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By E. H. Wells

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ABSTRACT

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The feasibility and merit of adapting the Goddard Experiment Package (GEP), developed for the Orbiting Astronomical Observatory (OAO), to Apollo Application Program (AAP) missions on the Lunar Surface are investigated in this study. Full consideration was given to an entire mission utilizing typical astronomical experiments. Data is provided to assist NASA in program planning of lunar surface optical astronomy missions and equipment. Evolutionary growth potentials were considered and all indications were that a 5- to 6-year period is realistic for the time required from initiation of the project to flight.

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RESEARCH PROJECTS LABORATORY
AND
ADVANCED SYSTEMS OFFICE
RESEARCH AND DEVELOPMENT OPERATIONS

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SUMMARY

The feasibility and merit of adapting the Goddard Experiment Package (GEP), developed for the Orbiting Astronomical Observatory (OAO), to Apollo Application Program (AAP) missions on the Lunar Surface are investigated in this study. Full consideration was given to an entire mission utilizing typical astronomical experiments. Data is provided to assist NASA in program planning of lunar surface optical astronomy missions and equipment. Evolutionary growth potentials were considered and all indications were that a 5- to 6-year period is realistic for the time required from initiation of the project to flight.

SECTION I. INTRODUCTION

The exploitation of space astronomy has exceptional advantages when conducted as a lunar surface operation. On Earth the best photographs of astronomical objects are usually limited in resolution to one-third of an arc second. This limitation is due to the atmosphere which distorts and diminishes delicate images. The vacuum of space removes the limitation and in so doing will make available the entire electromagnetic spectrum. It is expected that the only limitation to the results of a lunar surface astronomy mission will be the size and quality of the telescope itself.

In June 1965 a study contract (NAS 8-20132) was awarded by MSFC to Kollsman Instrument Corporation for the investigation summarized in this report. The study was conducted to provide NASA management with creditable data to be used in planning Apollo Applications Program (AAP) lunar surface astronomy missions. The period of performance of the contract, including extensions, was from June 1965 through April 1966. The value of the contract was $144,000.

Details of the study are documented in the following final report:

"Optical Astronomy Package Feasibility Study for Apollo Application Program (U)," Volumes I and II, Kollsman Instrument Corporation, Contract NAS8-20132, March 1966.

SECTION II. OBJECTIVES AND SCOPE

A. Objectives

The objectives of the Optical Astronomy Package (OAP) study were to:

1. Examine in detail the technical, operational, and programmatic feasibility of adapting the Goddard Experiment Package (GEP) to AAP and lunar surface missions.

2. Perform analyses related to the probable range of astronomical investigation possible with GEP instruments used with AAP.

3. Provide an initial assessment of desirable post-AAP optical astronomical equipment for lunar surface missions.

B. Scope

The scope of the program involves analyses of potential lunar surface astronomical investigations with the potential capabilities of the OAP system. Equipment and instrumentation requirements associated with the OAP and its support subsystems are identified. Various operational concepts are considered. The results of this program are intended to provide NASA management with creditable data to assist in the program planning of AAP lunar surface optical astronomy missions and equipment.

To enable proper overall system design, it was necessary to consider a range of potential lunar surface astronomy experiments. Typical scientific investigations to which the basic GEP could be adapted when used with AAP include:

1. Investigation of distribution patterns and densities of interstellar gas through emission line spectrometry and investigation of galactic periods of near-by stars.

2. Survey by photoelelectric methods of selected stars in sky fields to test the brightness-color-distance relationships leading to further classification.

The study defined in detail the necessary support systems and operational requirements outlined above within the constraints of the LEM Shelter configuration. The feasibility of mounting telescopes separately from the LEM was considered, as well as capabilities of the integrally mounted systems.

SECTION III. STUDY GUIDELINES

A. General

For the study, a basic GEP is assumed with a .97-meter diameter and a 4.8-meter focal length. Modifications to this GEP will be kept to a minimum and will be considered only when such modification is required for compatible operation of the OAP, LEM/Shelter, and human operators. The OAP will utilize the Apollo Excursion LEM/Shelter as its vehicle to the lunar surface, will be able to perform the same functions as the basic GEP, and will be modified to provide twelve additional functions.

A typical experiment profile was used in order to obtain realistic operational and engineering analyses. It is in no way final nor does it restrict other experimental approaches within the OAP capabilities. It is realized that the experiments described cannot all be completed within the manned experiment time limitation. Experiments may be selected according to the desires of the scientific community.

