NEO Defense by Impulsive Interactions

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The orbital deflection velocity (δV) required to divert a near-Earth object away from a collision course with Earth depends on the NEO mass (M) and a momentum/energy coupling coefficient (C_M) that depends on the energy transfer mechanism and NEO material properties. These parameters determine the required interaction energy magnitude (δE), related by the equation $M\ \delta V = C_M\ \delta E$ (our unit convention puts C_M in units of dyne s/J).

The deflection velocity depends on the desired displacement distance and is inversely proportional to the time interval (δt) between the impulse delivery and projected Earth impact. For short-warning-time objects (less than a few years), δt must be maximized by using existing launch vehicles to quickly intercept the NEO and deliver high-energy-density payloads without attempting a time-consuming low-velocity rendezvous. For long-warning-time objects (decades or more), the same strategy must be held in reserve as a "backup plan" in the event of failure of the slower payload-intensive methods. Whatever mitigation mission option is ultimately pursued, a necessary first step depends on systematic characterization of the coupling coefficient over a wide range of impulse methods and material properties.

Determining values of C_M for a variety of targets and energy sources requires extensive experimental and analytic research. This work involves high-energy-density momentum coupling using chemical propellants, high explosive, kinetic impact (> 8 km/s), lasers, concentrated solar energy, and nuclear explosive (NE) radiation. This research has been performed over the past 12 years at Sandia National Laboratories (SNL) and other national laboratories, as well as USAF testing facilities. Related planetary physics and equation-of-state (EOS) target analysis on target responses to high pressure is being carried out at Harvard.

A stand-off, surface, or shallow buried nuclear explosive is necessary when 1) short warning times for deflection eliminate all other options, 2) the NEO is too large to be diverted by any other means, or 3) a more elaborate but slower method fails. In the first case, there would be no time to characterize the materials or internal structure of the NEO. Under these circumstances, the energy transfer method must be reliable and effective regardless of the properties of the NEO. Stand-off bursts that critically depend on near-surface absorption coefficients are not likely to work for all types of NEO. We are currently using numerical and semi-analytical methods to evaluate the use of relatively low yield (kiloton to 10 kiloton) surface and shallow nuclear explosions as the most robust means of providing sufficient δV to any NEO without knowledge of its properties prior to the intercept.

A cube-root (or any sub-linear) energy scaling law means that low-yield shallow bursts have the highest coupling coefficients. By using multiple low-yield explosions, impulsive loading can also be distributed over both space and time. Distributing the impulse over an entire hemisphere of an NEO reduces the volume of material that experiences high shock, shear, and tensile stresses, thereby reducing the likelihood (for a given total yield) of fragmenting the object. Moreover, the spatial distribution of impulse ensures that if the NEO is disrupted, all fragments would still be accelerated with a sufficient δV to avoid Earth impact. Finally, the ability to distribute impulse over time would allow large NEOs to be accelerated in a controlled "predictor-corrector" fashion over time. We will present 2D and 3D numerical simulation results, with comparisons to empirical scaling and semi-analytical estimates.

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