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File



National Aeronautics and Space Administration
Procurement and Contracts Division
General Research Procurement Branch
Houston, Texas 77058

28 August 1969

Attention: Mrs. Hilda Bolling Edwards
Subject: Contract NAS 9-5829 (EASEP) Schedule II
Final Report
Enclosure: (1) Two copies Final Report MA-29/BSR-2733
dated 8 July 1969

Gentlemen:

Pursuant to the requirements of the subject contract, Exhibit F, Item 43, and Exhibit F-1, Item 46, enclosure (1) is forwarded herewith.

The twenty-five copies of the Final Report required by Exhibits F and F-1 were forwarded directly to the Lunar Surface Program Office by Bendix, transmitted on 27 August 1969.

Should you have any questions regarding this report, please contact the undersigned.

Very truly yours,

THE BENDIX CORPORATION
AEROSPACE SYSTEMS DIVISION

G. D. Ballard
Contract Administrator

GDB:ms



Final Report

EARLY APOLLO SCIENTIFIC
EXPERIMENTS PACKAGE (EASEP)

MA-29/BSR-2733

8 July 1969

REVISIONS

LTR.	DATE	PAGE	DESCRIPTION

TYPE

II

PRELIMINARY

FINAL



**Aerospace
Systems Division**

BENDIX DOCUMENT:

EASEP-MA-29

DATE: 8 July 1969

TITLE

Final Report - Early Apollo Scientific Experiments Package (EASEP)

MSC DOCUMENT

DELIVERY REQMT.

Exhibit E, Para. 3.1.3
Exhibit F, Item 43
Exhibit F-1, Item 46

MSC CONTRACT

S/A 65S
to NAS 9-5829

APPROVALS

NASA/MSC

COGNIZANT MANAGER

PROGRAM MANAGER

BENDIX

[Signature]

COGNIZANT MANAGER

[Signature]

PROGRAM DIRECTOR

FOREWORD

This report is published to document and fulfill the requirements of S/A 65S to NAS 9-5829, Exhibit E (Paragraph 3.1.3) and Exhibits F and F-1 (Items 43 and 46, respectively) for a final report on the Early Apollo Scientific Experiments Package (EASEP). The EASEP program was authorized by NASA/MSC-Houston to provide a lunar surface instrumentation package for the Apollo 11 spacecraft, scheduled for flight to the Moon on 16 July 1969 from NASA/KSC. The EASEP flight system, consisting of Subpackages 1 (PSEP) and 2 (LRRR), was formally accepted by NASA/MSC on 29 April 1969.

The information presented herein is compiled and summarized primarily from data presented in monthly progress reports issued during the EASEP program. The period covered by this final report runs from 1 October 1968 through 15 June 1969.

Internal
Memorandum

Date 19 June 1969 Letter No. 981-208

To C. J. Weatherred

From K. Hsi

Subject EASEP/PSEP Final Report

The engineering activities on PSEP have been organized by the functional groups which were primarily responsible for the activities although several groups usually participated in each activity. The accomplishments of the various groups are summarized below.

1. System Engineering

1.1 Isotope Heater Integration

An interface meeting was held at the AEC Headquarters on October 31, 1968 to discuss the heater requirements and to work out a preliminary interface description.

A second interface meeting was held at MSC on November 27 during which the complete interface was defined including major milestones and hardware delivery dates. An interface control drawing (ICD) was signed at this meeting. An interface control specification (ICS) draft was also reviewed. The ICD was then updated and routed to Mound Laboratory, AEC and MSC for approval.

A presentation of the interface factors and constraints was made to the Project Certification Panel at MSC on March 6, 1969 at which time the panel approved the use of the heaters on EASEP. Mechanical and electrical heater models were received from Mound Labs during February for use in qualification and acceptance system tests. The flight heaters were delivered by the AEC to KSC on April 4 which was one month ahead of schedule.

1.2 PCU - Solar Panel Compatibility

Engineering tests were made of the PCU - solar panel electrical interface by use of a flight-type PCU and a solar panel simulator. This simulator was capable of duplicating voltage versus current characteristics for various sun angles relative to the solar panels. These tests verified the feasibility of using the PCU, including shunt regulator with the solar panel concept. There was no degradation in stability or regulation. The test results are described in EATM-17

1.3 Specifications

The following specifications were prepared and updated as required:

- a. KSC Handling Model Specification, CP 100013
- b. PSE Specification, AL 270000, Add. 1
- c. PSEP CEI Specification, CP 100500, Parts I & II
- d. Interface Specification for Radioisotope Heaters, IC 314127

1.4 Studies and Reports

Following is a listing of some of the studies and reports generated on the PSEP program:

a. Antenna Pointing Analysis

A study was made to determine the down link signal strengths with variables of lunar landing site, local lunar slope, deployment alignment errors, hardware alignment errors and lunar librations. A computer program was written to calculate the signal strengths versus time for several worst case combinations. It was determined that 30' antenna reflectors are adequate for most of the PSEP mission life. The study is described in EATM-12.

b. Measurement Requirements Document

This is an updating of the ALSEP Measurement Requirements to delete measurements of experiments not being carried and to incorporate measurements unique to PSEP. This document is EASEP-SE-01 with the A revision of 15 April 1969 version being the latest version.

c. **Command List**

The PSEP Command List, EATM-4B, 25 April 1969, is an update of the ALSEP Command List.

d. **Weight**

Weight estimates were made at several points in the program and published in EATM-3.

e. **Central Station Modifications**

Studies were made to determine the optimum changes for ALSEP Flight 2 central station in the conversion to PSEP.

f. **Power Balance Studies**

Studies were made to determine power requirements, optimum regulator range, power balance for several operating conditions and operational constraints. These studies are documented in EATM's 32, 33, 38, 40 and 44.

g. **Radiation Effects**

It was verified that radiation from the radioisotope heaters will have no effects on the PSEP. This study is presented in EATM-41.

h. **Design Certification Review Report**

This report provides detailed documentation of the Design Certification of EASEP. The performance is described and the program of testing this performance is summarized.

i. **On-Pad Inspection of Connectors**

Two approaches were used to meet this requirement: radiographic and continuity. These studies are described in EATM's 58 and 75.

