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Orbital evolution of the BepiColombo Mercury Planetary Orbiter (MPO) in the gravity field of Mercury

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Abstract

We analyzed the influence of Mercury's gravity field on the orbit of the Mercury Planetary Orbiter (MPO) which is the part of the European-Japanese mission BepiColombo. The gravity field of Mercury was determined from radio tracking data of the NASA's spacecraft MESSENGER. Due to the highly eccentric orbit of MESSENGER, the calculated gravitational harmonic coefficients are afflicted with uncertainties. Therefore, the orbital evolution of MPO is predictable but with some inaccuracy. For this reason, different plausible gravity fields were generated using a Monte Carlo Method. Furthermore, scale factors 1, 3, 5 and 10 were used for generating the gravity fields for the conservative consideration of the estimations for the harmonic coefficients [4]. The simulations for prediction of the orbital evolution of MPO were performed using generating gravity fields with above-mentioned scale factors. The results of the simulations were analyzed and compared with each other.

1. Introduction

By preparation of the space mission, it is very important to be able to predict and analysis the changes in the orbital elements of a spacecraft over time. A critical point for the instruments on the board of MPO is the spacecraft altitude. If the periherm falls below 200 km, the thermal stress on the instruments may cause an overheating an could damage therm. Therefore, the analysis of the simulations focused on the changes in periherm.

2. Data and methods

The generation of the random gravity fields was performed using the gravitational coefficients up to degree and order of 100 and their uncertainties, which were determined by Erwan Mazarico [3]. For that, a function, based on Gaussian distribution, was used. This function was implemented in a numerical orbit integrator developed by DLR, Berlin.

For the simulations, the values for input state vector of MPO and its associated mission start date were taken from the BepiColombo Mercury Cornerstone Consolidated Report Mission Analysis (CREMA) [2]. The data is put in relation to the inertial Mercury equatorial system.
The simulations were performed with the numerical Integrator which uses the SPICE kernels. They provided ephemerides, orientation and mass parameter for natural bodies, as well as leap seconds. Moreover, the Integrator was configured and controlled using a Python interface. The Python modules numpy, scipy and matplotlib were used for the analysis and visualisation of the results.

3. Definition of boundary conditions

Before performing the simulations for orbital prediction of MPO, the boundary conditions were determined. The number of the simulations was set to 10,000 per scale factor, the degree and order of the gravity field was limited to 50. The time frame of the mission was set to 2 Earth years, which covers the nominal and the extended mission phases. The distribution of some important harmonic coefficients was checked and the impact of the gravitational and non-gravitational forces affecting the motion of MPO was determined. As expected, the main accelerations are caused by the gravity field of Mercury, followed by the gravity force of the Sun. The third and fourth disturbing forces are the solar radiation pressure and indirect radiation pressure. The smallest perturbations are caused by the remaining solar system bodies.

4. Summary and Conclusion

The main acceleration acting on the motion of MPO is caused by the gravity field of Mercury. The performed simulations show that the geopotential of Mercury causes an increase in the eccentricity and a decrease in the periherm altitude. The semi-major axis and the inclination have a periodic character but

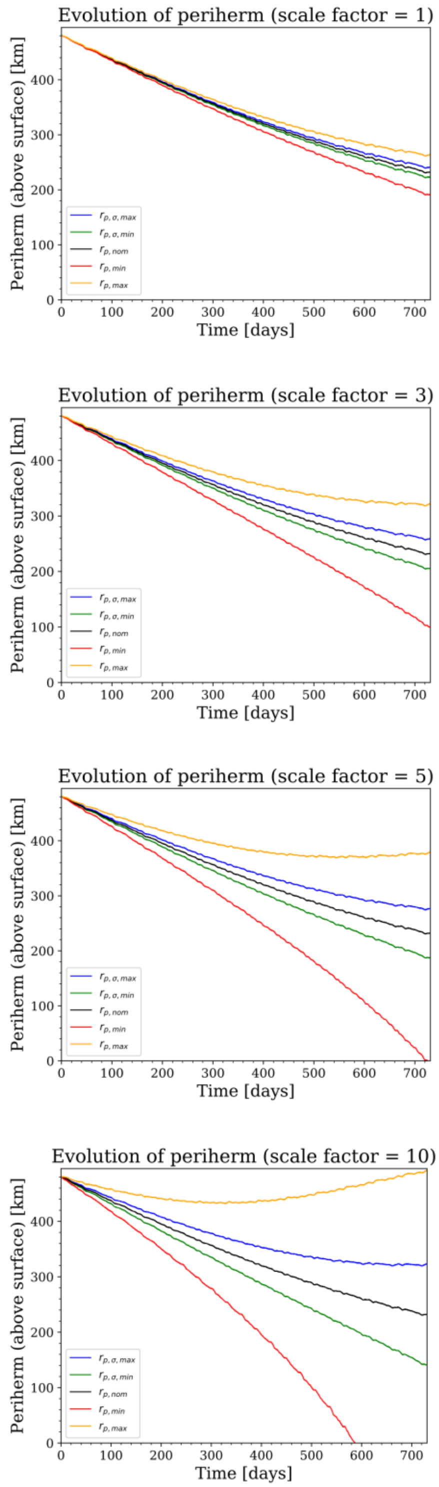

Figure 1: The evolution of the periherm of MPO dependent on the scale factor over 2 years

remain almost constant. The longitude of ascending node decreases slowly with periodic fluctuations. The argument of periapsis falls almost linear. The standard deviations, as well as the differences between the minimal and maximal values of the orbital elements get larger with growing scale factor and over time. The values of the elements lie in an acceptable range after 1 year while the change, for example, in the periherm after 2 years could be already considered as critical for the scale factor 1, whereas there is a chance of 0.02 % that the periherm falls below 200 km. The likelihood that the periherm lies under the critical value after 2 years increases with the rising scale factor and amounts to 11.74 % for the scale factor 3, to 23.69 % for the scale factor 5 and to 36.21 % for the scale factor 10. Furthermore, the satellite ends up with the collision into the planet in 0.01% of the simulations for the scale factor 5 and in 1.51 % of the simulations for the scale factor 10. Figure 1 show the evolution of the periherm of MPO dependent on the scale factor over 2 years.

In addition, the influence of the gravity of the Sun was investigated. The results show that the Sun has a positive effect on the evolution of the periherm of MPO after 2 years. Taking into account Mercury's gravity field, the gravity of the Sun, radiation pressure and the solar system bodies, the results of the simulations are very similar to the case with the consideration of the geopotential of Mercury and of the Sun. Thus, the orbital evolution of MPO in mainly affected by the gravity of Mercury and the Sun.

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