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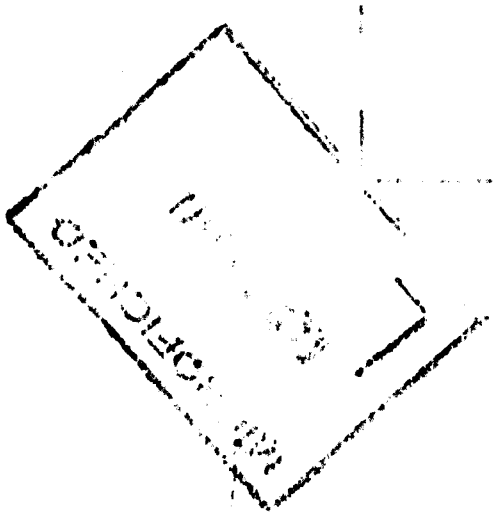
Apollo Lunar Surface Experiments Package



Prepared for
NASA/Manned Spacecraft Center

by

Bendix Aerospace Systems Division

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FINAL REPORT

APOLLO 14 LASER RANGING RETRO-REFLECTOR EXPERIMENT (LRRR)

BSR 3040

31 October 1970

REVISIONS

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Bendix Aerospace Systems Division

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MSC DOCUMENT	DELIVERY REQMT. Exhibit E, Para. 3.1.3 Exhibit F-1, Item 36	MSC CONTRACT S/A 92S to NAS 9-5829

APPROVALS

NASA/MSC	BENDIX
_____ COGNIZANT MANAGER	COGNIZANT MANAGER
_____ PROGRAM MANAGER	PROGRAM DIRECTOR

FOREWORD

This report is published to document and fulfill the requirements of S/A 92S to NAS 9-5829, Exhibit E (Paragraph 3.1.3) and Exhibit F-1 (Item 36) for a final report on the Apollo 14 Laser Ranging Retro-Reflector Experiment (LRRR). The Apollo 14 LRRR program was authorized by NASA/MSC-Houston to provide a laser ranging experiment package for the Apollo 14 spacecraft, scheduled for flight to the Moon on 31 January 1970 from NASA/KSC. The Apollo 14 LRRR flight model was formally accepted by NASA/MSC on 28 August 1970.

The information presented herein is complied and summarized primarily from data presented in monthly progress reports issued during the Apollo 14 LRRR program. The period covered by this final report runs from 20 March 1970 through 31 October 1970.

Internal
Memorandum

Bendix Aerospace Systems Division

Ann Arbor, Michigan

Date 31 October 1970 Letter No. 978-951-077

To P. S. Curry

From J. Brueger

Subject Apollo 14 LRRR Final Report

The significant program 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. A summary of the major milestones, including scheduled dates and actual dates, is shown in Table I.

1. Mechanical Design

a. The basic design concept of the Apollo 14 LRRR was developed from the earlier EASEP LRRR design and in response to new basic requirements of lower weight, low program cost, short schedule and deployment at off-equator sites. The new requirements were specified in the contract specification, developed by Bendix and NASA/MSC prior to go-ahead. Development of the concept design was initiated upon contract go-ahead, which was given by NASA/MSC on 20 March 1970, immediately subsequent to the completion of contract negotiations.

b. The first informal design review of the program (Crew Concept Review) was held at Bendix on 7 April 1970. An LRRR soft mock-up was fabricated by 6 April for concept evaluation, crew deployment tests and inspection by attendees at the Crew Concept Review. At the Review the design concept was accepted with the incorporation of minor changes in the UHT socket locations, bubble level light diffuser design and back support design. In addition, the crew training model design concept was accepted. (Reference a.)

c. The training model drawings were completed and released by 21 April, ahead of the scheduled date.

Table I
Final Listing
Apollo 14 LR[3] Milestones

	Schedule	Actual
Contract Go-Ahead	20 March 1970	20 March 1970
Complete Concept Mock-Up	6 April 1970	6 April 1970
Concept Mock-Up Review	6 April 1970	7 April 1970 (1)
Release Training Model Drawings	24 April 1970	21 April 1970
ADL Cavity Design Review and Decision on Cavity Change	28 April 1970	Review: 28 April 1970 Decision: 30 April 1970 (1)
Informal Program Review (CDR)	29 April 1970	30 April 1970(1)
Complete Qual and Flight Models Detailed & Subassembly Drawings	8 May 1970	8 May 1970: 85% 21 May 1970: All Remainder
Training Model Buy-Off at BxA	15 May 1970	14 May 1970 (except DD-250) 27 May 1970 (DD-250)
Go-Ahead for Fra Mauro Site	2 June 1970	2 June 1970
New Drawings and Drawing Changes Released	15 June 1970	11 June 1970
ADL Deliver Flight Array	7 July 1970	26 June 1970
Modified Training Model Buy-Off	9 July 1970	8 July 1970
Informal Program Review (QTRR & FTRR)	27 July 1970	29 July 1970(1)
Complete Qual Model Fab	31 July 1970	31 July 1970

(1) Date changed per MSC suggestion.

