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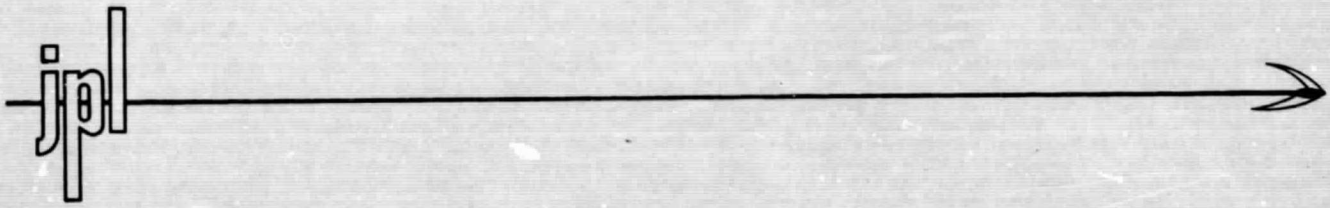



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JET PROPULSION LABORATORY
LUNAR STUDIES

Document 760-43

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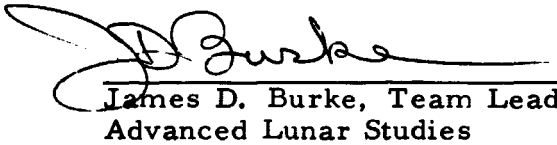

James D. Burke, Team Leader
Advanced Lunar Studies

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
October 15, 1969

# CONTENTS

# TABLES

# JET PROPULSION LABORATORY

## LUNAR STUDIES

## I. INTRODUCTION

Advanced lunar studies at JPL are summarized here to aid in planning FY 70 study efforts throughout NASA. The Advanced Lunar Study Team at the Laboratory has been active since mid-1966, studying future lunar missions with primary emphasis in areas of JPL experience and competence. In addition, the Team has provided consulting assistance to related lunar study efforts by the Manned Spacecraft Center (MSC), Marshall Space Flight Center (MSFC), and U.S. Geological Survey (USGS).

## II. RESULTS OF PREVIOUS STUDIES

Progress of the JPL studies is summarized in Table 1. The work has proceeded from the general to the particular. First the Team outlined the main scientific objectives of a lunar exploration program, assuming it to be part of a systematic attack on the questions of origin and evolution of the terrestrial planets (Ref. 1). An investigative rationale was developed to show logical sequences of experiments and their interactions in a program proceeding from early, branch-point experiments to later, more detailed exploration along the paths found to be valid in the initial surveys (Refs. 2 and 3). This experimental program was then examined by engineers to assess its demand for new technology, types of spacecraft, and mission capabilities (Refs. 4-7). These studies brought out the importance of (1) certain instrumentation in lunar orbit, preferably on independent spacecraft that could be launched either from earth or as subsatellites from the Apollo CSM, and (2) instrumentation carried on long (e.g., hundreds of Kilometers) surface traverses.

The surface traverse problem, because of its need for new automated spacecraft and control concepts, gave rise to further engineering studies which

are continuing, with the aid of laboratory and field tests and contractor support, at JPL, MSFC, and USGS. The JPL part of this work is described in Section IV of this document.

## III. AREAS OF STUDY IN FY 70

The studies outlined or in progress for FY 70 at JPL fall into three categories (Table 2):

(1) Studies of the lunar program, with emphasis on scientific objectives and methods involving automated equipment, sponsored by Dr. M. W. Molloy of the Apollo Lunar Exploration (MAL) Office.

(2) Studies of scientific aspects of the long, automated lunar traverse, sponsored by Dr. Molloy.

(3) Studies and advanced development for some of the engineering aspects of the traverse, proposed for sponsorship by B. Milwitzky, MAL.

In the first category, the information developed is provided as input to NASA planning documents such as the Program Memorandum or the reports of Lunar Exploration Working Groups. Also consulting is provided ad hoc, as was done for the Group for Lunar Exploration Planning (GLEP) and the 1967 Summer Study at Santa Cruz, California. The problems to be studied in FY 70 will include late Apollo orbital and surface science, the role of surface traverses, some international aspects of the lunar program, and initial planning for scientific aspects of an integrated post-Apollo flight program to identify needed advanced developments and aid in decisions on precursor or long-lead-time items. In the second and third categories, the information developed is supplied in the form of JPL informal reports, items in JPL bimonthly summaries, or publications in the open literature (see References).

