enriched uranium, 5 to 50 $\mu g/cm^2$, were evaporated onto annealed pieces of mica. Each was then covered with a second piece, and these samples were placed in vacuum for periods varying from 16 hours to 6 days. The uranium deposits were dissolved off with nitric acid, and both pieces of mica from each sandwich were etched with 40 percent HF for 3 hours. No appreciable increase in etch pit density was seen above background. Based on $\alpha$ counting of the samples, the limit was $< 1$ percent of the density expected for an infinitely thin source. Presumably the evaporated deposits were thicker than indicated, and there may have been surface films which prevented the recoils from reaching the mica with sufficient energy to give observable tracks.

In natural samples of mica with dissolved U and Th impurities, there is no problem with surface deposits. In each decay chain a series of six or eight $\alpha$ particles is emitted, and the recoils vary in energy between 70 and 169 kev. The probability is about 80 percent that each recoil will register a track. If there is no appreciable diffusion of daughter products in the mica, each cascade of $\alpha$ recoils will register as a single fossil track with virtually 100 percent efficiency. Thus, the $\alpha$-recoil method of dating mica should be as reliable as fission track dating but three orders of magnitude more sensitive.

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## Gravity: First Measurement on the Lunar Surface

Abstract. *The gravity at the landing site of the first lunar-landing mission has been determined to be 162,821.680 milligals from data telemetered to earth by the lunar module on the lunar surface. The gravity was measured with a pulsed integrating pendulous accelerometer. These measurements were used to compute the gravity anomaly and radius at the landing site.*

A gravity measurement at one point on the surface of the moon can be used for the following purposes. (i) If the lunar gravity measured is very different from normal (theoretical) gravity, it would suggest the order of magnitude of other anomalies to be expected and, perhaps, would provide a guide for future surveys; (ii) the difference between the observed gravity and the gravity for a homogeneous moon indicates the degree of homogeneity of the moon; and (iii) the radius of the moon at an observation point can be determined independently of other methods of measurement.

To obtain the gravity anomaly, the radius at the observation point must be assumed. In the determination of the radius, it is assumed that the measured value of gravity is a representative value, unaffected by anomalies; the radius is treated as an unknown. In the determination of the gravity anomaly, the radius is treated as a known quantity and is used to compute normal gravity. The normal gravity may then be compared with the observed gravity.

Because of the limitations imposed on scientific experiments by constraints on the mass load and on the time available to the crew for scientific experiments during the first lunar-landing mission, it is very important to deduce as much information of scientific value as possible from tasks performed for operational reasons. The data used to determine gravity were collected primarily for operational reasons and were telemetered to earth from the lunar module on the lunar surface.

The format of the telemetered data is controlled by the lunar module guidance computer. The coast-and-align format contains the actual readings from the pulsed integrating pendulous accelerometer (PIPA). The PIPA is a system for the measurement of acceleration and velocity which can be synchronized with a digital computer. The PIPA readings are velocity increments along the inertial measurement unit (IMU) (stable member) *X*-, *Y*-, and *Z*-axes. The IMU is the main unit of the Apollo inertial guidance system, consisting of a stabilized platform (inertial platform) which contains (i) three inertial reference-integrating gyroscopes and (ii) three PIPA's. The IMU can determine any attitude changes or accelerations of the spacecraft. An inertial reference-integrating gyroscope is one with a single degree of freedom which senses displacement of the stable platform on which it is mounted and generates signals accordingly. Measurements of gravity on the earth with accelerometers have been described by Bock and Wing (*1*), Bowin *et al.* (*2*), and Wing (*3*).

The PIPA readings along the *X*-, *Y*-, and *Z*-axes are designated by PIPAX, PIPAY, and PIPAZ, respectively. The PIPA's were zeroed every 81.93 seconds while the lunar module was on the lunar surface. The PIPA readings are given in stable-member coordinates. The nominal value of one PIPA is 1 cm/sec.

