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☒ **Mitigation Techniques & Missions**

TARGET SELECTION AND MISSION DESIGN TRADEOFFS FOR A HAIV (HYPERVELOCITY ASTEROID INTERCEPT VEHICLE) FLIGHT VALIDATION MISSION

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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 had a significant role in shaping Earth's biological and geological histories. The planetary defense community has been examining a variety various options for mitigating the impact threat of near-Earth objects (NEOs). This paper discusses the preliminary study results of selecting small (100-m class) NEO targets and mission design tradeoffs for flight validating some key planetary defense technologies. In particular, this paper focuses on a planetary defense demo mission for validating the effectiveness of a Hypervelocity Asteroid Intercept Vehicle (HAIV) concept, currently being investigated by the Asteroid Deflection Research Center (ADRC) for a NIAC (NASA Advanced Innovative Concepts) Phase 2 project [1, 2].

The ADRC has also been developing a mission design software tool, which combines the effectiveness of evolutionary algorithms with the speed and efficiency of GPU (Graphics Processing Unit) computing [3, 4]. Thousands of asteroids, with many possible mission types, can be determined in a quick, efficient manner using such a GPU-accelerated mission design tool. Innovative, but yet cost-effective, flight demo missions can be explored, which allow a small rendezvous spacecraft and a hypervelocity kinetic impactor. By utilizing this GPU-accelerated software tool, we find potential target asteroids in the 2018-2022 timeframe, which require very low mission ΔV along with low departure C3.

Table 1: Top 3 target asteroid candidates selected for a HAIV flight validation mission with realistic mission constraints.

Asteroid	a (au)	e	Diameter (m)	Departure C3 (km^2/s^2)	S/C Δ-V (km/s)	Approach Angle (deg)	Departure Date	TOF (days)
2006 CL9	1.35	0.23	104	11.99	0.00	3.04	2-Aug-19	121.41
2009 QO5	1.59	0.23	105	12.50	0.00	28.05	27-Mar-19	124.38
2004 BW18	1.37	0.25	97	12.49	0.00	34.21	7-Apr-19	268.45

Additional flight demo mission design constraints are to

- Require very low ΔV from the HAIV
- Intercept the asteroid with favorable Earth communication
- Intercept with a final approach that has sufficient lighting conditions to ensure impact and mission success.

- Time-of-flights of less than 1 year (to simulate a last-minute intercept mission)

Only potential asteroids with orbits that can't be perturbed sufficiently to impact the Earth are considered in this study. To ensure this, we consider only Amor and Atira NEOs. These are, the NEOs that do not cross the Earth's orbit, with Atira NEOs orbiting interior to the Earth and Amor NEOs orbiting exterior the Earth.

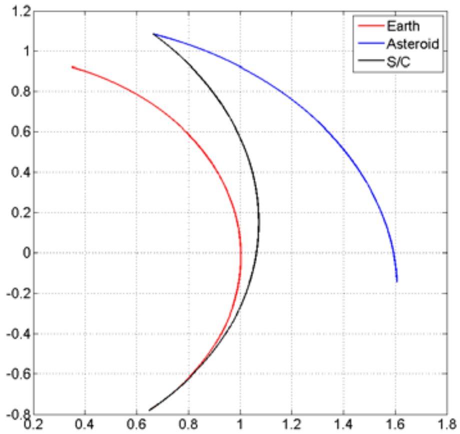

Figure 1: Heliocentric trajectory of a kinetic impact mission to asteroid 2006 CL9.

The first mission type analyzed is one in which the HAIV is launched directly into an Earth escape orbit, which targets the target NEO, by a launch vehicle. For these missions, the C3 value is limited to 12.5 (km/s)^2 and an arrival speed of at least 5 km/s is enforced. If either of these conditions is not met, the HAIV is required to perform a ΔV maneuver to ensure the mission requirements to be met. In addition, further mission requirements are enforced by penalizing the cost function that is being optimized. Two main penalties have been enforced. The first ensures that the S/C doesn't intercept the asteroid on the opposite side of the sun from the Earth (to ensure constant communication with the HAIV), and the second penalty shapes the solution in such a way that the S/C has sufficient lighting conditions upon impact. In this case, a penalty is added when the spacecraft doesn't approach from the sunlit side of the asteroid. To enforce such penalties, the solution can be shaped in a way that results in optimal targets with trajectories that can easily be achieved. The top 3 target asteroids, along with relevant mission characteristics, are listed in Table 1. A reference optimal trajectory for asteroid 2006 CL9 is shown in Figure 1.

In addition to the simple direct intercept mission with realistic constraints, more advanced mission types, which allow for an observer S/C to be launched with the HAIV and rendezvous with the asteroid prior to impact, will be presented in this paper.

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