THE EFFECTS OF DISSIPATION IN THE MOON ON THE LUNAR PHYSICAL LIBRATIONS; C. F. Yoder, W. S. Sinclair and J. G. Williams, Jet Propulsion Laboratory, Pasadena, CA 91103

Since 1969, about 2000 laser ranges to the various retroreflectors emplaced on the moon have been measured at McDonald Observatory. Reduction of the lunar laser ranging residuals has been accomplished primarily through increasing the complexity of the dynamical model describing the lunar orbit and the rotations of the moon and earth. Presently, typical range accuracies are at the 10 cm (.7 nanosecond) level while the rms range residuals obtained after fitting the observations to the model are about 2.74 nanoseconds. Part of these residuals can be attributed to errors in the input model for earth rotation and polar motion derived from B.I.H. circulars D. After allowing for these corrections, we still find signatures in the range residuals suggestive of incomplete modeling of the lunar physical librations (rotations).

Peale (1) has previously studied the effect of inelastic earth tide and rotational deformations of the lunar figure and discovered to effect greater than ".01 in longitude. Significant perturbations would allow us to solve for the lunar potential Love number k_2 and the dissipation function, Q.

A careful analysis of the latitude perturbations reveal terms of magnitude $2''k_2$, and $230''k_2/Q$. The latter term represents a constant offset of the lunar spin axis from the time average plane formed by the ecliptic and lunar orbit normals. In the absence of dissipation, these three vectors are on the average coplanar. Estimates of the solid body Q for the earth and Mars are of order 100 while the expected value for $k_2 \simeq .02$ (2). Thus we might expect libration perturbations of order .04" from both terms.

We have added these effects to the JPL physical libration numerical integrator and solved for k_2 and k_2/Q. We find that $k_2 = .015 \pm .02$ and $k_2/Q = 1.4 \pm .6 \times 10^{-3}$. This suggests that Q may be as low as 10. The resulting ".3 offset in the spin axis reduces the rms residuals by .1 nanoseconds and improves the quality of the solutions for some of the third harmonics.

The apparent offset in the spin axis is not a unique aspect of solid body friction and other physical mechanisms are possible causes. Viscous core-mantle coupling could produce a similar effect, at least in the week coupling limit. Preliminary analysis indicates that if core mantle coupling is responsible then the core radius must be greater than 250 km. Seismic evidence (3) suggests that these may be a fluid core whose radius is between 190 km and 360 km. For a core of radius 360 km the required kinematic viscosity ν is $\sim$ 50 stokes, this is 10^2 larger than the most physically reasonable estimates of ν in the earth's fluid core (4). The signature of the perturbations produced by core mantle coupling differ from that due to viscous body friction at the .01" level. Also models with constant Q and Q $\propto$ 1/frequency differ at about .04". Thus we will attempt to test each possibility by determining which model best fits the data.

If the spin axis offset is real, then Calame's (5) amplitudes for the free motions, especially the nearly 2" free libration in longitude, are incompatible with the short damping times (less than 10^5 yrs for the free libration) derived by Peale (6).

Also significant solid body friction in the moon would alter its tidal orbit evolution, especially that of the lunar inclination I . We estimate

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that I would be greater than 10° at $a = 35R_{\oplus}$ where the lunar spin axis makes the transition from Cassini state 1 to state 2 (7).

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