A Piloted Orion Flight to a Near-Earth Object:

A Feasibility Study

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[Abstract] A recent study has been sponsored by the Advanced Programs Office within NASA's Constellation Program to examine the feasibility of sending the Crew Exploration Vehicle (CEV; also known as the Orion spacecraft) to a near-Earth object (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 and lunar outpost build up at the end of the next decade (~2020). Sending a human expedition to a NEO demonstrates the broad utility of the Constellation Program's Orion CEV capsule and Ares launch systems. This mission would be the first human expedition to an interplanetary body outside of the Earth-Moon system and would help NASA regain crucial operational experience conducting human exploration missions outside of low-Earth orbit, which humanity has not attempted in nearly 40 years.

Nomenclature

a	=	semi-major axis
AU	=	astronomical unit; 149.598 x 10^6 km
CEV	=	Crew Exploration Vehicle (also known as the Orion spacecraft)
Cx	=	abbreviation for Constellation (CxP – Constellation Program)
Δv	=	delta v; change in velocity; acceleration integrated over time
e	=	orbital eccentricity
EELV	=	Evolved Expendable Launch Vehicle (e.g., Atlas 5 and Delta 4 Heavy)
ESAS	=	Exploration Systems Architecture Study
LSAM	=	Lunar Surface Access Module
NEO	=	near-Earth object
PHO	=	potentially hazardous object (i.e., coming to within 0.05 AU of the Earth)
VSE	=	the Vision for Space Exploration (as announced by President Bush on 14 January 2004)

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I. Introduction

The notion of a piloted mission to a near-Earth object (NEO) was first discussed in 1966 as an alternate follow-on utilization of the Apollo spacecraft and Saturn 5 hardware for a piloted mission to the asteroid 433 Eros. The mission would have been a flyby for the 1975 opposition of 433 Eros (Smith, 1966)[1]. During the 1975 opposition, Eros came within 0.15 AU of the Earth and Smith (1966) detailed the necessary capabilities to upgrade the Apollo/Saturn 5 hardware for a 500+ day round trip mission!

More than 20 years later, NASA re-examined the ideas of visiting NEOs in greater depth as part of the Space Exploration Initiative in 1989 (Davis *et al.*, 1990)[2]. Since then, four other studies have examined the details of sending humans to NEOs (Nash, *et al*., 1989; Jones, *et al*., 1994, 2002; Mazanek, *et al*., 2005)[3,4,5,6]. The most recent assessment has been undertaken by the Advanced Programs Office (APO) within NASA's Constellation Program. This particular study team includes representatives across NASA and is examining the feasibility of sending a Crew Exploration Vehicle (CEV), the Orion spacecraft, to a NEO. Depending on the suite of spacecraft and integrated components, a mission profile would include two or three astronauts on a 90 to 120 day spaceflight; including a 7 to 14-day stay at the NEO itself.

The most significant advantage of piloted missions to a NEO is that it strengthens the foundation for the Vision for Space Exploration (VSE) and Exploration Systems Architecture Study (ESAS) in the run up to the lunar sorties and Moon base development beginning at the end of the next decade (~2020). This mission is motivated by the desire to perform an early developmental test of exploration hardware and operations in the middle part of the next decade – before the completion of the Ares 5 heavy lift launcher and the LSAM lunar lander. In order to minimize the impact to current CEV development and to maximize the applicability and validity of this mission to Constellation test objectives, an unmodified Block II CEV is assumed.

Missions to NEOs reinforce the Constellation Program with an uncanny suite of benefits: deep space operational experience (i.e., the manned CEV will be several light-seconds from the Earth); risk reduction for space hardware; confidence building for future mission scenarios (e.g., lunar poles and farside, other NEOs, and eventually, Mars); early *in situ* resource utilization (ISRU) evaluation; as well as a rich scientific return. Sending a human expedition to a NEO, within the context of the VSE and ESAS, will help NASA regain crucial operational experience conducting human exploration missions – which has not attempted since *Apollo 17*.

Further, in terms of Δv and propellant requirements, NEOs are more easily accessible than the Moon. This incremental step along the way towards Mars can serve as the next generation *Apollo 8* for the Constellation Program, marking humanity's first foray beyond the Earth-Moon system.

II. NEO Background

Near-Earth objects (NEOs) include asteroids and comets whose orbits approach or intersect the Earth's orbit about the Sun (and are, therefore, distinguished from main belt asteroids which orbit the Sun between Mars and Jupiter). NEOs range in size from a few meters across to as large as ~40 km across, with smaller objects greatly outnumbering larger objects. Because of the volatiles they contain, near-Earth comets (NECs), while in Earth's vicinity to the Sun, would not make an attractive target for a crewed mission, so the study will focus on what we know to be near-Earth asteroids (NEAs). However, we use the term 'NEO' to be all-inclusive of all objects throughout this report. From ground-based observations and the study of meteorites that have fallen to Earth, we know that the general makeup and structure of NEOs is wide-ranging – from those comprised of loose conglomerations of rock and stone to those consisting of mostly iron. Due to their small size and relative similarity of their orbits to Earth, many NEOs are more easily accessible than the Moon due to the significantly less Δv required.

