Radiation Detection and Dosimety Workshop

John Connolly
Manager, Lunar Lander Pre-Project
CxPO/Advanced Projects Office

CONSTELLATION

Topics

- ESAS Architecture
- Changes Since ESAS
- Lunar Sortie Design Reference Mission
- Lunar Outpost Design Reference Mission
- The Radiation Risk Challenge

Immediate Answers to Big Questions

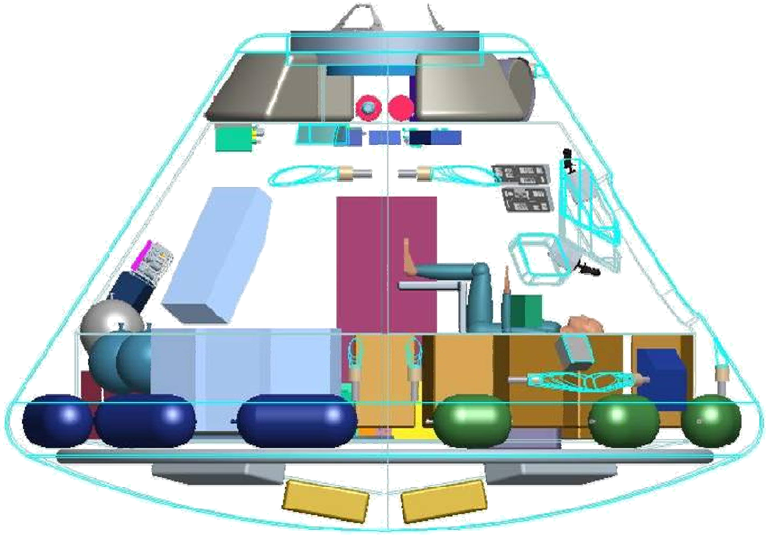
ESAS was chartered by the NASA Administrator to answer 4 immediate questions:

- (1) Complete assessment of the top-level Crew Exploration Vehicle (CEV) requirements and plans to enable the CEV to provide crew transport to the ISS and to accelerate the development of the CEV and crew-launch system to reduce the gap between Shuttle retirement and CEV IOC.
- (2) Definition of top-level requirements and configurations for crew and cargo launch systems to support the lunar and Mars exploration programs.
- (3) Development of a reference exploration architecture concept to support sustained human and robotic lunar exploration operations.
- (4) Identification of key technologies required to enable and significantly enhance these reference exploration systems and a reprioritization of near-term and far-term technology investments.

CEV Overview - Crew Module

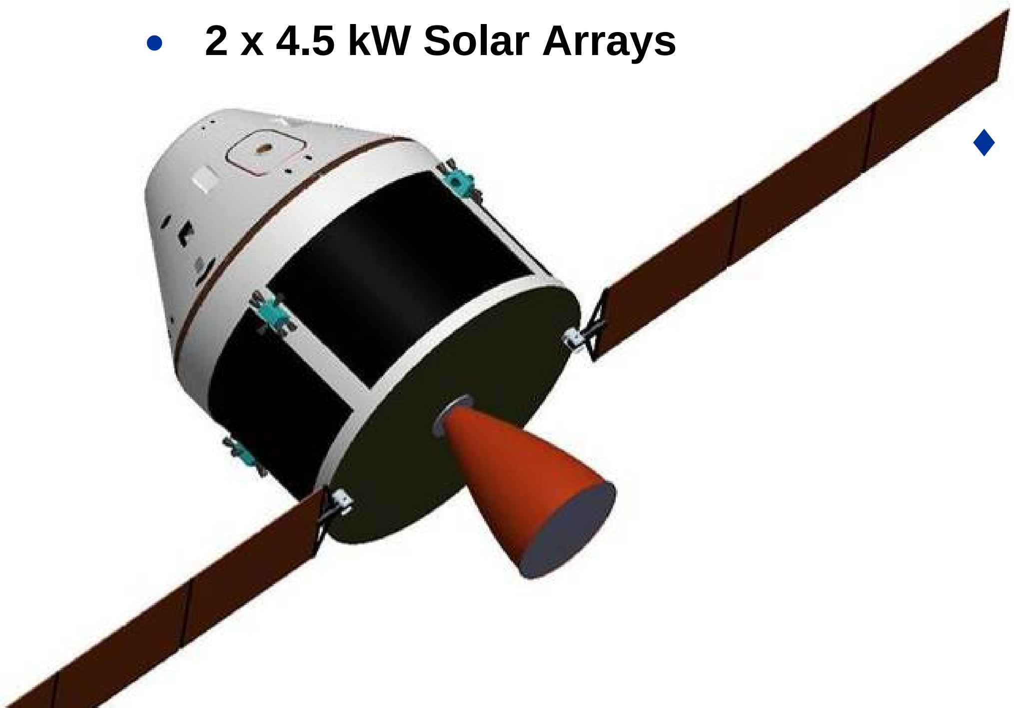
Functions

- CM attitude control propulsion (GO2/Ethanol)
- Docking system (LIDS)
- Contingency EVA
- Crew Accommodations
- Avionics: DMS, C&T, GN&C, VHM
- Life Support and Thermal Control
- Earth Atmospheric Entry and Recovery

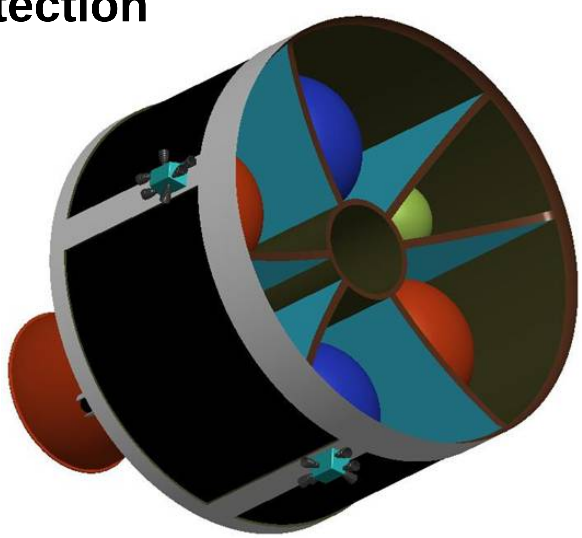


CEV Overview – Service Module

- **Avionics**
  - Health sensors, embedded processors
- **ECLSS/ATCS**
  - 60% propylene glycol / 40% H_2O single-phase fluid loop, 4 x 7 m^2 body-mounted radiator
- **Power**
  - 2 x 4.5 kW Solar Arrays



- **Propulsion**
  - 1 x 15,000 lbf pressure-fed LOX/Methane OMS engine @ 362 s Isp, 24 x 100 lbf Lox/Methane RCS engines @ 315 s Isp, Al-Li graphite wrapped Lox/Methane tanks @ 325 psia, He pressurization
- **Structure**
  - Graphite epoxy composite skin & stringer/ring frames construction
- **Thermal Protection**
  - Insulation

