National Aeronautics and
Space Administration

National Academies
Committee on NASA Mission Critical Workforce, Infrastructure, and Technology

NASA Technology Topics Information Request

The Ask

- The National Academies Committee on NASA Mission-Critical Workforce, Infrastructure, and Technology has multiple Information Requests of the Agency as they perform their Study.
- This presentation responds to one specific ask for the status of 10 Technology Topics as outlined on the next slide.

Technology Topics

- Crew Health (in-space)
- Crew Health (radiation)
- Environmental Control and Life Support (ECLS)
- Orion
- Space Launch System (SLS)
- Exploration Ground Systems
- Gateway
- Extra Vehicular Activity (EVA), Suits, Human Surface Mobility
- Human Landing Systems
- Mars Entry, Descent, and Landing
- In-space Propulsion and Power
- Nuclear Propulsion
- On-Orbit Servicing
- Cryogenics
- ISRU (gas and solid)

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Crew Health (In-Space)

Major advancements over last 10 years

- ISS Exercise countermeasures (multiple exercise devices: resistive, treadmill, cycle ergometer) and prescriptions largely effective in mitigating bone, muscle, and cardiovascular deconditioning
- Significant advances in Commercial Of The Shelf (COTS) portable medical device technology
- Suited human injury model validation and application to landing injury prediction and mitigation
- Planetary EVA prebreathe protocol validated for 8.2 psia / 34% O_2 / 66% N_2 saturation atmosphere

Current TRL and relevance to NASA human exploration

- ISS exercise countermeasures are high mass (2,000kg), high volume (19 m^3), and crew-time intensive (2.5 hrs/day)
- Food system relies on frequent resupply which includes:
  - Standard foods with at least 18 months shelf-life
  - Preference foods on specific missions, which can include commercial items that meet spaceflight requirements
  - Limited short shelf-life foods, such as fresh produce
  - Food hydration levels of ~50%
- Health & performance monitoring and decision support primarily ground-based for ISS

Current major technology challenges

- Effective, reliable, low-mass, low-volume exercise countermeasures including Vibration Isolation
- Countermeasures to maintain behavioral health & performance for multi-year missions with delayed and intermittent space-to-ground communication
- Sensorimotor countermeasures to enable and reduce time before unassisted landing egress and EVA on Mars surface
- SANS countermeasures to maintain visual acuity and protect ocular health
- Miniaturized autonomous medical equipment and decision support systems
- Integrated medical data and records for in-flight use during communication delays and disruptions
- Improved food shelf-life (5-year) with controlled environment and packaging
- Validated models to enable prediction and mitigation of decompression sickness and suited injury for frequent surface EVAs

Outlook for technology development in the next 10 years

- Orion Flywheel Exercise Device - TRL 8 in 2024
- European Enhanced Exploration Exercise Device (E4D) - TRL 6 in 2024
- CHP Integrated Data Architecture Tech Demo – TRL 7 in ~2027
- Initial Sensorimotor Countermeasures Tech Demo – TRL 7 in ~2027
- Multifunctional Medical Device & Mini IV Generator – TRL 7 in ~2027
- Mini X-Ray Tech Demo – TRL 5 in ~2027
- Spacesuit Fit & Injury Models - TRL 6 in ~2027
- ISS OHALO Crop Production Tech Demo – TRL 7 in ~2027
- Initial Exploration Food System - TRL 6 in ~2028
- EVA Biomedical Decision Support Tool - TRL 6 in ~2029
- Validated Decompression Risk Tool - TRL 6 in ~2030

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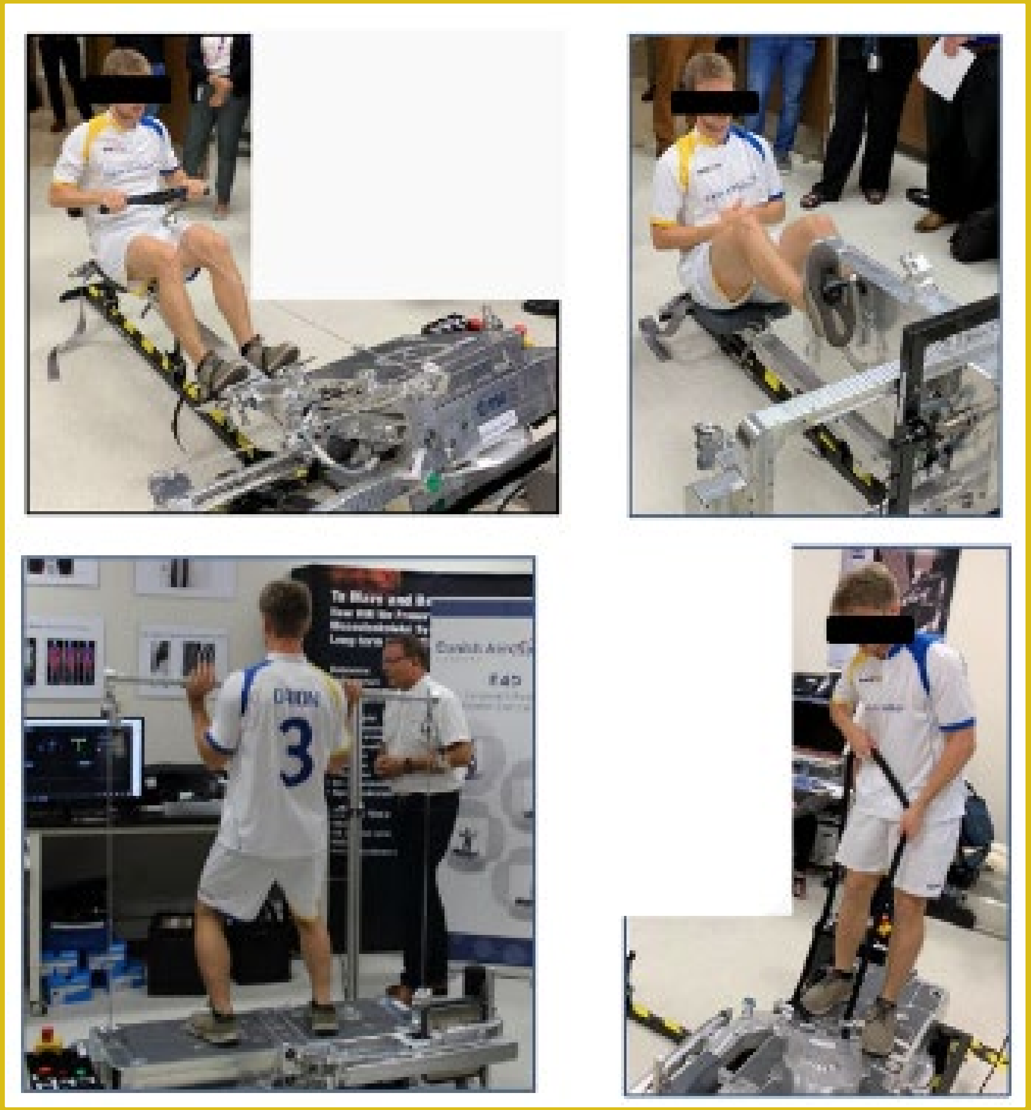
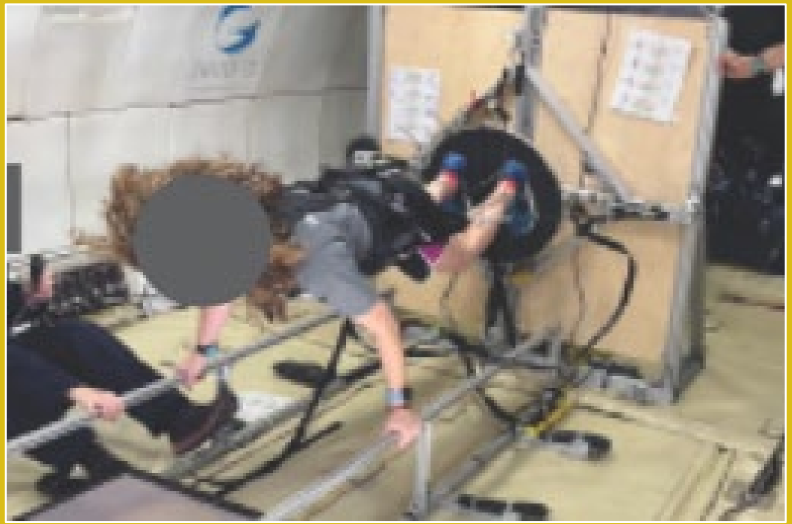
Crew Health (In-Space)



ESA's E4D Exercise Device Prototype

Airflow test in Ohalo growth chamber prototype

Reduced Water Content Food



Sensorimotor Balance Board

COTS Multi-purpose Medical Device is being evaluated on ISS Tech Demo

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Crew Health (Radiation)

Major advancements over last 10 years

- Evolution of TimePix technology to Hybrid Electronic Radiation Assessor (HERA) used on Artemis-1 and subsequent flights
- Refined and consolidated multiple solar event occurrence and duration predictive models into single user interface for Artemis mission decision support (used on Artemis 1)
  - Allows near-real-time radiation risk assessment
- Mature solar particle event shielding design tools
  - Oltaris and HZETRN2020 physics design and transport codes
- Galactic cosmic radiation (GCR) beam simulator for biological research and improved electronics testing
- Conceptualized and performed small scale beam verification of electro-static GCR shielding technology

Current TRL and relevance to NASA human exploration

- Space radiation environments must be characterized to determine astronaut crew exposures; information that is vital to influence vehicle design and mission planning
  - Crew exposure to radiation needs to be As Low As Reasonably Achievable (ALARA) to maintain crew heath during and after the mission – monitoring, modeling, and mitigation
- ISS/Artemis/Gateway/HLS HERA @ TRL 9
- ISS Crew Active Dosimeter @ TRL 9
- Artemis Radiation Forecasting Scoreboards @ TRL 9

Current major technology challenges

- Galactic cosmic radiation (GCR) shielding
  - Passive thick shielding techniques are excessively mass intensive
  - Active shielding technologies are low TRL and require significant mass, power, and vehicle complexity
- GCR predictive forecast models of solar cycle modulation
- Biological biomarker monitoring and personalized countermeasures
- Improved 24-hour prediction of solar storm duration and intensity, >90%
- Advanced space radiation environment characterization
  - Electron and proton detectors
  - High energy neutron detectors
- Earth independent monitoring and forecasting

Outlook for technology development in the next 10 years

- Annual model updates to Artemis forecasting scoreboards
- Active Radiation Environment Sensor (ARES) for HLS, Gateway, and future missions – TRL 8 in 2024
- Compact Electron Proton Spectrometer – TRL 6 in 2026
- Next Gen Fast Neutron Spectrometer - TRL 8 in ~2027

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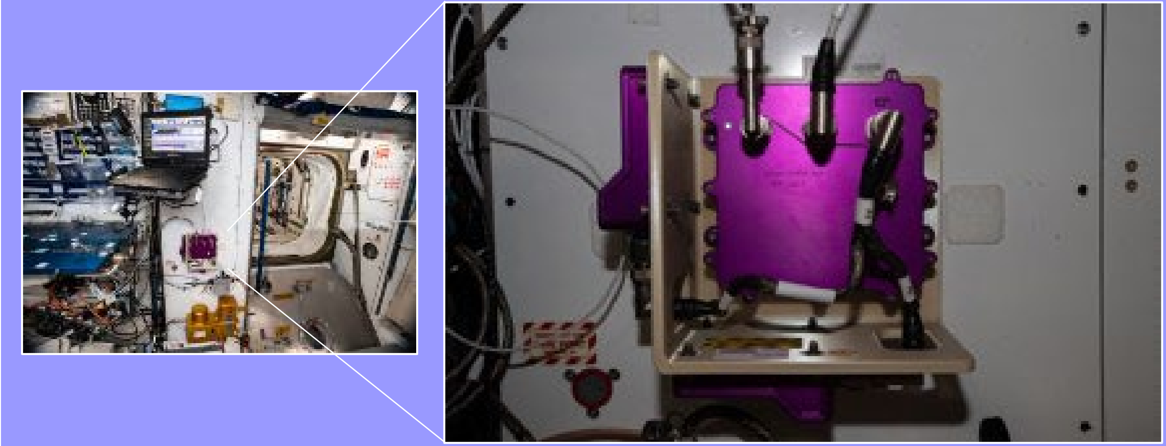
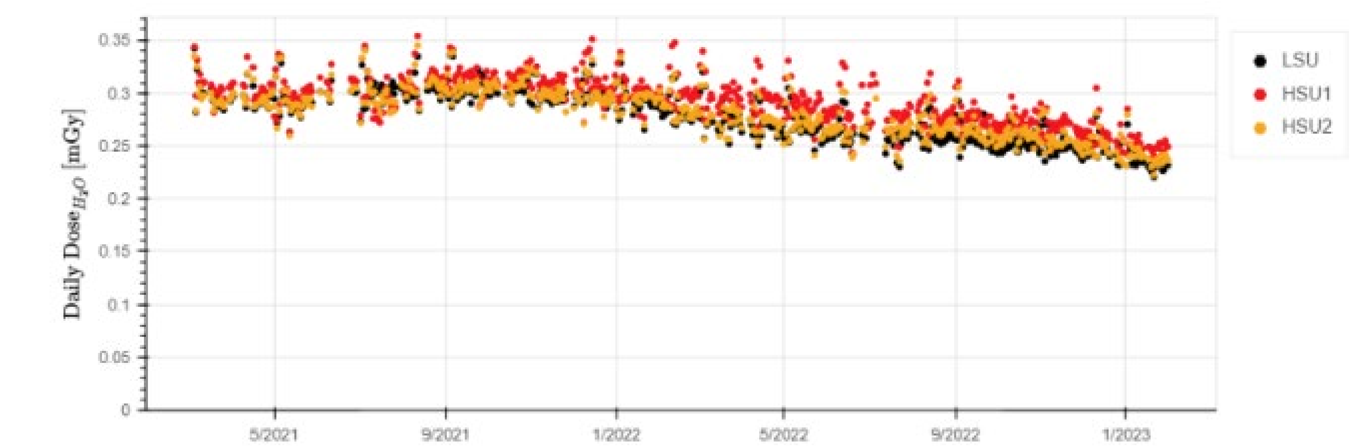
Crew Health (Radiation)

