DESIGN OF SPACECRAFT MISSIONS TO TEST KINETIC IMPACT FOR ASTEROID DEFLECTION

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There are currently over 8,000 known near-Earth asteroids (NEAs), and more are being discovered on a continual basis. More than 1,200 of these are classified as Potentially Hazardous Asteroids (PHAs) because their Minimum Orbit Intersection Distance (MOID) with Earth's orbit is ≤ 0.05 AU and their estimated diameters are ≥ 150 m. To date, 178 Earth impact structures have been discovered, indicating that our planet has previously been struck with devastating force by NEAs and will be struck again. Such collisions are aperiodic events and can occur at any time.

A variety of techniques have been proposed to defend our planet from NEA impacts by deflecting the incoming asteroid. However, none of these techniques have been tested. Unless rigorous testing is conducted to produce reliable asteroid deflection systems, we will be forced to deploy completely untested—and therefore unreliable—deflection missions when a sizable asteroid on a collision course with Earth is discovered. Such missions will have a high probability of failure.

We propose to address this problem with a campaign of deflection technology test missions deployed to harmless NEAs. The objective of these missions is to safely evaluate and refine the mission concepts and asteroid deflection system designs. Our current research focuses on the kinetic impactor, one of the simplest proposed asteroid deflection techniques in which a spacecraft is sent to collide with an asteroid at high relative velocity. By deploying test missions in the near future, we can characterize the performance of this deflection technique and resolve any problems inherent to its execution before needing to rely upon it during a true emergency.

We first identify the subpopulation of NEAs whose orbits lie either entirely outside or inside Earth's orbit; those NEAs are classified by orbit as Amors and Atiras, respectively. By choosing NEAs whose orbits do not cross Earth's orbit for the proposed test missions, we ensure that Earth will never be threatened by test activities, regardless of what might go wrong during the deflection test mission. We also seek low Δv missions for the sake of affordability, and therefore only selected Amor and Atira NEAs with heliocentric orbit inclination $\leq 20°$ for this study.

Besides safety and affordability, an additional constraint is that the deflection imparted to the NEA by the kinetic impactor must be easily measured by an observer spacecraft that has rendezvoused with the NEA prior to the collision of the kinetic impactor. To compute the change in a NEA's orbit due to a kinetic impactor, we developed a new method of computing the momentum imparted to the NEA that accounts for any angle of impact at any point along the NEA's orbit.

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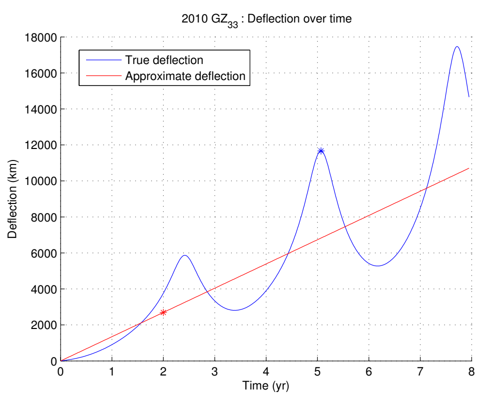
This is an improvement over previous models that only estimate the change in the NEA's momentum by assuming that the kinetic impactor intercepts the NEA at perihelion and imparts momentum only along the NEA's velocity vector, such as the model presented in Ref. 1.

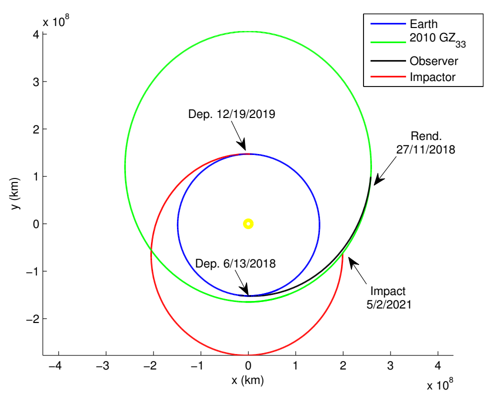
For the sake of computational efficiency we use an approximate method to compute the amount by which the NEA orbit is deflected over time. Our method is based on Gauss' form of the Lagrange Planetary Equations, and is similar to the method proposed by Koenig in Ref. 2. Unlike the method given in Ref. 2, ours does not restrict either the impactor approach angle or the location along the NEA's orbit at which impact occurs. A comparison between our approximate deflection model and the true deflection is shown in Figure 1(a) for the case of asteroid 2010 GZ_{33}. To ensure a measurable experiment, we enforce the constraint that the approximate deflection of the NEA's orbit must be at least 100 km 2 years after impact.

We surveyed the aforementioned NEA subpopulation using three simulated mission design concepts. In the first case, the observer and impactor spacecraft are launched separately on two launch vehicles. In the second case, the observer and impactor launch together on one launch vehicle into Low Earth Orbit (LEO) and then depart LEO at different times. In the third case, the observer and impactor launch together on one launch vehicle into an Earth escape trajectory that takes the observer directly to rendezvous with the NEA. The impactor separates from the observer after launch but before observer arrival at the NEA by performing a maneuver such that it will collide with the NEA after the observer has spent adequate time gathering data on the NEA. In all cases, we enforced the constraint that the observer spacecraft must arrive between 3 months and 3 years prior to the impactor's collision with the NEA. An example mission trajectory is shown in Figure 1(b).

In this paper we present the methodology and results of our survey, including lists of NEAs for which safe and effective kinetic impactor test missions may be conducted within the next decade. Full mission designs are also presented for the NEAs which offer the best mission opportunities.



(a) True and approximate deflection.



(b) Maximum deflection trajectory solution.

Figure 1. Maximum deflection trajectory solution for asteroid 2010 GZ_{33}.

REFERENCES

[1] B. Wie, "Astrodynamic Fundamentals for Deflecting Hazardous Near-Earth Objects," *60th International Astronautical Congress, IAC-09-C1.3.1*.

[2] J. D. Koenig and C. F. Chyba, "Impact Deflection of Potentially Hazardous Asteroids Using Current Launch Vehicles," *Science and Global Security*, No. 15, 2007, pp. 57–83.