Problems to be studied in FY 70 include traverse mission goals and methods, lunar rover payload design and operations criteria, rover imaging systems, traverse routes and navigation schemes. Contractor support will be used in the area of ground-based operations and control. Specific contents of these studies are described in Section IV. The objective throughout these

efforts has been, and will continue to be, to identify problems and attack the ones whose solution appears essential in advance of development for flight.

As the various parts of the lunar exploration program are reviewed within the Government and either rejected or continued toward development, the study content is expected to change. Before a commitment, the emphasis has been on options and aids to decision. Afterwards (as in the case of lunar mobility aids for astronauts during FY 69) the studies have been oriented toward outlining and, where possible, solving specific problems expected to be troublesome in development projects. Clearly, this process is most effective when it influences Supporting Research and Technology and Advanced Technical Development (SRT/ATD) efforts toward concentration on the problems of most immediate concern. To a limited extent, the FY 69 studies have had this effect at JPL; for example in the areas of vehicle navigation and vehicle-surface interaction research.

## IV. STRUCTURE OF FY 70 STUDIES

Tables 3 and 5-10 list the JPL Advanced Lunar Studies in progress in FY 70, and Tables 4 and 11-14 list those proposed as modifications or extensions in collaboration with the lunar roving vehicle (LRV) programs started at MSFC in FY 69.

Sensitivity. For the most part the JPL study results have been treated as non-sensitive, non-proprietary, but non-public material. Study reports have been freely circulated within NASA Headquarters and Field Centers. Apart from the JPL Bimonthly Summaries and one seminar report (Ref. 7), no formal distribution has been made to contractors; however, the contractors interested in LRV development have shown that they are aware of most of the JPL results.

Interagency Aspects. The JPL work, particularly as it concerns lunar traverses, is clearly related to tasks in progress at the Astrogeology Center of USGS, and coordination is maintained at both Headquarters and field levels.

Overlapping Areas of Interest. Overlaps exist between the JPL and MSFC tasks; for example, in areas related to vehicle navigation and vehicle-surface interaction, and it has been an early FY 70 objective to present a

coordinated plan for these studies to the Headquarters sponsor, B. Milwitzky. At the same time, joint research is in progress; for example, MSFC is using a JPL test vehicle and JPL personnel in an experimental mobility program at the Waterways Experiment Station, Vicksburg, Mississippi. Overlaps between NASA Headquarters Offices are expected to have only minor effects in FY 70 at JPL, since almost all of the work related to the lunar program is sponsored by the Apollo Lunar Exploration Office. A slight overlap may exist with future studies to be sponsored by OSSA/SL in areas related to planetary surface mobility; such missions can clearly benefit from precursor work done for the Moon.

Table 1. JPL advanced lunar study progress

☐ = Report (see Reference for full title)

A. OBJECTIVES — Origin and Evolution of Planets and Life

→ Terrestrial Planets

→ Utility of Moon — 900-28

B. INVESTIGATIVE RATIONALE

→ Major Lines and Interactions — 1967 Winter Study

→ Program Requirements — 760-5

C. PROGRAM ELEMENTS

Earth-Based

Orbital — 760-8

Surface - Stationary — 760-11

- Mobile — 760-5, 760-26

| Route Analysis | LRV Operations Concepts | Traverse Mission Analysis | Science Subsystem Design |
|---|---|---|---|
| | 760-39 | 760-27 | 760-36 |
| | 760-42 | 760-37 | Samplers |
| | | 760-41 | Analysis Instruments |
| | | | Imaging |

Table 2. JPL FY 70 lunar study areas

| Area | Sponsor | Information To Be Developed |
|---|---|---|
| Program Studies (in progress) | Molloy | Objectives and strategy, feasible project concepts, planning document inputs, ad hoc consulting |
| Traverse Studies (in progress) | Molloy | Mobile payload design and operations criteria, imaging criteria and feasibility assessments. Traverse routes and tactics. Mission functional analysis, assessment of science-navigation interface and operations problems. |
| LRV Pre-project Studies (proposed, coordination with MSFC) | Milwitzky | Vehicle-surface interaction data and design criteria, hazard determination and avoidance concepts, navigation and control criteria. |

Table 3. JPL advanced lunar studies, FY 70

MAL (Molloy)