The orbits of NEOs are often quite similar to the Earth's orbit, and therefore require a fairly small Δv for rendezvous provided launch occurs near a close approach. In addition, due to their small size and consequent shallow gravity wells, only a very small Δv is required to brake into the vicinity of, and to depart from, a typical NEO. For comparison, the Δv required to brake into or depart from lunar orbit is of order 0.8 km/sec, which when combined with the 3.2 km/sec lunar transfer Δv means that an *Apollo 8* type mission requires a Δv ~4.8 km/sec. For comparison, the *Apollo 17* (including the landing, descent orbit burn, CSM orbit plane change, the LEM powered descent, etc.) total Δv was ~9.1 km/sec (Orloff, 2001; Adamo, 2007)[7,8]. Thus, many NEOs are more easily accessible than lunar orbit (let alone the lunar surface) due to the significantly less Δv required.

Due to the impact threat they pose, in 1998 NASA accepted the mandate to detect and catalogue 90% of NEOs larger than 1 km. To date [as of 9 August 2007], 4754 NEOs have been discovered. The NASA Authorization Act (2005) directs NASA to detect and characterize NEOs down to 140 meters in size. The number of such smaller asteroids is vastly greater than the number of larger asteroids (Figure 1). This means that the discovery rate will increase greatly over the next ten years, even if only two new search telescopes begin operations; namely, Pan-STARRS (Panoramic Survey Telescope and Rapid Response System) and the Large Synoptic Survey Telescope (LSST), but especially if NASA is provided funds to perform the greater than 140 meter survey to 90% completeness by 2020. By the middle of the next decade we expect that there will be hundreds – if not thousands – of possible new candidate NEOs accessible for a CEV mission.

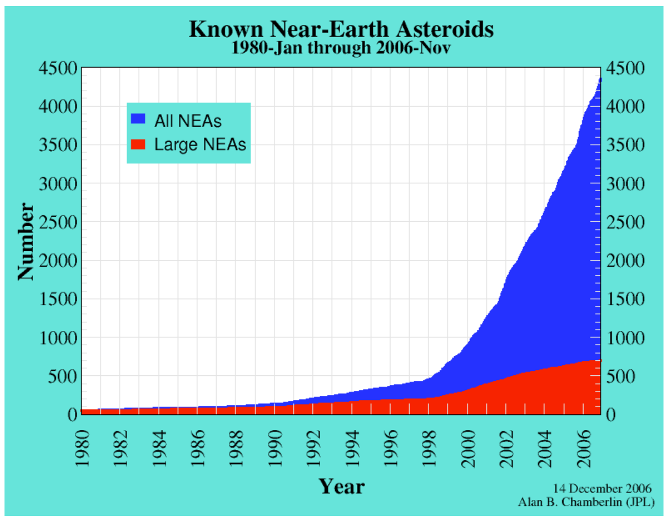

Figure 1: A plot showing the relative increase in the number of detected NEAs from January 1980 through December 2005. The current number of known NEOs is now approaching 4800 objects (Chamberlin, 2006)[9].

This could present a target-rich opportunity for the Exploration Systems Mission Directorate (ESMD), the Space Operations Mission Directorate (SOMD), and Science Mission Directorate (SMD), to cooperate and mount a piloted CEV test flight to a NEO. So little is understood about the sheer numbers, origin, and characteristics of NEOs, that a manned mission *to even one of these* with sample return will expand humanity's deep space experience base for future missions to the Moon and Mars as well as harvest an unimaginable scientific return for the benefit of all mankind.

To date, robotic spacecraft have visited only a handful of asteroids (see Figures 2 and 3); only two of which have explored NEOs (see the science section beginning on Page 10). Prior to launching a piloted expedition to a NEO, it will be prudent execute a set of robotic precursor missions to NEOs that would potentially be explored by a human crew. Perhaps a new paradigm, ala *Clementine*, could be invoked to do this more cheaply than current so-called Discovery-class planetary science missions (currently cost-capped at $425 million life-cycle cost).

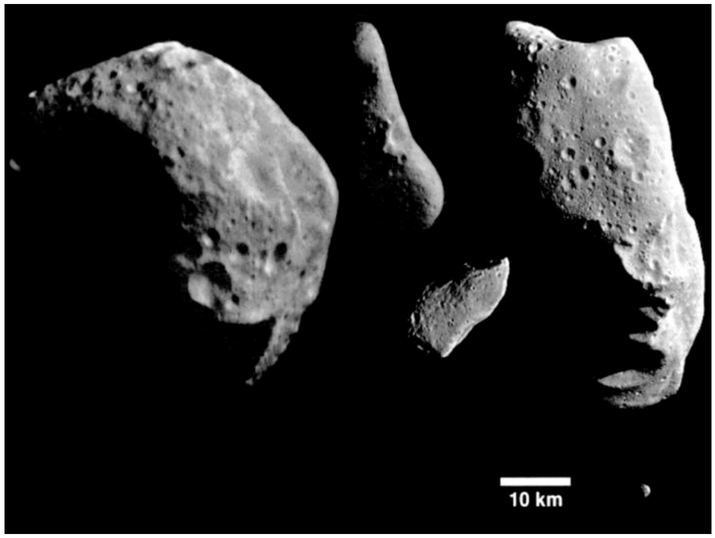

Figure 2: From left to right: Asteroids 253 Mathilde, 433 Eros, 951 Gaspra, and 243 Ida & Dactyl (small 'dot' to the lower right) to scale. (Of this 'set' of asteroids, only 433 Eros is a NEO.) The large crater at left center (and mostly in shadow) on Mathilde is ~20 km across. The asteroid Itokawa, (see Figure 3), recently visited by the *Hayabusa* spacecraft, is smaller than Dactyl.

