National Aeronautics and Space Administration

Roadmap for Human Exploration of Small Bodies

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Outline

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Introduction

- **Human Exploration of Near-Earth Objects Part of U.S. National Policy**
  - President Obama's speech at Kennedy Space Center on April 15, 2010
  - Officially National Policy June 28, 2010
  - One of Six Goals: Pursue human and robotic initiatives to develop innovative technologies, foster new industries, strengthen international partnerships, inspire our Nation and the world, increase humanity's understanding of the Earth, enhance scientific discovery, and explore our solar system and the universe beyond.
  - Civil Space Guideline #1: Set far-reaching exploration milestones. By 2025, begin crewed missions beyond the moon, including sending humans to an asteroid. By the mid-2030s, send humans to orbit Mars and return them safely to Earth.
- **Human Exploration of NEOs Relevant to NASA Planetary Science Goals**
  - Strategic Goal: Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space.
- **Human Exploration of NEOs Also Relevant to Planetary Defence and Resource Utilization Communities**

Identification of NEO Targets

- **Identification of NEO Targets Relevant and Viable for Human Exploration**
  - Dynamical considerations with respect to exploration systems
    - Orbit Knowledge, Distance, Delta Velocity, Mission Mass, Launch Infrastructure, Mission Duration, and Launch Opportunities
- **Discovery of Additional NEO Targets for Human Exploration**
  - Ground-based assets
    - Existing NEO Search Telescopes (*e.g.*, Catalina Sky Survey)
    - Panoramic Survey Telescope and Rapid Response System (Pan-STARRS)
    - Large Synoptic Survey Telescope (LSST)
  - Space-based assets
    - NEO Survey Telescope (Trailing Venus Orbit, Sun-Earth Lagrange 1, Sun-Earth Lagrange 2)
    - Optical vs. IR
    - Opportunities for follow-up tracking and characterization
- **Synergy Between Exploration, Science, and Planetary Defence Communities**
  - Accessible NEOs for human missions are also potentially hazardous objects

Characterization of Mission Targets

- **Selection of NEO Targets Compatible for Spacecraft Rendezvous/Proximity Operations**
  - Physical characterization considerations with respect to human interaction
    - Size, Spin Rate/Mode, Presence of satellites/companions, Indication of Activity/Debris Fields, Internal Structure, Mechanical Stability, Composition
- **Selection of NEO Targets for *In Situ* Resource Identification/Utilization**
  - Identification of metallic or volatile-rich NEOs (*e.g.*, water)
- **Basic Reconnaissance**
  - Ground-based Observing Campaign for Faint Targets
    - Optical systems must be relatively large
    - Radar systems must have good viewing opportunities
  - Space-based Observing Campaign
    - Most accessible NEOs are in Earth-like orbits
    - Not observable from Earth due to their long synodic periods
- ***In Situ* Characterization**
  - Robotic Precursor Detailed Physical Characterization
    - Reduces mission risk, aids in planning for proximity operations/surface interactions by astronauts, and enables better science return

Laboratory and Simulation Support

- **The Physical Environment of NEOs Is Unlike Large Planetary Objects**
  - NEOs have a wide diversity of compositions/internal structures/shapes
  - Also exist in a micro-gravity regime → micro-gravity geology
- **Laboratory Support Needed to Understand the Types of Materials Present and How They React in Their Environment**
  - Behaviour of materials in micro-gravity conditions
    - Electrostatic, adhesive, and cohesive forces
    - Movement/levitation of particles (*e.g.,* sampling and surface operations)
    - Effects of small particles on equipment and human physiology
- **Simulant Development Useful for Understanding Aspects of Geotechnical Properties**
  - Mobility and attachment/anchoring technologies for astronauts, rovers, and payloads
- **Physics-based Simulations for Understanding Dynamical Interactions in NEO Environments**
  - Astronauts, spacecraft, and robotic assets operating in close proximity
  - Refinement of guidance, navigation, and control

