NASA TECHNICAL NOTE

NASA TN D-7885

NASA TN D-7885

APOLLO EXPERIENCE REPORT - ELECTRICAL WIRING SUBSYSTEM

Lyle D. White

Lyndon B. Johnson Space Center
Houston, Texas 77058

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

1. Report No. NASA TN D-7885	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle APOLLO EXPERIENCE REPORT ELECTRICAL WIRING SUBSYSTEM		5. Report Date March 1975
		6. Performing Organization Code JSC-07618
7. Author(s) Lyle D. White		8. Performing Organization Report No. JSC S-413
9. Performing Organization Name and Address Lyndon B. Johnson Space Center Houston, Texas 77058		10. Work Unit No. 914-11-00-00-72
		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

The general requirements of the electrical wiring subsystems and the problem areas and solutions that occurred during the major part of the Apollo Program are detailed in this report. The concepts and definitions of specific requirements for electrical wiring; wire-connecting devices; and wire-harness fabrication, checkout, and installation techniques are discussed. The design and development of electrical wiring and wire-connecting devices are described. Mission performance is discussed, and conclusions and recommendations for future programs are presented.

17. Key Words (Suggested by Author(s)) ˙Wiring ˙Connectors ˙Insulation ˙Harnesses	18. Distribution Statement STAR Subject Category: 12 (Astronautics, General)

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	14	$3.25

* For sale by the National Technical Information Service, Springfield, Virginia 22151

APOLLO EXPERIENCE REPORT

EDITORIAL COMMITTEE

CONTENTS

FIGURES

APOLLO EXPERIENCE REPORT

ELECTRICAL WIRING SUBSYSTEM

By Lyle D. White
Lyndon B. Johnson Space Center

SUMMARY

The general requirements of the electrical wiring subsystems and the problem areas and solutions that occurred during the major part of the Apollo Program are detailed in this report. Thick-wall Teflon wiring insulation was used initially in the Block I command and service modules but was changed to thin-wall Teflon for Block II. This change resulted in substantial weight savings, although the thinner insulation was more susceptible to handling damage. These and other related problems were considerably reduced by the implementation of special training programs. Thin-wall polyimide tape-wrap (H-film) wiring insulation was used in the lunar modules, and a 26-gage minimum wire size was used to achieve an overall weight savings. Initial handling problems subjected lunar module wiring to considerable damage, but implementation of special training programs and incorporation of high-strength alloys for the 26-gage wire-conductor material reduced these and other related problems to an acceptable level. Experience gained during the Apollo Program indicates that the use of polyimide-film insulation, nickel-plated wire, and high-strength alloys for small-gage wire will satisfy the requirements of most spacecraft environments. Additional reliability and weight savings are expected in future programs through investigation, research, and trade-off studies in the areas of flat conductor cables and lightweight, high-temperature insulation and conductor materials. This subsystem performed well during the many and various spacecraft missions.

INTRODUCTION

Considerable experience was gained with the electrical wiring subsystems during the Apollo Program in the process of establishing requirements, procuring components, implementing procedures for fabrication and installation, and resolving problem areas. The purpose of this report is to record these experiences for the possible benefit of future space programs. Because of the large amount of wiring used and its impact on weight, volume, and the function of other subsystems, the importance of maintaining electrical wiring and connecting devices as a subsystem cannot be overemphasized. Specifically, the command and service module (CSM) contains approximately 33 700 meters (110 500 feet) of wiring that weighs approximately 600 kilograms (1330 pounds). The CSM wiring comprises approximately 30 000 wire segments and

60 000 wire connections. Similarly, the lunar module (LM) contains approximately 22 900 meters (75 000 feet) of wiring that weighs approximately 200 kilograms (460 pounds) and comprises approximately 20 000 wire segments and 40 000 wire connections.

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

CONCEPT AND DEFINITION OF SPECIFIC REQUIREMENTS

This commentary includes electrical wiring, wire-connecting devices, and harness fabrication and installation techniques for both the LM and the CSM.

