ORBITAL PERTURBATION WITHIN BINARY ASTEROID DIDYMOS DUE TO IMPACT-INDUCED DEFORMATION OF THE PRIMARY AFTER THE DART IMPACT EXPERIMENT. M. Hirabayashi[1], D. J. Scheeres[2], D. C. Richardson[3], E. G. Fahnestock[4], P. Michel[5], S. P. Naidu[4], L. A. M. Benner[4], A. F. Cheng[6], and A. S. Rivkin[6], [1]Purdue University, West Lafayette, IN 47907, USA, (thirabayashi@purdue.edu), [2]The University of Colorado Boulder, Boulder, CO 80305, USA, [3]The University of Maryland, College Park, MD 20742, USA, [4]JPL/Caltech, Pasadena, CA 91190, USA, [5]Observatoire de la Côte d'Azur, Nice 06304, France, [6]APL/The Johns Hopkins University, Laurel, MD 20723, U.S.A.

Introduction: The proposed NASA Double Asteroid Redirection Test (DART) mission, a part of the Asteroid Impact & Deflection Assessment (AIDA) mission concept, will target the binary Near-Earth asteroid (65803) Didymos in October 2022 [1]. In this mission, the DART spacecraft is planned to collide with the secondary of Didymos. The primary mission goal is to demonstrate a measurable deflection of the orbit of the secondary. If possible, the momentum transfer coefficient, β, will also be estimated. In this scenario, there are two potential complicating factors. First, the primary of Didymos appears to be nearly structurally unstable at present [2, 3]. Second, the ejected particles are likely to reach the primary [4], and some of them possibly have speeds of a few km/s [3, 5], depending on the impact condition and the secondary's shape, which is currently unknown. Such impacts of the ejecta on the unstable primary might cause significant shape modification, perturbing the orbital motion of the system.

The primary needs some shear strength to keep its original shape: The primary of Didymos is a spheroidal object with an equatorial ridge [6]. Recent works have shown that the primary may experience a certain amount of tension in its body at present, depending on its bulk density [2, 3]. Figure 1 shows the primary's failure mode at its current spin period. The contours show the stress ratio, a ratio of the current stress to the yield stress, computed by a plastic finite element model (FEM). Regions with a unity stress ratio are expected to fail structurally. The internal region is more sensitive to failure than the surface because shear induced by vertical compression and horizontal tension becomes high in the interior. This mode provokes vertically inward deformation along the spin axis and horizontally outward deformation in the equatorial plane, causing the primary to become more oblate (Figure 1). To resist failure, the primary would need to have a cohesive strength higher than 30 Pa if the mechanical friction angle is 35 deg.

Impacts of ejecta from the secondary on the primary may induce the primary's deformation: When the DART impactor hits the surface of the secondary, some ejecta may reach the primary with speeds of a few km/s. The potential landing sites are widely spread over the primary's surface facing the secondary [4, 5]. Impact processes weaken the shear resistance of the affected material [7]. Because the bulk porosity is high, a strong centrifugal force induces material flows. Additionally, cohesion tends to increase the amount of the flow, while seismic vibrations by impacts fluidize the materials, enhancing the deformation process [8].

In the following, we discuss the deformed shape of the primary on the assumption of axisymmetric deformation. We assume that the mass of the ejecta hitting the primary is negligible, and the angular momentum of the primary is constant during the process. Also, we do not account for the effect of cohesion on dynamic deformation processes. Figure 2 shows the spin period limit of an oblate shape at a given aspect ratio, i.e., the ratio of the semi-minor axis to the semi-major axis, with different friction angles (the black lines) [9]. In this plot, given a friction angle, the oblate shape is structurally stable above that angle's curve. The red line describes the deformation path of the primary as a result of the angular momentum conservation; the blue dot at the bottom right is the current condition, and the green dots indicate the intersections with the contour curves of friction angles of 35 deg and 0 deg, respectively. If static friction controls the deformation process, the shape may settle at a typical friction angle of 35 deg. However, since dynamical friction, which is usually smaller than static friction, is critical to this process, the body may become more oblate but should not reach the aspect ratio at a friction angle of 0 deg. Therefore, the deformed shape may be situated at an aspect ratio between 0.4 and 0.7.

The primary's deformation causes strong orbital perturbation within Didymos: We analyze the mutual motion of Didymos after the DART impact. The primary and the secondary are assumed to be an oblate body and a sphere, respectively. This setting isolates the orbital motion from the attitude motion. The secondary is assumed to be orbiting in the equatorial plane of the primary. We neglect the deformation process and the mass loss of the secondary due to the impact. In the simulations, the initial distance between the bodies is 1200 m, and the initial eccentricity is less than 0.03 [6]. To model the DART impact, we fix the mass of the spacecraft and the incident speed at 500 kg and 6 km/s, respectively [1]. To induce high orbital perturbation due to the impact, we set β as 3.0 [10].

We demonstrate four cases here. The first case is the regular orbit that does not experience the DART impact, later known as the normal case. The second one is the case when the secondary experiences the impact, but the primary does not deform at all (the impact-only case). The third corresponds to a situation in which the primary deforms to have an aspect ratio of 0.7 after the impact (Case A in Figure 2). The last case is for when the aspect ratio becomes 0.4 (Case B in Figure 2). Figures 3 and 4 show the orbital motion in each case relative to that in the normal case.