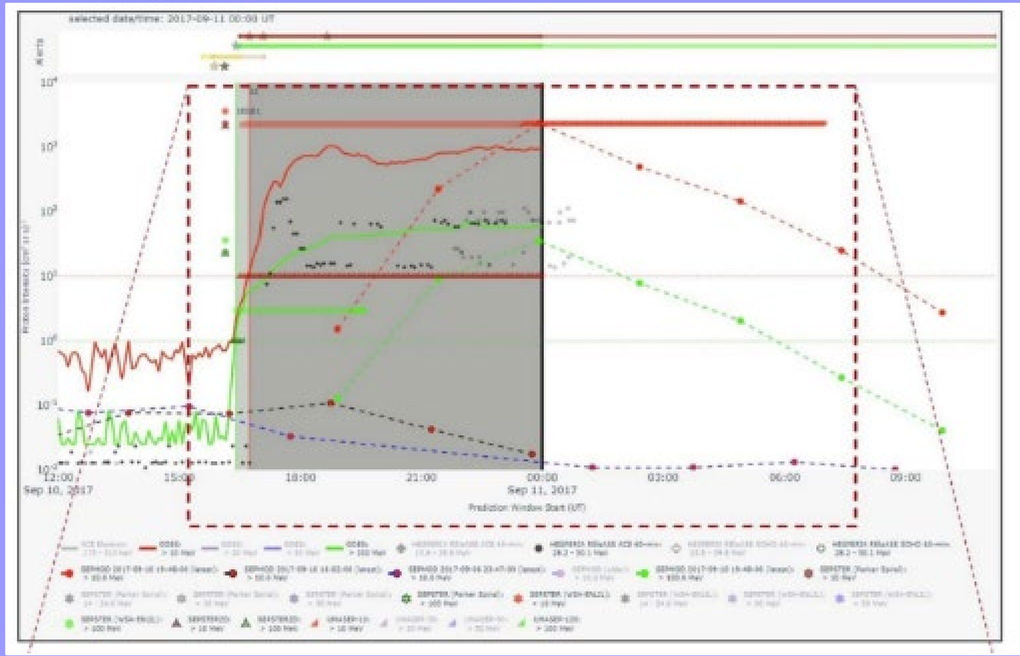


Hybrid Electronic Radiation Assessor (HERA) on ISS

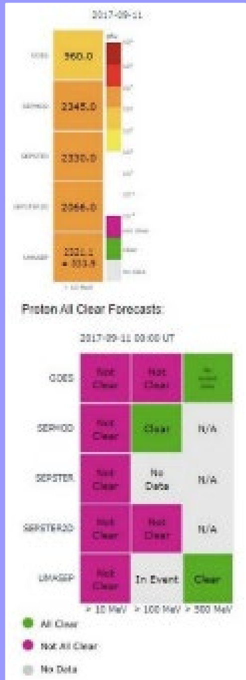


Tech Demo data from Artemis HERA on ISS (AHoSS) to validate operation for Artemis (HSU = HERA Sensor Unit)

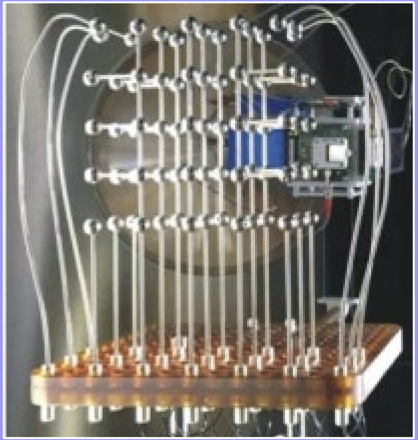
ISS Crew Active Dosimeter (CAD)



Space Weather: Artemis Forecasting Scoreboard – Detailed projects of event flux over time



Artemis Scoreboard Ensemble Model Summary for Solar Event Intensity and Duration Forecast



Subscale ion beam testing of Active GCR shielding concept at Brookhaven National Laboratory

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Environmental Control and Life Support (ECLS)

Major advancements over last 10 years

- Upgraded ISS ECLS systems with design improvements to improve performance, maintenance, and reliablity
  - Water recovery increased from 84% to 98%
  - Oxygen recovery from 0% to 45% demonstrated
- Conducted 5 'large-scale' fire tests in Cygnus vehicles to improve µg materials modeling, test monitors, and cleanup
- Developed ISS RFID autonomous logistics tracking capability
- Demonstrated in-flight microbial speciation and trace gas analysis capabilities
- Developing human waste and trash processing hardware to support long duration missions with ISS demos planned

Current TRL and relevance to NASA human exploration

- Without regenerative life support ~28,000 kgs of water, oxygen, and food are required to support an 860-day Mars mission
- Life support systems must have low uncertainty in their operating life and failure modes to minimize spares mass
  - Continue ISS as a test bed for Exploration ECLSS upgrades
  - Existing ISS systems are high TRL but require additional run time to substantiate component lifetimes
  - Parallel ground reliablity testing of key ECLSS systems will come on-line 2023-2026 to inform Mars transit mission design
  - Targeting Commercial LEO Destination for new µg tech demos

Current major technology challenges

- Recovery of water processing after long dormant periods
- Test verified reliability data for determining ECLS spares mass allocations for Mars mission
- Autonomous time critical unplanned repair/stabilization with large communication delays
- High pressure (~3,500 psia) for EVA recharge
- Increasing oxygen recovery to >75%
- Materials testing to validate partial-gravity fire models and detection monitors in potentially dusty surface habitats
- Mars planetary protection for ECLS venting and trash disposal
- Improved clothing and non-metallics for ~36%O_2 flammability
- In-flight chemical and microbial identification and quantification of air, water, surfaces for >3-years without sample return

Outlook for technology development in the next 10 years

- ISS and Orion Anomaly Gas Analyzers (fire by-products) in 2024
- Initiate broad spectrum trace gas atmospheric monitor ISS TD in 2024
- Initiate Advanced Oxygen Generator ISS Tech Demo (TD) in 2025
- Improve oxygen recovery
  - Improved Sabatier ISS TD in 2025 (45% O_2 recovery)
  - Methane reduction device to TRL 6 in ~2028 (>75% O_2 recovery)
  - Reduce launched pre-packaged food water content to <30% by 2030
    - Required to achieve mass savings from increased O_2 recovery
- Dormancy tolerant condensing heat exchanger ISS TD in ~2026
- Medical oxygen concentrator ISS TD in ~2026
- Broad spectrum water impurity monitor ISS TD in ~2028
- Ground testing of water dormancy mitigation and water biocide technologies 2024-2029

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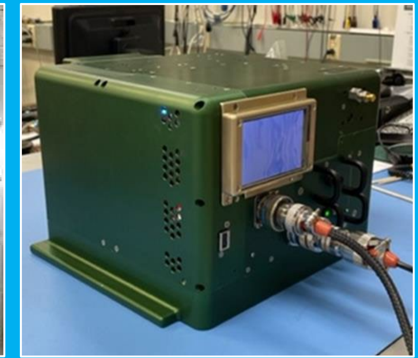
Environmental Control and Life Support

ISS Thermal Amine Scrubber (CO_2 removal)

ISS 4-Bed CO_2 System (CO_2 removal)



ISS Spacecraft Atmospheric Monitor (major and trace gas analysis)

Upgraded ISS Urine Processor Distillation Assembly (85% water recovery)

eXploration Potable Water Dispenser

Carbon Vapor Deposition System Ground Brass board (CO_2 reduction)

H_2 Sensors for future Advanced Oxygen Generation System (improved reliablity, testing with existing ISS OGA)

Orion Laser Air Monitor (major gas analysis)

Airborne Particle Monitor TD in ISS Lab

BioMole/MinION (first microbial DNA sequencing on ISS)

ISS Urine Brine Processor Assembly (increases total water recovery to 98%)

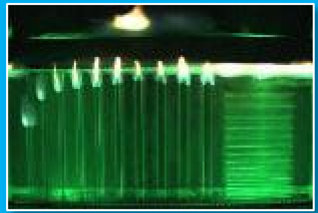
Mobile RFID inventory reader on ISS Astrobee

Trash Processing and Compaction System (compacted tile in ground prototype)

Advanced Sabatier System in ground testing (45% O_2 recovery)

ISS Anomaly Gas Analyzer in ground tests

Advanced Quiet Cabin Air Fan Prototype



Spacecraft fire safety demonstrations (Saffire) – large format material and flow characterization tests on Cygnus

National Aeronautics and Space Administration

NASA

National Academies
Joint Meeting of the Aeronautics and Space Engineering Board and Space Studies Board

For All Humanity: Progress and Plans for Deep Space Human Exploration

Lakiesha Hawkins
Assistant Deputy Associate Administrator (ADAA)
for Moon to Mars Program Office (M2MPO)
Exploration Systems Development Mission Directorate (ESDMD)

NASA Headquarters | Washington, D.C.

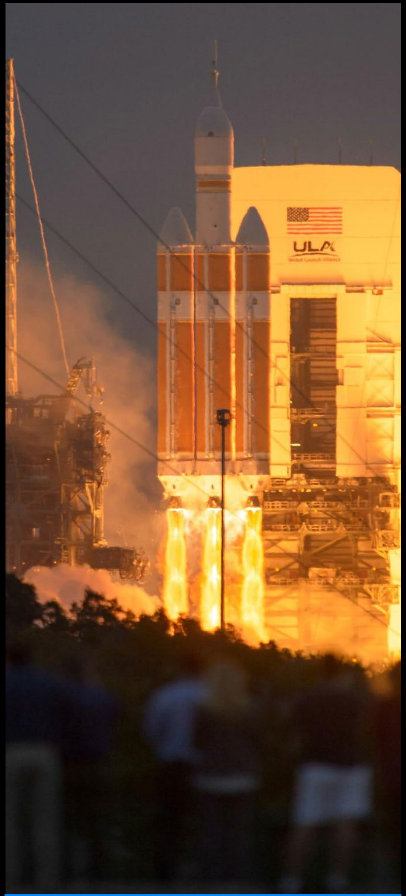
December 4, 2023

The Last 10 Years *represent a steady march toward development of capabilities and their integration to complete the overall deep space transportation system*

PA–1
Test Flight
May 6, 2010

COMPLETE

EFT–1
Test Flight
December 5, 2014



COMPLETE

AA–2
Launch Abort System Testing
July 2, 2019

COMPLETE

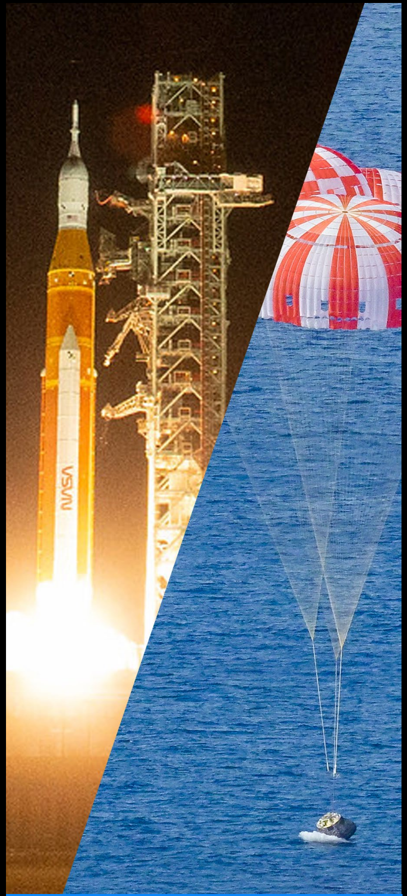
Green Run
Space Launch System Core Stage Testing
January 2020 to April 2021

COMPLETE

Mobile Launcher
Artemis I Rollout
August 17, 2022

COMPLETE

Artemis I
Uncrewed Flight Test
November 16 to December 11, 2022

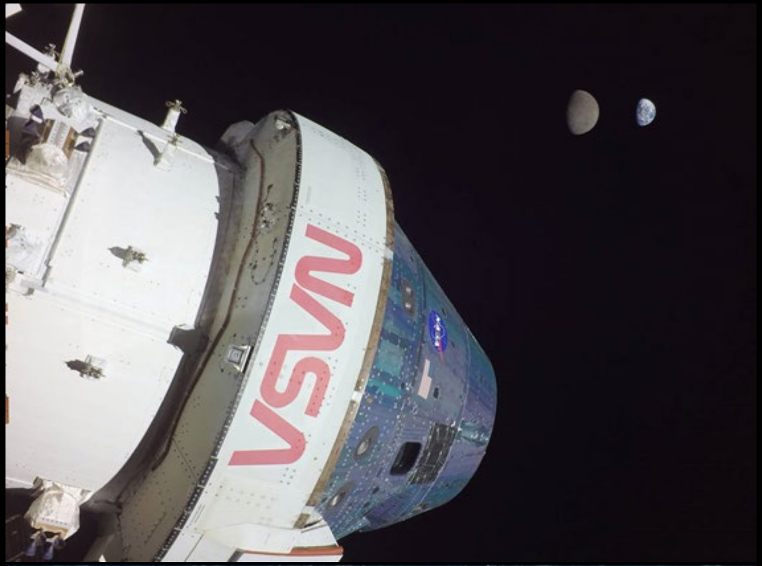


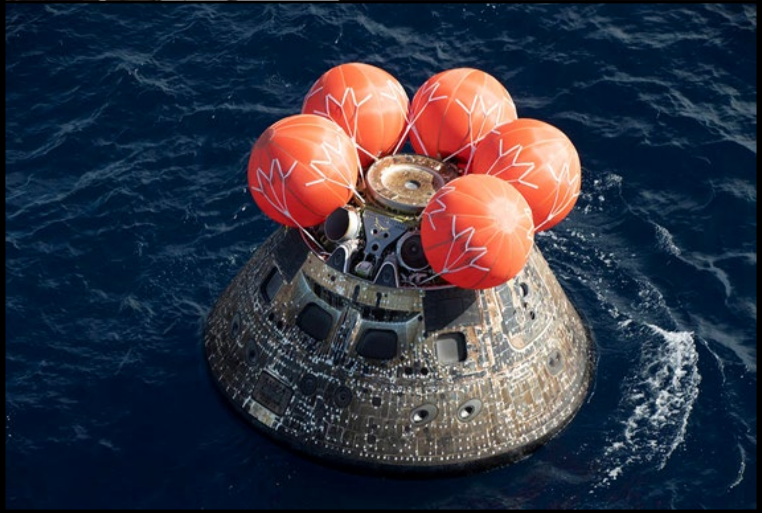
COMPLETE

Artemis I Mission Success

Achieved 140+ Flight Test Objectives

- Demonstrated Orion's heatshield can withstand the high speed and heating conditions on Earth return
- Retrieved Orion as expected post-splashdown
- Certified optical navigation camera
- Performed vehicle modal survey
- Characterized solar array wing camera wi-fi
- Performed crew and service module surveys
- Demonstrated large file delivery protocol uplink
- Performed star tracker thermal assessment
- Tested radiator flow control loop
- Examined solar array wing plume
- Characterized propellant slosh
- Demonstrated search acquire and track mode
- Conducting a thorough post Artemis I Lessons Learned process



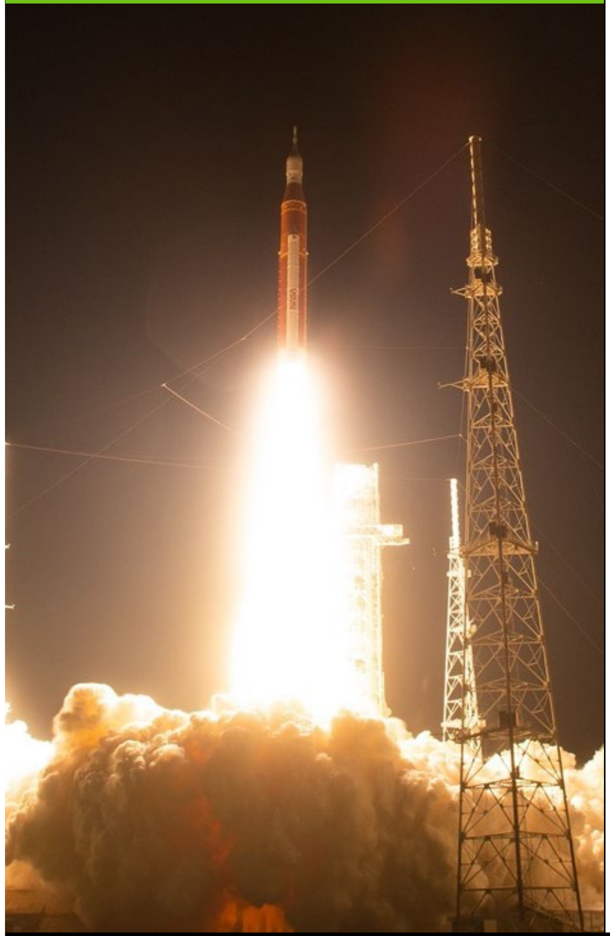


Top: Orion with Moon and Earth in the distance
Bottom: Successful splashdown and recovery of Orion

