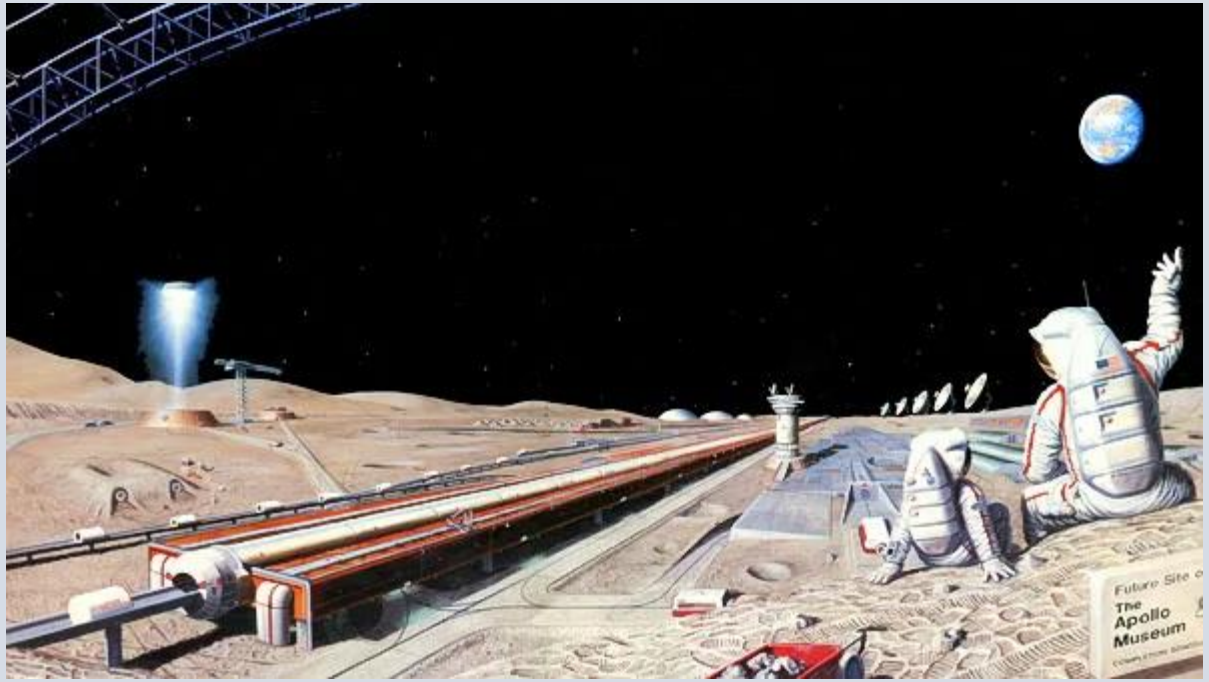


Human Exploration and Operations Committee

NASA Advisory Council

August 10, 2022

N. Wayne Hale, Jr.

HEO Committee meetings and Focus

- HEO Committee meetings:
  - Fact finding briefings from NASA HQ on reorganization
  - Virtual Joint meeting with Science Committee July 13, 2022
  - Virtual meeting July 20, 2022 to finalize recommendations & findings

- HEO Committee membership

Wayne Hale (chair)	Kwatsi Alibaruho
James Voss	George Sowers
Mark McDaniel	Doug Ebersole
Pat Condon	Lynn Cline
Mike Lopez-Alegria	Ellen Stofan (just appointed)
Nancy Ann Budden	Pat Sanders (ex officio)

HEO split into SOMD and ESDMD

- HEO committee continues to advise both at the current time
- Fact finding sessions indicate generally good organizational results
  - Both AAs and their organizations working smoothly together
- HEO committee plans to schedule additional meeting to gain clarification on organizational concerns:
  - Lack of single Artemis Program Manager
  - Integrated Systems Engineering and Integration
  - Risk Management decision making – Risk acceptance authority

Updates since March NAC meeting

- Commercial activities in LEO remain strong
  - ISS Crew and Resupply continuing
    - Concern about potential loss of NG Cygnus/Antares future
  - HEO Committee stands by recommendation for no gap in LEO human presence
    - Watching Commercial LEO Development organization/budget closely

- ISS continues to function well, and NASA utilization is important
  - Authorized to continue through 2030
  - Russian cooperation strong at the working level
    - Despite questions about leadership intention

