NASA TECHNICAL NOTE

NASA TN D-7949

NASA TN D-7949

APOLLO EXPERIENCE REPORT - GUIDANCE AND CONTROL SYSTEMS: LUNAR MODULE MISSION PROGRAMER

Jesse A. Vernon

Lyndon B. Johnson Space Center
Houston, Texas 77058

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1975

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TN D-7949		

4. Title and Subtitle	5. Report Date
APOLLO EXPERIENCE REPORT GUIDANCE AND CONTROL SYSTEMS: LUNAR MODULE MISSION PROGRAMER	April 1975
	6. Performing Organization Code
7. Author(s) Jesse A. Vernon	8. Performing Organization Report No. JSC S-414
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058	10. Work Unit No. 914-50-00-00-72
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	13. Type of Report and Period Covered Technical Note
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A review of the concept, operational requirements, design, and development of the lunar module mission programer is presented, followed by a review of component and subsystem performance during design-feasibility, design-verification, and qualification tests performed in the laboratory. The system was further proved on the unmanned Apollo 5 mission. Several anomalies were detected, and satisfactory solutions were found. These problems are defined and examined, and the corrective action taken is discussed. Suggestions are given for procedural changes to be used if future guidance and control systems of this type are to be developed.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
• Automation • Checkout • Remote Controls	STAR Subject Category: 12

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	12	$3.25

APOLLO EXPERIENCE REPORT
GUIDANCE AND CONTROL SYSTEMS:
LUNAR MODULE MISSION PROGRAMER

By Jesse A. Vernon
Lyndon B. Johnson Space Center

SUMMARY

The lunar module mission programer was designed to enable the lunar module to meet the requirements for unmanned near-Earth orbiting missions and to be adaptable to restricted unmanned lunar landing missions within the capability of the ultra-high-frequency/very-high-frequency communication links if adequate command and service module transmission capability were provided. An onboard lunar module mission programer would not preclude a manned mission involving two crewmembers.

The mission programer was used for sequencing functions in an unmanned spacecraft to prove proper functioning of the system and to ensure spacecraft readiness for manned flights. The lunar module mission programer was composed of the following functional components: (1) a program reader assembly, (2) a digital command assembly, (3) a program coupler assembly, and (4) a power distribution assembly.

The functional components of the mission programer were subjected to design-feasibility, design-verification, and qualification tests. The units successfully completed all tests with only minor problems. However, from the beginning of the program, the program coupler assembly was plagued with relay problems, many of which were a direct result of contamination inside the sealed relay can. Others were unexplained — no contamination or other causes of failures were ever found.

The lunar module mission programer performed all the required functions throughout the Apollo 5 mission. From lift-off until 6 minutes 10 seconds into the flight, the programer was operated in the primary mode with the guidance computer in control; then the backup mode was activated, and the programer controlled all sequencing throughout the mission. The lunar module mission programer was flown on only one mission. A modified mission programer, the ascent-engine arming assembly, was flown on the Apollo 9 and 10 missions. This assembly permitted the ascent engine to be armed after crew departure and to be fired to fuel depletion after the ascent stage was separated from the command and service module.

INTRODUCTION

Electrical and electronic equipment has been used in many areas to perform functions previously performed by man. Technologists have continued to develop automated techniques and have extended the scope to include the sequencing of functions in an unmanned spacecraft to prove proper functioning of the system and to ensure spacecraft readiness for manned flights. The lunar module mission programer (LMP) is one such device. The LMP concept, design, development, and flight performance are described in this report. The LMP was flown on only one mission (Apollo 5/lunar module 1 (LM-1)) and performed all required functions when it was activated 6 minutes 10 seconds after lift-off.

As an aid to the reader, where necessary the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). The SI units are written first, and the original units are written parenthetically thereafter.

CONCEPT

The LMP was designed to enable the LM to meet the requirements for unmanned near-Earth orbiting missions and to be adaptable to restricted unmanned lunar landing missions within the capability of the ultra-high-frequency (uhf)/very-high-frequency (vhf) communications links if adequate command and service module (CSM) transmission capability were provided. An onboard LMP would not preclude a manned mission involving two crewmembers.