ARTEMIS I

First mission
(uncrewed flight test)

COMPLETED



ARTEMIS II

First crew

CREW SELECTED

ARTEMIS III

First human
surface landing

ARTEMIS IV

First lunar space station
assembly mission

Gateway

Human landing system, spacesuits

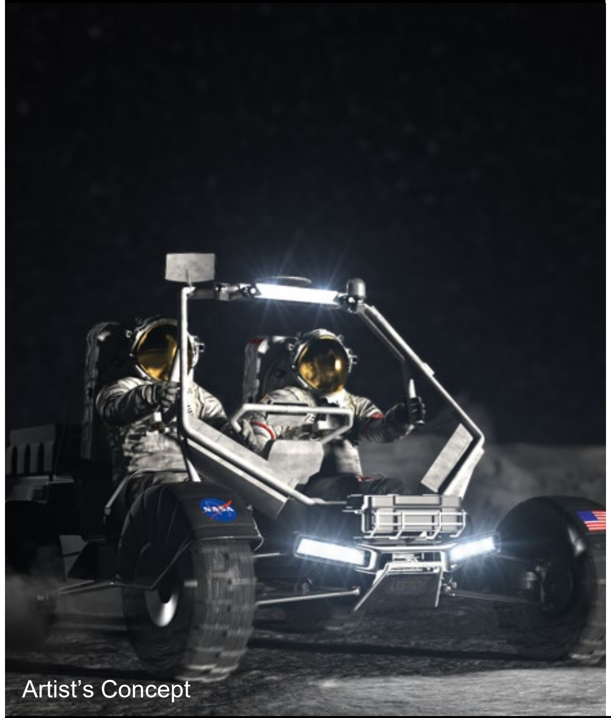
Crew

Space Launch System rocket, Orion crew spacecraft, Exploration Ground Systems

Conducting science and demonstrating technology and operations

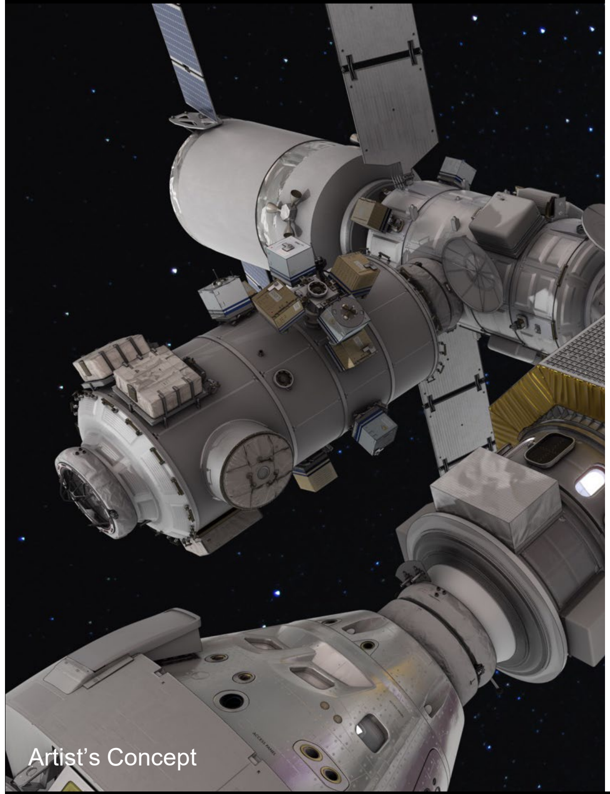
ARTEMIS V

First unpressurized rover



ARTEMIS VI

Gateway assembly complete



ARTEMIS VII AND BEYOND

Longer missions = preparation for human Mars missions
Access to more of the Moon = new scientific discoveries

Pressurized rover, surface habitat, and other new elements

Gateway airlock module

Lunar terrain vehicle; Gateway refueling and robotics

Crew conducting science and demonstrating technology in orbit and on the surface;
Space Launch System rocket; Orion crew spacecraft; Exploration Ground Systems; Gateway space station

Moon to Mars Program Office

Content Description and Strategy

- NASA has established the new Moon to Mars Program Office at NASA Headquarters to carry out the agency's human exploration activities at the Moon and Mars for the benefit of humanity
- This new office resides within the Exploration Systems Development Mission Directorate

The Program Office will:

- Help ensure that NASA successfully establishes a long-term lunar presence needed to prepare for humanity's next giant leap to the Red Planet
- Focus on hardware development, mission integration, and risk management functions for programs critical to the agency's exploration approach that uses Artemis missions at the Moon to open a new era of scientific discovery and prepare for human missions to Mars
- Lead planning and analysis for long-lead developments to support human Mars missions

Artemis Programs under the Moon to Mars Program Office

Orion; Space Launch System; Exploration Ground Systems; Gateway; xEVA and Human Surface Mobility; Human Landing System

Artemis II Crew Training

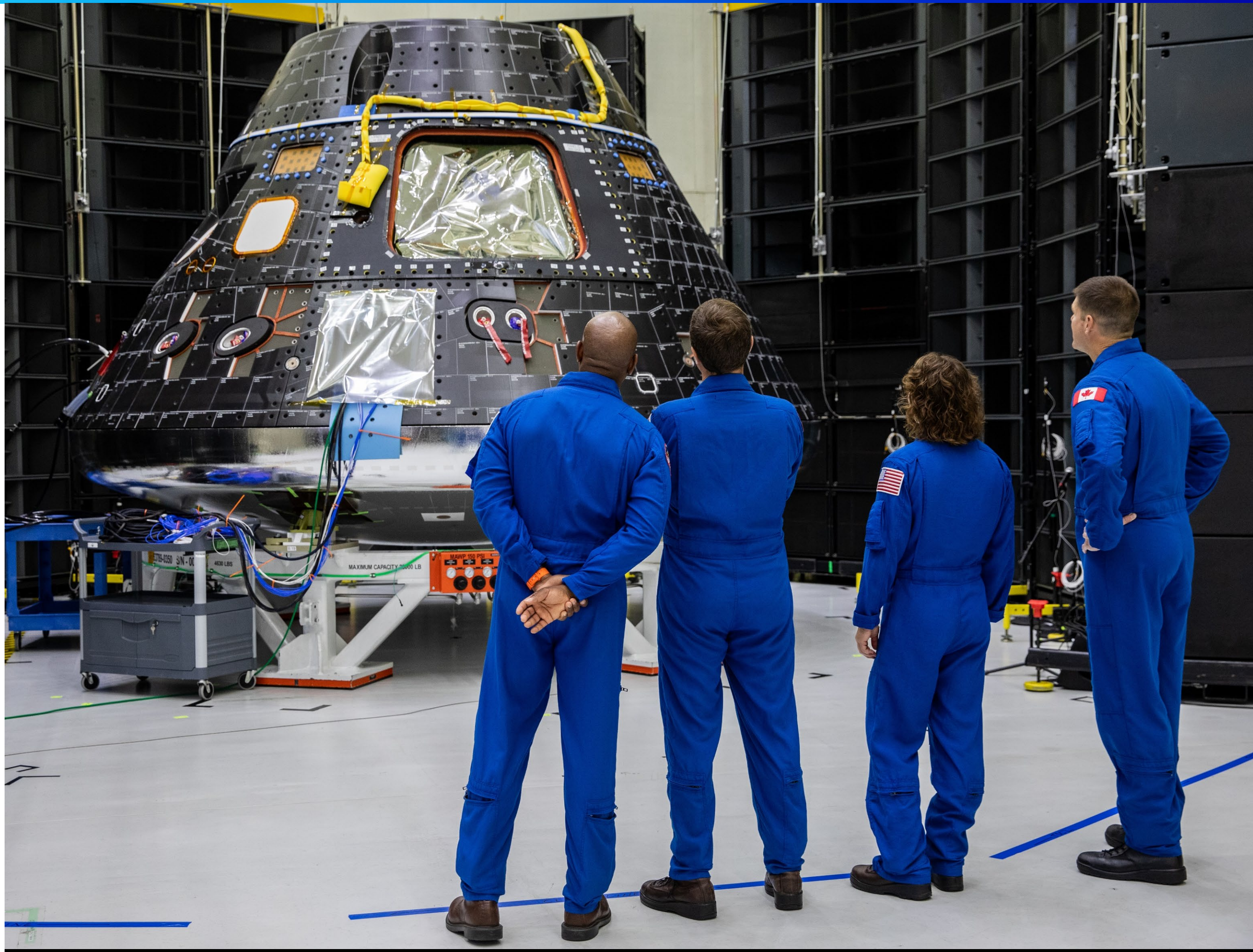
- Crew of four announced in Spring 2023: Commander Reid Wiseman, pilot Victor Glover, and mission specialist Christina Koch from NASA, and mission specialist Jeremy Hansen from the Canadian Space Agency
- Finished the first part of their training known as fundamentals in August 2023
- Koch and Hansen, alongside several other astronauts, took part in geology training in September 2023
- The full crew successfully completed the first in a series of integrated ground system tests in September 2023

The crew stand on the crew access arm of the mobile launcher at Launch Pad 39B as part of an integrated ground systems test.

Orion

Content Description and Strategy

- Exploration vehicle capable of transporting humans to orbit around the Moon and sustain them for long duration beyond low-Earth orbit
- Provides capability to return crew safely to Earth and emergency abort capability
- Rendezvous, Proximity Operations and Docking (RPOD) capability with Human Landing System (HLS) for Artemis III and Gateway for Artemis IV and beyond



Artemis II Crew visits their ride around the Moon, Kennedy Space Center.

Orion—Activities

Artemis II—First Crewed Flight Test

- Orion crew and service modules joined
- Power up the combined crew and service module
- Altitude chamber testing, which will put the spacecraft through conditions as close as possible to the environment it will experience in the vacuum of deep space

Artemis III—First Crewed Lunar Landing

- European Service Module assembly continues in Bremen
- NASA Docking System install and test
- Perform Crew and Service Module AI&P
- Integrate and test Artemis III Launch Abort System functions

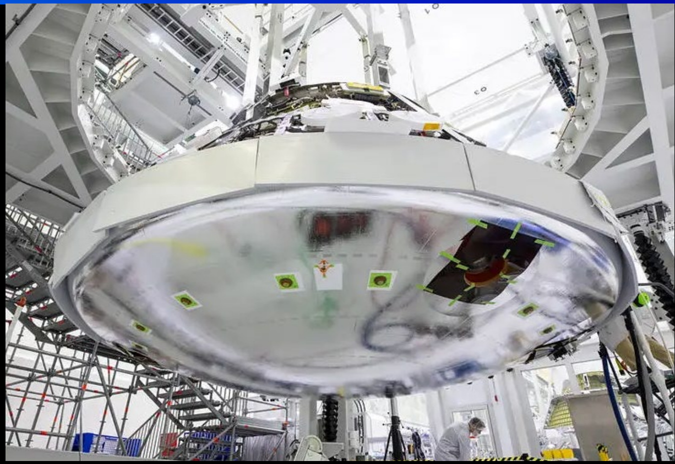
Artemis IV—Second Crewed Landing, Lunar Gateway

- Continue structural assembly, proof test, and subsystem installations
- European Service Module assembly continues in Bremen

Artemis V—Third Crewed Landing, Lunar Gateway

- Deliver pressure vessel parts to Michoud Assembly Facility
- European Service Module assembly continues in Bremen

The Artemis II astronauts, set to launch on a trip around the Moon, stand in front of the Orion spacecraft's European Service Module-2.



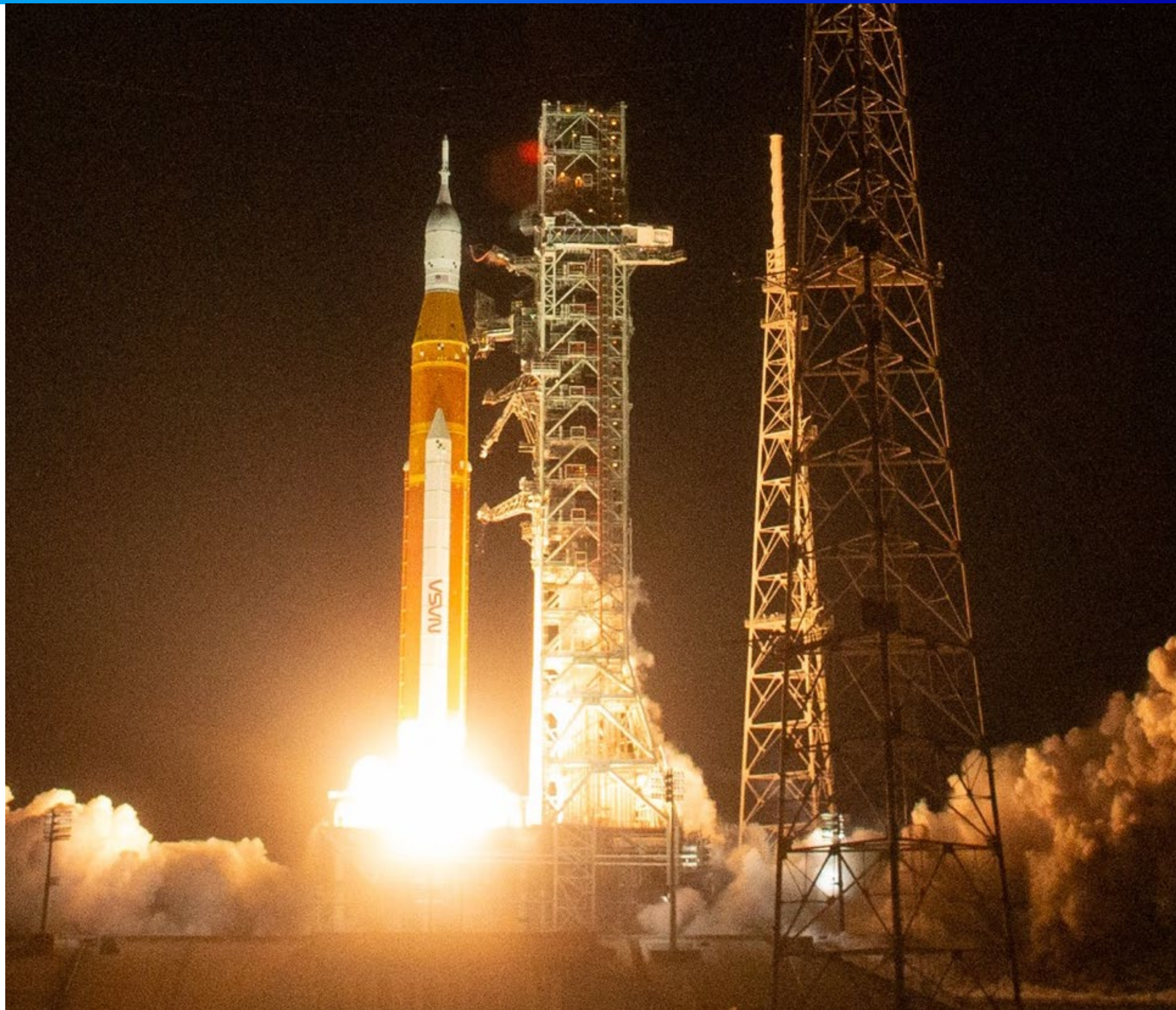
Heatshield is installed on the Artemis II Orion spacecraft at NASA's Kennedy Space Center.

