EPSC Abstracts
Vol. 6, EPSC-DPS2011-1441, 2011
EPSC-DPS Joint Meeting 2011


# Libration and tides of synchronously rotating icy satellites

**T. Van Hoolst**, R.-M. Baland, A. Rivoldini
Royal Observatory of Belgium, Belgium (tim.vanhoolst@oma.be)

## Abstract

As is well known for the Moon, the gravitational forcing from a central planet not only induces tides in synchronously rotating satellites but also small periodic variations in the rotation rate, or forced longitudinal librations. We calculate the effect of the tidal deformations on the forced longitudinal librations of icy satellites. For entirely solid satellites, we show that the forced librations are well approximated by the rotation variations for a rigid body. When the satellite has a global internal subsurface ocean, different solid layers, separated by the liquid layer, can rotate differently, leading to additional torques between layers. Moreover, the layers also respond differently to tidal forcing. As a result, the forced longitudinal librations of the surface will be affected by the liquid layer and the global internal structure of the satellite. Results are presented for the Galilean satellites and Titan, satellites for which accurate rotation data is already available thanks to the Cassini mission or will be measured in the future by missions to the Jupiter system, under study by ESA and NASA. Observations of rotation data have the potential of yielding information on the interior structure of icy satellites and may reveal the existence of putative subsurface oceans.

## 1. Introduction

Longitudinal librations of a satellite represent variations in the rotation rate around the equilibrium rotation. The main libration signal has a period equal to the orbital period and an amplitude which depends on the non-spherical shape of the satellite and is proportional to the orbital eccentricity. The actual non-Keplerian orbital motion also introduces long-period librations, which can have amplitudes as large as or even larger than the amplitude of the main libration at orbital period for the Keplerian problem, as has been shown for the Galilean satellites (Rambaux et al. 2011). However, these long-period librations do not depend on the interior structure, and we here only consider the main libration signal at orbital period.

The librations are due to the gravitational torque of the central planet on the aspherical satellites. The variable orbital speed of the satellites in an eccentric orbit leads to misalignment of the long axis with the direction to the planet and a non-zero gravitational torque. The torque depends on the equatorial flattening of the satellite, which is determined largely by the static tides raised by the central planet. In previous studies of the libration of icy satellites only the torque on the static shape of the satellites has been taken into account and the torque on the periodic tidal deformation has been neglected in analogy with studies of the rotation variations of the Earth. Here, we also include the latter torque.

## 2. Solid satellites

The libration amplitude is usually calculated by assuming that the satellite reacts rigidly to the gravitational torque. The amplitudes, expressed as a shift at the surface of the orientation of the long axis compared to the mean rotation rate, can then be up to a few hundred meters (Comstock and Bills 2003).

When tidal deformation is included, the libration amplitude is about a factor $(\kappa - k_2)/\kappa$ smaller than the classical amplitude for a rigid solid satellite. Here, $k_2$ is the degree-two gravitational tidal Love number and $\kappa$ the fluid Love number.

As an example, the libration amplitude for an entirely solid Europa but deformed by periodic tides ($\kappa = 1.057$, $k_2 = 0.015$, Moore and Schubert 2000) is about 132 m at the equator, which is 1.5% smaller than the rigid amplitude of 134 m (Van Hoolst et al. 2008).

## 3 Satellites with a subsurface ocean

### 3.1 Existence of liquid layers

Several lines of evidence suggest that most of the large icy satellites may have a subsurface ocean and some possibly a liquid iron core (e.g. Hussmann et al. 2006, Schubert et al. 2006). In particular, Galileo observations of an induced magnetic field at Europa, Ganymede and Callisto indicate that those satellites have a subsurface ocean beneath an ice shell, and Ganymede shows evidence of a self-generated magnetic field, which could indicate the existence of a liquid outer core above a growing solid inner core.

We have shown before that a deep liquid core has a negligible effect on the libration of the ice shell when considering rigid solid layers (Baland and Van Hoolst 2010), and here only consider the effect of a subsurface ocean.

### 3.2 External and internal coupling

Like the surface, interfaces between solid and liquid layers are flattened due to rotation and static tides. We calculate the flattenings (relative difference in length between the axes of principal moments of inertia) assuming that the satellites are in hydrostatic equilibrium. The interfaces are then triaxial ellipsoids, with the longest axis approximately in the direction to the central planet. Because of the equatorial flattening (relative difference in length between the equatorial axes) of the internal layers (Fig. 1), the central planet exerts a gravitational torque on each layer.

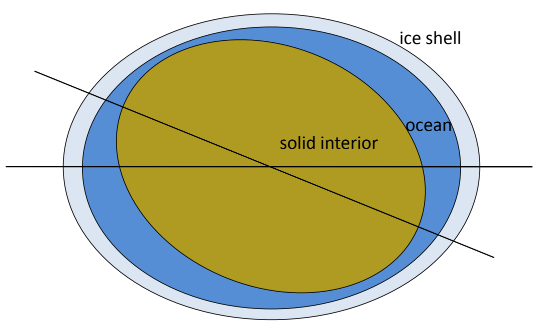


Figure 1: Schematic representation of the different orientations of the internal regions

We express the torque exerted by the planet on each layer $j$ of the satellite in terms of the equatorial flattening of the layer and Love numbers $k_2^j$ and $\kappa_j$ of layer $j$. Because of the equatorial flattening, misalignment of the solid layers due to differential rotation results in gravitational and pressure coupling between the internal layers (Fig. 1). The torques associated with the misalignment of the static shape of the layers are calculated according to Van Hoolst et al. (2009) and Baland and Van Hoolst (2010).

### 3.3 Results

In the lowest-order approximation of the theoretical developments decribed above, tides reduce the libration amplitude of icy satellites with a subsurface ocean by a factor of about two with respect to the situation in which the tidal effect is neglected. The libration amplitude decresases with increasing thickness of the ice shell and increases sharply for thin shells as a result of a resonance with a free mode. Compared to a solid satellite, the libration amplitude for satellites with a subsurface ocean is about an order of magnitude larger. As a consequence, libration observations can be used to determine the existence of a subsurface ocean and to constrain the thickness of the ice shell, provided that the libration amplitude can be measured with sufficient precision. With an orbiter mission to icy satellites such as currently under study at ESA for the Galilean satellites, a precision on the order of several meters is expected, which is sufficient to constrain the interior structure.

## References

[1] Baland, R.-M., Van Hoolst, T., Icarus 209, 651-664, 2010

[2] Comstock, R.L., Bills, B.G., J. Geophys. Res. 108, doi:10.1029/2003JE002100, 2003

[3] Hussmann, H., Sohl, F., Spohn, T., Icarus 185, 258-273, 2006

[4] Moore, W.B., Schubert,, G., Icarus 147, 317-319, 2000

[5] Rambaux N., Van Hoolst T., Karatekin Ö., Astronomy and Astrophysics 527, A118, doi:10.1051/0004-6361/201015304, 2011

[6] Schubert G., Anderson J.D., Spohn T., McKinnon W.B., in: Jupiter, The Planet, Satellites and Magnetosphere, 281-306, 2006

[7] Van Hoolst, T., Rambaux, N., Karatekin,Ö., Dehant, V., Rivoldini, A., Icarus 195/1, 386-399, 2008

[8] Van Hoolst, T., Rambaux, N., Karatekin, Ö., Baland, R.-M., Icarus 200, 256-264, 2009