Artemis Plans

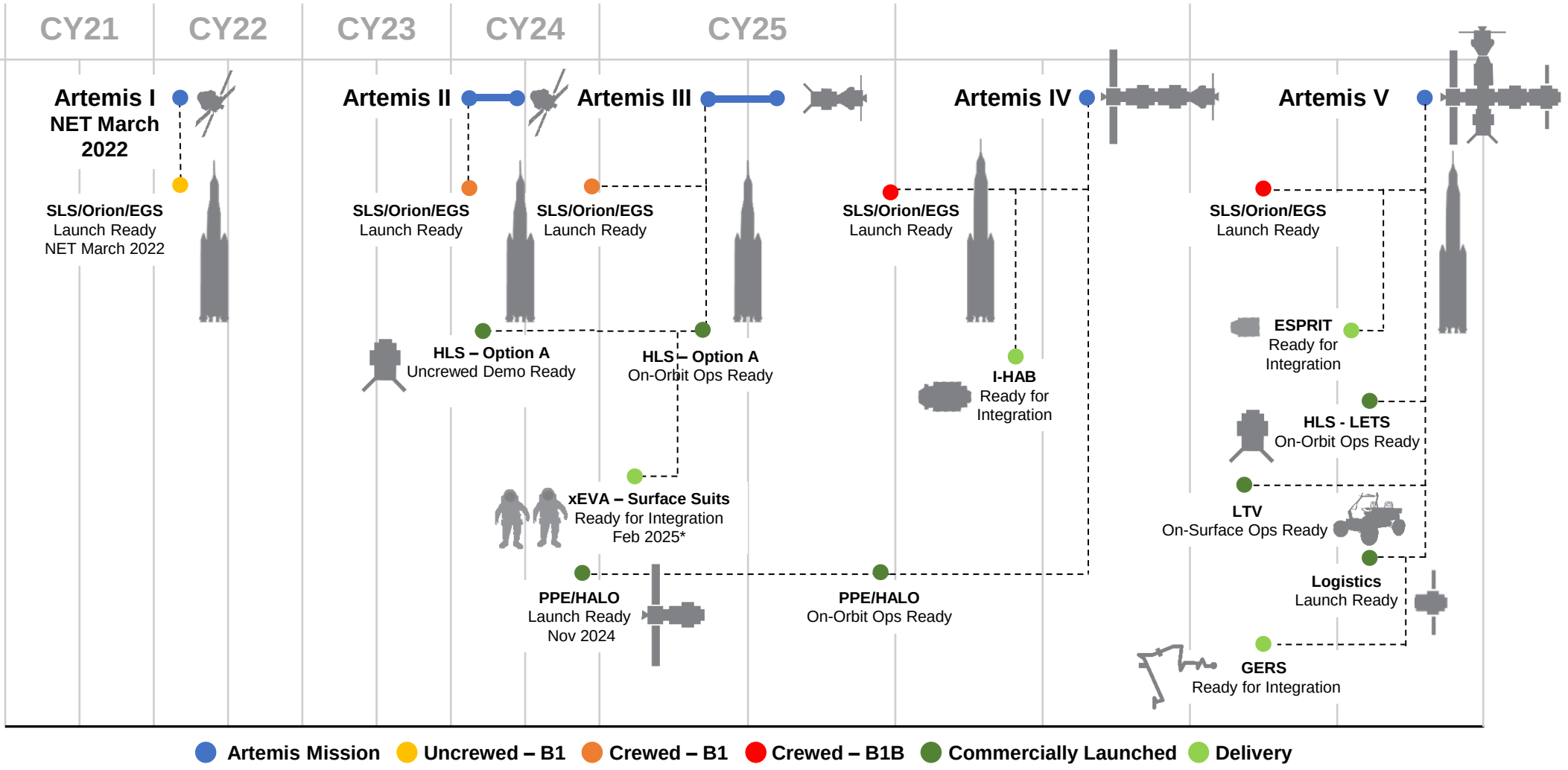
- Artemis I No Earlier Than August 29
  - Uncrewed mission to Lunar Distant Retrograde Orbit and return
  - Largely an engineering test but significant science objectives
- Artemis II 2024-ish
  - First crew mission, Lunar flyby with no orbit
  - Largely an engineering test but with significant science objectives
- HLS (SpaceX) Demonstration uncrewed Lunar Landing approx. 2024
- Artemis III 2025 (current plan)
  - Demonstration Lunar Landing with 2 crew, short stay
- Gateway initial assembly 2026
- Regular (Sustained) Human presence after 2026
- Notional Mars campaign starting later

Working Manifest for Technical Integration

Key Terminology:

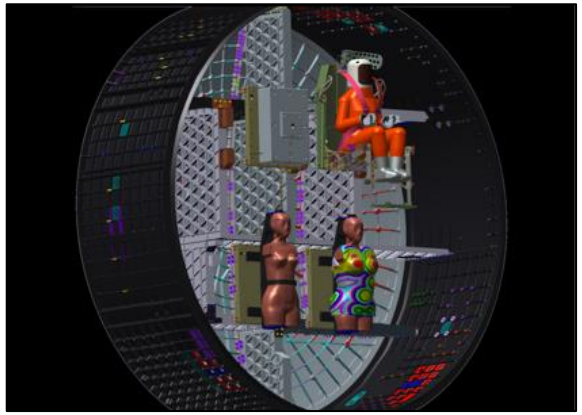
B1: Block 1 (SLS with ICPS)
B1B: Block 1B (SLS with EUS)
EGS: Exploration Ground Systems
ESPRIT: European System Providing Refueling, Infrastructure & Communications
EUS: Exploration Upper Stage
GERS: Gateway External Robotics System
HALO: Habitation and Logistics Outpost
HLS: Human Landing System
ICPS: Interim Cryo Propulsion Stage
I-HAB: International Habitat
LETS: Lunar Exploration Transportation Services
LTV: Lunar Terrain Vehicle
PPE: Power & Propulsion Element
SLS: Space Launch System
xEVA: Exploration Extravehicular Activity

