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Robust deployment of landers to asteroid surfaces

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Abstract

We investigate the ballistic deployment of landers to the surface of asteroids, with an emphasis on binary asteroids. We use binary 1999 KW4 as representative of binary asteroids in general, but also generalize our conditions to other binary systems. Our goal is to develop robust and simple methods for deploying probes to asteroid surfaces, fully accounting for the strongly unstable motion that can occur at these bodies.

1. Introduction

Binary asteroid systems represent about 15% of the total population of Near-Earth Asteroids (NEAs) of diameter larger than 300m [1, 2], and are considered prime targets for future asteroid rendezvous missions due to the additional geophysical insight available due to their binarity – as a case in point the currently proposed MarcoPolo-R mission will visit a binary asteroid. A future goal of these missions will be the deployment of probes on the surfaces of these bodies, to enable the measurement of fundamental mechanical and geophysical processes. In this abstract we consider the development of simple and robust methods of deployment using a ballistic trajectory to the asteroid surface, meaning that active guidance is not needed.

On closer inspection, small bodies prove to be challenging targets to land on. They exhibit rapid rotation, irregular surfaces, and strongly non-spherical gravity that can cause unexpected trajectories. Furthermore, their low gravity makes reaching their surface only a part of the problem, as a lander will generally bounce after first impact and could be ejected from the asteroid back into orbit and even into an escape trajectory. A proper study and analysis of ballistic deployments to an asteroid surface will enable the development of robust deployment and mission designs that can accommodate these issues. For deployment to binary asteroids we can bring in our understanding of the restricted 3-body problem (R3BP) to enable these goals.

The nominal delivery system we anticipate is modeled as a spring that will give the lander a predetermined impulse which can be estimated prior to launch for a binary system. For precision control, the main spacecraft will adjust its position, orientation and velocity so that, at the moment the spring is released, the lander has a position and velocity that will ensure it reaches the surface of the asteroid and settles there.

2. Results for the 1999 KW4 system

In a previous paper, Tardivel and Scheeres showed that the task of landing on the secondary body of the 1999 KW4 system – namely Beta – was feasible and quite robust. The lander is jettisoned from a zone close to the L_2 libration point, called the *neck region*, which is a surface that crosses the throat defined by the zero-velocity surfaces at their narrowest location (Fig. 2). The Jacobi integral of the lander is fixed in the R3BP, thus assigning for every position in the neck region the magnitude of the velocity, whereas the direction of the velocity can be varied. Four outcomes can occur for a generic lander launched along this trajectory: it can miss Beta and transit through to Alpha (the primary), crossing the L1 neck (**transit**); it can impact the surface of Beta (**landing**); it can cross through the neck region again back into the outer realm (**escape**); or it can theoretically enter into a **bounded** motion with none of the previous events occurring (although this is highly unlikely). We must also consider the possibility that the lander has a "landing" followed by a "transit" or "escape" due to its recoil with the surface of Beta.

Our initial analysis of this problem made a few simplifying assumptions for the system that will be revisited for the current presentation. Under the hypotheses (stated in [3]) it can be shown that a robust strategy for deployment of a lander to Beta for 1999 KW4 can be developed, with dynamical guarantees that the lander will be trapped on the surface of Beta. The necessary precision for the deployment of the probe is relatively lax, with velocity precision on the order of cm/s sufficient and positional control on the order of 10's of meters – all very feasible for a spacecraft. In this deployment strategy the lander strikes a relatively precise location on the secondary (see Fig. 1). Even if the lander has a subsequent bounce, we can show that for a coefficient of restitution less than 0.93 the body will be trapped to the secondary surface and eventually settle.

We will also report on deployment analyses onto Alpha, which prove to be more challenging due to the rapid rotation of that body. In this approach we design the landing trajectory such that it travels faster than the asteroid surface, ensuring that the body will be scattered backwards after its initial impact, and given a lower speed than the asteroid surface. In subsequent impacts the lander will eventually come to rest on the asteroid surface. Fig. 3 shows the general strategy for choosing the impact velocity of the probe.

3. Generalization of the strategy

We use binary asteroid 1999 KW4 for the development of our analysis as it is a very well known system. Although it is an NEA, its orbit around the sun makes it unsuitable for a rendezvous mission. However, we can use our detailed analysis for this body to serve as a basis for generalizing our results to a range of NEA binaries which are more accessible. We will provide details on this generalization, which will be a function of the semi-major axis of the system, the mass ratio of the system, and the spin rate of the primary. An initial indication of the sort of constraints we can provide is mentioned in the caption of Fig. 2.

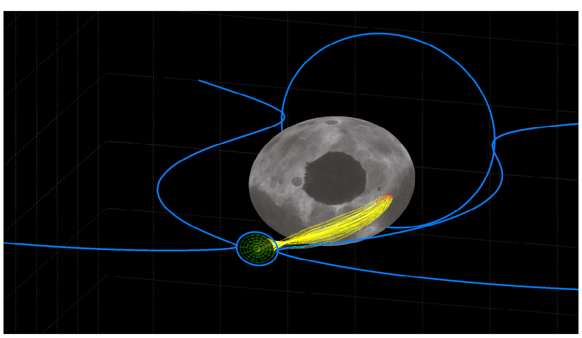

Figure 1: 1999 KW4. A bundle of trajectories (yellow lines) initialized in the L2 neck region (green web) spreading over the whole landing zone (red web). A random texture, not representative of Beta's actual shape, is shown.

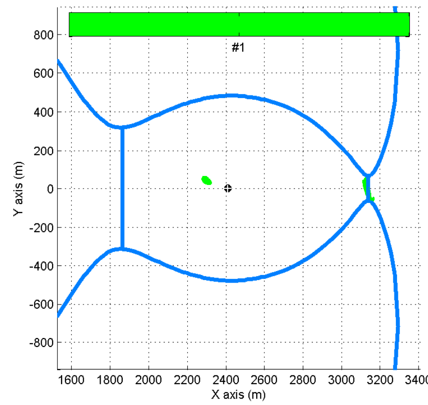

Figure 2: 1999 KW4, mass-ratio $\mu \simeq 5.5\%$. The first periapsis region (green zone inside the central region) is very close to the center of the secondary ($\oplus$). The minimum radius of Beta is about 140m; the radius-to-orbit ratio is about 5.4%. Any binary system with $\mu \simeq 5.5\%$ will then need a radius-to-orbit ratio of at least 5.4% to ensure reaching the surface.

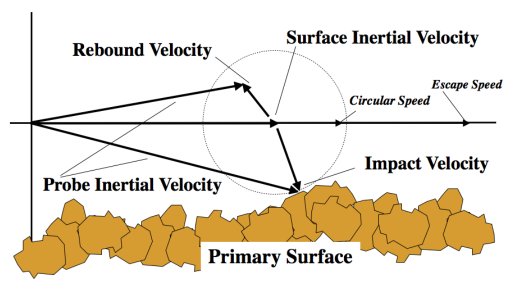

Figure 3: Deployment strategy to the binary primary.

References

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