(Note: includes consultant support to MSFC LRV efforts)

| Name | NASA Code | MY | $(K) |
|---|---|---|---|
| ALS General | 195-06-01-01-55 | 2.0 | 50 |
| Mission Analysis | 10-01 | 2.0 | 250 |
| Mission Operations | 10-02 | 1.5 | 110[a] |
| Payload Phase B | 10-03 | 5.0 | 300 |
| Imaging | 10-06 | 1.5 | 240 |
| Route Analysis | 10-07 | 0.5 | 100 |
| Total | | 12.5 | 940 |
| | | [a]FY 69 C/O | 110 |
| | | | 1050 |

August 27, 1969

Table 3A. JPL advanced lunar studies, FY 70
(Revised 22 October 1969)

| Name | NASA Code | MY | $(K) |
|---|---|---|---|
| ALS General | 195-06-01-01-55 | 2.0 | 80 |
| Payload Definition | 10-02 | 5.0 | 265 |
| Imaging | 10-06 | 2.5 | 270 |
| Route Analysis | 10-07 | 1.0 | 30 |
| Sub-Total Prog. 195 (Molloy) | | 10.5 | 645 |
| Mission Analysis | 9xx | 2.0 | 80 |
| Mission Operations | 9xx | 2.5 | 190 |
| Vehicle-Surface Int. | 9xx | 1.0 | 100 |
| Obstacle Detection | 9xx | 0.5 | 40 |
| Landmark Nav. Aids | 9xx | 1.5 | 50 |
| System Integration | 9xx | 1.0 | 40 |
| Sub-Total Prog. 9xx (Milwitzky) | | 8.5 | 500 |
| TOTAL (includes FY'69 carryover) | | 19.0 | 1145 |

(This Table supersedes Tables 3 and 4)

August 27, 1969

Table 4. JPL LRV system technology proposals, FY 70

MAL (Milwitzky)

(Note: No JPL manpower allocated above ALS 12.5 MY)

| | MY | $(K) |
|---|---|---|
| Mobility R&D | 1.0 | [a] |
| Tactile Obstacle Detection | | 40 |
| Navigation and Guidance Instruments | | 150 |
| Scanning Laser | 4.5 | 310 |
| Landmark Navigation Computer Aids | | 50 |
| Remote Control Testing | | 40 |
| Operations Study (Transfer from ALS) | 1.5 | [a] |
| Operations Test Support | 1.0 | 50 |
| Operations Study Contract (Hughes) | 1.0 | 100 |
| System Integration | 1.0 | 60 |
| Total (Net Increase Over ALS) | 10.0 | 800 |

[a]To be adjusted based on FY 69 carryover.

August 27, 1969

Table 5. ALS General Studies - Work Unit 195-06-01-01-55

PURPOSE – Support NASA program planning.

PRINCIPAL TASKS – Continue review of lunar exploration program plan. Define feasible project concepts for further study. Analyze exploration objectives and strategy. Contribute to NASA planning documents such as FY 71 Program Memorandum, GLEP, and LEWG reports.

RESULTS EXPECTED – Improved understanding and presentation of program options.

USE OF RESULTS – Aid in defining FY 71 and subsequent lunar programs.

TIMING RELATIVE TO DECISION POINTS – Inputs provided on request to meet schedules of planning groups such as PSG.

FY 70 MAN-YEARS – 2.0.

FY 70 DOLLARS – 50,000.

REMARKS – None.

Table 6. LRV Mission Analysis - Work Unit 195-06-10-01-55

PURPOSE – Define lunar traverse mission constraints, goals and tactics. Define mission profiles and implementation plans.

PRINCIPAL TASKS – In coordination with USGS and MSFC, prepare mission analysis reports describing traverse profiles and giving rationale for experiments, operations, and alternate courses of action. Assess and document requirements for orbital mapping coverage in support of traverses. Examine tradeoffs and identify low-risk alternates to prime mission.

RESULTS EXPECTED – Improved awareness of traverse mission desiderata and hazards. More explicit requirements for mapping coverage. Input to LRV design and operations studies and SRT/ATD.

USE OF RESULTS – Guidance to development effort on vehicles, payloads, and ground systems. Aid in decisions on orbital instrumentation.

TIMING RELATIVE TO DECISION POINTS – Study scheduled to precede LRV Phase C; reports due mid-CY 70.