***Date based on Government planning and estimates; not contract informed**



Artemis I Pressurized Payloads

Payloads that will fly inside of the Orion crew module, returning data during and after the mission



ESA Active Dosimeters *

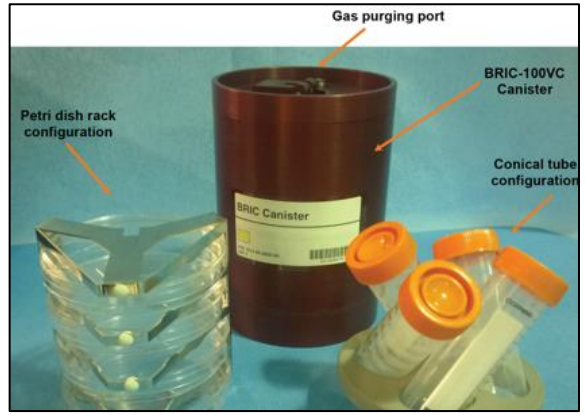
Radiation monitoring system that will fly up to 5 monitoring units

Crew Interface Technology Payload (CITP)

Creates an interactive experience between Orion and the public during the mission

Matroshka AstroRad Radiation Experiment (MARE) *

Radiation shielding Personal Protection Equipment (radiation vest) for astronauts



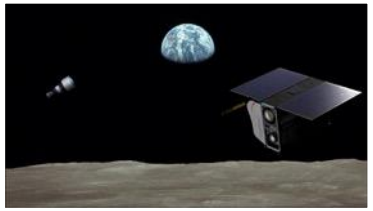
Bio-Experiment-1

Battery-powered life sciences payload for biology research beyond low-Earth orbit (LEO)

***International Collaboration**

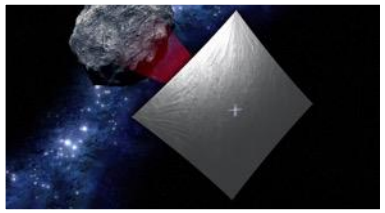
Artemis I Science Payloads

Science and technology investigations and demonstrations paving the way for deep space human exploration



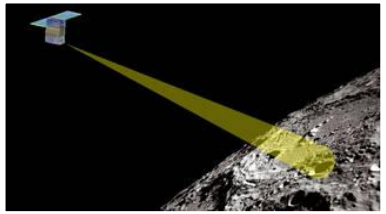
ArgoMoon *

Photograph the Interim Cryogenic Propulsion Stage (ICPS) CubeSat deployment, the Earth and Moon using HD cameras and advanced imaging software.



Near-Earth Asteroid Scout (NEA Scout)

Detect target NEA, perform reconnaissance and close proximity imaging.

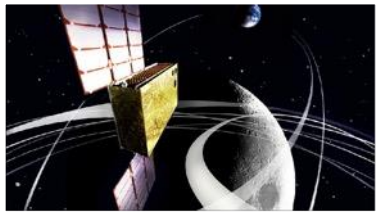


LunIR

Use a miniature high-temperature Mid-Wave Infrared (MWIR) sensor to characterize the lunar surface.

LunaH-Map

Perform neutron spectroscopy to characterize abundance of hydrogen in permanently shaded craters.

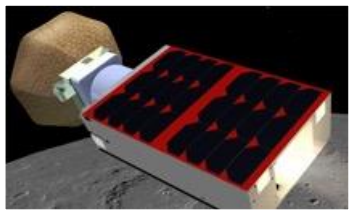


EQUULEUS *

Demonstrate trajectory control techniques within the Sun-Earth-Moon region and image Earth's plasmasphere.

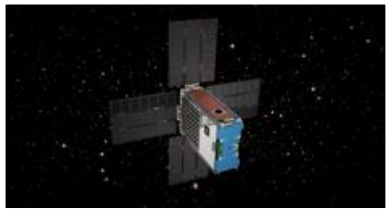
Team Miles

Demonstrate propulsion using plasma thrusters; compete in NASA's Deep Space Derby.



OMOTENASHI *

Develop world's smallest lunar lander and observe lunar radiation environment.

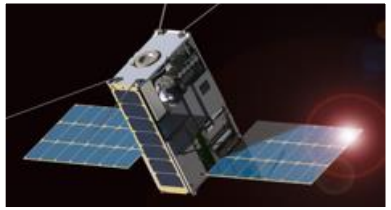


BioSentinel

Use yeast as a biosensor to evaluate the effects of ambient space radiation on DNA.

CubeSat to Study Solar Particles (CuSP)

Measure incoming radiation that can create a wide variety of effects on Earth.



