DART'S PLANETARY DEFENSE INVESTIGATION AND ACHIEVING THE MISSION'S LEVEL 1 REQUIREMENTS: CURRENT STATUS AND ONGOING ACTIVITIES. Nancy L. Chabot[1], Andrew S. Rivkin[1], Andrew F. Cheng[1], Elisabetta Dotto[2], Olivier Barnouin[1], Eugene G. Fahnestock[3], Derek C. Richardson[4], Angela M. Stickle[1], Cristina A. Thomas[5], and the DART Investigation Team. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA. (Nancy.Chabot@jhuapl.edu) [2]INAF Osservatorio Astronomico di Roma, Monte Porzio Catone RM, Italy. [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA. [4]University of Maryland, College Park, MD, USA. [5]Northern Arizona University, Flagstaff, AZ, USA.

Introduction: DART, the Double Asteroid Redirection Test, successfully impacted asteroid Dimorphos on September 26, 2022, becoming the first mission to demonstrate asteroid deflection. Shared live via a NASA broadcast, over a million concurrent viewers around the world watched as the DART spacecraft streamed images to Earth up to the final second before its impact with Dimorphos. Autonomously targeting a small asteroid with limited prior knowledge at high speed was a key accomplishment for the DART mission and one of the mission's Level 1 requirements. Since that time, the DART Investigation Team has been working to address the remaining Level 1 requirements [1] that drive the mission and to document the achievement of the Level 1 requirements in the peer-reviewed literature. This presentation will provide the latest status and ongoing activities of the Investigation Team related to the mission's Level 1 requirements.

Requirement DART-1: *DART shall intercept the secondary member of the binary asteroid (65803) Didymos as a kinetic impactor spacecraft during its 2022 September–October close approach to Earth.*

The Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO) onboard the DART spacecraft first detected the Didymos system 61 days prior to impact, and at four hours prior to impact, the spacecraft's Small-body Maneuvering Autonomous Real Time Navigation (SMART Nav) system took control of the spacecraft navigation. The SMART Nav system started tracking Dimorphos at 68 minutes prior to impact, and at 50 minutes prior to impact, SMART Nav began targeting and maneuvering toward Dimorphos. DART successfully impacted Dimorphos on September 26, 2022, at 23:14:24 UTC at 6.1 km/s, accomplishing this Level 1 requirement with details provided in [2].

Requirement DART-2: *The DART impact on the secondary member of the Didymos system shall cause at least a 73 s change in the binary orbital period.*

This requirement factored into the design of the DART spacecraft and the mission's trajectory. Analysis conducted during DART's 10-month cruise period indicated that given the spacecraft's mass, speed, and planned intercept design, any impact of the DART spacecraft with Dimorphos would result in a period change of greater than 73 seconds, including grazing impacts that occurred well off-center from the body. The DART spacecraft successfully impacted within 25 meters of the center of figure of the 151-m volume-equivalent mean diameter of Dimorphos [2]. During a NASA press conference on October 11, 2022, the DART team announced their initial result that the binary orbit period of Dimorphos had been changed by 32 minutes with an uncertainty of ±2 minutes, accomplishing the Level 1 requirement of DART-2.

Requirement DART-3: *The DART project shall characterize the binary orbit with sufficient accuracy by obtaining ground-based observations of the Didymos system before and after spacecraft impact to measure the change in the binary orbital period to within 7.3 s (1σ confidence).*

Photometric observations from 2015–2021 obtained by 11 different telescopes were combined with data from observations obtained in 2003 to determine the pre-impact binary orbital period of Dimorphos about Didymos. [3] The pre-impact binary orbital period was determined with two separate analysis models, with both models yielding consistent values of 11.921624 ±0.000018 hr [4] and 11.921487 ±0.000028 hr [5]. These high precision pre-impact results positioned the post-impact observations to be able to meet this Level 1 requirement without being limited by the pre-impact knowledge of the orbital period of Dimorphos.

