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Orbital stability during the mapping and approach phases of the MarcoPolo-R spacecraft

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Abstract

In support of the Marco-Polo-R mission we are analyzing the motion of the spacecraft in the vicinity of its primary target, the binary asteroid system 175706 (1996 FG3). We ran simulations in order to support the general mapping, the approach, and the sampling phase

1. Introduction

The Marco-Polo-R spacecraft shall be launched in 2020-2024 and rendezvous with the binary asteroid 175706. After a mapping phase, the spacecraft shall approach the main asteroid, land, collect a sample and return it back to earth.

During our study we investigate:

- the feasibility of maintaining a stable orbit around the binary system without station keeping maneuvers,
- the stability of orbits around the Marco-Polo-R backup targets,
- the feasibility of moving near the secondary either from stable orbits or quasi-orbits,
- the approach phase,
- the visibility of the secondary, and the Sun at the landing site. Availability of a radio link to Earth and illumination conditions.

2. Method

We developed a numerical tool which solves the equation of motion.

Several perturbing forces affect the movement of the spacecraft during its rendezvous with the target.

We used SPICE kernels for the ephemeris of solar system bodies. The two bodies of the binary asteroid are modeled as tri-axial ellipsoids. Besides the gravitational forces the solar radiation pressure is also included. The sum of these accelerations leads to the following generic equation:

$$\ddot{\vec{r}} = \overbrace{-\frac{GM}{r^3}\vec{r}}^{\text{Main Body}} + \overbrace{\ddot{r}_{HT}(\vec{r},t)}^{\text{Higher Terms}} + \overbrace{\sum_{SB}\ddot{r}_{SB}(\vec{r},t)}^{\text{Perturbing Bodies}} + \overbrace{\ddot{r}_{SRP}(\vec{r},t)}^{\text{Solar radiation pressure}}$$

Our tool is capable of solving this generic equation with various numerical algorithms and makes it possible to describe the movement of the spacecraft in the vicinity of the binary system or any other body.

3. Results

The spacecraft in the gravity field of the target is highly affected by the perturbing forces. Especially the solar radiation pressure is a large contributor. During the approach phase the solar radiation pressure also has an indirect contribution from reflected sunlight and from the thermal radiation of the asteroid.

In addition the rotating irregular gravity field of the asteroid causes significant perturbations of the spacecraft when it comes closer than a few km to the asteroid surface. Recent observations of shape and rotation state of the asteroid by Benner et al. (2012) [3] are used to constrain the model.

Stable orbits are found if the normal to the spacecraft orbital plane is pointed at the Sun ("Terminator Orbits") [1]. Therefore the initial conditions are crucial for the stability of the orbit.

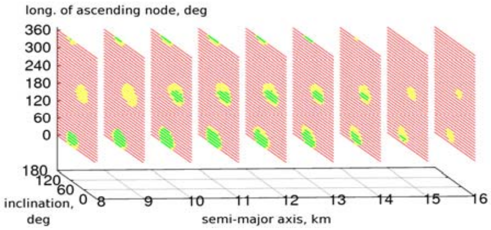

Figure 1: orbit stability of a S/C in the vicinity of 1996 FG3 depending on its initial conditions (further initial conditions: starting eccentricity 0; argument of pericenter: 0 deg; mean anomaly: 0 deg). Red regions are unstable orbits. Yellow regions are stable over one month and green regions are stable for three months or more. Orbits are considered as stable if their maximum eccentricity does not exceed 0.5.

As shown in figure 1 the movement of a spacecraft around the asteroid can rapidly lead to instability. Especially when the S/C is located between the two bodies of the binary system the secondary body causes strong perturbations. We are verifying whether it is possible to orbit the secondary and what is needed to maneuver within the binary system. The perturbing forces may make it impossible to orbit the secondary directly or in a quasi-orbit without using the propulsion system.

During approach phase and shortly before surface contact the illumination conditions for optical characterization and context of the landing site are also of high scientific interest.

We simulate these conditions based on the latitude of the landing site (Figure 2). From such analysis the timing for taking the sample can be optimized.

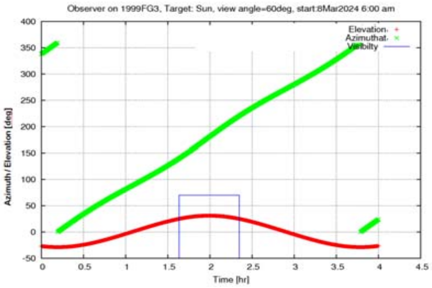

Figure 2: Movement of the sun seen from landing site at 60° latitude on the primary. The blue frame gives the time when the S/C has optimal illumination conditions for sampling.

Besides we look for resonance effects in a three-body problem of the primary and secondary asteroid and the spacecraft.

Furthermore we will investigate if stability at Lagrange Points exists and if regions can be found where dust particles or small meteoroidal objects can accumulate.

4. References

[1] Hussmann et al., 2012. Stability and Evolution of Orbits around the Binary Asteroid 175706 (1996 FG3): Implications for the Marco-Polo-R Mission. Planetary and Space Science, submitted 2011

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[3] Benner et al., 2012. Arecibo and Goldstone Radar Observations of Binary NEA and MarcoPolo-R Mission target (17506) 1996 FG3. ACM Meeting, Niigata, Japan, May 16-20, 2012. Abstract #6403.