Table I
Final Listing
Apollo 14 LR[3] Milestones (Cont'd)

	Schedule	Actual
Complete Flight Model Fab	11 August 1970	12 August 1970
Qualification Tests	3-20 August 1970	3-13 August 1970
Flight Acceptance Tests	12-22 August 1970	13-19 August 1970
Deliver Flight Model	29 August 1970	CARR: 25 August 1970 DD-250: 28 August 1970

d. The Second Informal Design Review of the program was held at Bendix on 30 April 1970. The design of the Flight/Qual models was approved for fabrication, provided it would easily accept a mod-kit change to adapt to both changes in launch date and lunar landing site. Two chits resulted: one requested an estimate of the effort required to conduct a thermal analysis of the effect of the new support structure design; the other requested an evaluation of the means by which adjustments could be made for changes in launch date and mod kits could be provided to incorporate changes for other lunar landing sites. (Reference b.)

e. The flight and Qual Model detail drawings were released in stages, with all drawings initially released by 21 May 1970. The top assembly drawing was released on 2 June.

f. The initial design effort was done for the specified Littrow lunar landing site and a launch date of October, 1970. The redesign go-ahead for a site change to Fra Mauro was received from NASA/MSC on 2 June 1970 (CCP 256). The site change involved a new sun compass assembly design, a new UHT socket design and leveling leg design changes. The design was to provide for launch dates from 1 December 1970 through 1 April 1971. Detail design was completed and all new drawings and drawing changes were released by 11 June 1970. The design is based on parameters selected for a nominal launch date of 1 February 1971, with no changes required for launches from 1 December 1970, to 1 April 1971, inclusive, since the resulting pointing errors are less than 0.5 degrees.

g. A drawing was prepared to support the fabrication of a very-light-weight (< 2 lb.) LRRR Envelope/Interface Simulator at Bendix/KSC. The simulator was identified late in the program as required for use at a Grumman C^2F^2. The very-light-weight requirement was based on a Grumman hardware limitation.

h. Mechanical design support through the remainder of the program consisted primarily of design maintenance (drawing changes), manufacturing support and test program support.

i. The mechanical design supervisor supported the LRRR CF^2 held at KSC on 15 October 1970. The exercise was a success from the standpoint of Flight Model and Training Model performance and acceptance by the Apollo 14 crew.

j. Ground Support Equipment: The EASEP/LRRR GSE is to be used for handling the Apollo 14 LRRR at KSC. Only the LRRR handling frame (P/N 2340562) required a minor modification to avoid rear support design complexity on the Flight Hardware.

2. Model Fabrication and Test

a. Crew Training Model

Initial fabrication of the Training Model was accomplished and an acceptance test and inspection was completed on 14 May. This acceptance activity included an additional re-run of the deployment test to be witnessed by NASA/ RALPO and C. G. Fullerton, MSC Astronaut Office. All documentation, except the DD-250, had been signed by 15 May when a weld crack was discovered in the left front interface bracket. Repair consisted of the replacement of the left front bracket and the reinforcement of the right front bracket. Reinspection on the LM interface tool and the DD-250 sign-off were accomplished on 27 May 1970. The Trainer was then stored at Bendix pending NASA/MSC direction to incorporate a landing site change and/or to ship the unit.

After receipt of direction to incorporate the site change and release of new drawings and drawing changes, modification of the Training Model was initiated. The modifications were completed, acceptance test and inspection was conducted and the training model was delivered and shipped to KSC on 8 July 1970.

b. Qualification Model

Fabrication of the Qualification Model got underway with the initial release of Qual/Flight drawings on 4 May 1970. The EASEP Qual Model Array was to be installed as the array, in accordance with the Statement of Work. After receipt of the direction to incorporate the site change, all new drawings and drawing changes were released by 11 June 1970.