1.5 **System Engineering Support to Test**

The system engineering support for the test effort consisted of review of the test procedures, participation in the pre- and post-test meetings and participation in the conduct of the tests.

2. Mechanical Design

The Mechanical Design Group was responsible for all of the design and integration activities related to utilization and modification of ALSEP Flight 2 hardware, design of a functional Crew Training Model, KSC Handling Model, Qualification Model and Flight Model.

2.1 Requirements and Constraints

The PSEP overall design philosophy had many parameters and constraints to satisfy. The major requirements from mechanical design considerations are summarized below:

- a. The critical schedule that was imposed on the EASEP program had a great effect on design decisions and was an influencing factor in the overall mechanical system design.
- b. The Flight Model had to be capable of being easily assembled while on the pad within the SLA (Spacecraft-LM-Adapter). This implied that the unit had to be designed to be assembled in "kit" form with minimum number of subassemblies.
- c. The Flight Model design had to be such that the system could be deployed within four minutes without astronaut tools, yet most phases of deployment had to be accomplished from a working height of twenty inches from the lunar surface.
- d. The design of the Training Model had three major constraints - it had to be lightweight, the design release had to be complete within three months after start of program and it had to reflect all of the functional requirements to be performed by the astronaut for the Flight Model design.
- e. The KSC Model design was also required early in the program, and had to reflect the subassembly levels for the Flight Model.
- f. Due to the requirements of the thermal design, a major design effort was required such that when deployed, all items on the package were isolated from the PSE Mounting Plate in order to minimize heat leaks from the Central Station.

2.2 Accomplishments

The major activities of the PSEP mechanical design are summarized below:

- a. Due to the early definition requirements of the two Isotope Heaters that were utilized, it was necessary to establish a Mechanical Interface very early in the program. The interface had to be such that it provided flexibility of mounting so that it could be easily assembled within the SLA, and also had to provide for mounting of the thermal insulation that was required. There was only one minor change made to the Mechanical ICD after its design release.
- b. Because of the long lead time required for the solar panels a major effort at the beginning of the program was the definition of the solar panel interfaces. It was necessary to make early decisions on the panel size, location, mounting method, deployment method and panel detail design. The panel design and the ICD for solar cell incorporation was accomplished and a sub-contract was given to LTV to fabricate the panel substrates.
- c. A second long-lead item requiring early detail design effort was the PSE Mounting Plate. The plate had to have the proper stiffness for dynamic response consideration of the PSE, and had to be compatible with the ALSEP Central Station and Primary Structure mounting. In addition, second surface mirrors were included on the plate, and the ICD for the mirror mounting had to be defined while the program was still in the preliminary design stage. The mounting plate design was completed early and the fabrication was subcontracted to LTV. The plates were then delivered to Lockheed where the second surface mirrors and vacuum metalizing was incorporated. Two PSE Mounting Plates were delivered to Bendix in February 1969.
- d. The modification to ALSEP Flight 2 and the requirement to thermally isolate the thermal plate and mounting plate from the structure necessitated the design of a new fastener system. Due to the conflicting requirements of structural rigidity and thermal isolation and the consideration for dynamic environments, an exhaustive

study was made which centered around "many fasteners of low strength but high thermal resistance" vs. "minimum quantity of high strength fasteners vs. low thermal resistance". A compromise design was developed which adequately met the needs of the thermal system, structural system, and dynamic considerations. The key to the design was a pin joint design which utilized the principle of minimum contact for thermal conduction, yet maintained rigidity in the critical loading axis.

- e. Modifications were made to the PSE subsystem to allow permanent installation on the subpackage. New mounting posts were designed to lower the experiment c. g., the cable reel was eliminated and the cables were shortened. The shroud skirt was also modified to enclose the thermal control system, and velcro was used as the method of fastening to the mounting plate. An additional thermal covering was required for plume heating effects, and was separately assembled within the SLA. Insulation was also added to the experiment cables to minimize heat leaks. An additional requirement imposed by the permanent mounting was that of electrical isolation. To accomplish this a special bolt was designed together with insulating washers. A test was performed to insure that transmissibilities thru the isolator system did not change the environment to the PSE.
- f. The ALSEP Primary Structure was utilized for the PSEP design. This presented a considerable design problem in that the structure was not initially designed to take the directional loading that was required for PSEP. Because of the thermal constraints, the solar panels, antenna, and boom support all had to be supported directly by the structure. In order to accomplish this the solar panels were supported such that fore and aft loading was absorbed by the front channel while the rear portion of the structure supported only X-axis loading. The structure was modified to include ample stiffeners to minimize deflections, the connectors were relocated, and the astronaut handle was rotated 90° so that it served the dual function of structural support for boom lowering as well as carrying on the lunar surface.

- g. The Central Station was modified slightly in that the reflector springs and thermal spacers previously used on Flight 2 were deleted, as well as cables previously used for other experiments. The Central Station heaters were removed and the power dissipation module was changed to include the resistors for a narrower range regulator and other dump loads.
- h. An automatically deployed antenna was one of the design features of the PSEP. From its stowed position, the antenna deployed to within astronaut reach, and a detent system was utilized to position the antenna to the five possible landing sites. The key feature was a dual pivot mechanism that maintained rigidity thru vibration, and became operational after deployment.
- i. There were approximately 450 new drawings released for the PSEP design for the four models. The Training Model and KSC Model had separate complete sets of drawings. The Qualification and Flight Models had most parts common, but required individual sets of Assembly Drawings.
- j. Extensive Engineering Support was provided (24 hour coverage) during the critical fabrication and assembly phases of the Qual and Flight Models. Support was also provided to monitor the mechanical testing during the qualification and flight acceptance tests.
- k. Vibration analyses were made to support the design and test activities. The dynamic environments for components on PSEP were somewhat different than for the corresponding components on ALSEP because of the changes in mounting hardware. These analyses are presented in EATM's 60, 77, 79 and 85.
- l. Also supporting the design activities, there were continual analyses made of mechanical stresses in the various components. Some of these analyses were documented in EATM's 62, 66, 67 and 70.
- m. A plume heating modification kit was also designed subsequent to the flight model delivery.
- n. Engineering support was provided for the KSC walk-thru, the astronaut deployment of the Flight Model at KSC, the installation of the thermal modification kit, and installation of PSEP within the SLA.

