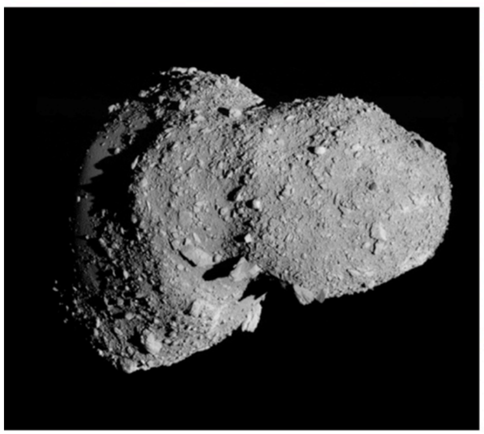
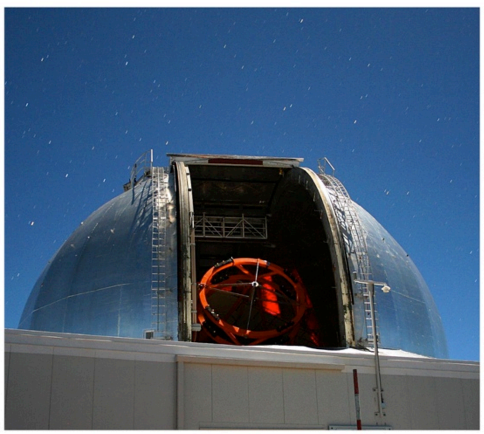
National Aeronautics and Space Administration

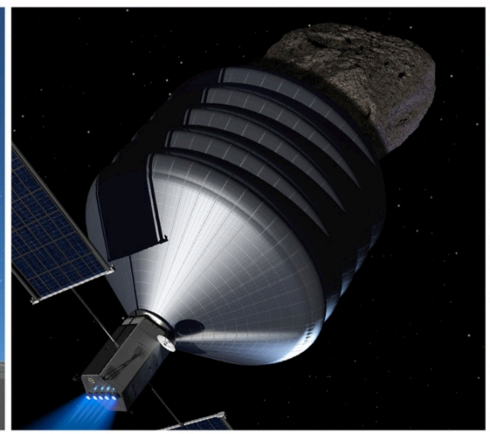
Asteroid Initiative Idea Synthesis

Asteroid Deflection Demonstrations

Dan Mazanek, Pat Troutman & Paul Abell







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Purpose of Asteroid Deflection Demonstrations

- **Deflect the trajectory of an asteroid using the robotic Asteroid Redirection Vehicle (ARV) that would be effective against objects large enough to do significant damage at the Earth's surface should they impact (i.e., > 100 meters in size).**

- **These demonstrations could include, but not limited to:**
  - a. Use of the ARV to demonstrate a slow push trajectory modification on a larger asteroid.
  - b. Use of the ARV to demonstrate a "gravity tractor" technique on an asteroid.
  - c. Use of ARV instrumentation for investigations useful to planetary defense (e.g., sub-surface penetrating imaging)
  - d. Use of deployables from the ARV to demonstrate techniques useful to planetary defense (e.g., deployment of a stand alone transponder for continued tracking of the asteroid over a longer period of time).

Selecting RFIs for Presentation

Top Rated RFIs, based on relevance, impact, maturity, and affordability from each of the categories below were selected

- **Area 1: Reposition a small asteroid or a portion of an asteroid to subsequently impact an incoming large asteroid**
- **Area 2: Use engine thrust to push an asteroid while using opposing thrust to hold relative position at a stand-off distance (e.g., ion beam deflection)**
- **Area 3: Low-cost kinetic impactor (key element applicable to mitigation approaches for the Grand Challenge, but probably only applicable at the end of the "pick up a rock" mission for the ARM)**
- **Area 4: Enhanced gravity tractoring with local mass augmentation**
- **Area 5: Vaporizing asteroidal material using solar energy for deflection of the asteroid**
- **Area 6: Swarm of small satellites attached to an asteroid to de-spin and redirect it**
- **Area 7: Applicable proposals spanning all areas of the mission envelope that support asteroid deflection**

Session Agenda (1 of 4)