Electrical Wiring

The general conductor requirements provide that the conductor be plated copper with a multistrand construction such that ductility, elongation, and brittleness do not affect flexibility or ease of handling. Other provisions include a maximum operating temperature of 478 K (400° F) for insulation materials, specific conductor resistances, and sizing tolerances.

The numerous insulation requirements include general categories of flexibility, abrasion and chemical resistance, dielectric properties, and flammability. The required upper operational temperature limit of 478 K (400° F) is maintained by the proper sizing of the circuit-protection devices.

Wire-Connecting Devices

Wire splices are either crimp or solder types. The general requirements include dielectric properties, flammability, tensile strength, and voltage-drop characteristics. Terminal boards are either the terminal stud or the modular plug-in type. The general requirements include dielectric properties, flammability, environmental sealing, and voltage-drop characteristics. Connectors are either the crimp or solder type. The general requirements include dielectric properties, flammability, environmental sealing, and voltage-drop characteristics.

Harness Fabrication, Checkout, and Installation Techniques

The general requirements for harness fabrication include determination of configuration, length, location of chafing protection, spacing of harness ties, and harness identification. The general requirements for harness installation include maximum spacing between harness supports, routing for chafing protection, separation of wiring to preclude electromagnetic interference, and specific spacing between harnesses and fluid lines. The general requirements include electrical checkout of the harness before and after installation to assure continuity and dielectric integrity. Three-dimensional harness tooling boards and mockups are essential to assure proper wire lengths and harness fit in the flight vehicle.

DESIGN AND DEVELOPMENT

Electrical Wiring

Conductors. - The conductor requirements for the CSM were met by selecting nickel-plated copper as the basic material. This material makes soldering to connector pins more difficult; as a result, most CSM connections are crimped rather than soldered. Twenty-four-gage wire was designated as the minimum gage wire to be used for vehicle harnesses.

The conductor requirements for the LM were met by selecting silver-plated copper as the basic material. This material combination is more susceptible to oxidation than nickel-plated copper but is slightly lower in resistance values. A few cases of severe oxidation (red plague) were noted; however, reasonable care during harness fabrication, such as disallowing the use of hygroscopic cleaning solvents and limiting the use of liquid fluxes, effectively eliminated this problem.

Twenty-six-gage wire was selected as the minimum size for LM vehicle harnesses. Because of breakage problems in handling this size wire, 22-gage wire was designated as the minimum size for display panels, and 26-gage high-strength wire was procured for use in other vehicle harnesses. This change in wire size requirements was effective in LM-9 and subsequent vehicles. Because the panels were removed many times for rework, excessive handling caused considerable breakage of the 26-gage wire, but the breakage was reduced to an acceptable level by the change to the 22-gage wire. The 26-gage high-strength wire was selected for general vehicle usage primarily because of weight considerations. This change also considerably reduced the wire breakage problem. As on the CSM, most connections on the LM are crimped rather than soldered, although solder connections were used in areas where ambient temperatures would not weaken the solder connection. Crimping was selected for the LM primarily because the process can be controlled more reliably than soldering. Because of the emphasis on weight savings, the use of aluminum conductors was investigated early in the Apollo Program. The investigation revealed little development in termination techniques and insufficient aircraft or spacecraft usage history; therefore, any further consideration of using aluminum was discontinued.

Insulations. - Off-the-shelf 254- to 381-micrometer (10 to 15 mil) wall thickness (thick-wall) Teflon insulation was used in the CSM Block I vehicles to satisfy insulation requirements (fig. 1). Various insulation materials were tested and evaluated to find a lighter weight material. As a result, a thin-wall insulation thickness of 177 micrometers (7 mils) of Teflon and 13-micrometer (0.5 mil) polyimide coating was implemented for all Block II vehicles. The Teflon insulation has good temperature, dielectric, abrasion-resistance, and chemical-resistance properties. The polyimide coating was added to provide additional abrasion resistance and to inhibit the tendency of Teflon to cold flow. This particular construction is available under Rockwell International/Space Division Specification MB0150-035.