The Qual Model was fabricated and ready for final installation of the array and final inspection on 31 July as scheduled. The GAC interface tool had previously been unavailable, due to an ALSEP requirement for it to be at LTV in Dallas, Texas, but the tool was returned and the Qual Model assembly was completed on 31 July 1970. It was ready for the start of Qual Test on 3 August, the scheduled date.

The LRRR Qual Test Readiness Review (QTRR) was conducted in conjunction with the Flight Test Readiness Review at Bendix on 29 July (rescheduled from 27 July at MSC request) (Reference c). Four test procedures were reported by Bendix as remaining to be approved by NASA/MSC. Two requests for change (RFC) were submitted; one was approved and one, deferred. The first RFC requested a UHT/Socket Load Test on the Qual Model. The second RFC requested a test to confirm the integrity of the UHT/Socket interface under extreme thermal conditions; it was deferred and an analysis of this condition was requested to confirm that a test was not required. (Reference d.)

All test procedures had been approved by NASA/MSC on 31 July for the start of testing, except that for the Qual Model Design Limit Vibration Test due to late submittal. The latter was approved on 7 August 1970, in sufficient time to perform the test without delay. Qualification testing was conducted as follows:

Mass Properties:	3 August 1970
Acceptance Level Vibration:	7-8 August
Design Limit Vibration:	9-10 August
Shock:	11 August
Mechanical Deployment	13 August

No failures were encountered during the testing and all tests were passed successfully.

A UHT/Socket load test was conducted on the Qual Model on 24 August, as requested by the QTRR RFC. The test was successful.

c. Flight Model

Fabrication of the Flight Model got underway with initial release of the Flight/Qual drawings on 4 May. The flight array assembly was available, at Bendix, from A. D. Little, on 26 June 1970. Assembly of the Flight Model was completed on 12 August 1970. The Flight Test Readiness Review (FTRR) was held in conjunction with the QTRR on 29 July 1970. (References c and d.)

All flight model test procedures had been approved by NASA/MSC on 31 July 1970.

Flight Acceptance testing was conducted as follows:

Acceptance Level Vibration:	13-14 August
Mass Properties:	15 August
Tumble:	18 August
Mechanical Deployment:	19 August

No failures were encountered and all tests were passed successfully.

The LRRR Customer Acceptance Readiness Review (CARR) was held, as scheduled, on 25 August. (Reference e and f.)

The LRRR was packaged with no remaining open items, and the DD-250 was signed on 28 Aug 1970. The unit was shipped to KSC on 31 Aug and arrived later that date. The unit passed inspection at KSC with no discrepancies. A fit check with the Grumman flight pallet was conducted successfully on 3 Sept 1970. The CF^2 was conducted at KSC on 15 Oct and the unit was accepted by the Apollo 14 crew. Installation into the LM is now scheduled for January 1971.

3. Experiment Engineering

This functional area included the fabrication and acceptance test of the retro-reflector array, the LRRR pointing and emplacement analyses, the preparation and coordination of engineering documentation and the LRRR engineering group's support of the test program.

a. Array Fabrication and Test

The fabrication and test of the flight model retro-reflector array was subcontracted to Arthur D. Little, Inc., (ADL) who had been responsible for these tasks on the EASEP/ LRRR program. Go-ahead was given to ADL on 24 March 1970. The initial array design was the same as the basic EASEP/LRRR array, except for the elimination of the astronaut handle brackets (not required by the Apollo 14 LRRR design). Acceptance testing at ADL included array acceptance level vibration tests and retro-reflector alignment tests, before and after vibration tests.

An array cavity design change evaluation was requested by Dr. Faller, LRRR Principle Investigator, and go-ahead for this effort was given to Bendix on 3 April (CCP 253). The design change involved an increase in the array cavity taper angle from 1 1/2° to 6°, for the purpose of decreasing obscuration at off-axis earth positions and thus increasing optical performance at these positions. The evaluation included analysis and mechanical tests to confirm that the integrity of the array assembly was not compromised and to establish the degree of thermal performance degradation (resulting from the effective decrease of solar radiation shading). Hardware changes involved changes in the retainer ring inside taper and upper configuration, removal of approximately 0.20 in of the upper thread in the array structure cavities, and retention of each ring in its cavity by a rivet rather than by thread-staking. Mechanical tests involved vibration tests of a single-corner mount and of the EASEP ETM-1 array, in which the new design was incorporated at 10 selected cavities.

The analysis and tests were completed and the results were reviewed at a meeting at ADL on 28 April. (Reference g.) The ADL recommendation was that the change be adopted and that the previous qualification was not invalidated. Bendix and the P.I. concurred. At the LRRR CDR which followed on 30 April, NASA/MSC accepted this recommendation and approved incorporation of the design change, concurring that previous qualification was not invalidated. (Reference b.)