3. Solar Power

The solar power activities were related to the development of the solar panel array, direction of the subcontracted effort and integration and test efforts. Following are some of the significant milestones:

- a. A subcontract package including specification and statement of work was prepared and bids requested during October. Two proposals were evaluated and the subcontract was awarded to Spectrolab. Negotiations with Spectrolab were completed by November 26. The program required Spectrolab to design, fabricate and qualify the solar cell panels. Two solar panel arrays with six solar cell panels each were delivered to Bendix, one for system qualification tests and one for integration into the flight model. Three additional panels were delivered as manufacturing spares.
- b. The Critical Design Review and the Qualification Test Readiness Review for the subsystem panel tests at Spectrolab was held on 12 December.
- c. The qualification tests at Spectrolab consisted of six cycles, in vacuum, of temperatures from -275°F to $+240^{\circ}\text{F}$; sinusoidal and random vibration; shock; and acceleration. Electrical performance was verified during and after these tests. These tests were conducted during December and January.
- d. A Qualification Assessment Review was held at Spectrolab on 24 January 1969. The test results were approved and the panels were qualified as a subsystem.
- e. System qualification panels were delivered to Bendix on 10 January and the flight panels on 21 January. Functional and environment acceptance tests were performed on these panels at Spectrolab before shipment to Bendix.
- f. A power subsystem integration test was conducted using three qualification solar panels to verify the solar panel - PCU compatibility.
- g. Following the system qualification tests three of the qualification panels (half of the array) were sent back to Spectrolab for performance verification. It was determined that no change in performance had occurred as a result of the system qualification tests.

- h. The final report on the Spectrolab qualification program is published as EATM-82.
- i. Engineering support was provided to manufacturing and test for integrating and testing the solar panels with qualification and flight models.
- j. As a related activity the engineering group provided help in the integration of the new GFE dust detector experiment. Two dust detectors were provided. One was used as a qualification model and the other was integrated into the flight unit.

4. Thermal Engineering

The PSEP has a new thermal control concept as compared to ALSEP because electrical power is available only during lunar daytime. The new system was engineered and designed to dissipate thermal operating and sun loads during the day and yet provide enough isolation and thermal energy to prevent the nighttime temperatures from falling below -65°F . The nighttime thermal energy is provided by two 15 watt radioisotope heaters mounted on the PSE mounting plate which is also the system radiator. Second surface mirrors were also located on this plate to provide optimum rejection of solar energy and yet retain good radiative properties. The design as shown by test and analysis, was completely successful. It not only met but exceeded the thermal design specification of -65 F to $+140\text{ F}$. The final lunar operational prediction (based on flight acceptance test data) is -58 F to $+134\text{ F}$ without any active dump commands or the plume heating modification kit.

Some of the activities of the thermal engineering group were:

- a. Parametric analyses of six PSEP basic configurations were performed to help determine the final configurations. A detailed study was performed to determine the optimum separation distance between the solar cell panels and the C/S.
- b. A detailed steady-state analytical model for PSEP was developed. This model consists of a computer program to determine heat flow, radiation interchange and steady state temperatures of the PSEP as deployed on the lunar surface. This model was continually refined and updated throughout the program to evaluate proposed changes on the system and optimize the system design.

- c. An isotope heater and masking pattern study was made to determine the best location for the heaters and to determine how much of the PSE mounting plate should be covered with mirrors. Consideration was given to heat flow paths and temperatures within the central station with the objective of minimizing temperature gradients and yet maintain the goal of a $+140^{\circ}\text{F}$ to -65°F day-night swing for the average plate temperature. Preliminary and final results of this study are given in EATM's 10 and 48.
- d. A special study was conducted to aid in the selection of a suitable fastener system to use between the primary structure and the component mounting plates. The objective was to minimize the conductance and yet provide adequate support for the mounting plates. The results of this study are summarized in EATM-23.
- e. A specification, interface control drawing, and statement of work were prepared for a subcontract for the second surface mirrors. This subcontract was awarded to the Aerospace Sciences Laboratory of the Lockheed Missiles and Space Co. Negotiations were completed in January 1969. The PSE mounting plates were shipped to Lockheed where the mirrors were installed.
- f. A PSE mounting plate skin thickness study was made to insure that the isotope heater input could be conducted throughout its entire area. The results are documented in EATM-39.
- g. A trade-off study was performed to minimize the heat leak through the PSE cables. It was determined that new cables with manganin inserts were not feasible within the program time constraints but that the cables and connectors could be insulated resulting in a decrease in the heat leak between the experiment and the structure.
- h. The thermal balance effects of various regulator ranges were studied to help optimize the setting for the much lower input power from the solar panels as compared to an RTG.
- i. Considerable effort was spent in thermal-vacuum test planning both for the qualification and flight models. This effort included design of the heater networks to simulate the thermal dissipation within the central station, design of heaters to force the solar panels to the proper temperatures, and general planning of the tests.