OPERATIONAL REQUIREMENTS

The operational requirements of the LMP were as follows:

1. Noncontingency mission performance without ground-command control of unmanned flights

2. Nonsimultaneous manned and LMP system operation on the same flight (manned operation possible before LMP activation and after LMP deactivation)

3. Control of LM subsystems as required to control functions in an optimum manner to meet flight test objectives

4. Ground-command selection of alternate test sequences in the backup mode or in the primary mode (within the capacity of the LM guidance computer (LGC))

5. Priority of ground command over onboard command

6. One LMP configuration compatible with all unmanned mission operations

EQUIPMENT DESCRIPTION

The LMP consisted of the following functional components: (1) a program reader assembly (PRA), (2) a digital command assembly (DCA), (3) a program coupler assembly (PCA), and (4) a power distribution assembly (PDA). The PRA contained a contingency program to be used if the primary mode failed or if special subsystem contingency operations became necessary. The DCA provided an uplink capability so that ground commands could be routed to the LGC, the PRA, or the PCA. The PCA provided coupling of the LGC, PRA, and certain DCA commands to control the basic LM subsystems. The PDA provided the dc power distribution and current protection for the LM components.

Program Reader Assembly

The PRA was programed to contain commands to provide open-loop backup sequencing if a failure was detected by the primary guidance, navigation, and control system (PGNCS). The PRA provided only those commands necessary to operate the LM subsystems for LM testing after a primary-mode failure. It did not provide vehicle guidance or attitude information. The PRA consisted of three subassemblies: (1) a power supply subassembly, (2) a tape reader subassembly, and (3) a program control subassembly.

The power supply subassembly provided the internal voltages required for PRA operation and supplied isolation of signal and power grounds within the PRA. It also protected the PRA from damage resulting from abnormal vehicle conditions.

The tape reader subassembly was a bidirectional reader using programed tape. The tape was capable of storing a maximum of 64 000 bits of information. The stored information was sensed by a read head. A tape "hole" was a binary one; a tape "no hole" was a binary zero. Capability to sense the beginning and end of the tape was incorporated in the PRA.

The program control subassembly was used to select, control, and issue — as a function of time — the information stored in the PRA. External control commands were provided to the PRA by means of uplink commands through the DCA. The program control subassembly placed the PRA in the standby mode or the normal (either search or readout) mode. To inform the ground station that the PRA was sequencing, the program control subassembly provided a "compare" pulse and, in the readout mode, transmitted a 1-pulse/sec clock pulse to the ground.

Digital Command Assembly

The DCA received, decoded, and processed commands received from the ground by uhf transmission. These commands were sent to the LGC to accomplish limited program control, to the PRA to enable selection and initiation of a segment of the PRA program, or to the ground relay matrix of the PCA to accomplish real-time control of certain functions of the LM subsystems. The DCA also had a self-test and verification capability controlled by the Manned Space Flight Network. The DCA consisted of a uhf receiver, two decoders (redundant), a phase-shift-keying (PSK) demodulator, and a power supply.

The uhf receiver was a miniaturized solid-state, double-conversion, superheterodyne device that received and demodulated frequency-modulation/PSK signals in the uhf band. The decoder decoded digital messages from the PSK demodulator and allowed partial messages from the residue of rejected messages to be received without transferring them to associated assemblies. The PSK demodulator converted the PSK signal from the receiver into a series of digital bits for the decoder and also provided a set of reference clock pulses for the decoder. The power supply provided the regulated power and signal ground isolation required for DCA operation.

Program Coupler Assembly

The PCA received commands from the LGC, the PRA, or the DCA and coupled these commands to the LM subsystems by means of magnetic latching relays. Each relay contained two directional diodes and was half-crystal can size. The PCA consisted of a decoder subassembly, a power supply subassembly, and a switching subassembly. The decoder subassembly selected and decoded command words from the LGC or the PRA. The LGC command word contained 12 bits (4 address bits and 8 data bits). The PRA command word contained only 8 data bits. The power supply subassembly provided the regulated power required for PCA operation and for isolation of power and signal grounds within the PCA. The switching subassembly contained two matrices of latching relays. The prime matrix was controlled by the LGC or PRA output commands by means of the decoder subassembly. These relays were controlled on a real-time basis. The real-time command relays were used to correct or compensate for failures of the programed relays and to correct or compensate for certain LM subsystem failures. The switching subassembly also contained the uplink-activated interlocking relays to allow ground-control priority if a PCA prime relay failed. These relays, when activated, disabled specific control circuits in the LMP prime-relay matrix.

