NUMERICAL SIMULATION OF TIDAL CAPTURE OF A LUNAR-MASS PLANETOID BY AN EARTH-LIKE PLANET: TWO-DIMENSIONAL LIMITS OF A PROGRADE STABLE CAPTURE ZONE; Robert J. Malcuit, Dept. of Geology and Geog., Ronald R. Winters, Dept. of Physics and Astron., Denison Univ., Granville, Ohio 43023.

Over the past few years we have been doing co-planar, three-body (sun, planet, planetoid) numerical simulations assessing the capture potential of planets for planetoids by tidal energy dissipation processes. Most of our work has been concentrated on the neptune-triton system [1] and the earth-moon system [2,3]. In general we have found (1) that the deformational properties of the planet are not important for tidal capture, (2) that only planetoids (whether icy or rocky) characterized by a low Q (specific dissipation factor) and a moderate h (displacement Love number) can dissipate sufficient energy within their bodies to cause tidal capture, and (3) that the orientation of the encounter relative to the planet's orbit is critical for attaining a stable post-capture orbit if sufficient energy is dissipated for capture. Here we report the results of a set of simulations for placing limits on a Stable Capture Zone (SCZ) for the case of lunar-like planetoid encountering an earth-like planet.

The computer program uses a 4th-order Runge-Kutta integration scheme and has an energy dissipation subroutine which operates within 20 earth radii (R_e) using equations for energy dissipation from [4,2]. The major variables in the calculation are (1) the displacement Love number (h) for each body, (2) the specific dissipation factor (Q) for each body, (3) the perihelion radius of the planet's orbit, (4) the perihelion radius of the planetoid's orbit, (5) the eccentricity of the planetoid's orbit, (6) the eccentricity of the planet's orbit, (7) the planet anomaly (the initial position of the planet in its orbit), (8) the planetoid anomaly (the initial position of the planetoid relative to the planet), and (9) the initial distance of separation between the planet and planetoid. In order to limit this set of variables we use (1) a circular planet orbit, (2) a constant set of Q values for the planetoid (Q=1 for the initial close encounter and Q=10 for all subsequent encounters), (3) a constant set of h and Q values for the planet (h=0.7 and Q=100), (4) a constant perigee radius (r_p) of 1.43 R_e for all initial encounters of encounter sequences (a distance well beyond the grazing encounter distance), and (5) an initial distance of separation of 600 R_e [which is well beyond the limits of the Hill sphere for planet earth (about 235 R_e)]. The major variables that were systematically varied for generation of this data set are the eccentricity of the planetoid's orbit, the planet anomaly, the planetoid anomaly, and the h of the planetoid.

A Stable Capture Zone (Figure 1) is defined as a zone of phase space (defined here in terms of planet anomaly and planetoid orbital eccentricity) in which any prograde encounter within r_p=1.43 R_e (with specified planetoid anomaly) will attain a stable capture orientation if the h of the planetoid is sufficiently high to dissipate the energy for capture. In general, capture of a lunar-like planetoid can take place with an h of 0.20 or higher depending on the position of the encounter within the SCZ. A higher h for the planetoid at the time of capture results in a smaller capture orbit and in a more stable orbit relative to subsequent solar gravitational perturbations. We have found that for stable prograde capture, the major axis of the initial geocentric orbit must be nearly perpendicular (+ or -5°) to the tangent of the planet's orbit. In contrast, for stable retrograde capture the major axis of the initial geocentric orbit must be nearly parallel (+ or -5°) to the tangent of the planet's orbit. Thus, all encounters within an SCZ must fulfill this orientation requirement.

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Because of the dynamics of the 3-body calculation there is a gradient in the value of the total orbital energy at the initial close encounter. The higher the negative total orbital energy is at the time of the initial close encounter, the lower the energy dissipation requirements are for stable capture. These values range from about -1.9 X 10^{28} joules in the upper right of the diagram (planet anomaly=320°, planetoid ecc.= 1.5%) to zero in the upper left part of the diagram (dashed line). h values necessary for capture vary from 0.2 (0.8 X 10^{28} joules to dissipate for capture) in the upper right to 0.7 (2.80 X 10^{28} joules to dissipate for capture) in the upper left along the dashed line. Thus the most favorable area in the SCZ for stable capture lies to the right of earth anomaly 240° because of the lower energy dissipation necessary for capture.

In addition to the SCZ described in Figure 1, we have identified two others that extend over several degrees of AN(E) (earth anomaly). A retrograde SCZ extends from AN(E)=225° to 245° (planetoid ecc.=0.75%) and another prograde SCZ extends from AN(E) 70° to 120° (planetoid ecc.=0.75%). Two-dimensional mapping of these SCZ's is in progress.

In summary, we have demonstrated (1) that tidal capture is physically possible within a certain range of conditions and (2) that Stable Capture Zones of significant two-dimensional extent exist for the Earth-Moon pair.

REFERENCES: [1] Malcuit, R. J., et al. (1992) Abstracts, LPSC XXIII, Lunar and Planet. Inst., 827-828; [2] Malcuit, R. J., et al. (1989) Proc., 19th LPSC, Cambridge Univ. Press and Lunar and Planet. Inst., 581-591; [3] Malcuit, R. J., et al. (1992) Proc. Vol., 3rd Int. Archaean Symp., Geol. Dept. & Univ. Ext., Univ. of Western Australia, Pub. 22, 223-235; [4] Peale, S. J., and Cassen, P. (1978) Icarus, 36, 245-269.

Figure 1. Plot of a prograde Stable Capture Zone for an earth-like planet and a lunar-like planetoid to the nearest 10° of planet anomaly and 0.25% of planetoid eccentricity. The dashed line on the upper left of the diagram is where the total orbital energy at the initial perigee passage is 0. Negative total orbital energy values increase to the right on the plot to -1.90 X 10^{28} joules in the upper right portion of the plot.