A Crewed Lunar Lander Concept Utilizing the SLS, Orion, and the Cislunar Deep Space Gateway

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Abstract **– As NASA focuses on Mars mission readiness, a crewed lunar lander concept may be timely, as there are both Mars exploration and lunar exploration motives for its development. A lunar lander can be used as a Mars lander technology demonstrator, including demonstrating technologies used in the final phase of Mars descent/landing, as well as technologies/techniques for habitation and ascent to orbit. Utilizing the cislunar Deep Space Gateway and Space Launch System (SLS) transportation capabilities, the addition of a lander would enable international and scientific communities to explore the lunar surface**

The Boeing lunar lander concept supports a crew of four on a two week (one lunar day) surface sortie and is extensible to longer duration missions with the addition of separately delivered surface assets such as a mobile habitat. The lander is optimized to take advantage of the cislunar Deep Space Gateway architecture; the lander elements are delivered using the SLS Block 2 cargo launch capability and the SLS Orion/cargo co-manifest capability. Overall mass of the ascent module was minimized by allocating habitation and crew surface access functions to the descent module. Recurring costs were reduced by designing a reusable ascent module.

This paper will describe the lander design and operation concept, key trade studies and rationale for the selected options. Trade studies were conducted in areas such as spacecraft elements, engines, propellant, airlock, and life support subsystems. Analysis of the Deep Space Gateway orbit is discussed with respect to its compatibility with: a) surface landing operations, b) earth-to-orbit element/cargo delivery operations, and c) access to various lunar surface regions. The paper will show that use of the SLS, Orion and the Deep Space Gateway in support of a human lunar lander exploration architecture is feasible and practical and will explain how the design described can be extensible to future Mars lander designs.

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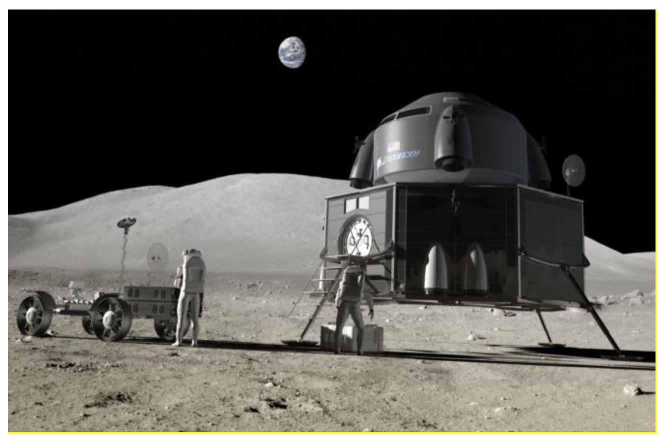

Figure 1 – Lunar Lander Sortie Spacewalk

1. INTRODUCTION & GOALS OF STUDY

Boeing recently developed a Lunar lander design concept (see Figure 1) with the intention of a) understanding how a lander interacts with and impacts the design of a cislunar Deep Space Gateway (DSG) and b) how a Lunar lander can, through extensibility, feed forward to an exploration architecture, including to a Mars lander. The study would determine the compatibility of the DSG architectures currently in development with human lunar exploration and investigate how a lunar lander can serve as a technology demonstrator and risk reducer for future Mars and Phobos/Deimos exploration. Accomplishing these goals required establishing a concept of operations, a functional analysis and allocation, a conceptual design, performance estimation, and assessments for extensibility.

2. STUDY CONSTRAINTS AND CON OPS

The exploration architecture makes use of NASA's proposed exploration element capabilities (see Figure 2), including the Space Launch System (SLS) Block 2 super heavy lift capability and the Deep Space Gateway as well as the Orion co-manifest launch capability. The SLS, Orion, and DSG-based architecture is fundamentally different from those of the Apollo and Constellation programs in that it makes use of the DSG in cislunar orbit.

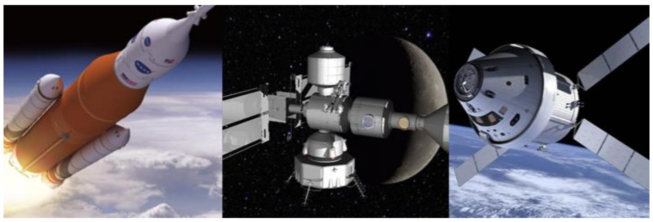

Figure 2 – Architecture Elements

In this architecture, the lander is subject to the DSG's chosen orbit for both its lunar surface departure and return rendezvous points, which has pro's and con's as described later in this paper.

The additional self-imposed constraints on the study were a crew of 4 (matching the exploration crew complement), and at least a 2-week sortie mission duration (i.e. make full use of a single lunar day). Based on analysis and critiques of heritage lander designs, Boeing also set goals to a) minimize the exit height from the vehicle for the surface walking crewmembers, b) minimize the intrusion of hazardous dust/regolith into the vehicle at the completion of a surface excursion, and c) make science and rovers accessible to the EVA crew from the surface without use of special/complex deployment systems.

Concept of Operations

The concept of operations involves delivery of the lander to the DSG either a) as an assembled vehicle onboard a SLS cargo mission, or b) delivered separately. If delivered separately, the ascent module (AM) could be co-manifested with Orion or delivered via a non-SLS launch vehicle; the descent module (DM) requires an SLS cargo launch.

Once in cislunar orbit, the lander elements would dock to the DSG (and to one another, in the case they are delivered separately). Later, when the crew arrives at the DSG, up to four crew enter the lander. The lander undocks, descends to the lunar surface and lands. After a surface stay of up to one lunar day (approximately two earth weeks), the crew boards the AM, ascends to the DSG, and docks. The crew can then return to Earth at the end of the mission in the Orion in the same manner as any other DSG-based mission.

Figure 3 – SLS Block 2 Launch Configurations

The largest contrast between this architecture's concept of operations and historical lunar surface architectures, including Apollo, is the use of the DSG as a staging area for joining the crew with the lander (see Figure 4). Utilizing the DSG as a staging base offers a number of benefits to the architecture when compared to the Apollo and Constellation architectures:

1. Delivery of the lander elements and the crew can be separated into different missions; the crew and lander can meet in cislunar orbit when it is operationally convenient. The crew and lander delivery missions require no special/unique operations concepts required beyond those used for typical crew transport and cargo resupply to the DSG.

