NEAR-EARTH ASTEROID RENEDEZVOUS MISSIONS WITH THE ORION CREW EXPLORATION VEHICLE.
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Introduction: The development of the Ares launch system and the Orion Crew Exploration Vehicle (CEV) open up a number of possible opportunities in the inner solar system for human exploration. Of particular interest in this regard are near-Earth objects (NEOs). Here we discuss a possible human exploration of a NEO and review the science and exploration goals for such a mission.

Science: A number of broad science themes can be identified for NEO science. The following list is from the National Acadamey study in 1998 entitled "Exploration of Near Earth Objects" [1]:

1. Measuring the Physical Characteristics of Near-Earth Objects;
2. Understanding the Mineralogical and Chemical Compositions of Asteroids;
3. Deciphering the Relationships Among Asteroids, Comets, and Meteorites;
4. Understanding the Formation and Geologic Histories of Near-Earth Objects.

These science themes are usually associated with groundbased and robotic exploration but would be augmented by human exploration missions.

In addition to addressing fundamental science questions, a human mission to a NEO would have applied science goals in light of the possible future hazard of NEOs impacting Earth. These applied science goals can be listed as:

1. Understand the physical properties of the surface of Near Earth Object so as to allow the design of systems that impact, or attach to these surface.

2. Understand bulk properties of NEOs so as to allow modeling of their response to impacts, detonations or external forces.

3. Determine the diversity of objects within the NEO population with respect to mechanical and bulk properties.

4. Calibrate the ability of Earth-observations to remotely determine the essential physical properties of NEOs.

In both applied science and fundamental science, A human mission to an NEA would produce a wealth of data, at the same time expanding our human spaceflight experience base beyond low-Earth orbit and the Earth-Moon system, proving space-qualified hardware directly applicable to lunar and Mars exploration, and providing a valuable and visible VSE 'milestone' akin to the impact of Apollo 8. An astronaut EVA to the surface of an NEO would be of value toward the applied and fundamental science goals listed above as well as providing an important public outreach and demonstration relavant to hazard mitigation.

Mission Design Considerations: The scheduled early development of the Ares-1 booster and Orion Crew Exploration Vehicle (CEV) components of the VSE will enable science-based, deep-space exploration missions prior to the first flight of the large Ares V booster and initiation of the program's lunar landing phase. Deep space missions to and beyond cislunar space, not requiring a 40-ton Lunar Surface Access Module (LSAM) may be undertaken by exploiting capability enhancements now planned for existing Extended Expendable Launch Vehicles (EELV) and their associated upper stages. However, upgrades to the Orion spacecraft to accommodate long duration missions might exceed the launch capacity of the Ares-1.

Current VSE strategy foresees missions to the Moon departing from a Low Earth Orbit (LEO) after a separately launched Earth Departure Stage (EDS) joins with an Orion spacecraft in an Earth Orbit Rendezvous (EOR). For deep space science missions, the EDS may be significantly smaller than that required for lunar landing missions, and thus, not require the lift capacity of an Ares-V booster. We anticipate capability growth of the Delta IV Heavy booster and its upper stage will allow replacing the EDS with a smaller Centaur-derived-EDS (CEDS) equipped with one or more RL-10 engines and a propellant capacity sized to the more modest mass and delta-v requirements of cis-lunar and deep space mission scenarios. We assume a 0.91 propellant mass fraction for the CEDS. It is worth noting that the RS-68 and CEDS RL-10 engines of the Delta IV Heavy are primary propulsive components of the Ares-5 and LSAM architecture so, early deep space missions using this hardware will garner valuable experience with VSE primary systems yielding operational dividends during the program's later phases

A basic, 23-ton Block II Orion, with a capability for a 1.7 km/sec velocity change and whose non-regenerative life support system is adequate to sustain a crew of 4 people for about 2 weeks, is adequate for lunar missions.

The existing Delta IV Heavy, able to place a 26-ton CEDS in low equatorial orbit, is sufficient to inject an Orion into a Lunar Flyby, free return trajectory. To do an Apollo 8-style lunar-orbit mission would require a modest capability upgrade to the Delta IV Heavy to allow launching a 31-ton CEDS. That planned improvement, is implemented by adding 4 (flight-proven) GEM60 strap-on solid fuel boosters [2]. The total delta-v required for a round trip to lunar equatorial orbit is less than 5 km/sec, provided by the CEDS (3.2 km/sec) and the Orion (1.7 km/sec).

