A SPACE DEBRIS-ENHANCED INTERVENTION MISSION TO A NEAR EARTH ASTEROID.

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Introduction: Earth impactors (EIs) are near-Earth asteroids (NEAs) with a high probability of striking the Earth. EIs represent a significant threat to the Earth and its inhabitants. A large EI impact could have a catastrophic effect on human civilization; smaller EIs could cause local or regional-level devastation. Ideally, a prospective EI would be detected in orbit, long before its projected date of impact.

With early detection, multiple strategies for EI intervention are possible. Three common strategies include a targeted nuclear strike, striking the EI with a significant mass or pulling it via the gravitational effect exerted by a significant mass, to change its orbit.

The latter two strategies require a significant amount of mass that may have no other particular use in the mission. However, this mass must still, under conventional models, be transported from the surface of the Earth to co-orbit (or impact) the EI. Humanity, however, has a significant amount of unwanted mass already in orbit which can be utilized to decrease the propellant requirements for the mission and, correspondingly, the cost.

Background: Significant work exists related to EI intervention and NEA visit missions. Olds, et al. [1] analyze the MADMEN deflection concept on two chosen target asteroids, Apophis and D'Artagnon. For D'Artagnon, the launch C_3 was 20 km^2/sec^2 which corresponds to a launch capacity of 43,000 kg (The values are for the Ares V). The arrival ΔV is 3,024 m/s for a C_3 of 8.737 km^2/sec^2. Gravity assist orbits were not considered for these targets.

For Apophis, a launch C_3 of 15 km^2/sec^2 was set which lowers the launch capacity to 1,350 kg. The arrival C_3 is 1.611 km^2/sec^2 meaning a ΔV of 1,265 m/s.

Olds, et al. also compare the launch masses using different deflection strategies. According to this, the launch mass varies from 5,000 kg to 50,000 kg for a gravity tractor with a one year time constraint (this requires the least momentum change at the target asteroid). A gravity tractor with 10 year timeframe would have a launch mass of 4,000-60,000 kg and offers approximately 100 times more momentum. The launch mass for the mass driver (MADMEN) approach uses 2,000-100,000 kgs, the change in effective momentum required at the target is about 100 for the least and the highest masses. This calculation is for a ΔV at the target of 3,000 m/s. These values are also discussed for the kinetic impactor and EP tug methods.

Schaffer, et al. [2] compare the various mitigation options in terms of their effectiveness in mitigating prospective EI threats. The change in the velocity of the impactor-asteroid for each mitigation strategy is given. The Kinetic impactor strategy and the gravity tractor method induce the least ΔV change of the target asteroid (3.8 and 0.4 mm/s respectively for an Apophis type asteroid and 28.4 and 0.3 mm/s for a D'Artagnan type of asteroid). The nuclear detonation gives a ΔV of 61.4 and 613.5 mm/s for each of these asteroids types, respectively. The number of launches required, however, is calculated to be one for both kinetic and gravity tractor methods. The probability of success of these mitigation options is given for the different categories of asteroids. For a rubble pile, the probability of success of a kinetic impactor is only 0.1 whereas the gravity tractor is 1. For carbonaceous type, the success probability is 1 for both. The applicability rating for each mitigation option is obtained using the probability of success for each NEO type. According to this, applicability rating for the gravity tractor was 1 for both Apophis and D'Artagnan types and kinetic impactor was 0.5 and 1, respectively. The nuclear detonation approach rated 0.85 and 1, respectively.

The major expenditure is to get to the GEO orbit for the collection of the objects from the graveyard orbit. Sonter [3] notes that the ΔV required to reach LEO is 8.0 km/s and from LEO to GEO is 3.5 km/s. The ΔV required to reach GEO from Earth's surface is 11.8 km/s. The launch cost of Delta IV Heavy per kg is around $17,200 to LEO [4]. A Don Quijote type impactor mission could possibly cost much lesser. The the average change in velocity to get to a near Earth asteroid from LEO is about 5.5 km/s and takes a minimum ΔV to rendezvous these at the aphelion or the perihelion depending upon their orbital characteristics. This value changes for the NEAs based on their type of orbit. Apollo type asteroids generally are in high eccentricity orbits and hence require a higher ΔV to rendezvous with them and are advantageous to rendezvous with at the aphelion. Short period comets may have to be encountered at the perihelion due to the large time required to get to it at, at its aphelion. Hohmann transfers are assumed in calculating these ΔV values. Low-eccentricity and low-inclination Amor type asteroids may be rendezvous with using spiral maneuvers for lower ΔV costs.

