PDC2023
Vienna, Austria

Deflection / Disruption Modeling & Testing

NASA's Double Asteroid Redirection Test (DART): Orbit perturbations due to Dimorphos's reshaping and mass loss after the DART impact

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Keywords: *DART, Didymos, Dimorphos, Reshaping, Mass loss, Orbit perturbation*

ABSTRACT

At 23:14 UTC on 9/26/2022, the DART spacecraft impacted Dimorphos, the smaller secondary member of the Didymos-Dimorphos binary asteroid system [1]. The impact reduced the orbit period by 33 minutes [2]. The momentum transfer enhancement factor, β, which quantifies the effectiveness of the kinetic impact, is currently estimated to be 2.2 to 4.9 for plausible ranges of physical properties of the system [3].

The DART impact may have modified Dimorphos's intermediate axis (Y-axis) by up to ~10–15 m, leading to reshaping beyond just forming a crater [4]. Furthermore, the images from LICIACube and HST suggest that a significant amount of material was ejected after the impact [5]. These observations imply that materials with sufficiently

high ejection speeds escaped the system [6], while material with low ejection speeds could be redistributed back onto Dimorphos, contributing to the reshaping of Dimorphos [7]. The observed orbit period change (i.e., 33 min) could thus be the result of spacecraft momentum, ejecta recoil, and reshaping.

Here, we extend the pre-impact analyses of Dimorphos's reshaping effect by Nakano et al. [8] to account for Dimorphos's mass loss due to ejecta during the reshaping process, to give better insight into Dimorphos's geophysical and dynamical responses to the impact.

We generated hypothetical shape models of a reshaped Dimorphos and simulated the mutual dynamics after reshaping. The mass loss was set equal to the total ejecta mass (m_{ejecta}), despite that some ejecta might remain within the system and/or fall onto the bodies. We considered m_{ejecta} up to 10^8 kg (i.e., 2% of Dimorphos's original mass), and included a range of plausible values for the material strength of Dimorphos [e.g.,9]. The momentum transfer by the DART impact was not modeled because the reshaping and impact effects are independent to first order [8]. Figure 1 shows the orbit period change, δP, solely as a function of reshaping along the Y-axis, δY. Without mass loss, the orbit period always becomes shorter ($\delta P < 0$) than the original orbit period without reshaping. More than 3 m of reshaping ($\delta Y > 3$ m) leads to an orbit-period change comparable to the required observation accuracy of 7.3 sec [10]. On the other hand, when m_{ejecta} is larger than ~10^7 kg, the orbit-period change could instead become longer ($\delta P > 0$) depending on δY.

These preliminary results suggest that β, if thought to be the result of spacecraft momentum and ejecta recoil alone, could be over/underestimated depending on δY and m_{ejecta}. Careful assessment is thus necessary to properly interpret the measured orbit period change and determine β accurately. This is also important when applying the DART mission results to future planetary defense missions. δY and m_{ejecta} will be further constrained by ongoing efforts in impact modeling and ejecta evolution analyses [e.g.,4,11]; in the presentation, we will explore possible shapes of a reshaped Dimorphos and statistically determine the orbit perturbations due to Dimorphos's reshaping and mass loss.

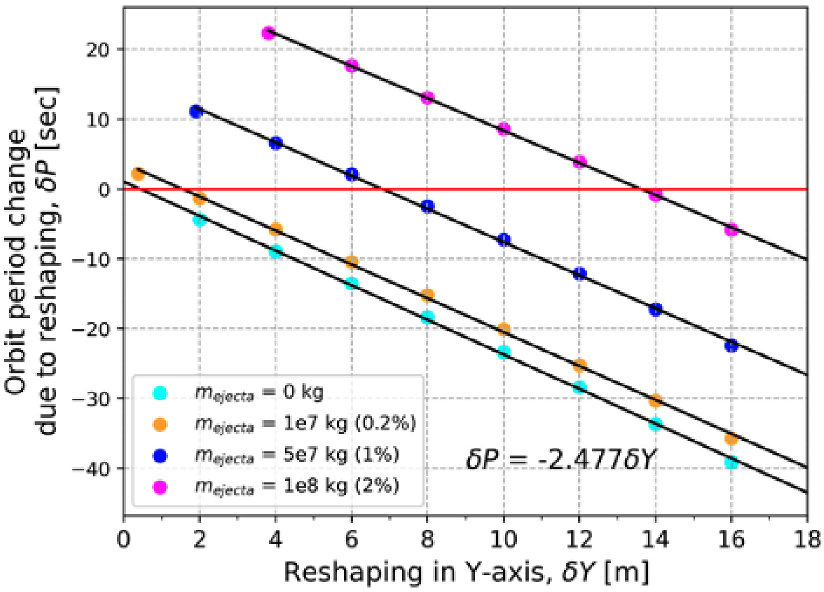

Figure 1. Orbit period change due to reshaping, δP, vs. reshaping in Y-axis, δY. The data points in different colors show different m_{ejecta}. The black solid lines are linear fits to the data points. δP indicates the orbit period change relative to the nominal pre-impact orbit period (i.e., 11.92 h [10]). $m_{\mathrm{ejecta}} < 10^7$ kg cases are not shown as they are almost indistinguishable from the $m_{\mathrm{ejecta}} = 0$ kg case.

Reference

[1] Daly+2022(submitted)
[2] Scheirich&Pravec 2022,AGUFM
[3] Cheng+2022(submitted)
[4] Raducan+2023,PDC
[5] Dotto+2022(submitted)
[6] Li+2022(submitted)
[7] Raducan+2022,PSJ
[8] Nakano+2022,PSJ
[9] Fahnestock+2022,AGUFM
[10] Rivkin+2021,PSJ
[11] Ferrari+2023,PDC

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Comments:

(Alternative session, Time slot, Oral or Poster, Etc…)