Enhanced Gravity Tractor Technique for Planetary Defense

Presented by Dan Mazanek¹

Co-authors: David M. Reeves¹, Joshua B. Hopkins², Darren W. Wade², Marco Tantardini³, and Haijun Shen⁴

¹NASA Langley Research Center; ²Lockheed Martin Space Systems Company; ³Independent; ⁴Analytical Mechanics Associates, Inc.

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• Early response requires less ΔV to deflect an impactor

• Rapid impulse techniques (e.g., kinetic impactors and nuclear detonations)
  – Require the least amount of warning time
  – Effectiveness depends on the Near-Earth Object (NEO) properties, which are uncertain and vary substantially
  – Application of a large, concentrated force has the potential to fragment the NEO

• “Slow push/pull” techniques (e.g., gravity tractor, laser ablation, ion beam deflection, etc.)
  – Require significant warning time
  – Accelerate the impactor in a uniform manner with only small forces any internal structural stresses
  – Effective against binary or even ternary systems
Introduction

• Standard Gravity Tractor
  – Requires low-thrust, high-efficiency propulsion
  – Applied force is exceedingly small
    • Depends on the mass of the spacecraft
    • Many years or decades of operations

• On March 25, 2015, NASA announced that the Asteroid Redirect Mission (ARM) robotic segment would visit a large near-Earth asteroid (NEA) to capture a multi-ton boulder and return it to the Earth-Moon system
  – Advanced 50 kW-class Solar Electric Propulsion (SEP) Asteroid Redirect Vehicle (ARV)
  – First demonstration of Enhanced Gravity Tractor (EGT) – technique conceived during mission concept development
• Once in the proximity of a hazardous NEO, the EGT operations consist of five phases:
  – Initial orbit determination
  – Characterization
  – Material collection
  – Tractoring
  – Final orbit determination
Comparison of Traditional and Enhanced Gravity Tractor

• 50 kW ARV-class SEP vehicle
  • 1.63 N maximum thrust

• 300 kW human-mission-class SEP vehicle
  • 9.78 N maximum thrust

• Common Assumptions:
  – Spherical asteroid with a constant density of 2 g/cm³
  – Minimum range of one asteroid radius above the assumed spherical asteroid’s surface
  – Assumed maximum thrust available independent of solar range and no specific asteroid orbit
Comparison of Traditional and Enhanced Gravity Tractor

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Mass Collection Option Examples

- Concept 1 – Collecting a Single Boulder
- Concept 2 – Collecting Multiple Boulders
- Concept 3 – Separable Collection Spacecraft and SEP Tug
- Concept 4 – Multiple Collection Spacecraft and SEP Tug

- Many other collection techniques (electromagnets, large quantity regolith collection, etc.) and operational concepts (tethers, solar sails, etc.) are possible
- Synergy with the extraction and processing of asteroidal resources
Operational Challenges of Mass Augmentation

• Collection Site Selection
  – Depends on many factors (lighting, communications, thermal, etc.)
  – Equatorial regions are likely rich in material and may facilitate collection due to maximum centripetal acceleration levels
  – Commercial interest in asteroid mining indicates that collecting many tons of mass from the surface is feasible

• Existence of Collectable Material
  – Centripetal acceleration for small, fast rotators can exceed the gravitational forces leading to a monolithic body without collectable material
  – Very few large asteroids have been observed to rotate above the ~2.3 hour rubble pile “speed limit”
  – Observations indicate that the vast majority of large asteroids have surface material that is loosely bound and readily collectable, thus making EGT a credible deflection technique for hazardous-sized impactors

Image Credit: Paul Sánchez and Dan Scheeres
• Analyzed the ability of a 50-kW EGT spacecraft like the ARV to deflect hypothetical asteroid “2015 PDC”

• Two major challenges in this scenario:
  – Only 5.5 years total duration assuming launch or departure in spring 2017 and impact in September 2022
  – Aphelion of 2.65 AU limits the power during parts of the diversion to only about 15% of the 1 AU insolation

• Found some solutions where deflection is possible
  – Stony asteroid with a mass of 1.7 million tons (H = 21.7, albedo = 0.3, and density of 2.5 g/cm³) – smaller and less massive than the most likely values, but reasonable
  – Assumed 2:1:1 ellipsoid with dimensions of ~87 x 87 x 175 m (spherical equivalent diameter of 110 m)

• Arrival at 2015 PDC on March 12, 2020
  – 3 month reconnaissance and mass collection
  – EGT performed for next 824 days

• Deflection from subterranean 2,790 km Earth periapsis radius (i.e., an impact) to 6,930 km allowing for a miss of 560 km altitude from the surface
• EGT can significantly overlap the kinetic impactor regime, especially if a SEP spacecraft like the ARV has been developed and operated or can be expediently refueled in space
  – ARVs ready to launch and/or already operational in space (e.g., cislunar logistics deliveries, Mars missions, etc.)
  – Repurposed for its critical new mission of planetary defense

• EGT spacecraft can also support other planetary defense techniques in a coordinated manner to maximize the successful deflection effort
  – Provide impact confirmation during rendezvous
  – Deliver payloads to the target asteroid’s surface or vicinity
  – Provide targeting support for a kinetic impactor – spotter spacecraft capable of follow-up deflection operations
  – With refueling, could be used as a kinetic impactor augmented by mass collected during normal operations
• The Enhanced Gravity Tractor technique is a novel, innovative variant of the traditional gravity tractor that can significantly reduce deflection time

• Augmentation with in-situ mass allows for significant increases in tractoring mass which greatly increases the gravitational force available

• NASA’s Asteroid Redirect Mission (ARM) robotic concept to collect a boulder from the surface of a hazardous-sized near-Earth asteroid would provide the first ever demonstration of the EGT technique and validate one method of collecting in-situ mass

• Advancements in SEP propulsion, autonomous vehicles, and robotic systems applicable to human and robotic exploration, commercial asteroid mining, and the used of space-based resources can synergistically help provide a robust defense against future Earth impacts
Thank you for your time and attention.

Questions?