen was followed by all test crewmen and manlock observers (table II). The prebreathing schedule was

TABLE II. - PREBREATHING SCHEDULE

Maximum altitude potential, ft	Denitrogenation time, hr
<18 500	0
18 500 to 27 000	2
>27 000	3

More data were obtained during the ground tests than normally were obtained in flight. During all phases of manned ground testing, the following data from within the suit of the test crewmen were displayed on the medical-officer console.

1. Oxygen partial pressure
2. Carbon dioxide partial pressure

3. Suit pressure
4. Electrocardiogram (axillary and sternal)
5. Respiration rate
6. Body temperature

In addition, three barostats were installed in the suit. If any two of the three barostats should indicate an oxygen pressure of less than 2.1 psia, a signal would be sent to re-pressurize the chamber automatically to 6 psia in 30 seconds using the ER system discussed earlier. The insuit instrumentation vest is shown in figure 14. The electrical characteristics of the instrumentation are listed in table III.



Figure 14. - The insuit instrumentation vest.

All signal and power wires entering the suit were fused at 250 milliamperes to minimize the potential hazards of electrical shock or fire in the space suits. The fuses were located outside the chamber and manlock to reduce the bulk of the equipment used by the test crewmen.

Two-way voice communications were maintained at all times with the test crewmen and the manlock observers. Although redundancies were incorporated into the prime and backup systems to increase reliability, a system of hand signals was developed to allow a safe backout of the test in case of voice-communications failure. Television cameras were mounted in strategic locations in the manlocks, the chamber, and the spacecraft to permit visual monitoring of test crewmen and manlock observers.

A heavy workload was imposed upon the test crewmen, particularly during ascent of the stairway. When the heart rate became excessive, the medical officer directed the crewmen to rest until the rate decreased to a satisfactory level.

A fully equipped emergency room was staffed during all manned tests. A checklist was used to ensure that all the required equipment (such as cardiac defibrillators and resuscitators) was operating.

TABLE III. - INSUIT INSTRUMENTATION ELECTRICAL CHARACTERISTICS

Sensor	Excitation voltage, V dc	Excitation current, mA	Signal voltage, V	Signal nominal current, mA	Fusing, mA
Oxygen partial pressure	-6 12	12 11	0 to 3	0 to 3	250
Carbon dioxide partial pressure	-6 12 12 (400 Hz)	12 11 50, peak to peak	0 to 5	0 to 3	250
Suit pressure	20	40	(a)	0.1	250
Baroswitches	6	1.66	(b)	0.6	None
Two electrocardiograms	10	5	0 to 5	4	250
Impedance pneumograph	10 -10	7 7	0 to 5	4	250
Body temperature	10 -10	5 5	0 to 5	0 to 5	250
Communications	16.8	40	2.2, peak to peak	200	250
Other lines (power returns)	Various	Various	--	--	250

^a0 to 100 mV.

^bSwitch closure.

An operational hyperbaric chamber was available in a building near the laboratory. This hyperbaric chamber had the capability of exerting a 75-psig pressure and was to be used if a loss of pressure caused a crewman to undergo decompression sickness. The chamber was staffed by trained personnel during all phases of manned testing.

EMERGENCY RESCUE

Manlock-Observer Equipment

Two manlock observers, wearing nonflammable Beta cloth coveralls and protective aviator helmets, were equipped with portable oxygen backpacks and radio-frequency communications. Each observer carried a knife and a rope for use during particular rescue situations and a bailout bottle for use by the test crewmen. Manlock observers and the equipment used for a rescue are shown in figure 15.

Procedure Development

Eleven different rescue procedures were needed to accommodate the various combinations of crewmember locations during the test. These locations included the manlock, the stairway, the platform, the spacecraft cabin (standing), and the cabin sling seats (sitting). The cabin sling seats are used only in ground tests. The procedures were developed by the use of mockups of the spacecraft, the platform, and the stairway. In the course of procedure development, a foldover slide was added to the stairs, and stanchions were added to the platform so that crewmen could be lowered down the slide. The slide rescue is shown in figure 13.

