THE DOUBLE ASTEROID REDIRECTION TEST (DART) ELEMENT OF THE ASTEROID IMPACT AND DEFLECTION ASSESSMENT (AIDA) MISSION. A. F. Cheng[1], P. Michel[2] , O. Barnouin[1], J. Atchison[1], P. Miller[4], S. Chesley[3], D. C. Richardson[5], A.S. Rivkin[1], A.M. Stickle[1], [1]JHU/APL, MD USA (andrew.cheng@jhuapl.edu), [2]Lagrange Lab., Univ. Côte d'Azur, Obs. Côte d'Azur, CNRS, Nice, France, [3]JPL, USA, [4]LLNL, USA, [5]Univ. MD, USA

Introduction: The Asteroid Impact Deflection Assessment (AIDA) mission will be the first space experiment to demonstrate asteroid impact hazard mitigation by using a kinetic impactor. AIDA is a joint ESA-NASA cooperative project, consisting of the NASA Double Asteroid Redirection Test (DART) kinetic impactor mission [1] and the ESA Asteroid Impact Mission (AIM), which is the asteroid rendezvous spacecraft [2]. The original AIM concept did not receive full funding in late 2016, but a rescoping of AIM is being undertaken at ESA.

The AIDA target is the near-Earth binary asteroid 65803 Didymos. During the Didymos close approach to Earth in October, 2022, the DART spacecraft will impact the Didymos secondary at 6 km/s and deflect its trajectory, changing the orbital period of the binary. This change can be measured by Earth-based optical and radar observations.

The primary goals of AIDA are to (1) perform a full-scale demonstration of asteroid deflection by kinetic impact; (2) measure the resulting deflection; and (3) validate and improve models for momentum transfer in high-speed impacts on an asteroid. The combined DART and AIM missions will provide the first measurements of momentum transfer efficiency from a kinetic impact at full scale on an asteroid, where the impact conditions of the projectile are known, and physical properties and internal structures of the target asteroid are also characterized.

AIDA with both DART and AIM will be the first fully documented impact experiment at asteroid scale, including characterization of the target's properties and the outcome of the impact to test and refine our understanding and models at an actual asteroid scale. AIDA will check whether current extrapolations of material strength from laboratory scale to asteroid scale are valid. AIDA will validate the kinetic impactor technique to deflect a small body and reduce risks for future asteroid hazard mitigation.

DART: The momentum transfer efficiency β of a kinetic impactor is the ratio of the momentum transferred to the target over the incident momentum. Because there is momentum carried away by impact ejecta released back towards the incident direction, this β generally exceeds unity [1,3,4]. There are many unknowns that affect β, which is critical to predicting the amount of deflection to be achieved by a kinetic impact. By performing a kinetic impact on an asteroid and observing the target both before and after the impact, AIDA will measure β and determine the magnitude and direction of deflection. It will measure physical properties of the target asteroid, especially density, and determine shape and geology of the impact site. It will further study outcomes such as changes in the target body rotation state and evolution of ejecta.

Mission and Payload: The DART kinetic impactor baseline mission has changed from that given in [1]. DART will launch as a secondary payload to geosynchronous orbit and use the NASA Evolutionary Xenon Thruster (NEXT) ion propulsion system to spiral out from Earth orbit and transfer to Didymos (see Table 1). For a launch on or before 31 March 2021, the Didymos impact will now occur on Oct. 7, 2022, a few weeks later than in [1]. With a larger ~490 kg spacecraft impacting at 6 km/s, the incident momentum is significantly increased from that in [1], leading to a larger target deflection and a larger crater.

Table 1. DART Mission Design with NEXT ion propulsion

Launch Date	NLT Mar. 31, 2021
Earth Escape Date	Nov. 23, 2021
Arrival Date	Oct. 7, 2022
Arrival Relative Speed	6.01 km/s
Maximum Earth Distance	0.077 AU
Earth Distance at Impact	0.07 AU
Solar Distance	0.977 AU – 1.025 AU
Arrival Solar Phase Angle	59.1°
Impact Angle to Orbit Plane	14.5°

The DART payload consists of a high-resolution visible imager to support the primary mission objective of impacting the target body through its center. The DART imager is required for optical navigation and for autonomous targeting. The DART imager is derived from New Horizons LORRI [5], which used a 20.8 cm aperture, f/12.6 telescope imaging at 1 arc second per pixel. DART will determine the impact location within 1 m and will characterize pre-impact surface morphology and geology to <20 cm/px.

