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THE LUNAR ENVIRONMENT[1]

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The NASA lunar exploration program has focused the attention of many scientific and technical groups on such questions as the relative value of lunar experiments, the advantages of manned versus unmanned exploration, and the proper time sequence for the steps to be taken in the exploration program. It is interesting to note that all the approaches to the problem require a definition of the lunar environment at an early stage in the program. The choice of scientific experiments and the design of the required instrumentation is based on our present knowledge of the Moon and on educated guesses as to what data may be obtained. The technical developments required to make possible both a lunar landing and continued operation of scientific

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equipment on the lunar surface also demand a definition of the lunar environment as a design condition.

The approach of the engineer to this problem of defining the lunar environment differs in several important respects from that of the scientist. The scientist prefers a careful examination of the state of knowledge of the Moon and the design of first-generation instrumentation capable of measuring a wide range of values where large uncertainties in the expected measurement exist. The engineer will also carefully examine the facts but prefers not to accept as a design condition a definition of the lunar environment which is so broad as to require a design which will operate in all eventualities. In the case of the engineering design of a lunar exploration spacecraft the choice of a broad design requirement will often result in a negative weight allowance for the scientific instrumentation. The preferred approach is a careful choice of the lunar environmental model which is adequately conservative for the intended task. Environmental models of this type represent a blending of known lunar data with educated guesses of the unknown parameters that are particularly important to the specific mission in question. Such models must be reviewed constantly and revised whenever new lunar data becomes available.

II. KNOWN LUNAR PHYSICAL CHARACTERISTICS

Present knowledge of the Moon is based on two types of observations. The dynamical properties such as volume, mass, density, and motions have been determined by the classical methods of celestial mechanics. Physical properties such as surface conditions, thermal properties, albedo, and atmospheric properties are derived from observations of the electromagnetic radiation from the Moon. Such observations include direct visual and photographic telescopic work, as well as spectrographic, photometric, polarimetric, radiometric, and radar measurement

The presently accepted knowledge about the Moon will not be summarized in this brochure since several excellent summaries of lunar data are available in the literature. Two such summaries are "Preliminary Revised Chapters for the Planets," by Harold C. Urey (Yale Univeristy Press, October 15, 1959) and "The Known Physical Characteristics of the Moon and the Planets," by Carl C. Kiess and K. Lassovzsky (Air Research and Development Command Technical Report No. 58-41, ASTIA Doc. No. AD 115-617, July, 1958).

III. LUNAR ENVIRONMENT MODELS

Models of the lunar environment will vary with the type of mission, with spacecraft design, and with scientific experiment and instrument design. Models for use in several spacecraft design studies are given below. No examples of models designed for scientific instrument studies are included at this time.

A. Ranger and Surveyor Programs

In the interest of specifying a relatively low-risk environment for the spacecraft, it is required that the landing site be in one of the maria-like regions.

For purposes of the design study, the following lunar environmental conditions are to be assumed:

1. The effects of certain factors in the environment will be small and shall not be considered as design conditions; these are: (a) meteorite particles, (b) magnetic and electric fields, (c) electromagnetic

radiation, except for the range of values that affect heat balance, and (d) corpuscular radiation.

2. The lunar atmosphere is a vacuum.

3. Slopes greater than 15 deg will not be encountered. Although this is an assumed design condition, it will be necessary to ascertain the probability of spacecraft survival if slopes greater than 15 deg are encountered.

4. Protuberances greater than 10 centimeters will not be encountered.

5. The hardness of the lunar surface will range from that of soft wood to that of very hard rock. The uncertainty assumed here implies that landing devices which intend to do work on the lunar surface material must be carefully planned.

6. Maps based on photographs taken from Earth are in the process of being prepared for the area of from 40 to 48 deg east longitude along the Moon's equator. These maps are primarily for early rough-landing spacecraft, but insofar as landing sites may coincide, these maps will be considered the primary source of information for these missions. As new landing sites evolve, additional maps will be prepared through JPL. Maps of the expected impact areas come largely from the study of photographs taken by Earth-based telescopes. The accuracy of these photographs does not resolve two points on the lunar surface closer together than one-third of a mile while treating the visible surface as a flat disk.

7. The lunar surface temperature falls from a maximum of around 400° K at the subsolar point to a nighttime value of approximately 120° K. The temperature deep in the lunar interior is 234° K. The thermal conductivity of the lunar material is less than 10^{-4} cal cm^{-1} sec^{-1} $(deg\ C)^{-1}$. The albedo on the maria is assumed to be 0.07.

8. Surface dust conditions are uncertain. Although it is necessary to consider this effect, it should not be considered a primary design condition.

