IAC-15-A3.4.8

AIDA: Asteroid Impact & Deflection Assessment

Andrew F. Cheng. JHU/APL, USA, andrew.cheng@jhuapl.edu
Patrick Michel, CNRS, France
Stephan Ulamec, DLR, Germany
Cheryl L. B. Reed, JHU/APL, USA

The Asteroid Impact & Deflection Assessment (AIDA) mission is a kinetic impactor experiment to demonstrate asteroid impact hazard mitigation by deflecting an asteroid. AIDA is an international cooperation between NASA and ESA, consisting of two mission elements: the NASA Double Asteroid Redirection Test (DART) mission and the ESA Asteroid Impact Mission (AIM) rendezvous mission. The primary goals of AIDA are (i) to demonstrate the kinetic impact technique on a potentially hazardous near-Earth asteroid and (ii) to measure and characterize the deflection caused by the impact. The AIDA target will be the binary asteroid (65803) Didymos, with the deflection experiment to occur in September, 2022. The DART impact on the secondary member of the binary at ~7 km/s will alter the binary orbit period, which can be measured by Earth-based observatories. The AIM spacecraft will characterize the asteroid target and monitor results of the impact in situ at Didymos. AIDA will return fundamental new information on the mechanical response and impact cratering process at real asteroid scales, and consequently on the collisional evolution of asteroids with implications for planetary defence, human spaceflight, and near-Earth object science and resource utilization. AIDA will return unique information on an asteroid's strength, surface physical properties and internal structure. Supporting Earth-based optical and radar observations, numerical simulation studies and laboratory experiments will be an integral part of AIDA.

I. INTRODUCTION

The Chelyabinsk impact on Feb. 15, 2013, of a roughly 20 meter object [1,2], released 500 kilotons TNT of energy and injured over 1500 people, serving as a dramatic reminder of the asteroid impact hazard. The kinetic impactor technique of deflecting a hazardous asteroid by a spacecraft impact has attracted considerable attention, leading to the ESA Don Quijote mission study in 2002-2007 and to the European Union NEOSHIELD Project [3]. Don Quijote was a two spacecraft mission, with a kinetic impactor to deflect an asteroid and an additional rendezvous spacecraft to observe the consequent change in the heliocentric orbit, as well as to study any physical changes.

AIDA is also a kinetic impactor demonstration mission, implemented as an international collaboration [4] between NASA and ESA and consisting of two parallel mission studies in Phase A at NASA and in Phase A/B1 at ESA. These two missions are the NASA Double Asteroid Redirection Test (DART) and the ESA Asteroid Impact Mission (AIM). These are independent but mutually supporting missions, where DART is the asteroid kinetic impactor and AIM is the rendezvous characterization spacecraft.

The AIDA target will be the binary asteroid (65803) Didymos, with the deflection experiment to occur in September, 2022. The DART impact on the secondary member of the binary at ~7 km/s will alter the binary orbit period, which can be measured by Earth-based observatories. The AIM spacecraft will rendezvous with Didymos in advance of the DART impact to characterize the asteroid target, and AIM will monitor results of the DART impact in situ, to measure precisely the deflection resulting from the kinetic impact experiment.

AIDA will return fundamental new information on the mechanical response and impact cratering process at real asteroid scales, and consequently on the collisional evolution of asteroids with implications for planetary defence, human spaceflight, and near-Earth object science and resource utilization. AIDA will return unique information on an asteroid's strength, surface physical properties and internal structure. Supporting Earth-based optical and radar observations, numerical simulation studies and laboratory experiments will be an integral part of the AIDA mission.

The kinetic impactor is one of the main techniques under consideration to deflect asteroids of up to a few hundred metres in size. However, the magnitude of the resulting deflection is highly uncertain, owing to the poorly understood contribution of recoil momentum from impact ejecta. An understanding of impact dynamics and fragmentation processes, over a wide range of physical scales, is essential to address fundamental questions of planetary science as well as a wide variety of technological problems. The efficiency of an asteroid mitigation strategy strongly depends on the physical properties of the asteroid target [5]. In particular, the deflection efficiency of a kinetic impactor depends on the asteroid subsurface and internal structures [e.g., 4,6,7], and so far no direct measurement of these properties has been performed on any asteroid.

