WHAT FACTORS CONTROL THE LONG WAVELENGTH SHAPE OF THE MOON?;
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To first order the present shape of the Moon is a sphere with maximum positive and negative deviations of ~8 km, both occurring on the far side (160°, 75° S; 240° E, -10° N) in the areas of Korolev and S.P.-Aitken. These departures from a sphere are the combined result of various processes in the Moon's early history. The two largest global-scale features are the center of mass/center of figure (COM/COF) offset, for which various possible causes have been offered, and the polar flattening, probably due to an earlier rotation rate, both of which are of the order of 2 km. In addition there are smaller wavelength deviations, due primarily to impact basins.

We have analyzed the Clementine laser altimetry and gravity data [1] in an initial attempt to understand the processes that have influenced the Moon's shape. A least squares fit to the radii measurements in 2°x2° blocks derived from the altimetry data indicates that the mean radius is about 1736995 ± 50 m and its center is displaced from the COM by (-1.6, -0.8, 0.2) km in the *x*-, *y*-, and *z*- directions, respectively. The radii measurements have an rms deviation about the best-fit (displaced) sphere of 2.1 km with a full dynamic range of nearly 16 km. The radius measurements within ±1° of the equator suggest that the mean equatorial radius is approximately 1.2 km larger than the mean radius while the two polar radii are about 800 m less than the mean. This leads to a flattening of 2.0±0.5 km. The large error estimate arises because the altimetry data do not extend beyond approximately latitudes 79° N and S and extrapolation to the poles is necessary. Further, the local topography in the polar regions is large compared to the flattening and is inseparable from it. The flattening of the Moon, even with the attendant uncertainty, provides evidence in addition to the significant depths of basins [1,3] and the variability of basin compensation states [1] that the outer region of the Moon exhibited considerable strength in its early history.

It has long been known that the Moon's COF was displaced from the COM [2], but as a result of the Clementine altimetry measurements we know this displacement is not exactly along the Earth-Moon line but is on the farside of the Moon displaced approximately 25° toward the western limb and slightly north of the equator [1], in the general direction of the highlands north of S.P.-Aitken (Fig. 1). This displacement is not surprising when viewed in the context of the overall shape of the Moon but is particularly interesting when compared to the gravity field of the Moon, which shows no such offset from the Earth-Moon line [4]. Long wavelength displacements that result from the irregular shape of the Moon are thus isostatically compensated [1], possibly by variations in crustal thickness, since density variations within the interior alone are probably insufficient to accomplish compensation [5], though may contribute significantly [6].

Another feature of the Moon that has implications for the forces that created its shape is the lack of any significant ellipticity in the equatorial plane. As shown in Fig. 1, the (2,2) terms in the spherical harmonic expansion indicate an amplitude in the equatorial plane of about 800 m with a maximum ~40°E longitude, smaller than the COM/COF offset, but aligned in the same general direction. In contrast, the Moon's equatorial gravity field is aligned almost exactly with the Earth-Moon line. Fig. 1 also illustrates that the (1,1) terms are more than a factor of two larger than the (2,2) terms, which indicates that the biggest topographic effect around the lunar equator is the COM/COF offset. The major axis of the equatorial ellipticity (2,2 terms) is offset from the Earth-Moon line by about 45° (E). Note also that the (1,1) terms are also offset about 30° (E) and presumably trying to satisfy the fact that the maximum elevation of the highlands is not at lon 180° but rather 210° E. Thus the major axis of the lunar shape does not directly align toward Earth, though the minimum moment of the lunar mass does so [7,8].

Another characteristic of the lunar shape is that the topographic signatures of the nearside and farside are very different. As shown in Fig. 2, the near side has a gentle topography with an rms deviation of only about 1.4 km with respect to the best-fit sphere compared to the farside which is twice as large. The shapes of the histograms of the deviations from the sphere show a peaked distribution slightly skewed toward lower values for the nearside while the farside is broader but clearly shows S.P.-Aitken as an anomaly compared to the rest of the hemisphere. The sharpness of the nearside histogram is a result of the maria.

