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ScienceDirect

Advances in Space Research xxx (2017) xxx–xxx

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Spacecraft design of a multiple asteroid orbiter with re-docking lander

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Received 31 January 2017; received in revised form 23 July 2017; accepted 29 July 2017

Abstract

Almost two years after the landing of Rosetta's Philae on the comet 67P/Churyumov-Gerasimenko, the triggered enthusiasm for small planetary bodies has not stagnated. Moreover, the interest has spread from mostly scientific enlargement of knowledge to a beginning curiosity about the exploitation of resources and their usage in space.

Within this context, this paper is focusing on the design of the multiple asteroid orbiter Titius-Bode. Titius-Bode consist of an orbiter Titius and a lander Bode which aims for the characterization, resource determination and internal composition of a sequence of asteroids in the main belt. The mission objectives and spacecraft systems are described in detail, taking into account the constraints of the overall mission goal and concept. The mass and power budget for both lander and orbiter are listed as final result.

The overall spacecraft design can be used for asteroid mining prospection as well as for purely scientific missions.

Keywords: System design; Systems engineering; Asteroid orbiter; Asteroids; Small planetary bodies; Asteroid mining

1. Introduction

Small bodies are left-over building blocks of the very early solar system formation process. The material they consist of offer hints to the chemical composition of the planets during their development. On those bodies, scientists also hope to find residues of organics that could be clues to the origin of life. Despite the scientific interest, potential collisions of asteroids with Earth pose a risk for the continuing existence of life on Earth. Another aspect in small body science is the rapidly growing idea to find valuable commodities to facilitate deep space human missions or re-supply of diminishing resources on Earth.

This scientific importance of the research on asteroids is in conflict with the knowledge on small bodies obtained yet. The surprises that Rosetta's arrival at the comet 67P/Churyumov-Gerasimenko had in store are a good example of how great the uncertainties of even thorough ground observation results can be. Hence, the proposal of experts is the close-up characterization of more small bodies from different classes and groups by spacecraft encounters in order to enlarge our picture of these bodies. But space missions are expensive and require a long development period in advance. One idea to increase the efficiency of the characterization process, also in consideration of the number of bodies known, is to visit more than one asteroid with one mission.

The concept of sequential visits of several objects has been subject of numerous trajectory design analyses over the last decade. Especially noteworthy are the results obtained in the frame of the Global Trajectory Optimization Competitions (GTOC) N° 2, 3 and 7 examining a multiple asteroid rendezvous (2, 2006), a multiple sample return (3, 2007) and a multi-spacecraft exploration of the asteroid main belt (7, 2014).[1] Building on first methodologies about multi-asteroid solar electric propulsion trajecto-

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[1] https://sophia.estec.esa.int/gtoc_portal/.

http://dx.doi.org/10.1016/j.asr.2017.07.041
0273-1177/

Please cite this article in press as: Probst, A., Förstner, R. Spacecraft design of a multiple asteroid orbiter with re-docking lander. Adv. Space Res. (2017), http://dx.doi.org/10.1016/j.asr.2017.07.041

ries examined by Bender and Bourke (1973), Bender et al. (1979) and Morimoto et al. (2002), the GTOC results identified the main challenges and proposed different solutions. Izzo et al. (2007) applied an approach in three steps: a combinatorial optimization phase dealing with many target candidates and hence a huge number of permutations, a global optimization phase that derives an optimized impulsive trajectory for each candidate sequence and a local optimization phase in case electric propulsion has been envisaged. Especially the first step introduces a complexity that originates from the many potential candidates and the exponential growth of possible sequences with each additional target. Hence, one focus on the proposed solutions has been on data base pruning methodologies (Alemany and Braun, 2008; Schütze et al., 2009). The latter have found applications to low-thrust trajectory optimization analyses for asteroid fly-by tours in the inner solar system (Di Carlo et al., 2017) as well as tours through the asteroid main belt (Carlo et al., 2016).