- j. A model was developed to predict system temperature in the thermal vacuum chamber. This model is different from the lunar model because of limitations of the lunar environment simulation in the chamber.
- k. A study was made of thermal paint and primer cure times so that manufacturing process time could be minimized.
- l. Round-the-clock thermal engineering support was provided during all thermal vacuum test set-up and operating time.
- m. The thermal-vacuum test data were processed into engineering units and analyzed. Selected channels have been machine plotted.
- n. Using the detailed analytical model and the test data, lunar surface operating temperatures were predicted.
- o. A special study was performed using the SEQ bay thermal data provided by NASA/MSC to determine the PSEP temperature at the time of withdrawal from the LM SEQ bay. It was shown that the SEQ bay should be painted black to reduce the PSEP temperatures to an acceptable level.
- p. The LM ascent stage plume heating effects on EASEP were determined based on heat flux provided by NASA/MSC. A plume heating protection system was engineered and designed (CCP-195). Engineering support was provided during the manufacture and installation of the Plume Heating Protection Mode Kits on both the Flight and Qualification models.
- q. Engineering support was provided during the planning, test setup and performance of the special PSEP creak test for the PI. The thermal-vacuum test data were processed into engineering units and analyzed.
- r. A transient analytical model was constructed for evaluating the PSEP thermal response over a complete lunar day-to-night cycle. This model will be employed for real-time data analysis during the lunar operational mission.

5. Crew Systems

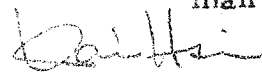
The crew systems group performed studies related to the astronaut interface. All of the design innovations which effected the crew in the deployment were evaluated by the crew systems group. Mockups were built and tested in various environments until the group was satisfied that the astronaut would be able to perform the intended function with a minimum of complexity. Significant new innovations were the boom handle interface, pallet handle rotation, and solar panel release scheme with lanyards. Some of the specific activities were:

- a. A demonstration of the PSEP crew concept model, tasks required and sequence was made for Dr. D. Lind on December 6, 1968.
- b. The Crew Training model was demonstrated and acceptance tested on January 15, 1969.
- c. A shirt sleeve deployment of the PSEP was made by Dr. Lind for astronauts Aldrin and Armstrong on January 20.
- d. Deployment tests in a 1/6 gravity condition aboard a KSC 135 were made by Dr. Lind. Deployment tests are described in EATM-31.
- e. The PSEP Crew Systems Interface Control Specification, IC 314219 was prepared and submitted to MSC.
- f. Deployment tests were performed during January in the Lockheed visual simulation laboratory with generally acceptable results.
- g. Fit checks and package removal from the LM 6 SEQ bay were made by astronaut Schmitt on February 18. These tests were successful.
- h. Practice deployment tests were made by Aldrin and Armstrong on 24 February with general acceptance of the tasks.
- i. Several time-line deployment sequences, both for one and two crew members, were developed during the program. These are detailed in EATM's 16 and 24.

6. Ground Support Equipment

The ground support equipment (GSE) group was responsible for the design of the GSE required to install the PSEP aboard the lunar module (LM). Because of schedule considerations, the PSEP equipment had to be loaded aboard the LM after the Apollo vehicle had been moved to the launch pad. This requirement led to design constraints for the flight equipment that permitted disassembly to the point where each subassembly could be moved through the hatches and reassembled inside of the Spacecraft-LM-Adapter (SLA). To accomplish this, a rather specialized line of GSE was required to house the various sub-assemblies of the Flight Model. Some of the activities associated with the development of this equipment included:

- a. Preliminary designs were established as soon as the flight equipment concepts began to evolve. Other design requirements were established such as the use of non-burnable materials for on-pad installation.
- b. A walk-through at KSC to firm up GSE requirements was participated in during December 1968.
- c. During January, the design of the Solar Panel and Antenna carrying cases were completed. A fiberglass and foam construction was arrived at for these cases primarily to meet the fire safety requirements. Designs for handling fixtures for the Central Station and PSE were also completed. The designs of a carrying case and handling tool for the Isotope Heaters and shroud was initiated during this period.
- d. During March the GSE was received from the vendor. The GSE was fit checked and modified as required prior to delivery to NASA.
- e. A specialized set of tools was required for the assembly of the units, and a tool kit was designed and delivered to KSC. The design of the tools included requirements for tethering and the ability to transfer the GSE and tools from man to man using a tethering system.


K. Hsi

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**Internal
Memorandum**

Date 26 June 1969 Letter No. 989-101

To C. J. Weatherred

From J. Brueger



Subject EASEP/LRRR Final Report

The significant engineering activities on LRRR have been organized by the functional areas which were primarily responsible for the reported activities, although several areas usually participated in each activity. The activities involved in the functional areas are summarized below.

1. Mechanical Design

The LRRR basic design concept was developed on the basis of preliminary requirements from Dr. Alley, the University of Maryland experiment P.I., and LSPO, NASA/MSC during September 1968. Additional requirements, which contributed to the design concept and the development program definition and which are reflected in the contract design specification and work statement, were established at a number of meetings with NASA, the P.I., ADL (the array suppliers for the University of Maryland experiment) and Bendix during early October 1968. Contract go-ahead for schedule purposes was 15 October 1968.

The design concept was reviewed and accepted, with minor revisions, by Astronaut D. Lind at Bendix on 16 October and by LSPO at NASA/MSC on 18 October 1968. Design data were provided to the Bendix Crew Systems group for the fabrication of a concept mockup.

Inputs from the concept mock-up deployment testing by Crew Systems and by D. Lind, NASA/MSC, and from a KSC walk-through with the concept mockup in a SLA mockup contributed to the establishment of the final LRRR design.

Design of the Flight/Qual models was pursued in parallel with the design of the Crew Trainer Model, with many parts involved in the crew interface being identical in design. The 15 January 1969 delivery date for the Crew Trainer Model required that drawings be released starting in November and that a majority be released by mid-December. This required an early agreement on the Crew Trainer design and, consequently, on those items of the Flight design involved in the Crew interface. NASA/MSC approval was provided at a Bendix design review on 3-4 December 1968.