Lunar IceCube

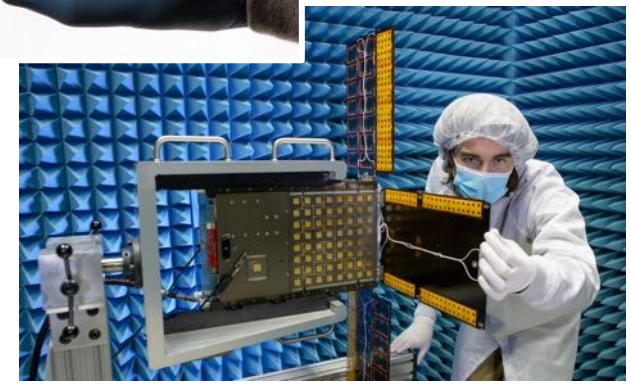
Search for water (and other volatiles) in ice, liquid and vapor states using infrared spectrometer.

*International Collaboration

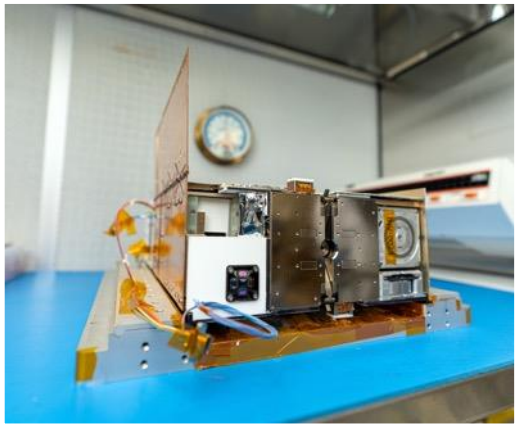
Artemis I CubeSats – additional information

BioSentinel

Use yeast as a biosensor to evaluate the effects of ambient space radiation on DNA.



Lunar IceCube

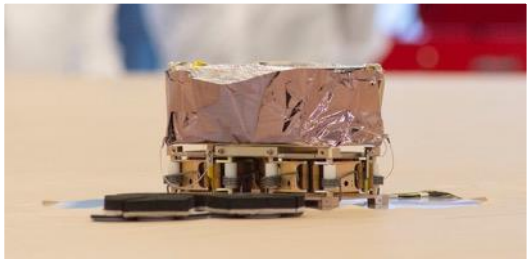


Search for water (and other volatiles) in ice, liquid and vapor states using infrared spectrometer.