DART Observable Outcomes: Figure 1 shows predicted orbit changes of the Didymos secondary from the DART impact, for an assumed $\beta = 1$, a Didymos system mass 5.28×10^{11} kg and a secondary mass of 4.8×10^{9} kg as in [1]. The binary orbit before the DART impact is assumed to be circular, since zero eccentricity is consistent with light curve observations [7]. Only the impulse component along the orbit velocity causes an orbital period change. The changes in the period, eccentricity, and inclination of the orbit depend on the orbit phase at which the impact occurs (Figure 1). The period change vanishes if the impact occurs at either of two orbit phases where the incident momentum is orthogonal to the orbital velocity; one of which is chosen as the zero of true anomaly. At two values of true anomaly, the magnitude of the period change is maximized at ~7 minutes, which is about 1% of the 11.92 hour Didymos orbit period. DART will target a true anomaly near 270°, where the impact decreases the orbit period. The chosen target geometry at impact is such that the night side of the target is illuminated by reflected light from the primary.

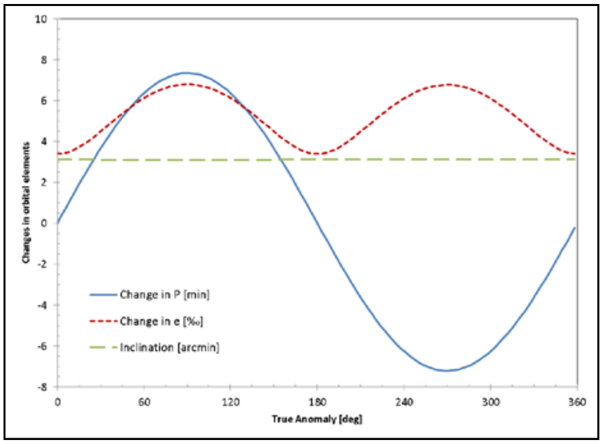

Figure 1. Changes in binary orbit period, eccentricity, and inclination after DART impact at 14.5° out of the orbit plane, assuming a total speed change of 0.6 mm/s and an initial circular orbit.

The DART impact not only changes the binary orbit period, but also produces significant eccentricity even if the orbit was initially circular. The DART impact may induce forced librations of the Didymos secondary of amplitude up to several degrees.

The crater size from the DART impact and the momentum transfer efficiency β can be predicted (Table 2) using crater scaling relations and assuming ballistic trajectories to find the momentum carried off to infinity by ejecta [1]. Crater scaling relations are from Housen and Holsapple [8]. Their four strength-dominated target cases are used (basalt labeled as B, weakly-cemented basalt WCB, perlite-sand PS, and sand-fly ash SFA).

The β predictions in Table 2 for the DART impact are similar to previous results [1,3,4,8,9], where the non-porous basalt case yields much higher values than the other cases. The predicted β from the DART impact is uncertain and could span at least the range of values shown in Table 2. In a laboratory impact experiment (Al projectile on a porous pumice target at 3.92 km/s), Flynn et al. found $\beta \sim 2.3$ [10], higher than the values found in porous target simulations [4,9] or the porous cases in Table 2.

Table 2 DART Kinetic Impact Scaling Law Predictions

	B	WCB	PS	SFA
Transfer efficiency β	3.074	1.09	1.23	1.30
Crater radius [m]	5.37	3.42	9.71	6.46

Target cases: B strong, non-porous; WCB 20% porous, medium strength; PS 60% porous, very weak; SFA 45% porous, weak

The DART kinetic impact will make a crater of ~7 to ~20 meters diameter (Table 2) that can be studied by AIM. The DART impact will also release a large volume of particulate ejecta that may be directly observable from Earth or even resolvable as a coma or an ejecta tail by ground-based telescopes [1]. The DART ejecta cloud will increase the amount of reflected sunlight in proportion to the cross-sectional area of ejecta compared to that of Didymos, assuming the ejecta to have the same albedo. The ejecta area is estimated assuming a size distribution adopted from the size distribution measured for Itokawa regolith (gravel, cobbles and blocks) by Hayabusa [11]. Table 3 shows the predicted brightening effect of the ejecta coma.

Table 3 Brightening of Didymos from DART Ejecta

	Basalt	WCB	PS	SFA
brightening (mag)	-0.1	-0.03	-0.5	-0.16

DART will return fundamental new information on hypervelocity impact responses of an asteroid as a function of its strength, surface physical properties, and internal structure, and it will improve and validate models and simulations of kinetic impact to reduce uncertainty of momentum transfer in future kinetic impactor missions.

References: [1] Cheng A. F. et al. (2016) Planet. Space Sci., 121, 27–35. [2] Michel P. et al. (2016) Adv. Space Res., *57*, 2529-2547. [3] Holsapple K. and Housen K. (2012) Icarus, 221, 875. [4] Jutzi M. and Michel P. (2014) Icarus, 229, 247. [5] Cheng A.F. et al. (2008) Spa. Sci. Revs. 140, 189. [7] Scheirich P. and Pravec P. (2009) Icarus, 200, 531. [8] Housen K. and Holsapple K. (2011) Icarus, 211, 856. [9] Stickle, A.M. et al (2015) Procedia Eng. 103, 577-584. [10] Flynn G.J. et al. (2015) Planet. Space Sci.107, 64–76. [11] Miyamoto H. et al. (2007) Science, 316, 1011.