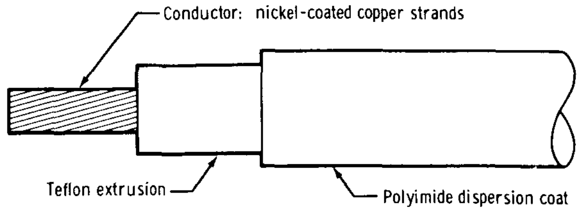

Figure 1. - Command module wire construction.

Some problems associated with this wiring were breakage, insulation damage, and radial cracking of insulation. Breakage and insulation damage were caused by mishandling; however, several handling procedures were effectively implemented to reduce the occurrence of these problems. These procedures included fabrication of special handling fixtures and special covers for harness ends, specific emphasis on careful handling, and promotion of quality awareness among the harness fabricators. Radial cracking of the insulation resulted from incomplete curing at elevated temperature during application of the insulation to the conductor. When this problem was first detected, a bend test was conducted to determine whether the insulation had been adequately cured. This test consisted of wrapping wire around a mandrel that had a diameter four times that of the wire. An improperly cured wire would develop cracks in the outer surface of the polyimide coating. The bend test was later found to be inadequate, and a "crazing" or solvent test was implemented that consisted of wrapping the wire around a tapered mandrel and immersing it in a solution of normal methylpyrrolidone. An undercured coating will appear crazed, whereas the properly cured coating will not. The solvent test was adopted as a standard test in the Apollo Program for this type insulation.

Throughout the LM program, a tape-wrap insulation was used that consisted of two oppositely wound layers, each with a 50-percent overlap. Each wrap was a bonded, laminated tape made from layers of Teflon and a polyimide film. After application of the outer tape-wrap on the conductor, a dispersion coating of Teflon was applied over the tape to provide an environmental seal and a chemically resistant barrier for the polyimide film (fig. 2). This particular construction is available under specification MIL-W-81381.

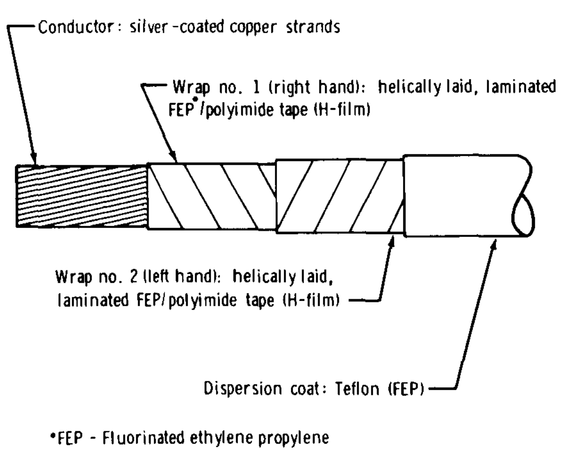

Figure 2. - Lunar module wire construction.

Chemical resistance was an important factor in both the CSM and LM wiring because of the presence of engine fuels, oxides, and water glycol. Teflon is impervious to these chemicals, but the polyimide readily degrades when exposed to the engine fuels. Because the polyimide coating on CSM wire was added primarily for abrasion resistance, degradation of the outer coating did not significantly affect the total insulation characteristics. The Teflon coating over the LM tape-wrap insulation was very critical because it protected the polyimide film in the tape, which would readily degrade and perhaps unravel sufficiently to expose the conductor. However, in both the LM and CSM, elaborate precautions were taken to guard against spills or leakage, and adequate cleaning procedures were established in case a problem occurred during ground servicing.

In the early stages of the program, separation of the layers was a problem because the exposed polyimide film was susceptible to the LM engine fuels. Insufficient curing time during the fabrication process again caused the problem. Other problems included breakage, insulation damage, and low surface-insulation resistance. Breakage and insulation damage were caused by mishandling, and handling procedures similar to those implemented for the CSM effectively reduced the occurrence of those problems. Breakage or insulation damage (or both) were checked before and after harness installation by a continuity check and a 100-megohm insulation/resistance check. Harnesses failing to meet the specified requirements were replaced.