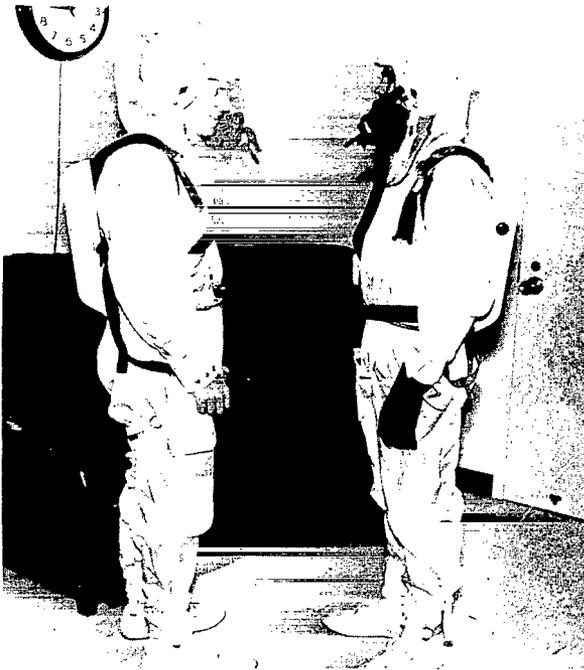


Figure 15. - The manlock observers and equipment.

Rescue Description

The basic rescue procedures (simplified) are as follows.

1. The observer enters chamber B at 6 psia.
2. The observer disconnects the crewman suit wrist ring to equalize the suit pressure.
3. The observer removes the crewman helmet.
4. The observer applies oxygen.
5. The observer moves the crewman to the manlock.
6. The manlock operator repressurizes the manlock to 14.7 psia at the rate ordered by the medical officer.
7. The medical officer enters the manlock to determine whether the crewmen should be carried to the hyperbaric chamber, the emergency room, or the hospital.

In the event of a fire, the observers would first remove the crewmen from the vicinity of the fire and then perform the appropriate procedures.

Each manlock observer received the following training.

1. Thirty hours of classroom training
2. Sixty hours of mockup training and timed drills
3. Five hours of inchamber training and timed drills

Classroom training included familiarization with the observer equipment, the pressure garment assembly, the gas and electrical umbilicals, and the rescue procedures. Mockup training included rescue demonstrations by the instructors, walk-through rescue practice by the trainees, and timed rescues from within the mockup cabin, using the complete observer equipment. The rescue subjects wore training pressure garments and umbilicals, as described previously. A performance critique followed each drill. Chamber training, with the use of complete observer equipment, included familiarization with the spacecraft hatch and cabin and timed rescues from the platform and stairway. Rescued subjects were not removed from the actual spacecraft because of possible damage to the cabin and the hatch area. The average times for all rescue teams, with the observer starting in the manlock and the rescued subjects simulating unconsciousness in pressurized suits, are listed in table IV. These rescue drills demonstrated that the orientation of the rescued subjects could affect rescue time to the extent that approximately 2 minutes might elapse before oxygen could be applied directly to the oronasal areas of both crewmen. However, it should be noted that the crewmen would not be totally without oxygen for the 2-minute interval, but would be at a total pressure of at least 6 psia (approximately 1.3-psia oxygen partial pressure) in 30 seconds following the initiation of the ER system.

TABLE IV. - RESCUE TIMES^a

Rescue posture	Time to administer oxygen to the crew, min:sec	Total time to the manlock, min:sec
2 crewmen on cabin floor	1:36	4:12
2 crewmen in cabin seats	1:37	4:42
2 crewmen on platform	1:12	^b 4:42
1 crewman on stairway	1:04	3:18

^aThe times listed do not include an additional 30 seconds required for chamber repressurization.

^bThis average time includes some rescue drills with the heads of both rescue subjects toward the ladder. If the feet of the rescue subjects were toward the ladder, the time required for the drill was approximately 1 minute less.

TEST-TEAM CERTIFICATION

In addition to classroom and on-the-job training in the various specialty areas, all test-team personnel were required to attend classroom training on the laboratory, on the test article, on high-altitude physiology, and on the hazards of oxygen-enriched fires. Each organization participating in the test program was responsible for maintaining current training records which were subject to audit. The records included the following entries.