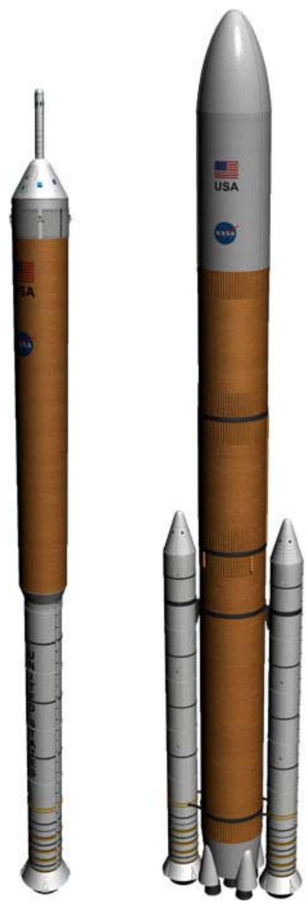


Launch System Selection

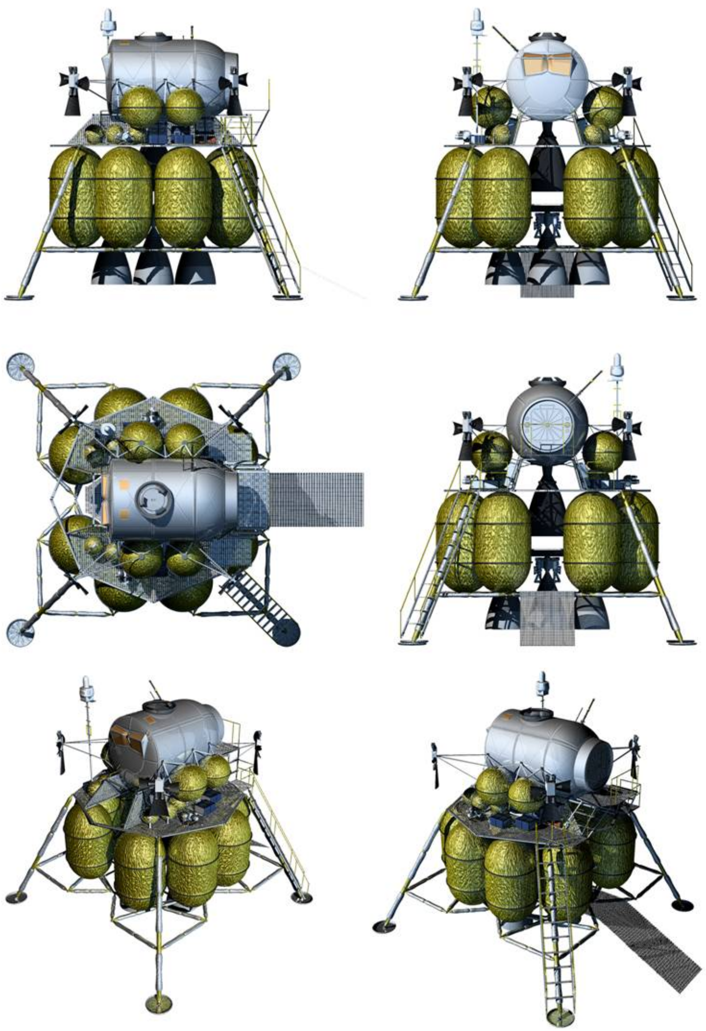
- **NASA will continue to rely on the EELV fleet for scientific and International Space Station cargo missions in the 5-20 metric ton range to the maximum extent possible.**
  - Commercial capabilities will be allowed to compete.

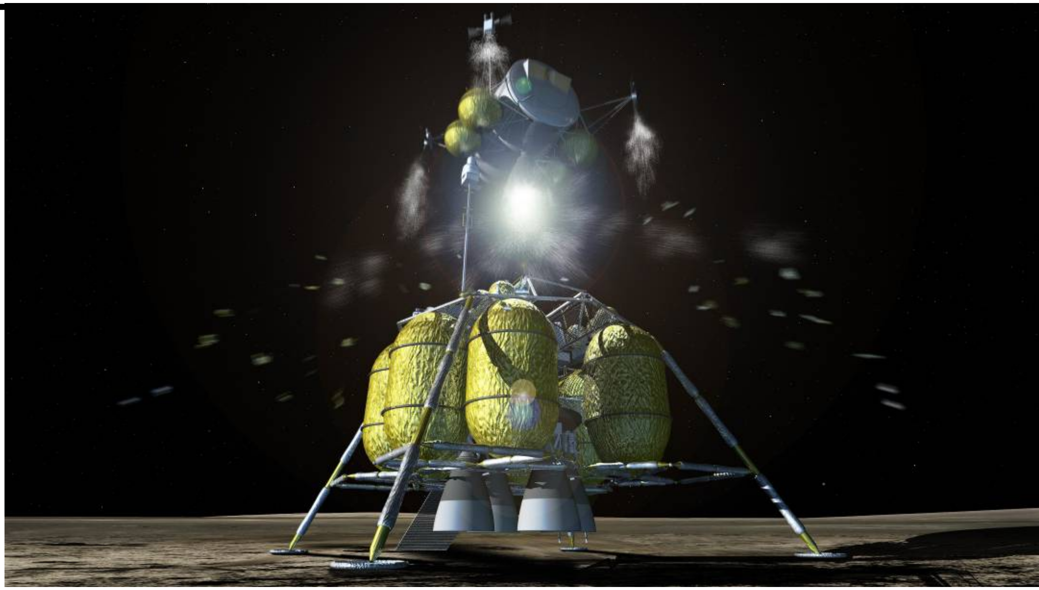
- **The *safest, most reliable, and most affordable* way to meet exploration crew launch requirements is a 25 metric ton system derived from the current Shuttle solid rocket booster and liquid propulsion system.**
  - Capitalizes on human rated systems and 85% of existing facilities.
  - The most straightforward growth path to later exploration super heavy launch.

- **125 metric ton cargo lift capacity required to minimize on-orbit assembly and complexity – increasing mission success**
  - A clean-sheet-of-paper design incurs high expense and risk.
  - EELV-based designs require development of *two* core stages plus boosters - increasing cost and decreasing safety/reliability.
  - Current Shuttle lifts 100 metric tons to orbit on every launch.