Two years before the Apollo Applications Program (AAP) came into being, Eugene Smith first analyzed the idea for a crewed mission to a NEO in 1966. Working for Northrup Space Laboratories (now Northrup-Grumman) Smith adroitly pointed out that while a number of studies had been undertaken to further examine piloted missions to the planets, none [at that time] had examined visits to small bodies and minor planets. Utilizing an upgraded Apollo spacecraft and Saturn 5 launch vehicle, Smith described a flyby mission to 433 Eros as an interim mission before sending crews to Mars (Smith, 1966).

More than two decades later, NASA first examined missions to NEOs in 1989 as part of the Space Exploration Initiative (Davis, Hartmann, Jones, *et al*., 1990). Mission scenarios to NEOs were once again by Jones, *et al*. in 1994 and more recently in 2002. The more recent Jones paper analyzes a 90-day roundtrip mission to asteroid 1991 VG including 30 days of proximity operations.

Mazanek, *et al.* (2005) conducted a cursory examination of potential NEO mission scenarios ranging from 45 to 90 day missions with crews of two (or three) astronauts. The stay time at the NEO was on the order of a few days to a week. Our feasibility study examined four possible combinations of Constellation hardware that could propel a manned CEV Orion to a NEO (i.e., dual launch of an Ares I/CEV + a Centaur upper stage atop an EELV; single launch of an Ares IV/CEV; single launch of an Ares V/CEV; and the standard dual launch of an Ares V/LSAM [modified for NEO mission] + Ares 1/CEV) with mission lengths of 90, 120, and 150 days to a variety of NEOs. We did not attempt to scope a design reference mission; rather, it was a feasibility study; the results of which are the subject of this paper. The next section suggests NEO mission scenarios (including robotic precursors). Finally, the last section concludes with the human and exploration science that can be accomplished at the NEO.

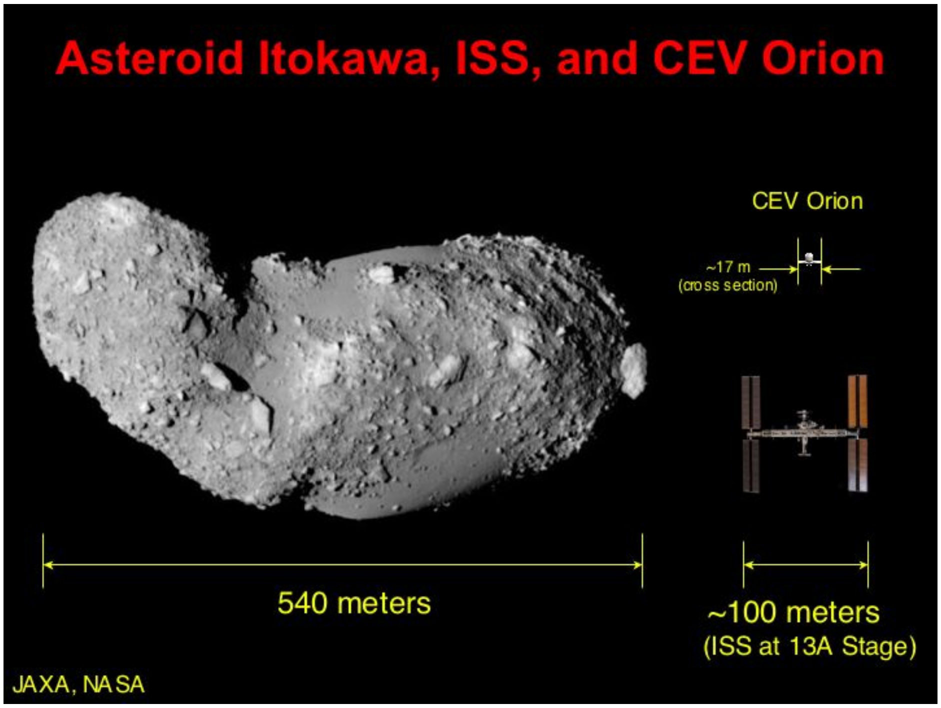

Figure 3: Comparison of 25143 Itokawa, the International Space Station and the Orion spacecraft to scale (courtesy JAXA and NASA).

III. Robotic & Precursor Missions to NEOs

Previous NEO Missions

To date, there have been only two spacecraft missions that have explored NEOs to any extent: NASA's *NEAR Shoemaker* spacecraft at asteroid 433 Eros in 1999 and the Japan Aerospace Exploration Agency's (JAXA) *Hayabusa* probe at asteroid 25143 Itokawa in 2005. Both of these robotic missions are considered to be extremely successful and have generated much scientific interest in NEOs. However, even though the scientific community has a better understanding of NEO physical properties and compositions based on the data from these missions, there are still many questions that remain unanswered. For example, data from the remote sensors on both spacecraft have been unable to identify the exact composition and internal structure of each asteroid after operations of several months in orbit and a few landings (one for *NEAR Shoemaker* and two for *Hayabusa*). Therefore, even though both missions are considered to have achieved almost all of their scientific goals, they still were limited by the capabilities of their spacecraft. For example, *NEAR Shoemaker* was not built for sample return, and *Hayabusa*'s collection mechanism was designed to obtain only two small samples of the asteroid. It is still not clear if *Hayabusa* managed to obtain a sample of asteroid Itokawa. Preliminary indications are that it did not. Subsequently the science results that came from both of these missions, although extremely valuable, are still somewhat limited in terms of determining exactly the compositions and internal structures of these NEOs.