At ADL, fabrication of all array components, including the newly-designed retainer rings, was then completed. Assembly of the array, including installation of retro-reflectors, was accomplished on schedule. The GFE retro-reflectors, as delivered to ADL from Perkin-Elmer, were found to be in better condition than was experienced, previously, on EASEP/LRRR.

An Acceptance Test Readiness Review, by Bendix QA, Configuration Management, and Engineering personnel, was held on 11 June at ADL. Acceptance tests of the array were completed on 22 June and the delivery of the unit made at Bendix on 26 June, ahead of schedule.

b. Pointing and Emplacement Analyses

A pointing analysis, to identify the array tilt angle and sun compass marking requirements for the Littrow lunar deployment site, based on an October launch was conducted at the start of the program. The results, reported in Reference h, were incorporated in the initial hardware design.

An emplacement analysis, to provide recommendations on the LRRR emplacement requirements (i.e., distance and direction from LM) at the Littrow site, an easterly site, was also conducted. The results of this initial analysis are reported in Reference i.

After the direction to incorporate the site change to Fra Mauro, another pointing analysis was conducted to determine the appropriate alignment parameters for the new site. The results of the analysis also showed that no adjustment of the hardware would be necessary for flights during the specified period (December 1970 through April 1971). The results are reported in Reference j.

An additional emplacement analysis was conducted since the new site was a westerly site, with respect to the sub-earth point on the moon, and the pointing direction of the LRRR, with respect to the LM orientation, was consequently changed. The results of the analysis are reported in Reference k. As a result of a subsequent NASA/MSC decision to deploy the LRRR with the ALSEP on EVA-1, the recommendations were revised at an informal meeting at Bendix on 18 August 1970 (Reference l). The meeting was attended by Bendix engineering, NASA/MSC and the LRRR Principle Investigator.

c. Specifications and Other Reports

The following specifications were prepared and/or updated during the course of the program:

(1) Crew Training Model Specification, CP 100025.

(2) LRRR Design and Performance Specification, Exhibit B-1.

(3) LRRR CEI Specification CP 100630 (Parts I and II).

The Design Certification Review Report (DCRR) which provides detailed documentation of the design certification of the LRRR was prepared (Reference m). The document describes the LRRR performance requirements and the program of performance testing. Support was provided to ALSEP System Support, in the form of inputs and document review, for the preparation of various KSC procedures and the LRRR Familiarization Manual.

d. **Test Program Support**

This support included inputs to, and review of, the LRRR Integrated Test Plan, Qualification and Flight Acceptance Test Procedures, participation as engineering representatives in pre- and post-test meetings and during the tests themselves, and the review of test reports.

4. Thermal Engineering

The thermal engineering effort consisted of analyses and support of the design, fabrication, and test activities.

The analyses involved, first, the analysis by ADL to evaluate the effect, on optical performance, of increasing the retroreflector array cavity taper angle. The results were reported in the array design review at ADL on 28 April. (Reference g.)

The subsequent thermal analysis was conducted by Bendix to evaluate the effect of the new LRRR support structure on thermal/optical performance. This effort was performed as CCP 259 and initiated on 25 June 1970. The results are reported in Reference n. In general, the results indicated an overall improvement in thermal/optical performance over that predicted for the EASEP LRRR.

5. Structural/Dynamic Analysis

The function of the structural analysis activities was to analyze the various LRRR structural components in support of the detail LRRR mechanical design. In addition, stiffness characteristics of the structural design were generated to support the dynamic analysis. The results of this stress analysis are documented in Reference o.

In addition, a stress analysis of the Universal Handling Tool (UHT)/Socket Interface was conducted early in the program, and published separately, in answer to an action item from the Concept Review. The results were transmitted to NASA/MSC on 4 May 1970. (Reference p.)

A separate analysis was also conducted to evaluate the effects of temperature extremes on the UHT/socket interface integrity.

This effort was in response to an RFC submitted at the QTRR/FTRR (Reference d). The results showed the design of the socket and the UHT are more than adequate at either temperature extreme condition. The analysis was documented in Reference q and transmitted to NASA/MSC on 14 August 1970.

The LRRR dynamic analyses effort was conducted to predict the dynamic loads resulting from the specified vibration environments, and thus confirm the loads used in the LRRR stress analysis effort. In addition, the dynamic analysis provided array input vibration parameters to confirm that the environment imposed on the array during acceptance tests at ADL was adequate. The results of the dynamic analysis are also reported in Reference o.