Numerical modelling studies are underway to improve our understanding of these processes, but confirmation of the validity of model results relies on verification with laboratory impact experiments at very small (centimetre) scales. Physical characterization of a near-Earth asteroid (NEA) and its response to an impact are crucial in order to understand the efficiency of the kinetic impactor deflection technique and to address various scientific problems in planetary science.

II. DART MISSION

The target of the AIDA mission will be a binary asteroid, in which DART will target the secondary, smaller member in order to alter its orbit around the primary. The resulting period change can be measured to within 10% by Earth-based observations. The asteroid deflection will be measured to higher accuracy, and additional results of the DART impact, like the impact crater, will be studied in great detail by the AIM mission. AIDA will return vital data to determine the momentum transfer efficiency of the kinetic impact and key physical properties of the target asteroid. The two mission components of AIDA, DART and AIM, are each independently valuable, but when combined they provide a greatly increased knowledge return.

The main objectives of the DART mission, which includes the spacecraft kinetic impact and Earth-based observing, are to:

- Impact the secondary member of the Didymos binary system during its close approach to Earth in September-October, 2022
- Demonstrate asteroid deflection by kinetic impact and measure the period change of the binary orbit resulting from the impact
- Determine the impact location on the target asteroid, the local surface topography and the geologic context.

DART is targeted to impact the smaller secondary component of the binary system [65803] Didymos. The satellite of Didymos orbits the primary with a period of 11.9 hours, a semi-major axis of 1.1 km, and a nearly circular orbit. The primary has a diameter of 750 m, the secondary 160 m. The presence of a satellite has allowed the density of the primary to be estimated as 2.4 g/cm^3. Ground-based reflectance spectroscopy of Didymos shows it to be a member of the "S complex" of asteroids, the most common compositional group of near-Earth objects.

The impact of the >300 kg DART spacecraft at 7 km/s will produce a velocity change on the order of 0.4 mm/s (assuming a simple transfer of momentum from impactor to target), which leads to a significant change in the mutual orbit of the Didymos primary and secondary, but only a minimal change in the heliocentric orbit of the system. This is because the target's velocity change from the impact is significant compared to its orbital speed ~17 cm/s, although it is quite small compared to the heliocentric orbit speed ~23 km/s. Thus the change in the binary orbit is relatively easy to measure compared with the change in the heliocentric orbit.

The momentum transfer from kinetic impact has been estimated using either crater scaling relationships or numerical simulations [e.g., 4,6,7]. Because impact ejecta are produced that carry off momentum back in the incident direction, the momentum transferred to the target exceeds the incident momentum. Measuring this amplification factor of the momentum transfer is a main objective of AIDA.

The DART mission will use ground-based observations to make the required measurements of the orbital deflection, by measuring the orbital period change of the binary asteroid. The DART impact is expected to change the period by ~0.5%, and this change can be determined to 10% accuracy within months of observations. The DART target is specifically chosen because it is an eclipsing binary, which enables accurate determination of small period changes by ground- based optical light curve measurements. In an eclipsing binary, the two objects pass in front of each other (occultations), or one object creates solar eclipses seen by the other, so there are sharp features in the lightcurves which can be timed accurately.

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 to support optical navigation on approach and autonomous navigation in the terminal phase. The imager is derived from the New Horizons LORRI instrument [8] which used a 20 cm aperture Ritchey-Chretien telescope to obtain images at 1 arc sec resolution. The DART imager will determine the impact point within 1% of the target diameter, and it will characterize the pre-impact surface morphology and geology of the target asteroid and the primary to <20 cm/px.

The DART kinetic impactor can be launched on a small-class launch vehicle in December 2020, to impact the Didymos secondary in late September, 2022. The DART trajectory remains near 1 AU from the Sun and has a maximum Earth distance <0.21 AU. At the opening of the launch window, the impact speed on Didymos is 7.03 km/s, but it is at least 6.67 km/s over the entire window. The approach direction is at an angle of 27.5° to the orbital plane of Didymos. The approach solar phase angle is favorable for imaging of the target at 44°.