Future NEO Missions

In October 2006, JAXA announced their intention to launch *Hayabusa 2* to the NEO 1999 JU_3, a C-type asteroid. The tentative plan is to launch in late 2010, rendezvous in 2013 and return samples to Earth ~2015. A next generation 'Hayabusa Mark 2' robotic spacecraft is planned to launch from Earth in 2015 and visit an extinct comet.

Don Quixote is a proposed European Space Agency (ESA) to launch to a NEO in the 2013-2017 timeframe. *Don Quixote* is comprised of two spacecraft: *Hidalgo*, which will impact the NEO and *Sancho*, which will orbit [station keep] above the NEO before, during and after Hidalgo impacts the target NEO. The NEO to visit has not been selected and the mission itself is pre-Phase A.

OSIRIS is a proposed NASA Discovery-class mission to visit a C-type NEO, 1999 RQ_{36}, launching in 2011. *OSIRIS* is also at the pre-Phase A stage and a selection decision on whether to go forward will be made in late 2007.

Precursor Missions

At the moment, there are no precursor missions planned to visit NEOs to which human crews might some day be sent to explore. Yet, a precursor 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 the potential NEO selected for study, and provide an important synergy between the robotic scientific programs of SMD and the human exploration of ESMD. Knowledge of such things as the gravitational field, object shape, surface topography, and general composition would aid in planning for later CEV proximity operations at the NEO. 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 previous 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 and an x-ray/gamma ray spectrometer for elemental distribution 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 will add to the current body of knowledge of NEOs in addition to characterizing initial potential mission targets for the CEV.

IV. An Orion (CEV) Mission to a NEO

The NASA Constellation Program (CxP) study focused on the feasibility of mounting piloted missions to NEOs utilizing the hardware developed for the return to the Moon as described within the existing, planned launch vehicle infrastructure. Further, this initial feasibility study limited modifications to the Orion (CEV) spacecraft (e.g., only flying two or three astronauts, inclusion of a SIM bay on the service module section of the Orion spacecraft, etc.). Over a four-month period, three centers – Ames Research Center, Johnson Space Center, and the Jet Propulsion Laboratory – were involved in the study. Four launch options were assessed from the lower 'bookend' (i.e., Ares 1/CEV + an EELV); to two 'mid-volume' single launch options (i.e., CEV atop an Ares IV and a CEV atop an Ares V); and the upper 'bookend' (i.e., an LSAM-like spacecraft atop an Ares V and the Ares 1/CEV).

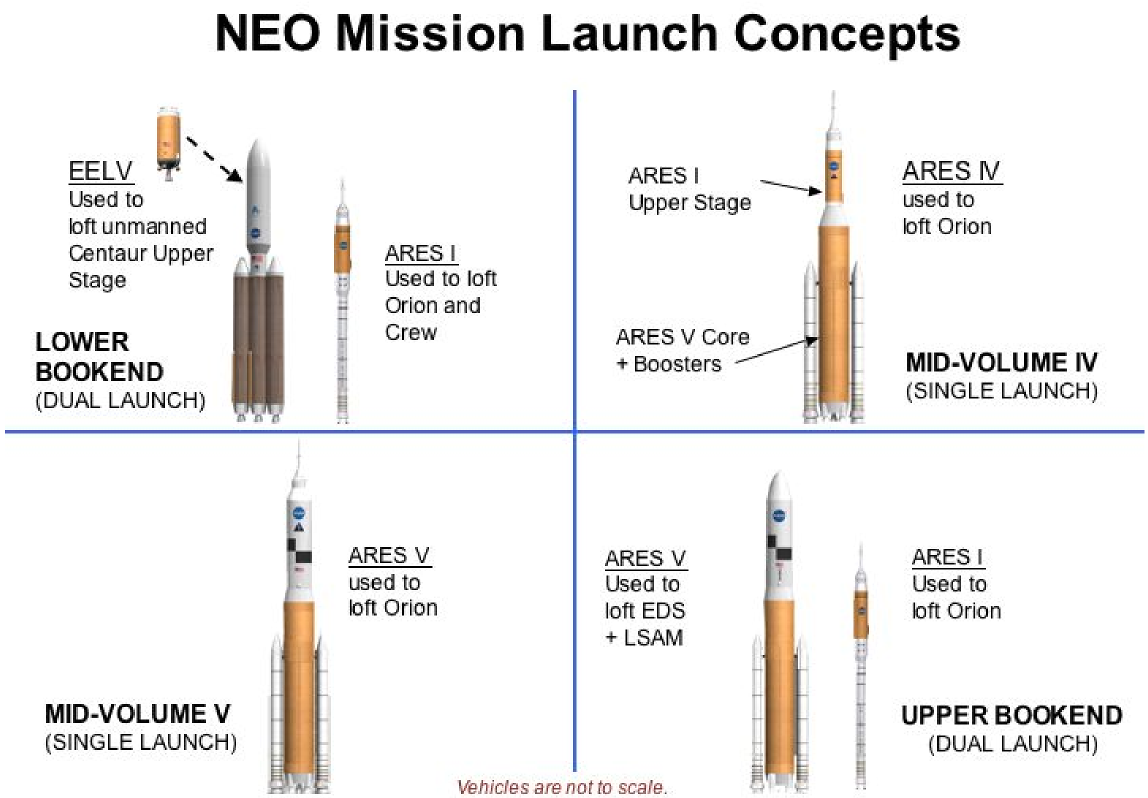

Figure 4: The range of NEO mission launch concepts. The total Δv for the lower bookend is just over 4.5 km/s; Ares IV → 6.3 km/s; Ares V → 7.25 km/s; and the dual-launch upper bookend (with only an LSAM descent stage) Δv ~ 6.0 km/s.