Conventional Mission Approach: A conventional NEA mission [e.g., 5, 6] can be conceived via considering to conic sections. First, the spacecraft is launched by rocket from Earth into a deployment orbit. Once deployed it journeys to the edge of the Earth's sphere of influence. Second, the spacecraft maneuvers to co-orbit the sun with the EI. Once in this orbit, it can either perform close-proximity maneuvers for deploying nuclear charges, ballistically impact the EI or position itself to exert gravitational influence.

Proposed Mission Approach: The proposed mission approach (which is suitable only for the ballistic impact and gravitational pull mission approaches) begins with a launch, via conventional rocket, into an orbit similar to the geostationary graveyard orbit. At this point, the craft would execute maneuvers to rendezvous with an existing space debris collection solution. The desired mass would be transferred from the debris collector to the intervention craft. The craft would then, using either a conventional rocket engine or tortile-style propulsion, exit the Earth's sphere of influence and maneuver to strike or co-orbit with the asteroid (for the gravity-pull approach).

Benefits of the Proposed Solution: The proposed solution offers benefit primarily in reducing the ΔV across which the full mission mass must be carried. Under a conventional solution, the mass begins on Earth and is carried by the rocket through the ΔV-expensive launch process. For the proposed mission, the bulk of the mission mass begins in the geostationary orbit's graveyard orbit and, thus, only the empty-container spacecraft (with propellant for the entire mission) needs to be launched from Earth. This benefit is partially offset by the level of propellant that is consumed maneuvering to rendezvous with the debris collection spacecraft. It is presumed that the debris collection spacecraft is already in position, performing debris reduction activities and/or that this unit would continue providing these activities after collecting the debris used for this mission. The costs associated with the debris collection vehicle (which would be difficult to quantify, prior to a solution being selected and thoroughly tested) are thus excluded from this calculation.

Quantitative Comparison of Approaches: Based on the average values presented by Sonter, it is projected that during 11.8 km/s of ΔV, only the mass of the spacecraft and the propellant utilized for moving the combined spacecraft/space debris impactor/tractor would be required. The whole (combined spacecraft/space debris impactor/tractor) assembly would need to be propelled for an additional 2 km/s of ΔV. The exact value of this to the mission, in terms of propellant is highly dependent on the comparative mass of the spacecraft versus the space debris incorporated for the impactor/tractor mission and the specific impulse of the propulsion technologies utilized. However, as the propellant requirements for the second phase would scale linearly with total mass, the benefit is represented by the equation:

$$Prop_{total} = \frac{Prop_{base}}{mass_{sc}} \times (mass_{sc} + mass_{sd}) \tag{1}$$

where $mass_{sc}$ is the mass of the spacecraft and $mass_{sd}$ is the mass of the space debris collected for use in the intervention mission. Based on this, relative propellant requirements for several prospective mission scenarios have been generated. These are presented in Table 1.

SC Mass	SD Mass	Relative Propellant
200 kg	1000 kg	6.00
200 kg	2000 kg	11.00
200 kg	5000 kg	26.00
500 kg	1000 kg	3.00
500 kg	2000 kg	5.00
500 kg	5000 kg	11.00
750 kg	1000 kg	2.33
750 kg	2000 kg	3.67
750 kg	5000 kg	7.67

Table 1. Relative Propellant Requirements for Different Levels of Spacecraft Mass.

Conclusions & Future Work: The work presented herein demonstrates the significant value of utilizing space debris to increase the mass of an Earth impactor intervention mission. Increasing mass allows less velocity to be used for an impactor mission (or more orbit shift occurs, if the velocity is held constant). Increasing mass for a tractor-style mission decreases the mission time requirements, making this option feasible in cases where it might not otherwise be, and decreasing mission duration -driven risk (e.g., hardware failure due to cumulative radiation exposure). Utilizing space debris significantly reduces mission cost.

References:

[1] Olds J.R., Charania A.C. Shaffer M.G. (2007) “Multiple Mass Drivers as an Option for Asteroid Deflection Missions,” Proc. Planetary Defense Conference.

[2] Schafer, M.G., Charania, A.C., Olds, J.R., “Evaluating the effectiveness of Different NEO Mitigation Options”, AIAA.

[3] Sonter, M.J. (1998) "The Technical and Economic feasibility of mining the NEAs", Acta Astronautica, Vol 41, 1998.

[4] Strickland J.K. The SpaceX Falcon Heavy Booster: Why is it Important? Available: http://www.nss. org/articles/falconheavy.html

[5] Straub J., Fevig R. (2012) “Earth Impactors: Threat Analysis and Multi-Stage Intervention Mission Architecture,” Proc. SPIE Defense, Security + Sensing Conference.

[6] McVey J.P., Melamed N. (2012) “Survey of Potentially Hazardous Object Threat Negation Campaign Options,” Acta Astronautica.

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