2-stage LOR LSAM with Single Crew Cabin and Integral Airlock



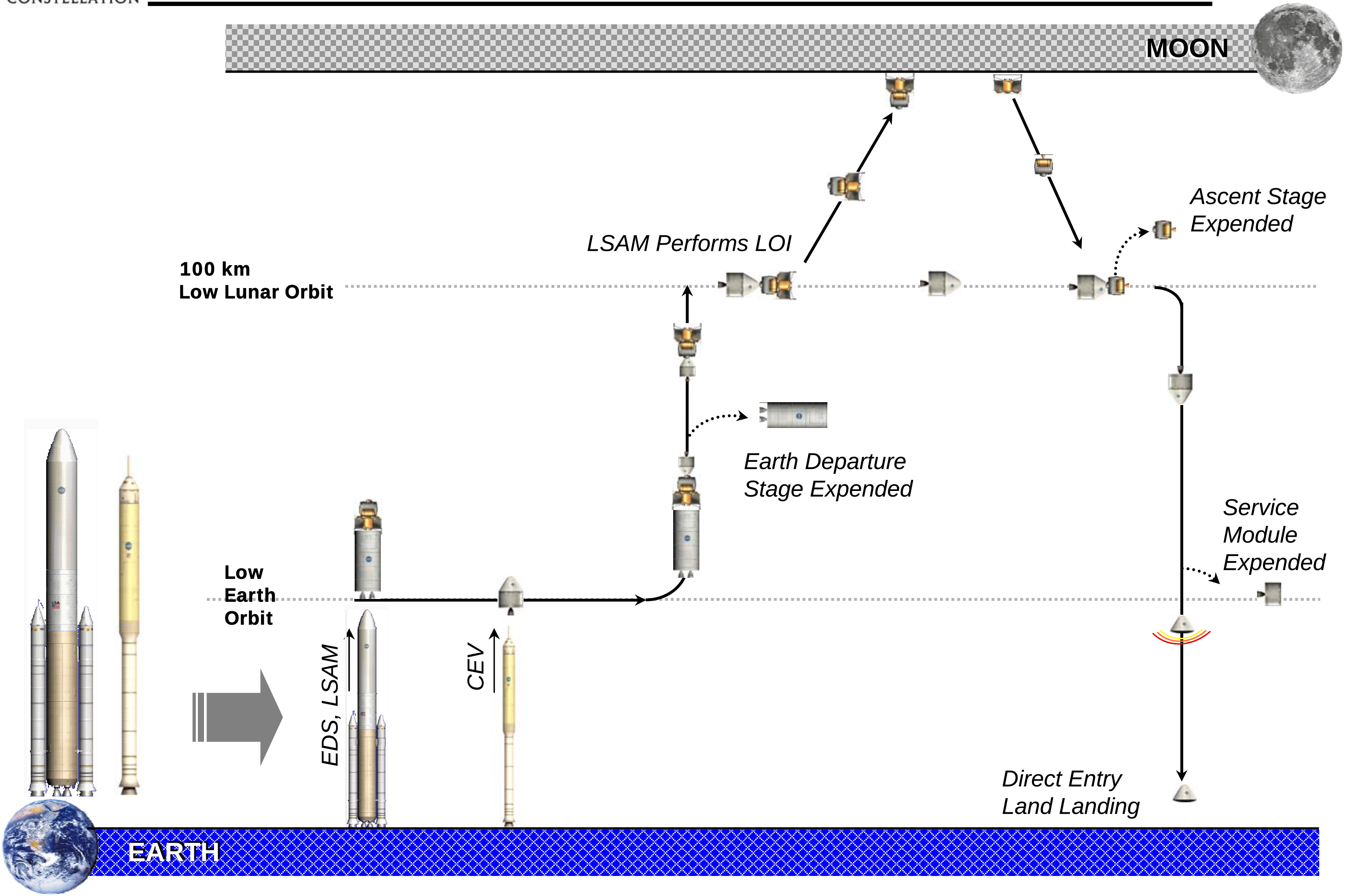


Lunar Surface Access Module (LSAM)

- 2-stage, expendable
- LOX/H_2 Descent Stage performs LOI, nodal plane change and lunar descent
    - RL-10 derivative throttleable engines
- LOX/Methane ascent stage
    - Same engine as CEV SM
    - ISRU compatible
- Single volume crew cabin with integral airlock
- 2700 kg + cargo capability

“1.5 Launch” EOR-LOR

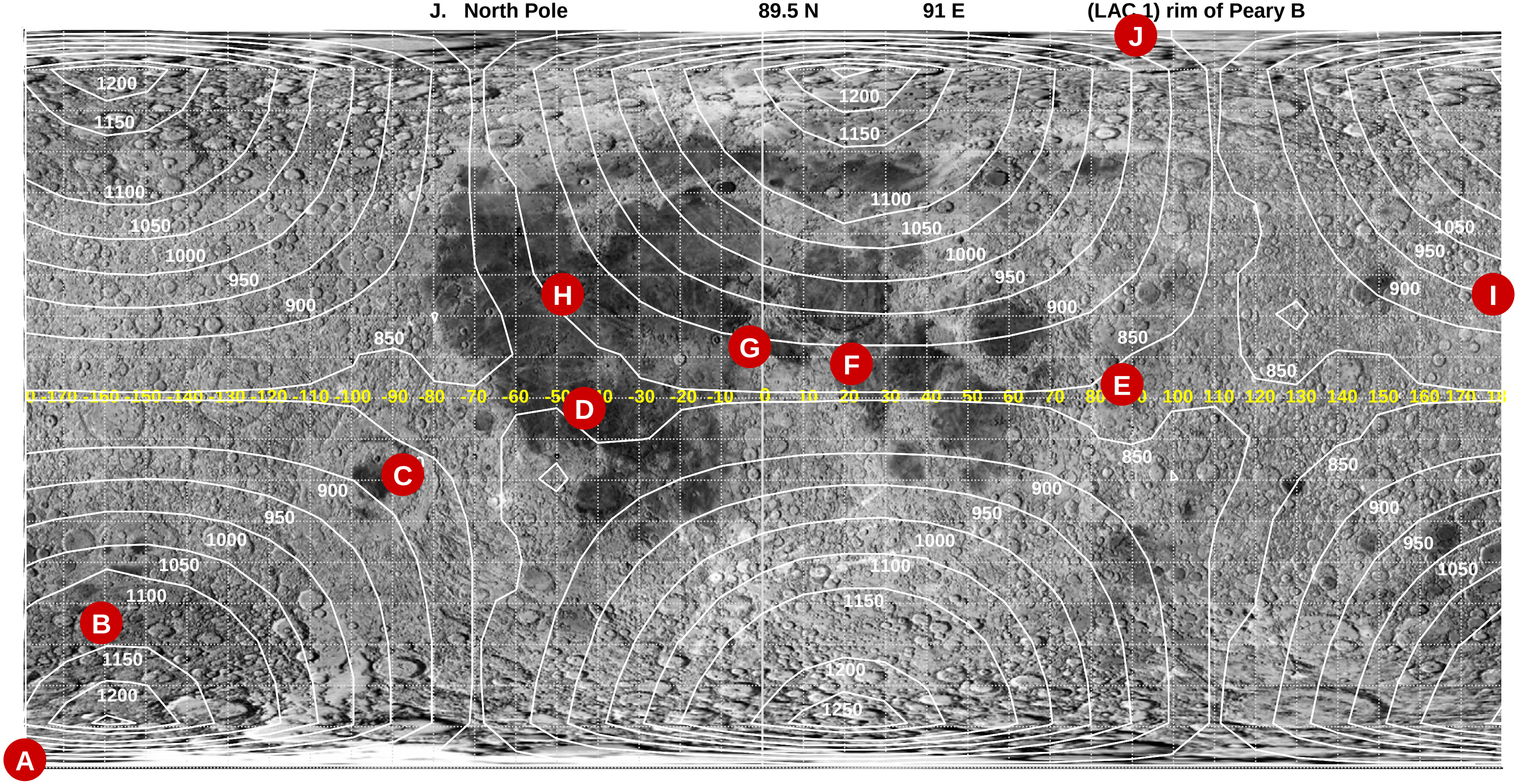
Vehicles are not to scale.



