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Target selection for a hypervelocity asteroid intercept vehicle flight validation mission

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ABSTRACT

Asteroids and comets have collided with the Earth in the past and will do so again in the future. Throughout Earth's history these collisions have played a significant role in shaping Earth's biological and geological histories. The planetary defense community has been examining a variety of options for mitigating the impact threat of asteroids and comets that approach or cross Earth's orbit, known as near-Earth objects (NEOs). This paper discusses the preliminary study results of selecting small (100-m class) NEO targets and mission analysis and design trade-offs for validating the effectiveness of a Hypervelocity Asteroid Intercept Vehicle (HAIV) concept, currently being investigated for a NIAC (NASA Advanced Innovative Concepts) Phase 2 study. In particular this paper will focus on the mission analysis and design for single spacecraft direct impact trajectories, as well as several mission types that enable a secondary rendezvous spacecraft to observe the HAIV impact and evaluate it's effectiveness.

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1. Introduction

Geological evidence shows that asteroids and comets have collided with the Earth in the past and will do so in the future. Such collisions have played an important role in shaping the Earth's biological and geological histories. Many researchers in the planetary defense community have examined a variety of options for mitigating the impact threat of Earth approaching or crossing asteroids and comets, known as near-Earth objects (NEOs).

As early as 1992, the idea of discovering and tracking near-Earth objects (NEOs) was proposed to the U.S. Congress [1]. That search effort, called the Spaceguard Survey, was later implemented in 1998 with the ultimate goal of finding 90% of the estimated asteroid population 1 km in diameter or larger by 2008. By focusing on only 1 km size or larger NEOs, that survey only intended to find NEOs large enough to cause global catastrophes. While not large enough to affect the entire globe, impacts by objects smaller than 1 km occur more frequently and are capable of causing significant damage. In 2005, the George E. Brown, Jr. Near-Earth Object Survey Act expanded the original Spaceguard search to include the detection and characterization of 90% of NEOs as small as 140 m by the year 2020. To date, none of the discovered objects are predicted to be on a collision course with the Earth, but the survey still has several more years before the mission is complete. Should a new NEO be discovered on a collision course with the Earth, a mitigation effort would be necessary in order to prevent a collision with the Earth.

Given a lead time (from initial detection of the incoming NEO) of at least 10–20 years, depending on circumstances, various proposed technologies such as kinetic impactors [2] or slow-pull gravity tractors [3] could be employed to successfully

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mitigate an impact threat by deflecting the NEO's heliocentric orbit just enough to avoid a collision with Earth. When the warning time is short, nuclear technologies for a standoff, contact, or subsurface explosion may be the only viable options [4,5]. However, as of the time of this writing none of the aforementioned mitigation options have been validated with a flight demonstration mission. The Asteroid Deflection Research Center (ADRC) has conducted a preliminary design for Hypervelocity Asteroid Intercept Vehicle (HAIV), a spacecraft capable of performing hypervelocity (>5 km/s) intercept of asteroids as small as a 50–100 m in diameter [6–8]. The HAIV concept, depicted in Fig. 1, involves a two-body spacecraft that creates a small crater in an asteroid's surface and then detonates a nuclear explosive within the crater, thus effecting a subsurface detonation. A subsurface detonation is more effective at coupling energy into an asteroid than a standoff or surface detonation, permitting disruption of an asteroid with a smaller nuclear device yield than would otherwise be required. The HAIV design is necessitated by the fact that penetrator technology can only protect the explosive payload from impact velocities of several hundred m/s, while impact velocities of >5 km/s are required for asteroid intercept missions, especially in the case of short warning times.

In this paper a variety of mission analysis results will be presented to illustrate candidate target asteroids for a flight validation of the HAIV concept. The mission concepts considered include direct intercept missions, in which the impactor is inserted directly on an intercept course by the launch vehicle and is only allowed to perform small ΔV maneuvers prior to impact, as well as missions which allow an observer spacecraft to rendezvous with the asteroid prior to the HAIV impact.