2. A lander delivered separately from the crew is also not time-constrained for its arrival in cislunar orbit and thus can use a low energy transfer to arrive at the DSG. This can reduce the dV by around 2/3 (and a corresponding amount of propellant) to reach cislunar orbit.

3. DMs and AMs at the DSG can be refueled via propellant transfer through the docking interfaces. Propellant can be supplied by typical logistics vehicles, enabling use of larger and more capable landers (because not all propellant is required to be onboard the AM & DM at launch).

4. The AM can be reused for multiple missions; AMs can remain attached to the DSG and be refueled/refurbished/packed for the next mission.

5. Conceptual design and operations analysis indicates that utilization of the SLS and DSG may allow for double the crew and more than four times the mission duration when compared with an Apollo mission (i.e. 4 crew for 14 days vs. 2 crew for 3 days). When compared with an Apollo mission, this represents more than nine times the surface crew-hours per mission!

6. Lastly, the DSG orbit inclination can be adjusted to access various lunar surface landing sites efficiently (i.e. the lander does not need to provide propellant for an inclination change to access its intended landing site). The orbit used for the Boeing architecture assessments is a roughly equatorial 10,000 km circular distant retrograde orbit (DRO).

The primary penalty for utilizing the DSG as the lander staging base is the proposed DSG orbit (10,000 km DRO). When compared with Apollo, both descent and ascent require ~40% to 50% more dV. The Apollo architecture reduced the dV burden on the lander module (LM) by capitalizing on the huge quantities of propellant in the Crew Service Module (CSM) that enabled access to very low lunar orbits (e.g. 100 km x 17 km). The trade to utilize the DSG and thus allocate more dV/propellant to the lander, however, results in a superior architecture that is both more flexible and reusable. Note that the DSG orbit selected for this study was chosen, in large part, based on a constraint that the maximum duration of each active lander phase (ascent and descent) be less than 12 hours; The 12 hour maximum crew time in the AM was selected as a generally accepted NASA rule-of-thumb that minimizes the habitability equipment & associated mass/volume/resources required for spacecraft with longer transit durations.

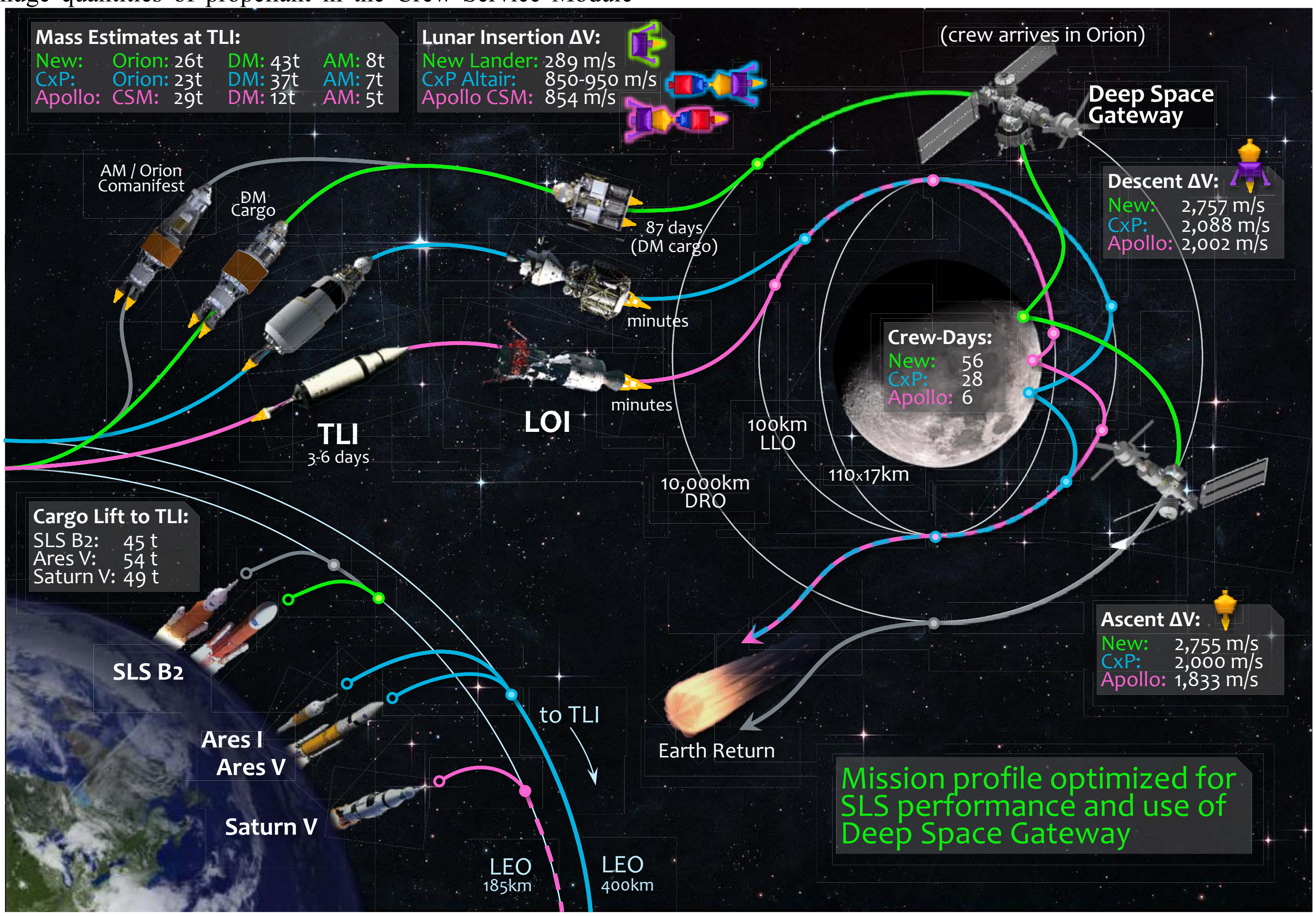

Figure 4 – Operations Comparison to Apollo & Constellation Architectures

3. System Description

Boeing's DSG-based Lunar Lander arrangement synthesizes multiple complementary features toward a compact and functional lander design. Key design goals achieved with this configuration include: 1) Internal habitat and airlock close to the lunar surface, improving surface access and protection, 2) Separated A/L volume arrangement mitigating dust/regolith accumulation and providing surface spacesuit stowage, 3) Common pressure vessel dome structures for mass efficiency and reduced complexity, and 4) Wide-base landing legs deploy to increase landing stability.