FY 70 MAN-YEARS – 2.0.

FY 70 DOLLARS – 250,000.

REMARKS – None.

Table 7. LRV Phase A Mission Operations - Work Unit 195-06-10-02-55[a]

PURPOSE – Define and analyze feasible ground operations concepts for automated LRV.

PRINCIPAL TASKS – Describe navigation and guidance concepts (Phase A), select one for analysis (Phase B). Create functional design for ground system. Define science data system, command and control requirements. Conduct simulation studies. Define feasible organizations. Maintain coordination with MSFC and vehicle contractors to achieve compatible spacecraft-ground system design interfaces. Exploit Hughes Aircraft Co. Surveyor operations experience via a supporting study contract.

RESULTS EXPECTED – Identification of ground-system problems and initial attack on them so that operations complex does not lag behind spacecraft development.

USE OF RESULTS – Guidance to design and development agencies and contractors to maximize operability of LRV. Aid in development decisions for ground facilities, equipment, software and organization.

TIMING RELATIVE TO DECISION POINTS – Study scheduled to precede LRV Phase C; reports due late CY 69 and mid-CY 70.

FY 70 MAN-YEARS – 1.5.

FY 70 DOLLARS – 0 [a](see remarks).

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[a]REMARKS – Supported by program 195 FY 69 carryover pending pick-up by program 9xx (Milwitzky) for FY 70. Interim authority granted for Hughes contract; $100,000 obligated and JPL Contract No. 952668 let on August 29, 1969.

Table 8. LRV Phase B Payload Definition - Work Unit 195-06-10-03-55

PURPOSE – Continue definition of payload concept and functional criteria for automated LRV science subsystem.

PRINCIPAL TASKS – Refine selected alternate concepts. Make laboratory and field tests to assess merit of concepts and reveal interactions among alternate combinations of instruments. Define preliminary payload functional specifications. Identify SRT/ATD requirements and prepare payload implementation plans.

RESULTS EXPECTED – Improved understanding of payload design problems and of interface to vehicle and ground system. Early attack on science payload control and operations problems, improved design criteria for spacecraft and ground systems.

USE OF RESULTS – Aid in defining requirements for LRV payload Phase C development.

TIMING RELATIVE TO DECISION POINTS – Study scheduled to precede LRV Phase C; tests to begin early CY 70, reports due mid-CY 70.

FY 70 MAN-YEARS – 5.0.

FY 70 DOLLARS – 300,000.

REMARKS – None.

Table 9. LRV Phase A Imaging - Work Unit 195-06-10-06-55

PURPOSE – Establish imaging requirements for automated LRV science and navigation.

PRINCIPAL TASKS – In conjunction with USGS and MSFC, define science and navigation criteria for imaging. Translate these into instrument, data system, and ground system functional characteristics and evaluate alternate mechanizations by analysis and test. Prepare imaging subsystem implementation plans.

RESULTS EXPECTED – Improved understanding of functional criteria and design options for LRV imaging. Assessment of utility of various kinds of image data in navigation-aiding computer programs.

USE OF RESULTS – Aid in selecting preferred imaging concept, define development problems, establish design goals.

TIMING RELATIVE TO DECISION POINTS – Study scheduled to precede LRV Phase C. Tests to begin CY 70, breadboard mid-70, implementation report early CY 71.

FY 70 MAN-YEARS – 1.5.

FY 70 DOLLARS – 240,000.

REMARKS – None.

Table 10. LRV Route Analysis - Work Unit 195-06-10-07-55

PURPOSE – Compare traverse routes, determine feasible routes for more detailed study in coordination with USGS.

PRINCIPAL TASKS – Analyze routes on existing photo coverage for mission value and feasibility (vehicle performance demand vs. hazard potential). Use results of USGS and JPL Mission Analysis (195-06-10-01-55) to help define alternate mission routes and timelines. Identify SRT/ATD and support requirements.

RESULTS EXPECTED – Improved understanding of traverse route selection criteria. Assessment of feasible routes and associated design and operating constraints.

USE OF RESULTS – Input to site and route selection, vehicle design and hazard criteria.

TIMING RELATIVE TO DECISION POINTS – Study scheduled to start in CY 70, route decisions not needed until LRV Phase D, but items affecting design needed for Phase C.