At first order, the NEOs that are good targets of opportunity for initial piloted missions are those which:

1) have Earth-like orbits (low eccentricity and low inclination),
2) that make close Earth approaches (i.e., ~0.05 AU of the Earth – a potentially hazardous object or PHO),
3) slow rotators (i.e., rotation period of ~10 hours or longer),
4) a single, solitary object (nearly 1/6th of all NEOs are binary objects)
5) an asteroidal body (i.e., not a cometary or extinct comet, or transition object)

More than 1200 potential NEO targets were assessed from existing JPL Horizons database, filtered by semi-major axis (*a*), eccentricity (*e*), and inclination (*i*) [with respect to the ecliptic]:

$$0.5 \text{ AU} < a < 1.5 \text{ AU}$$

$$e < 0.5$$

$$i < 3°$$

Only 71 (6%) of the NEOs in this subset have inclinations < 2° and 237 (19%) have inclinations < 5°. (Every degree of orbital inclination requires 0.5 km/s of post-Earth escape Δv.) We assessed the best 84 candidate NEOs based on the NEO catalog (as of late 2006]. We matched the required Δv's to their respective NEO orbits and constructed two-dimensional Δv contour plots within a given semi-major axis (*a*) and eccentricity (*e*). We then overlaid the current known NEO catalog over the contour plot. This allows a quick assessment of new NEOs as opportunities and discoveries are made. However, it does not capture highly elliptical or Earth-transiting NEOs.

Some 35 candidate NEOs [for exploration by piloted CEV missions] were found in the current NEO catalog. (The number of potential candidates is expected to grow substantially in the next decade as Pan-STARRS 4 and possibly the LSST come on line and begin their NEO survey work.) Several trajectories and mission lengths from 90 to 180 days were examined. JPL's Team X, conducted a focused study on a lower bookend 90-day mission scenario to the asteroid 2000 SG_{344}. While the trajectories shown in Figures 5a and 5b are for 2069, there is a favorable opposition of 2000 SG_{344} in 2028. (Table 1 in the Appendix shows all NEO opportunities based on the currently known NEOs beginning in 2017 through 2100.)

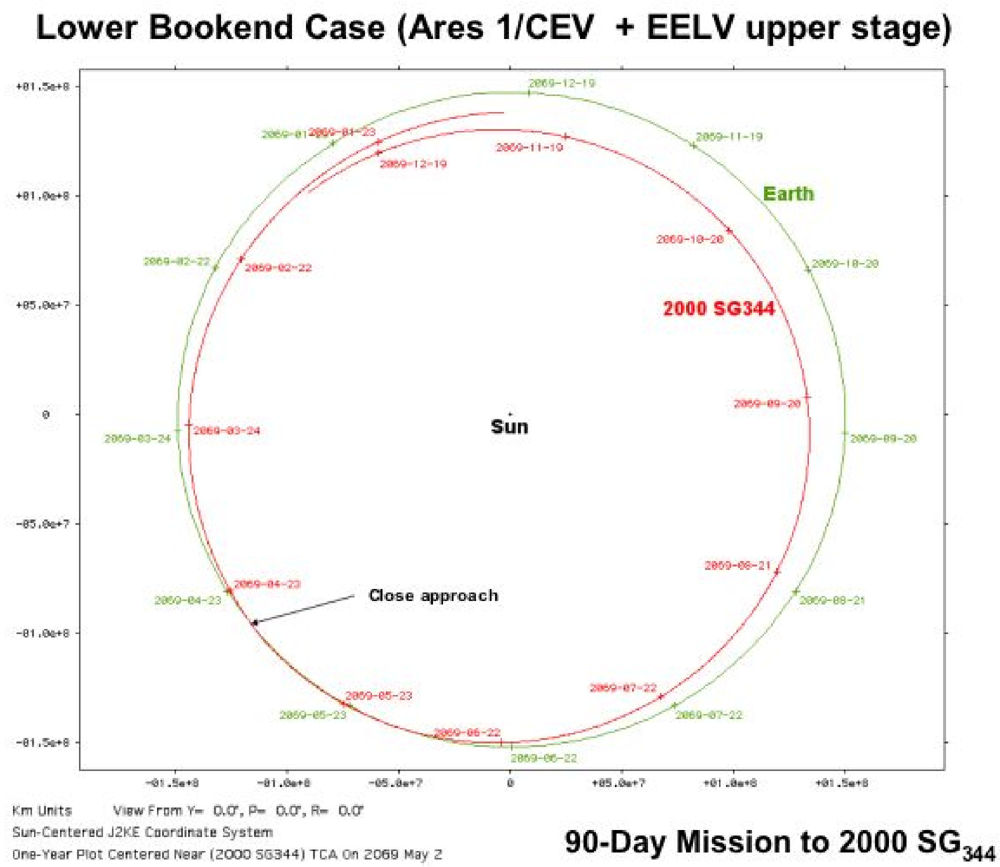

Figure 5a: Heliocentric view of a 2000 SG_{344} and the Earth. This trajectory was examined by JPL Team X for the lower end 'bookend' scenario utilizing a Centaur upper stage and CEV atop an Ares 1.

