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Enhanced Gravity Tractor Derived from the Asteroid Redirect Mission for Deflecting Hypothetical Asteroid 2017 PDC

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Extended Abstract—

The Asteroid Redirect Mission (ARM) concept would robotically visit a hazardous-size near-Earth asteroid (NEA) with a rendezvous spacecraft, collect a multi-ton boulder and regolith samples from its surface, demonstrate an innovative planetary defense technique known as the Enhanced Gravity Tractor (EGT), and return the asteroidal material to a stable orbit around the Moon, allowing astronauts to explore the returned material in the mid-2020s. Launch of the robotic vehicle to rendezvous with the ARM reference target, NEA (341843) 2008 EV_5, would occur in late 2021 [1,2]. The robotic segment of the ARM concept uses a 40 kW Solar Electric Propulsion (SEP) system with a specific impulse (I_{sp}) of 2600 s, and would provide the first ever demonstration of the EGT technique on a hazardous-size asteroid and validate one method of collecting mass in-situ. The power, propellant, and thrust capability of the ARM robotic spacecraft can be scaled from a 40 kW system to 150 kW and 300 kW, which represent a likely future power level progression.

The gravity tractor technique uses the gravitational attraction of a station-keeping spacecraft with the asteroid to provide a velocity change and gradually alter the trajectory of the asteroid. EGT utilizes a spacecraft with a high-efficiency propulsion system, SEP, along with mass collected in-situ to augment the mass of the spacecraft, thereby increasing the gravitational force between the objects [3]. As long as the spacecraft has sufficient thrust and propellant capability, the EGT force is only limited by the amount of in-situ mass collected and can be increased several orders of magnitude compared to the traditional gravity tractor technique in which only the spacecraft mass is used to generate the gravitational attraction force. This increase in available force greatly reduces the required deflection time. The collected material can be a single boulder, multiple boulders, regolith, or a combination of different material types using a variety of collection techniques. The EGT concept assumes that the ability to efficiently collect asteroid mass in-situ from a wide variety of asteroid types and environments is a capability that will be developed and perfected in the future by the asteroid mining community. Additionally, it is anticipated that the mass collection would likely be performed by a single or multiple separable spacecraft to allow the SEP spacecraft to operate at safe distance from the asteroid.

The key characteristics of asteroid 2017 PDC, such as its orbit, diameter (100-250 m), density, and spin state, are not well known prior to arrival at the asteroid. A potential impact in July 2027 provides approximately ten years to rendezvous with the asteroid, confirm its characteristics and that it is on an Earth-impacting trajectory, perform the deflection operations, and verify that the deflection was successful. Due to the limited warning time, a deflection effort derived from the ARM robotic spacecraft to deflect the hypothetical asteroid 2017 PDC assumes that the ARM mission has already successfully demonstrated the spacecraft operations associated with the EGT technique and that at least one ARM-derived spacecraft, along with the necessary supporting infrastructure, is operational and supporting robust asteroid mining and exploration operations and can be repurposed to support a deflection campaign.

Asteroids with diameters of 100-250 m, consistent with the expected range of 2017 PDC, and bulk densities of 2 and 4 g/cm^3 are assessed. A SEP system with an efficiency of 0.70 and I_{sp} of 7,000 s (higher than the ARM robotic spacecraft) is assumed with three different operating power levels, where the power level refers to the total power available to the SEP thrusters at 1 AU. The 40-kW system provides 0.82 N of thrust at 1 AU (lower thrust than ARM robotic spacecraft with 40 kW); the 150-kW system provides 3.06 N at 1 AU; and the 300-kW system provides 6.12 N at 1 AU. Additionally, the system is assumed to be designed to be able to use the higher power available at a solar range (r) of less than 1 AU, and that the available power and resulting thrust varies as 1/r^2. Finally, it is assumed that the derived EGT system would be able to acquire the required mass that is needed to maximize the thrusting capability utilizing the halo method to station-keep with the asteroid during the EGT deflection operations [2]. The collected mass varies from tens of tons for the 40-kW system to several hundred tons for the 300-kW system.

