Requirements and Constraints for Exploration of Binary Asteroid Systems: From Didymos to Hektor.

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Motivation

Over the last few years, there has been an increasing interest in binary asteroid systems, and in sending spacecraft to them (to cite only a few references, see [1, 2, 3, 4, 5, 6, 7]). Studying binary asteroid systems has been shown to provide valuable incentives and benefits in terms of potential science discoveries. In particular, studying two small bodies at once provides opportunities to better understand the implications of space weathering, fast and slow rotators, and the effect of solar radiation. And since their bulk densities are related to their mutual period and shape, more insights into their interior composition can be obtained. In addition, since their translational and rotational dynamics are coupled, having a closer look may tell more on other planetary systems, and may help validate current theories on formation and evolution of binaries among the small body populations.

A lot of questions remain regarding the possible close orbit operations and spacecraft applications at a binary. We present some important requirements and constraints for missions at a binary, including recent work on out-of-plane orbits, influence of the solar radiation pressure, and contact binaries.

Current mission opportunities

To date, there has been a few preliminary studies for mission to binaries. For instance, we count LEONARD [3] (CNES) with the binary 1996FG3 as target, and from which Marco Polo is partly derived, PARIS[4] (ESA), a sample return to the Trojan binary Hektor, ILion [8] (NASA) to Trojan asteroids at L_5, DEx [9] (NASA AMES) to (65803) Didymos, and SHOTPUT [10] (JPL) also including Hektor as one target. A few other feasibility studies are in the pre-phase A stage, and other missions such as Hayabusa-2 and Marco Polo still regard binaries such as 1996 FG3 as backup potential targets.

These binary system targets include a wide range of asteroid types and configurations. Didymos is a fairly small scale system, with a primary of 750 m in diameter, separated by 1.1 km from its 200 m diameter secondary [11]. 1996 FG3 is about twice Didymos' system size [12]. On the other hand, many main belt and Trojan asteroids are kilometers in size [13], and of a wide range of densities. Hektor is an elongated suspected contact binary of 363 km by 207 km in size [14] with a small satellite, S/2006, of 15 km in diameter orbiting more than 1000 km away [15]. At this distance, S/2006 doesn't contribute to the analog Three Body Problem generally associated with binaries, but the nature of Hektor itself, being a contact binary, implies interesting dynamics.

Each mission has its own approach strategy and corresponding proximity operations based on science objectives; the NEAR, Stardust, Rosetta, or Hayabusa mission provide good examples. The flyby, rendezvous, or sample return also depend on the spacecraft configuration, and most likely dictate some of the necessary operations to be performed. But, as for single asteroids, the different binary targets involve particular dynamics, and we look into how a binary system physical parameters can influence the orbits stability and drive ΔV requirements. For instance, the landing and escape velocities for Didymos, or other small scale Near Earth Asteroid binaries, are of the order of 10 to 100s cm/s, as opposed to 10 to 100 m/s for Trojan or km-sized asteroids. Altitudes of stable orbits, direct or retrograde, which influence mapping operations, vary also accordingly and are influenced by the asteroid shapes. In addition, the presence of a secondary may put bounds on safe altitudes due to third body perturbations, and so hovering or orbiting may be disturbed unexpectedly. Other perturbations, such as the solar radiation pressure reduces by three orders of magnitude for the same spacecraft located at 1AU and 5AU.

Approach and close operations

For a binary, timing of the approach becomes more important, since binary orbit rates are of the order of 10-20 hours. Earlier studies have looked at approaches in the plane of the binary, through the smaller body of the system [5, 9]. The reasoning behind this approach is in part driven by a usually faster, more unstable primary environment, such as the well studied case of 1999 KW4 [16]. In this case, it was shown that the primary spins fast enough that loose particles would tend to ”fall” towards the equator and accumulates, making a bulged body. Other cases of interest such as Didymos or 1996FG3 have similar behavior [11].

In addition, the energy distribution in a commonly observed spherical primary and smaller ellipsoidal secondary makes the smaller asteroid a safer “entry” place, as it implies a minimal escape probability [5]. The smaller gravity of the secondary may also be more attractive for the softer landing and lower escape velocities, when considering dropping surface packages or looking

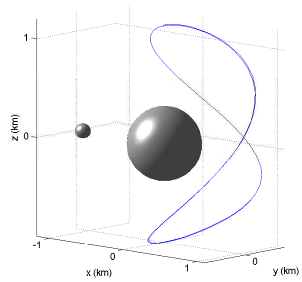

Figure 1: Quasi out of plane periodic orbits for Didymos.

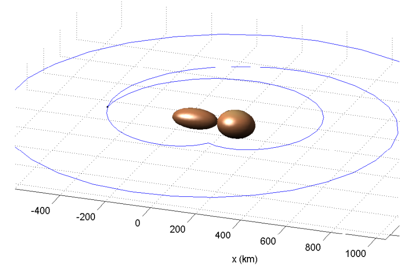

Figure 2: Perturbations during close orbit operations at contact binary Hektor leading to escape. Model taken from [14].

at getting samples. The surface motion following the surface stability of rotating bodies tends to be more predictable for slow rotators [17].

Orbiting in the plane can take advantage of analog R3BP properties. We can also show that the solar radiation pressure may be averaged out from the in-plane dynamics, depending on the system parameters. However, in-plane motion involves longer eclipse times, driving power needs, size and mass requirements, and possible non-negligible disturbances from the secondary.

As for earlier mission to small bodies, out of plane orbits may be more suitable, for both systems requirements and mapping operations. Recent work have shown that quasi out-of-plane periodic orbits exist for binaries, circular and elliptic orbits, and for various mass distribution. We show analytical and numerical results applicable to spacecraft missions and to possible dust hazards depending on orbits stability.

For a small scale binary system having bodies less than 1 km in size, the secondary may pose more challenge than the primary, as the navigation requirements become too tight for to the actual spacecraft capabilities. Systems such as Didymos may be near impossible to orbit. Hence, hovering, such as the strategy used for Hayabusa, becomes more appropriate. On larger systems, fuel requirements and operations timeline will influence the decision between hovering and orbiting. And perturbations from the secondary may complicate or challenge the close orbits operations.

Finally, we worked on larger systems, and contact binaries, and studied the influence of stable and unstable equilibria for such systems. The suspected contact binary Hektor shows non negligible effects on spacecraft dynamics. Analytical methods and results are shown for both in-plane and out-of-plane dynamics.

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