SCIENTIFIC EXPLORATION OF NEAR-EARTH OBJECTS VIA THE CREW EXPLORATION VEHICLE.

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Introduction: The concept of a crewed mission to a Near-Earth Object (NEO) has been analyzed in depth in 1989 as part of the Space Exploration Initiative [1]. Since that time two other studies have investigated the possibility of sending similar missions to NEOs [2,3]. A more recent study has been sponsored by the Advanced Programs Office within NASA's Constellation Program. This study team has representatives from across NASA and is currently examining the feasibility of sending a Crew Exploration Vehicle (CEV) to a near-Earth object (NEO). The ideal mission profile would involve a crew of 2 or 3 astronauts on a 90 to 120 day flight, which would include a 7 to 14 day stay for proximity operations at the target NEO.

One of the significant advantages of this type of mission is that it strengthens and validates the foundational infrastructure for the Vision for Space Exploration (VSE) and Exploration Systems Architecture Study (ESAS) in the run up to the lunar sorties at the end of the next decade (~2020). Sending a human expedition to a NEO, within the context of the VSE and ESAS, demonstrates the broad utility of the Constellation Program's Orion (CEV) crew capsule and Ares (CLV) launch systems. This mission would be the first human expedition to an interplanetary body outside of the cislunar system. Also, it will help NASA regain crucial operational experience conducting human exploration missions outside of low Earth orbit – which humanity has not attempted in nearly 40 years.

Scientific and Practical Rationale: Piloted missions using the CEV to NEOs will not only provide a great deal of technical and engineering data on spacecraft operations for future human space exploration, but have the capability to conduct an in-depth scientific investigation of these objects. Essential physical and geochemical properties of NEOs can best be determined from dedicated spacecraft missions. Although ground-based observations can provide general information about the physical properties (rotation rates, taxonomic class, size estimates, general composition, etc.) of NEOs, spacecraft missions to NEOs are needed to obtain detailed characterizations of surface morphology, internal structure, mineral composition, topography, collisional history, density, particle size, etc. Such missions to NEOs are vital from a scientific perspective for understanding the evolution and thermal histories of these bodies during the formation of the early solar system, and to identify potential source regions from which these NEOs originated.

NEO exploration missions will also have practical applications such as resource utilization and planetary defense; two issues that will be relevant in the not-too-distant future as humanity begins to explore, understand, and utilize the solar system. A significant portion of the NEO population may contain water, an attractive source of life support and fuel for future deep space missions. The subject of planetary defense from impacting asteroids has garnered much public and Congressional interest recently because of the increasing discovery rate of asteroids with a small, but non-zero probability of striking Earth. NASA has already been directed by Congress in the 2005 Authorization Bill to report on options for deflecting a threatening asteroid should one be found. Many proposed deflection schemes depend critically on asteroid characteristics such as density, internal structure, and material properties – precisely the parameters that a crewed mission to a NEO could measure.

Precursor Missions: A robotic mission would be required in order to maximize crew safety and efficiency of mission operations at any candidate NEO. Such an in depth reconnaissance by small robotic spacecraft would help to identify the general characteristics of potential NEOs selected for study, and provide an important synergy between the robotic scientific programs of the Science Mission Directorate (SMD) and the human exploration program of the Exploration Systems Mission Directorate (ESMD). Knowledge of such things as the gravitational field, shape, surface topography, and general composition would aid in planning for later CEV proximity operations. Precursor missions would also be useful to identify potential hazards to the CEV (and any of its deployable assets) such as the presence of satellites, or non-benign surface morphologies, which may not be detectable from ground-based observations. The precursor spacecraft should ideally have a visible camera for surface feature characterization, and a spectrometer capable of obtaining surface spectra in both visible and infrared wavelengths for compositional investigation. Other instruments such as a laser altimeter for surface topography may also be useful for constraining additional characteristics of the NEO. It should be noted that the data from all of the instruments on the precursor spacecraft would add to the current body of knowledge of NEOs in addition to characterizing potential mission targets for the CEV.