The LRRR Program required that a retro-reflector array for either a University of Maryland experiment (Dr. C. Alley, P.I.) or for an AFCRL experiment (Dr. D. Eckhardt, P.I.) was to be incorporated in the LRRR design. A common attachment interface was established early in the LRRR design effort for both array designs at the tilt axis pins, the rear tie-down pins and the aiming handle attachment brackets. The University of Maryland array was supplied by Arthur D. Little, Inc. under a subcontract to Bendix for which the mechanical interface was defined in ICD 2342000. The AFCRL array was to be assembled by Bendix with the array structure designed and fabricated by Bendix, the retro-reflector assemblies supplied by General Electric, Valley Forge and the retro-reflectors by Orbitex Optical Corp. (Initially these retro-reflector assemblies were to be GFE but, under the final contract SOW, they were supplied under subcontract directly with Bendix. Also the number of assemblies required on each array changed from two to four). The design of the AFCRL array structure was performed in the Mechanical Design group and was completed for the LRRR CDR, about the time the array design decision was to be made by NASA. Drawings were not released for fabrication, however, because of the NASA/MSC decision to pursue only the University of Maryland experiment design to program completion.

Initially, the LRRR was designed to permit handling in the SLA as a total assembly, with the exception of the boom attachment assembly. The Bendix design review on 3-4 December, however, established that the LRRR would be handled as five disassembled parts and the design was to permit LRRR assembly in the Apollo SLA, outside the LM SEQ door. Some additional design effort was required to accommodate this change. This handling requirement was later modified at the LRRR CDR to require only installation of the rear support and boom attachment assembly on the LRRR in the SLA.

The ability to disassemble and assemble the array and the angle indicator bracket on the pallet assembly in the SLA was retained in the design, however.

The LRRR Critical Design Review was held on 15-16 January 1969. The LRRR Flight/Qual design was completed and accepted, with requests for only a few minor changes. The basic design of the Flight and Qual Models differed only in the use of a pallet having LM-3 interfaces and no boom attachment for the Qual Model.

The Crew Trainer Model was delivered on 16 January, at MSC request (it was available on 15 January, as scheduled); Mechanical Design provided liaison throughout the fabrication of this model and a number of inputs to the Flight/Qual design resulted from this fabrication experience.

The design of the KSC Handling Model was begun in December 1968, with many parts being the same design as for the Flight Model, to meet a 10 March 1969 delivery date. This model was provided to permit confirmation of the handling capabilities of the LRRR in the SLA and installation into LM and for training of the KSC crews to be eventually involved in this activity with the Flight Model. The design provides the capability for array removal and installation in the SLA, as in the Flight Model, though this requirement was deleted at the LRRR CDR.

The KSC model design was reviewed and approved by NASA/MSC at a CDR follow-up meeting on 5-6 February 1969. Again, Mechanical Design provided liaison throughout the fabrication of this model and the KSC handling model was delivered on 14 March. This date was later than the scheduled date of 10 March as a result of a new NASA requirement to fit-check the model with the Flight GSE.

The initial design of the LRRR defined sun compass plates and array angle indicator brackets which provided markings and indexes, respectively, for 4 or 5 potential landing sites, based on a time schedule for potential landing sites provided by NASA/MSC in early program verbal communication.

Different sun compass plates were designed to compensate for changes in sun latitude with launch date. In addition, pointing accuracy could be improved by providing markings on the sun compass plates and index holes on the array angle indicator brackets for only 4 sites when the number was compatible with the landing site schedule.

Communication received after the CDR, and later confirmed at program reviews, defined the need to provide for 5 landing sites throughout the launch schedule and, in addition, revised the site identification number assignments. Exact site locations were defined in a letter from NASA/MSC dated 22 January 1969, as modified by a telecon communication on 10 March 1969. These changes necessitated a number of drawing changes and some new drawings for sun compass plates. The final Flight design provides for array aiming and alignment at any one of 5 lunar landing sites for launch dates through February 1970.

Go-ahead was provided by MSC on 18 February 1969 to design and fabricate an array protective cover to be deployed by the astronaut during LRRR deployment on the lunar surface. A proposal for this effort was requested as a CDR action. The purpose of the cover was to protect the array retro-reflectors from dust, debris, and contaminants primarily while in the LM SEQ Bay. A concept mock-up was fabricated to permit concept evaluation and establishment of the final design at Bendix. The mockup was reviewed at a PDR at NASA/MSC on 21 February. Protective covers were fabricated and installed on the Crew Training Model, KSC Handling Model, the Qual Model and the Flight Model.

A Qual Test Readiness Review of the LRRR was held at Bendix on 25-26 February. Mechanical Design provided liaison and support throughout the entire fabrication and assembly of the Qual and Flight Models. The Qual Model was completed on 25 March. Liaison and support was then provided to the EASEP Test Department during the Qual test program which ran from 27 March to 14 April.

A Flight Test Readiness Review of the LRRR was held at Bendix on 25-26 March. The Flight Model was completed on 9 April. Liaison and support was provided to the Test Department during the Flight Acceptance test program which ran from 10 to 14 April.

Two failures, which occurred during the Qual Model mechanical functional deployment test, resulted in subsequent design changes. The forward spring retainer collar bonding on the aiming handle failed when the handle was deployed. A design change added two spacers, bonded to the handle, to supplement the shear force capability of the collar.

Also the right trigger release mechanism on the alignment handle did not release when pulled by the test operator. A design change was made to re-orient the lock assembly on the release mechanism

to utilize the normal rotational motion of the mechanism to pull it free after retraction. After incorporation of these changes in the Qual and Flight Models, both models deployed successfully on every subsequent occasion (ie., test, demonstration and Apollo 11 astronaut deployment at KSC).

The EASEP Qualification Assessment Review was held at Bendix on 18 April and the LRRR was deemed to be qualified. The EASEP Customer Acceptance Readiness Review was held at Bendix on 28-29 April and the LRRR was accepted for delivery. The only open items were incorporation of the signed CEI specification in the ADP and submission of the DCR report. Both of these items were subsequently accomplished; the former, on 29 April and the latter on 7 May. The DD-250 was signed on 29 April and the LRRR Flight Model was shipped to KSC on 30 April.