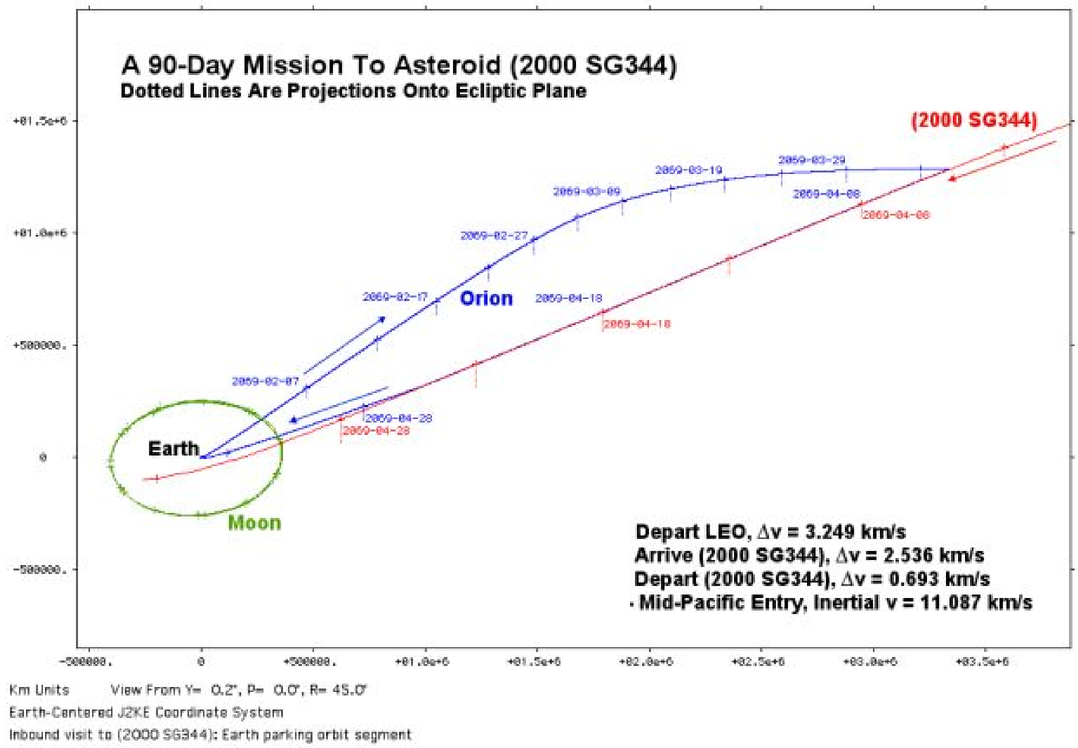

Figure 5b: Earth-fixed trajectory plot showing departure from and return to the Earth. The orbit of the Moon about the Earth is shown to scale. All of our mission scenarios assumed 7 to 14 days at the NEO itself. Atmosphere entry is similar to that experienced by the Apollo crews returning from the Moon. *Apollo 13*, the fastest return from the Moon, inertial velocity ~11.3 km/s.

In general, the total mission Δv can be reduced with longer missions (i.e., 150, 180, perhaps even 210 days), shorter stay times at the NEO (say, 3 to 5 days), lunar gravity assist (provided the mission trajectory can be crafted to swing by the Moon; additional Δv ~200 m/s). There are two roughly equal launch windows on either side of the NEO close approach to Earth. As NEO mission could depart prior to close approach and then return to Earth at/near closest approach; or, the NEO mission departs at/near close approach and returns to Earth just prior to the NEO receding beyond the range of CEV.

Proposed Mission Capabilities of the CEV at NEOs

The CEV would have several basic capabilities in order to complete the scientific and technical objectives of the mission. These would involve aspects of remote sensing, deployment/re-deployment of surface experiment packages, and surface sampling techniques. The precursor mission to the NEO should have adequately characterized the surface and near-space environment to reduce the risk to the CEV and its assets. Hence the majority of CEV operations should take place during close proximity (~ a few to several hundred meters from the surface) to the NEO. Such operations have been found to be challenging for remotely controlled spacecraft due to round trip light delay times of several seconds or minutes, but will probably be inconsequential for piloted operations from a vehicle like the CEV.

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 wanted 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 of the object. This would allow 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 may have major implications for future hazard mitigation techniques of such objects.

Another advantage of the CEV is the capability to place and re-deploy relatively small scientific packages on the surface of the NEO with a significant amount of precision. Such packages as remotely operated (or autonomous) rovers/hoppers 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 materials/component extraction equipment. One experiment that the CEV could do very well is to deploy a series of seismic sensors across the surface of the NEO, and then detonate one (or more) small explosive charges to help determine its interior structure. 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 Earth impact in the future.

Undoubtedly the biggest asset that the CEV has at its core is the crew. The crew can adapt to specific situations and adjust experiments and operations with much more flexibility than a robotic spacecraft. The crew has an added advantage for EVA capability and sample collection during close proximity operations. The ability for the crew to land, traverse, and then collect one or more macroscopic samples from specific terrains on the surface of an NEO is the most crucial scientific aspect of this type of mission. Having a human being interacting in real time with the NEO surface material and sampling various locales (e.g., Muses Sea region or the Little Woomera terrain on asteroid Itokawa) 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.

To date, the planetary scientific 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 inter-planetary dust particles found 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 the development of 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.). Hence, there is a vast amount of potential to gain from a targeted sample return mission using the CEV to a NEO.