Figure 1 shows that an ARM-derived, 40 kW SEP system operating with an I_{sp} of 7,000 could deflect 2017 PDC sizes up to 100-m diameter at 2 g/cm^3 in ≤ ~3.5 years and up to 150-m diameter in ≤ ~7 years by providing a Zeta deflection > 1 in the Opik *b*-plane[4], which is assumed to be sufficient for the successful deflection with the deflection performed continuously starting at the indicted time before impact (in years) until closet approach with. A Zeta deflection < 1 could lead to an Earth impact for near center initial impact locations. Larger asteroids and/or higher densities require more power or more deflection time. Figure 2 shows that a 150-kW system can deflect 2017 PDC sizes up to 200-m diameter at 2 g/cm^3 in ≤ 6 years and Figure 3 shows that a 300-kW system can deflect 2017 PDC sizes up to 250-m diameter at 2 g/cm^3 in ≤ ~6 years.

As demonstrated by this case study of the hypothetical asteroid 2017 PDC, the EGT can effectively deflect hazardous asteroids in years rather than the decades typically needed for the standard GT. Initial trajectory analyses show that these systems can be delivered in a timely manner to the target asteroid utilizing reasonably-sized chemical propulsion departure stages along with SEP for transit. In cases where the EGT is not able to provide sufficient capability to deflect 2017 PDC, a hybrid deflection approach could be performed using multiple techniques. On-orbit resources and expertise in interacting with asteroids are critical to responding in a timely manner (i.e., eliminate time for development and launch). The ability to capture and manipulate significant mass from an asteroid will be developed by the asteroid mining community and is enabling for the EGT option, allowing it to become viable for planetary defense missions with rendezvous opportunities and years, not decades, of warning time. It is the opinion of the authors that the planetary defense community should look to work closely with the asteroid mining community to develop synergistic solutions applicable to both communities.

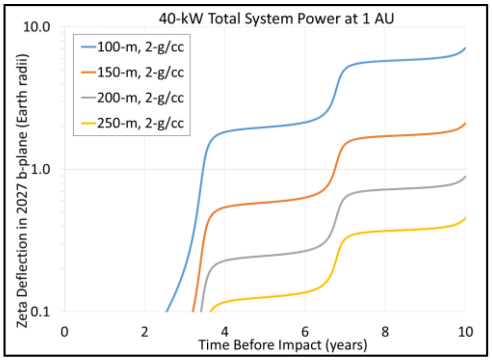

Figure 1: 40-kW System Deflection of 2017 PDC

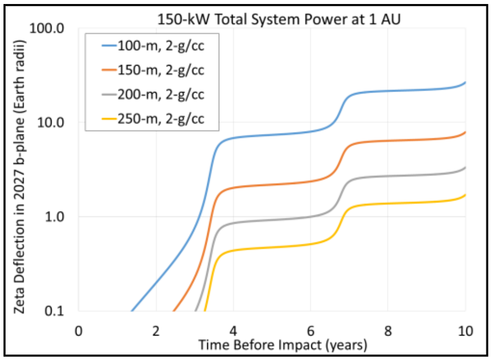

Figure 2: 150-kW System Deflection of 2017 PDC

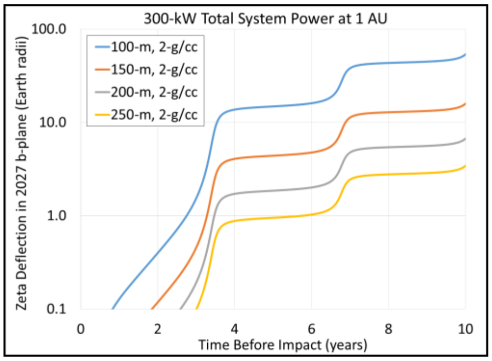

Figure 3: 300-kW System Deflection of 2017 PDC

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