Subsequent to the delivery, go-ahead was given by NASA/MSC to design, fabricate and install a protective cover mod kit over the array insulation on the Flight Model at KSC. Actual installation was accomplished on 11-12 May by the Mechanical Design group.

A decal mod kit, provided as GSE, was also installed on the Flight Model at KSC to aid astronaut deployment. Support was provided to complete a successful Apollo 11 crew deployment test of the Flight Model and Crew Trainer Model on 16 May, to restow the Flight Model and to install the Flight Model in the LM-5 on Apollo 11 on 25 May.

Procedures were prepared for astronaut handling of contingencies which could possibly arise during LRRR deployment in the Apollo EVA. It is planned to support the real-time EVA at NASA/MSC during the Apollo 11 mission.

2. Experiment Engineering

The experiment engineering area covered the complete development of the retro-reflector array for the University of Maryland experiment and the initial phase of the development of an array for the AFCRL experiment.

a. University of Maryland Experiment (Dr. C. Alley, Principal Investigator)

The array design concept was established on the basis of the Principal Investigator's design decisions reported at a NASA Headquarters meeting on 8 October 1968. These design decisions resulted from studies performed by the University

of Maryland and by ADL, for the U of Md., and were dictated primarily by program schedule constraints. The concept definition was then reflected in the design requirements defined in the LRRR contract specification and the array design specification which governed the ADL development of the LRRR array.

The array structural attachment interface was established early in the program at the forward tilt axis pins and the rear tie down pins; attachment interfaces for the array aiming handle brackets were also defined. These mechanical interface requirements, as well as envelope requirements, were formalized in ICD 2342000.

The retro-reflectors to be installed in the array were developed by Perkin-Elmer and Boxtton-Beel under contract to the University of Maryland; they were supplied GFE to ADL/Bendix for the array development tests and for the Flight and Qual Model arrays. The retro-reflector envelope and the performance characteristics, for ADL analysis purposes, were formally defined in ICD 2342001. ADL was given the task of designing the array to support 100 individual retro-reflectors and to maintain their alignment throughout exposure to mechanical and thermal flight and lunar environments and to provide a passive thermal control system which would, as a design goal, minimize performance degradation due to the lunar thermal environment.

The program at ADL was to be conducted in two phases; Phase A, to design the array and conduct development tests to verify the design to the extent permitted by the time available; Phase B, to complete development testing and to fabricate, test and deliver a qual array and a flight array to support the Bendix LRRR system qual tests and LRRR Flight Model tests and delivery schedule. Initiation of Phase B was contingent on a NASA decision to select either the University of Maryland experiment or the AFCRL experiment for continuation at the end of Phase A.

Design reviews, attended by the P.I., were conducted by Bendix at ADL in October and at Bendix in November. Single corner mounts, with ADL-procured retro-reflectors installed, were subjected to mechanical tests and thermal conductance

tests to establish the retro-reflector mount design. Although the GFE retro-reflectors for the array Engineering Test Model (ETM) were delivered late, ADL successfully completed all ETM mechanical tests planned for Phase A prior to the array CDR on 3 January 1969.

As a result of direction given at the LRRR program review on 3-4 December, a requirement for retro-reflector orientation control was established, and accepted by ADL with no schedule impact, and consideration was given to reducing the array louver height-to-width ratio; after considering the thermal control - incident ray blockage trade-offs, the original louver height-to-width ratio requirement was retained by the P. I.

The array design was approved by Bendix, the P. I. and NASA at the array CDR on 3 January 1969, subject to the implementation of a number of changes. The only significant design changes involved those required to accommodate a change in retro-reflector height (requested by the P. I.) and finalization of the retro-reflector retaining ring torque (based on a trade-off between mechanical effects and thermal effects).

The University of Maryland experiment was selected by NASA for continuation into Phase B. Results of the ADL CDR were summarized at the Bendix LRRR CDR; a geometry change in the array retainer ring, to reduce off-axis obscuration, was proposed by Dr. Faller, Associated P. I. Based on results of a Bendix/ADL evaluation, the change was directed by NASA with no program impact.

ETM thermal distortion tests were successfully completed in January and results of all ETM tests were presented for Bendix, NASA and the P. I. at an ADL review on 3 February.

GFE retro-reflector deliveries to ADL for the Qual and Flight model arrays were started on 4 February. However, requirements to rework a large number of the retro-reflectors and fabrication limitations at Perkin-Elmer resulted in final delivery of all corners by 8 March. (Scheduled date was 24 February). ADL was able to "work-around" this problem and a subsequent requirement to re-run the Qual model array acceptance tests due to a hardware failure with minimal schedule impact. The array delivery delays were limited to about one week for both the Qual

and Flight Model arrays. (21 March versus 14 March for Qual, 27 March versus 21 March for Flight.)

The hardware failure at ADL occurred during the initial acceptance vibration tests of the Qual Model array. A number of retaining rings vibrated loose and a revised staking technique was developed and incorporated on both the Qual and Flight Model arrays. Both models passed the acceptance vibration tests and the optical alignment tests at ADL. The arrays also subsequently passed system level Qual tests and Flight acceptance tests at Bendix.

Pre-deployment protective covers, supplied by Bendix were installed on the arrays at Bendix prior to testing. A thermal protection cover, designed and fabricated by Bendix, was installed over the array insulation on the Flight Model after delivery to KSC.

b. Air Force Cambridge Research Lab (AFCRL) Experiment (Dr. D. Eckhardt, Principal Investigator)

The AFCRL array design concept was established at a NASA/Bendix meeting at Bendix on 11 October 1968. The concept was basically a Bendix-designed array structure supporting two GFE AFCRL retro-reflector assemblies (later changed to four Bendix-furnished AFCRL retro-reflector assemblies), with the structure providing the interface with the pallet support structure. The interface was to be common with that provided for the University of Maryland experiment array to permit the design of a single pallet structure which is directly applicable to both experiments.