Following DART's kinetic impact, both photometric observations and planetary radar observations contributed to determining the post-impact binary orbital period of Dimorphos. Results obtained from post-impact observations taken through October 13, 2022, were used to determine a post-impact orbital period of 11.372 ±0.017 (3σ), indicating an orbital period change of –33.0 ±1.0 (3σ) minutes [6]. Telescopic observations have continued beyond this initial dataset and will continue through March 2023. Analysis of these telescopic observations is ongoing by the team and on a path to achieve the Level 1 requirement of determining the post-impact orbital period within 7.3 s with a 1σ confidence level.

Requirement DART-4A: *The DART project shall use the velocity change imparted to the target to obtain a measure of the momentum transfer enhancement* *parameter referred to as "Beta" (β) using the best available estimate of the mass of Dimorphos.*

Using the sizes and shapes of Didymos and Dimorphos determined from DRACO's approach imaging to estimate the mass of Dimorphos [2] and the orbital period change determined from telescopic observations [6], an initial assessment of the momentum transfer enhancement parameter β yielded a range of values from 2.4 to 4.9 [7]. The large range in β values is due to the uncertainty in the bulk density of Dimorphos, as the mass of Dimorphos was not measured by the DART mission. If Dimorphos is assumed to have the same density as Didymos of 2,400 kg/m^3, then the resulting β value is 3.61 (+0.19, –0.25, 1 σ) [7]. These β values are within the range of pre-impact predictions [8] and indicate that significantly more momentum was transferred to Dimorphos from the escaping impact ejecta than was incident with the DART spacecraft.

While this Level 1 requirement has been achieved with this result, the DART Investigation Team is continuing in its analysis efforts to further refine and understand the β value produced by DART's kinetic impact. In particular, including more detailed modeling and analysis of the ejecta produced by the impact as observed by space-based [9] and ground-based telescopes as well as by the Light Italian CubeSat for Imaging of Asteroids (LICIACube), contributed by the Italian Space Agency [10], can provide further insight into the β value, as can simulations of DART's kinetic impact event. Such analyses are ongoing within the DART Investigation Team.

Requirement DART-4B: *The DART project shall obtain data, in collaboration with ground-based observations and data from another spacecraft (if available), to constrain the location and surface characteristics of the spacecraft impact site and to allow the estimation of the dynamical changes in the Didymos system resulting from the DART impact and the coupling between the body rotation and the orbit.*

The DART Investigation Team is actively working on a range of activities to accomplish this broad Level 1 requirement. In particular, ground-based and space-based observations are currently ongoing to continue to study the evolution of the ejecta tail produced by DART's impact. Analysis of the many months of telescopic data is yielding insights into the properties of the ejecta and the Didymos system. Images obtained by LICIACube are being used to study the surfaces of both asteroids as well as the characteristics of the ejecta and its complex morphology. The location of the spacecraft impact site has been determined [2], and work is in progress to understand the geology and surface characteristics of the impact site. Studies to model the ejecta formation and evolution, DART's kinetic impact event, and the dynamics of the Didymos system are underway, as are efforts to investigate the origin and formation of the binary asteroid system. All of these efforts will contribute to addressing this Level 1 requirement for the mission.

Conclusion: The DART Investigation Team includes roughly 300 scientists from over 100 different institutions that represent 28 different countries, supporting international cooperation for the international issue of planetary defense. The DART Investigation Team will continue their work through the end of NASA's DART project in September 2023. DART's pioneering planetary defense mission is followed by ESA's Hera mission [11], and the DART and Hera teams have worked closely throughout the development of the two missions. Planned for launch in 2024, Hera will rendezvous with the Didymos system in late 2026 and conduct a robust remote sensing campaign in 2027, including determining the mass of Dimorphos as a crucial measurement to better understand the β value from DART's kinetic impact. The combined efforts of the DART and Hera missions will provide fundamental insight into understanding the kinetic impactor technique as a potential method of asteroid deflection, taking the first steps to develop a capability to potentially prevent an asteroid impact with the Earth in the future, if such a need should arise.

Acknowledgments: This work was supported by the DART mission, NASA Contract 80MSFC20D0004, and by the Italian Space Agency (ASI) within the LICIACube project (ASI-INAF agreement AC n. 2019-31-HH.0).

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