NASA's DART MISSION TO DIDYMOS: THE EFFECT OF SHAPE DEFORMATION OF THE PRIMARY AND ELLIPTICITY OF THE SECONDARY ON POST-IMPACT ORBITAL PERIOD.

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Introduction: The NASA Double Asteroid Redirection Test (DART) mission, part of the joint ESA-NASA Asteroid Impact & Deflection Assessment (AIDA) mission concept, will target the binary near-Earth asteroid (65803) Didymos in 2022 [1]. The ESA-led component of AIDA is now optimized as a new mission called Hera [2]. AIDA will assess the performance of asteroid deflection technologies [1, 2]. To do this the DART spacecraft impacts the secondary of Didymos [1] while Hera's 6U CubeSat later observes the system to help determine the momentum transfer coefficient of the impact, β [2]. As one scientific question for AIDA, the effect of shape deformations of the primary due to collisions of DART-generated ejecta was examined to see if it could induce additional orbital perturbation of the secondary [3] (hereafter Hi2017). This scenario was considered as the primary is spinning with a period of 2.26 hr [4] and may be structurally sensitive to shape deformation [3, 5]. Thus, even small inputs of energy may fluidize surface materials on the primary [6, 7]. The present work extends our earlier investigation that assumed the secondary was spherical, and now accounts for the effect of the secondary's elongation. Our results show that the elongation causes a systematic shortening of the secondary's orbital period relative to the spherical case.

Modeling gravitational interactions between the primary and the secondary: Hi2017 considered the primary shape to be modeled using a radar-derived shape model [4] while the secondary was assumed to be a sphere. However, lightcurve observations imply that the secondary might be elongated [8]. Thus, we wish to study the more general and realistic case that the secondary is non-spherical.

We consider the gravitational interaction to be modeled by the second-order inertia integral expansions. Analytical expressions were reported previously [9, 10], so we directly follow that formulation while assuming that the orbital motion is constrained to a reference plane, and the rotational axis is always along the out-of-plane direction. Note that DART is now designed to collide with the secondary with an out-of-plane angle of 17.5 deg. However, Hi2017 identified that this has a negligible effect on the orbital period change. Also, because radar observations indicate that the primary is a roughly top-shaped body, its shape is assumed to be oblate: with semi-major axis equal to semi-intermediate axis.

Case when the secondary is spherical: We compare the results from our new model with those from Hi2017. Their work considered a case when DART approaches the secondary at 27.5 deg out of the reference plane to make an approximaly head-on collision. When β=1, the horizontal velocity change of the secondary after the DART impact is 5.6×10^{-4} m/s backward [Hi2017]. We examine the orbital period change of the secondary as a function of the primary's post-impact aspect ratio (Fig. 1). Our model is consistent with Hi2017 although deviations become large at a small aspect ratios. This difference arises as the deformation of the primary [4] in Hi2017 may not produce a perfectly symmetric body. However, because shape deformation of this magnitude are unlikely to occur, our work's assumption is still reasonable when the aspect ratio is close to the original value, i.e. 0.939.

Hi2017 showed a limited number of cases and assumed β=1, although this quantity is highly uncertain. Thus, using the present model, we show the orbital period change as a function of the orbital velocity change of the secondary and the aspect ratio of the primary after the DART impact (Fig. 2). The velocity change ranges from 0 to 10^{-3} m/s, and the aspect ratio is between 0.69 and 0.939. Note that the local horizontal velocity change is ~6.0×10^{-4} m/s when β=1. The results show that as the aspect ratio decreases and the velocity change increases, the orbital period change monotonically grows up to 2.5×10^{3} s.

Case when the secondary is elongated: Here we consider that the secondary is elongated with the semi-intermediate axis equal to the semi-minor axis. In the following simulations, we fix the aspect ratio of the semi-minor axis to the semi-major at 0.9. Note that this value was arbitrarily chosen because the real value is not well constrained [4]. Given the same initial conditions as the spherical secondary case, we compute how the orbital period changes by following the technique in Hi2016. Figure 3 shows the orbital period change in the elongated-secondary case relative to that in the spherical-secondary case. If this quantity is zero, the orbital period change corresponds to the spherical-secondary case. The positive values indicate that the orbital period in the elongated-secondary case becomes shorter than that in the spherical-secondary case. This change results from the fact that the secondary's rotation can soak up angular momentum from the system's orbital motion.

We demonstrate the case when the initial velocity change is 6.0×10^{-4} m/s and the primary's aspect ratio after the DART impact is 0.9. A comparison of the spherical-secondary and elongated secondary cases is given in Fig. 4. It is found that while the evolution of the distance from the primary is similar, the rotational angle has a secular deviation.

Conclusion: Quantifying interactions between a post-impact aspect ratio of the primary and an elongation of the secondary will provide important insights for placing constraints on *ß*. The elongation of the secondary is likely to contribute to shortening the orbital period after the DART impact, and this effect becomes large as shape deformation of the primary is significant. Lastly, the Hera mission will further help provide critical information such as the post-impact surface conditions of Didymos that allows us to fully understand the AIDA impact experiment.