The results show that the orbital perturbation due to the primary's deformation is much higher than that for the impact-only case. This feature comes from the fact that the deformation process generates a significant change in the gravity field. Although the present study assumes that the deformation process is axisymmetric, recent work has shown that it might not be so [11]. For this non-axisymmetric case, the orbital motion is coupled with the attitude motion, and both become more complex [12]. Therefore, we suspect that an asymmetric deformation process would induce more distinctive orbital evolutions than the axisymmetric deformation.

References: [1] A. F. Cheng et al. (2016) Planetary snd Space Science 121, p. 27-35. [2] D. C. Richardson et al. (2016) LPSC #1501. [3] D. C. Richardson et al. (2016) DPS #123.17. [4] Yu et al. (2017) Icarus 282, p.313-325. [5] J. E. Richardson and D. P. O'Brien. (2016) DPS #329.06. [6] P. Michel et al. (2016) Advances in Space Research 57, p.2529-2547. [7] G. S. Collins et al. (2004) Meteoritics & Planetary Science 39, P. 217-231. [8] J. E. Richardson et al. (2004) Science 306, p.1526-1529, [9] K. A. Holsapple (2001) Icarus 154, p.432-448. [10] K. A. Holsapple and K. R. Housen (2012) Icarus 221, p.857-887. [11] P. Sánchez and D. J. Scheeres (2016) Icarus 271, p.453-471. [12] D. J. Scheeres (2006) CMDA 94, p.317-349.

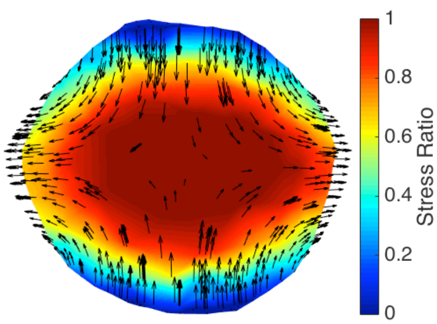

Figure 1. The stress ratio mapped onto the cross-section of the primary. The arrows show the deformation vector on the cross-section. The spin axis is in the vertical direction.

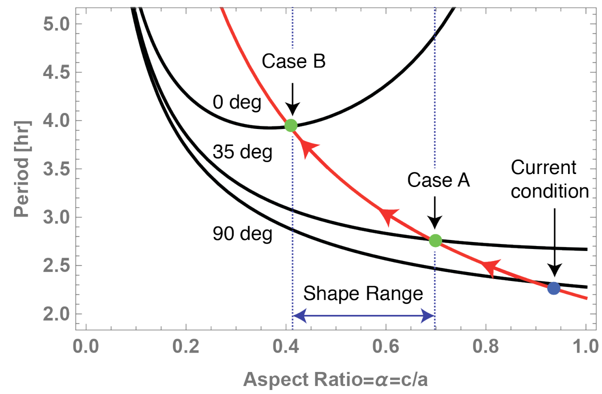

Figure 2. The spin period limit at a given aspect ratio with different friction angles and zero cohesive strength [8], and the deformation path of the primary.

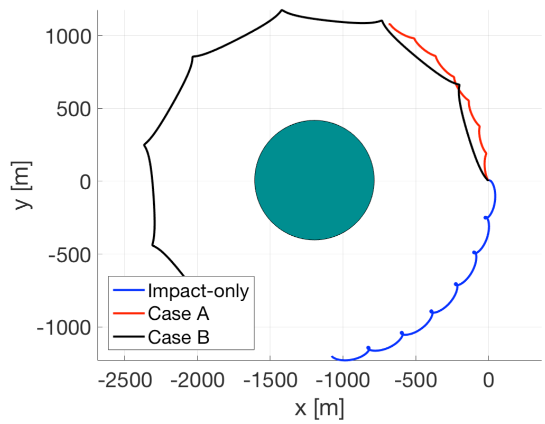

Figure 3. The position of the secondary in each case relative to that in the normal case in the frame rotating with the position in the normal case. The impact initially accelerates the secondary in the +y direction.

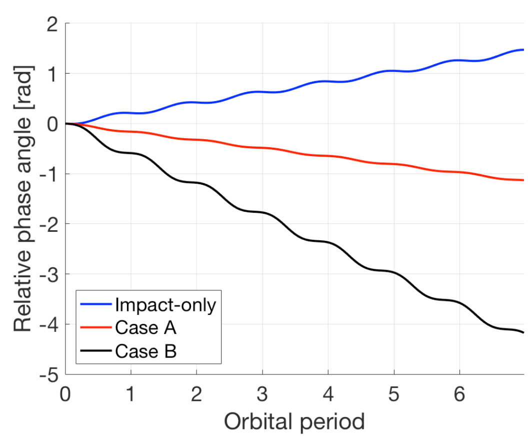

Figure 4. The phase angle of the secondary in each case relative to that in the nominal case as a function of time in orbital periods, one orbital period being 11.92 hr [5].