Integration of the crew and service modules for the Artemis II Orion spacecraft was completed at NASA's Kennedy Space Center.

Space Launch System

Content Description and Strategy

- Rocket capable of sending Orion, astronauts, and cargo directly to the Moon in a single launch
- Evolve SLS vehicle for Block 1B capability for Artemis IV
- Deliver RS-25 production restart engines
- Continue production on already awarded Artemis V+ content (Engines follow on production, Boosters)
- Continue development of Block 2 capability required for future Artemis missions



November 16, 2022: The first uncrewed integrated flight test of NASA's Orion Spacecraft and Space Launch System vehicle which demonstrated NASA's commitment and capability to extend human presence to the Moon and beyond.

Space Launch System—Activities

Artemis II—First Crewed Flight Test

- Final processing to support launch

Artemis III—First Crewed Lunar Landing

- Complete Core Stage 3, ICPS 3, LVSA 3, and OSA 3

Artemis IV—First Crewed Landing Block 1B

- Continue production of Core Stage 4 and boosters
- Block 1B development—continue production of Exploration Upper Stage (EUS), Upper Stage Adapter, Payload Adapter

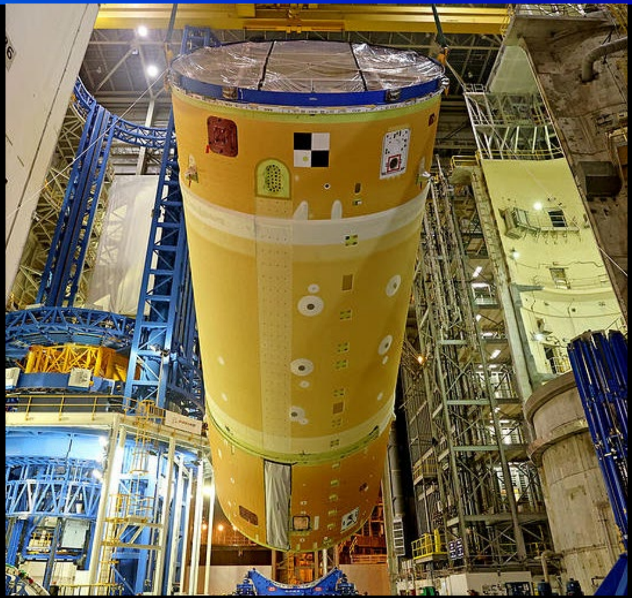
Artemis V and Future Missions

- RS-25 Engine Production Restart design certification review (DCR)

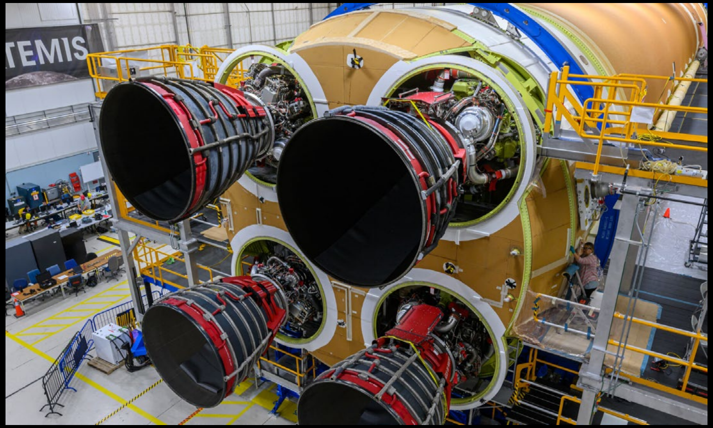
Artemis IX and Future Missions

- Booster Obsolescence and Life Extension (BOLE) DDT&E continues

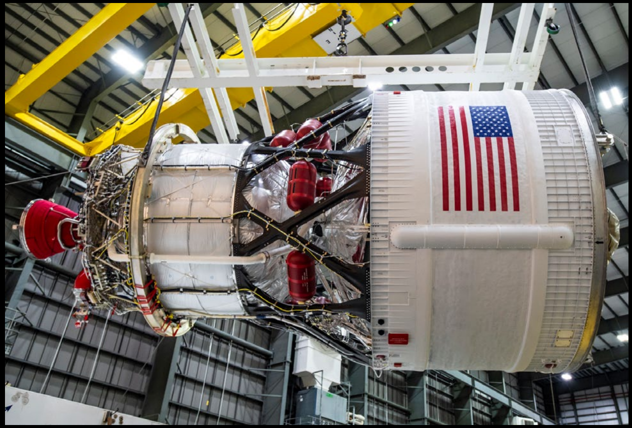
Artemis II booster motor segments complete



Five major structures of the Artemis II SLS rocket Core Stage are connected.



All four RS-25 engines are complete and installed onto the Artemis II SLS rocket Core Stage.



Artemis III Space Launch System Upper Stage

Exploration Ground Systems

Content Description and Strategy

- Develop/operate U.S. systems and facilities necessary to process and launch SLS and Orion during assembly, transport, and launch
- Implement new launch infrastructure for crewed Artemis missions and SLS Block 1B operations (including Mobile Launcher-2)
- Support complex propellant loading operations
- Support processing, launch, and recovery of Orion
- Operate and maintain assets in Vehicle Assembly Building (VAB), Mobile Launcher-1, Launch Pad 39B, Crawler and Rotation, Processing and Surge Facility (RPSF), propellant storage facilities
- Quickly turn around equipment and facilities between missions as we work towards an annual cadence of missions

The mobile launcher, carried by the crawler-transporter 2, rolls out from its park site location to Launch Pad 39B at NASA's Kennedy Space Center in Florida on August 16, 2023.

Artemis II NASA astronauts stand in the white room on the crew access arm of the mobile launcher at Launch Pad 39B as part of an integrated ground systems test at Kennedy Space Center.

Exploration Ground Systems—Activities

Artemis II and III

- Complete remaining Artemis II development and Validation & Verification (V&V) efforts to support the Artemis II crewed launch
  - Complete construction and start V&V of Emergency Egress System at Launch Pad 39B
  - Complete post Artemis I repairs and modifications to Mobile Launcher-1 (ML–1) and begin Multi-Element V&V at the pad to support crewed missions
- Conduct integrated Underway Recovery Test-11 (URT–11) with the U.S. Navy and Lockheed Martin off the coast of San Diego
- Complete Artemis II Booster Offline Processing and prepare for Core Stage Stacking and integration operations

Artemis IV

- Complete the remaining procurements and make significant progress related to the construction of the ML–2 structural framework required for future B1B crewed missions
- Design, build, and install new servicing stands for Exploration Upper Stage (EUS) and the Interstage in HB-4
- Construct Launch Pad 39B LN2 cold gaseous helium system for EUS RL10 chill down

Artemis II Mobile Launcher water flow test

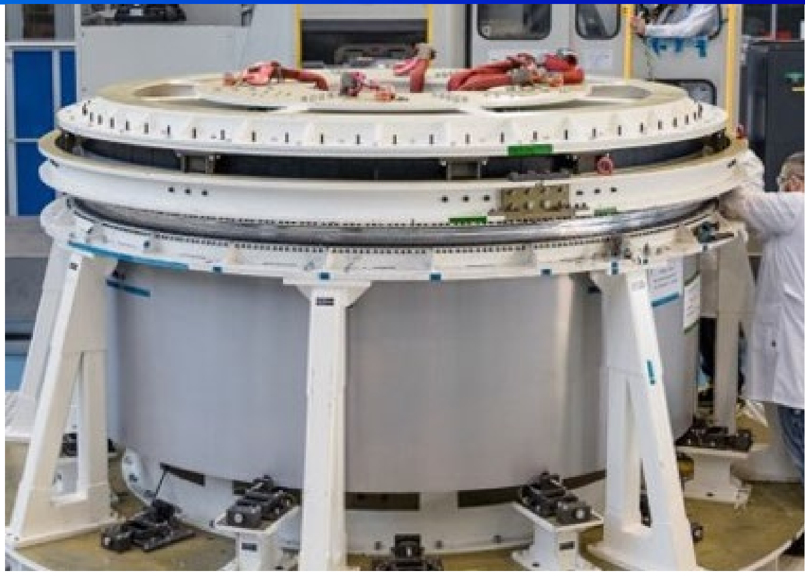
New LH2 sphere at the pad for Artemis II

Gateway

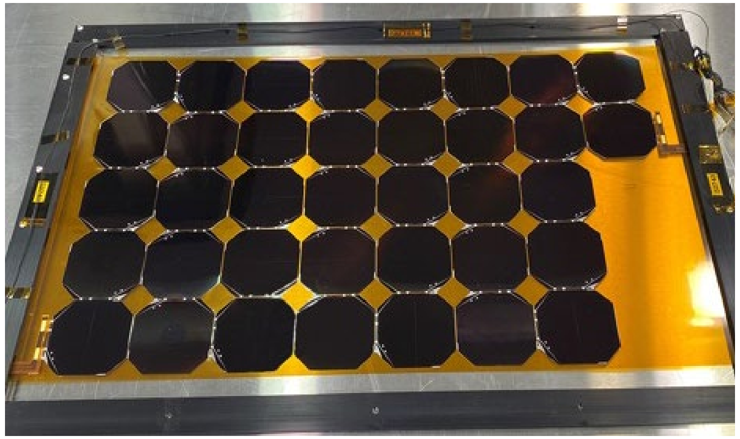
Content Description and Strategy

- A multi-purpose space station orbiting the Moon to provide essential support for long-term human return to the lunar surface
- Research platform in the unique deep space environment of lunar orbit
- Provide lunar capabilities and gain lessons learned and expertise that will support future Mars missions
- Built in collaboration with International Partners
- Agreements in place with European Space Agency (ESA), Canadian Space Agency (CSA), and Japan Aerospace Exploration Agency (JAXA)
- Deep Space Logistics (DSL) to supply missions
- Autonomous operations when the station is uncrewed
- Software and Satellite Communications Systems to ensure good communication relay from the lunar surface, back to Gateway and to Earth

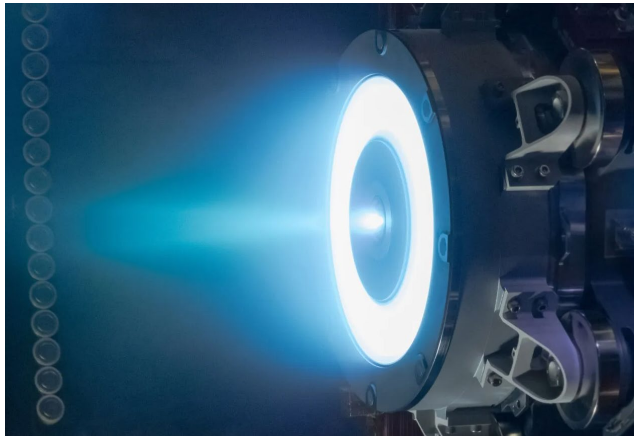
Habitation and Logistics Outpost Mockup



Habitation and Logistics Outpost primary structure assembly



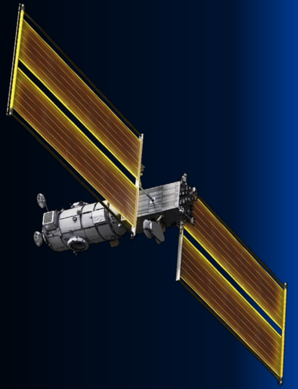
Power and Propulsion Element solar array power module



Power and Propulsion Element 12-kilowatt solar electric propulsion test

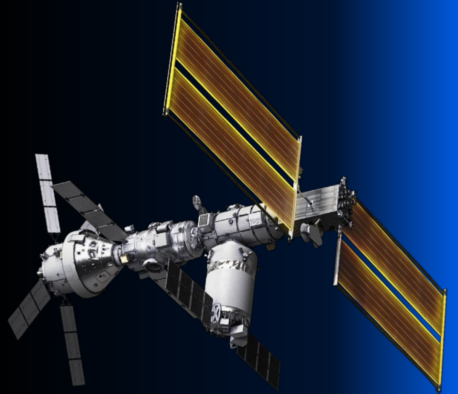
Gateway Buildup Plan

PPE/HALO LAUNCH



Gateway's two foundational elements, Power and Propulsion Element (PPE) and Habitation and Logistics Outpost (HALO) launch on a SpaceX Falcon Heavy rocket to pre-stage in lunar orbit

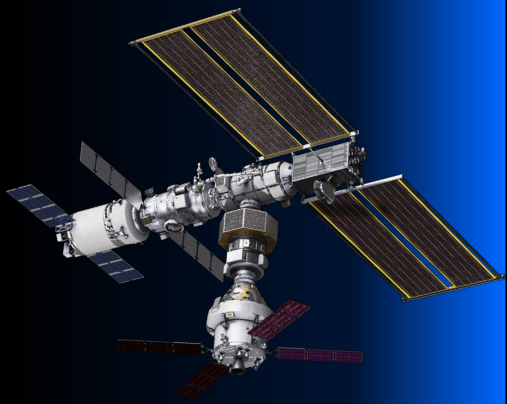
ARTEMIS IV



Orion and the International Habitat (I-Hab) module launch on the Space Launch System (SLS) Block 1B (B1B) rocket

Integration of I-Hab with Gateway in NRHO

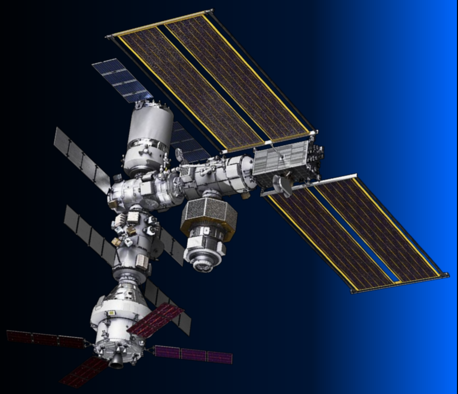
ARTEMIS V



Orion and the ESPRIT Refueling Module (ERM) launch on the SLS B1B rocket and a logistics spacecraft delivers Canadarm3

Integration of ERM and Canadarm3 with Gateway in NRHO

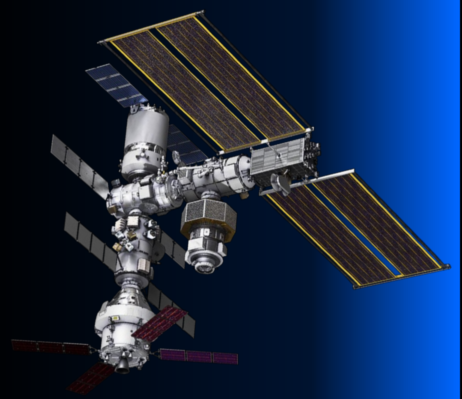
ARTEMIS VI



Orion and an airlock module launch on the SLS B1B rocket

Integration of the airlock with Gateway

ARTEMIS VII+



Crew to live and work on Gateway in a regular cadence of missions

All Artemis missions: crew transfer to the human landing system for surface expedition, unique science in NRHO, deep space logistics flights