The problem of low surface-insulation resistance occurred when the black coloring added to the dispersion coating was found to contain an excess of carbon, which made the coating less resistive than the minimum specification value of 5 megohms. This condition was not a problem in the 28-V dc or 115-V ac power circuits, and an extensive circuit analysis indicated that this can become a potential problem only in the caution and warning sensing circuits by shunting their signals through a 4-megohm (or less) resistance path to ground. A resistance greater than 4 megohms does not affect these signals. This path to ground can only occur when the conductive coating comes into contact with the wire conductor and then makes contact with ground through a resistance path of 4 megohms (or less). As shown in the cutaway views in figures 3, 4, and 5, the coating may make contact with the conductor through the metallic portions of crimp and solder splices. If the wire conductor strands are "birdcaged" by a compressive force applied axially along the wire, the coating may also make contact with connector contacts. Figure 6 shows that, with the heat-shrinkable-type tubing installed over all the splices, the shortest possible distance to ground from the conductor through the conductive coating is 1.27 centimeters (0.5 inch). If an adjacent wire is at ground potential, the path to ground is even greater. The case is similar with LM connectors (fig. 6), all of which are potted. Much of this wire was returned to the vendor; however, some wire was already installed in several vehicles. Because the resistance value of this "shortest distance to ground" was found to be greater than the 4-megohm susceptibility limit, no vehicle wiring had to be changed. Acceptance testing did not originally include surface-insulation resistance; however, a change was implemented to include this testing for the LM program. This problem did not occur in the CSM program.

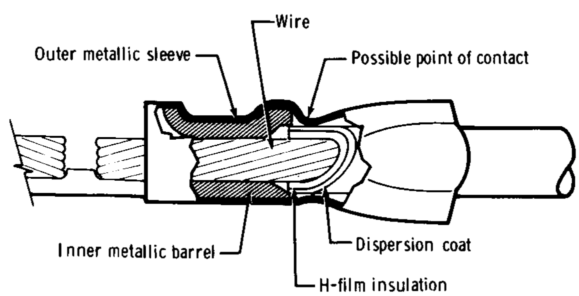

Figure 3. - Lunar module crimp splice (cutaway).

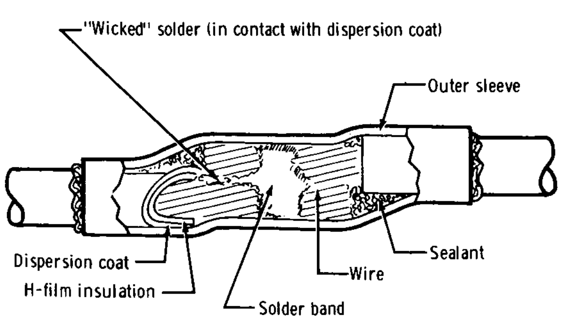

Figure 4. - Lunar module solder splice (cutaway).

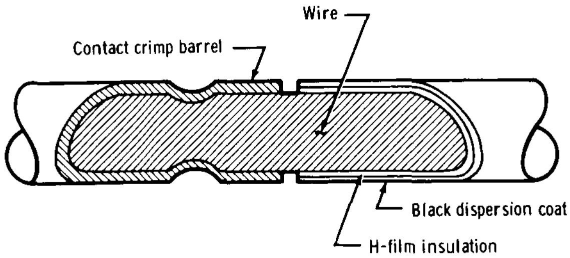

Figure 5.- Crimp connector contact (cutaway).