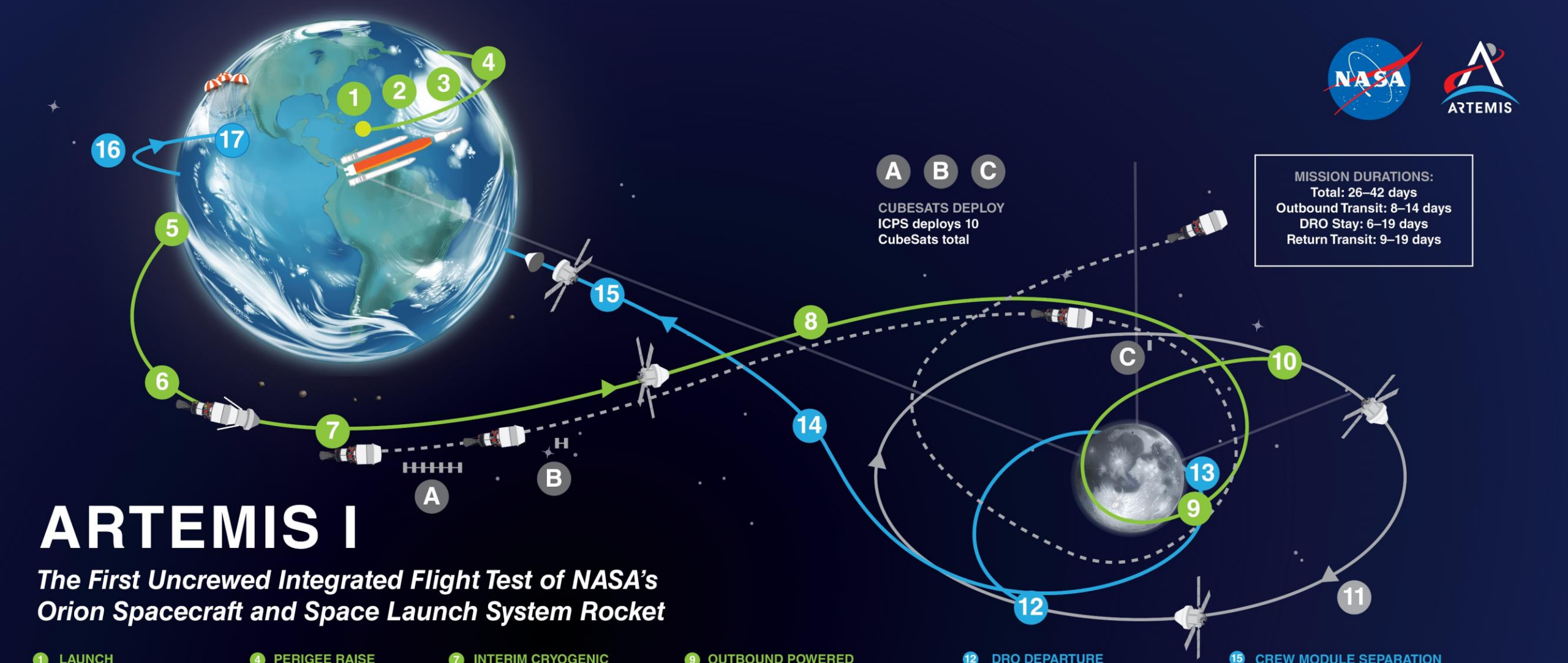
LunIR

Use a miniature high-temperature Mid-Wave Infrared (MWIR) sensor to characterize the lunar surface.

Near-Earth Asteroid (NEA) Scout



Detect target NEA, perform reconnaissance and close proximity imaging.

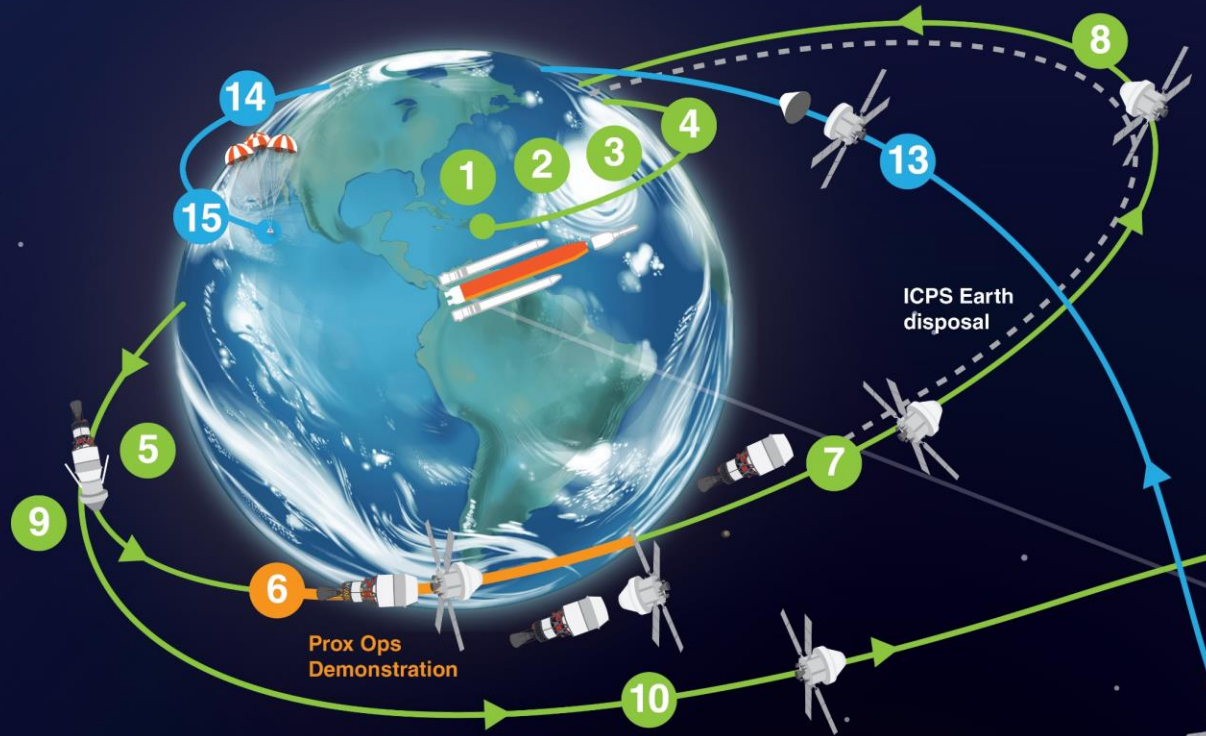


ARTEMIS I

The First Uncrewed Integrated Flight Test of NASA's Orion Spacecraft and Space Launch System Rocket

1. **LAUNCH**
   SLS and Orion lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **PERIGEE RAISE MANEUVER**
5. **EARTH ORBIT**
   Systems check with solar panel adjustments.
6. **TRANS LUNAR INJECTION (TLI) BURN**
   Maneuver lasts for approximately 20 minutes.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL**
   ICPS commits Orion to moon at TLI.
8. **OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS**
   As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).
9. **OUTBOUND POWERED FLYBY (OPF)**
   60 nmi from the Moon; targets DRO insertion.
10. **LUNAR ORBIT INSERTION**
    Enter Distant Retrograde Orbit.
11. **DISTANT RETROGRADE ORBIT**
    Perform half or one and a half revolutions in the orbit period 38,000 nmi from the surface of the Moon.
12. **DRO DEPARTURE**
    Leave DRO and start return to Earth.
13. **RETURN POWERED FLYBY (RPF)**
    RPF burn prep and return coast to Earth initiated.
14. **RETURN TRANSIT**
    Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere.
15. **CREW MODULE SEPARATION FROM SERVICE MODULE**
16. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
17. **SPLASHDOWN**
    Pacific Ocean landing within view of the U.S. Navy recovery ship.

