

THE SPACE LAUNCH SYSTEM AND THE PROVING GROUND: PATHWAYS TO MARS. K. Klaus¹,¹The Boeing Company, 13100 Space Center Blvd, MC HB4-20, Houston TX 77059, kurt.k.klaus@boeing.com.

Introduction: The Space Launch System (SLS) Program is making progress toward delivering a new capability for Beyond Earth Orbit (BEO) exploration. Developed with the goals of safety, affordability and sustainability in mind, SLS will start with 10% more thrust than the Saturn V that launched astronauts to the Moon 40 years ago. From there it will evolve into the most powerful launch vehicle ever flown, via an upgrade approach that will provide building blocks for future space exploration. The SLS provides a critical heavy-lift launch capability enabling diverse deep space missions. Enhanced capabilities enable missions including human exploration, planetary science, astrophysics, heliophysics, planetary defense and commercial space exploration. We will focus on mission concepts relevant to NASA's Cislunar Proving Ground and the Global Exploration Roadmap (GER).

Pathways to Mars: Cislunar space provides an excellent 'proving ground' for readying systems, operations concepts and risk mitigation strategies for missions further into space, including missions to Mars. [1] The GER demonstrates how cislunar missions are a meaningful step to Mars and a stepping stone to the lunar surface. NASA's Evolvable Mars Campaign (EMC) adds missions to cislunar space that were missing from the earlier capability driven architecture, chiefly the Exploration Augmentation Module (EAM), robotic lunar surface missions and missions to the lunar surface with international participation. We have been exploring how these missions could fit into the current planning through EM-2 through EM-6.

EM-2 – Orion and the Asteroid Retrieval Vehicle (EAV): Bill Gerstenmaier at the NASA Lunar Science Institute (NLSI) meeting in July 2013 referred to the ARM in part as a mission to the lunar vicinity. The ARM mission requirements result in system design based on a modified version of our 702 spacecraft product line. Including a NASA Docking System (NDS) on the Asteroid Redirect Vehicle allows for easier crewed exploration mission integration and execution. The SEP ARV could be used as a cislunar tug in the event that the ARM is cancelled or deferred.

EM-3 - Orion and the EAM: 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 Exploration Augmentation Module (EAM) 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.

Cislunar Exploration Platform: The EAM 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. 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 several 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 SLS and Multi-Purpose Crew Vehicle (MPCV) to allow serious consideration for a platform located in the Earth-Moon Libration (EML) system or a Distant Retrograde Orbit (DRO). [2]

EM-4 – Orion with a Robotic Lander – We envision EM-4 as a human tended sample return mission to the lunar farside. We chose Schrödinger Crater as the target for our study but we fully realize that the target for this mission would be chosen by the science community. While this mission could be Moonrise with samples returned by the crew and Orion, the SLS has enough mass margin that this could be re-imagined as a mission with a more capable rover telerobotically operated by the crew in the EAM. After the initial mission, the long lived rover could continue to rove and be operated from the earth while the crew is absent using the EAM as a communication relay from the lunar farside. It could be possible for a rover of this nature to continue on to Shackleton and/or Amundsen after finishing Schrödinger traverses.

EM-5 – Orion with Commercial Resupply to EAM – With assets in place, it is now possible to provide resupply to the EAM. This could be commercial resupply launched on the SLS along with the Orion and crew. The concept we studied used a cargo module based on The Orbital Sciences Cygnus. The resupply could be used to extend the mission to 80 days, prepare for EM-6, and/or extend operations at the asteroid if warranted.

EM-6 – Humans to the Lunar Surface: In the current environment, it's likely that the lander will initially be provided by one of our international partners. The mission objectives are to provide lunar surface access for crew and cargo and to provide as much system reuse as possible. Subsequent missions to the

surface can reuse the same lander and Lunar Transfer Vehicle. [3] We envision refueling initially with propellant brought from earth and stored near the EAM. Eventually the propellant will be produced from ISRU plants on the lunar surface.

Beyond the proving ground – missions to Mars

Vicinity: The International space community has declared that our unified long term goal is for a human mission to Mars but major work remains to define how it will be done. Translunar infrastructure and heavy lift capability are key to this approach. Recent analysis has suggested that a habitat-based gateway in translunar space would be helpful as an assembly node for Mars and for many other missions. The moons of Mars would provide an excellent stepping stone to the surface. As a “shake-down” cruise before landing, a mission to Deimos or Phobos would test all of the systems except those needed to get to the surface and back. This test would provide confidence for the in-space transportations and crew habitat systems.

Conclusions - The ISS has established a firm basis for a vibrant exploration program with a proven management model and proven existing designs. A Deep Space capability based on ISS technology provides flexibility and is an enabling capability for key cost-reducing strategies:

- Mobility within the libration system
- Reuse of expensive spaceflight hardware
- Base for assembly of complex, deep space mission systems

International collaboration has been proven effective on ISS and could be improved and expanded for exploration. It appears that the US may embrace the International Space Exploration Coordination Group (ISECG) Global Exploration Roadmap (GER). We need to apply the lessons learned from the International Space Station program and the experiences of the current partnership

- Strong coordinated support from the associated transportation programs (Shuttle, Soyuz, Ariane, H2B)
- International partnership with strong political support
- Adequate funding to accomplish the objective
- Agreements on hardware/software interface and construction standards

References: [1] Laurini K. (2014) Science Enabled by Crew and Infrastructure in the Lunar Vicinity, GER Workshop [2] Klaus K., Post, K.E. and Lawrence S. (2013) AIAA 2013-0436. [3] Raftery M and Derechin A. (2012) IAC-12- B3.1.