In order to maximize the mission capability of the architecture (i.e. crew surface time and science cargo delivered), a key focus of the Boeing Lunar Lander design concept was to minimize the mass returned to orbit following the lunar surface stay. Because this mass is delivered to the DSG, descended to the lunar surface, and returned to cislunar orbit, it has the largest propellant mass penalty of any portion of the architecture. This premise drove the function allocation to minimize the mass of the reusable AM and drove the long duration habitation and exploration functions into the DM (see Figure 5).

The AM (see Figure 6) is designed to provide short duration transit to and from the surface (<12 hrs) and is the reusable portion of the lander. This ~7.5 mt (wet) module is capable of transporting 4 crew and provides independent spacecraft functions such as GN&C, communications, avionics, ARPO, and docking. The AM's four peripherally mounted bi-prop engines allow for COTS-derived propulsion system thrusters and tanks, thereby reducing costs and improving safety; they also permit the AM configuration to incorporate centerline attachment of two passive IDSS-compatible docking adapters. One docking adapter is dedicated for attachment to the DSG; the other adapter is used for docking to Orion during comanifested delivery to the DSG and for attachment to the DM for descent and landing

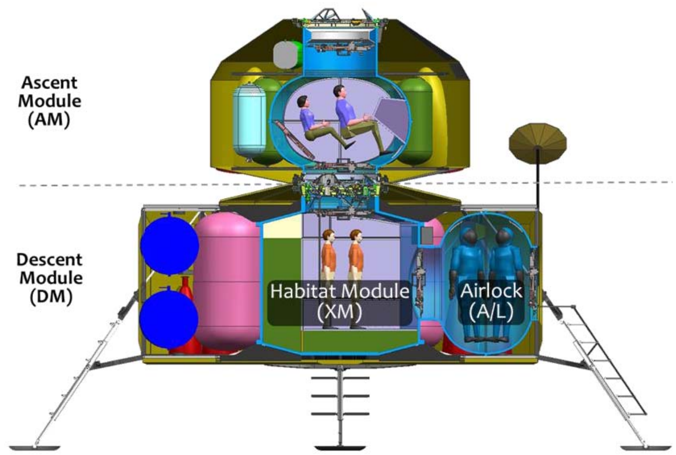

Figure 5 – Lander ModularConfiguration

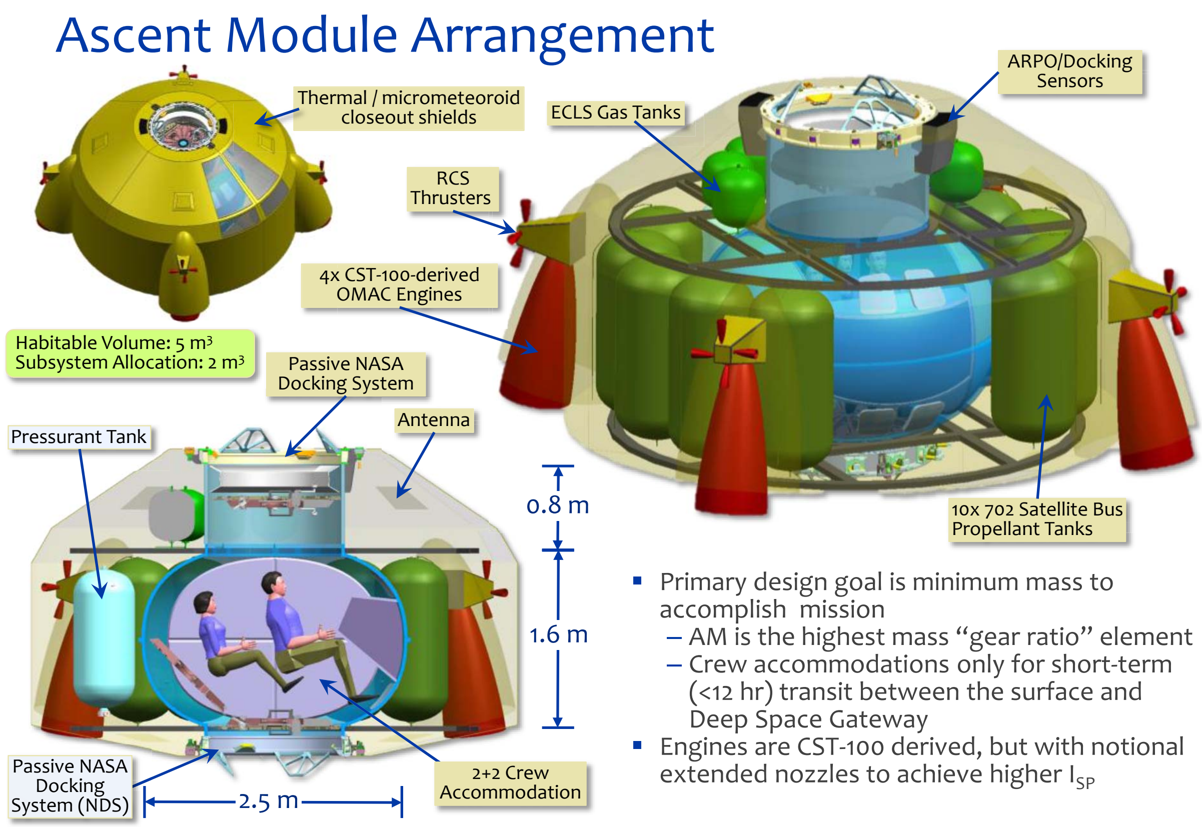

Figure 6 – Ascent Module Arrangement

The ~43.5 mt (wet) DM (delivered via SLS Block 2 cargo variant) includes: the Habitat Module (XM), the Airlock Module (A/L), propulsion, landing mechanisms, as well as independent spacecraft functions such as GN&C, communications, avionics, ARPO, and docking (see Figure 7). The DM provides power generation, storage, and distribution from TLI separation through the duration of the two week surface mission.