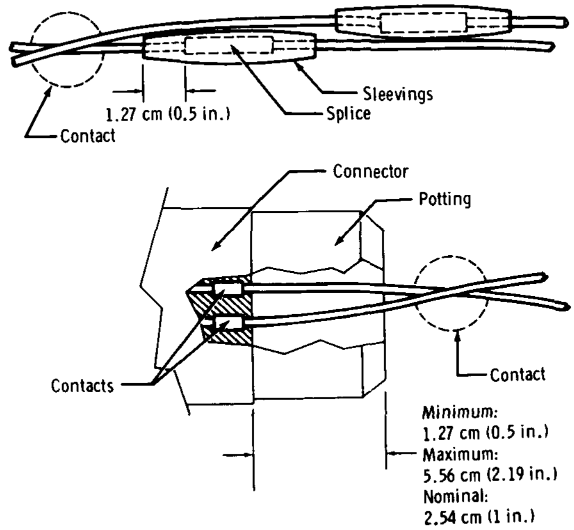

Figure 6.- Lunar module connector and splices (shortest path to ground).

Wire-Connecting Devices

Wire splices.- Crimp splices rather than solder splices were selected for the CSM to achieve better compatibility with nickel-plated wire. Approximately 250 splices were used on the CSM; the balance of "wire splicing" was accomplished by modular plug-in-type terminal boards. Because of emphasis on procedures that included several specific inspection points, sample pull tests, and daily calibration of crimping handtools, relatively few problems have occurred with these splices. Pull tests detect such problems as defective crimp tools, incorrect wire and ferrule sizes, and some operator errors. Problems early in the program included inadequate crimping, which allowed the wire to pull out, and overcrimping, which crushed the wire strands and made them brittle and more susceptible to breakage.

Splices were selected for the LM as the primary means of joining two or more wires to a common point. Early vehicles had approximately 2500 splices, but in later vehicles this number was reduced to approximately 1300. Early vehicles also used more solder splices than crimp splices, but the later vehicles reverted to approximately 900 crimp and 400 solder splices. Either type of splice is compatible with the LM silver-plated wire. (See fig. 7 for typical solder splice.) A major problem with solder splicing occurred early in the program after a considerable number of splices had already been installed in several vehicles. A large number of these splices failed during the solder-splice qualification testing because the solder joint was either underheated or overheated. In some cases, this resulted in a weak joint that would not pass preestablished values for pull testing. An extensive requalification program and implementation of more comprehensive inspection and training procedures eventually resolved this problem for LM-4 and subsequent vehicles. Those splices already installed and accessible were reinspected, and several splices were removed and pull

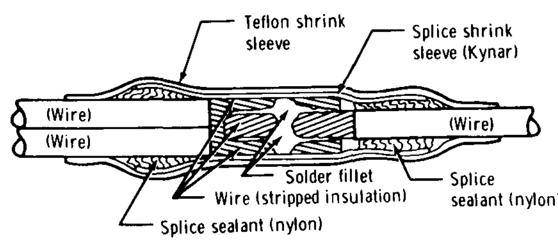

Figure 7.- Lunar module solder splice.

tested to determine their validity. Lunar module 1 was to be used for an unmanned test flight and LM-2 became a ground test vehicle. The LM-3 vehicle was scheduled for an Earth-orbital test flight, within easy rescue by the command module; therefore, crew safety would not be jeopardized. Lunar modules 1 and 3 were flown successfully after completion of only minor rework.

Later in the program, an electronically controlled, presettable soldering gun was used in an attempt to fabricate a more consistent solder splice, thus reducing fabrication time and producing a higher quality splice. However, this attempt was not successful because of the large number of variables such as the amount of solder in a splice, the number of wires, the wire size, and the color of wire insulation.

Terminal boards. - Modularized plug-in-type terminal boards were selected for the CSM as the primary method of joining two or more wires at a common point (fig. 8). Typical problems included improper seating of pins into the board and intermittent or no contact between the pins and the bus bar. The latter and most serious problem was caused by component dimensional tolerances being too great. Changes were made by the vendor to correct these tolerances, but the potential problem was not flagged by the vendor and a number of boards susceptible to this problem were installed on vehicles up to the spacecraft for Apollo 16. Because of circuit criticalities, a few terminal boards were replaced with the newer boards that had the design modification to eliminate the susceptibility to this problem. Strict control over vendor changes must be maintained to preclude this type problem. These boards were also X-rayed after the wiring was installed to help verify proper seating of the plug-in pins.