Major impact basins have imparted significant stochastic variations on the lunar shape. The magnitude of basin topography is greater than the lunar equatorial ellipticity and comparable to the flattening, which imposes a significant challenge in interpreting the fundamental lunar figure. The floors of unflooded basins and mare surfaces of flooded basins do not define an equipotential surface, which discounts hydrostatic arguments for the absence of significant farside maria.

References. [1] Zuber M.T et al. (1994) *Science, 266,* 1839. [2] Kaula W.M. et al. (1974*) Proc. Lunar Sci. Conf., 5th,* 3049. [3] Spudis P.D. et al. (1994) *Science, 266,* 1848. [4]Lemoine F.G. et al. (1996) *JGR,* submitted. [5] Neumann G.A. et al. (1996) *JGR,* in press. [6] Wieczorek M. and R.J. Phillips (1996) *Nature,* submitted. [7] Ferrari A.J. et al. (1980) *JGR, 85,* 3939. [8] Dickey J.O. et al. (1994) *Science, 265,* 482.

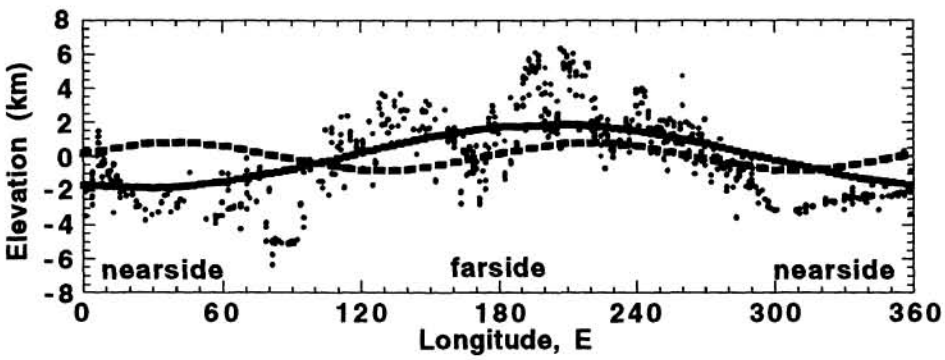

Figure 1. All lunar radii measured by Clementine within 1° of the equator. The values are subtracted from a mean of 1738.0 km. The solid line shows the (1,1) term of the spherical harmonic expansion of the topography and the dashed line shows the (2,2) term.

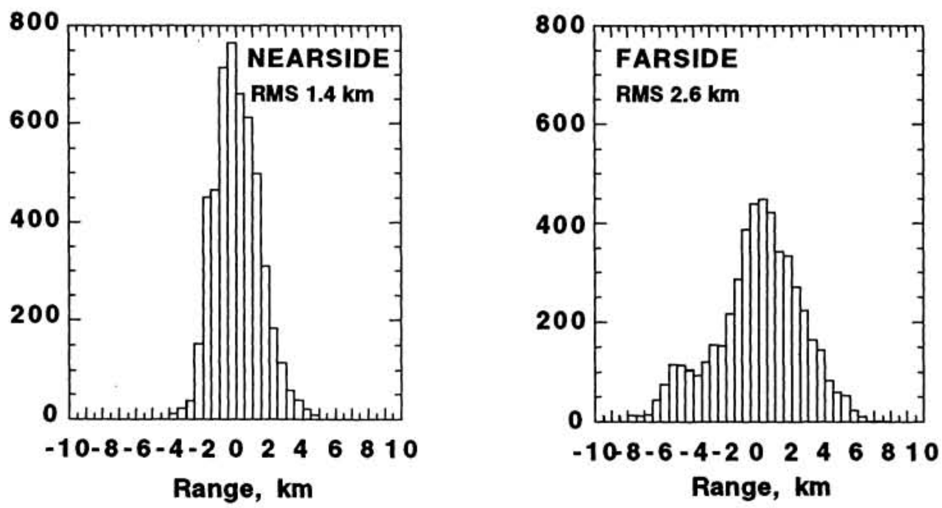

Figure 2. Histograms of the departure of the Moon from a sphere for the nearside and farside.