The DM also has provisions for delivering external payloads and surface equipment such as a lunar rover. It provides gas storage for life support including O_2 & N_2. The XM provides two weeks of life support including CO_2 removal & humidity control, inter-module ventilation, crew accommodations, sleep systems, galley, waste management, IVA science, and radiation protection. The A/L supports EVA accommodations such as spacesuits, pressure control, and umbilical interface (power/H2O). See Figure 8 for a description of the overall function allocation between modules of the lander.

Similar to the AM, the DM implements multiple peripherally-mounted inexpensive COTS-derived bi-prop thrusters and tanks. For the DM, they provide the additional benefits of enabling the thruster outlets to remain within the outer mold line (OML) of the DM, which permits the use of short landing legs and offers the lowest and safest possible spacewalk hatchway exit height. This configuration also allows for a simple XM structure with a centerline-mounted docking system for attaching to the AM, without the intrusion of a large centerline-mounted engine.

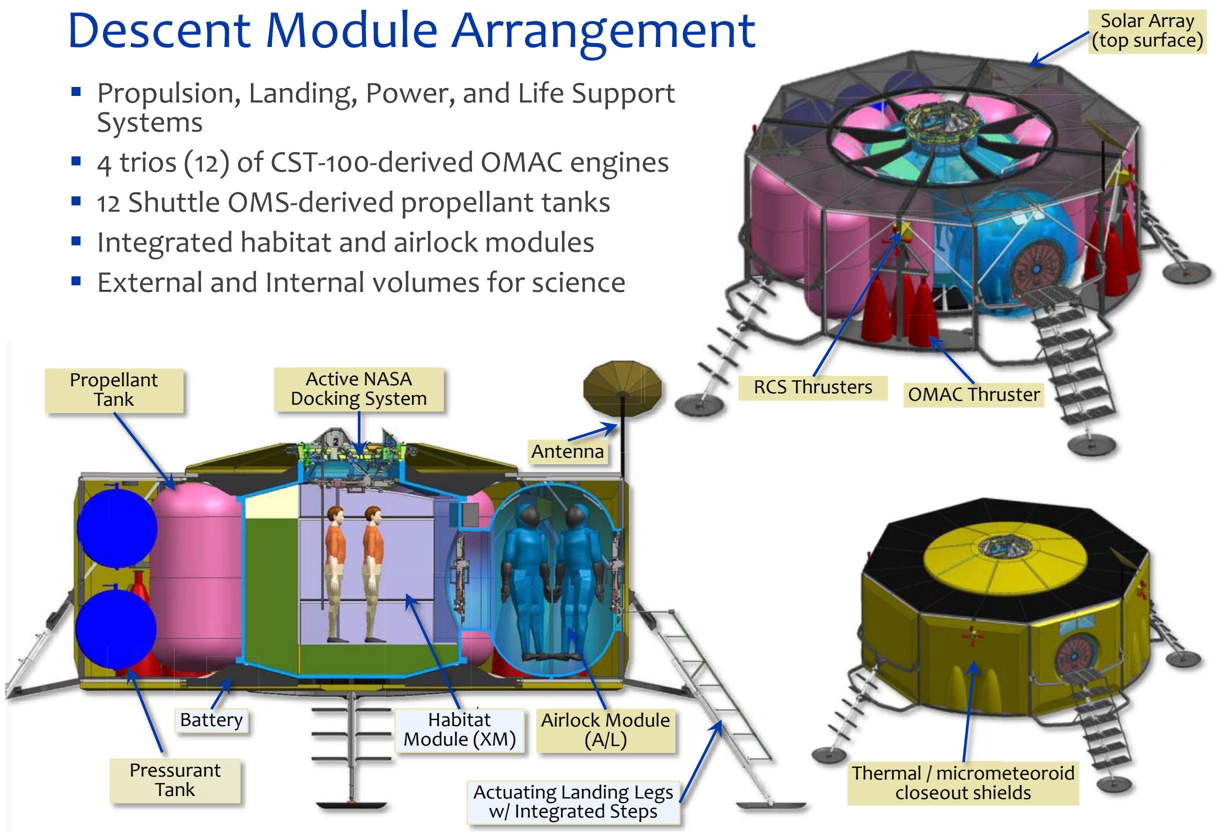

Figure 7 – Descent Module Arrangement

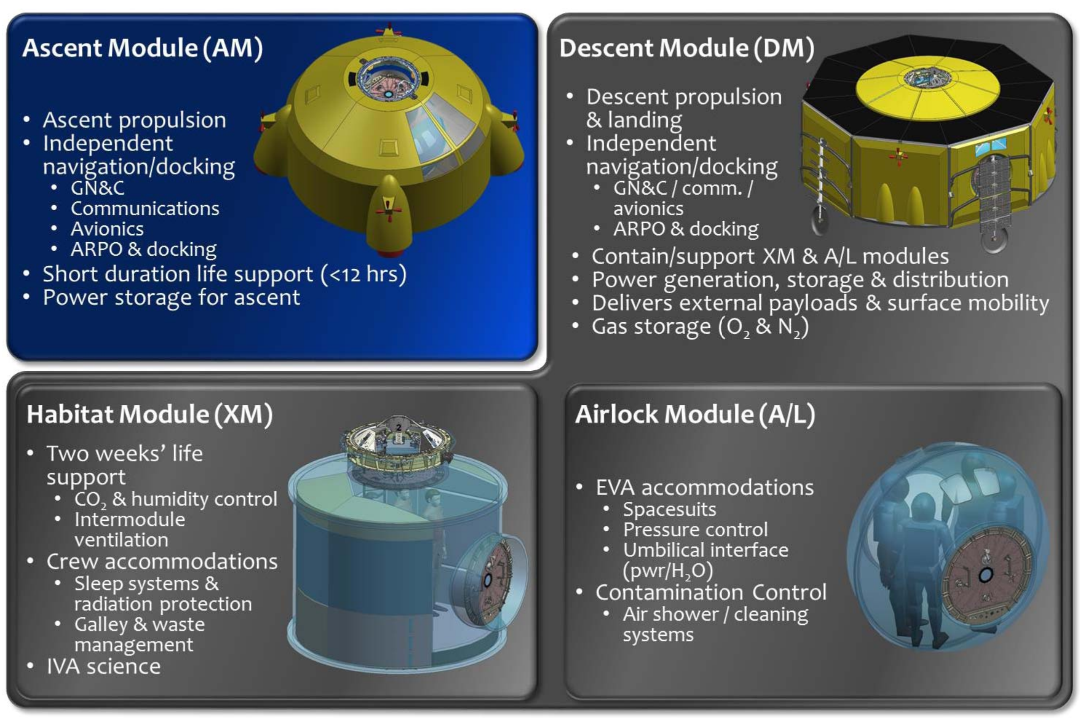

Figure 8 – Function Allocation between Modules

4. SURFACE OPERATIONS DUST MITIGATION

Historical evidence from the Apollo missions revealed the deleterious effects of lunar dust on spacesuits, hardware and operations[1]. The powdery dust is known to abrade spacesuit fabric, degrade thermal surface performance, interfere with seals and connectors resulting in pressure losses, and penetrate mechanisms causing degraded performance. Inside the lunar module, Apollo astronauts were exposed to this dust when they removed their dust coated spacesuits causing concerns for health. Consequently, NASA has identified dust as a critical environmental challenge to overcome for future lunar surface missions characterized by this dusty environment.

The Boeing lunar lander architecture incorporates a multi-tiered approach to minimize impacts due to dust contamination utilizing different passive and active techniques at various levels. Cleaning techniques are applied to reduce dust contamination during Extra Vehicular Activities (EVA) and to minimize dust entry into the habitat interior. The strategy incorporates three levels of dust mitigation:

I. Dust protection and cleaning during EVA to minimize dust accumulation on:
   a. Exploration spacesuits and
   b. Hardware exposed to lunar dust during EVA

The cleaning system for the exterior of the lunar habitat utilizes novel active electrostatic and passive coating techniques

II. Interior A/L cleaning and protection to minimize entry of dust into the habitable volumes

The cleaning system for the A/L utilizes active gas pressure cleaning methods. This allows further cleaning of exploration suits post EVAs and cleaning the A/L free of lunar dust

III. Interior Habitat Module cleaning

The cleaning system for the habitat interior incorporates air quality maintenance using air filters and dust particulate detection and monitoring system within the habitat volume. This system can be extended into the AM to maintain clean air.