The DART launch is close to the time of the AIM launch in late October, 2020. AIM arrival at Didymos is in late May-early June, 2022, allowing more than 3 months for characterization of the Didymos system prior to the DART impact. The DART time of flight is less than two years to impact the Didymos secondary on Sept. 20, 2022. The DART mission design is summarized in Table 1.

Table 1 DART Mission Design

Launch Date	Dec 18, 2020
Launch C_3	6.0 km^2/s^2
Arrival Relative Speed	7.03 km/s
Time of Flight	640 days
Maximum Earth Distance	0.21 AU
Solar Distance	0.95 AU – 1.06 AU
Earth Distance at Impact	0.087 AU
Solar Phase Angle	44°
Impact Angle to Orbit Plane	27.5°

III. AIM MISSION

ESA's Asteroid Impact Mission (AIM) is a small mission of opportunity to explore and demonstrate new technologies for future science and exploration missions while addressing planetary defence and performing asteroid scientific investigations. Thus, AIM will determine bulk physical properties of the Didymos secondary, including orbit and rotation state, size, mass and shape, as well as surface geology and surface properties such as strength and porosity. In the AIDA mission together with the DART kinetic impact, AIM will observe the impact crater and derive collision and impact properties. AIM will further demonstrate a number of technologies including deep-space optical communication and inter-satellite network in deep-space with a number of CubeSats deployed in the vicinity of the Didymos system and lander on the surface of the secondary.

The AIM mission objectives are summarized as:

- Characterize the Didymos secondary component by determining the dynamical state, mass, geophysical properties, surface and subsurface structure.
- Demonstrate optical communication technology in deep space and implement an inter-satellite communication network with CubeSats and lander.
- Deploy the MASCOT-2 lander on the Didymos secondary asteroid and sound its interior structure.

When AIM is operated together with DART, the mission covers supplementary objectives:

- Determine the momentum transfer resulting from DART's impact by measuring the dynamical state of Didymos after the impact and imaging the resulting crater.
- Study the shallow subsurface and deep-interior structure of the secondary after the impact to characterize any change.
- Study the impact response of the target asteroid and measure distributions of impact ejecta providing valuable data to validate impact models.

AIM with DART provides for the first time an opportunity to measure the outcome of an impact on an asteroid where the impactor properties and impact conditions are known, at a large scale that is well beyond what is achievable in the laboratory and that is relevant to understanding the formation and evolution of the Solar System. AIM will contribute measurements from which initial conditions of the impact, such as the impact angle to local topography, can be determined, and will relate the position of the impact point on the target measured by DART to the detailed properties of the whole object. This knowledge is fundamental for a correct interpretation of the momentum transfer efficiency measurement. Moreover, although the asteroid deflection is planned to be observed from Earth-based observatories, AIM will provide much greater accuracy and will fully characterize dynamical changes in the binary system after the impact. AIM observations of the DART impact outcomes will allow testing and refinement of hypervelocity impact models and scaling laws.

AIM's baseline payload is summarized in Table 2. The visible imager VIS is part of the spacecraft Guidance and Navigation Control (GNC) subsystem but also obtains detailed images of the surface. The two radars HFR and LFR collect for the first time direct information on the subsurface and internal structures of a small asteroid. The HFR will sound the first tens of meters of the regolith of both the primary body and its moon in order to image their structure with a meter-resolution, before and after the DART impact. The LFR will probe the deep interior of the secondary body and characterize the structural homogeneity. LFR is a 60 MHz bistatic radar with a unit on the AIM spacecraft and on the MASCOT-2 lander, based on the CONSERT bistatic radar on Rosetta and Philae [9].

Table 2 AIM Baseline Payload

Payload	Name
Visible Imager	VIS
Monostatic high frequency radar	HFR
Bistatic low frequency radar	LFR
Lander (with low frequency radar)	MASCOT-2
Thermal infrared imager	TIRI
Optical terminal	OPTEL
CubeSat opportunity payloads	COPINS

MASCOT-2 is a ~10 kg lander, based on the MASCOT lander on the Hayabusa-2 mission [10]. It will be deployed from AIM onto the secondary. After several bounces and possible re-location by an internal hopping mechanism, it will operate for several months and provide detailed information about the landing site and the physical properties of the surface material. Besides the lander unit of the LFR, it will include a camera to obtain high resolution images of the landing area.