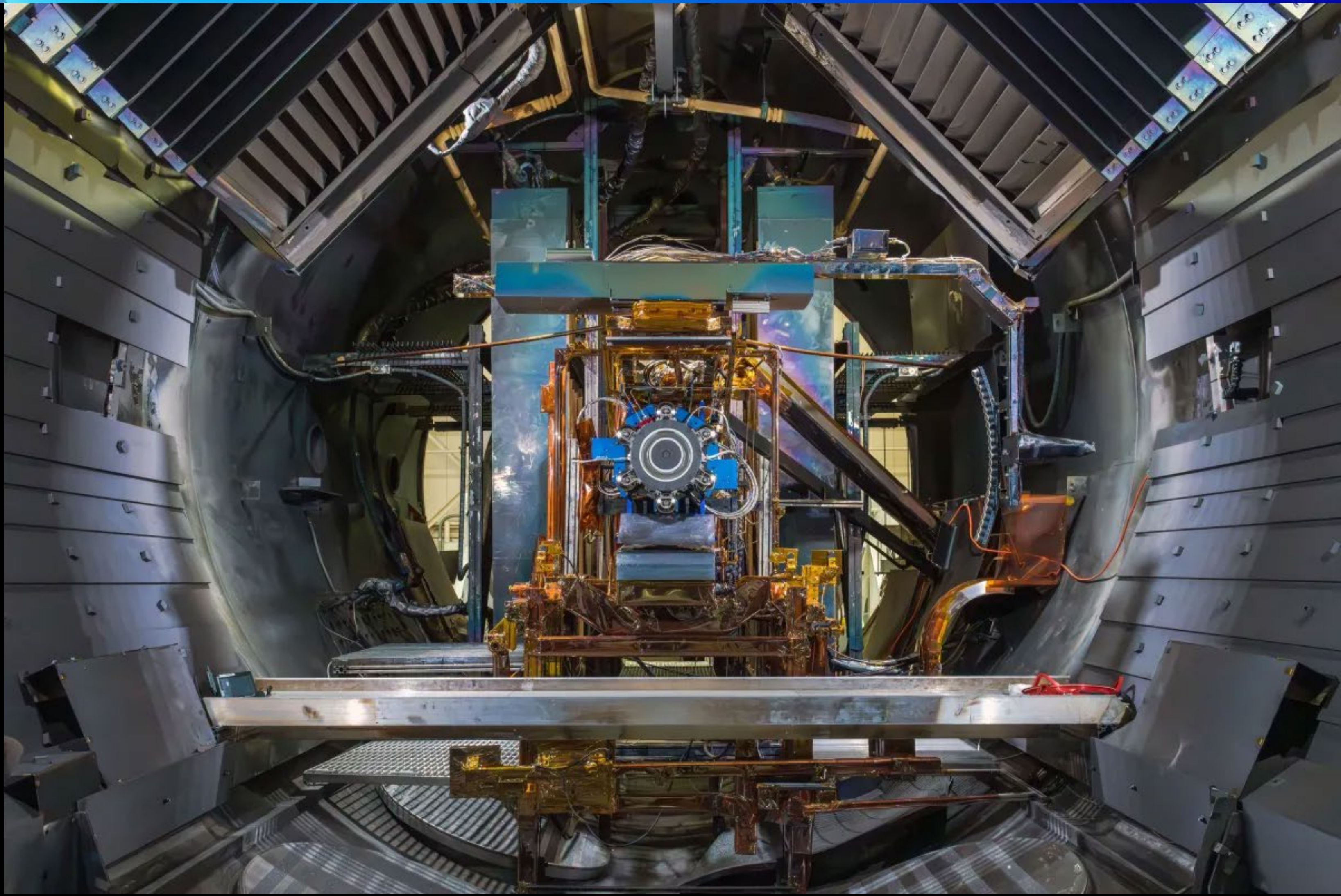
Gateway—Activities

Advanced Electric Propulsion System (AEPS)

- Qualifications testing ongoing at NASA's Glenn Research Center

Weld of Habitation and Logistics Outpost (HALO)

- Primary structure underway



The Advanced Electric Propulsion System qualification thruster inside one of the vacuum chambers at NASA Glenn's Electric Propulsion and Power Laboratory

xEVA and Human Surface Mobility

Content Description and Strategy

- Advance technologies associated with human mobility on the lunar surface
- Provide lunar capabilities and gain lessons learned and expertise that will support future Mars missions
- Collaborate with U.S. industry partners on developing lunar capabilities to increase productivity of relevant systems allowing crew to accomplish more during Artemis missions
    - Lunar spacesuits and related systems and tools
    - Lunar Terrain Vehicle (LTV), an unpressurized lunar rover
    - Pressurized Rover for longer duration lunar exploration
- Integration of lunar surface mobility systems provided by multiple partners to enable multiple combinations and possible mission profiles for increased capability on future missions

Artist's Concept

Artist's Concept

xEVA and Human Surface Mobility Program—Activities

Extravehicular Activity (EVA) Spacesuits, Tools, and Vehicle Interfaces that include advanced safety features, more flexibility, and support a larger range of the astronaut population

- NASA has selected Axiom Space and Collins Aerospace to advance spacewalking capabilities in low-Earth orbit and on the Moon
    - Axiom Space will develop a next generation Artemis spacesuit and supporting systems, and demonstrate their use on the lunar surface during Artemis III
    - Collins Aerospace will develop a spacewalking system for use on the International Space Station

White cover layer of the Axiom Extravehicular Mobility Unit (AxEMU) spacesuit prototype

Lunar Terrain Vehicle (LTV)

NASA has received proposals for provision of Lunar Terrain Vehicle services and is in the process of reviewing them

The Pressurized Rover team is developing system requirements toward a pressurized rover that can support both crewed missions and uncrewed phases by remote operation

Artist’s concept

Human Landing System

Content Description and Strategy

- Provide the transportation service that will take astronauts from lunar orbit to the surface and back again safely
- Both contractors (SpaceX and Blue Origin) use architectures reliant on the management of cryogenic fuel—SpaceX with liquid methane and Blue Origin with liquid hydrogen. Both use in-space propellant transfer, another key area of technology development for HLS.

July 28, 2023: Full-pressure test of the newly installed Starship flame deflector, part of the redesigned orbital pad at SpaceX's Starbase in Boca Chica, Texas.

September 12, 2023: John Couluris, Blue Origin Senior Vice President for Lunar Transportation, and Lisa Watson-Morgan, NASA HLS Program Manager, stand in front of a New Glenn fairing at Blue Origin's facility in Cape Canaveral, Florida. New Glenn will be the launch vehicle used in Blue Origin's HLS mission architecture.

Human Landing System—Activities

SpaceX

- Several milestones completed including a vacuum-optimized Raptor performance test that successfully confirmed the engine can be started in the extreme cold conditions resulting from extended time in space
- Completed their second Starship flight test and are moving quickly towards their third, which will include a propellant transfer demonstration

The 281-second throttle test demonstrated the engine's ability to meet the demands of a descent burn to the lunar surface. Credit: SpaceX

Blue Origin

- Mockup delivered
- Several reviews and contract milestones upcoming

Full-scale engineering mockup showcases two elements of the National Team's multi-element architecture—the Ascent Element and Descent Element. Credit: Blue Origin

Summary

- Artemis I mission was a successful flight demonstration of a crew capable vehicle traveling around the Moon and returning safely to Earth
- Significant content is currently in work to build upon that success with the Artemis II, Artemis III, and Artemis IV missions all planned to occur within the next 4 fiscal years
- Aligning Artemis programs to balance and optimize a funding profile with adjusted mission dates
- Completion of a defined architecture for lunar and Mars exploration will inform out year budget development and demonstrate a feasible plan
- ESDMD is leveraging work across NASA Mission Directorates to drive the mission forward:
  - Science and technology payloads delivered to lunar surface by Commercial Lunar Payload Services
  - STMD provided technologies to buy down risk for cislunar activities
  - SMD science operations hosted on Gateway and SMD actively defining lunar surface science priorities
  - SOMD platforms are aligned to develop, build, operate, and test capabilities to enable Moon to Mars missions

Segment Order and Presenters

- Mars, Entry Descent, and Landing: ELD Systems Capability Lead) - Michelle Munk, Michael Wright
- In-space Propulsion & Power: In-Space Transportation Systems Capability Lead) - John Dankanich
- Nuclear Propulsion: Nuclear Portfolio Manager in STMD - Anthony Calomino
- On-Orbit Servicing: RPOC Systems Capability Lead - Bo Naasz
- Cryogenics: In-Space Transportation Systems Capability Lead) - John Dankanich
- ISRU (gas and solid): ISRU Systems Capability Lead - Jerry Sanders, Julie Kleinhenz

Michelle Munk, Michelle.M.Munk@nasa.gov
Mike Wright, Michael.J.Wright@nasa.gov

MARS ENTRY, DESCENT & LANDING

- Major advancements over last 10 years:
  - Mars 2020: Landed mass of 1,050 kg, use of Terrain Relative Navigation to land at hazardous site
  - LOFTID Earth flight test of 6-m hypersonic inflatable aerodynamic decelerator (HIAD) at Mars-like conditions
  - Supersonic Retropropulsion ignition demonstrated by SpaceX booster return; cold gas wind tunnel testing and DOE supercomputing CFD demonstration
  - Aeroshell instrumentation on MSL and M2020: aero, aerothermal model improvement and validation
  - [Development of 3D woven thermal protection systems to TRL6; establishment of domestic PICA TPS source]

- Current TRL & relevance to NASA human exploration
  - Viking-style EDL system and skycrane: TRL9 but limited to ~2-3 t (not relevant to human exploration)
  - Terrain Relative Navigation: TRL9 at Mars
  - HIAD at 6 m scale: TRL7 (flexible TPS and inflatable structure components)
  - Supersonic Retropropulsion: TRL3
  - Aeroshell instrumentation: TRL9
  - Aero, aerothermal model: MRL4-6 (varies with phenomenon)
  - [3D woven thermal protection systems: TRL6]
  - [PICA-D: TRL6, being implemented on SRL]

- Current major technical obstacles in development
  - Scale-up of systems to land ~25 t of payload; full-scale (18 m) flight tests at Earth (hypersonic-to-supersonic transition) are very costly but necessary for validation
  - Integrated GN&C during EDL for 50 m landing precision
  - Knowledge of retropropulsion aero forces on vehicle
  - Understanding of Mars plume surface interaction effects
  - Ability to predict system failure modes
  - Computing power to enable timely analysis and human certification

- Outlook for technology development in the next 10 years (*they also asked for estimated date for when we will reach TRL 6, if relevant*)
  - Mars Sample Return will use Viking-heritage EDL to land >2 t (no relevant system tech dev; may observe PSI)
  - Terrain Relative Navigation, LIDAR velocimetry to be demonstrated at Moon in 2024+; expect hazard detection by 2026. Xogdor closed-loop Earth testing platform (2025).
  - Earth flight test of HIAD at 10.6-m scale, increased load planned for 2026 by ULA (PPP with NASA)
  - [3D woven TPS: return to Earth on MSR EES (2031+)]
  - [PICA-D: Mars entry on SRL (2028+); Titan entry 2034]

[ ] = not directly applicable to current human Mars approach

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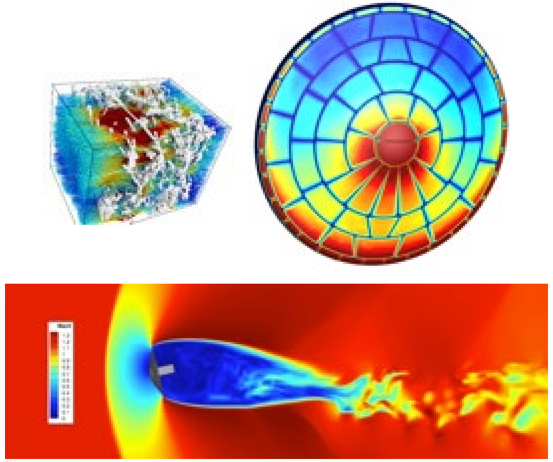
Mike Wright, Michael.J.Wright@nasa.gov

Current/Recent STMD Investments to Achieve ~25 t Mars Landings

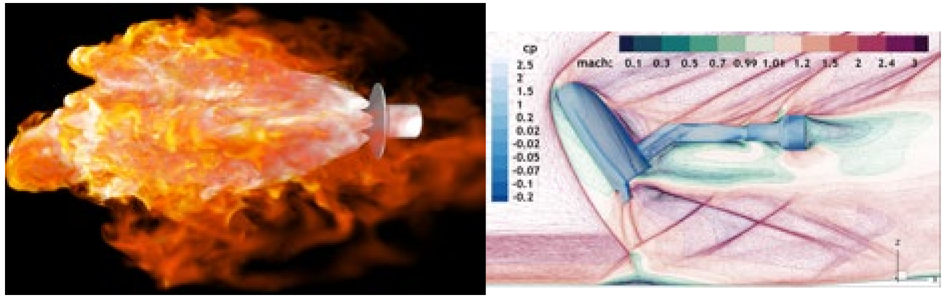
LOFTID
6m inflatable aeroshell test with United Launch Alliance (ULA) – Nov 2022

***SPLICE**
Precision Landing/Hazard Detection sensor, computing, and algorithm development, flight testing, and commercialization

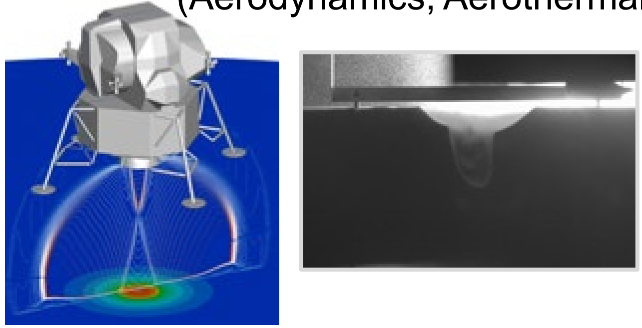


Entry Systems Modeling (ESM)
Advancing core capabilities and reducing mission risk through validation (Aerodynamics, Aerothermal, TPS, GN&C)

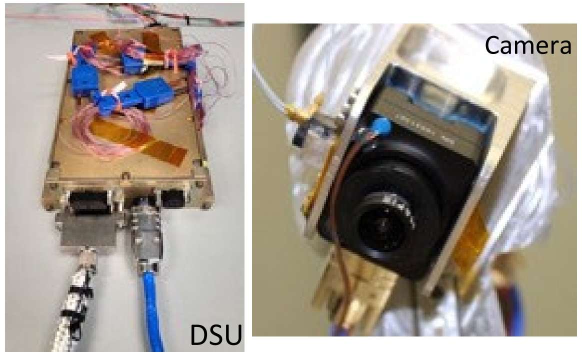
MEDLI-2 (complete)
Heating and pressure sensors on Mars 2020 aeroshell; provided aero/aerothermal model validation data, deep-dive analysis complete



Descent Systems Study
Mid L/D configuration,
HIAD & SRP testing FY22/23



***Plume Surface Interaction (PSI) Mini-Suite**
Flight instrument maturation to measure PSI phenomena; in HLS vacuum ground test (2024)



