Hera proximity operations - trajectories and autonomous navigation around binary asteroid Didymos

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Abstract. Hera is a planetary defense mission under development by the EuropeanSpace Agency for launch in 2024. It will rendezvous in late 2026 with the binary asteroid (65803) Didymos and in particular its moon, Dimorphos, which has been impacted by NASA's DART spacecraft on 2022 September 26 as the first asteroid deflection test. The trajectories during Hera's proximity operations shall be designed to achieve the science objectives (e.g. high-resolution imaging of the crater, global coverage of Dimorphos surface with different illumination conditions), to ensure safety of the spacecraft (avoid collision with asteroid), to allow observations for the navigation, and to minimize cost of ground operations.

Keywords:autonomy, navigation, trajectory.

1 Extended abstract

HERA is ESA's contribution to the AIDA international collaboration, which will be the first test of the kinetic impactor technique for asteroid deflection. NASA's DART spacecraft has collided with the moon of a binary system (Didymos). HERA will study the effect of such impact and characterize for the first time a binary asteroid.The main goals of Hera are the detailed characterization of the physical properties of Didymos and Dimorphos and of the crater made by the DART mission, as well as measurement of the momentum transfer efficiency resulting from DART's impact.

As a mission of opportunity, HERA provides the optimal balance between risk and innovation to test novel technologies for future planetary missions like autonomous Guidance, Navigation and Control (GNC) technologies or deep-space cubesats.In particular, high on-board autonomy permits longer science operations, more accurate instrument pointing and flying closer to the surface of the asteroid.

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HERA mission has very tight cost budget and implementation schedule. Therefore, the trajectories for proximity operations are designed to avoid introducing very demanding requirements on the spacecraft and the ground segment (for instance critical operations requiring very fast ground turnaround time). In addition, given the uncertainties on the spacecraft performances and asteroid properties, significant margins have been considered in the design.

The proximity operations are performed in hyperbolic trajectories to ensure safety of the spacecraft in case of contingencies. These trajectories have to require delta-Vs with a pattern of 3-4-3-4 days to fulfil the ground operation schedule. The trajectories shall have a pericentre velocity larger than the escape velocity (aka parabolic velocity); with a safety margin ensuring no collision during the arc in presence of manoeuvre execution errors. To avoid large relative delta-V execution error, the minimum delta-V for the nominal proximity operations is 5 cm/s. The nominal proximity operations shall take place in the dayside of Didymos in order to ensure valid AFC images for optical navigation. The maximum reachable Sun phase angle (Sun-Didymos-SC angle) is 90 deg.

The trajectories are designed to reach closer distances as the knowledge of the Didymos system is improved and the models are generated to permit the autonomous GNC to fly at closer distances. The initial trajectories looks like rectangles seen from the Sun. After the deployment of the cubesats, the trajectories fly closer to the asteroid and looks like an 8 seen from the Sun. There is a minimum pericenter distance for these trajectories that fulfil all the constraints, around 4 km. Below that distance, dedicated fly-bys are flown including few delta-Vs to decrease progressively the pericenter altitude at given distances from asteroid when the navigation knowledge is sufficiently accurate.

Traditional ground based attitude profiles cannot ensure proper pointing of the instruments during the long arcs without ground intervention. Processing images from a dual-use camera (for science and navigation), the autonomous GNC shall ensure that the instruments point to the desired target.Very low altitude flybys of Didymoon are required to characterize the area surrounding the DART impact crater. The trajectory needs to be adjusted progressively to achieve the desired low altitude but not jeopardizing the safety of the spacecraft. The fusion of the image processing and the laser altimeter provides high accuracy navigation relative to Didymoon and can enable onboard guidance to compute safe maneuvers to decrease the minimum altitude and adjust the flyby.