The AIM rendezvous mission design is driven by the relative geometry of Earth and asteroid (65803) Didymos and the DART high velocity impact on the Didymos secondary in late September, 2022. AIM is required to arrive at its first observation station (a location about 35 km distant from the asteroid) in May, 2022, allowing time for target asteroid characterization before DART arrival. The rendezvous mission design is summarized in Table 3.

Table 3 AIM Mission Design

Launch date	27/10/2020
Escape velocity [km/s]	4.994
Escape declination [deg]	25.9
Deep-space maneuver date	20/12/2020
Deep-space maneuver size [m/s]	118
Asteroid arrival date	22/04/2022
Transfer duration [d]	544
Rendezvous maneuver [m/s]	1132
Total ΔV [m/s]	1250

The launch opportunity for AIM is identified in late 2020 with an interplanetary transfer duration of ~19 months, arriving in mid-2022. This trajectory is based on a Soyuz 2.1b/Fregat MT launch from Kourou with a 21-day launch window. The spacecraft will have a maximum Sun distance of 2.2 AU and a maximum Earth range of 3.2 AU. A superior conjunction in Oct/Nov 2021 will interrupt communications but does not interfere with critical operations.

Observation of the Didymos system begins from a formation-flying quasi-orbit at a distance of around 35 km from the primary allowing for a safe distance, out of the sphere of influence of both Didymos components. This station point will be within the plane of the asteroid around the sun but offset by around 45° from the direction towards the sun. Thus, the spacecraft would be positioned above the illuminated side of the asteroid at a favorable phase angle for optical observing of surface morphology.

Conclusions: The AIDA mission will combine US and European space experience and expertise to address an international concern, the asteroid impact hazard. AIDA will perform the first demonstration of asteroid deflection by a kinetic impactor. AIDA will be a valuable precursor to human spaceflight to an asteroid, as it would return unique information on an asteroid's strength and internal structure. AIDA will furthermore return fundamental new science data on impact cratering, surface properties and interior structure.

Acknowledgements: Authors would like to thank the mission design teams at APL and ESTEC-CDF for the valuable discussions and dedication throughout the studies. The AIDA study at APL was funded by NASA.

References

1. Popova, O.P. et al. (2013) Chelyabinsk Airburst, Damage Assessment, Meteorite Recovery, and Characterization. Science 342, 1069-73
2. Brown, P.G. et al. (2013) A 500-kiloton airburst over Chelyabinsk and an enhanced hazard from small impactors. Nature 503, 238-41
3. Harris, A. W. et al. (2013). The European Union funded NEOShield Project: a global approach to near-Earth object impact threat mitigation, Acta Astronautica 90, 80-4
4. Cheng AF et al (2015). Asteroid Impact and Deflection Assessment Mission. Acta Astronautica 115: 262-269, doi:10.1016/j.actaastro.2015.05.021
5. Michel, P. (2013). Physical properties of Near-Earth Objects that inform mitigation. Acta Astronautica 90, 6-13
6. Holsapple, K. A., and K. R. Housen (2012), Momentum transfer in asteroid impacts. I. Theory and scaling, Icarus, 221, 875–887
7. Jutzi, M., and P. Michel (2014), Hypervelocity impacts on asteroids and momentum transfer. I. Numerical simulations using porous targets. Icarus 229, 247-253
8. Cheng A. F. et al., (2008), Long-Range Reconnaissance Imager on New Horizons, Space Science Reviews, 140, 189, doi:10.1007/s11214-007-9271-6.
9. Kofman, W., et al. 2007. The Comet Nucleus Sounding Experiment by Radiowave Transmission (CONSERT).A short description of the instrument and of the commissioning stages. Space Science Review 128, 413-432
10. http://www.dlr.de/irs/en/desktopdefault.aspx/tabid-7902/13482_read-34316