Potential Lunar Exploration Sites

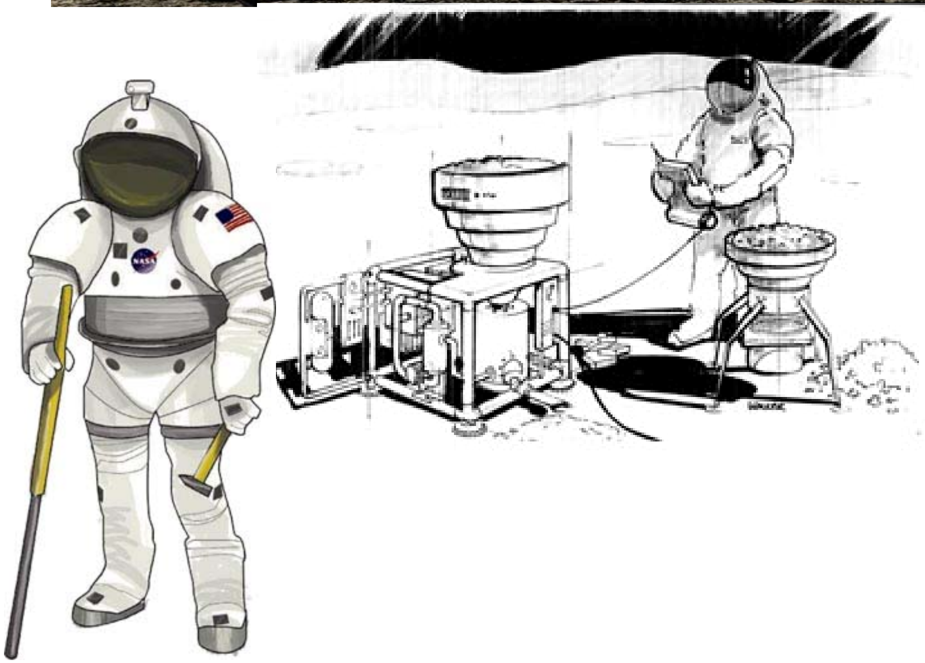
NOTE: Contours represent LOI delta-V (m/sec) required to access that point on the lunar globe

Landing Site	Latitude	Longitude	Notes
A. South Pole	89.9 S	180 W	(LAC 144) rim of Shackleton
B. Far side SBA floor	54 S	162 W	(LAC 133) near Bose
C. Orientale basin floor	19 S	88 W	(LAC 91) near Kopff
D. Oceanus Procellarum	3 S	43 W	(LAC 75) inside Flamsteed P
E. Mare Smythii	2.5 N	86.5 E	(LAC 63) near Peek
F. W/NW Tranquilitatis	8 N	21 E	(LAC 60) north of Arago
G. Rima Bode	13 N	3.9 W	(LAC 59) near Bode vent system
H. Aristarchus plateau	26 N	49 W	(LAC 39) north of Cobra Head
I. Central far side highlands	26 N	178 E	(LAC 50) near near Dante
J. North Pole	89.5 N	91 E	(LAC 1) rim of Peary B



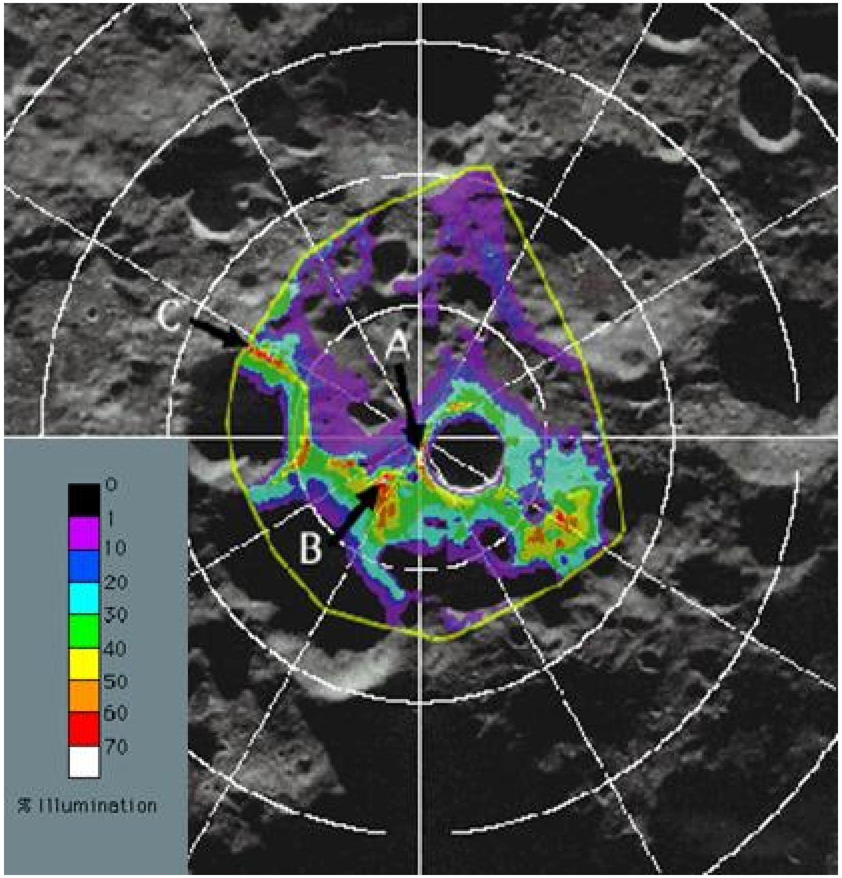
Lunar Sortie Crew Missions Surface Operations Concept

- Sorties do not depend on pre-deployed assets and can land at any location on the Moon
- Four crew members lives out of landed spacecraft for up to 7 days
- EVAs can be conducted every day with all crewmembers
  - Crew can work as two separate teams simultaneously
- Unpressurized rovers for surface mobility (2 for simultaneous but separate EVA ops) gives crew approximately 15-20 km range from lander
- Sortie mission surface activities focus on three activities
  - Lunar science (geology, geophysics, low frequency radio astronomy, Earth observations, astrobiology)
  - Resource identification and utilization (Abundance, form and distribution of lunar hydrogen/water deposits near lunar poles; geotechnical characteristics of lunar regolith)
  - Mars-forward technology demonstrations and operational testing (autonomous operations, partial gravity systems, EVA, surface mobility)



