Multiple NEO Rendezvous, Reconnaissance and In Situ Exploration. K. Klaus, M. S. Elsperman, D. B. Smith, T. S. Cook, The Boeing Company, 5301 Bolsa Avenue, Huntington Beach, CA 92647, kurt.k.klaus@boeing.com, michael.s.elsperman@boeing.com, david.b.smith8@boeing.com, tim.s.cook@boeing.com

Introduction: In order to perform multiple Near Earth Object (NEO) rendezvous, surface mapping, and in-situ surface exploration, we propose a two spacecraft mission. This concept mimics the likely architecture approach that human explorers could potentially use: a "Mother Ship"(MS) designed to get from Earth to and between the NEO and a "Small Body Lander"(SBL) that performs in situ investigation on or close to the NEO's surface.

The MS carries the SBL to the target NEO. Once at the target NEO, the MS conducts an initial reconnaissance in order to produce a high resolution map of the surface. This map is used to identify coordinates of interest which are used by the SBL. The SBL separates from the MS and autonomously navigates to the identified location, performs tasks using the MS as a data relay to Earth.. Landings are possible, though the challenges of anchoring to the NEO surface are significant, particularly if the defined tasks require manipulation of surface material. The SBL design is flexible and adaptable, enabling science data collection on or near the surface.

After surface investigations are completed on the first NEO, the SBL will autonomously rendezvous and dock with the MS. The MS then proceeds to the next NEO target. During transit to the next NEO, the SBL could be refueled by the MS, a TRL8 capability demonstrated on the DARPA/NASA Orbital Express mission in 2007, or alternately sized to operate without requiring refueling depending on the mission profile. The mission goals are to identify surface hazards; quantify engineering boundary conditions for future human visits, and identify resources for future exploitation.

Solar Electric Propulsion: NEO missions benefit greatly by using high ISP (Specific Impulse) Solar Electric Propulsion (SEP) coupled with high power generation systems. Boeing is developing an Advanced Modular Power System (AMPS) concept as part of the DARPA FAST (Fast Access Spacecraft Test bed) program. This solar concentrator approach can produce high (multi Kw) power levels with significantly lower system mass (specific power densities of ~130watts/kg) than current solar power system technologies. This power can be used to operate the SEP system and provide higher than typical power to science experiments and spacecraft operations. A flat panel approach that uses increased solar cell density called Integrated Blanket/Interconnect System (IBIS) for Thin Multi-junction solar cells also produces the high specific power density comparable to FAST, but without the solar concentrators. Both systems use the same solar wing deployment and power management approaches based on existing technology in use on many Boeing Geosynchronous communication satellites today.

Mission Goals: The mission goals will be accomplished through the execution of key mission objectives: (1) high-resolution surface topography; (2) surface composition and mineralogy; (3) radiation environment near NEO; and (4) mechanical properties of the surface. Essential SBL instruments include: a) LIDAR (Obj. 1); b) 3D, high- resolution hyperspectral imaging cameras (Obj. 2); c) radiation sensor package (Obj. 3); and d) strain gauges (Obj. 4). Additional or alternative instruments could include: e) x-ray fluorescence or laser-induced breakdown spectroscopy (LIBS) sensor package (Obj. 2); f) gamma ray/neutron spectrometry package (Obj. 2); and g) radiometer package (to address variations in thermal environment).

Relationship to Human Exploration: The NEO Exploration System powered by AMPS could also serve as a technology demonstration for a SEP enabled architecture for human exploration of asteroids, Phobos, and eventually Mars. The exploration architecture uses components that are currently being assessed by NASA as they work to define the approach for continued manned space exploration after the Space Shuttle era. It incorporates the use of the

International Space Station (ISS) as an assembly node for constructing the crewed Deep Space Vehicle (DSV). It also uses a variant of a Heavy Lift Launch Vehicle also under study by NASA.

The major components of the DSV are launched to Low Earth Orbit (LEO) on 3 separate launches to the vicinity of the ISS. The DSV also includes inflatable habitat modules, a docking node, a modified cryogenic upper stage for crew delivery and NEO orbit injection, an Orion Command Module for earth re-entry, and the AMPS system. It is assembled at the ISS to enable human control and intervention to overcome problems that may occur during assembly.

After the DSV is assembled it then self propels out to a High Earth Orbit (HEO) using SEP for checkout and to await the crew. By using SEP to self propel from LEO to HEO, the Initial mass to Orbit requirements are reduced by over 50% as compared to an all chemical system. This is because chemical propellant is such a large portion of the total system mass of chemical systems. A plot of mass vs event sequence is shown to illustrate the major mission events and operations scenarios for a crewed NEO mission using the DSV.

After the DSV is checked out the crew travels from LEO to HEO via a cryogenic upper stage burn in the Orion to provide a rapid transit through the Van Allen radiation belts to minimize crew exposure. The DSV is then launched on its NEO trajectory using another Cryogenic burn to leave the Earth sphere of influence. The DSV then fires the SEP system to begin the extremely low thrust but very efficient burn to reach the NEO.

System trade studies indicate that a DSV could enable crewed exploration of multiple NEOs and even the Martian moons in roughly 1 year travel time beginning in the early 2020-2025 timeframe given a focus on maturing key enabling technologies and using existing infrastructure/capabilities where possible. The improvements in SEP afforded by AMPS could be flight proven on the precursor exploration missions necessary prior to any crewed exploration of NEOs or Martian moons.

Conclusion: The ability to reach, survey, sample, and analyze multiple NEOs at close proximity is an enormous capability that can enable NASA to rapidly achieve the primary Exploration Precursor Robotic Mission (xPRM) Program goal of characterizing NEOs for future human exploration. Instead of launching multiple dedicated missions to each NEO of interest, a multi-NEO sortie mission can be planned and executed to achieve the same mission objectives with one launch, dramatically reducing the cost of NEO exploration.

Collectively, our NEO Exploration System Architecture provides solutions for a wide variety of exploration activities using a common spacecraft bus and common core instrumentation for the spacecraft. This engineering consistency will substantially improve the probability of mission success, increase the likelihood of maintaining an aggressive launch schedule, and decrease the total cost of multiple missions. NASA successfully used this approach with the robotic precursors leading up to the Apollo missions, and we see significant benefits from this same programmatic approach for the xPRM program.