B. OAP Configuration

The basic differences in the telescopes of the GEP and the OAP are defined by the OAP study as follows:

1. The incorporation of additional thermal shielding on the OAP

2. The focusing mechanism for varying the prime focus position

3. The incorporation of a 45-degree mirror for reflecting the prime focus into a starfield photographic system

4. The incorporation of a relay lens system for an Optical/TV View-finder system

5. The addition of a second spectrometer mirror and a 45-degree flat strip mirror for reflecting the spectral image into a photograph system

6. The construction of the photon counter and grating mountings to permit "on site" experiment change.

C. Typical Experiment Profile for Manned Phase

1. Acquire in any order and track typical stars such as: Capella, Gamma Velorum, Zeta Puppis, Antares, Aldebaran, Beta Centauri, Spica, Achemar, Rigel, Sirius, Deneb, Canopus, Procyon, and Arcturus. Perform the following experiments on each of the stars:

a. UV photon counting (fine, medium, and coarse modes)

b. UV spectral photography

c. Visual spectral photography

e. Image photography on starfield camera or electron camera.

2. Acquire and, by using the time program track mode, track the planets: Mars, Venus, Earth, Mercury, Saturn, and Jupiter. Perform the following experiments:

a. Wide-band image photography using starfield camera

b. Narrow-band (100 A) image photography (4 filters) using starfield camera

c. Total field image magnitude using photometric adjunct to the starfield camera

d. Polarimetry using previously calibrated optics and birefringent filters.

D. Typical Experiment Profile for Unmanned Phase

1. Acquire in any order and track typical star (constant or variable) of magnitude of 10 or brighter. UV photon counting can then be performed (fine, medium, and/or coarse modes). Tracking may be via fine guidance system or programmed track mode.

2. UV photon counting on the solar corona may be performed at different solar radii just prior to lunar sunrise using the program track mode.

3. The Magellanic clouds may be extensively investigated during the lunar day to limit the OAP thermal problems and eliminate sunshade requirements.

E. Mission Characteristics

1. Stowed Phase. The stowed phase is expected to last up to three calendar months. During this phase it is only necessary that knowledge of the probability of operation during a later phase be determined. Therefore, an OAP stowed station checkout capability is incorporated into the equipment.

2. Manned Phase. The manned phase commences on touchdown of the LEM/Taxi. The astronauts then deploy the telescope and operate it for the rest of their stay on the lunar surface. When they leave, they retrieve all exposed film data and place the equipment in a mode of operation which permits remote control of experiments from Earth.

3. Unmanned Phase. The unmanned phase commences once the OAP is placed in the remote control mode and the astronaut secures the LEM/Shelter. In this mode the equipment will be permitted to operate until a failure in the system prevents the earth from obtaining any useful information. At present, this time is estimated to be in the order of one year with an 80-percent probability.

F. Operational Processes

1. Deployment. The sequence of operation indicates that the first function to be performed by the astronaut in connection with the OAP is its

deployment. The problem of telescope deployment is complicated by many factors including those relating to the LEM/Shelter, the manned interface, and the actual construction of the mockup to be used for training. The designs that were evaluated during the course of this study may conveniently be grouped into the following three classes:

Class 1 - Manual erection of derrick followed by manual deployment and erection of telescope

Class 2 - Automatic or semi-automatic erection of derrick followed by manual erection of the telescope

Class 3 - Automatic erection of both derrick and telescope. A decision was made to have some form of class 2 deployment.

2. Calibration. After the OAP is deployed to the top of the LEM/Shelter, it must be calibrated (referenced) to a coordinate system to enable simple operation by the astronauts and remote operation from Earth. The control panel itself will enable the astronauts to perform the initial coordinate calibration with sufficient accuracy for his use, and permit remote updating of calibration constants to ±1 second of arc using Earth-based computers.

G. Operational Data Handling

The Operational phase of the mission consists of gathering data from various experiments. This data is in two basic forms:

1. Film Data. The major emphasis during the manned phase is expected to be placed on the photographic data since its resolution (spectral) is much greater than the photon counter. The range of spectral data which can be gathered will be limited by the dynamic range of the film and its spectral response. The transportation of the film to the lunar surface poses a serious problem in terms of exposure to radiation of solar flares, and transition through the Van Allen Belt. The effects of these exposures and possible solutions were analyzed during the study. Photographic film will also be used for the starfield image recording since relative star magnitude can be obtained from that data. Processing (monobath type) will be included for all film to prevent loss of data through radiation exposure on the return trip to Earth.