To measure the performance and success of the HAIV it would be useful to have an observer spacecraft at the asteroid prior to the time at which the HAIV impacts the asteroid, as suggested in other studies [2]. However, due to mission and launch vehicle cost constraints it is highly desirable to perform the entire mission using one launch vehicle. Towards that end, we have designed the flight validation mission such that an observer spacecraft is not strictly required; instead, the HAIV transmits adequate telemetry to Earth for reconstruction of the asteroid impact event. The flight validation mission design is made even more cost-effective by incorporating advanced interplanetary mission design techniques including optimally placed deep space maneuvers (DSMs) and both powered and unpowered gravity assists via planetary flybys.

1.1. Previous and future NEO missions

To help determine the mission requirements and constraints it is useful to examine past and proposed future robotic missions to NEOs. Space agencies such ESA, JAXA, and NASA have had several successful missions that demonstrate technologies and mission capabilities that are relevant to the proposed HAIV demonstration mission, including terminal guidance targeting and/or landing capabilities.

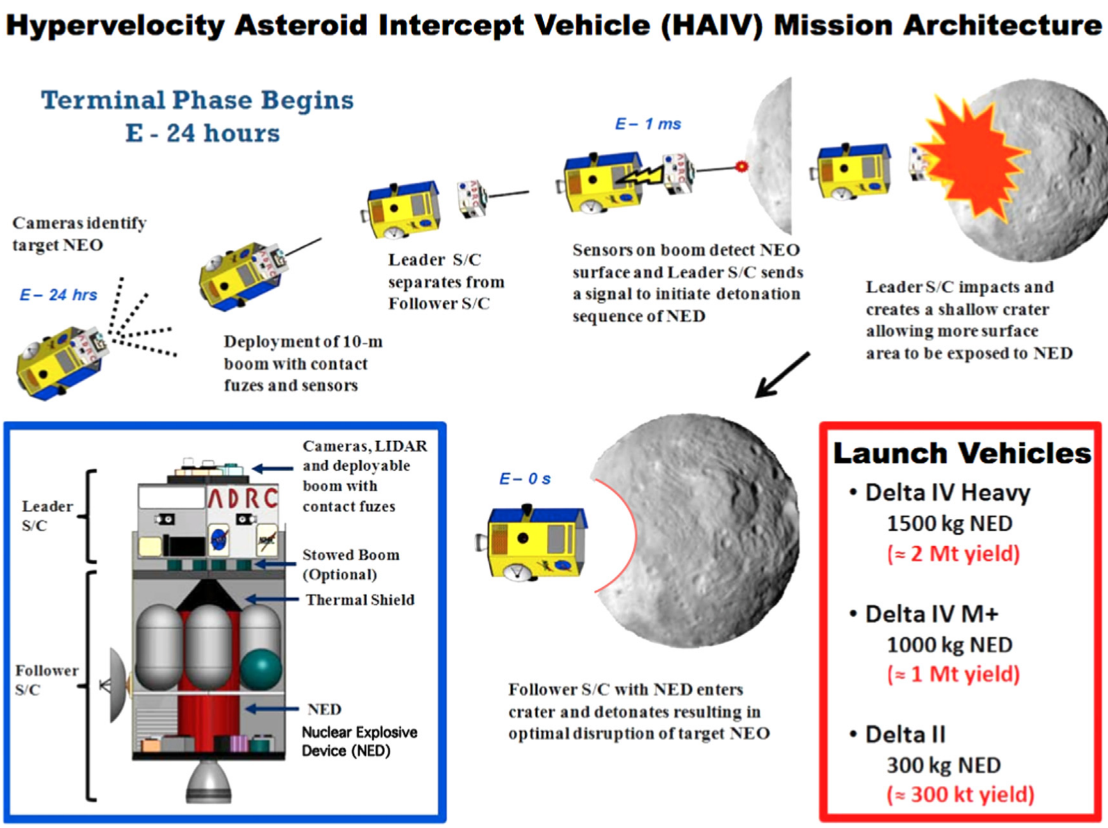

Fig. 1. A baseline HAIV and its terminal-phase operational concept [9].