- **Concepts for Asteroid Trajectory Deflecting Using an ARV, Mike Elsperman, The Boeing Company**
  - ARM flight vehicle based on Boeing 702MP GEO communication spacecraft utilizing gravity tractor and ion beam shepherding (IBS) acting on small NEA (2009 BD)
- **Low-risk, High-heritage Approach for Asteroid Deflection/ Capture Implementation, Howard Eller, Northrop Grumman**
  - NGC Eagle-3 spacecraft with AstroArray (derived from AstroMesh) design to demonstrate gravity tractoring, direct SEP thrusting, and albedo modification
- **Affordable Spacecraft with Capabilities to Enable Multiple Deflection Schemes, Andy Turner, Space Systems/Loral**
  - SSL 1300 bus, along with MDA robotics technology to test and/or perform four diverse techniques: direct push, electrostatic tractoring, gravity tractoring on a 200 m NEA with 160-t captured boulder, and kinetic impactors. Additionally, ion beam deflection could be performed.

Session Agenda (2 of 4)

- **ARV-based Kinetic impactor and Multiple ARV Gravity Tractors for Orbit Modification, Bong Wie, Iowa State University**
  - Use ARV and captured mass (assumed 500 t) as kinetic impactor against large NEA target and/or multiple SEP-based gravity tractors in halo orbit. Overview of Hypervelocity Asteroid Intercept Vehicle (HAIV) mission concept for blended kinetic impact and subsurface nuclear explosion approach for mitigating threats with short warning times.
- **Asteroid Repositioning for Planetary Defense, Geoffrey Landis, NASA Glenn Research Center**
  - Use of the ARV along with a 7- to 10- meter diameter asteroid returned to a halo orbit around one of the Earth-Moon LaGrange points (L4 or L5) to provide kinetic impact defense against a large incoming hazardous NEA.
- **Gravity Tractoring with Local Mass Augmentation, Tim McElrath, NASA Jet Propulsion Laboratory**
  - Use of mass augmentation to make gravity tractoring an attractive method for moving asteroids – examples: Apophis deflection and repositioning of 2000 SG344 to near-Earth space for extended periods to provide target for future human and resource utilization missions.

Session Agenda (3 of 4)

- **Mass Augmented Gravity Tractor, Josh Hopkins Lockheed Martin**
  - Mass augmented gravity tractor to provide Earth avoidance velocity changes (1 cm/s) to 200-350 m size NEAs using 1,000 t boulder or regolith.
- **Ion Beam Deflection (aka Push-Me/Pull-You), John Brophy, NASA Jet Propulsion Laboratory**
  - Use of Ion Beam Deflection (IBD) to provide impulse to a NEA with potential advantages over other asteroid deflection systems, such as gravity tractor and kinetic impactors, and possible despin of smaller NEAs to simplify capture process.
- **Multiple Independent, Scott Sevcik, Prospect Dynamics**
  - Micro Attach Vehicle (MAV) architecture based on existing commercial satellites and CubeSats to provide scalable, flexible, and low-cost coordinated slow push or explosive re-direct operations for a NEA.

Session Agenda (4 of 4)

- **Utilization of Surface Material for Asteroidal Deflection, Rob Mueller, NASA Kennedy Space Center**
  - Asteroid deflection by ejecting in situ surface material through propulsion devices using volatiles or mass drivers. Also proposed utilizing ejected regolith or ion engine interactions to cause catastrophic disruption of a large loose asteroid (rubble pile) by accelerating its spin rate past the fissure limit.
- **The Solar Collector Option for Maneuvering Near Earth Asteroids, Rob Adams, NASA Marshall Spaceflight Center**
  - Use of solar collector to ablate NEA surface material for deflection operations.
- **The ISIS Mission: An Impactor for Surface and Interior Science, Steven Chesley, NASA Jet Propulsion Laboratory**
  - Impactor for Surface and Interior Science (ISIS) concept to provide a low-cost kinetic impact demonstration at Bennu with OSIRIS-REx as observer, and to address small body exploration Strategic Knowledge Gaps (SKGs). This mission concept could be implemented for a large NEA using ARV as an observer spacecraft
- **Impactor and other Deployable Devices for Planetary Defense Demonstration, Jonathan Wrobel, Honeybee Robotics**
  - Overview of Honeybee Robotics spacecraft mechanisms in support of planetary defense efforts – sensors, small instrumented impactor, surface sampler, harpoon probe, percussive drill, pneumatic sampling and excavation, snare system, and self-opposing multimode anchor.