References: [1] A. F. Cheng et al. (2016) Planetary snd Space Science 121, p. 27-35. [2] P. Michel et al. (2017) Advances in Space Research, In Press. [3] Hirabayashi et al. (2017) MNRAS 472, 2, 1641-1648. [4] P. Michel et al. (2016) Advances in Space Research 57, p.2529-2547. [5] Zhang et al. (2017) Icarus 294, 98-123. [6] Garcia et al. (2015) Icarus 253, 159-168. [7] N. Murdoch et al. (2017) MNRAS 468, 2, 1259-1272. [8] P. Pravec (2006) Icarus 181, 63-93. [9] D. J. Scheeres (2006) CMDA 94, p.317-349. [10] J. Ashenberg (2007) CMDA 99, 149-159.

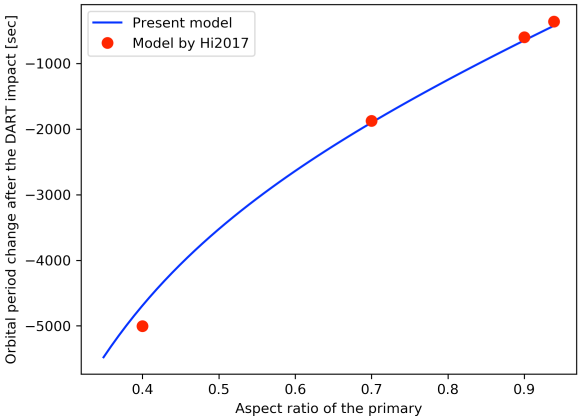

Figure 1. Orbital period change after the DART impact from the present model and from Hi2017.

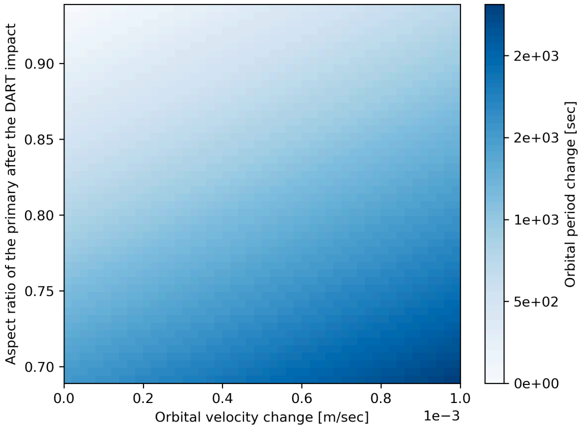

Figure 2. Orbital period change after DART impact as a function of the impulsive orbital velocity change of the secondary and the post-impact aspect ratio of the primary. The top edge (primary post-impact aspect ratio = 0.939) represents no primary deformation.

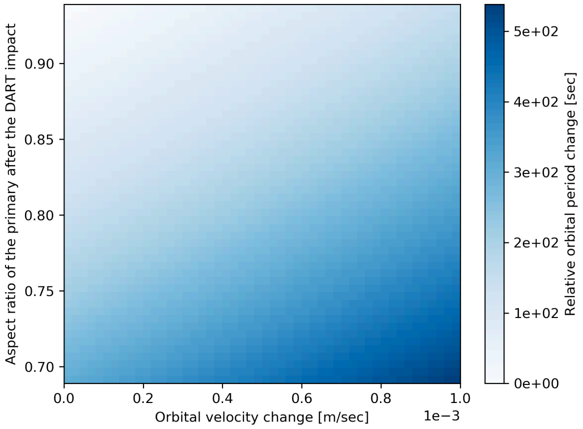

Figure 3. Relative orbital period change after DART impact as a function of the impulsive orbital velocity change of the secondary and the post-impact aspect ratio of the primary. Secondary aspect ratio = 0.9.

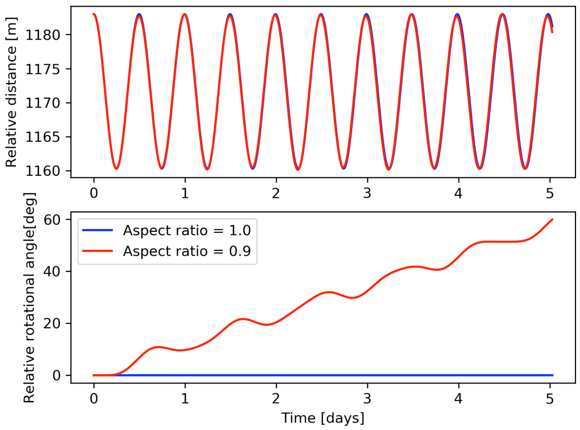

Figure 4. Evolutions of the inter-component distance (top) and rotational angel (bottom) after the DART impact relative to those before the impact.