1. Duty-station description, function, responsibilities, and authority
2. Duty-station requirements for educational background, classroom instruction, and on-the-job training

Each organization submitted a list of names, grouped according to duty station, which certified acceptable training and performance of personnel. The personnel whose actions were likely to affect crew safety were certified both physically and mentally by the medical officer. All other personnel were certified similarly by their supervisors. Upon request, the medical officer assisted the supervisors in evaluating personnel.

The I/E procedures and crew-operated equipment were developed with the test crewmen using training equipment on a mockup. Several I/E simulations were performed. Each simulation identified additional modifications to hardware and procedures. While using the test hardware in the final configuration, each of the test crewmen (pressurized above ambient conditions) performed the I/E procedures in the test volume. Figures 10 and 11 illustrate I/E activity.

With all test-team members at the assigned duty stations, the tests were simulated using the test procedures, and the team was evaluated for proper performance. Credible emergencies were simulated and repeated until the response was satisfactory. The final approved procedures were distributed to the test team at least 24 hours prior to the start of the simulations and at least 48 hours prior to the start of a TV test.

THE LTA-8 (LM-3) TEST PROGRAM

The following manned tests were conducted to satisfy the requirements of the LTA-8 test program.

1. Facility ECS man-rating tests
2. LTA-8 man-rating test
3. LTA-8 TV hot-case test, first manning
4. LTA-8 TV hot-case test, second manning
5. LTA-8 cold-case test, first manning

6. LTA-8 TV cold-case test, second manning
7. LTA-8/PLSS test

Facility ECS Man-Rating

After the unmanned qualification of the facility ECS, two manned tests were conducted in one of the chamber B manlocks. These tests involved final verification of the capability of the ECS and of the ECS distribution system to perform all normal operations safely in conjunction with pumpdown, repressurization, umbilical transfer, and backup ECS module transfers. In addition, these tests provided an opportunity to verify the detailed valve-sequencing procedures that are involved in the umbilical transfer operations planned for the actual hard-vacuum ingresses. The tests were successful in demonstrating the adequacy of the facility ECS, the biomedical/communications (BIOMED/COMM) system, and the operating procedures.

The LTA-8 Man-Rating Test

A separate test was conducted on the test spacecraft to qualify the LTA-8 for manned use. This manned test followed two earlier unmanned TV simulations which served to qualify the basic vehicle operation. Ingress to the LTA-8 was made in a 6-psia environment. The suit of the crewman was pressurized to 3.7 psid oxygen by the use of the umbilical transfer sequences developed for hard-vacuum ingress. Time lines were obtained for each task.

After the crewmen completed the ingress, a series of circuit-breaker and control-switch operations was conducted in the 6-psia-oxygen environment of the spacecraft to demonstrate system control prior to reaching vacuum conditions in the chamber. Difficulty was encountered in verifying the 95-percent (minimum) oxygen concentration in the spacecraft until air leaks into the gas sampling line were located and eliminated.

Following the completion of the systems verification at 6 psia oxygen, the vacuum man-rating test was started. This test involved operation of most spacecraft systems under 4.8- and 0-psia cabin conditions. Also, the test involved use of the Apollo PLSS in the LTA-8 cabin under vacuum conditions. Difficulty in establishing communications with the PLSS resulted in termination of PLSS operations and in startup of the subsequent test sequence. It soon became evident that delays resulting from these difficulties had prolonged the test to the point that the man-rating test could not be completed without subjecting both the test crewmen and the test team to excessive fatigue. Accordingly, the test was terminated, and the chamber was repressurized (using the dry stored gas mentioned earlier) to a 6-psia environment. An alternate method of crew egress was accomplished by the use of bailout bottles and oxygen masks.

The LTA-8 TV Tests

The TV test series consisted of mission simulation of hot- and cold-case tests. Chamber B conditions (-300° F shroud and less than 1×10^{-5} torr) were the same for

both tests. All spacecraft thermal simulations were performed by means of heaters on the spacecraft thermal skins and on the descent- and ascent-stage engines to simulate the thermal effects of spacecraft maneuvers.

