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ASTEROID'S ORBIT AND ROTATIONAL CONTROL USING LASER ABLATION: ADVANCES IN PHYSICAL AND SIMULATION MODELLING

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ABSTRACT

This article presents an advanced analysis of the coupled orbit and attitude dynamics of an asteroid deviation mission through laser ablation. A laser beam is focused on the surface of an asteroid to induce sublimation. The resulting thrust induced by the jet of gas and debris from the asteroid, directed as the local normal to the surface, can be employed to contactless manipulate its orbit. The effect of an off-set of the induced thrust vector with respect to the centre of mass can produce a variation of the angular velocity. In turn, this produces a variation of the sublimation that affects both the orbital and attitude motion. Thus, the control of the coupled orbit and rotational motion of the asteroid represents one of the key aspects contributing to the success of this deflection technique. Previous studies considered a technological demonstrator for a 4 m diameter asteroid, where simplified models in both physical characterisations of the ablation process and of the asteroid's ellipsoidal regular shape were used.

This paper focuses on the laser-based deflection and rotational control of a 50 m diameter Earth-crossing asteroid, considering 3 up to 20 years operations. An application of the method is also shown for the case of the asteroid 2013 PDC15.
Based on the theoretical model of a laser-based deflector, an optimal hovering distance for the spacecraft operations and required power are first computed. The computation includes, among others, the effect of contamination which has an impact on the available power at the laser and consequently on the achievable

thrust. The deflection of the asteroid over the pushing time with respect to its nominal orbit is then simulated through a semi-analytical approach. Before starting the actual deflection phase the laser will be pointed to create a suitable control torque such to decrease the angular velocity in order to improve the efficiency of the process in terms of larger laser impingement time over specific surface locations.

The asteroid is modelled as a tumbling object with an arbitrary polyhedral shape, using actual asteroid data from radar observations scaled down to the considered mean dimension. Once the desired rotation rate is obtained, the laser will be pointed such that the resulting thrust is directed in the needed direction. This will require controlling the rotational velocity after certain intervals if the thrust alignments is such that to accelerate the rotation. The results will be compared to the ones obtained using an equivalent regular ellipsoid and nominal operating conditions with no angular control. Results show that the fact that the laser needs to adjust continuously its pointing affects the net deflection, reducing the overall effectiveness of the ablation process. Nonetheless the rotation rate control benefits the laser efficiency such to mitigate this effect.
The case of the asteroid 2013 PDC15 shows that the achieved deflection is not enough to reduce the impact risk in 2022, unless very high powers at lasers and longer periods of operations are considered.

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