Continued upgrades in Delta IV Heavy and upper stage performance would enable Orion missions to *Lunar Polar Orbit* and beyond. A 35-day mission to the *Sun-Earth Second Libration* point (SEL2) is possible with little more capability than that required for a mission to lunar orbit [3].

Calculations indicate a 3 to 6 month round trip to Near Earth Object 1998 KY_{26}, shown in Figure 1, should be possible. Launch windows occur in Spring 2013 and 2024 when Earth-object separation is within 20 and 12 million km respectively. However, significant upgrades to the payload capacity of the Delta IV Heavy and the Ares-1 (or crew rating the Delta IV Heavy) are required. Orion life support capability must be enhanced, perhaps by incorporating a modification of the International Space Station's (ISS) semi-regenerative Environmental Control and Life Support System (ECLSS), to allow much longer mission durations. There may also be a need for an upgrade to the Orion propulsion capability.

Assuming life support modifications and science payload account for a CEV mass increase of less than 500 kg, and a 2 km/sec delta-v allowance for rendezvous and Earth return, the Orion's mass is about 27 tons. This exceeds the capability of the Ares-1 booster and so would require an upgrade or shift to an enhanced Delta IV Heavy. To reach the target object, the CEDS must impart a velocity of about 4.2 km/sec. The Initial Mass in Low Earth Orbit (IMLEO) necessary to accomplish the mission is less than 90 tons, divided between a 62-ton CEDS and 27-ton Orion.

If the capability for long duration life support can be added to the Orion without exceeding the 25-ton payload limit of the Ares-1, and its propulsion system modified to use methane and oxygen propellants, with a specific impulse of about 360 seconds, then the mission can be staged with about a 10% reduction in the initial mass in LEO (IMLEO), or just over 80-tons.

The results described herein represent a conservative, first-order estimate of a candidate mission design for a NEO (1998 KY_{26}) that is among the most accessible (but not necessarily the most desirable target). There are other, more accessible NEO targets and continued observational research during the years required for flight hardware development may reveal more desirable candidates for human exploration.

Conclusion: The scientific exploration of near earth objects will advance our understanding of the broad questions of the origin and composition of the Earth as well as help us evaluate their potential as natural hazards. A mission to a NEO, if staged prior to the first VSE lunar landing would combine two major national goals in the same effort, it will enable us to study these objects as potential hazards and develop our options for their mitigation, and it will serve to drive and validate the development of our capabilities for manned interplanetary space flight.

Such a mission could be done sooner and with less infrastructure buildup than a mission to the moon or Mars. It would be a good test of our long duration life support capability that would be safer than going down the gravity well of the Moon on the first flight. A NEO mission could be done well before the first lunar landing and would serve to build and sustain public and Congressional support for the larger goals of the VSE.

References: [1] *Exploration of Near Earth Objects*, Committee on Planetary and Lunar Exploration, National Research Council International Academy, ISBN: 0-309-52407-5, 44 pages, 8.5 x 11, (1998) [2] Delta IV Technical Summary, Boeing Corp. Tech. Pub. 3M133, July 2004. [3] of Astronautics, (2004) *Final Report: The Next Steps in Exploring Deep Space, a Cosmic Study*, 9 July 2004. Available online at: (http://www.thespacereview.com/article/759/1).

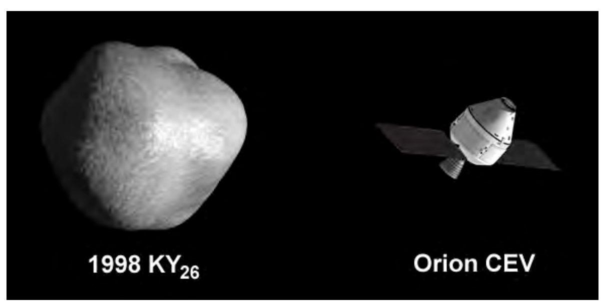

Figure 1. Depicts rendezvous of Orion with 1998 KY_{26} and shows their approximate relative sizes. Image credits, NASA.