TILTMETER FOR INTERNATIONAL LUNAR NODE: TIDAL DISTORTION OF THE MOON AND LONG-PERIOD SEISMOMETRY. James H. Roberts, Ralph D. Lorenz, *Applied Physics Lab, Johns Hopkins University, Laurel, MD 20723 (James.Roberts@jhuapl.edu)*.

Introduction: Tidal Tilt

A ground-based lunar network offers the prospect of making a novel geophysical measurement that provides information on the rigidity of the lunar interior. This measurement is simply one of the tilt of the ground (or equivalently, the changing orientation of the local gravitational vector to the surface) which can be made with quite simple and robust instrumentation which complements other proposed measurements.

In essence, the horizontal component of the changing tidal acceleration on a satellite in an elliptical orbit is expressed in a tilt of the local gravity relative to an inertial frame. A lander on a perfectly rigid satellite would measure this changing tilt (see figure 1). However, if the surface of the satellite itself distorts in phase in response to the changing tide, then the tilt measured on the surface is reduced.

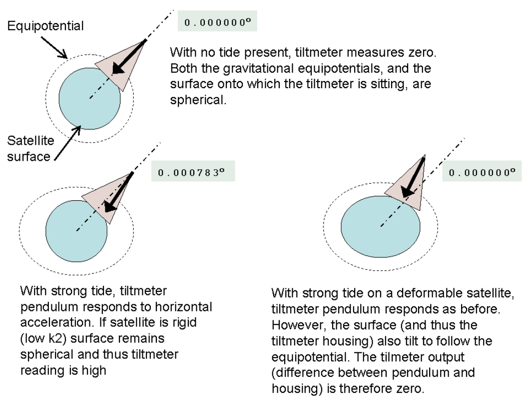

Figure 1: Changing tilt on a tidally-excited satellite.

The tilt measurement effectively measures the difference in tidal Love numbers (h_2-k_2-1). An in-situ measurement of the lander tilt in this way is strongly complementary to orbital measurements, such as laser altimetry and Doppler tracking measure these Love numbers separately [1,2]. Unlike the orbital measurements, which are greatest when the planet is lest rigid, the tilt sensed on the surface is greatest for a high rigidity, such that the planet does not deform to follow the changing equipotential. Figure 2 shows the amplitude of the expected tidal tilts on the Moon for three different values of h_2 (relative to the tilt measured at perigee). The Love number is a function of the satellite's rigidity (for a purely fluid planet, $h_2 = 2.5$ and the tilt is zero). However, the expected tilts for even a rather weak interior ($h_2 = 0.25$) are well above the expected measurement resolution of a few nanoradians.

Long-Period Seismology

The tidal tilt history shown in figure 2 is perfectly analytical,

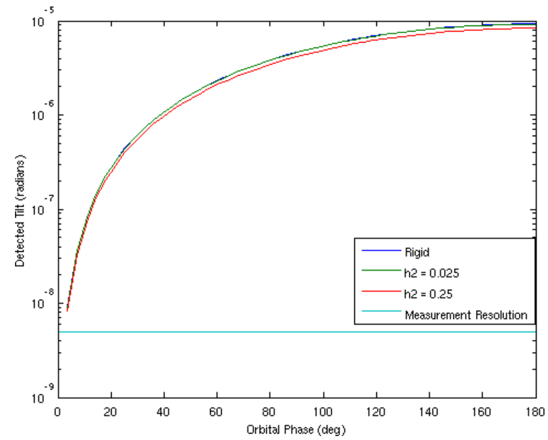

Figure 2: Tidal tilt relative to perigee as a function of orbital phase.

and corresponds to a uniform crust responding with no phase lag. In reality, there may be some phase lag which could be detected through an asymmetry of the curve.

A pendulum tilt meter acts as a long-period seismometer (indeed, responding to DC signals) and thus a tiltmeter can augment or replace other seismic instrumentation. For a pendulum a few tens of cm in length, the angular resolution acheivable corresponds to 10 nanometers, amply sensitive to detect teleseismic events.

In some ways, this would be the reverse of an attempt to measure tides by the Apollo Passive Seismic Experiment. In that instance, the long period seismometer was expected to behave as a short-period pendulum, with the goal of detecting tidal tilts and changes in gravity. The seismometers detected Earth tides during functional tests [3].

Instrumentation and Requirements

A tiltmeter is an intrinsically simple instrument. A variety of sensing techniques is possible - a common approach is to use a conductive fluid in a vial (e.g. figure 3 - comparable tilt sensors were used on the Huygens probe to Titan [4]

For a lander application a simple pendulum sensor may be better (e.g. figure 4). Modern optical or capacitive position sensing techniques can be used - the best approach to use should be considered taking the lander environment into account. Preventing large temperature changes nearby is important to avoid thermally-induced tilts via differential expansion.

In the case of a pendulum-style tiltmeter, a star tracker telescope can be rigidly mounted to the pendulum (figure 4). The star tracker measures the orientation of the system with respect to the celestial sphere to a few microradian accuracy, and measures the Moon's rotation state. A combined star-

Figure 3: Commercial fluid-bubble geophysical tiltmeter, able to achieve <10 nanoradian precision.

Figure 4: Commercial capacitive-sensing tiltmeter with star tracker, also able to achieve nanoradian precision. System is about 40 cm tall.

tracker/tiltmeter obviates the need for precision alignment. A realistic lander orientation will be within 5° of horizontal. A tiltmeter on a lander needs to incorporate a leveling mechanism to set the pendulum measurment within 1°. Such leveling needs to be performed only once, shortly after landing. The combined system can also be used to measure thermal distortion in the ground, discriminating thermal expansion from tidal forcing at the same period.

Data over two tidal periods (60 days) would be desirable to reliably characterize the tidal cycle. For that measurement, only a few tens of measurements, at 2 axes x 24 bits each - say 5000 bits total - is adequate. Measuring seismic activity obviously demands a larger dataset, perhaps exploiting event-driven sampling and data compression.

The mass of the pendulum structure and position sensors can be quite small (<1 kg). The leveling mechanism may entail 0.3kg, and the star-tracker and imager may add another 2 kg. However, these values depend strongly on the impact decelerations expected on the lander and on the range of angles that the leveling mechanism must accommodate. A nominal total on the order of 9W is ample for continuous operation, although the instrument can be operated at a low (10%) duty cycle if this is considered prohibitive.

A similar approach has been studied for measuring tides on Europa [5]; adaptation of such an instrument package for lunar geophysics should be simple in comparison. Delivery of a payload to the lunar surface is far simpler than to Europa, solar power is much more abundant, and the radition environment on the Moon is considerably more benign.

References: [1] Wahr, J. et al. (2006) *JGR, 111*, E12005. [2] Wu, X. et al. (2000) *GRL, 28*, 2245-2248. [3] Latham, G. et al. (1969) *Science, 165*, 241-250. [4] Lorenz, R. D. et al. (2007) *Planet. Space Sci., 55*, 1936-1948. [5] Lorenz, R. D. (2009) Tiltmeter for Europa Lander: Tidal Distortion of the Ice Crust and Long-Period Seismometry. *International Workshop on Europa Lander: Science Goals and Experiments*, Space Research Institute Moscow.