Candidate Lunar Outpost Site - Lunar South Pole

Lunar South Pole (from Bussey et al, 1999)

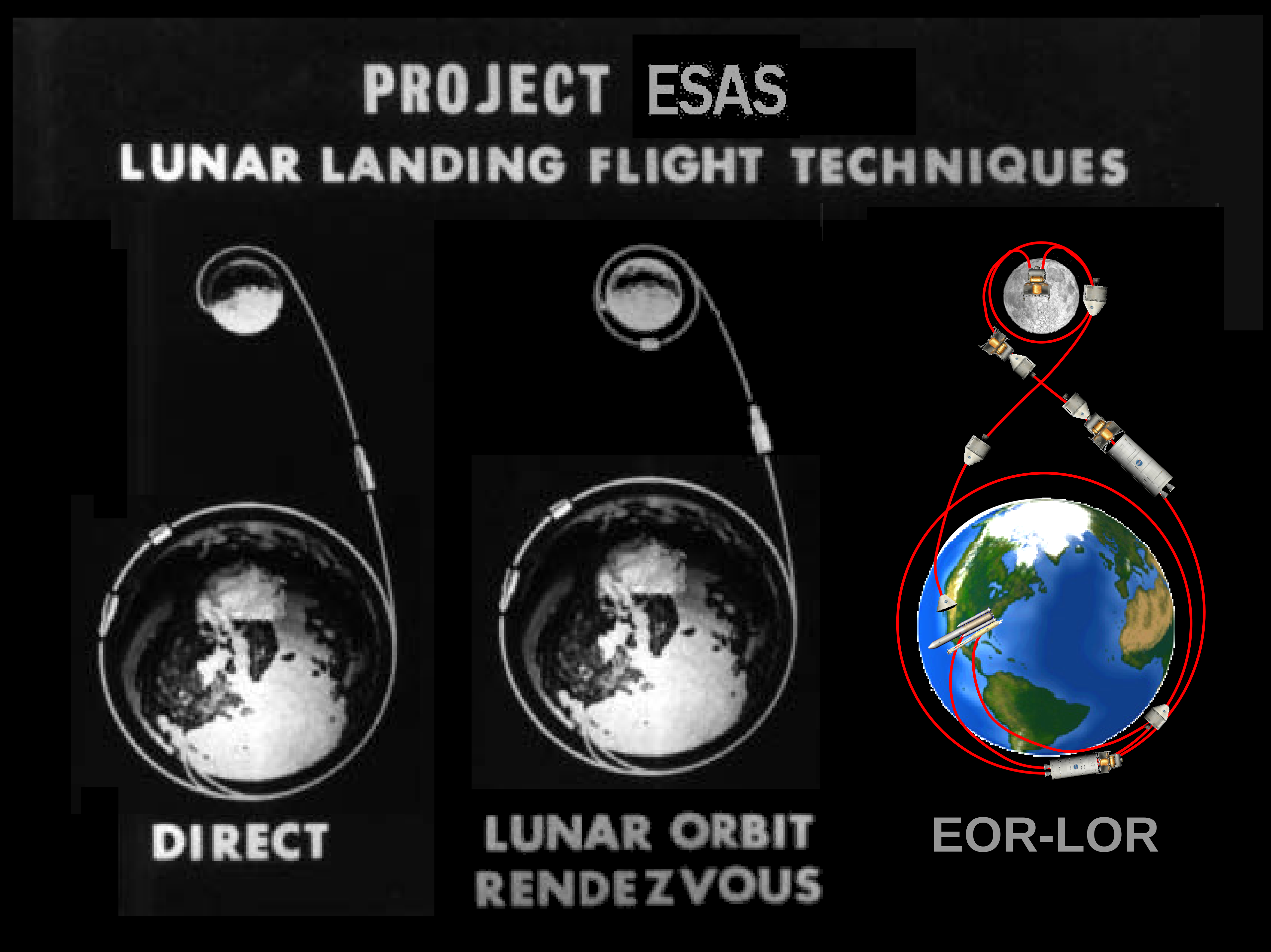


Robotic Lunar Exploration Program (RLEP) must answer the open issues with the lunar south pole

- **Advantages**
  - Lunar South Pole is a candidate for outpost site based on its greatest 'potential' over other sites
  - Elevated quantities of hydrogen, possibly water ice (e.g., Shackelton Crater)
  - Areas with greater than 50% sunlight
    - Area (A) exists with approx. 80% illumination, with the longest darkness period of approximately 50 hours
    - Areas B and C have more than 70% illumination, with longest dark periods of 188 and 140 hours, respectively
  - Less extreme diurnal temperatures
    - Avg. for sunlit areas -53 °C ± 10 °C
    - Avg. for shadowed areas -223 °C(?)
- **Disadvantages**
  - Undulating highland terrain (e.g., Apollo 16)
    - Outpost layout, ISRU
  - Extreme environment in shadowed craters
    - Operating machinery at -223 °C
    - Nature of 'frozen' regolith
  - Low sun angle, long shadows
  - No constant line of sight communications with Earth

Architecture Recommendations

- **CEV**
  - 5.5 meter diameter blunt body, Apollo-derivative capsule
  - 32.5 degree SWA
  - Nominal Land Landing (Water Back-up) Mode
  - CEV Reusable for 10 Missions, Expendable Heatshield
  - Pressure-fed LOX/Methane SM propulsion, sized for lunar mission (1450 m/sec TEI ΔV)
- **Crew Launch Vehicle**
  - 4 Segment RSRB
  - 1 SSME Upper Stage
- **Cargo Launch Vehicle**
  - Shuttle-derived, in-line ET-diameter with 5 Block II SSMEs
  - 5 Segment RSRBs
  - Upper Stage/ Earth Departure Stage w/ 2 J-2S+
- **EOR-LOR Mission Mode, “1.5 launch”**
- **Global Lunar Access with Anytime Return**
- **South Pole Lunar Outpost Using an Incremental Build Approach**
- **2-stage LSAM**
  - LOX-Hydrogen descent propulsion (1100 m/sec LOI + 1850m/sec Descent ΔV)
  - Pressure-fed LOX-Methane ascent propulsion
  - Airlock
  - Up to 7 day surface sortie capability