The retro-reflector assembly design was defined in GE and Orbitex drawings supplied by NASA. The Orbitex Optical Corp., under subcontract to Bendix, was to provide the retro-reflectors required for the Qual and Flight Model arrays. The General Electric Company - Space Systems, Valley Forge, Pa., under subcontract to Bendix, was to provide the retro-reflector assemblies (i. e., mount the retro-reflectors on a support and thermal control structure) for the Qual and Flight models and to conduct vibration and thermal cycle tests on a GFE unit.

As in the case of the University of Maryland experiment, the program was divided into two phases: (1) Phase A, in which to fabricate and deliver to Bendix, four Qual retro-reflectors and to procure glass for, and partially fabricate, six Flight

retro-reflectors at Orbitex; to conduct a thermal analysis of the design, to vibration test and thermal cycle test a GFE retro-reflector assembly, to fabricate parts for the four Qual retro-reflector assemblies and to procure materials for the six Flight units at G.E; (2) Phase B, in which to fabricate, test and deliver to Bendix, six Flight retro-reflectors at Orbitex; to fabricate, test and deliver to Bendix, four Qual and six Flight retro-reflector assemblies at G. E.

The AFCRL final program requirements were defined in late November 1968 and the Orbitex and GE programs were initiated on 9 December. Vibration tests were conducted by GE on the existing retro-reflector assembly provided by AFCRL. In addition, shock and acceleration tests were run under AFCRL direction. Based on visual inspection, the unit survived all tests.

A CDR on the AFCRL retro-reflector assembly design was held at Bendix on 18 December. A Bendix design evaluation of the AFCRL retro-reflector assembly was initiated, for completion by 3 January, to support final LRRR experiment selection by NASA. It was also established that a solar optical test was to be run with the GFE retro-reflector assembly at GE for AFCRL, prior to the thermal cycle test contracted by Bendix. The results of the thermal cycle test were thus not to be available for the January 3 Phase A completion date.

Solar optical tests, simulating lunar night and lunar morning, were completed and results indicated that the retro-reflector assembly, as designed, will only operate satisfactorily during lunar night. Crazeing of the retro-reflector, in the vicinity of the support/reflector bond areas, which constitutes a failure of the bond, was also observed after the tests. It was concluded by Bendix, GE and Orbitex that redesign of the mount and verification testing was required in Phase B if the AFCRL experiment was to be continued. AFCRL prohibited use of the existing retro-reflector by GE to perform the thermal cycle tests for Bendix.

A problem had also developed in the availability of BK7-G glass for flight retro-reflectors. The wrong glass was initially ordered by Orbitex and was not acceptable as a

substitute. By the end of the Phase A effort Orbitex had, however, obtained the correct glass for four retro-reflectors and started fabrication; glass for the additional two retro-reflectors was in transit. Orbitex delivered four Qual retro-reflectors at the end of Phase A.

General Electric had fabricated thermal blankets, sunshades and holder parts for the four Qual retro-reflector assemblies and had procured material for the six flight assemblies, by the completion of Phase A.

No effort was expended on Phase B in accordance with the NASA decision to pursue only the University of Maryland experiment to program completion.

3. System Engineering

a. Analyses, Studies and Reports

- (1) Design analyses were conducted to provide design inputs or confirm design adequacy. These included analyses of rear support height requirements to prevent package tipping, alignment handle and rear support optical blockage effects (EATM-43), array tilt angle and alignment angle tolerances (EATM-72 and 73) and functional evaluation of various subassemblies and parts as the design developed.
- (2) Mass properties analyses, which were reported in EATM-34 and 34A, were made to ensure that the design would meet specification weight and c. g. requirements.
- (3) Pointing analyses, which initially identified parameters involved and confirmed specified mechanical tolerances (EATM-5), defined array tilt angle and sun compass (i. e. azimuthal) angle requirements (EATM-11A and 71) and predicted pointing errors resulting from all the parameters involved (EATM-69), were conducted.
- (4) Performance analyses, which provided parametric data to show the trade-off of retro-reflector size and number of reflectors, the effect of louver height/width ratios and the effects of array retainer ring geometry changes, were conducted.
- (5) The Design Certification Review Report, which provides detailed documentation of the design certification of the LRRR and PSEP, was prepared. The performance is described and the program of performance testing is summarized.

b. Specifications

The following specifications were prepared and updated as required:

- (1) KSC Handling Model Specification, CP 100015
- (2) Crew Trainer Model Specification, CP 100014
- (3) EASEP/KSC Interface Specification, IC 314126
- (4) LRRR CEI Specification, CP 100620/Parts I and II

c. Support of EASEP System Support

This support consisted of inputs to, and review of, KSC procedures, the EASEP Familiarization Manual and the Transportation and Handling Manual.

d. Support of LRRR Test Program

This support included review of the EASEP Integrated Test Plan and the LRRR system qualification and flight acceptance test procedures, participation as the engineering representative in pre- and post-test meetings and participation in the conduct of the tests.

4. Thermal Analysis

The major thermal analysis effort of the LRRR experiment was that involved in the thermal design of the University of Maryland experiment array, as performed by ADL. The goal of the overall LRRR thermal design was to minimize the vertical and radial temperature gradients in the retro-reflectors throughout the lunar cycle. These temperature gradients lead to optical distortion effects and therefore degradation of the laser return. The ADL analysis covered two basic areas: (1) the prediction of temperature gradients in the retro-reflectors throughout the lunar cycle, (2) the prediction of retro-reflector optical performance by ray trace analyses. One of the functions of the Bendix thermal analysis was to provide technical monitoring, support and evaluation of the ADL thermal control analyses.

A thermal model was set up by Bendix to perform parametric analyses involving sun angles, array tilt angles and various surface thermal properties for the array top, array insulation and pallet top.

