THE SPACE LAUNCH SYSTEM AND LUNAR MISSIONS. K. Klaus, The Boeing Company (13100 Space Center Blvd, Houston TX 77059, kurt.k.klaus@boeing.com).

Introduction: The Space Launch System (SLS) is the most powerful rocket ever built and provides a critical heavy-lift launch capability enabling diverse deep space missions. The exploration class vehicle launches larger payloads farther in our solar system. The vehicle's 5 m to 10 m fairing allows utilization of existing systems which reduces development risks, size limitations and costs. SLS lift capacity and superior performance will shorten mission travel time. Enhanced capabilities enable a myriad of missions including human exploration, planetary science, astrophysics, heliophysics, planetary defense and commercial space exploration endeavors. This paper will focus on mission concepts to the lunar vicinity and surface.

Asteroid Redirect & Return Mission (ARRM): Bill Gerstenmaier at the NASA Lunar Science Institute (NLSI) meeting in July 2013 refered to the ARRM in part as a mission to the lunar vicinity. Our mission concept for ARRM advocates for a dual manifest launch on the SLS for the Asteroid Retreival spacecraft and a habitable volume with an airlock to help reduce the requirements on the Orion by providing storage, habitable volume, abort destination, and opportunity for International Partner contributions.

Boeing has developed an Asteroid Redirection Vehicle (ARV) concept that leverages the benefits of our commercial spacecraft portfolio, extensive Solar Electric Propulsion design, integration, and operations heritage, and successful autonomous rendezvous and capture expertise from Orbital Express. These key attributes provide an affordable flight system with the required capabilities to execute the Asteroid Redirect Mission (ARM). The ARM mission requirements result in system design based on a modified version of our 702 commercial spacecraft product line. The Boeing 702 spacecraft is a sturdy platform that can accommodate large (> 10,000 kg) propellant loads with minimal structural modifications. The expansive payload deck can accommodate a large capture/redirect system with established interfaces for power, telemetry, and other payload services. Including a NASA Docking System (NDS) on the ARV allows for easier crewed exploration mission integration and execution. Key to our concept is that the ARV also enables potential reuse as a cargo tug or power/propulsion system for any translunar assets in the vicinity after the ARM is complete.

Boeing has a broad experience base with complex mechanisms for spacecraft. On the International Space Station alone, Boeing successfully led the integration of 27 complex mechanisms in a wide variety of applications. Our design studies of the capture systems envision a stand-alone capture pallet mated to the capture vehicle. Left attached to the asteroid and fitted with a docking or grapple interface, it would allow for future potential commercial exploitation of the asteroid once the NASA mission is complete. Boeing recognizes that all the capture methods will require close-loop control dynamic simulations that model the interaction between the capture system and the GN&C system of the capture vehicle. Lessons learned from the assembly of the ISS are extensive in this area, and are directly applicable to an asteroid capture mission. Boeing also brings experience as the integrating contractor for the NASA Docking System (NDS) which is an excellent candidate for consideration on the ARM

Asteroid Exploration Module: Crew operations at a redirected asteroid could be significantly enhanced by providing additional systems and EVA capabilities beyond those available from Orion only missions. An Asteroid Exploration Module (AEM) located with the asteroid would improve the science and technical return of the asteroid mission while also increasing Orion capability through resource provision and providing an abort location and safe haven for vehicle contingencies. Additional volume and EVA capable elements could significantly increase the effectiveness of asteroid exploration by increasing mission duration and providing more utilization options and tools for the ARRM. Orion mission capability will be stretched to the limit by asteroid missions and could be augmented by an AEM that provides resources such as power and atmosphere revitalization to extend mission duration and a storage location that saves launch mass for the Orion by storing needed items. The AEM would also provide an abort location for an Orion mission and sustain the vehicle and crew while problems are identified and resolved. At the end of the asteroid mission, the AEM would remain a viable and extensible element that could provide translunar capabilities and services and could be reused to enhance future missions or as a building block in a new architecture. We envision the AEM as the first component of a Lagrange point exploration platform. An AEM could be created using existing hardware from a number of sources. International partner space systems are well developed and ideal for these new uses, such as adapting current Russian Science Power Module (SPM) and node designs for translunar use. Study and work already done on new ISS node development could be continued. Hardware from the Space Shuttle and International Space Station (ISS) programs, such as the Orbiter Docking System

(ODS) and the ISS node test article, could be combined with existing satellite hardware with a long operational history in the GEO environment.