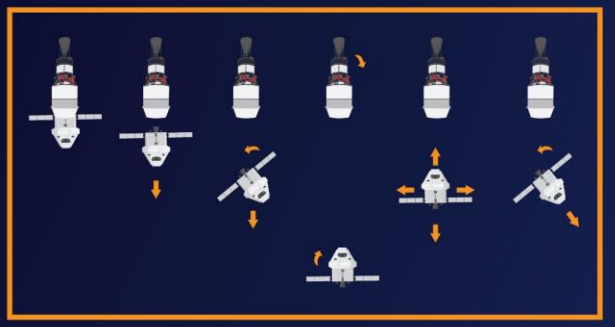
10/7/2021



ARTEMIS II

First Crewed Test Flight to the Moon Since Apollo

1. **LAUNCH**
   Astronauts lift off from pad 39B at Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **PERIGEE RAISE MANEUVER**
5. **APOGEE RAISE BURN TO HIGH EARTH ORBIT**
   Begin 24 hour checkout of spacecraft.
6. **PROX OPS DEMONSTRATION**
   Orion proximity operations demonstration and manual handling qualities assessment for up to 2 hours.
7. **INTERIM CRYOGENIC PROPULSION STAGE (ICPS) DISPOSAL BURN**
8. **HIGH EARTH ORBIT CHECKOUT**
   Life support, exercise, and habitation equipment evaluations.
9. **TRANS-LUNAR INJECTION (TLI) BY ORION'S MAIN ENGINE**
   Lunar free return trajectory initiated with European service module.
10. **OUTBOUND TRANSIT TO MOON**
    4 days outbound transit along free return trajectory.
11. **LUNAR FLYBY**
    4,000 nmi (mean) lunar farside altitude.
12. **TRANS-EARTH RETURN**
    Return Trajectory Correction (RTC) burns as necessary to aim for Earth's atmosphere; travel time approximately 4 days.
13. **CREW MODULE SEPARATION FROM SERVICE MODULE**
14. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
15. **SPLASHDOWN**
    Ship recovers astronauts and capsule.