PROJECT ESAS
LUNAR LANDING FLIGHT TECHNIQUES
DIRECT
LUNAR ORBIT RENDEZVOUS
EOR-LOR

ISS – Moon – Mars Architecture Linkages

- 3 to 6 crew + payload
- Crew rotation
- ISS cargo

Crew Exploration Vehicle

- 4 crew
- Earth-moon transfer

- Mars 6 crew departure and return

- Safe crew launch

Earth-to-Orbit Transportation

- Safe crew launch
- Heavy Payload: 125mt
- Large Volume: 8m dia

- Safe crew launch
- Multiple, Heavy Payload Launches
- Large Volume Payloads

- Oxygen-Methane propulsion

Technology Maturation

- ISRU Systems
- Oxygen-Methane propulsion

- ISRU Systems
- Oxygen-Methane propulsion

- AR&D
- Autonomous operations

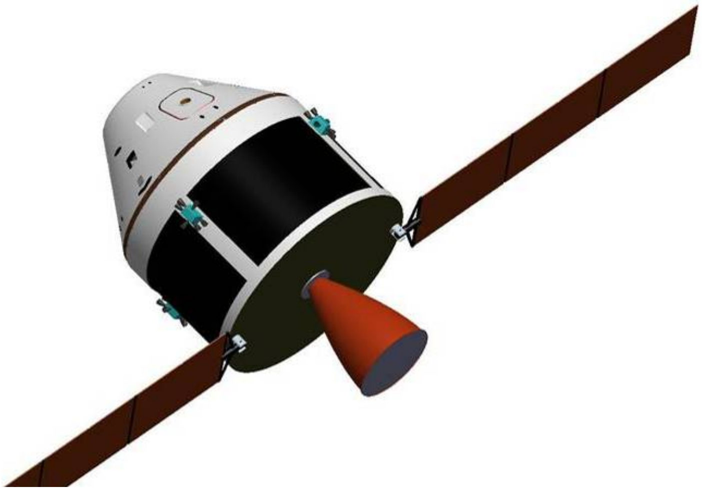
Operations and Systems

- Autonomous operations
- Partial gravity systems
- EVA, Surface mobility

- Autonomous operations
- Partial gravity systems
- EVA, Surface mobility

Changes Since ESAS - Crew Exploration Vehicle (CEV)

- **CEV Command Module**
  - Mold Line: Apollo-Derived Capsule
  - Crew: 6 for ISS & Mars, 4 for Moon
  - Size: 5 Meter Diameter
  - Docking Mechanism: APAS or LIDS
- **CEV Service Module**
  - Propulsion: Hypergolic (MMH/NTO)
  - Some Capability for Delivering Unpressurized Cargo
- **Unpressurized Cargo Variant No Longer Required**
- **Ongoing Analysis**
  - Impact of Reducing CEV Volume
  - Trading Functionality between Command and Service Module
  - Eventual Migration to Non-Toxic Propellants



CONSTELLATION

Changes Since ESAS - Crew Launch Vehicle (CLV) & Heavy Launch Vehicle (HLLV)

♦ Crew Launch Vehicle

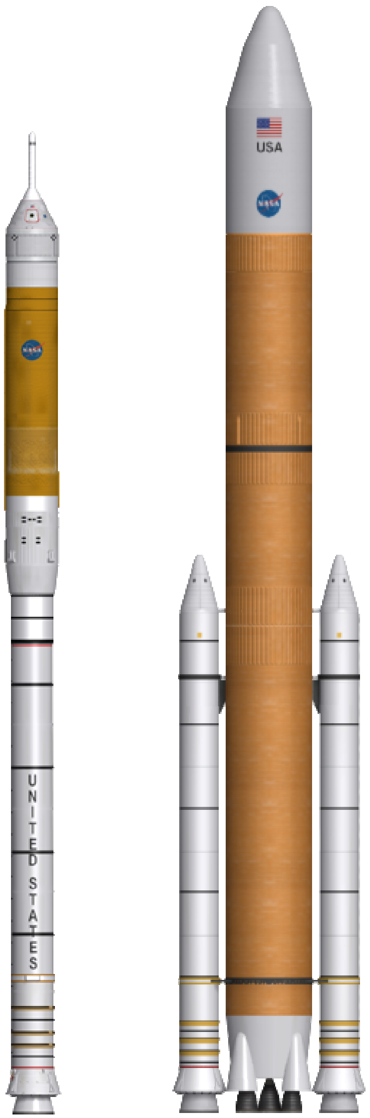
- Single 5 segment RSRB/M 1st stage
- Upper stage powered by a single engine derived from the Saturn J-2
- Given a 5 Meter CEV, Exploring Options for Upper Stage Diameter

♦ Cargo Launch Vehicle

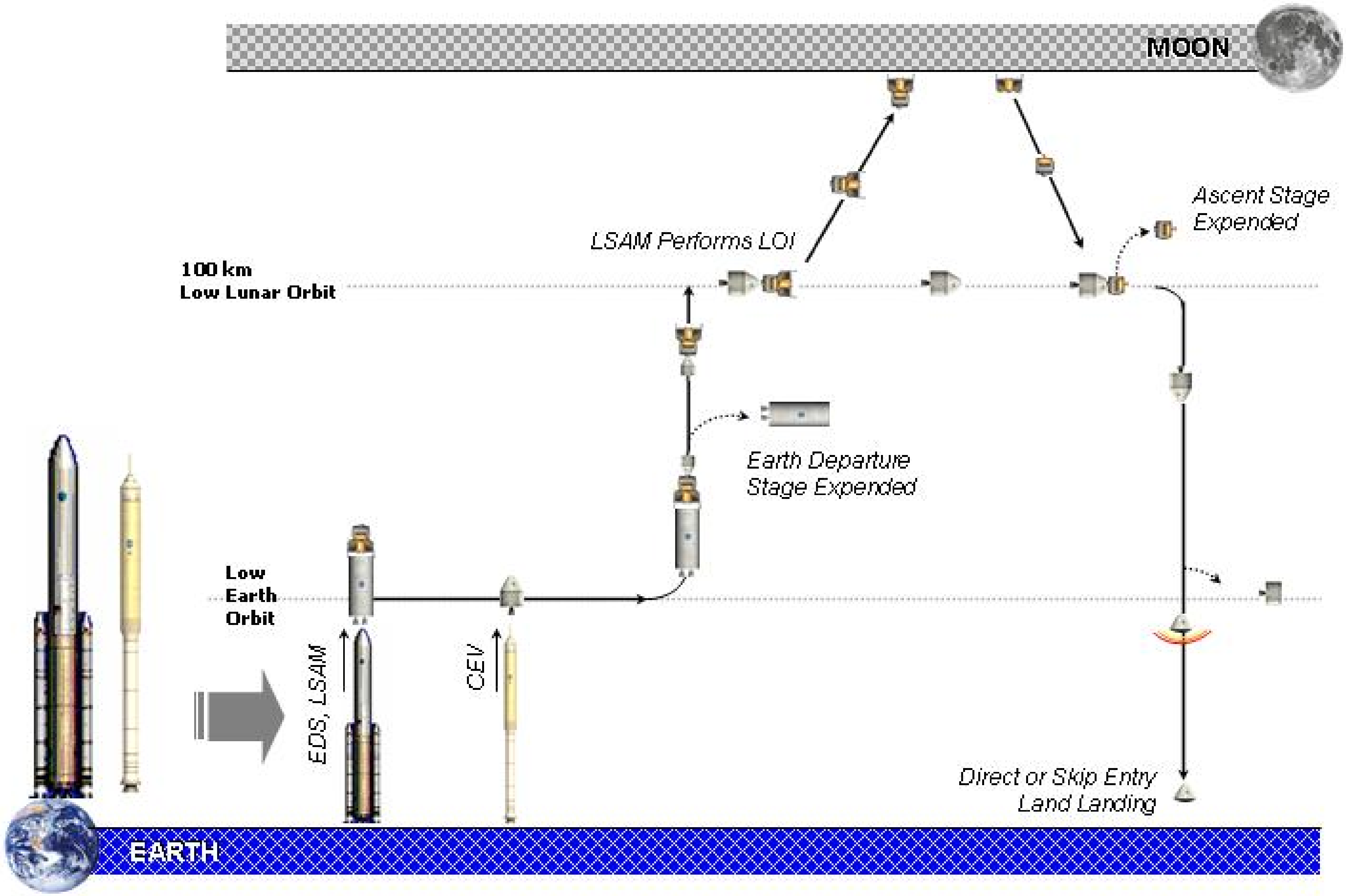
- Twin 5 segment RSRB/M 1st stage (from CLV)
- Core stage derived from the External Tank
- First stage main engine decision forthcoming
- CLV-derived avionics