6. Crew Engineering

The crew engineering effort involved studies and tests related to the astronaut interface. All design innovations which affect crew deployment were evaluated by crew engineering. A concept soft mock-up was built and tested to confirm that the Apollo crew would be able to perform the intended deployment functions.

Specific activities included the following, in addition to design review and inputs:

a. Suited test of the concept soft mock-up on 25 March 1970.

b. Shirt-sleeve demonstration of the concept soft mock-up at the Concept Review, 7 April 1970.

c. The Crew Training model was demonstrated and acceptance tested in shirt-sleeves, on 13 and 14 May 1970 and, finally on 7 July 1970, after incorporation of the site changes.

d. Shirt-sleeve deployment tests of the Qualification and Flight Models on 13 August and 19 August, respectively.

e. The LRRR/Astronaut Interface Specification was prepared and submitted to NASA/MSC.

f. The preparation and review of Apollo mission deployment and contingency procedures were supported.

g. Crew Systems analysis reports were initially prepared and submitted as Reference r. After direction to proceed with the change to Fra Mauro, two analyses were updated and submitted as References k and s.

7. Reliability Engineering

The reliability effort included the review of the design during its evolution and all subsequent design changes. Documentation included the Failure Modes and Effects Analysis (Reference t), Contractor Parts List (Reference u) and the Qualification Status List (Reference v), all of which were submitted in preliminary form prior to the CDR and, in final form for the CARR. Reliability review included the surveillance of the Array Acceptance Tests at ADL, as well as the LRRR Qualification and Flight Acceptance Test Program at Bendix. In addition, reliability engineering supported the array design change evaluation effort at ADL, early in the program.

J. Brueger

J. Brueger, LRRR Experiment Supervisor

Approved by:

W. Tosh

W. Tosh, ALSEP Experiments Manager

REFERENCES

a. Minutes, LRRR Concept Crew Review, 9713-951-004, dated 4-7-70.

b. Minutes, LRRR Critical Design Review, 9783-951-013, dated 30 April 1970.

c. Minutes, LRRR QTRR and FTRR, 978-951-031, dated 7-29-70.

d. Minutes, Board Meeting, LRRR QTRR and FTRR, 978-951-032, dated 7-29-70.

e. Minutes, LRRR Customer Acceptance Readiness Review (CARR), 978-951-041, dated 25 August 1970.

f. Minutes, LRRR CARR, Board Meeting, 978-951-042, dated 25 Aug 1970.

g. Minutes, ADL Meeting, LRRR Array Design Change Review, 9783-951-015, dated 4-28-70.

h. ATM-870, Apollo 14 LRRR Pointing Analysis, dated 15 May 1970.

i. ATM-875, LRRR Emplacement Range and Azimuth from LM, dated 27 May 1970.

j. ATM-902, Apollo 14 LRRR Pointing Analysis - Fra Mauro Site, dated 15 July 1970.

k. ATM-890, LRRR Emplacement Range and Azimuth from LM for Fra Mauro Landing Site, dated 12 June 1970.

l. Bendix Internal Memorandum, LRRR Deployment Site for Apollo 14, 70-260-181, dated 8-21-70.

m. Bendix Report, BSR 3009, Design Certification Review Report for the Apollo 14 Laser Ranging Retro-Reflector Experiment, dated 15 September 1970.

n. ATM-899, Apollo 14 LRRR Thermal Analysis Final Report, dated 20 July 1970.

REFERENCES (Cont'd)

o. ATM-871, Structural/Dynamics Analysis Report, dated 15 May 1970.

p. Bendix Internal Memorandum, Stress Analyses of UHT, 9783-951-012, dated 29 April 1970.

q. Bendix Letter, Subject: Fit Check at Extreme Temperature of the UHT/Socket Interface for the Apollo 14 LRRR, 70-970-3861, dated 14 August 1970.

r. ATM-883, Crew Systems Analyses Report for LRRR, dated 28 May 1970.

s. ATM-888, LRRR Task Sequence/Timeline for Fra Mauro Landing Site.

t. ATM-868 (Rev. A), Failure Modes and Effects Analysis - LRRR, dated 20 August 1970.

u. ATM-869 (Rev. A), A. D. Little LRRR Contractor Parts List, dated 20 August 1970.

v. ATM-867 (Rev. A), Apollo 14 LRRR Qualification Status List, dated 20 August 1970.