***SCALPSS 1.0 and 1.1**
Stereo Cameras to measure Plume Surface Interaction under CLPS landers (2024)

Early-Stage investments such as SBIR and academic efforts contribute to most projects shown

**Orange = Demonstration for Lunar missions in Near Term; Lunar-focused investments feed forward directly to Mars*

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In-Space Propulsion

- Major advancements over last 10 years

- Advanced Manufacturing transformed propulsion system development
  - Shorter cycle times
  - Lower cost
  - Enables advanced thermal and structural performance
- Reusability of launch propulsion systems
- First All Electric Propulsion NASA Mission, Psyche
- Magnetic Shieling for Hall Effect Thrusters
- General proliferation of Electric Propulsion (i.e. more EP systems flown in the past 2 years than all combined spacecraft previously)
- Green propulsion demonstration and operational systems (LMP-103 and ASCENT)
- Wide and disparate domestic industry base of smaller institutions

- Current TRL and relevance to NASA human exploration

- Large Scale Cryogenic Fluid Transfer, required for HLS and all Mars Transportation Options – TRL 4
- Solar Electric Propulsion (i.e. for Gateway) – TRL 5
- Xenon propellant transfer / resupply, desired for gateway and required for NEP and SEP Mars Transportation Options – TRL 3
- Nuclear Thermal Propulsion – TRL 2 (With HALUE)
- Nuclear Electric Propulsion – TRL 2 (Most elements significantly higher)

- Current major technical obstacles in development

- Resources for cross-cutting capability investments versus specific mission systems
- Qualification, reliability demonstration, and timely transitions to flight (i.e. the pace of innovation vastly exceeds traditional system lifecycles)
- In-Situ Resource Utilization propellant production capability at relevant scale
- Plume Surface Interaction

- Outlook for technology development in the next 10 years

Wide range of disparate new propulsion systems to the market

- New Start-up Company Systems at all scales
- Demonstration of nuclear propulsion
  - Nuclear Thermal Propulsion
  - Nuclear Electric Propulsion
- Potential elimination of hydrazine for common applications
  - Transition to green propellant alternatives
- Flight of the Mars Ascent Vehicle (MAV) for Mars Sample Return
- In-Space refueling, potentially depots
- Reliable high performance SmallSat propulsion

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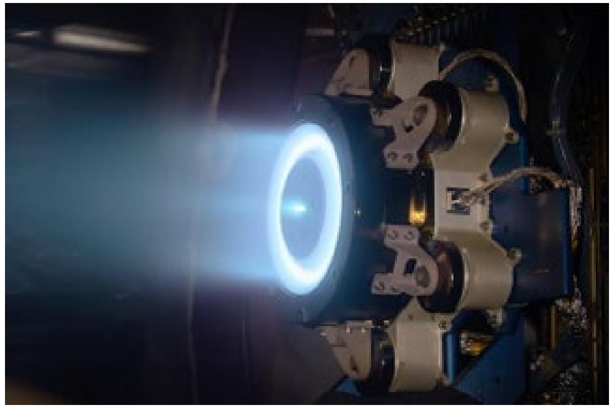
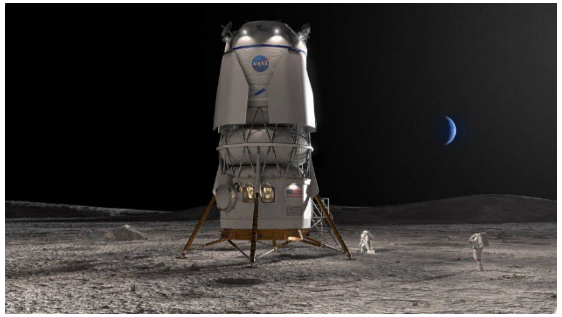
In-Space Propulsion


Advanced Electric Propulsion System:
12.5kW Magnetically Shielded Thruster


SpaceX Starlink Train

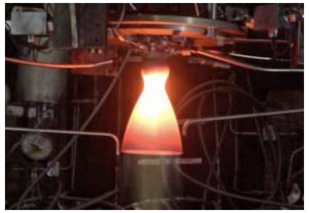

Blue Origin National Team
Human Landing System


Blue Origin BE-4 engine testing


3D Printed Propulsion Systems


Psyche All Electric
Propulsion Spacecraft

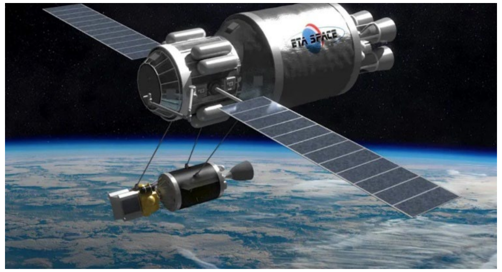

NEXT-C Mounted on the
DART Spacecraft


TALOS for CLPS


SpaceX StarShip


Mars Ascent Vehicle Mockup

DARPA DRACO NTP


Eta Space Cryo Depot

Dr. Anthony Calomino, anthony.m.calomino@nasa.gov

Space Nuclear Propulsion

- **Major advancements over last 10 years since Daniels/Lunine report**
  - **Nuclear Thermal Propulsion**
    - Fuels, materials and fabrication methods have matured to make a 900 sec Isp engine feasible – particularly in carbide fuel forms and reactor moderator materials for the use of LEU fuels
    - Advanced design concepts for an integrated engine funded through industry engagements
    - Continued R&D investments in hydrogen propellent long term storage
  - **Nuclear Electric Propulsion**
    - Same advances for terrestrial power fuels, materials and fabrication methods are applicable to NEP reactor subsystems operating at lower temperatures
    - Agency investments in FSP have direct application to critical NEP subsystem development
    - Ability to leverage electric thruster technology
    - Investment in Brayton power conversion systems

- **Current TRL and relevance to NASA human exploration**

Nuclear Thermal Propulsion Overall TRL 3			
Subsystem	**TRL**	**Subsystem**	**TRL**
Fuels	4	Non-nuclear engine	4
Reactor & Reactor Control	3	Thermal Management	4
CFM	4	Thrusters	4

Nuclear Electric Propulsion Overall TRL 3			
Subsystem	**TRL**	**Subsystem**	**TRL**
Fuels	4	Power Management	4
Reactor & Reactor Control	4	Thermal Management	5
CFM	4	Thrusters	4
Power Conversion	3		

- **Current major technical obstacles in development**
  - **Nuclear Thermal Propulsion**
    - High reactor operating temperatures (>2800K)
    - Power balance modeling and operations
    - Long-term storage of cryogenic propellants
    - Regulatory challenges for space nuclear systems
  - **Nuclear Electric Propulsion**
    - Long-term operational reliability
    - Subsystems needs to be scaled orders of magnitude in power
    - Complex system operation and lack of test experience
    - Integrated system complexity of five critical subsystems
    - Regulatory challenges for space nuclear systems

- **Outlook for technology development in the next 10 years** (*they also asked for estimated date for when we will reach TRL 6, if relevant*)

  Outlook is promising for continued nuclear propulsion system development with interagency and industry engagement
  - **Nuclear Thermal Propulsion**
    - NASA teamed with DARPA for the Demonstration Rocket for Agile Cislunar Operations (DRACO): Targets a NTRE flight demo as early as FY2028
    - Operational system maturity and risk reduction test in mid-2030s
  - **Nuclear Electric Propulsion**
    - Cooperating with USSF on Joint Energy Technology Supplying On-Orbit Nuclear Power NEP project
    - Concept Design for NEP demonstration stage (10 kWe) critical technology elements designs in the early 2030's
    - Possible large-scale NEP Risk reduction testing in the early 2030's

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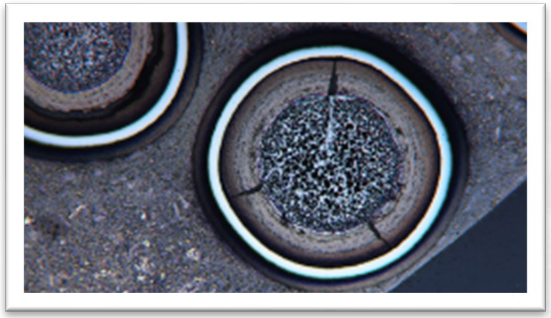
Space Nuclear Propulsion

Artists Conception: DARPA for the Demonstration
Rocket for Agile Cislunar Operations (DRACO) NTRE Flight Demo

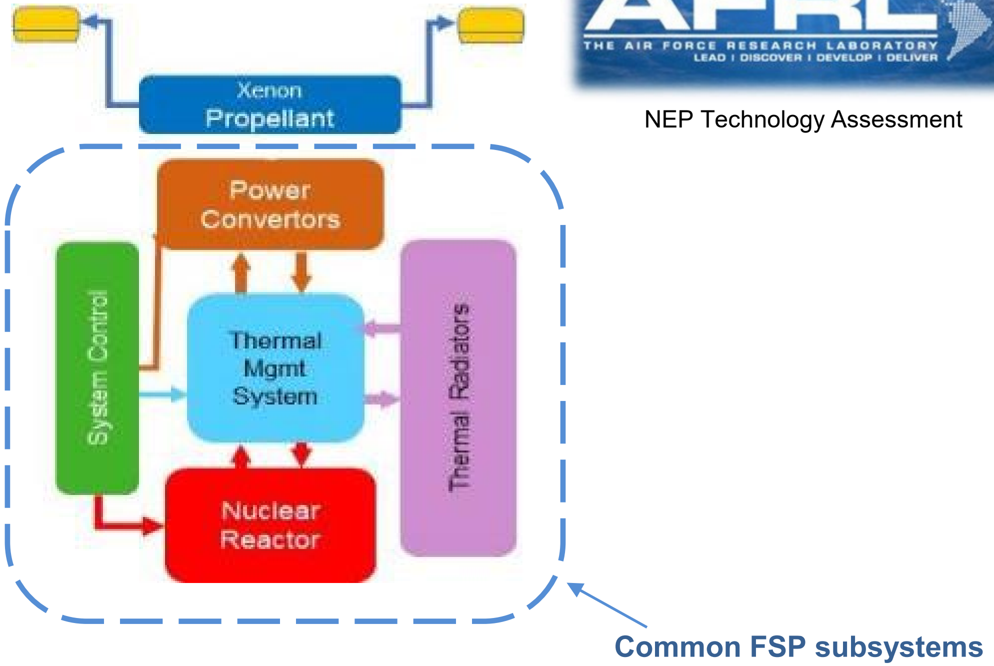
Above: NEP Conceptional Vehicle; Below: NEP major subsystems

NEP Technology Assessment



Nuclear Propulsion Fuels Development

Nuclear Fuel Materials Testing



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On-Orbit Servicing

Major advancements over last 10 years – After the Space Shuttle and crew performed final crewed Hubble servicing in LEO in 2009, including instrument upgrade and repair (card-level replacement), and spacecraft bus module replacement, Great Observatory focus shifted to fully robotic servicing, with eye towards new observatories at the Sun-Earth Lagrange Point 2 (SEL2). Several foundational capabilities were lacking, including commercially available robotic manipulation systems, rendezvous, proximity operations, and capture (RPOC) systems, and fluid transfer systems. Customer confidence in these systems was virtually non-existent, and robotic on-orbit servicing was stuck in a "chicken-and-egg" situation, with neither servicers nor prepared clients available to demonstrate the next phase of robotic on-orbit servicing capabilities.

In 2010, the NASA On-Orbit Satellite Servicing Study identified refueling as high-priority, near-term application of these foundational capabilities, and the Robotic Refueling Mission used ISS and Dextre robot in three flights (2011-2018) to demonstrate advanced robotic manipulation and fluid transfer techniques. In 2016, the Raven ISS payload demonstrated autonomous relative navigation and computer vision using visible, thermal, and 3D imagers.

Several commercial ventures were attempted in, and finally in 2019 and 2020 Space Logistics LLC Mission Extension Vehicles 1 and 2 performed fully commercial autonomous captures and life extension operations with two non-prepared commercial communications satellites at GEO

DARPA Geosynchronous Earth Orbit (GEO) robotic servicing mission concepts continued to push relocation and repair capabilities throughout the decade, and after reboots on mission concept and partner, will culminate in the operational RSGS/MRV robotic servicing mission, and the first US-built robot to operate in the space microgravity and vacuum environment.

On a similar trajectory, NASA's servicing Technology Demonstration Mission OSAM-1 has developed two variations of commercially provided robotic manipulators: a) 2m-class arms to demonstrate fully robotic on-orbit servicing in LEO, including challenging capture and refueling operations; and b) commercial SPIDER payload using a 5m-class arm to demonstrate the first-ever assembly of an aperture in space.

Current TRL and relevance to NASA human exploration – ISS was assembled and has been maintained by human and robots for decades now. A significant portion of the external maintenance work is completed by robots controlled from Earth and with no on-orbit crew intervention. Cargo is routinely delivered to ISS, with RPOC and robotic unloading and replacement of hardware modules fully operational (TRL 9) in Low Earth Orbit. ISS astronauts and robotics continue to maintain the station, and commercial cargo and crew programs advance key autonomous RPOC capabilities and demonstrate the value of a service-based approach.

Future human exploration will continue the use of servicing capabilities. Commercial LEO Destinations will continue to need crew and cargo delivery capabilities, and will support replacement of external hardware. They will likely also require refueling. Lunar and Mars exploration will also require assembly and servicing capabilities to enable a long-term sustainable presence on the moon, and increased performance and volume, and reuse of Mars transit ships.

Current major technical obstacles in development –

Robotic manipulation systems require more demonstration and utilization in space to establish an affordable supply chain. While more than 500 RPOD events have been completed worldwide, these events are isolated to a few providers. For both areas, an increase in supply via maturation of new providers is necessary to enable increased utilization. While storable refueling has been completed on ISS (by the Russians) challenges remain in fluid transfer systems, especially for bi-prop and pressure regulated, Xenon, high pressure, and cryogenic fluids.

Client-side demand will grow with increased availability and reduced cost, but also requires development of standards and system-level demonstrations to increase trust and confidence. Additionally, space systems currently fail to adequately consider use of servicing approaches, and none of our programmatic tools, solicitations, life-cycle costing tools, etc. properly account for the benefits of servicing.

Outlook for technology development in the next 10 years –

TRL of servicing outside of LEO is much lower, but efforts on Gateway will soon have them at TRL 9 in cislunar space, as well. The Gateway ESPRIT element, provided by the European Space Agency, will conduct refueling of Gateway's Power and Propulsion Element (the first ever *operational* refueling of a US-built propulsion system.) The Canadian Space Agency-provided Canadarm 3 on Gateway will use increased levels of autonomy over the ISS robotics systems and will provide payload manipulation services there.

On the client side, NASA's Roman Space Telescope, leveraging these capability advancements, has been "prepared" for robotic servicing (designed with interfaces specifically designed for RPOC and refueling). Next up, the Habitable Worlds Observatory is forming architecture working groups, and will be designed for planned instrument upgrade via robotic servicing at SEL2.