♦ Earth Departure Stage

- Upper stage derived from the External Tank
- Powered by a single J-2 upper stage engine - 2 burn capability
- CLV-derived main propulsion systems and avionics



Lunar Sortie DRM



Lunar Sortie DRM

- **Up to four crew members can explore any site on the Moon for four to seven days**
- **Sortie missions allow for exploration of high-interest science sites or scouting of future Lunar Outpost locations.**
- **Sortie crews have the capability to perform daily extra-vehicular activities (EVAs) with crew members egressing the vehicle through an airlock.**
- **A Lunar Sortie mission requires the following elements: a CLV, a CEV, a CaLV (with EDS), an LSAM.**
- **The mission mode is a combination Earth orbit Orbit Rendezvous and Lunar Oorbit Rendezvous (EOR-LOR)**
  - LSAM and EDS are pre-deployed in a single launch to low Earth orbit using the CaLV
  - A second launch, with the smaller CLV, delivers the CEV and crew to Earth orbit where the two vehicles (CEV and LSAM/EDS) rendezvous and dock.
  - The EDS performs the TLI burn for the LSAM and CEV and is then discarded.
  - Upon reaching the Moon, the LSAM performs the LOI for the two mated elements.
  - The entire crew will transfer to the LSAM, undock from the CEV, and perform descent to the surface.
  - The CEV is left unoccupied in low lunar orbit.
  - After a four to seven day surface stay, the LSAM returns the crew and their cargo to lunar orbit where the LSAM and CEV dock and the crew transfers back to the CEV.
  - The CEV then separates from the LSAM, performs the TEI maneuver and returns the crew to Earth
  - The LSAM is disposed via impact on the lunar surface.
  - The CEV re-enters Earth's atmosphere via a direct or skip entry and lands in the western U.S.

Sortie Crew Mission Timeline (1)

CEV, LSAM and Crew in LEO 24-120 hours

CEV, LSAM and and Crew in Earth-moon transit 72 hours

Event	Active Element	Other Elements	Event Duration (hours)	Notes	CEV In-Flight Active Duration (hours)	CEV Quiescent Duration (hours)	LSAM Active Duration (hours)	LSAM Quiescent Duration (hours)
Cargo launch	CaLV/EDS	LSAM	0.8	Launch of the EDS and LSAM into the Earth Rendezvous Orbit. (approximately 48 minutes)	-	-	-	0.8
DS/LSA 1 Loiter n LEO	EDS	LSAM	Up to 2,280	EDS and LSAM must be capable of maintaining themselves in the ERO until the crew launch, which could be as long as 95 days. (TBR-001-030)	-	-	-	2,280
Crew ıunch to EAST	CLV	CEV	0.1	Launch of the crew to the Earth Ascent Staging Target. CEV separates from the CLV at the Earth Ascent Staging Target. (approximately 8 minutes)	0.1	-	-	0.1
CEV Ascent	CEV	-	0.7	CEV performs remainder of ascent, circularization burn, and phasing into the Earth Rendezvous Orbit. (approximately 40 minutes)	0.7	-	-	0.7
endezvous and Dock, Earth Orbit Loiter	CEV	EDS, LSAM	24 to 120 (TBR-001-016)	CEV performs rendezvous and dock with the EDS/LSAM stack. Includes two day rendezvous sequence and three loiter days, which provides for four consecutive days of crew launch attempts. All systems are checked out and verified operational prior to TLI. Crew may also enter and run systems checks on the LSAM.	120	-	-	120
Trans-Lunar ıjection	EDS	LSAM, CEV	0.3	EDS is the active element performing the TLI maneuver. LSAM and CEV are considered payloads with the CEV and ground monitoring the maneuver. (approximately 15 minutes). EDS performs self-disposal post-TLI.	0.3	-	-	0.3
Trans-Lunar Coast, Mid-Course ɔrrection	LSAM	CEV	72	This time reflects a balance between propulsive performance and the desire to minimize crew exposure to deep space conditions. (typically three to four days)	72	-	-	72
Lunar Orbit ısertion, heckout	LSAM	CEV	24	Twenty-four hours for three impulse capture into LLO. The CEV is placed in quiescent mode prior to LSAM separation.	24	-	6 Note (3)	18

Sortie Crew Mission Timeline (2)