2. Electronic Data. The Electronic Data System will be used during the manned phase of the mission as a recording system. Several experiments will be run to evaluate its performance and to permit the accurate calibration of reference coordinates for use during any program track modes. The main use of the Electronic Data System will occur during the unmanned phase of the mission. The various functions of the Electronic Data System are tabulated below. The functions listed are not intended to be confined in packaging concepts by their relative listing:

a. Accept, decode, and store command information

b. Command the execution of stored command data

c. Appropriately program the operation of the OAP for command experiments

d. Gather format and store experimental data

e. Monitor format and store equipment status (digital and analog) data

f. Provide for readout and transmission of stored data, via the communication link, in either a delayed storage mode or real time

g. Provide the electronic interface for operation of the OAP from the control console during manned mission phase.

H. Supporting Substudies

In order to arrive at the tradeoff points of the experimental capabilities versus practical configurations, several supporting studies were undertaken. These studies are summarized below.

1. Servo System. The servo system was analyzed on the basis of a controlled driving force producing a low rotational velocity during tracking on a unit of large mass with rolling friction and stiction. The major problem was the transient effect on displacement when it was assumed that the rotational rate went through zero. Several solutions were analyzed (i.e., decrease in mount stiction through "dither" techniques, constant velocity tracking servos, etc.). A second problem was the slewing of the OAP to new coordinates. Due to the acceleration and deceleration times and distances, a small constant supply of power was required on the servo system torques during slew to overcome the constant friction force.

2. Experiment Power System. The OAP is required to supply its own power during the manned and unmanned phase of the mission. An RTG (Radio-isotope Thermoelectric Generator) system, with a battery for peak loads, would satisfy the mission requirements for the year of operation. The power consumed during the experiment change (surge power) and the power consumed during the experiment are different. A total of 100 watts will be required from the RTG system. Two units of fifty-watt capability are expected to suffice with minor power make-up from the LEM/Shelter fuel cells during the manned phase of the mission.

3. Human Factors. The sleep-work cycle (time-line) was the major factor affecting the equipment and its use for experimental and operational functions.

4. Thermal Analysis. The thermal analysis of the Optical Astronomy Package (OAP) was conducted to determine the probable temperatures to be experienced by components critical to the optical performance of the system. Temperature gradients and levels of major optical and structural elements were computed from lunar touchdown through the stowed period for the OAP, deployment, and manned and unmanned operations. The equipment must be able to tolerate a continual temperature change during the manned phase of the mission and remain operational. This requirement will definitely affect the design of the equipment.

SECTION IV. BASIC DATA GENERATED AND CONCLUSIONS

A. Basic Data Generated

All tradeoffs were based on the following parameters:

1. Minimum required through maximum desired experiment capabilities

2. Theoretically feasible through easily constructed equipment configurations.

Maximum emphasis is placed on the desire for a wide range of capabilities incorporated into a single practical equipment configuration.

This complex configuration will have the following system characteristics when the desired range of capabilities includes all possibilities of the typical experiment profile listed above.

OPTICAL ASTRONOMY PACKAGE SYSTEM CHARACTERISTICS

General

Weight .... 2500 lb (1134 kg) max, 2375 lb (1070 kg) est

Telescope Mounting Type .... Alt-Azimuth

Location .... Top of LEM/Shelter on docking hatch

Method of Deployment .... Power-aided manually deployed derrick

Environmental Capabilities

Shock .... Equal to or better than LEM/Shelter on launch

Vibration

Non-operating .... Equal to or better than LEM/Shelter on launch

Operating .... Not affected by normal astronaut movements

Temperature .... Capable of operating during lunar day and night

Size of Major Components

Telescope .... 43 in. (1.1 m) dia x 9 1/2 ft (2.85 m) long

Yoke .... 14 in. square box-type fork on 26 in. AZ ring (.66 m)

Derrick (deployed) .... 16 ft electrically positionable tripod with electric hoist

Work Platform .... 6 1/2 sq ft + 3 sq ft fold-down

Control Console .... 1.7 cubic ft (.047 m^3)