Additionally, the US Space Command has issued a challenge to make future spacecraft completing "Dynamic Space Operations" refuelable. This pressure will likely result in increased TRL and availability of commercial servicing capabilities

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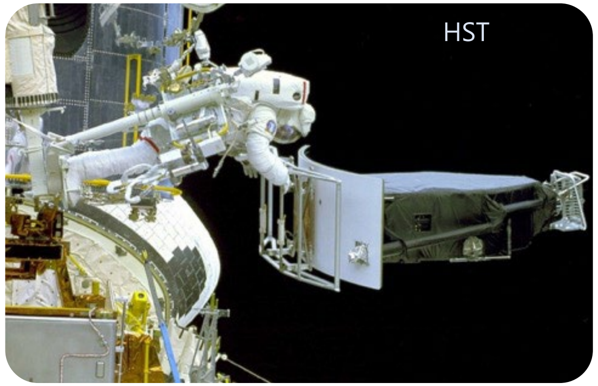
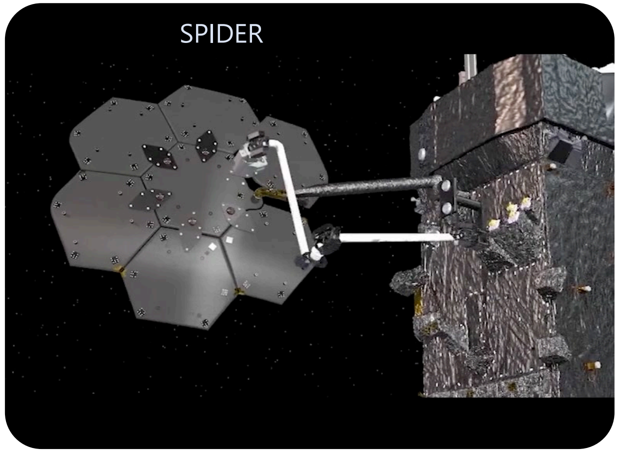
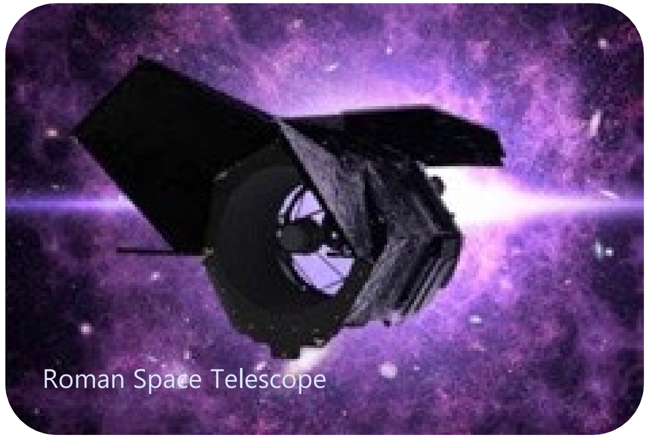
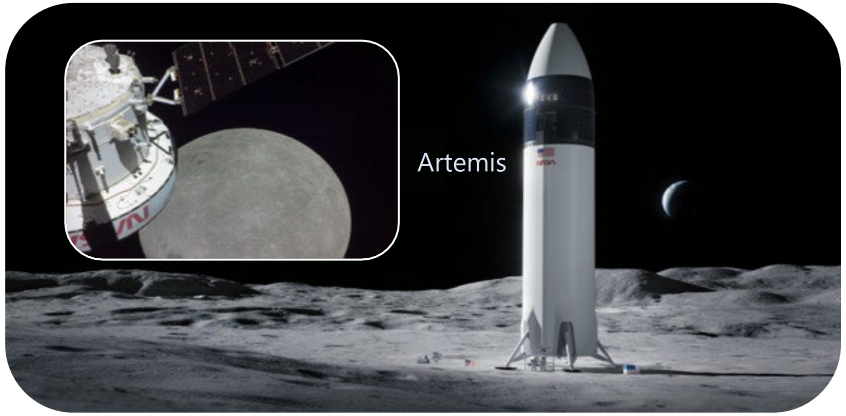
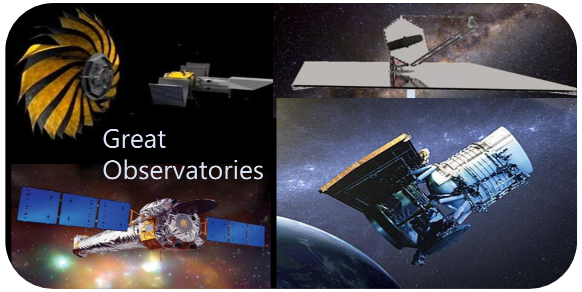
On-Orbit Servicing

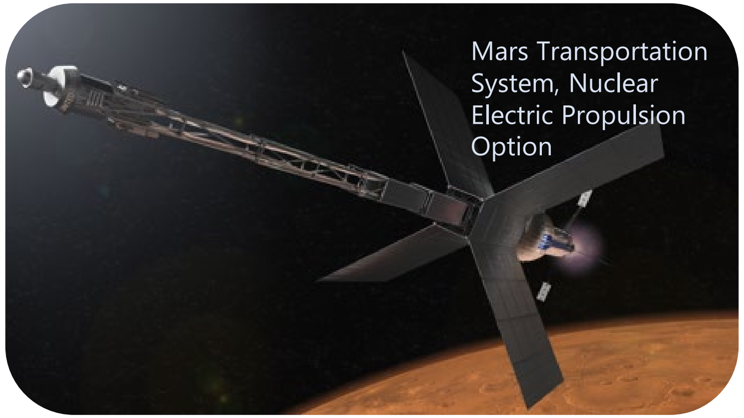












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Cryogenics (Cryogenic Fluid Management)

- Major advancements over last 10 years

- Matured a portfolio of cryogenic fluid management elements
  - Critical components
  - High-lift Cryo Cooler Systems: 90k and 20k
  - Insulations, coatings and structures for optimized thermal performance
  - Propellant mass gauging
  - Reduced boiloff architectures
- Completed multiple integrated system ground demonstrations
  - Propellant Transfer
  - No-vent tank filling
  - Mixing processes
- High Performance Cryogenic Fluid Modeling

- Current TRL and relevance to NASA human exploration

CFM Critical Technology Gaps	Current TRL	CFM Critical Technology Gaps	Current TRL
Low Conductivity Structures	6	Advanced External Insulation	4
High Vacuum Multilayer Insulation	6	Automated Cryo-Couplers	4
Sun Shields (deployment mechanism)	5	Cryogenic Thermal Coating	4
Tube-On-Shield BAC	5	High Capacity, High Efficiency Cryocoolers 90K	4
Valves, Actuators & Components	5	Soft Vacuum Insulation	3
Vapor Cooling	6	Structural Heat Load Reduction	3
Propellant Densification	5	Propellant Tank Chilldown	4
Unsettled Liquid Mass Gauging	5	Transfer Operations	4
Sub-surface Helium Pressurization in Micro-g	5	High Capacity, High Efficiency Cryocoolers 20K	4
Line Chilldown (MPS, iRCS, Transfer)	5	Liquefaction Operations (MAV & ISRU)	4
Pump Based Mixing	5	Para to Ortho Cooling	4
Thermodynamic Vent System	5	Cryogenic Flow Meter	4
Tube-On-Tank BAC	5	Autogenous Pressurization in Micro-g*	4
Liquid Acquisition Devices	5		

Critical for In-Space Transportation, Sustaining Lunar Development Human Landing System (HLS) and future ISRU

- Current major technical obstacles in development

- Integrated system validation in the relevant environment (i.e. long duration microgravity testing required.
  - Technologies are highly interdependent
  - Majority of technologies are matured through ground system demonstrations

- Telemetry and high-fidelity data for model validation without data rights constraints

- Outlook for technology development in the next 10 years

Multiple funded opportunities for flight demonstration of a range of configurations and cryogenic fluid management technologies
- Tipping Points
  - SpaceX: Lare-Scale Cryo Settled Propellant Transfer (2024)
  - Lockheed Martin Cryo Demo Mission: 15 critical technologies (2025)
  - Eta Space LOXSAT-1: 10 CFM technologies for depots (2025)
  - ULA LOx/LH2 Smart Demo: 3 key technologies (2026)
- Human Landing Systems
  - SpaceX, Artemis 3: LOx/CH4 w/ propellant transfer (2025)
  - Blue Origin's National Team, Artemis V: LOx/LH2 w/ propellant transfer and long duration boiloff (2029)
  - Multiple interim demonstrations under HLS Development

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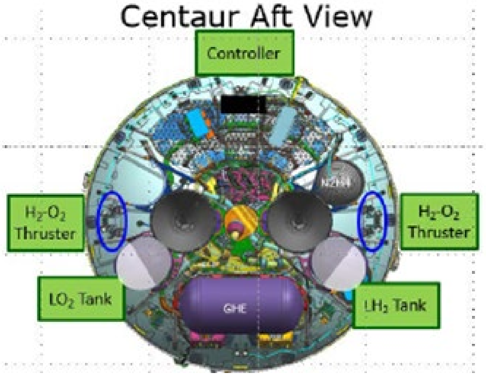
Cryogenics (Cryogenic Fluid Management)

SpaceX StarShip

Eta Space Cryo Depot

Lockheed Martin Cryo Demonstration Mission (CDM)

Blue Origin National Team Human Landing System



ULA Cryogenic Smart Propulsion Flight Demonstration

Gerald Sanders, gerald.b.sanders@nasa.gov

In Situ Resource Utilization (ISRU)

- Major advancements over last 10+ years
  - Lunar ISRU (2006 to 11 & 2019 to today)
    - 2 analog tests of full ISRU oxygen extraction systems
    - Broad portfolio of technology development and significant scale up in operations and complexity
    - Two flight missions (PRIME-1 & VIPER) and LIFT-1 RFI
  - Mars ISRU (2015 to today)
    - MOXIE flight demonstration on Mars
    - Mars atmosphere ‘full scale’ technologies and subsystems demonstrated in lab and Mars env.
    - Technologies for Mars water mining and Rodwell hardware demonstrated in lab and Mars env.

- Current TRL and relevance to NASA human exploration
  - Lunar ISRU
    - Oxygen from regolith (TRL 3-5); Metal extraction (TRL 3)
    - Water extraction (TRL 3 to 4); water collection & cleanup (TRL 4); water electrolysis (TRL 5+)
  - Mars ISRU
    - MOXIE flight demonstration (1/200th scale) on Mars
    - Atmosphere ‘full scale’ tech. and subsystems to TRL 5
    - Breadboard hardware for Mars water mining (TRL 4) and Rodwell subsurface ice extraction hardware (TRL 5)
  - ISRU is highly relevant to human exploration and commercial space but needs ‘pull’ usages/market

- Current major technical obstacles in development
  - Lack of data on the form, distribution, concentration of water on the Moon. VIPER is not enough
  - System level integration and testing to demonstrate performance, interfaces, and operations
  - Environmental test facilities that can support regolith and lunar/Mars pressure/temperature environments, esp. for icy regolith on the Moon or deep ice on Mars
  - Good simulants in large quantities to support technology & system advancement and prepare for flight
  - Actual lunar flight demonstrations of ISRU hardware that interacts with lunar regolith and environment

- Outlook for technology development in the next 10 years (*estimated date for when we will reach TRL 6*)
  - The outlook for lunar ISRU in the next 10 years is very good (assuming budget) for ground development and flight demonstrations; significant industry investment exists
    - TRL 6 with breadboard hardware in 3 years for oxygen from regolith and 4 to 5 years for metal extraction/purification
  - The outlook for Mars ISRU is moderate depending on budget priorities and the human Mars architecture.
    - TRL 6 with breadboard hardware is achievable in 3 yrs.
  - Need more missions to understand water on Moon & Mars

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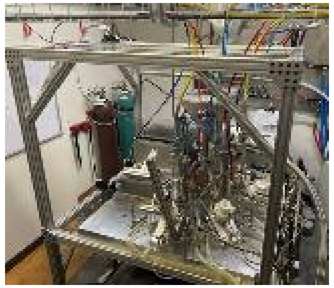
In Situ Resource Utilization (ISRU)

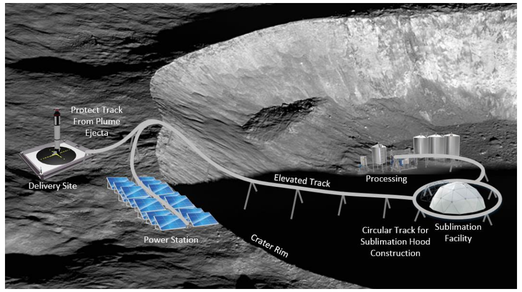

Oxygen from Mare Regolith – Carbothermal Reduction (2010)

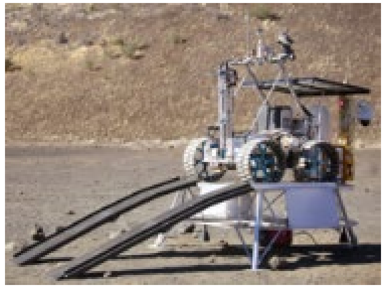
Oxygen from Mare Regolith – Molten Regolith Electrolysis (2009)


Oxygen from Highland Regolith – Carbothermal (2022)

Oxygen from Highland Regolith – Molten Regolith Electrolysis


Oxygen from Highland Regolith – Carbothermal (2022)

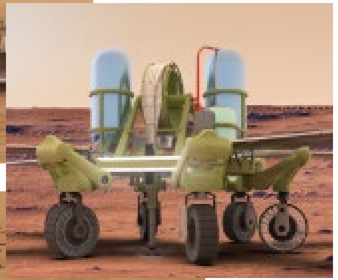


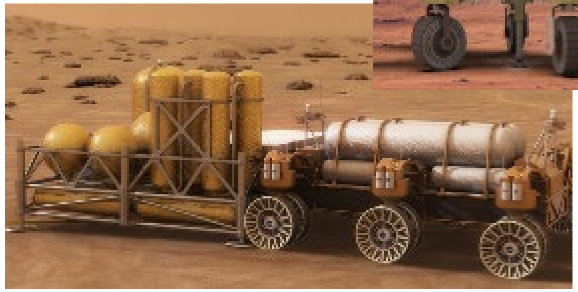

Resource Prospector Analog Demonstration (2012)

Lunar Ice Extraction Reactor (2020)


PRIME-1 Drill and Mass Spectrometer (2019)

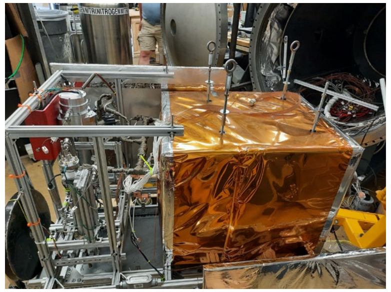
Lunar Ice Capture, Cleanup, and Electrolysis (2023)



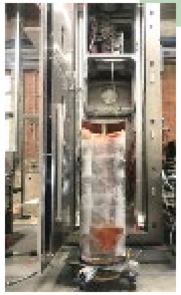



MOXIE CO2 Solid Oxide Electrolysis (SOE) (2018)


Full-scale SOE Stack (2020)


Full-scale Water SOE Stack (2022)


Mars CO2/Water SOE & CH4 Production (2022)