Novel Dust Technology for Exploration Suits and Exterior Surfaces

Exploration spacesuits may utilize the SPacesuit Integrated Carbon nanotube Dust Ejection/Removal (SPIcDER) system that can autonomously repel dust to protect spacesuits and similar flexible surface structures from lunar dust [2] [3]. This system has dual action 1) to prevent accumulation of dust particles and 2) to repel dust particles that may have already accumulated on the spacesuit surface.

SPIcDER comprises specialized design for autonomous dust cleaning of flexible surfaces. Simplified version of SPIcDER is suitable for cleaning rigid surfaces (ex: solar cells, thermal radiators, optical surfaces). Developed at the Boeing Company, SPIcDER leverages the efficient Electrodynamic Dust Shield (EDS) concept which was developed at NASA for use on solar cells and rigid surfaces[4]. The SPIcDER system utilizes parallel conductive yarns made of Carbon nanotube (CNT) flexible fibers embedded into the outerlayer of the spacesuit. The CNT yarns are energized with a multi-phase AC voltage signal ('cleaning signal'), which forms a travelling wave of electric field around the spacesuit surface that levitates and repels dust particles away from the proximity of the active area of the fabric (See Figure 9). The result is a self-cleaning spacesuit that can repel lunar dust. Cleaning can be further optimized by adding a passive coating such as the Work Function Match Coating (WFM)[5]. An equivalent construction can be made on rigid surfaces. The SPIcDER concept (for flexible surfaces and rigid surfaces) applies electrostatics and dielectrophoretic forces to levitate and repel both charged and uncharged dust particles, thus making it an ideal choice for lunar dust mitigation.

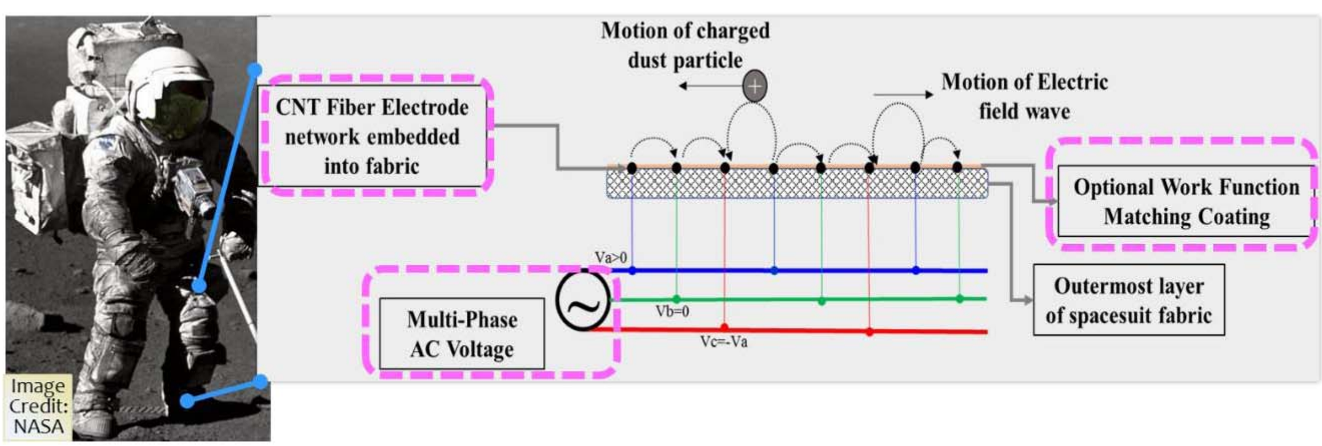

Figure 9. Schematic of SPIcDER Operations

Interior Dust Cleaning and Protection

The A/L within the architecture provides an independent volume separate from the main habitable volume. This allows for efficient management of regolith and dust contamination. Residual dust that remains on spacesuits and/or equipment entering the A/L after EVAs, will be further cleaned utilizing the A/L integrated air shower and a dedicated vacuum cleaner. The air shower can feature directional jets. The air shower system can be integrated into a partitioned decontamination zone within the A/L. This zone, dedicated for cleaning operations, can include a grated floor with filters under the grate to collect the dust. In addition, the interior surfaces of the airlock can be coated with WFM coating or similar dust repellent passive coating to minimize adhesion of dust to the surfaces. The separation of the A/L volume from the main habitat reduces air loss and inhibits the dispersal of lunar regolith contamination into the modules. Filtered air is resupplied to the main habitable volume upon depress. Air filter mechanisms such as the electrostatic precipitator can be applied to further clean the air entering the habitable volume. Controlling airflow with pressure differentials can provide an additional means to prevent dust from entering the habitat. Implementation of dust particulate monitoring within the habitable volume would further contribute to astronaut safety.