Power Distribution Assembly

The PDA provided dc power distribution and current protection for the DCA, the PCA, and the PRA and provided the dc power required for LMP control of the ac inverters. The PDA contained manually operable circuit breakers that enabled and disabled the LMP. Additional relays performed high-power switching functions required for proper LM operation. These relays were controlled by relays in the PCA.

DESIGN

The LMP was designed and constructed to satisfy the individual specification requirements of structural and electrical design and of performance.

The calculated reliability goal for a DCA was met through the use of redundancy in the digital decoder section only. A self-checking and fail-safe feature was included to prevent an invalid message from performing a function. Integrated circuits were used wherever possible in designing the DCA because of their high reliability, low power consumption, small size, and light weight. Discrete components were used in those areas in which the circuit constraints precluded the use of integrated circuits.

The PCA design goal was to achieve high reliability. To accomplish this goal, numerous broad-based design objectives — such as minimum weight, optimum thermal design, high packaging density, and adaptability to design changes — were met early in the PCA design.

The minimization of weight was a prime consideration. The following design concepts were used to fulfill the rigorous environmental and operational requirements effectively while maintaining the concept of minimum weight.

Integrated circuits were used instead of discrete components where practical. A single flatpack performed the task of approximately 34 discrete components with obvious weight-saving results. Welded-wire cordwood assemblies were used, where practical, rather than conventional solder. This procedure added reliability to the electrical junction and provided substantial weight savings. All parts used represented the state-of-the-art high-reliability versions of products being manufactured at the time.

To provide the best possible thermal path from heat-dissipating parts to the mounting flange, all parts and components were bonded directly to the module web with an adhesive having high thermal conductivity. All cordwood assemblies were completely encapsulated. The encapsulant then paralleled the path of the part lead, which resulted in a further reduction in thermal resistance.

Every effort was made to design a package that incorporated high-density design concepts. In many cases, the electrical requirements and the available parts limited the miniaturization effort (i.e., transformers, chokes, capacitors, relays, etc.).

Because of the nature and functions of the PCA, the conceptual design within the PCA and the several interfacing electronic assemblies changed. Therefore, designing the PCA to accept these changes was difficult. The use of flexible harness and the inclusion of spare terminals on each module to provide the simplest means for executing changes are examples of the adaptability to design changes. If a hardwired multilayer or printed circuit board (mother board) had been used, a complete redesign would have been necessary to incorporate a change in module interwiring.

The PRA had an integrated planar photodiode array, which was used to read digital data stored on 35-millimeter photographic film. The tape (photographic film) was advanced by a simple step servosystem that required a minimum number of moving parts and gears. The tape-transport system, drive sprockets, and supply and takeup spools were identical in concept to the components and system used in space-flight-proven programers. The programed film was, for all practical purposes, indestructible. This was not true for magnetic-tape and magnetic-core systems in which the data can be inadvertently erased. The decision to use a photoelectric readout was based primarily on a program to develop an integrated planar photodiode array that was significantly more reliable than any existent reader. The program tape had an end-of-tape word that, when sensed, stopped either the forward or reverse search mode. The end-of-tape word was repeated three times; hence, a forward or reverse search command issued in the same direction after the word was first sensed could cause the program tape to unwind off the tape spool. The corrective action to minimize program impact was to repeat the end-of-tape word many times, which would make unwinding the tape from the tape spool almost impossible.

DEVELOPMENT

Developmental tests were performed to provide data that were used to support the design of a specific component or subassembly. Developmental tests were also used to determine operating characteristics under off-design conditions. In conjunction with the general thermal design, developmental tests were performed on the equipment in a simulated thermal environment to ensure that the thermal requirements had been satisfied. Developmental tests were categorized as design-feasibility tests and design-verification tests.

The design-feasibility tests included all tests performed for the following purposes:

1. Selection of components and parts

2. Investigation of the performance of breadboard models, components, and subassemblies under various environmental conditions

3. Selection of materials

4. Substantiation of safety margins or of other analytical assumptions

The design-verification tests were performed on two production models in simulated ground and flight environments and under off-design conditions to determine whether the design would meet mission requirements. The equipment was subjected to numerous environmental conditions. No replacement of parts, adjustments, or maintenance was permitted during design-verification testing. Successful completion of these tests, excluding overstress, was a prerequisite to the start of qualification tests.