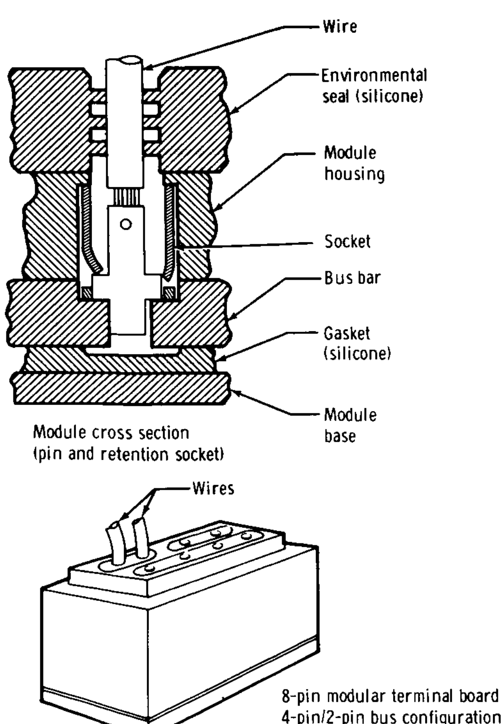

Figure 8. - Typical modular terminal board.

Connectors. - The connectors selected for the CSM had crimp-type, removable contacts with a rear environmental seal that did not require potting. The connectors selected for the LM had crimp-type contacts with a rear environmental seal and added potting for additional sealing. The potting was added primarily because of the concern that the environmental seal would not adequately seal around the LM thin-wall, tape-wrap wire insulation. Subsequent testing proved that the environmental seal around the tape-wrap insulation was adequate; however, the potting was still used as an added precaution.

Bent pins, recessed contacts, and seal damage were the most common problems and were typical of both the CSM and LM programs. Bent pins resulted mostly from mishandling, such as contact with structure or misalinement of connectors during mating. Corrective action for this problem included plastic covers for demated connectors, solid plastic inserts with predrilled hole patterns to fit over male contacts while demated, and prealinement markings on the connector shells to aid in more adequate mating. The plastic inserts were also an aid in determining that pins were not bent before mating and could, in some cases, straighten bent pins. To reduce rework or replacement of connectors due to bent pins, testing was performed to determine the number of times and the extent that pins could be straightened without pin degradation. A bent-pin log was established for each vehicle to track the history of each bent pin to ensure that the established criteria were maintained. If the criteria were exceeded, the pin was replaced.

Recessed contacts were caused mainly by technicians' failure to ensure that contacts were properly seated after insertion, although some cases resulted from broken spring retention clips.

Seal damage falls into two categories, the facial seal and the rear grommet wire environmental seal. The facial seal ensures an environmental seal at the receptacle/ connector interface. Damage to this seal can be caused by the connector pins if the connector is not properly alined before mating. Rear seal damage is generally caused by improper use of, or damaged, contact insertion tools. Either the damaged tool or its improper use can cut the seal such that its environmental integrity is destroyed. This seal can also be damaged if the wires are routed too sharply to one side and pulled too tightly, thus elongating the circular seal to the extent that no environmental seal is possible.

The occurrence of these problems was greatly reduced by the use of pictorial aids, by additional training, and by special emphasis on quality and pride in workmanship.

Harness Fabrication, Checkout, and Installation

Fabrication. - Early fabrication problems included wires that were too short or too long, sharp edges on tooling boards and mockups, lack of protective covers during fabrication, lack of support of harness during transportation to vehicle, and inadequate personnel training. To reduce these problems, the tooling boards were improved to eliminate potential damage areas, and the termination points were more accurately located to ensure proper wire lengths. Some tooling boards incorporated extensive three-dimensional fixtures for correction of these problem areas. Protective covers were added during fabrication for completed portions of the harness, and improvements were made in the tooling aids to prevent damage during transportation to the vehicle. Personnel training was improved to create an awareness of the technical details required to create consistent quality during fabrication. Implementation of more frequent inspection points also greatly improved the final product.