9. The friction properties of the lunar surface are uncertain.

10. Radar Reflectivity Model. Lunar reflection properties (wave length = 1 m to 10 cm):

Average η (refectivity)*	0.01 to 0.05
Average μ' (relative permeability)	~ 1
Average ϵ' (relative permittivity) . . .	1.2 to 1.4
Average θ (angle of slope of surface with respect to local horizon . . .	3.5 to 7 deg
Average depth of layer	several meters
Average density of layer	0.05 to 0.10 (Silica)
$P(\theta) > 30$ deg** base line, 1 meter	~ 0.01

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*η = radar cross section (scatter component)/Lambert cross section.

**$P(\theta)$ = probability of θ.

The ratio of power in the scatter component to power in the specular component (cpr) is about 0.15 for ranges in excess of 1,700,000 kilometers.

As estimate of the value of cpr as a function of distance from the surface (isotropic antenna) is given by

$$\text{cpr}\ (R) = \text{cpr}_{\infty} \left[1 + \frac{\rho}{R}\right],$$

where R is range to surface, ρ is radius of Moon, and $\text{cpr}_{\infty} = 0.15$. For ranges less than 100 kilometers, the surface is estimated to behave essentially as a scatterer. A sample calculation indicates that the scattering cross section for a full beam width of 10 deg at an altitude of 100 kilometers would be about 70 db (normalizing factor, 1 m^2) if the pulse width was greater than 1 microsecond. The power required per cycle for an snr = 20 db is -2 dbw/cycle when the wave length = 0.1 meter. Thus, a peak power of about 1 megawatt would be necessary when the pulse width is 1 microsecond.

B. Lunar Orbiter Program

The environment in which the Lunar Orbiter is required to operate is not expected to be dissimilar from the general environment of cis-lunar space. Therefore, no particular lunar environment model has been generated for this program.

C. Prospector Program

The following lunar environmental conditions are to be assumed for the purpose of engineering design studies of the Prospector roving vehicle:

1. The effects of certain factors in the environment will be small and shall not be considered as design conditions. These factors are: (a) meteorite particles, (b) magnetic and electric fields, (c)

electromagnetic radiation, except the range affecting heat balance, and (d) corpuscular radiation.

2. The lunar atmosphere is a vacuum.

3. Surface conditions.

   a. Slopes greater than 15 deg will not be encountered. Although this is the assumed design condition, it will be necessary to ascertain the probability of spacecraft survival if slopes greater than 15 deg are encountered.

   b. Protuberances larger than 10 centimeters will not be encountered on the greater portion of the lunar surface. The larger protuberances which may occur occasionally should be avoided by maneuvering the roving vehicle.

   c. The degree of existence of crevices or rills on the lunar surface is unknown. Design studies will assume that such features may be avoided by maneuvering the roving vehicle.

   d. The surface layer of the Moon consists of loose particles approximately 0.3 mm in diameter composed of material with a high silica content which is a very good insulator (with a value of $K\rho c \sim 10^{-6}$ in c.g.s. units, where K is the thermal conductivity, ρ the density, and c the specific heat of the material). Thickness of this surface layer is between 1 and 10 cm.

   e. The material directly beneath the surface dust layer is not composed of loose particles but is solid in nature. The nature of this solid may vary from a basaltic type of rock to a low density rock froth. The value of $K\rho c$ for this material is approximately 10^{-4} in c.g.s. units. This layer of material extends to considerable depths and determines the competence of the lunar surface. Design studies of the roving vehicle will assume a minimum crushing strength of 200 psi (14,000 g/cm^2).

f. The friction properties of the lunar surface are determined by the surface dust layer.

4. The lunar surface temperature falls from a maximum of around 400°K at the subsolar point, to a nighttime value of approximately 120°K. The temperature deep in the lunar interior is 234°K. The average albedo, or reflecting power of the lunar surface, is 0.07.

5. Maps based on photographs taken from Earth are in the process of being prepared for the area of from 40 to 48 deg east longitude along the Moon's equator. These maps are primarily for early rough-landing spacecraft, but insofar as landing sites may coincide, these maps will be considered the primary source of information for these missions. As new landing sites evolve, additional maps will be prepared through JPL. Maps of the expected impact areas come largely from the study of photographs taken by Earth-based telescopes. The accuracy of these photographs does not resolve two points on the lunar surface closer together than one-third of a mile while treating the visible surface as a flat disk.

D. Lunar Sample-Return Program

At the present time the Lunar Environment Model for the Ranger and Surveyor Programs provides the best model for all lunar landing studies.