QUALIFICATION

Qualification tests were performed on two production units to demonstrate attainment of design objectives, including margins of safety. The qualification test was performed in two separate phases: (1) the design-limit test (equipment subjected to test-sequential, singly applied environments at design-limit conditions), and (2) the endurance test (equipment subjected to one operational cycle and one subsequent mission cycle at nominal mission conditions).

Program Reader Assembly

The PRA, part number LSC-300-72, had the following physical parameters: weight, 6.24 kilograms (13.75 pounds); length, 24.64 centimeters (9.7 inches); width, 13 centimeters (5.12 inches); and height, 17.8 centimeters (7.0 inches). The PRA was subjected to the qualification test in accordance with the test plan (Certification Test Requirement (CTR) LCQ-300-005). Each of the qualification-test programs (design limit and endurance) was successfully implemented in accordance with the applicable specified requirements and was approved with no deviation or waiver requested or issued. Data generated during the performance of the qualification-test programs indicated that each PRA successfully completed all the requirements specified for operation and performance during acceptance testing with no waivers or deviations.

Power Distribution Assembly

The PDA, part number LDW-390-28153-1, had the following physical parameters: weight, 4.08 kilograms (9 pounds); length, 64.77 centimeters (25.5 inches); width, 17.15 centimeters (6.75 inches); and height, 19.68 centimeters (7.75 inches). The PDA was subjected to the qualification test in accordance with test plan LTP-390-15 (CTR LCQ-390-015).

The test article was initially configured with a polyurethane collar between the circuit breaker panel and the main assembly of the PDA. The purpose of the collar was to provide vibration isolation to the MS-type circuit breakers. After the successful completion of these tests, data from the lunar test article 3 (LTA-3) vibration test indicated that significantly lower vibration levels should have been used. Testing at the lower vibration levels indicated that the vibration isolation provided by the polyurethane collar was not required. In consideration of the potential fire hazard of polyurethane and of the reduced vibration levels, the polyurethane collar was eliminated, the circuit breakers were hard mounted, and the PDA was successfully tested in a supplemental qualification test.

Program Coupler Assembly

The PCA, part number LSC-300-710-5, had the following physical parameters: weight, 23.59 kilograms (52 pounds); length, 70.49 centimeters (27.75 inches); width, 13.018 centimeters (5.125 inches); and height, 19.05 centimeters (7.5 inches). The PCA was subjected to the qualification test in accordance with test plan LTP-303-20 (CTR LCQ-300-004).

A number of relay failures occurred on the qualification endurance assembly. These were of two types: shorts to case caused by contaminants (tipoff pin) inside the relay case and shorts to case caused by the diode leads.

The changes incorporated into the high-reliability-type relay to prevent these kinds of failures were as follows:

1. A new tipoff pin was used that had a head large enough to prevent it from dropping into the relay case.

2. Two layers of insulating Mylar were put on the coil-diode assembly to prevent possible shorts of diodes to the case.

3. Different assembly techniques were applied to the coil-diode unit, and more rigid inspections were used to eliminate any possibility of an internal diode in the relay shorting to a coil.

It was recommended that the PCA be requalified because of the relay failures that occurred during the qualification test. The requalification testing was consistent with the requirement not to jeopardize the status of the particular PCA unit as a flight spare. The requalification or delta-qualification test was aborted on the first start because of two relay failures, one of which could not be explained. The second attempt at the delta-qualification test was completed with one failure (attributed to contamination). The delta-qualification test was abbreviated to preserve the flight integrity of the particular PCA unit. It should be noted that there was never a functional failure of this particular PCA unit; that is, there was never a failure of a redundant relay and a primary relay that caused the loss of a function. Therefore, the decision was made that this particular unit was flight qualified.

Digital Command Assembly

The DCA, part number 380-0050, had the following physical parameters: weight, 6.24 kilograms (13.75 pounds); length, 29.85 centimeters (11.75 inches); width, 17.15 centimeters (6.75 inches); and height, 17.78 centimeters (7.0 inches). The DCA was subjected to the qualification test in accordance with test plan LTP-4614-11 (CTR LCQ-380-005).