FY 70 MAN-YEARS – 0.5.

FY 70 DOLLARS – 100,000.

REMARKS – None.

Table 11. LRV-Surface Interaction - Work Unit 9xx[a]

PURPOSE — Aid in defining LRV design criteria and lunar hazard limits for safe operation.

PRINCIPAL TASKS — Wheel-soil research to obtain basic design data for low-pressure systems on soils having characteristics measured by Surveyor and Apollo. Use of Surveyor Lunar Roving Vehicle (SLRV) in cooperative test program with MSFC.

RESULTS EXPECTED — Design criteria for mobility subsystems, operating criteria for traverse planning, and assessment of tradeoffs between the two sets of criteria.

USE OF RESULTS — Guidance to mobility-related SRT/ATD at JPL, MSFC and contractors, aid in specifying LRV design and placard limits for operation.

TIMING RELATIVE TO DECISION POINTS — Manned-mode LRV design proceeding without subject data; data can be used after the fact to set placard limits, tradeoffs less critical because man can judge hazards. Automated mission Phase C can use results, first tests completed mid-CY 69, reports due early CY 70.

FY 70 MAN-YEARS — 1.0.

FY 70 DOLLARS — See remarks

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[a]REMARKS — Carried at approximately $5,000/month rate by program 195 (Molloy) pending 9xx (Milwitzky) review.

Table 12. LRV Navigation - Work Unit 9xx[a]

PURPOSE – Determine feasible concepts for automated LRV navigation, evaluate data acquisition and display, assess computer-aided hazard avoidance and control methods.

PRINCIPAL TASKS – Analyze tactile obstacle detection schemes. Define functional criteria for navigation sensors and compare candidate mechanizations. Assess potential of scanning laser and computer aids to motion control. Use Surveyor Lunar Roving Vehicle (SLRV) and/or other available platforms (MSFC, USGS) for remote control tests.

RESULTS EXPECTED – Improved understanding of design criteria and tradeoffs for navigation subsystem and its interfaces to science payload, vehicle, data system, and ground control complex.

USE OF RESULTS – Specification of interfaces for above named systems. Aid in MSFC guidance to LRV contractors. Improvement of criteria for SRT/ATD applicable to planetary roving missions.

TIMING RELATIVE TO DECISION POINTS – Study scheduled to precede LRV Phase C. Tests in progress throughout CY 69, report due mid-CY 70.

FY 70 MAN YEARS – 4.5.

FY 70 DOLLARS – 590,000.

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[a]REMARKS – Carried by 195 pending 9xx review.

Table 13. LRV Phase B Mission Operations - Work Unit 9xx[a]

PURPOSE – Continue effort described in Table 7. Add test support for LRV payload subsystem test activities, so operations system can evolve with payload.

PRINCIPAL TASKS – See Table 7. Add preparation and conduct of ground-system operations supporting (closed-loop) and benefiting from payload tests (Table 8).

RESULTS EXPECTED – Data to support integration of spacecraft design and operations.

USE OF RESULTS – More timely decisions and more orderly development of ground system.

TIMING RELATIVE TO DECISION POINTS – Schedule matches test schedule for science subsystem (Table 8). Reports due late CY 70.

FY 70 MAN-YEARS – 3.5 (including 1.5 from Table 7).

FY 70 DOLLARS – 150,000.

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[a]REMARKS – Held pending 9xx (Milwitzky) review, except for Hughes contract (see Table 7).

Table 14. LRV System Integration - Work Unit 9xx[a]

PURPOSE – Combine efforts in Tables 6-13, together with related SRT/ATD, into a coordinated system activity.

PRINCIPAL TASKS – Prepare, with MSFC, a compatible system-development plan. Establish subtask schedules and review study content for correct interfaces. Establish system test plan for JPL part of effort, and assess compatibility of same with MSFC schedules.

RESULTS EXPECTED – Identification of technical and schedule interface problems for automated LRV mission.

USE OF RESULTS – Redefinition of subtasks, coordination with SRT/ATD, and attack on interface problems in advance of development.

TIMING RELATIVE TO DECISION POINTS – Too late for FY 70 planning at MSFC and JPL; can be made effective for FY 71. Reports due late CY 70.

FY 70 MAN-YEARS – 1.0.

FY 70 DOLLARS – 60,000.

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[a]REMARKS – Held pending 9xx review.

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