Results of these analyses were used to finalize the thermal coatings for the LRRR support structure (including pallet) and were provided to ADL to support their thermal analyses. The results were presented at the CDR and were documented in EATM-35.

A more complex thermal model was set up to include the thermal conductivity effects of the array support structure. This model was used to predict the conductive heat leaks into, and out of, the array as a function of sun angle and lunar landing site (i. e. array tilt angles). Preliminary results of the analysis were also presented at the CDR. The final results of the thermal analyses of the integrated array and support structure were documented in EATM-61.

The detail test plan for the LRRR system qual thermal/vacuum test was generated and support was provided in the review of the final procedures, performance of the test and analysis of the test results. A test analysis report was documented as EATM-81.

5. Structural/Dynamic Analysis

The function of the LRRR structural analysis activities was to analyze the various structural components in support of the detail LRRR mechanical design. In addition, structural characteristics of the two basic array designs were generated to support the LRRR dynamics analyses. The results of this effort, leading to the design presented for acceptance at the CDR, are documented in EATM-28.

The LRRR dynamic analysis effort was to confirm the mechanical environments specified early in the program for the University of Maryland array being developed by ADL. This analysis effort was also to generate requirements for the design of the AFCRL experiment array structure to limit the dynamic inputs to the already-designed AFCRL retro-reflector assemblies. This extensive analysis effort was required because the program schedule did not permit the fabrication and test of a structural model to establish these parameters. The results of this effort are documented in EATM-2, 8, 19, 20, and 53A. Also, the ADL array structural design was monitored from the standpoint of dynamic analyses and ETM mechanical test results. It was concluded that the array was conservatively designed and this was confirmed by the ETM test results.

6. Crew Systems

The crew systems group performed studies and tests related to the astronaut interface. All of the design innovations which affected the crew in the deployment were evaluated by the crew systems group. Mockups were built and tested in various environments until the group was satisfied that the astronaut would be able to perform the intended function with a minimum of complexity. Significant new crew innovations were the alignment handle, the aiming handle, array aiming and alignment devices and an astronaut-removable predeployment protective cover. Some of the specific activities were:

- a. A demonstration of the LRRR crew concept model, tasks required and deployment sequence was held for astronaut Dr. D. Lind on 30 October 1968. Results are reported in EATM-26.
- b. The Crew Training model was demonstrated and acceptance tested on 15 January 1969.

- c. A shirt sleeve deployment of the LRRR Crew Training Model was made by Dr. Lind for astronauts Aldrin and Armstrong on 20 January 1969.
- d. Deployment tests of the Crew Training Model in a 1/6 gravity condition aboard a KSC 135 were made by Dr. Lind. Deployment tests are described in Bendix Memo 68-218-14 dated 14 February 1969.
- e. The LRRR Experiment/Crew Systems Interface Control Specification, IC 314128 was prepared and submitted to MSC.
- f. Deployment tests were performed during December using the crew concept mockup in the Lockheed visual simulation laboratory with generally acceptable results. Results are described in EATM-26.
- g. Fit checks and package removal from the LM 6 SEQ bay were made using the LRRR Crew Training Model, by astronaut Schmidt on 18 February 1969. These tests were successful.
- h. Practice deployment tests were made with the LRRR Crew Trainer Model by Aldrin and Armstrong on 24 February with general acceptance of the tasks.
- i. Several time-line deployment sequences, both for one and two crew members, were developed during the program. These are detailed in EATM-16.
- j. A deployment test of the LRRR Flight Model and the Trainer Model were performed by the Apollo 11 Crew on 16 May at KSC. No discrepancies were noted in the Flight Model and Astronaut N. Armstrong who will deploy the LRRR during the EVA appeared to be satisfied with the performance of the model.

7. Ground Support Equipment

The ground support equipment (GSE) group was responsible for the design of the GSE required to install the LRRR aboard the lunar module (LM). Because of schedule considerations, the LRRR equipment had to be loaded aboard the LM after the Apollo 11 vehicle had been moved to the launch pad. This requirement led to design constraints for the flight equipment that permitted disassembly to the point where each subassembly could be moved through the hatches and reassembled inside of the Spacecraft-LM-Adapter (SLA). To accomplish this, a rather specialized

line of GSE was required to contain the various subassemblies of the Flight Model. Some of the activities associated with the development of this equipment included:

- a. Preliminary GSE designs were generated on the basis of the requirements established at a design review on 3-4 December. The basic requirement, as defined by NASA, was to handle the LRRR as five separate subassemblies: (1) pallet, (2) array, (3) angle indicator bracket, (4) rear support and (5) boom attachment assembly. This requirement was a result of conclusions reached from a walk-through at KSC using the crew concept mockup and concept GSE on 18-19 November 1968.
- b. At the CDR, the preliminary GSE designs were presented for review and the LRRR basic handling requirement was changed to reduce the number of units handled in the SLA and the time required for assembly. This change was apparently made possible by a NASA/KSC re-evaluation of the LRRR envelopes and weights and the SLA space and hoisting equipment availability. The LRRR was to be handled as three subassemblies: (1) pallet/array assembly, (2) rear support and (3) boom attachment assembly. Other design requirements were established, such as the use of flame-retardant materials for an on-pad installation. These requirements necessitated some re-design and some new design effort.
- c. During January, the design of the boom attachment and rear support carrying case was completed. A fiberglass and foam construction was arrived at for this case primarily to meet the flame-retardant safety requirements. Design of a handling fixture for the pallet/array assembly was also completed. The designs were again presented for review at the CDR follow-up meeting on 5-6 February.
- d. During March, the GSE items were received from the vendors. The GSE was fit checked with the KSC handling model and modified, as required, prior to delivery to NASA. A number of additional modifications were initiated as a result of a KSC walk-through with the GSE and KSC handling model.
- e. In May, the LRRR Flight Model was placed in the GSE and on 25 May the LRRR Flight Model was transported into the SLA of Apollo 11 and installed in the SEQ bay of LM-5.

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