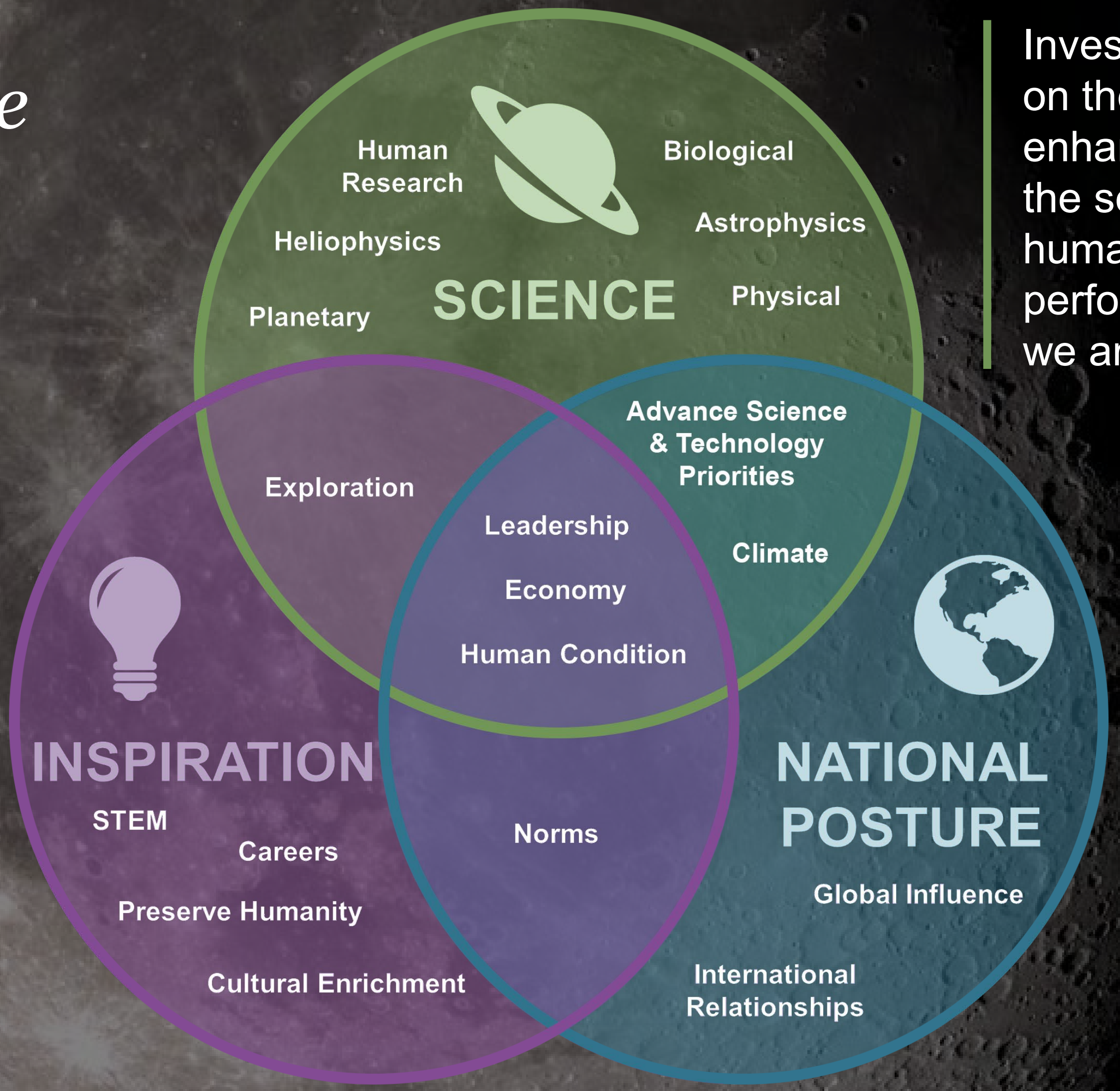

Redwater Mars Drill (2022)

Backup

Benefits to Humanity

Why We Explore

Investigations in deep space, on the Moon, and on Mars will enhance our understanding of the solar system, Earth, the human body, and how to perform new operations while we are out there exploring.



Accepting audacious challenges and succeeding through perseverance and tenacity in the face of adversity motivates current and future generations to dare mighty things.

What we choose to do, how we do those things, and who we do them with greatly impacts our place in the world today, our quality of life, and our possibilities for the future.

Exploration Systems Development Mission Directorate (ESDMD) Goals

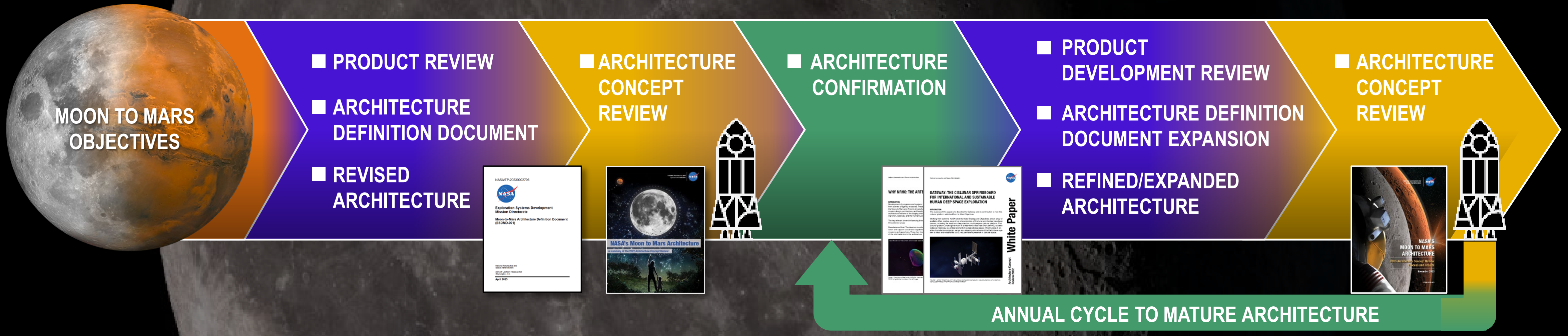
Meet the Agency's goals for human exploration by:

- Building a sustainable Artemis architecture that creates a lunar exploration plan and establishes a clear path to the human exploration of Mars
- Aligning with and supporting NASA's Moon to Mars objectives
- Moving toward a more affordable exploration crew transportation system that will enable a national launch capability
- Fostering high standards of program and project management
- Aligning Artemis programs to balance and optimize a funding profile with adjusted mission dates
- Collaborating with centers and committing to maintaining a highly-skilled and capable workforce
- Clearly communicating status and plans for all stakeholders

Moon to Mars Architecture

Evolutionary Architecture Process

Formulating architecture and exploration strategy based on objectives



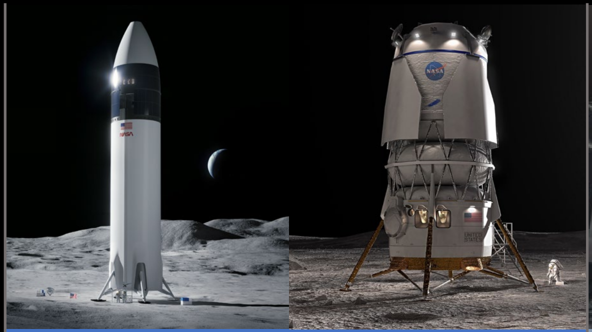
Key Components of the Approach

TRACEABILITY
Decomposition of Blueprint Objectives to executing Architecture elements

ARCHITECTURE FRAMEWORK
Organizational construct to ensure system/element relationships are understood and gaps can be identified

PROCESS AND PRODUCTS
Clear communication and review integration paths for stakeholders

Moon to Mars Implementation Strategy



Human Lunar Return

Initial capabilities, systems, and operations necessary to re-establish human presence and initial utilization (science, etc.) on and around the Moon.

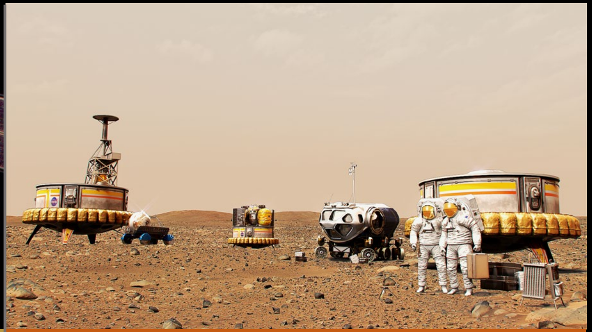
Focus for ACR 22

Foundational Exploration

Expansion of lunar capabilities, systems, and operations supporting complex orbital and surface missions to conduct utilization (science, etc.) and Mars forward precursor missions.

Sustained Lunar Evolution

Enabling capabilities, systems, and operations to support regional and global utilization (science, etc.), economic opportunity, and a steady cadence of human presence on and around the Moon.



Humans to Mars

Initial capabilities, systems, and operations necessary to establish human presence and initial utilization (science, etc.) on Mars and continued exploration.

Focus for ACR 23

Strategy and Architecture Office (SAO)

Content Description and Strategy

- Establishes an annual baseline process for review and assessment of the architecture aligned with annual budget cycle:
  - Aligns annual strategy analysis cycle (SAC) to culminate in an annual architecture concept review (ACR)
  - Incorporates technology and partnership evolutions into architecture planning
  - Publishes and updates products that elucidate the architecture, including the Architecture Definition Document (ADD)
- Conducts trade studies and to identify technologies gaps in the Moon to Mars architecture
- Supports pre-formulation activities and reviews that align elements to architectural needs
- Maintains technical integration required to support the Artemis missions and future exploration plans
- Supports in-house workforce across eight NASA centers, JPL, and 60 contractors
  - Develops strategies and identifies systems to feed into lunar sustainability and future Mars efforts
  - Develops and integrates technical, schedule, and cost for the Moon to Mars effort
- Coordinates international partner strategy and concept development, engagement, and pre-formulation activities

Architecture Concept Review 2023

Strategy and Architecture Office—Activities

The 2024 Fiscal Year will be first full, annual cadence for the new Architecture Concept Review

- The architecture team endeavors to ensure repeatability and identify lessons learned for subsequent cycles
- The volume of needed analysis, integration, and workload will be matched to available agency resources
- Our priority is producing quality assessments that can be supported programmatically in implementation while ensuring communication with and feedback from the NASA community and government, industry, academic, and international stakeholders

➢ Upcoming Events

Executive Council
Review of ACR23 Results
January 18, 2024

ACR23 Products Debut
ADD Revision A, White Papers
January 22, 2024

2024 Architecture Workshop
For International Partners
February 20, 2024

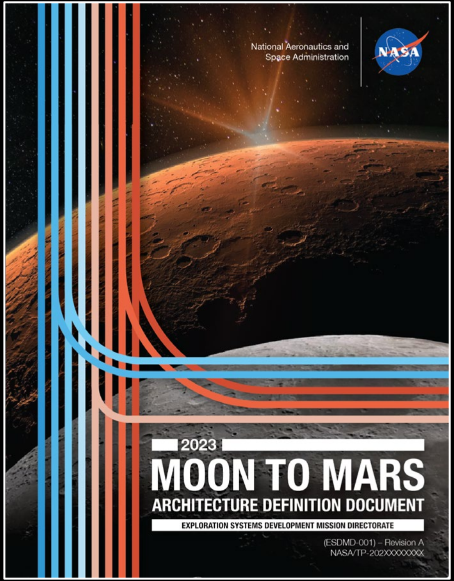
2024 Architecture Workshop
For Industry and Academia
February 22, 2024

➢ White Papers

- Mars Communication Disruption and Delay
- Mars Mission Abort Considerations
- Surface EVA Architectural Drivers
- Lunar Communications and Navigation Architecture
- Mars Surface Power Generation
- Lunar Logistics Drivers and Needs
- Safe and Precise Landing at Lunar Sites
- Exploration Lessons Learned from the Space Station
- Human Health and Performance for Mars Missions
- Lunar Site Selection
- Analytical Capabilities In-situ vs. Returned
- Round Trip Mars Mission Mass Challenges

Suggestion from 2023 Architecture Workshops

➢ ADD – Rev. A



Acronym List

ACD	Artemis campaign development
ACR	architecture concept review
ACSC	advanced cislunar and surface capabilities
AFRC	Armstrong Flight Research Center
AI&P	assembly, integration, and processing
ARC	Ames Research Center
ASI	Italian Space Agency
ATP	authority to proceed
Ax	Axiom Space
BOLE	booster obsolescence and life extension
CDR	critical design review
CECR	construction and environmental compliance and restoration
CESD	Common Exploration Systems Development
CFT	Crewed flight test
CLPS	commercial lunar payload services
CLV	commercial launch vehicle
CM	crew module
CMV	co-manifested launch vehicle
COF	construction of facilities
CPL	co-manifested payload
CSM	crew service module
CSA	Canadian Space Agency
DCR	design certification review
DDT&E	design development test and evaluation
DSL	deep space logistics
ECLSS	environmental control and life support system
EHP	xEVA and human surface mobility
EM	exploration mission
EMU	extravehicular mobility unit
ESA	European Space Agency
ESDMD	Exploration Systems Development Mission Directorate
ESM	European service module
ESPRIT	European Systems Providing Refueling Infrastructure and Telecommunications
EUS	exploration upper stage
EVA	extravehicular activity
FOD	Flight Operation Directorate
FRR	flight readiness review
GEDI	global ecosystem dynamics investigation
GERS	Gateway extravehicular robotics system
GNC	guidance navigation and control
GRC	Glenn Research Center
HALO	Habitation and Logistics Outpost
HB	high bay
HERA	human exploration requirements and architecture
HLS	human landing system
HRP	Human Research Program
HSFO	Human Spaceflight Operations
HTV	H-II transfer vehicle
I-Hab	International habitation module
ICPS	interim cryogenic propulsion stage
IGCE	independent government cost estimate
IP	international partner
IROSA	International Space Station roll-out solar array
ISP	in space production
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
JCL	joint confidence level
JSC	Johnson Space Center
KPLO	Korea Pathfinder Lunar Orbiter
KSC	Kennedy Space Center
LaRC	Langley Research Center
LVSA	launch vehicle stage adapter
LC	launch complex
LEO	low-Earth orbit
LETF	Launch Equipment Test Facility
LH2	liquid hydrogen
LM	Lockheed Martin
LN	liquid nitrogen
LOX	liquid oxygen
LOX/LCH4	liquid oxygen liquid methane
LRD	lunar relay development
LTV	lunar terrain vehicle
LV	launch vehicle
MCD	Mars Campaign Development
MD	Mission Directorate
ML	mobile launcher
MOU	memorandum of understanding
MPH	multi-purpose habitation
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NDS	NASA docking system
NG	Northrup Grumman
NRHO	near-rectilinear halo orbit
OGA	oxygen generation assembly
OSA	Orion stage adapter
PFP	program financial plan
PBR	president’s budget request
PDR	preliminary design review
PPBE	planning, programming, budgeting, and execution
PPE	power and propulsion element
R&D	Research and Development
RFP	request for proposal
RPSF	Rotation, Processing, and Surge Facility
RPOD	rendezvous, operations, and docking
SLC	space launch complex
SLD	sustaining lunar development
SLS	space launch system
SM	service module
SMD	Science Mission Directorate
SSC	Stennis Space Center
SOMD	Space Operations Mission Directorate
STEM	science, technology, engineering, and math
STMD	Space Technology Mission Directorate
TOSC	Test and Operations Support Contract
UCSD	University of California, San Diego
ULA	United Launch Alliance
USAF	United States Air Force
V&V	validation and verification
VAB	Vehicle Assembly Building
xEHR	exploration electronic health record
xEMU	exploration extravehicular mobility unit
xEVAS	exploration extravehicular activity services