To simulate the complete mission time line, two mannings of approximately 12 hours each were required for each test. Four ingresses and two egresses were made under TV conditions. The remaining two egresses, which were the second egresses of each test, were made in a 6-psia environment with a chamber free-air temperature of approximately 0° F. The following are the ingress times from arrival of the crew at the manlock to the closing of the spacecraft hatch.

1. TV hot-case test, first manning, duration 3 hours, with a 1-1/2-hour hold for biomedical instrumentation troubleshooting
2. TV hot-case test, second manning, duration 1 hour 33 minutes
3. TV cold-case test, first manning, duration 2 hours 10 minutes, with manlock pumpdown delay caused by gas load from ice on the manlock-door liquid nitrogen lines
4. TV cold-case test, second manning, duration 1 hour 37 minutes

Ingress times included transfer from portable oxygen ventilators to the facility ECS, BIOMED/COMM checks, suit checklists, pumpdown to manlock blankoff (50 to 100 microns), and the actual umbilical transfer operations that were required to move from the manlock, up the stairs, and into the spacecraft. All ingresses were conducted smoothly and without incident, primarily because of the extensive training that the crewmen received.

The following are the egress times from the opening of the spacecraft hatch to the exit of the crewman from the manlock.

1. TV hot-case test, first manning, duration 58 minutes (hard-vacuum egress)
2. TV hot-case test, second manning, duration 49 minutes (6-psia egress)
3. TV cold-case test, first manning, duration 62 minutes (hard-vacuum egress)
4. TV cold-case test, second manning, duration 48 minutes (6-psia egress)

Egress took less time than ingress. The reasons for this include the relative ease of descending compared with ascending the stairway, the shorter manlock-repressurization time compared with pumpdown time, and the lack of extra activities such as suit-integrity checks.

Although appearing to take less time, the 6-psia egresses actually took more time if the time required to repressurize the chamber to 6 psia and to warm the air temperature to 0° F was considered. This process took approximately 2 hours, during which time the crewmen accomplished the shutdown of the spacecraft and waited for the proper chamber conditions to be achieved.

The LTA-8/PLSS Test

As previously mentioned, one of the objectives of the LTA-8 test program was to operate the PLSS in a depressurized LM environment to validate the transfer sequences from the LM ECS to the PLSS and back to the LM ECS. Because of problems with the LTA-8 communications relay and the accidental discharge of the PLSS battery, attempts to accomplish this objective during the man-rating and TV tests were unsuccessful. Because this validation was considered to be a mandatory test objective, a separate pumpdown (vacuum only) of chamber B was made. The crew ingressed and egressed at atmospheric pressure with the use of portable oxygen ventilators. The PLSS operated perfectly, and all test objectives were accomplished.

The LTA-8 (LM-5) Tests

After modification of LTA-8 to a later configuration, two more series of TV tests were performed. During five manned periods totaling more than 64 hours, the spacecraft response to a wide range of lunar-mission thermal loads was evaluated.

CONCLUDING REMARKS

The successful manned operations of the tests bear evidence that the planning, preparation, reviews, and specialized techniques developed were sound. The problems that arose were solved without compromising safety or unduly delaying the test program. Although this major test series in the development of the Apollo lunar module involved many complex and potentially hazardous test techniques, the combined efforts of the test crewmen and the NASA and contractor engineers and technicians were successful in the completion of this essential manned test program.

Manned Spacecraft Center

National Aeronautics and Space Administration

Houston, Texas, November 26, 1969

914-50-20-19-72

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APPENDIX A

ACRONYMS

APC	absolute pressure controller
BIOMED/COMM	biomedical/communications
CH	chamber
DPC	differential pressure controller
ECS	environmental control system
ECSIN	environmental control system interconnect
ER	emergency repressurization
I/E	ingress/egress
LM	lunar module
LTA-8	LM test article 8
ML	manlock
MSC	Manned Spacecraft Center
MTOB	Manned Test Operations Board
ORI	operational readiness inspection
PI	pressure indicator
PLSS	portable life support system
PS	pressure switch
SC	spacecraft
SESL	Space Environment Simulation Laboratory
SETD	Space Environment Test Division
TRRB	Test Readiness Review Board
TS	temperature switch

TV

thermal vacuum

VUCS

ventilation umbilical connector system

APPENDIX B

SAFETY REQUIREMENTS FOR MANNED GROUND TESTING

The following are safety requirements for conducting manned ground testing.

