EPSC Abstracts
Vol. 13, EPSC-DPS2019-488-4, 2019
EPSC-DPS Joint Meeting 2019

EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Rigid nutations of Mars

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Abstract

The presence of a liquid core can amplify the nutations of Mars. We compute accurate series for the nutation of a rigid Mars, which are required to avoid introducing bias in the determination of Mars core characteristics from the future nutation measurements with the RISE (Rotation and Interior Structure Experiment, onboard InSight) and LaRa (Lander Radioscience, onboard ExoMars2020) radioscience experiments.

1. Context

The RISE and LaRa radioscience experiments will determine the rotation (length-of-day variations, polar motion, and precession/nutation) of Mars [1, 2]. The nutations are short-period (e.g. the revolution period of Mars and its harmonics) oscillations of the spin axis in space mainly due to the periodical changes in the Solar torque acting on Mars and to the torques exerted by Phobos and Deimos. The amplitude of the largest (semi-annual) nutation is a few hundreds mas, see Table 1. One mas (milliarcsecond) corresponds to a displacement of 1.6 cm at the surface of Mars.

Mars has a liquid core [3, 4]. Depending on the size and shape of the liquid core, the semi-annual nutation can be amplified by 5 to 30 mas. The retrograde ter-annual nutation can be amplified by more than 10 mas [5]. The accuracy on the measured main nutation terms is currently not sufficient to constrain the core characteristics [6, 7], but it will be improved with RISE and LaRa to a level that allows not only to detect the effect of the liquid core contribution to the signal, but also to constrain the core radius [2, 8]. To avoid introducing systematic errors, an accurate representation for the nutation of a rigid (withtout liquid core and deformations) Mars is needed. This study aims at assessing the accuracy of existing rigid nutations models [9, 10, 11] and at providing an up to date rigid nutation model consistent with the latest orbital ephemerides of the bodies of the Solar system.

2. Comparison between existing rigid nutation models

Reasenberg and King (1979) [9] computed the Solar torque on Mars as evolving on a unperturbed precessing elliptic orbit. They obtained the main nutation terms for the motion of the **axis of figure** in space. These series are currently used to define the rotation model of Mars and to analyse radio-science data (e.g. [12, 13]), but are wrongly taken as equivalent to the **angular momentum axis** series. As the difference in orientation between the figure and angular momentum axes is a few mas, following this approach could lead to large bias in the core characteristics determination.

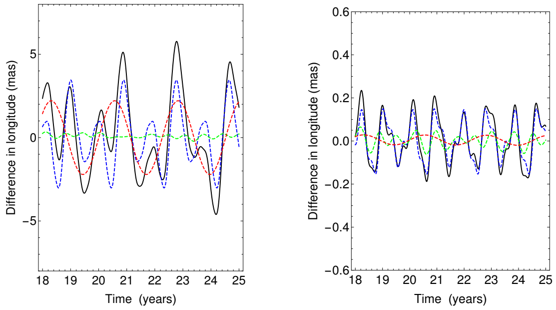

Figure 1: Left: in black, differences between the nutations in longitude computed from the series of [10] and of [11], as a function of time. Blue, green, and red curves are for the differences between the Solar, planetary perturbation, and moons' related terms, respectively. The time is measured in years from J2000.0. The differences in Solar terms are mainly related to the annual and semi annual terms. The differences in moons' terms is mainly related to Phobos. Right: as in left panel, except that [10] series are rescaled to the precession constant H_D and Phobos mass used in [11] and that [11] series are recomputed using modern computer capabilities.

Unlike [9], Bouquillon and Souchay (1999) [10] and Roosbeek (1999) [11] obtained periodic series for the motion of the **angular momentum axis** in space. Their series are also more detailed than those of [9] because they included the indirect effects of the planets of the Solar system which perturb Mars' orbit, as well as the direct effects of Phobos and Deimos. [10]

work in the Hamiltonian approach, whereas [11] considers the torque approach. The agreement between the two series, term by term, is 1 mas. In the temporal domain, the difference between the two series can be as large as 6 mas in longitude (see Fig. 1) and 2 mas in obliquity (not shown). Such differences are intriguing since both series are based on the same planetary ephemerides (VSOP87 [14]), and too large to be ignored, as the effect of the fluid core on the nutation amplitude can be of that order.

A large part of the difference between [10] and [11] results from the different values used for the mass of Phobos and the precession constant H_D which is the ratio of the difference in polar and equatorial dynamical flattenings over the polar dynamical flattening $(C - A)/A$. By rescaling [10] series to the scaling factor and Phobos mass of [11], and by recomputing the [11] series taking advantage of modern computer performances, the differences in the temporal domain between the two series decrease to 0.2 mas in longitude and 0.05 mas in obliquity (< 0.1 mas term by term). These differences are acceptable, compared to the expected precision on future measurements. Ultimately, as their accuracy is proven to be similar, both the Hamiltonian and torque approaches could be considered in order to interpret the measurements. We prefer the torque approach, for its simplicity of implementation.

3. Update of the nutation model

Based on the torque approach of [11], we update their series using a more recent version of the planetary ephemerides (VSOP2000 [15]). In Table 1, we give the prograde and retrograde amplitudes of the first main terms of the nutation series obtained with VSOP87 and VSOP2000 planetary ephemerides. The small differences (< 0.01 mas) in nutation series introduced by a change in ephemerides will be investigated further by using recent numerical ephemerides (e.g. JPL DE ephemerides).

Table 1: Amplitude of the prograde ($\mathcal{P}$) and retrograde ($\mathcal{R}$) main Solar terms of the rigid nutation series, based on the VSOP87 (first lines) or on the VSOP2000 planetary ephemerides (second lines), obtained following [11] approach. The arguments of the main nutation terms are multiple of Ma, the mean longitude of Mars.

Arg.	Period (days)	$\mathcal{P}$ (mas)	$\mathcal{R}$ (mas)
1 Ma	686.980	102.104	136.702
		102.106	136.702
2 Ma	343.490	498.080	18.033
		498.078	18.031
3 Ma	228.993	107.898	4.705
		107.898	4.705
4 Ma	171.745	18.301	0.843
		18.301	0.843
5 Ma	137.396	2.825	0.133
		2.825	0.133
6 Ma	114.497	0.415	0.020
		0.415	0.020

Acknowledgements

This work was financially supported by the Belgian PRODEX program managed by the European Space Agency in collaboration with the Belgian Federal Science Policy Office.

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