Control Panel .... 17 in. wide x 9 1/2 in. high (.43 x .24 m)

Power Requirements

Manned

During experiment	100 watts avg
Each target change	.5 watt-hour +70 watts surge peak

Unmanned

During experiment	90 watts avg
Awaiting data transmission	65 watts avg
Each target change	.5 watt-hour +60 watts surge peak
Each data transmission	9 watt-hours +80 watts surge peak

Slew Rate	1°/second at 50 watts above friction loss
Experiment Data -- Film	Astronaut return of processed exposures
Transmission -- Electronics	Memory storage and programmed readout with automatic encoding and S-band transmission
Servo System Stability (exclusive of stiction)	± 1 arc sec

Resolution Acquisition

Display Systems

Optical Relay	1 arc sec
Closed Loop TV	1.2 arc sec
Coordinate Pointing	± 30 arc sec
Fine Guidance	.1 arc sec

OPTICAL ASTRONOMY PACKAGE SYSTEM CHARACTERISTICS (Cont'd)

Acquisition Pointing System

Manual Control	±15 arc sec
Remote Control	±1 arc sec
Fine Guidance Tracking	
4 Magnitude or brighter	±1 arc sec
7 to 4 Magnitude	±3 arc sec
10 to 7 Magnitude	±5 arc sec
Program Tracking	±1 arc sec

Acquisition Field of View

Coarse Viewfinder	8 deg dia
Main Optics	20 min dia
Fine Guidance	±2.25 min square

Telescope Parameters

Focal Length	190 in. (4.8 m)
Aperture	38 in. (.97 m)
Type	Modified Ritchey-Chretien
Focal Ratios	
Main Optics	f/5
Spectrometer	f/5
Spectrograph	f/5
Fine Guidance	f/5
Optical Relay	f/5
Spectral Range	
UV	900 Å to 4000 Å
Visual	3000 Å to 10,000 Å
Airy Disk (main optics)	1 arc sec at 5461 Å

OPTICAL ASTRONOMY PACKAGE SYSTEM CHARACTERISTICS (Cont'd)

Spectral Dispersion	
Photon Counters	
UV	8 Å/mm
Visible	16 Å/mm
Spectrograph	
UV	16 Å/mm
Visible	32 Å/mm
Spectral Resolution	
Photon Counters	
UV	2, 8 and 64 Å
Visible	4, 16 and 128 Å
Spectrograph (Film resolution 100 lines/mm)	
UV	.4 Å Based on 1 arc sec Airy disc size and
Visible	.8 Å perfect tracking
Star Field Resolution (Film resolution 100 lines/mm)	1 arc sec over a 10 arc min field. Better than 5 arc sec over a 20-arc min field
Total Manned Experiment Time (alternate astronaut sleeping)	225 hours
Total Manned Mission Time	332 hours
Calibration Capabilities	True lunar coordinates from any orientation, lunar location and tilt up to 15 deg
Remote Focusing Capabilities	1. Position of prime focus focal plane via remote positioning of secondary mirror

2. Position of spectral camera-to-prime-focus focal plane
3. Position of star field camera-to-prime-focus focal plane

B. Conclusions

The primary objective of the program plan was to outline those actions that must follow to make possible the creation of an Optical Astronomy Package that is fully operational and integrated with the LEM/Shelter. The program plan is based upon anticipated schedules for the Apollo Applications Programs. These schedules seem to indicate that the 1970-1971 time frame would be realistic for a lunar landing. The earlier Apollo flights will probably not include any astronomical observations.

Growth potentialities of the system were divided into two basic categories: (1) those that are evolutionary in nature and can be accomplished within the framework of the AAP plan and (2) those that are presently considered for post-AAP application. Typical of the first category are:

High resolution TV link to Earth

Diffraction limited optics ((16-inch (.4 m) and 18-inch (.5 m))

Simultaneous calibration of density and spectrum on the spectrographs

Density calibration on starfield photographs

Typical of the second category are:

60-inch (1.52 m) DL telescope

100- (2.54 m) to 120-inch (3 m) diffraction limited telescope

Equatorial tracking systems.

SECTION V. FUTURE ACTIVITIES

The advanced aspects of two primary areas of this study require further investigation. The primary areas are: (1) Production of a diffraction limited 38-inch (.97 m) mirror and (2) remote control from Earth.

APPROVAL

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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