CEV Science Capabilities: A CEV-type mission will have a much greater capability for science and exploration of NEOs than robotic spacecraft. The main advantage of having piloted missions to a NEO is the flexibility of the crew to perform tasks and to adapt to situations in real time. Robotic spacecraft have only limited capability for scientific exploration, and may not be able to adapt as readily to certain conditions encountered at a particular NEO. The *Hayabusa* spacecraft encountered certain situations that were a challenge for both it and its ground controllers during close proximity operations at Itokawa. A human crew is able to perform tasks and react quickly in a microgravity environment, faster than any robotic spacecraft could (rapid yet delicate maneuvering has been a hallmark of Apollo, Skylab, and shuttle operations). In addition, a crewed vehicle is able to test several different sample collection techniques, and to target specific areas of interest via extra-vehicular activities (EVAs) much more capably than a robotic spacecraft. Such capabilities greatly enhance any scientific return from these types of missions to NEOs.

In terms of remote sensing capability, the CEV should have a high-resolution camera for detailed surface characterization and optical navigation. A light detection and ranging (LIDAR) system would be essential for hazard avoidance (during close proximity operations) and detailed topography measurements. In addition, the CEV should be outfitted with a radar transmitter to perform tomography, enabling a detailed look at the interior structure of the NEO. Given that several NEOs appear to have a high degree of porosity (e.g., Itokawa is estimated to be 40% void space by volume), it is important to measure this characteristic of the target NEO. Such information on its internal structure not only has implications for the formation and impact history of the NEO, but also may have implications for future hazard mitigation techniques.

Another advantage of the CEV is the capability to place precisely and re-deploy relatively small scientific packages on the surface of the NEO. Such packages as remotely operated (or autonomous) rovers with one or two instruments could greatly enhance the amount of data obtained from the surface, and fine-tune the site selection for subsequent sample collection. Other packages that may be deployed could be in-situ experiments designed to test such technologies as surface anchors/tethers, drills/excavation equipment, or material extraction equipment. The CEV could also deploy a transponder to the surface of the object for a long-term study of the NEO's orbital motion. This could be particularly useful for monitoring such objects that have the potential for a possible future Earth impact.

The crew has the added advantage of EVA for sample collection during close proximity operations. The ability for the crew to traverse and collect one or more macroscopic samples from specific terrains on the surface of an NEO is the most important scientific aspect of this type of mission. Having a human being interacting in real-time with the NEO surface material and sampling various locales in context would bring a wealth of scientific information on such things as particle size, potential space weathering effects, impact history, material properties, and near-surface densities of the NEO.

Conclusions: To date, the planetary science community has based much of its interpretation of the formation of asteroids and comets (i.e., parent bodies of the NEO population) on data from meteorite and interplanetary dust particles recovered on Earth. These materials are known to come from such objects, but the exact location of the specific parent bodies within the solar system is not generally known. Unfortunately direct connections of these samples to specific objects cannot be made with any degree of certainty, which limits the ability of scientists to put their findings in a larger context. However, with pristine samples from known locations within the solar system, scientists can start to "map outcrops" and glean new insights into the compositions and formation history of these NEOs. While such knowledge will aid in a better understanding of our solar system, it also has the potential for more practical applications such as resource utilization (water, precious metals, oxygen, etc.) and NEO hazard mitigation (material properties, internal structures, macro-porosities, etc.). These scientific, commercial, and hazard mitigation benefits, along with the programmatic and operational benefits of a human venture into deep space, make a mission to a NEO using Constellation systems a compelling prospect.

References: [1]Davis, D. R. et al. (1990) The Role of Near-Earth Asteroids in the Space Exploration Initiative. SAIC-90/1464, Study No. 1-120-232-S28. [2]Jones, T. D. et al. (1994) Human Exploration of Near-Earth Asteroids. In *Hazards Due to Comets and Asteroids*, 683-708, Univ. of Arizona Press, Tucson, AZ. [3]Jones, T. D. et al. (2002) The Next Giant Leap: Human Exploration and Utilization of Near-Earth Objects. In *The Future of Solar System Exploration*, 2003-2013 ASP Conference Series, 272,141-154.