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HUMAN EXPEDITIONS TO NEAR-EARTH ASTEROIDS: IMPLICATIONS FOR EXPLORATION, RESOURCE UTILIZATION, SCIENCE, AND PLANETARY DEFENCE

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Introduction: Over the past several years, much attention has been focused on human exploration of near-Earth asteroids (NEAs) and planetary defence. Two independent NASA studies examined the feasibility of sending piloted missions to NEAs, and in 2009, the Augustine Commission identified NEAs as high profile destinations for human exploration missions beyond the Earth-Moon system as part of the Flexible Path. More recently the current U.S. presidential administration directed NASA to include NEAs as destinations for future human exploration with the goal of sending astronauts to a NEA in the mid to late 2020s. This directive became part of the official *National Space Policy of the United States of America* as of June 28, 2010. With respect to planetary defence, in 2005 the U.S. Congress directed NASA to implement a survey program to detect, track, and characterize NEAs equal or greater than 140 m in diameter in order to access the threat from such objects to the Earth. The current goal of this survey is to achieve 90% completion of objects equal or greater than 140 m in diameter by 2020.

Dynamical Assessment: Given that velocity change and mission duration are the most critical factors in any human space flight venture, the most accessible NEAs are those that have orbits similar to Earth's (i.e., semi-major axis near ~1 AU, low eccentricity, and low ecliptic inclination). If total mission durations for the first voyages to NEAs are to be kept to less than one year, with minimal velocity changes, then NEA rendezvous missions ideally will take place within 0.1 AU of Earth (~15 million km or 37 lunar distances). It should be noted that due to the nature of their orbit dynamics, NEAs that are viable human space flight targets are also the most likely objects to impact the Earth.

NEA Space-Based Survey and Remote Characterization: The most suitable targets for human missions are NEAs in Earth-like orbits with long synodic periods. However, these mission candidates are often not observable from Earth via ground-based telescopes until the timeframe of their most favourable human mission opportunities, which does not provide an appropriate amount of time for mission development. A space-based NEA survey telescope could more efficiently find these targets in a timely, affordable manner. Such a system could be ready to launch within a few years of project commitment and find most NEA targets within two years of launch if optimized for human mission target selection. In addition to being able to discover new objects, a comprehensive space-based NEA survey also needs to be able track and remotely characterize objects of interest for human space flight consideration and detect potentially hazardous asteroids that may threaten Earth. This could be accomplished directly with the survey telescope or with complementary assets working in a coordinated manner. Such a comprehensive survey would serve both planetary defence and human exploration objectives, as well as facilitate the advancement of the scientific knowledge of the NEA population and mapping of the potential resources available from these small planetary bodies.

Robotic Precursor Missions: Once suitable candidates have been identified, robotic precursor spacecraft need to be sent to perform basic reconnaissance of a few NEAs under consideration to inform the subsequent human-led mission. Robotic spacecraft will assess targets for any potential hazards that may pose a risk to the deep space transportation vehicle, its deployable assets (e.g., surface science packages, rover system, etc.), and the crew. Additionally, the information obtained about the NEA's basic physical characteristics during the reconnaissance will be crucial for planning operational activities, designing in-depth scientific/engineering investigations, and identifying sites on the NEA for sample collection. This information would also be extremely valuable to design and/or test experiments and investigations relevant for planetary defence initiatives.

Human Exploration Considerations: These missions would be the first human expeditions to interplanetary bodies beyond the Earth-Moon system and would prove useful for testing technologies required for human missions to Mars, Phobos and Deimos, and other Solar System destinations. Missions to NEAs would undoubtedly provide a great deal of technical and engineering data on spacecraft operations for future human space exploration while conducting detailed scientific investigations of these primitive objects. Current analyses of operational concepts suggest that stay times of 15 to 30 days may be possible at these destinations. In addition, the resulting in-depth scientific investigations conducted by the human explorers would refine designs for future extraterrestrial *in situ* resource utilization (ISRU), and assist in the development of hazard mitigation techniques for planetary defence.

Conclusions: The scientific and hazard mitigation benefits, along with the programmatic and operational benefits of a human venture beyond the Earth-Moon system, make a mission to a NEA using NASA's proposed exploration systems a compelling endeavour.