International Space Station

- **Utilization of the International Space Station (ISS) to Further NEO Exploration as a Technology Demonstration Platform**
  - Training for micro-gravity EVA operations at/near a NEO surface
  - Coordination of combined human-robotic interaction (robotic arms, humanoid systems, free flyers) for simulated NEO operations
  - Research and development of resource extraction techniques on relevant planetary materials (*e.g.*, meteorites) and simulants
  - Testing of attachment or anchoring techniques for NEO surface interaction
    - Simulated NEO material properties under extended micro-gravity conditions
  - Development of micro-gravity mobility systems
  - Testing inflatable modules for habitation relevant for long duration, deep space missions to NEOs and other destinations (*e.g.*, Phobos, Deimos, Mars)
  - Continued testing and development of environmental control and life support systems (ECLSS) required for long duration missions to NEOs

Robotic Precursor Missions

- **Initial Assessment and Operations**
  - Qualify the target is suitable for human visitation via extended rendezvous operations
  - Perform detailed characterization with surface interaction
- **Support for Crew Activities on Target**
  - Provide a 3rd party perspective to aid astronaut activities and ground control situational awareness
  - Contribute additional sensors to perform science activities during crew rest periods or during crew activity at other areas
  - Act as a communications relay for mission assets that may be out of line of sight from the main spacecraft and/or Earth
- **Extended Operations After Crew Departure**
  - Observe high kinetic experiment(s) at the NEO to monitor crater excavation and formation, ejecta processes, and internal composition/structure
  - Monitor NEO orbital and rotational characteristics over long periods of time (*e.g.*, Yarkovsky and YORP effects)
  - Act as a data relay for any long-duration experiment packages left at the NEO
  - Monitor momentum transferred to the NEO
    - Planetary defence interests

Human Missions

- **Preliminary Assessment of NEO Performed via Ground-based Systems and Robotic Spacecraft**
- **More Detailed Investigations of the Complex and Dynamic NEO Environment Performed by Astronauts**
  - Adaptability and utility of humans to react rapidly to changing environment and micro-gravity conditions – level of autonomy due to light delay time
  - Greater capability for science return via EVAs collecting macroscopic samples and materials in geological context
- **Human Missions to NEOs Would Combine Remote Sensing Observations, *In Situ* Analyses, and Sample Collection Techniques**
  - Majority of operations would take place in close proximity to the NEO
- **NEO Operations Extend for at least Several Days or More at the Target**
- **Crew would perform experiments for Science, Exploration, Engineering, and Planetary Defence Objectives**
- **Public Engagement of Exploration at a New World Well Beyond the Earth-Moon System**
  - Data and PAO pressure would require high data rates/band width

International Cooperation

- **International Agencies, Aerospace Companies, and Research Institutions Have Shown Considerable Capability and Interest in the Following Fields of NEO/Small Body Exploration**
  - Ground-based observations and research
  - Laboratory research
  - Launch Vehicles
  - Instrument Development
  - Spacecraft systems
  - Re-entry and recovery technologies
- **International Mission Experience to Small Bodies is also Growing as Agencies such as JAXA (Hayabusa) and ESA (Rosetta) Continue to Build on their Successes and Plan for Future Missions**
- **International Coordination and Cooperation in Small Body Exploration Would be Mutually Beneficial**
  - Leveraging previous expertise and/or technologies
  - Coordination to enable more capable missions to small bodies
  - Joint development of specific technologies identified for future missions

Feed Forward to Other Destinations

- **NEO Missions Enable Human Exploration of Other Solar System destinations as Stepping Stones**
  - The Moon
  - Mars
  - Mainbelt Asteroids
- **Small Body Materials Contain Resources that May Provide Propellant for Future Robotic and Human Expeditions Beyond Low-Earth Orbit**
- **NEO Missions Aid in the Development of Extended Deep Space Mission Systems and Technologies that will be Utilized on Long Duration Missions**
  - Radiation shielding
  - Advanced life support
  - Advanced propulsion
- **NEO Missions Allow for Development of Specific Technologies Required to Interact Near or on Planetary Surfaces that can be used as Staging Points for Future Exploration of the Solar System**
  - Phobos and Deimos