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Deployment of a lander on the binary asteroid (175706) 1996 FG3, potential target of the european MarcoPolo-R sample return mission

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ABSTRACT

The idea of deploying a lander on the secondary body of the binary primitive asteroid (175706) 1996 FG3 is investigated. 1996 FG3 is the backup target of the European sample return space mission MarcoPolo-R under assessment study at the European Space Agency in the framework of the M3 Medium-Class mission competition. The launch will take place in 2022–2024, depending on its selection at the end of 2013. A lander is indicated as an optional payload, depending on mass availability on the spacecraft. Obviously, the possible complexity of a lander deployment is also an important parameter to take into account. Here we demonstrate that, considering worst case scenarios and low requirements on the spacecraft GNC and deployment mechanism, the operations are easy to implement and safe for the main spacecraft. The concept of operations is to deploy a light lander from the L_2 Lagrange point of the binary system, on a ballistic trajectory that will impact the secondary asteroid. The fundamental principles of this strategy are briefly presented and a detailed model of 1996 FG3 is considered, to which the strategy is applied. We show that the deployment is successful in 99.94% of cases.

1. Introduction

Binary asteroids represent about 16% of the Near-Earth Object (NEO) population [1]. The most promising scenario of their origin is the breakup of a single body as a result of the increase of its rotation frequency due to the thermal YORP effect. When this happens, the outcome can be a binary system. Several models have been proposed to simulate this process but they have different implications on the internal structure of the progenitor and on the properties of the resulting system [2–5]. A space mission to a binary would allow discriminating between the models and investigating various geological processes that may be particular to this kind of systems.

The European Space Agency is currently performing the assessment study of the MarcoPolo-R space mission, in the frame work of the M3 (Medium number 3) class competition of its Cosmic Vision Program. MarcoPolo-R is a sample return mission to a primitive asteroid, whose backup target is the binary asteroid (175706) 1996 FG3 [6,7]. Until very recently, 1996 FG3 was the baseline target, however, following recommendation of the science team, the single asteroid 2008 EV5 was preferred, and 1996 FG3 is now a backup target. The assessment study phase takes place until fall 2013, at which time a study report called "Yellow Book" is submitted, and the final selection of the M3-class mission to be launched in 2022–2024 takes place at the end of 2013.

Although the main objectives of MarcoPolo-R is to return a sample from a primitive asteroid for analysis in

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terrestrial laboratories, some in situ investigations are planned in order to place the sample in its geological context. Those investigations are done using cameras and spectrometers in different wavelengths. Since the sample is planned to be taken on the primary of the binary system, there is nothing envisaged in the mission for the investigation of the secondary apart from possible remote observations from the spacecraft. However, MarcoPolo-R was also proposed with an optional lander, and if such a lander could be accommodated, it may be relevant to use it for a more detailed investigation of the secondary. One of the benefits to go to a binary is that information can be obtained about two space rocks for essentially the price of one (in terms of trajectory from Earth), and if there is a way to access this information without affecting the mission cost and risks, it should be seriously considered. The reason to eventually prefer asteroid 2008 EV5 to 1996 FG3 is that, although the asteroids share the same level of interest for sample science, 2008 EV5 allows for a much shorter, hence simpler and cheaper, mission. Nevertheless, 1996 FG3 is selected as a target for Marco Polo R, albeit as a backup.

We have recently developed a theoretical model of trajectories around binaries in order to investigate strategies of deployment of science packages on binary asteroids. Building on previous analyses of the dynamics at play in a binary asteroid environment [8–10] we found that in general, a deployment on the secondary can offer some advantages [11]. In this paper, we apply this theory to the particular case of 1996 FG3, for which radar observations have been done allowing the derivation of a model of the system. Our aim is to investigate whether the conclusions from our first study hold true and to make a more detailed analysis for this particular binary to which a space mission is under study. The decision to carry a lander on MarcoPolo-R depends on various parameters, one of which being the possible operation complexities. Thanks to the analysis presented in this paper, we can determine whether some particular strategies of deployment in the case of a binary allow minimizing the risks and operational complexities.

In Section 2, we briefly summarize the theory and model developed by Tardivel and Scheeres [11] and a possible implementation of the deployment strategy. Section 3 presents in details an application of this theory to the particular case of 1996 FG3, discussing every aspect of the deployment from the approach of the main spacecraft to the specifications on the damping coefficient of the lander. Implications of the results on the specifications on the lander, especially in terms of required coefficient of restitution, are exposed in Section 4. Section 5 gives the conclusions.

2. Methods

In the context of a binary asteroid, the deployment of science packages can be performed with great robustness if the natural features of the Restricted 3-Body Problem (R3BP) are used appropriately. Tardivel and Scheeres [11] explained how these features make such deployment easy to achieve and very reliable. Here, we recall the fundamental principles of this deployment strategy and a possible implementation for the MarcoPolo-R mission.

2.1. Performing deployments from Lagrange points

Before presenting the strategy, we set up the mathematical framework of this study. When coordinates are mentioned, and unless stated otherwise, they are given in the binary asteroid system rotating frame. This frame is centered on the bodies barycenter, its $\hat{\mathbf{x}}$-axis points from the primary to the secondary and its $\hat{\mathbf{z}}$-axis points along the system mutual orbit normal. As the orbit is supposed circular, one will notice that the $\hat{\mathbf{y}}$-axis is therefore aligned with the orbital velocity of the secondary and that this frame is rotating at a constant rate $\boldsymbol{\omega} = n\hat{\mathbf{z}}$ where n is the mean motion of the mutual orbit of the bodies. Fig. 1 shows the system of 1996 FG3 in this frame; notice the Lagrange point locations and numbering, as well as the zero-velocity curves defined by some specific values of the integral of Jacobi.

In essence, as ballistic motion follows natural manifolds, landers should be deployed on ballistic trajectories in regions of space where the natural manifolds lead to an impact on the targeted asteroid. Of course, releasing a lander at very low altitude (*e.g.* a few meters) could be considered the simplest and most practical strategy. But this strategy actually requires great operational constraints as coming so close to the surface poses a threat to the main spacecraft. A safe and convenient strategy should constantly keep the main spacecraft out of harm's way while ensuring, considering operational margins, the deployment of the lander.

Hence, the three collinear Lagrange points become interesting locations for investigating such a deployment: they are far from the two components of the binary system

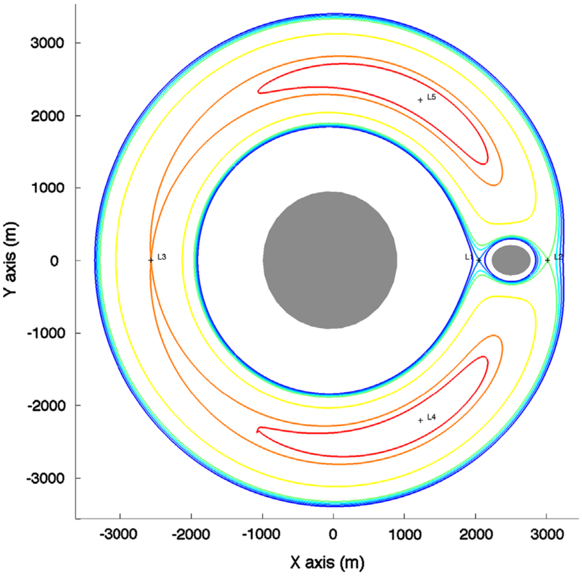

Fig. 1. A model of the binary asteroid system (175706) 1996 FG3 with zero-velocity curves corresponding to specific values of the integral of Jacobi. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)