Cislunar Exploration Platform: The AEM could be repurposed as a cislunar exploration platform that advances scientific research, enables lunar surface exploration and provides a deep space vehicle assembly and servicing site. We have been studying an architecture for Cislunar Development that includes early deployment of an Exploration Platform at one of the Earth – Moon Lagrange points. The Exploration Platform provides a flexible basis for future exploration, since it reduces cost through reuse of expensive vehicles and reduces the number of launches needed to accomplish missions. International Space Station (ISS) industry partners have been working for the past two years on concepts for using ISS development methods and residual assets to support a broad range of exploration missions. These concepts have matured along with planning details for NASA's Space Launch System (SLS) and Multi-Purpose Crew Vehicle (MPCV) to allow serious consideration for a platform located in the Earth-Moon Libration (EML) system. [1]

Lunar Surface: The mission objectives are to provide lunar surface access for crew and cargo and to provide as much system reuse as possible. The reusable lander is a single stage, bi-propellant system which is sized to transport crew from a 100Km circular low lunar orbit to the surface and back. The lander is used in conjunction with another vehicle which we call a Lunar Transfer Vehicle (LTV) whose job is to shuttle the lander between high lunar orbit (HLO) and low lunar orbit (LLO). A polar orbit provides the ability to land at any site on the lunar surface. The platform is relocated to HLO in order to reduce the overall propellant requirements for the landing system.

The first surface expedition crew departs the AEM in the lander and performs a rendezvous and docking with the LTV. The LTV propulsion system is used to perform the transfer from HLO down to LLO. The crew next performs the necessary maneuvers to descend and land under pilot control. Subsequent missions to the surface can reuse the same lander and LTV. [2]

Secondary Payloads: We continue to examine using the mass margin available on the 2017 un-crewed ORION/SLS EM-1 to launch secondary payloads that advance science and exploration objectives. As an example, there is sufficient volume and mass margin for a number of small sats that could be used for science and technology demonstration payloads that could be included in EM-1 and subsequent missions. This capability could be made available with every SLS launch.

International Partnerships: On a global scale, space exploration provides a visible and unifying challenge to humanity and offers opportunities for broad international engagement and participation. It can contribute to global societal security through sharing of knowledge, international cooperation and economic development. All of the major space-faring nations have shown interest in long-term Solar System exploration.

Although most countries' space programs contain nationalistic perspectives, most also recognize the benefits of cooperation. Budgetary pressures of conquering new frontiers in space will make it difficult for any nation to go it alone. Given the fact that the International Space Station has now merged the human space flight programs of several space-faring nations, it seems a natural consideration that future exploration planning be inclusive of an international approach.

Stakeholder consultation and engagement activities have always been an important element in the planning process for space exploration activities. There is an accepted acknowledgement that industry perspective is important and complimentary to the planning currently underway within the major space-faring nations working to define future exploration initiatives. While our team cannot speak for our respective national agencies, we offer an international industry perspective on international partnerships for deep space exploration.

Summary: The SLS offers a great deal of flexibility with regard to missions to the lunar vicinity, lunar surface and beyond. We have shown how these missions open the door for international participation and can reduce cost through reuse of assets. Every SLS launch has capacity for secondary science and technology payloads. We advocate cislunar development as the next logical step to extend our reach beyond low earth orbit (LEO).

References:

[1] Klaus K., Post, K.E. and Lawrence S. (2013) *AIAA 2013-0436*. [2] Raftery M and Derechin A. (2012) *IAC-12- B3.1*.