Extensibility of Human Asteroid Mission to Mars and Other Destinations

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Asteroid Redirect Mission Overview

Overall Mission Consists of Three Main Segments

**Identify**

**Asteroid Identification Segment:**
Ground and space based NEA target detection, characterization and selection

**Redirect**

**Asteroid Redirection Segment:**
Solar electric propulsion (SEP) based robotic asteroid redirect to trans-lunar space

**Explore**

**Asteroid Crewed Exploration Segment:**
Orion and SLS based crewed rendezvous and sampling mission to the relocated asteroid
Observation Campaign Extensibility

• Leverages off of NASA’s Near-Earth Asteroid (NEA) discovery and characterization effort
• Utilizes existing ground and space-based observation assets
• New telescopes are coming online, and existing surveys are being upgraded with greater time allocations and improved cameras in support of ARM observation campaign
  – Will increase discovery rate of candidate asteroids for ARM
• These enhancements are also applicable to discovery of hazardous asteroids in general

Catalina Sky Survey Telescope
Spitzer Infrared Space Telescope
Asteroid Redirect Robotic Mission Extensibility

Solar Electric Propulsion (SEP)

• Capability of SEP system on ARRV could be used in other human exploration missions
  – Longer duration near-Earth missions in cislunar space
  – Cargo delivery for human Mars missions
    • Will require higher power for SEP systems; addressed via solar array systems being demonstrated under current STMD effort (extensible to 125 kW per wing via modularity and scalability)
Asteroid Resource Utilization

- Accessibility to asteroid material in cislunar space allows in-situ resource utilization (ISRU) demonstrations to determine if material can be converted into useful products
  - Benefits future human exploration of the solar system
  - May be critical in advancing commercial efforts to mine asteroids

Asteroid Propellant Processing Concept
Robotic Boulder Capture (RBC)

- Use of robotic arms to interact with an asteroid is applicable to other NASA missions
  - Satellite servicing and refueling
  - Providing surface contact and manipulation for a future crewed mission to NEAs or Martian moons

- End-effector/grippers (i.e., microspine technology) can be used for:
  - Future robotic exploration (lunar, Mars, Mars moons)
  - Exploration of bodies like NEAs, Phobos, Deimos, and main belt asteroids like Ceres
Planetary Defense

- Planetary Defense techniques and experience possible through the Robotic Boulder Capture (RBC) option are relevant and extensible to future missions
  - Demonstrations performed on large NEA
    - Potential demonstrations include Enhanced Gravity Tractor (EGT), Ion Beam Deflection (IBD) and kinetic impact approach
- Current RBC option mission timeline includes EGT technique demonstration
  - Applicable to diverting NEAs from Earth-impacting trajectories given sufficient warning time
- Kinetic impact demonstration could be conducted and effectiveness compared to EGT

Demonstration of Enhanced Gravity Tractor on a Large NEA

Kinetic Impact on Comet 9P/Tempel by the Deep Impact Mission
**Common Automated Rendezvous and Docking/Capture Sensors**

- NASA needs automated rendezvous and docking/capture (AR&D) sensors for multiple missions.
- NASA is pursuing a common suite of AR&D sensors to apply across multiple AR&D missions starting with the asteroid missions.
  - Visible cameras paired with selectable lenses per mission needs
    - Medium resolution (narrow angle)
    - High resolution (wide angle)
  - 3D LIDAR
  - Infrared camera
- NASA created a common specification addressing environment and performance for each sensor which will fulfill each mission’s AR&D needs.
- NASA released a BAA to pursue sensors meeting this spec.

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<th>Long Range</th>
<th>Medium Range</th>
<th>Close Range</th>
<th>Application of Common Suite</th>
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<tr>
<td>S-Band Transponder for Range/Range Rate to reduce timeline; Star Tracker for bearing</td>
<td>High Resolution Camera for bearing</td>
<td>3D LIDAR for precise alignment for docking</td>
<td>High Resolution Camera / 3D LIDAR</td>
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<td>Medium Resolution Camera for asteroid acquisition, spin rate and bearing to the asteroid</td>
<td>3D LIDAR for asteroid characterization and alignment for bag capture</td>
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<td>Medium Resolution Camera / 3D LIDAR</td>
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<td>Medium Resolution Camera for bearing to the asteroid</td>
<td>Medium and High Resolution Cameras for spin rate, 3D map of the surface and boulder identification</td>
<td>3D LIDAR for 3D range images to the target boulder</td>
<td>High Resolution Camera / 3D LIDAR</td>
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*Addition of infrared camera on asteroid missions for robustness is being assessed.*
Extravehicular Activity (EVA)