Each of the qualification-test programs (design limit and endurance) was completed; however, three failures occurred during these tests. These failures were related in nature and were traced to a workmanship problem that involved (1) an open weld connection (discovered during vibration testing) and (2) a loose cordwood (a potted module) that caused breakage of interconnecting leads (also discovered during vibration testing). The vibration spectrum exceeded the specification levels except for a small portion in the high-frequency region. However, the test levels always remained above the actual LTA-3 vibration levels, which were used to check validity of requirements. After the two qualification models were modified, no further deviations were necessary, and the tests were successfully completed.

RELIABILITY AND QUALITY CONTROL

A reliability and quality-control program was established for the LMP in accordance with NASA publications NPC-200-2 and NPC-200-3. The implementation of this program included inspections and testing to determine conformance of the system to contractual and specification requirements before submission of the article to NASA for acceptance. Identification and traceability were controlled in accordance with the approved quality-control program. Quality-control procedures were also implemented to ensure interchangeability, as required. A reliability program was also implemented in accordance with NASA reliability publication NPC-250-1 and the LM-contractor-approved reliability program plan (LPL-550-1).

MISSION PERFORMANCE

The LMP performed all required functions throughout the Apollo 5 mission (the only mission on which a complete LMP, as previously described, was flown). From lift-off until 06:10:00 ground-elapsed time (GET), the LM was operated in the primary mode with the LGC in control. At 06:10:00 GET, the backup mode was activated. In this mode, the LMP controlled all sequencing. Sequences III and V were used. Periodically throughout the mission, the ground-command capability was used; and, except for periods of abnormal signal strength, performance was nominal. Abrupt changes of approximately 34 decibels in spacecraft-received uhf-signal strength were detected throughout the mission. These abrupt changes in received power frequently caused the command signal to be below the message-acceptance threshold. Corresponding changes did not occur in the ground-received signal strength from the vhf data transmitters that shared the same antennas through a diplexer. Consequently, command transmission had to be delayed or repeated. The variations in received signal power were consistent with an intermittent condition in the DCA radiofrequency stage, in the coaxial-cable assembly connecting the diplexer and DCA, or in the internal diplexer connections.

On subsequent missions (Apollo 9 and 10), a modified LMP was used. The Apollo 9 LMP consisted of the DCA and the ascent-engine arming assembly (AEAA). The AEAA permitted the ascent engine to be armed and to be fired to fuel depletion after ascent-stage separation from the CSM. The Apollo 10 LMP consisted of the digital uplink assembly, which replaced the DCA, and an AEAA of a different configuration. This AEAA performed the same function on the Apollo 10 mission that the AEAA did on the Apollo 9 mission. In addition, it contained a provision for switching the guidance from the PGNCS to the abort guidance system after the ascent engine was started for the burn-to-depletion maneuver.

CONCLUDING REMARKS

Data from the design-verification test, the qualification test, and the subsequent vehicle tests as well as data from the mission show that the lunar module mission programer fulfilled all design requirements.

After qualification testing, the program reader assembly had one anomaly that might warrant one minor design change if the unit were to be redesigned. The program tape had an end-of-tape word that, when sensed, stopped either the forward or reverse search mode. The end-of-tape word was repeated three times; hence, a forward or reverse search command issued in the same direction after the word was first sensed could cause the program tape to unwind from the tape spool. The corrective action to minimize program impact was to repeat the end-of-tape word many times so that it was almost impossible to unwind the tape from the spool. If the unit is redesigned, a more positive end-of-tape sensor should be incorporated.

The program coupling assembly was plagued with relay problems from the beginning of the program. Many of the problems were a direct result of contamination inside the sealed relay can; others were unexplained problems in that no contamination or other causes of failures were ever found.

Each relay contained two directional diodes and was half-crystal can size. Therefore, the relay complexity was greatly increased. Two recommendations for redesigning the relays are that (1) the switching matrix should be a solid-state device and (2) the directional diodes should remain outside the relay can if the relay is to be used in the switching matrix.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, September 9, 1974
914-50-00-00-72

NASA-Langley, 1975 S-414

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—National Aeronautics and Space Act of 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546