All systems within the Boeing lunar lander that may be exposed to lunar regolith, both exterior and interior to the lander are designed to be easily cleaned after operating in the dusty environment. The multi-tiered dust control and cleaning approach described above can help alleviate dust contamination problems during surface operations for the Boeing lunar lander architecture concept (See Figure 10).

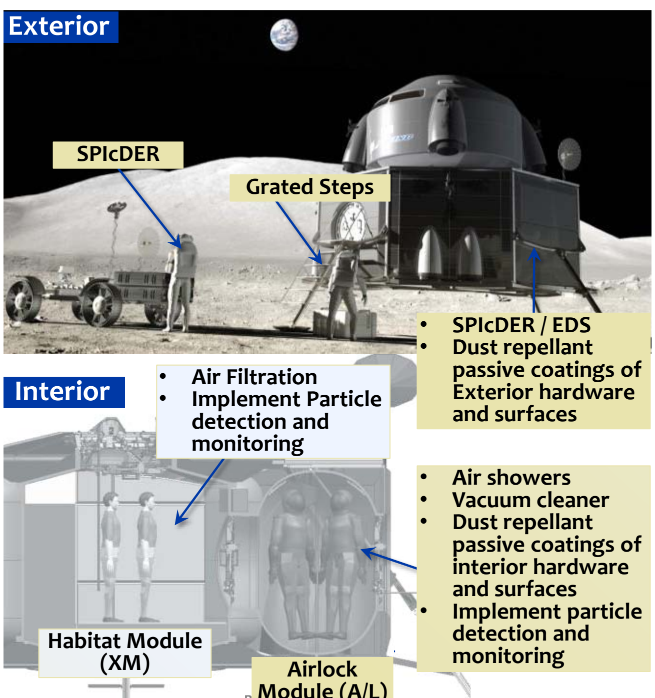

Figure 10 - Proposed surface dust control strategy for the Boeing lunar lander concept

This multi-tiered approach built into the architecture minimizes the adherence of lunar dust to spacesuits/ exterior surface hardware, minimizes dust entry into the habitable volume, and reduces astronaut exposure to dust. The Boeing lunar lander architecture recognizes the benefit of combining several dust cleaning technologies in a multi-tiered approach during various levels of the operational timeline which is inspired by the layered approach proposed by NASA[6].

Finally, with a multi-year lifetime, it is particularly important to keep lunar dust from getting to the DSG. These multiple layers of dust mitigation, keeping as much dust as possible outside the vehicle and capturing the dust that does enter the vehicle, minimize the chances of carrying dust into the Ascent Module and ultimately, to the DSG.

5. Extensibility

Lunar Global Access

This Lunar Lander study architecture was based on a single, roughly equatorial, DSG cislunar orbit (10,000 km DRO). This orbit is optimally suited for landing within +/- 10 degrees of the lunar equator, but not for accessing the scientifically interesting and potentially useful (from an In-Situ Resource Utilization (ISRU) perspective) lunar poles. Gaining accessibility to more of the lunar surface can be accomplished with additional dV/propellant in the lunar lander DM & AM (see Figure 11), but these changes in this particular lander concept would exceed the SLS launch mass limitations. A promising alternative, however, is to select a favorable cislunar orbit/inclination for the DSG to achieve a particular desired landing site. Assuming Orion can access the favorable orbit, the lunar lander design/architecture could remain the same while accessing scientifically important zones of the lunar surface. Use of the DSG's highly efficient solar electric propulsion for the orbit changes is also far more launch mass efficient overall vs. utilizing the hypergolic propellant in the lander to achieve the desired landing site. Additional mission design analysis is recommended to further develop this concept.

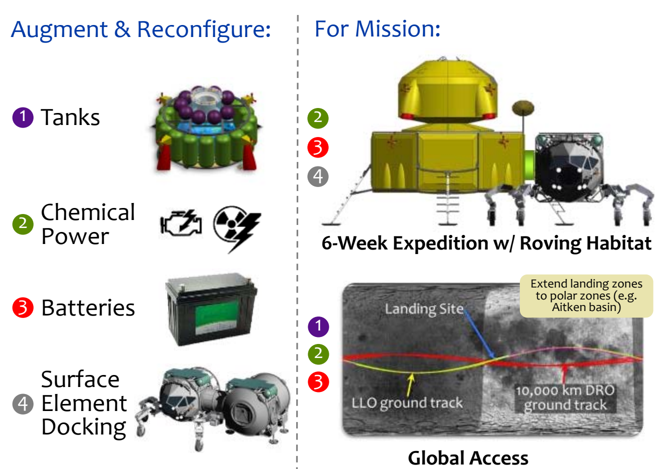

Figure 11 – Lunar Mission Extensibility

Another consideration for surface missions in scientifically interesting locations, such as the Aitken Basin, that put the lander in shadow is power generation needed for life support, heating, lighting etc. The power generation could be accomplished from a variety of means, including chemical-based and nuclear-based generators delivered to the landing site separately.

Mars Lander

Arguably the most important element of a lunar lander design concept is its use as a demonstrator and proving ground for extensibility to a Mars lander. Humans haven't landed on another celestial body in nearly 45 years, and the systems and operational concepts of doing so could be invaluable in mitigating risks associated with the early Mars surface missions. To that end, designing a lunar lander that is extensible from a design and operations perspective to a Mars lander is a focus of the Boeing architecture. Figure 12 depicts the Mars Lander design concept on the Martian surface; the reader will notice it has no externally visible differences from the Lunar version.