Scientific Rationale for a CEV mission to NEOs

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. As discussed above, a robotic spacecraft has only limited capability for scientific exploration, and may not be able to adapt to certain conditions encountered at a particular NEO. The *Hayabusa* spacecraft encountered certain situations which 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 much more quickly in a micro-gravity environment, even with a delay of just several light seconds, than any robotic spacecraft can manage. In addition, a crewed vehicle is able to test several different sample collections techniques, deploy and re-deploy any scientific surface payloads, and able to target specific areas of interest via extra-vehicular activities (EVAs) much more easily than a robotic spacecraft. Such capabilities greatly enhance any scientific return from these types of missions to NEOs. Such capabilities greatly enhance any scientific return from these types of missions to NEOs. Scientific operations in the vicinity of and at the surface of the asteroid will resemble micro-gravity operations than lunar surface operations due to the extremely low surface gravity of the NEO.

V. Conclusion

On occasion, asteroids collide with the Earth and have potential to do catastrophic damage. NEOs are the most easily accessible bodies in the solar system. As we look beyond the ISS program and towards the VSE, near-Earth asteroids offer a feasible, attractive stepping stone to the Moon and beyond. As new telescopes com on line in the next few years (e.g., Pan-STARRS in 2010 and the LSST in 2014), and/or as an expanded survey by NASA gets underway, the detections of new NEOs is expected to grow exponentially. Depending upon their orbital parameters and geometries (relative to Earth), these newly discovered NEOs offer additional options to visit one of these bodies with the Ares vehicles and Orion spacecraft, truly demonstrating an early interplanetary capability of the Constellation hardware.

Appendix

Table 1 (below): listing of NEOs accessible using Constellation hardware. The first row across the top denotes magnitude, semi-major axis (SMA), eccentricity (ECC), orbital inclination (INC), launch date (LD), flight time (FT), $\Delta v_{post\text{-}escape}$ (DVPE) and Δv_{tot} (DVT). Color scheme for Ares 1 + EELV is purple; Ares IV is orange; Ares V in yellow.

Ares I + EELV
Ares IV SL
Ares V SL

NAME	MAG	SMA	ECC	INC	LD	FT (days)	DVPE	DVT
2003_YN107	26.3	0.9887	0.013937	4.32	2065-SEP-14	90	3.72	7.06
2000_SG344	24.8	0.983476	0.064707	0.11	2069-APR-30	90	1.95	5.27
2006_QQ56	25.9	0.983077	0.047744	2.79	2090-SEP-02	90	3.50	6.86
2000_SG344	24.8	0.935934	0.083499	1.23	2098-MAR-01	90	2.91	6.20
2006_UB17	26.3	1.142558	0.105095	2.00	2045-JUN-10	120	3.97	7.29
2006_QQ56	25.9	0.984886	0.045619	2.80	2051-SEP-05	120	3.56	6.92
2000_LG6	29.0	0.912819	0.11469	2.75	2063-FEB-25	120	3.84	7.15
2003_YN107	26.3	0.9887	0.013937	4.32	2065-AUG-15	120	2.81	6.16
2000_SG344	24.8	0.983476	0.064707	0.11	2069-APR-30	120	1.66	4.98
2005_LC	26.8	1.138541	0.105021	2.82	2085-JAN-24	120	3.78	7.06
2006_QQ56	25.9	0.983077	0.047744	2.79	2090-AUG-31	120	2.85	6.19
2000_SG344	24.8	0.935934	0.083499	1.23	2098-JAN-30	120	2.37	5.63
1991_VG	28.4	1.027002	0.049169	1.45	2017-JUL-26	150	3.06	6.45
1999_AO10	23.9	0.912076	0.110731	2.62	2025-SEP-19	150	3.74	7.06
2000_SG344	24.8	0.977537	0.066916	0.11	2028-APR-25	150	3.67	7.00
2006_DQ14	27.0	1.027738	0.052967	6.30	2030-SEP-21	150	3.20	6.93
2000_LG6	29.0	0.916169	0.11107	2.83	2036-JAN-30	150	3.49	6.78
2001_FR85	24.5	0.982789	0.027917	5.24	2039-SEP-29	150	2.74	6.41
2005_LC	26.8	1.132666	0.101787	2.80	2040-JAN-09	150	3.57	6.89
1999_VX25	26.7	0.901573	0.138112	1.74	2040-JUN-12	150	3.87	7.23
2006_UB17	26.3	1.142558	0.105095	2.00	2045-MAY-17	150	3.58	6.87
1999_VX25	26.7	0.901738	0.137394	1.75	2046-JUN-23	150	3.40	6.85
2006_WB	22.7	0.852614	0.176115	4.89	2050-JUL-01	150	3.75	7.11
2006_QQ56	25.9	0.984886	0.045619	2.80	2051-SEP-02	150	3.08	6.42
1999_AO10	23.9	0.912627	0.110188	2.58	2052-SEP-24	150	3.57	6.95
2000_LG6	29.0	0.912819	0.11469	2.75	2063-JAN-28	150	3.45	6.72
2003_YN107	26.3	0.9887	0.013937	4.32	2065-JUL-16	150	2.04	5.41
2000_SG344	24.8	0.983476	0.064707	0.11	2069-APR-30	150	1.50	4.82
1999_AO10	23.9	0.912421	0.11019	2.50	2079-SEP-13	150	3.98	7.29

