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Stability and Evolution of Orbits around Binary Asteroids: Applications to the Marco Polo Mission Scenario

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Abstract

We have analyzed the orbit stability of a spacecraft moving around a small Near-Earth-Asteroid (NEA), focusing on the primary target of the Marco Polo Mission: 175706 (1996 FG3). The simulation showed that most orbits are unstable over time but under certain conditions the S/C stays in orbit without crashing or escaping into space.

1. Introduction

In the time-span 2020-2024 the Marco-Polo-R spacecraft shall be launched into space to rendezvous with the binary asteroid 175706 (Table 1). After the interplanetary cruise and the approach phase the spacecraft shall be injected into a Self-Stabilised Terminator Orbit (SSTO) and stay there for several months before landing [1].
This paper describes the results of modeling the behavior of a potential spacecraft by varying 18 independent parameters which have a more or less strong impact on the stability of the orbit (see Sec. 2).

Table 1: Physical properties of 1996 FG_3 [1]

Primary diameter:	1.4 ± 0.2 km
Primary spin period:	3.595 ± 0.002 h
Primary density:	1.4 ± 0.3 g/cm^{-3}
Secondary to primary diameter ratio:	0.28 ± 0.02
Secondary orbital semi-major axis:	3.1 ± 0.5 km
Secondary orbital eccentricity:	0.1 0.1
Secondary orbital period around primary:	16.14 ± 0.01 h

2. Method

Based on ephemeris data generated with JPL's HORIZONS tool we have constructed SPICE ephemeris kernels for the target asteroid. In addition we used the given SPICE kernels for the ephemeris of solar system bodies. The primary and secondary asteroids are modeled as tri-axial ellipsoids. Besides the gravity based accelerations a force caused by the solar radiation pressure (srp) is also included leading to the following equation:

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

With this equation it was possible to run multiple simulations by varying 18 parameters consisting of 6 Keplerian elements as starting condition, 4 independent properties of the primary asteroid (mass, shape, orientation of the rotation axis and the rotational period), 4 properties of the secondary (mass, shape, orbit orientation and orbital period), 3 spacecraft properties (mass, surface area, reflectivity) and the orbital insertion date and therefore the relative position to the sun (srp strength) and to all other planets. The strengths of the perturbing accelerations affecting the S/C are shown exemplarily in Figure 1.

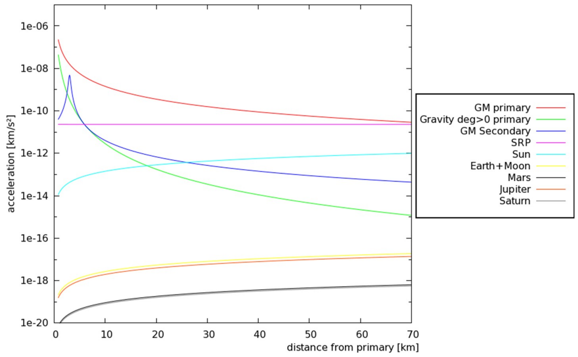

Figure 1: Perturbing accelerations over distance to the 1996 FG_3 primary

3. Results

All simulations showed no real stability as the assumed gravity force of the asteroid is too small compared to the srp. All simulated orbits had to be considered as chaotic and in most cases the spacecraft was either ‘blown away’ by the srp or crashed into the asteroid. Nevertheless for some starting conditions the orbital eccentricity did not exceed 0.5 over 6 months and these resulting orbits were then considered as temporarily stable (Figure 2). A more precise investigation showed that the semi-major axis, the inclination, the right ascension of ascending node (RAAN), the total GM of the binary and the acceleration caused by the solar radiation pressure have the biggest effect on the spacecraft behavior. All stable orbital planes lie (within a certain range) perpendicular to the srp while the center of gravity of the binary is lying above the orbital plane. The srp is therefore pushing the plane backwards relative to the center of gravity.

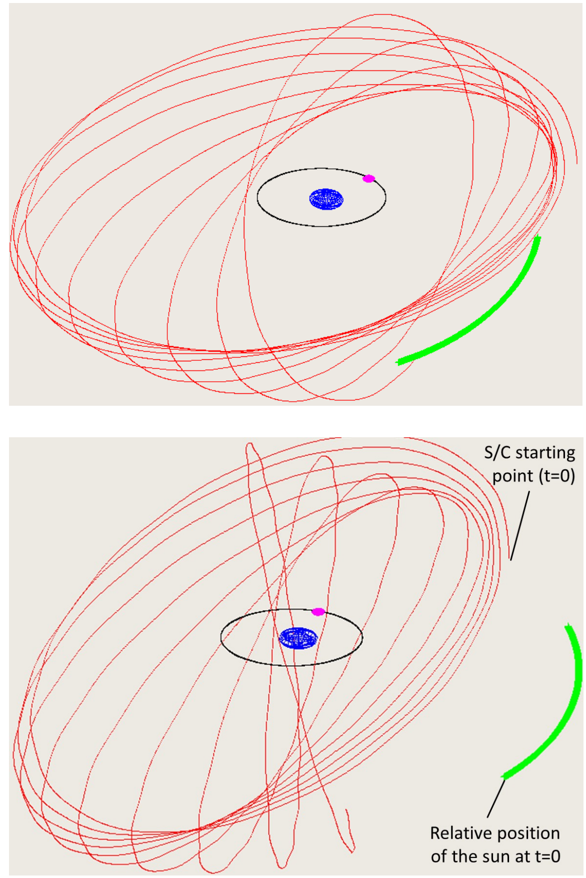

Figure 2: S/C behaviour in orbit of 1996 FG_3.
Start: 01/May/2026
End: 01/Aug/2026.
The pictures show the S/C motion from two different perspectives. The orbital planes are following the sun.

References

[1] Barucci, M.A. et. al. MarcoPolo-R - Near Earth Asteroid Sample Return Mission - submitted 2011.