PROXIMITY OPERATIONS DEMONSTRATION SEQUENCE

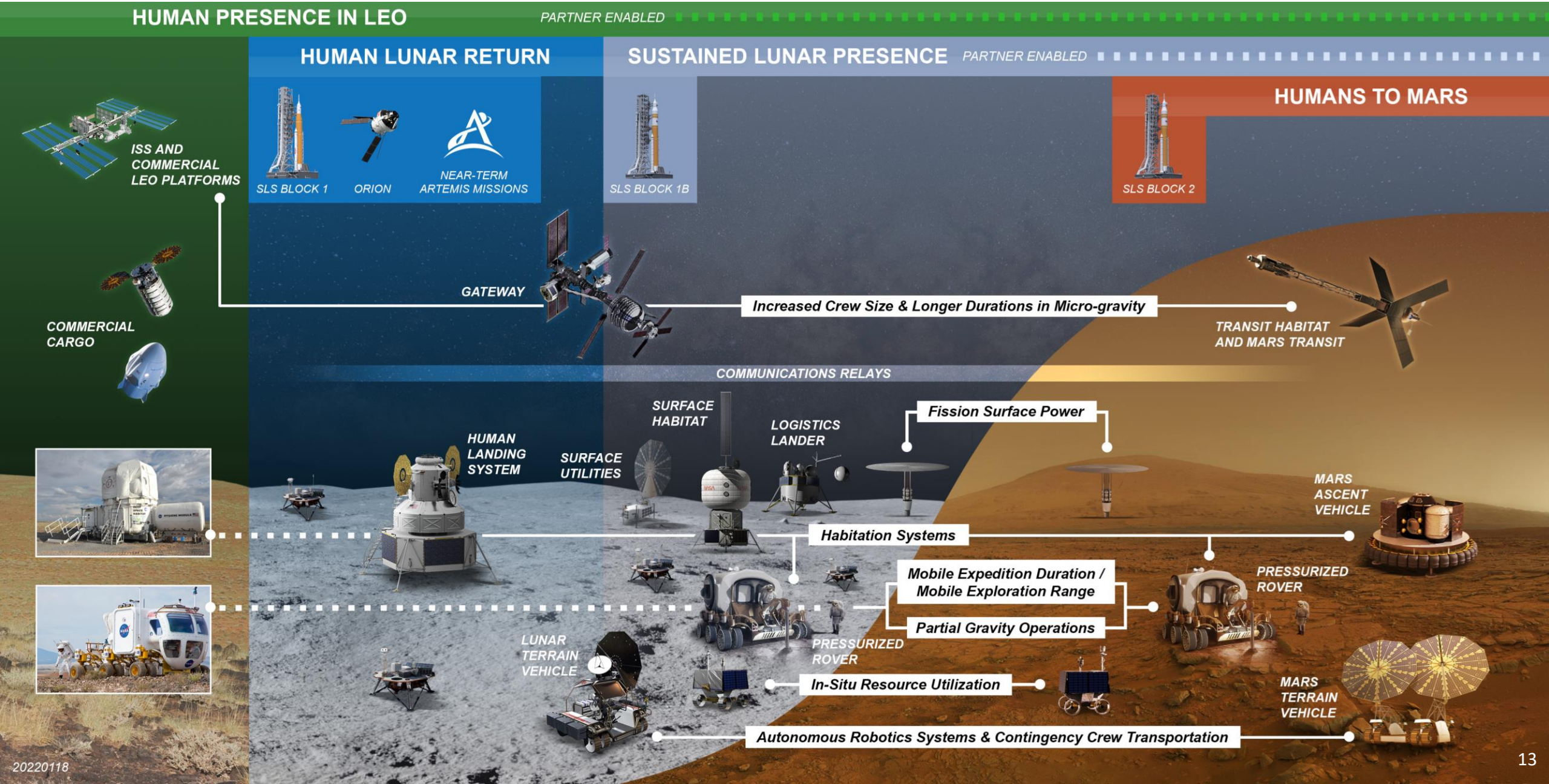
10/7/2021

ARTEMIS III

Landing on the Moon

1. **LAUNCH**
   SLS and Orion lift off from Kennedy Space Center.
2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
3. **CORE STAGE MAIN ENGINE CUT OFF**
   With separation.
4. **ENTER EARTH ORBIT**
   Perform the perigee raise maneuver. Systems check and solar panel adjustments.
5. **TRANS LUNAR INJECTION BURN**
   Astronauts committed to lunar trajectory, followed by ICPS separation and disposal.
6. **ORION OUTBOUND TRANSIT TO MOON**
   Requires several outbound trajectory burns.
7. **ORION OUTBOUND POWERED FLYBY**
   60 nmi from the Moon.
8. **NRHO INSERTION BURN**
   Orion performs burn to establish rendezvous point and executes rendezvous and docking.
9. **LUNAR LANDING PREPARATION**
   Crew activates lander and prepares for departure.
10. **LANDER UNDOCKING AND SEPARATION**
11. **LANDER ENTERS LOW LUNAR ORBIT**
    Descends to lunar touchdown.
12. **LUNAR SURFACE EXPLORATION**
    Astronauts conduct week long surface mission and extra-vehicular activities.
13. **ORION REMAINS IN NRHO ORBIT**
    During lunar surface mission.
14. **LANDER ASCENDS TO LOW LUNAR ORBIT**
15. **LANDER PERFORMS RENDEZVOUS AND DOCKING**
16. **CREW RETURNS IN ORION**
    Orion undocks, performs orbit departure burn.
17. **ORION PERFORMS RETURN POWERED FLYBY**
    60 nmi from the Moon.
18. **FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN**
    Precision targeting for Earth entry.
19. **CREW MODULE SEPARATION FROM SERVICE MODULE**
20. **ENTRY INTERFACE (EI)**
    Enter Earth's atmosphere.
21. **SPLASHDOWN**
    Ship recovers astronauts and capsule

Exploration Campaign & Segments



RECOMMENDATIONS AND FINDINGS

4 HEO COMMITTEE RECOMMENDATIONS TO AAs

2 HEO COMMITTEE FINDINGS

Short Title of Recommendation: Recommendation on Transitioning Lunar Activities

Recommendation to ESDMD AA: NASA should begin to study how to transition sustaining Lunar activities to other entities following successful Artemis missions establishing long duration Lunar capabilities

Major Reasons for the Recommendation:
NASA has started to study how to build on the sustained Lunar activities which will be the result of the Artemis missions and use the knowledge and systems to advance toward human Mars missions. This plan, although at a high level, is sound. However, the difficulty for NASA will be in managing resources to transition from Lunar to Martian activities. Currently there is no plan that the NAC is aware of that allows NASA to disengage from Lunar activities while not causing them to cease. The transition of limited resources toward a Mars campaign will probably tax NASA in the decades following the establishment of sustained Lunar operations. It is important that sustained Lunar operations continue for commercial and scientific reasons, but NASA may not be able to lead them for the long term. NASA must begin to study now on how to transition those activities to other organizations, be they governmental or commercial**.**

Consequences of No Action on the Recommendation:
Without proper planning, when NASA turns its attention from the sustained Lunar activities toward a humans to Mars campaign, either the Lunar activities will cease which is undesirable, or the Mars campaign will lack resources to be effective.

Short Title of Recommendation: Advanced Exploration Systems

Recommendation to ESDMD AA: NASA should consider reconstituting the Advanced Exploration System group as part of the new ESDMD organization to provide a single focus to the concept development of systems needed for sustained lunar presence and transition to Mars.