2001_FR85	24.5	0.983913	0.026268	5.24	2080-OCT-13	150	2.18	5.76
2005_LC	26.8	1.138541	0.105021	2.82	2084-DEC-26	150	3.51	6.80
2006_UB17	26.3	1.147694	0.108491	2.04	2088-MAY-19	150	3.83	7.11
2006_QQ56	25.9	0.983077	0.047744	2.79	2090-AUG-29	150	2.49	5.82
2006_DQ14	27.0	1.034098	0.054564	6.33	2093-SEP-08	150	2.58	6.33
2000_LG6	29.0	0.907987	0.120291	2.62	2095-MAY-12	150	3.35	6.87
1999_VX25	26.7	0.904491	0.134617	1.71	2096-JUN-14	150	3.40	6.80
2000_SG344	24.8	0.935934	0.083499	1.23	2098-JAN-02	150	2.13	5.38
1991_VG	28.4	1.027002	0.049169	1.45	2017-JUL-17	180	2.32	5.66
2001_GP2	26.9	1.037761	0.074018	1.28	2020-APR-06	180	3.69	7.01
2001_QJ142	23.4	1.062177	0.086275	3.11	2024-APR-24	180	3.40	6.89
1999_AO10	23.9	0.912076	0.110731	2.62	2025-AUG-22	180	3.54	6.85
2003_LN6	24.5	0.856814	0.209499	0.66	2025-DEC-21	180	3.69	7.02
2000_SG344	24.8	0.977537	0.066916	0.11	2028-APR-27	180	3.22	6.56
2006_UQ216	27.3	1.103814	0.162567	0.47	2028-AUG-15	180	3.55	7.26
2006_DQ14	27.0	1.027738	0.052967	6.30	2030-AUG-27	180	2.10	5.87
1999_CG9	25.2	1.061891	0.063564	5.16	2033-AUG-18	180	3.08	6.61
1999_VX25	26.7	0.901265	0.137967	1.67	2034-SEP-25	180	3.45	7.09
2000_LG6	29.0	0.916169	0.11107	2.83	2036-JAN-02	180	3.21	6.48
1991_VG	28.4	1.032353	0.052434	1.43	2038-DEC-07	180	2.88	6.33
2005_LC	26.8	1.132666	0.101787	2.80	2039-DEC-13	180	3.31	6.62
2001_FR85	24.5	0.982789	0.027917	5.24	2039-SEP-24	180	1.79	5.40
1999_VX25	26.7	0.901573	0.138112	1.74	2040-MAY-15	180	3.70	7.01
1997_YM9	24.4	1.095331	0.103663	7.84	2044-DEC-27	180	2.36	6.42
2006_UB17	26.3	1.142558	0.105095	2.00	2045-APR-22	180	3.45	6.74
1999_VX25	26.7	0.901738	0.137394	1.75	2046-MAY-25	180	2.77	6.14
2001_GP2	26.9	1.023376	0.069058	1.40	2049-JAN-27	180	2.88	6.35
2006_WB	22.7	0.852614	0.176115	4.89	2050-JUN-01	180	3.25	6.70
2006_QQ56	25.9	0.984886	0.045619	2.80	2051-MAR-07	180	2.47	5.92
1999_AO10	23.9	0.912627	0.110188	2.58	2052-AUG-27	180	3.20	6.52
2006_HC	25.5	1.108862	0.072677	7.83	2054-APR-20	180	3.19	7.14
1992_JD	25.0	1.032142	0.030384	13.55	2054-NOV-04	180	1.65	6.97
2005_LC	26.8	1.138262	0.1051	2.81	2056-DEC-21	180	3.79	7.12
2004_QA22	27.9	0.952497	0.122746	0.58	2056-MAY-06	180	3.58	7.10
2000_LG6	29.0	0.912819	0.11469	2.75	2062-DEC-30	180	3.24	6.50
1991_VG	28.4	1.029946	0.050953	1.43	2062-JUN-19	180	3.69	7.16
2003_YN107	26.3	0.9887	0.013937	4.32	2065-DEC-12	180	1.26	4.76
2000_SG344	24.8	0.983476	0.064707	0.11	2069-APR-30	180	1.41	4.73
1999_CG9	25.2	1.058169	0.060403	5.16	2070-AUG-12	180	2.77	6.40
1999_VX25	26.7	0.906172	0.135333	1.65	2071-SEP-21	180	3.34	6.98
1999_AO10	23.9	0.912421	0.11019	2.50	2079-AUG-16	180	3.86	7.16
2001_FR85	24.5	0.983913	0.026268	5.24	2081-MAR-21	180	1.72	5.28
1999_CG9	25.2	1.05975	0.061876	5.16	2082-AUG-13	180	2.72	6.33
1991_VG	28.4	1.030488	0.0513	1.43	2084-DEC-15	180	3.29	6.77
2005_LC	26.8	1.138541	0.105021	2.82	2084-NOV-28	180	3.38	6.72

2003_YS70	28.8	1.285537	0.235716	0.35	2086-JUL-26	180	4.04	7.27
2006_UB17	26.3	1.147694	0.108491	2.04	2088-APR-24	180	3.75	7.03
2006_QQ56	25.9	0.983077	0.047744	2.79	2090-FEB-25	180	1.56	4.98
1997_YM9	24.4	1.094587	0.103723	7.82	2091-DEC-27	180	2.72	6.70
2001_QJ142	23.4	1.062272	0.086822	3.13	2093-APR-22	180	3.36	6.85
2006_DQ14	27.0	1.034098	0.054564	6.33	2093-AUG-27	180	1.74	5.43
2000_LG6	29.0	0.907987	0.120291	2.62	2095-MAY-08	180	2.94	6.42
1999_VX25	26.7	0.904491	0.134617	1.71	2096-MAY-17	180	3.02	6.36
2000_SG344	24.8	0.935934	0.083499	1.23	2097-DEC-04	180	2.04	5.28
2002_AA29	24.1	0.992654	0.012999	10.75	2097-JUL-08	180	2.21	6.73

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