In order to complement the existing studies on trajectory design and tour analysis, this paper proposes a spacecraft design for a multi-body rendezvous mission in the asteroid main belt called **Titius-Bode** that aims for the scientific gaps formulated by the research status from today.

2. The Titius-Bode mission

The here presented S/C design is based on a mission concept and preliminary composite architecture of Probst et al. (2015) and is called **Titius-Bode**. It consists of a carrier **Titius** and a re-docking lander **Bode**, named after two astronomers whose findings significantly influenced the discovery of the asteroids between Mars and Jupiter. Titius-Bode is designed to investigate a sequence of asteroids in the asteroid main belt by orbiting its targets for about six months and dispose Bode on the surface. After a detailed characterization in terms of physical and chemical characteristics, Bode re-ascents and re-docks with Titius, before they continue in docked configuration their main belt tour to the next target. This operational concept requires next to other things a complete navigation suite on Bode to enable controlled orbiting, landing, re-ascent, rendezvous and docking. In Fig. 1, a sketch of the operational concept is provided.

Bode will be separated at an approximate height of 10 km from the asteroid's surface. It will perform a controlled landing on a pre-selected landing site. With the fully equipped guidance, navigation and control suite, it is able to perform hopping on the asteroid's surface in order to investigate more than one surface area.

Both entities Titius and Bode are designed as typical cubic satellite platforms with an edge length of 2.4 m for Titius and 1.0 m for Bode. Fig. 2 shows the spacecraft in docked configuration.

In the following, the design process including requirements and parameters are explained for each subsystem.

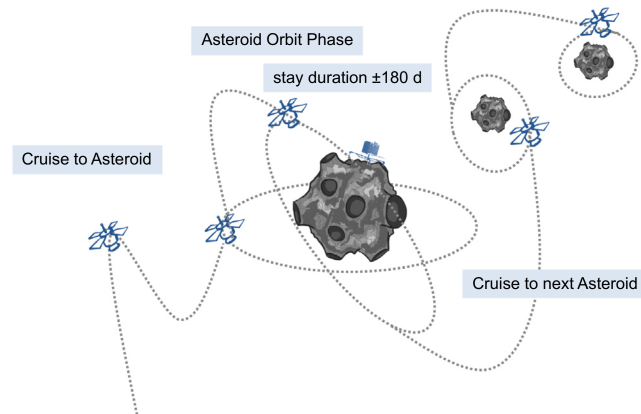

Fig. 1. Operational Concept Sketch. Adapted from González Peytaví et al. (2015).

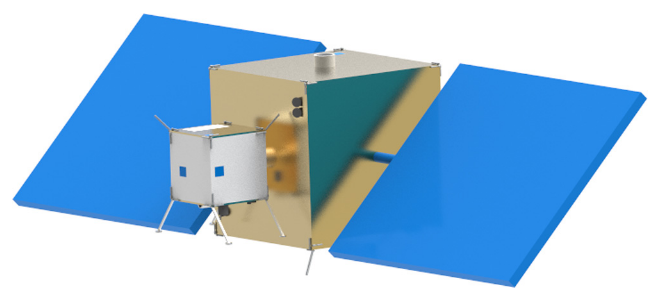

Fig. 2. Titius-Bode in docked configuration for the high-thrust option.

The power and mass budgets are listed in Section 5.9 for Titius and in Section 6.9 for Bode.

3. Science objectives

Following that, the Titius-Bode mission has the purpose to achieve two main goals: to *determine the internal composition of the target asteroids* and to *characterize more than one asteroid* to enhance the productivity as a whole.

Derived from the two main goals, the mission responds to three science questions:

1. What resources are available on the study object?
2. How is the composition distributed on the study object?
3. What are the physical properties of the study object?

Those three science questions are addressed by the following science objectives:

A. Characterize the chemical properties of the target surface
B. Determine the internal composition of the target
C. Detect abundances of metals and other volatiles
D. Provide a global map of the asteroid interior
E. Determine the global physical properties of the target
F. Determine the physical surface properties of the target

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