- Aspects of the EVA segment within ARCM that are extensible to other missions include:
  - Providing contingency EVA capability to all manned Orion missions
    - Use of MACES (Orion LEA suit) with mobility enhancements
  - Exploration Portable Life Support System (PLSS) technologies applicable to exploration missions
    - Rapid Cycle Amine (RCA) swing bed for carbon dioxide removal
      - Vacuum missions only; addition of sweep gas required for use on Mars surface
    - Suit Water Membrane Evaporator (SWME) for thermal conditioning
  - Exploration PLSS combined with Z suit will be the EVA suit for all future human exploration missions
  - EVA tools and worksite stability techniques are extensible to any microgravity EVA including moons of Mars
Sample Collection

• Sample collection tools/techniques developed for ARCM that are extensible to future NASA missions include:
  – Collection of macroscopic samples from various locations on surface and/or interior
  – Sampling operations on small, airless body under low-gravity conditions
  – Methods to store and maintain samples during return journey for subsequent laboratory analyses on Earth

• Lessons learned from ARM can be applied to EVA planning for sample site assessment, documentation, sampling operations, and storage/containment activities on Phobos/Deimos
Automated Docking

- Use of International Docking System Standard (IDSS)-compliant NASA Docking System (NDS) as standard docking system for all spacecraft allows delivery of different assets in separate flights that can be integrated later during the mission
  - Enables missions to Mars vicinity (Phobos and/or Deimos)
- Power and data transfer capabilities supports integrated stack control and power sharing
Extended Crewed Missions to Asteroid in DRO

- Many possible opportunities for further utilization of the Asteroid
  - Testing of anchoring techniques
  - In-situ Resource Utilization (ISRU) Demonstration
  - Additional Asteroid Sample Collection
  - Lunar and Mars sample return
  - Scientific Experiments
  - Many other possibilities

- Addition of utilization elements provide:
  - Extended crewed mission duration and additional EVA capability
  - Enhance crew safety with more robust systems and infrastructure
  - Testbed for crew operations and systems required to sustain life for longer deep-space missions
Mars Phobos Mission

- ARV-derived SEP requires “Split-Sprint” mission approach
- SEP used to pre-deploy crew habitat, Phobos systems, and return propulsion stage to Mars orbit
- Crew sent on “one-way” mission to Mars orbit via high-thrust chemical propulsion (critical rendezvous at Mars)
- Crew utilizes pre-deployed assets for Phobos exploration and eventual return to Earth

ARRV-Derived SEP Cargo Tug

- Performance estimates indicate that ARRV-derived SEP may be sufficient for Phobos exploration
- Further assessments required to confirm performance including determining how this type of strategy can feed forward to future landed missions (heavier cargo elements such as Mars landers)
Lunar Mission

- ARM operational experience and systems could be leveraged to support exploration of the lunar surface
  - Delivery of uncrewed assets to lunar vicinity using SEP system, allowing for additional payload/mission capabilities
  - SEP bus could be derived from ARRV
Extensibility to Missions Post-ARCM (Cont.)

Capability Driven Framework (CDF)

- ARM technologies support the CDF as they enable implementation of many possible missions
  - ARM SEP system could be used to support lunar missions
    - Power level could be evolved to preposition assets for Mars missions
  - AR&D sensor suite directly support lunar, Mars, and other possible missions
  - Orion and SLS systems enable “extending reach beyond LEO”
  - Provides operational experience working on low gravity bodies (“exploring other worlds”)
Conclusion

• The Asteroid Redirect Mission has great promise for extensibility
  – SEP, AR&D sensors, and RBC Capture mission are all extensible to possible lunar or Mars moon missions
  – Docking and EVA systems generically support all human exploration missions

• Investment in ARM concept provides logical stepping stones to future exploration goals
Acknowledgments

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