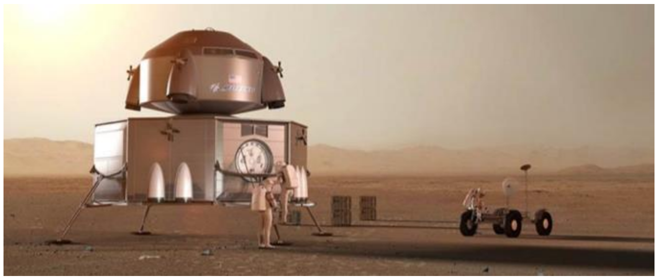

Figure 12 – Mars Lander Sortie Spacewalk

There are a handful of fundamental differences in a lunar landing compared to a Mars landing that need to be accounted for, including aerodynamics/drag, orbits and dV, solar/thermal environments, and surface stay duration. Boeing's concept utilizes the same structures, mechanisms, avionics, habitability systems, EVA systems etc. etc., but modifies the key subsystems affected by the fundamental mission differences.

Figure 13 – Mars Lander within a Decelerator

For Mars descent/landing, the lander utilizes an aerodynamic decelerator with retro-propulsion to achieve ~95% of the entry dV (see Figure 13).

In comparison with the lunar lander, this reduces the required lander descent module propellant and provides available volume that could potentially be used to expand the habitat, add electrical power generation, or to increase unpressurized storage capacity (see Figure 14).

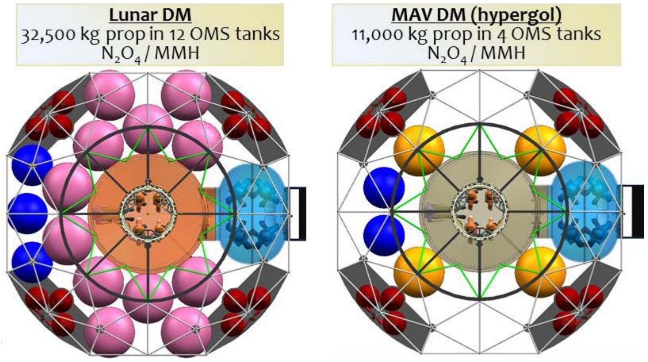

Figure 14 – Lunar vs Mars Descent Propellant Load

Mars ascent, on the other hand, requires more dV than in the lunar case and requires additional propellant tankage; extensibility to this extra tankage configuration was considered (i.e. protected for) in the development of the lunar lander's secondary structures and outer mold line etc. (see Figure 15)

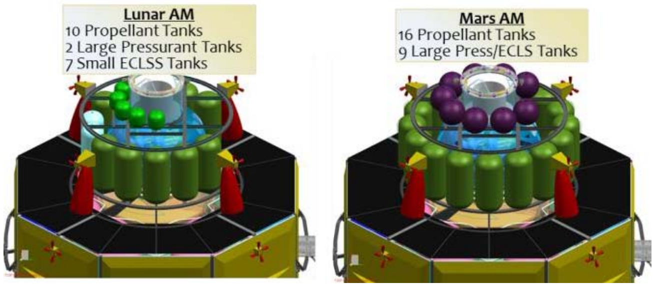

Figure 15 – Lunar vs Mars Ascent Propellant Load

Thus, for a relatively short duration Mars sortie, the only major differences between the Mars lander design and the Lunar lander design concept is the number and configuration of propellant tanks and the addition of a decelerator. Reuse of critical systems between Lunar and Mars missions increases their predicted reliability and reduces overall mission risk and improves crew safety. This use of proven technology also allows early explorers to prove out ISRU techniques to enable future missions to reduce costs by, for example, generating oxidizer from the Martian atmosphere.

This use of the lunar lander as a technology and operations demonstrator for Mars missions highlights that a lander vehicle has significant value in one of the primary roles of the DSG, which is to serve as a technology demonstration platform and to mature technologies and thereby reduce Mars mission risks. Demonstrating and perfecting the operations and systems involved with landing, ascent, surface habitation, spacewalks, and even science system operations are likely all to be valuable towards increasing the likelihood of Mars mission success and improving crew safety.

Phobos or Deimos Interaction

Another possible extension of the Lunar Lander design could include a low gravity body interaction (e.g. for interacting with Phobos or Deimos). In this concept, a variant of the DM is prepositioned on the low-G surface before crew arrival and uses special surface attach features in place of typical landing pads (see Figure 16). Once the crew arrives in a nearby orbit (e.g. Mars orbit) along with a variant of the AM; the AM is used as a short-duration taxi to access the pre-positioned DM. The AM docks to the DM in the low-G environment similar to a visiting vehicle docking to the ISS.

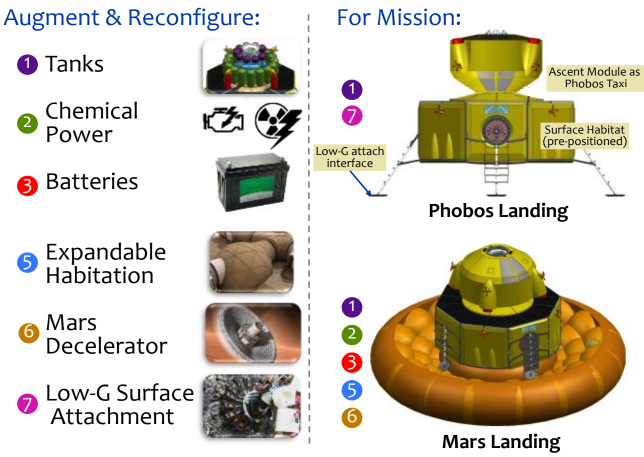

Figure 16 – Mars Mission Extensibility

6. DSG Design Implications

A primary purpose for the Boeing Lunar Lander architecture study was to determine the implications for the DSG to support a reusable lunar lander and ensure that the DSG mission, design and operational features support both robotic and crewed lunar access (see Figure 17).