1. Hardware design must include fail-safe features, backup systems, and adequate controls to minimize the possibility of injury to personnel.
2. Certification of test-team personnel must include demonstration of a thorough knowledge of duty-station operations, training in high-altitude physiology, and familiarization with the hazards of oxygen-enriched fires. Test personnel also must be certified as physically and mentally qualified.
3. A safety group, separate from the test organization, must review and approve the test activities.
4. Standard procedures for configuration control, calibration, technical review, and readiness approval for testing must be used.
5. A quality-control group, separate from the test organization, must use well-defined procedures to assure compliance with documented requirements.
6. System analysis to include failure modes and cleanliness requirements of all test hardware must be performed.
7. Test personnel shall not be subjected to a test environment in which a credible single-point failure will result in injury.
8. Medical surveillance of test subjects is required, as is the provision of appropriate emergency treatment equipment, including hyperbaric facilities. The surveillance includes the authority to terminate the test.
9. A rigid material-control plan must be established, hazardous material must be kept to the minimum, and the use of flammables must be analyzed carefully for safety considerations.
10. Test checkout operations must include personnel briefings, ambient dry runs, simulated emergencies, and an unmanned environmental test to exercise personnel and equipments prior to manned tests.
11. Detailed test procedures approved by medical, quality, safety, and other personnel must be developed for normal and emergency operations.

APPENDIX C

SAFETY REVIEW GROUPS

Operational Readiness Inspection

Senior technical experts from outside the test organization ascertained and certified the operational readiness of the laboratory. Consideration was given to the adequacy of design, training, documentation, quality control, configuration control, failure-effects analysis, support services, spares, and safety provisions. All tasks recommended by the operational readiness inspection (ORI) committee were resolved satisfactorily.

The MSC Manned Test Operation Office

In accordance with the MSC Safety Manual, test safety officers participated in all phases of manned test activities. The test safety officers were knowledgeable in the operations of the test facility and the test article. The officers reviewed and approved test plans and procedures and had the authority to order discontinuance of any test operations deemed to be unsafe.

Industrial Safety at the MSC

The normal hazards expected around a large industrial complex, such as cryogenic handling, flammable storage areas, and high-pressure fluids, were kept under surveillance by the MSC industrial safety group. Periodic inspections were made of the entire laboratory complex to ensure that safe practices were maintained.

Contractor Safety Groups

Both the vehicle contractor and the laboratory operating contractor established safety groups whose activities were coordinated by NASA. Each group reviewed laboratory practices, plans, procedures, equipment, and so forth to assure safe operations. Under NASA direction, each contractor organized fire-control and rescue teams and held periodic unscheduled emergency drills to ensure team proficiency.

Laboratory Safety Groups

At the MSC, all supervisors are responsible for safety. In the SETD, one person was assigned the responsibility for coordination of industrial safety, fire drills, and hazardous work permits. All aspects of manned testing in the laboratory were reviewed by the Manned Test Operations Board (MTOB). The board consisted of representatives from the SETD, environmental medicine, test crew, crew equipment, quality, and safety NASA organizational elements and laboratory and spacecraft contractors. The board investigated such items as hardware, normal and emergency procedures,

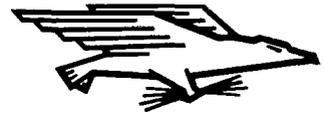
training, systems integration, and conformance with the MSC Safety Manual requirements listed previously.

Test Readiness Review Board

Within the week prior to performing the series of TV tests, a test readiness review was conducted. The purpose of the review was to evaluate the spacecraft, the crew equipment, and the ground-support equipment, the data-acquisition system, and the test facility readiness to achieve the test objectives safely. The Test Readiness Review Board (TRRB) was composed of senior officials of the MSC organizations involved in the test.

The TRRB reviewed work accomplished after the ORI discussed previously, and reviewed the status of discrepancies and open work. In addition, the TRRB determined the qualification/certification status, reviewed material deviations, and specified the actions necessary prior to testing. Only after final approval by the TRRB could the testing begin.

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