Key Topics Discussed (1 of 3)

- **Three classes of demonstrations presented**
  - Deflection demos with little or no additional costs (use of ARRM assets)
  - Deflection demos with additional costs (e.g., kinetic impact, solar collector, micro-satellites, etc.)
  - Demonstration of devices that are applicable to future planetary defense approaches, but are not deflection demos based on the ARRM concept
- **Potential to combine approaches and techniques to provide a more effective or comprehensive demonstration**
- **In order to implement effective deflection demonstrations, analyses of the time required to develop necessary technologies should be performed with respect to any impacts on the overall ARM mission budgets and schedule**
- **Enhanced gravity tractor (EGT), ion beam deflection (IDB), and post-mission kinetic impactor (KI) using the ARV with or without the returned mass were all considered as deserving further study for the ARRM mission**

Key Topics Discussed (2 of 3)

- **Demonstrating adequate navigation accuracy for kinetic impactor deflection technique against smaller NEAs (10's of meters in size)**
- **Terminal phase maneuvering for mass augmented kinetic impactor (e.g., 500 t s/c). This can be mitigated by observer spacecraft at target.**
- **Deflection demos need to be binned into the ARM or the Grand Challenge to make sure that ideas are not discarded due to near-term budgetary constraints.**
- **Demos don't need a large deflection to prove their effectiveness (~0.1 mm/s with observing s/c).**
- **Planetary defense demonstrations can be performed on very small (<10 m) NEAs, but they are more relevant to larger NEAs (100+ m)**
- **Other ideas discussed:**
  - ESPA-based SEP module
  - Use of LV upper stage for impactor mass
  - Solar sails for passive deflection

Key Topics Discussed (3 of 3)

- **Deflection approaches that utilize direct push by interacting with the NEA surface need further assessment to determine their effectiveness**

Findings Relevant to Asteroid Redirect Mission (1 of 2)

- **Enhanced gravity tractor (EGT), ion beam deflection (IBD), and post-mission kinetic impactor (KI) using the ARV with or without the returned mass (e.g., placed in lunar vicinity) were all considered as innovative, vaild concepts with potential benefits**
  - Comparison of cost, relative effectiveness, risks, and applicability to small NEAs and large NEAs needs to be assessed in a consistent manner
- **Other demonstrations that don't affect the ARRV, such as kinetic impactor with the ARRV observing at a large target NEA, are recommended if budget permits**
  - Provides direct comparison of slow push technique(s)

Findings Relevant to Asteroid Redirect Mission (2 of 2)

- **Demonstration of a nuclear planetary defense capability is not compatible with the ARRM (budget, schedule, etc.). However, some of the hardware and operations needed could be tested.**

- **Robotics spacecraft mechanisms in support of planetary defense efforts (e.g., surface sampler, pneumatic sampling and excavation, snare system, or self-opposing multimode anchor) could be used or evaluated during ARRM if additional cost can be shared.**

Findings Relevant to Grand Challenge

- **Many demonstrations, such as kinetic impactor, solar collector or use of in situ materials for a mass driver or propulsion, could be important to addressing the Grand Challenge.**
  - These concepts should be analyzed in more detail given the wide range of ideas and uncertainty in how or if they could be accommodated on the ARRM.
  - These ideas could be pursued under the ARRM if additional funding is available or cost sharing can be provided.

Session "Nuggets" (1 of 2)

- **NGC (Eller) suggestion to off-point solar arrays to provide high bandwidth communications using AstroArray concept.**
- **SSL (Turner) concept of having SEP thrusters on arms so that some thrusters can be rotated to perform IBD demonstration more efficiently (currently TRL 9).**
- **Separable spacecraft concept to provide better operations near a large NEA and situational awareness.**
- **Possible use of E-M L4/L5 points as long-term storage locations for use of ARV+material for future kinetic impact demo or actual planetary defense.**

Session "Nuggets" (2 of 2)

- **McElrath suggestion of leaving mass close to the NEA for the "pick-up-a-boulder" (PUB) approach using EGT.**
  - Short tether/boom could keep mass close to parent body.
  - Could reduce operational risk by keeping s/c further away.
- **Brophy (per Andy Thomas) suggestion of using IBD to slow down the spin of a <10 m size NEA to improve capture dynamics.**
- **Cubesat to provide a low-cost transponder to test tracking capability for future monitoring of hazardous NEA.**
- **ISIS kinetic impactor could be very low cost approach for demonstration on ARRM.**