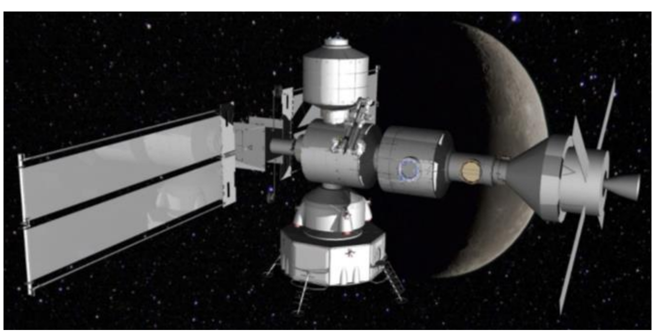

Figure 17 – Lunar Lander attached to a DSG Concept

Some early conclusions included: 1a) the DSG docking system at one (or more) radial port should have active soft capture and hard capture to allow a lower-mass passive docking system on the lander, 1b) the DSG active docking port should have propellant transfer to an attached reusable lander module, 2) Worst case total DSG mass to assume (for GN&C purposes) should including AM/DM masses and could be >75 mt. (without Orion), 3) Lander AM is likely parasitic to DSG for power while docked, 4) DSG should store/process lunar surface samples with some volatiles, possibly requiring cryogenic storage (-140°C), and 5) Provisions in DSG should demonstrate tele-robotic operations to lunar surface satisfying Mars proving ground objective. Additionally there are DSG and/or lander modifications needed to support polar lunar landing site access. These modifications could include either DSG transit capability to access favorable lunar orbit (e.g. polar), or support lander DM refueling for additional dV.

7. Conclusions & Future Focus Areas

This Boeing study demonstrated the compatibility of a DSG-based architecture with human lunar exploration and highlighted some key benefits of use of the DSG. The study also revealed the benefits of a lunar lander vehicle for use in developing future Mars and Phobos/Deimos exploration capabilities. Further human lander work in the areas of lunar global access and more detailed assessment of the potential for Mars exploration extensibility are recommended.

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Biography

Matthew Duggan *Matthew Duggan graduated in 1988 from Texas A&M University with a BS in Mechanical Engineering and in 1990 from Texas A&M University with a MS in Mechanical Engineering. In 1990, be began work developing assembly and activation procedures for the International Space Station (ISS). In 1997, he joined The*

Boeing Company to continue preparation for the assembly of ISS and became a Mission Evaluation Manager responsible for leading operations in the ISS Mission Evaluation Room. In 2005, he became the ISS Mission Operations manager, responsible for leading real-time, on-orbit sustaining engineering support to the ISS. At Space Shuttle retirement in 2011, he was named the ISS Systems Integration manager, responsible for leading ISS technical integration across all ISS system teams. In 2013, he became the ISS Integrated Analysis manager, responsible for structural, thermal, electrical, life support, avionics and human factors analysis for the ISS program and also started leading deep space exploration projects. Currently, he is the Boeing Manager for Exploration and leads advanced development projects on extending human presence to cislunar space and Mars with focus on mission architectures, international cooperation and enabling technologies.

James Engle *graduated in 1986 from Brigham Young University (BYU) with a BS in Mechanical Engineering and in 1992 from Cal-State University at Long Beach (CSULB) with a MS in Mechanical Engineering (Management Option). In 1987 he began work for Rockwell Space Transportation Systems in Downey, California on the Space Shuttle Program. In 1992 James transferred to Florida and in 1996 became Manager of the Advanced Software and Technology Applications group for Shuttle improvements and new vehicle/systems development. In November of 2000 he became Director, SE&I for Boeing Florida Space Shuttle Operations. He transferred to Houston in January of 2005 to become Deputy Program Director for Shuttle Program Integration and later was SE&I Manager for Boeing's Space Exploration Division. He was the SEIT lead for the ISS Docking Hub and bus study. In 2011 he became Chief System Architect for the Docking Systems Program and additionally leads cislunar habitation studies.*

Travis Moseman *graduated in 2003 from Texas A&M University with a BS in Mechanical Engineering. Travis joined the NASA Johnson Space Center Safety & Mission Assurance directorate in 2004, where he performed systems engineering and safety assurance tasks for various Space Shuttle, ISS & Constellation program flight hardware projects. In 2013, Travis followed behind the transition of the NASA Docking System to join the Boeing team. With Boeing, Travis performed the systems safety engineering analysis for the International Docking Adapter and led the NASA Docking System Block 1 design and analysis teams through the five Design Analysis Cycles leading up to the Critical Design Review. He currently performs systems integration functions on a variety of Boeing design trade studies in addition to his duties as a member of the ISS system safety analysis integration team.*

Kavya K. Manyapu *graduated in 2006 from Georgia Institute of Technology with a BS in Aerospace Engineering, 2010 from MIT with a MS in Aeronautics and Astronautics and 2017 from University of North Dakota with a Ph.D. in Aerospace Sciences where she worked on novel technologies for lunar planetary spacesuits and dust mitigation. She currently works on the CST-100 Starliner program in Flight crew operations and testing leading Ascent and Entry suit integration and Human in the loop verifications tests. Kavya has also led the Pad Abort flight test integration for CST-100. She is certified as an ISS Mission Evaluation Room (MER) Duty officer and supports ISS on-orbit operations. She previously worked at Lockheed Martin on the Orion-Constellation program leading integrated analysis of the Orion system with the Altair lunar lander and other constellation systems.*

Xavier Simón *graduated in 1994 from the University of Virginia with a BS in Aerospace Engineering, followed by a MS in Aeronautical Science from Embry-Riddle Aeronautical University in 1996. He began his engineering career in 1992 as a conceptual designer of wing-in-ground-effect aircraft with Aerocon Incorporated. In 1996, Xavier joined the Lockheed Martin Skunk Works as the configuration design engineer for the X-33 Technology Demonstrator and various X-33 derivative proposal opportunities. In 2003, Xavier joined Boeing Advanced Space Exploration to lead the configuration design of the Orbital Space Plane commercial spacecraft project and later the Boeing/Northrop Grumman Crew Exploration Vehicle. Since 2009, Xavier has been the Technical Lead Engineer for configuration and outfitting of the Boeing CST-100 Starliner commercial human spacecraft, from defining the early arrangements to leading the design team through subsystem layouts and current problem-solving of system-level vehicle design challenges.*