Checkout. - Completed harnesses on the Apollo spacecraft were checked for continuity, conductor resistance, insulation resistance, and dielectric strength. These checks were performed on the harnesses both before and after installation on the vehicle and aided substantially in locating wiring errors and damage to wiring insulation.

These checks can be performed at various voltage levels but must always be limited to 75 percent of the voltage rating of the lowest-rated connector on the vehicle harness to preclude damage to connector components.

Installation. - Installation problems included damage from sharp edges, damage from technicians working on adjacent harnesses, connector damage, and wire breakage caused by handling during installation and rework. These problems were substantially reduced by the addition of chafe guards, permanent harness tray covers, temporary harness covers, and connector protective covers. Increased personnel training and emphasis on awareness of quality workmanship also helped reduce installation problems.

MISSION PERFORMANCE

Electrical Wiring

The wiring in both the CSM and LM functioned very well during the various missions. None of the mission anomalies are known to be the result of a wiring failure.

Wire-Connecting Devices

Of the many thousands of CSM and LM wire-connecting components involved in the Apollo missions, only the terminal boards were the cause of two mission anomalies: specifically, the failure of one reaction control system engine circuit and the failure of one oxygen tank heater circuit on the spacecraft for Apollo 11. Both failures were attributable to the overtolerance boards that resulted in intermittent or open circuits. All suspect boards were eventually phased out of the later vehicles.

CONCLUDING REMARKS

Electrical Wiring

Conductors. - Based on Apollo experience, either silver or nickel plating is generally adequate for electrical wiring. The use of nickel plating results in a higher temperature capability and a 5-percent higher conductor resistance. In future programs, application of aluminum conductors for the large, heavy-gage power feeders should be investigated for possible weight savings. For small-gage wiring (24 gage or less), the high-strength alloy conductors should be used. A typical example is the 26-gage copper-chromium-cadmium alloy wire developed for and used on the lunar module; this wire is equivalent in physical strength to the 22-gage standard copper conductor.

Insulation. - Although some problems have been experienced with the combination polyimide/Teflon tape-wrap wire insulation, it is still considered to be one of the best and lightest weight insulations presently available and is recommended for future programs. Research and development are still continuing in search of a better, lighter weight, and more cost-effective insulation.

Wire-Connecting Devices

Wire splices and terminal boards. - Based on past and potential problem areas, it is recommended that crimp-type wire splices be used in future programs instead of solder-type or modular-type plug-in terminal boards for joining two or more wires to a common point. The reliability advantage of the crimp splice is that before-and-after samples can be made and tested to ensure the quality of splices installed in a vehicle. The crimp splice also has a weight advantage over terminal boards. A minimum of 5.4 kilograms (12 pounds) of terminal boards is required to terminate the same number of wires that can be terminated by 0.5 kilogram (1 pound) of wire splices. The major advantage of the modular terminal board is that wires may be easily connected and disconnected and, if specific procedures are followed, a reliable connection will result. Generally, the main disadvantage of wire splices is that environmental sealing of two or more wires in one end of the splice is difficult to control and must be closely inspected.

Connectors. - For future programs, connectors incorporating a rear environmental seal that does not require the additional potting procedure for sealing purposes are recommended. The connector pins ideally would be crimped or welded to the incoming wire and would be removable from the rear of the connector. Elimination of the potting saves weight and assembly time, whereas the rear-removable pin can potentially save retest time if pin replacement is necessary. This feature precludes the need for connector demating and often obviates subsequent retesting of all affected circuitry in the connector.

In conclusion, the proper selection of materials and hardware for wiring and connecting devices can result in weight savings, reduced manpower expenditures, and increased reliability.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas, September 5, 1974
914-11-00-00-72

NASA-Langley, 1975 S-413

"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