On the basis of this nominal value, the magnitude of the gravity vector $g$ (to a first approximation) can be computed as follows:

$$g = \left[ \left(\frac{XI}{\Delta T}\right)^2 + \left(\frac{YI}{\Delta T}\right)^2 + \left(\frac{ZI}{\Delta T}\right)^2 \right]^{1/2} \quad (1)$$

where

$$XI = X_2 - X_1$$
$$YI = Y_2 - Y_1$$
$$ZI = Z_2 - Z_1$$
$$\Delta T = T_2 - T_1$$

Accelerometer readings from two discrete times are used. The PIPA's were read every 2 seconds; however, it is better that there be as much time difference as possible between readings for the computation of gravity. For example, while the lunar module was on the lunar surface, the PIPA's were read at 123 hours 26 minutes 52 seconds (time $T_1$). Thus $X_1$ equals the PIPAX reading at $T_1$, $Y_1$ equals the PIPAY reading at $T_1$, and $Z_1$ equals the PIPAZ reading at $T_1$. The PIPA's were read at 123 hours 28 minutes 12 seconds (time $T_2$). Thus $X_2$ equals the PIPAX reading at $T_2$, $Y_2$ equals the PIPAY reading at $T_2$, and $Z_2$ equals the PIPAZ reading at $T_2$. The quantities $XI$, $YI$, and $ZI$ represent the changes in the PIPA's during the 80 seconds. To determine the PIPA readings for 1 second, the PIPA reading for the entire time interval is divided by $\Delta T$ in seconds.

In reality, the values of the PIPA's are never exactly equal to 1 cm/sec. The exact value of a PIPA is determined by the scale factor, and it must be determined by calibrating the accelerometers. This calibration is performed before launch. In addition to the scale factor, each PIPA has a bias. The best place to determine the bias is in free fall. Fortunately, the lunar module is in free fall much of the time during a mission (that is, during translunar orbit and lunar orbit, except when the thrusters are firing). The PIPA's are read while in orbit (these readings should be zero). A reading of any magnitude, whether negative or positive, is an error or bias. In addition, the bias can change with time. The bias and scale factor are entered into the guidance computer memory of the lunar module before launch. During the mission, the bias can be changed in the guidance computer of the lunar module. The bias was redetermined after the flight of Apollo 11. After these values are determined, they must be applied to the original PIPA readings by means of the following equations:

$$\frac{XC}{\Delta T} = \frac{(1+SX)\,XI}{\Delta T} - BX \quad (2)$$

$$\frac{YC}{\Delta T} = \frac{(1+SY)\,YI}{\Delta T} - BY \quad (3)$$

$$\frac{ZC}{\Delta T} = \frac{(1+SZ)\,ZI}{\Delta T} - BZ \quad (4)$$

where $XC$, $YC$, and $ZC$ are the corrected values of the PIPAX, PIPAY, and PIPAZ readings, respectively; $SX$ is the scale factor for $X$, $SY$ is the scale factor for $Y$, and $SZ$ is the scale factor for $Z$; $BX$ is the bias for $X$, $BY$ is the bias for $Y$, and $BZ$ is the bias for $Z$. Values of the scale factor and bias for the PIPA during the lunar-landing mission were:

$$SX = -0.00027 \qquad BX = 0.66$$
$$SY = -0.00115 \qquad BY = 0.04$$
$$SZ = -0.00062 \qquad BZ = -0.029$$

To a second-order approximation, the gravity can be computed from Eq. 5

$$g = \left[\left(\frac{XC}{\Delta T}\right)^2 + \left(\frac{YC}{\Delta T}\right)^2 + \left(\frac{ZC}{\Delta T}\right)^2\right]^{1/2} \quad (5)$$

The gravity observation from the PIPA's is an absolute observation. Values of $g$ were computed from Eq. 5 for 16 time intervals from data obtained from the lunar module on the lunar surface. The mean of these 16 values of $g$ was 162,821.680 mgal. The standard deviation was 13.098 mgal.