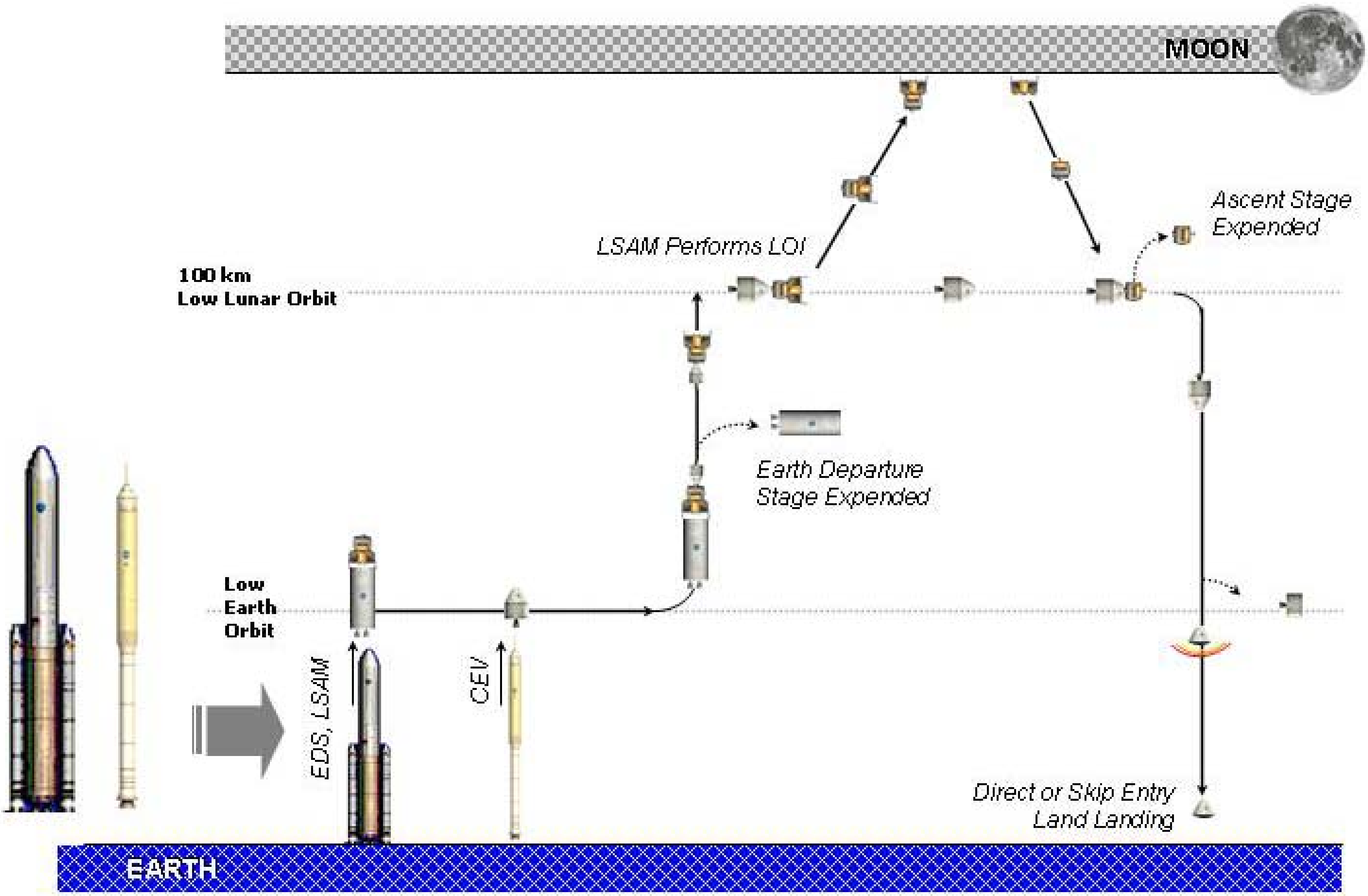
Phase	Event	Active Element	Other Elements	Event Duration (hours)	Notes	CEV In-Flight Active Duration (hours)	CEV Quiescent Duration (hours)	LSAM Active Duration (hours)	LSAM Quiescent Duration (hours)
LSAM and Crew in LLO 25 hours	LSAM eparation	LSAM	CEV	0.3	Crewed LSAM separates from the CEV (estimated 15 minutes for separation sequence)	-	0.3	0.3	-
LSAM and Crew in LLO 25 hours	Descent and Landing	LSAM	-	1	LSAM performs descent and landing to the desired landing site.	-	1	1	-
96-168 hours on lunar surface (sortie); Up to 180 days (Outpost)	CEV uiescent Mode. LSAM Surface peration Prepare r Ascent	LSAM	CEV	96 to 168	Lunar Sortie mission provides from 4 to 7 days on the lunar surface. Both the CEV and LSAM are prepared for ascent. CEV may need to perform LLO plane change to support LSAM ascent stage rendezvous.	6 [Note (1)]	160	168	-
CEV and Crew in LLO 32 hours	Ascent, endezvo s, Dock	CEV, LSAM AS	-	3	Represents in-plane, in-phase rendezvous.	3	-	3	-
CEV and Crew in LLO 32 hours	Post-Ascent peration s	CEV	LSAM AS	3	Crew and cargo transfer from the LSAM to the CEV. LSAM and CEV closeout operations.	3	-	3	-
CEV and Crew in LLO 32 hours	CEV eparation	CEV	LSAM AS	0.3	Crewed CEV separates from the LSAM ascent stage (estimated 15 minutes for separation sequence).	0.3	-	0.3	-
CEV and Crew in LLO 32 hours	LSAM Disposal	LSAM AS	-	2 [See (4)]	LSAM performs self-disposal to the lunar surface post-TLI.	-	-	2	-
CEV and Crew in LLO 32 hours	Trans-Earth njection	CEV	-	24	Twenty-four hours for TEI three impulse departure from lunar orbit assuming significant Earth-Moon orbital misalignment.	24	-	-	-
CEV and Crew in Earth-moon transit 85-109 hours	Trans-Earth Coast, Mid-Course orrection	CEV	-	84 to 108	This time reflects a balance between propulsive performance and the desire to minimize crew exposure to deep space conditions. +/-12 hour variability from a nominal 4 day return trajectory is provided to allow for longitude control using Earth's rotation.	108	-	-	-
CEV and Crew in Earth-moon transit 85-109 hours	Entry, Descent, Landing	CEV CM	-	1	Direct or skip entry with landing at CONUS landing site	1	-	-	-
	ecovery	CEV CM	-	24 to 36	Recovery of crew and vehicle	Note (2)	-	-	-
	ontingen cy	CEV	LSAM	72	Contingency active operational time for the CEV. If used for post-LOI loiter in LLO, this contingency can be used to close the Sortie global access coverage without reducing the LSAM payload to the lunar surface.	72	-	-	72
					Total Duration (hours)	434.3	161.3	183.5	2563.9
					Total Duration (days)	18.1	6.7	7.6	106.8

x hours at the end of the lunar surface phase is counted as active for the CEV to support checkout and LLO plane change (if quired) to support LSAM rendezvous.
ne recovery phase is not included in the CEV In-Flight total duration because it has unique nctional requirements.
ne LSAM is assumed to be active for two hours for each burn in the three-burn LOI sequence, or six hours total. The remainder the 96 hours is listed as quiescent.
ne LSAM is assumed to be active for two hours following CEV separation to enable phasing and execution of the de-orbit burn r safe LSAM disposal to the lunar surface.

Lunar Outpost Crew DRM

- **The same suite of vehicles developed to support Lunar Sortie exploration is also required for Lunar Outpost missions**
- **Additionally, a surface habitat, power/communications systems, and other infrastructure elements are required**
- **Outpost deployment options:**
  - Rapidly deploy infrastructure on a few large cargo landers (20 mt per lander)
  - Land crewed missions repeatedly to one selected site and incrementally building upon useful infrastructure left behind after the completion of each mission.
- **The Outpost will eventually be permanently occupied, with crews rotating every 180 days.**

Lunar Outpost Crew DRM



The 3-Part Radiation Risk Challenge

- **We need to understand the real radiation risk to human space travelers**
  - Better understand and characterize the environment
    - Lunar neutron environment
    - High energy proton environment
    - Develop reliable monitors
  - Better model the transport of radiation and understand how to build more inherent radiation shielding into our spacecraft designs
    - Integrating ALARA into the design
    - Use of Carbon composites in vehicle structures, shielding and components early in the design, and providing recommendations on design optimization
    - Long lunar stay missions will likely require increased shielding over short stay, the development of strategies to reduce chronic risk and GCR impacts
  - Better understand the biological effect of radiations on humans