Major Reasons for the Recommendation: Responsibility for concept development of new systems beyond LTV, like habitats, surface systems, ISRU, etc. are buried within the technical integration or under Mars Campaign within the Exploration capabilities. To provide the essential focus these new systems need, a single level 2 organization should be created. This organization should also provide a single point of technology pull from STMD.

Consequences of No Action on the Recommendation: Systems and capabilities required for lunar sustainability and Mars transition will not be available when needed,

Short Title of Recommendation: Plan for Lunar Sustainability

Recommendation to ESDMD AA: NASA should develop a plan for lunar sustainability beyond the currently planned Artemis missions. This plan should include the required capabilities/systems and timelines for development. The plan should include commercial and international involvement and be used to develop preliminary funding requirements.

Major Reasons for the Recommendation: The current Artemis missions do not result in a sustained lunar presence as required by US policy. Many capabilities will be required that are not planned beyond initial technology development.

Consequences of No Action on the Recommendation: The risk is that Artemis will end like Apollo, with more flags and footprints, but no sustained presence.

Short Title of Recommendation: Resource Exploration

Recommendation to ESDMD AA: NASA should establish organizational responsibility and a plan for lunar resource exploration (prospecting), with priority given to lunar polar ice deposits.

Major Reasons for the Recommendation: Aside from a single proof of concept mission, Viper, there is no plan for identifying and characterizing the ice deposits at the poles of the Moon as Reserves to be utilized by processing the ice into rocket propellant. An economically viable source of propellant on the Moon will significantly lower the cost of a sustained lunar presence and enable missions to Mars.

Consequences of No Action on the Recommendation: Forgoing or delaying the development of lunar water ice resources entails an enormous opportunity cost. A sustained lunar presence and human missions to Mars may not be feasible if all propellant must be brought from Earth.

SHORT TITLE FINDING:

The Space Operations Mission Command Mission Directorate (SOMD) and the Exploration Systems Development Mission Directorate (ESDMD) Partnership is working exceptionally well.

Due to the numerous and diverse programs that were managed by the previous Human Exploration and Operation Mission Directorate (HEOMD), it was necessary and appropriate to establish the SOMD and the ESDMD. With the reorganization from one Human Exploration and Operations Directorate into two, separating development and operations, the leadership team of the new Directorates have identified the key issues related to integration and the timing for transition of responsibility from development to operations. The current leadership team is working well together. The very essence of the United States is to be explorers and pioneers of new and uncharted territories. As our Nation establishes bases on the moon, launches Gateway into lunar orbit, and works on future Mars landings, NASA is prepared to face new challenges and discoveries that we cannot imagine at this time. The SOMD and ESDMD are uniquely organized to manage the current programs and the many new revolutionary discoveries forthcoming.

NASA appears to have made excellent use of international and commercial partnerships in defining the architecture and equipment for use in Artemis, both in lunar orbit and on the surface of the moon. These arrangements and collaborations allow NASA to take advantage of good ideas and concepts for robotic and human operations and exploration that might otherwise be unavailable for Artemis.

The Human Exploration and Operations Committee commends NASA Associate Administrators, Kathy Lueders and Jim Free, and the entire SOMD and ESDMD Team for their continuous outstanding leadership and performance.

SHORT TITLE FINDING: Finding on Lessons Learned

A body of useful knowledge exists, pertaining to the Human Exploration of the Moon and Mars, that could provide valuable tips as "Lessons Learned" for future exploration planning. Some of these documents may be 30 years or older, but nevertheless provide helpful insights and conclusions for human missions.
NASA offices planning future planetary missions should consider executing a disciplined, thorough review of archived documents, workshop reports and publications to inform mission planning and avoid potential duplication of effort. Some of the titles of the NASA offices may have changed over the years.
A few examples include those managed by former NASA Johnson Space Center/Lunar and Mars Exploration (Program) Office:

-Exploration Analogs: (Antarctica, Death Valley/Meteor Crater, JSC Life Sciences Human Habitat Study);
-AnaBlogs (Blogs from Analog Missions)
https://blogs.nasa.gov/analogsfieldtesting/page/11/?cdt=1273608711527
(Includes Desert Research and Technology Studies (Desert RATS);
-Earthshine Study (Dean Eppler, Budden);
- Lunar Architectures (Multiple);
- Mars Architectures (Multiple, i.e. "Mars Direct");
-Lunar Site Workshops (several held at Lunar Planetary Institute (LPI), Houston TX) ;
-Mars Site Workshops (several held at LPI) ;
-Lunar & Mars Payloads: Instrument Catalog;
- L&M Workshop Reports (Sites, Exploration plan, objectives);
-Mars Space Suit Studies;
-Using Geologic tools in improved space suits/gloves
- Desert Rats (Eppler)
- Geologic Tool Studies - Eppler)
-Dr. Paul Spudis- multiple papers and books, on the Human Exploration of the Moon. Includes book on Smithsonian Planetary Series "Once and Future Moon."
https://spudislunarresources.com/Bibliography/Biblio.htm