The gravity should be compared to a theoretical (normal) gravity $\gamma_0$ at the lunar-landing site. The normal gravity is computed as follows:

$$\gamma_0 = GM/R^2 \quad (6)$$

where $GM$ is the product of the gravitational constant and the mass of the moon and $R$ is the radius at the observation point. According to Eq. 6, it is assumed that the moon is spherical and homogeneous. The effects of the lunar rotation and oblateness are neglected. It is assumed that the value of $R$ is obtained from sources other than gravity measurements. In the Apollo 11 mission, the location of the touchdown point of the lunar module relative to the topographic features of the lunar surface was determined from 16-mm sequence-camera photographs taken during descent. The touchdown point was then located on Lunar Orbiter photographs. From Apollo 10 data, the radius at the touchdown point of the lunar module was determined to be 1,735,575 m. From the Lunar Orbiter data, the radius was determined to be 1,735,177 m.

The value adopted in the Apollo project for $GM$ is $4902.778 \pm 0.2$ km$^3$ sec$^{-2}$. The value of $GM$ is determined from the relation

$$GE/GM = M_e/M$$

where $M_e/M$ is the earth/moon mass ratio and $GE$ is the product of the gravitational constant and the mass of the earth. In the calculation of $GM$, a value for $M_e/M$ of $81.3015 \pm 0.0033$ was determined by tracking Mariner 2 (*4*). The value of $GE$ was determined by tracking satellites of the earth to be $398{,}603.2 \pm 3$ km$^3$ sec$^{-2}$ (*5*).

Tracking data from a spacecraft near the moon can give a value for $GM$. There have been several flights near the moon, for example, the Ranger spacecraft. However, the former method still gives the best results for $GM$.

A new value for $M_e/M$ of $81.301 \pm 0.001$ was determined by tracking Mariner 5 (*6*), and a new value for $GE$ of $398{,}601.2 \pm 0.7$ km$^3$ sec$^{-2}$ was determined by tracking the Ranger spacecraft (*7*). This changed the value of $GM$ to $4902.78 \pm 0.06$ km$^3$ sec$^{-2}$; however, there was a large improvement in the standard deviation.

If we use $GM = 4902.778 \pm 0.2$ km$^3$ sec$^{-2}$ and $R = 1{,}735{,}575$ m, $\gamma_0 = 162{,}762.914$ mgal; if we use the same value of $GM$ and $R = 1{,}735{,}177$ m, $\gamma_0 = 162{,}837.589$ mgal.

If the gravity anomaly $\Delta g$ is defined as the difference between the observed gravity and the normal gravity (that is, $\Delta g = g - \gamma_0$), then $\Delta g = 58.766$ mgal if $R = 1{,}735{,}575$ m, and $\Delta g = -15.909$ mgal if $R = 1{,}735{,}177$ m.

The radius at the observation point can be computed from $GM$, which was determined from tracking data, and $g$, which was measured with the lunar module accelerometers. From Eq. 6, we have

$$R = (GM/g)^{1/2} \quad (7)$$

Equation 7 can be used to compute $R$ independently of other measurements of $R$

$$R = \left(\frac{4.902778 \times 10^{18}\ \text{cm}^3\ \text{sec}^{-2}}{1.62821680 \times 10^2\ \text{cm sec}^{-2}}\right)^{1/2} = 1{,}735{,}261.76\ \text{m}$$

$$R = \left(\frac{4.90278 \times 10^{18}\ \text{cm}^3\ \text{sec}^{-2}}{1.62821680 \times 10^2\ \text{cm sec}^{-2}}\right)^{1/2} = 1{,}735{,}262.12\ \text{m}$$

These radii are in good agreement with the radius computed from Apollo and Lunar Orbiter data.

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## Fungi Associated with Stalactite Growth

Abstract. *A fungus,* Cephalosporium lamellaecola, *was found to be regularly associated with the active tip of stalactites; crystallization of $CaCO_3$ occurred on hyphae suspended from the stalactite wall in the terminal drop.*

During an aerological and ecological survey of Lehman Caves, in the Wheeler Peak area of Eastern Nevada (*1*), fungal hyphae were found to be regular inhabitants of all walls, stalac-