National Aeronautics and Space Administration

Returning to the Moon: NASA's Artemis Missions

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NASA Ames Research Center

ARTEMIS

PERSONAL INFORMATION

- Project Manager for Orion (Multi-Purpose Crew Vehicle) operations at NASA Ames Research Center
  - Orion is one of the elements of NASA's Artemis program with objective to land the first woman and next man on Moon by 2024
- Project Manager for Science mission proposals
- Prior to current role, I spent 11 years in Entry Systems division designing, developing and testing heatshield materials and systems. I had the opportunity to work on many different projects at NASA.
  - Mission concept studies to send probes to Ice giants
  - Thermal analysis of Entry vehicles
  - Asteroid entry on Earth and their break-up

ARTEMIS

Twin sister of Apollo and goddess of the Moon in Greek mythology, Artemis is the torch-bringer personifying our path to the Moon. During the next era of human exploration, we will discover life-saving, Earth-changing science and technology along the way.

NASA’s goal is to land the first woman and first person of color on the Moon and return them safely to Earth. When the Artemis astronauts land on the lunar surface, they will step into the future, bringing all of humanity with them.

VALUABLE LUNAR SCIENCE

- Study of Planetary Processes
- Understanding Volatile Cycles
- Impact History of Earth-Moon System
- Record of the Ancient Sun
- Fundamental Lunar Science
- Platform to Study the Universe

LUNAR SURFACE SCIENCE OBJECTIVES

Mission Needs Drive Design

LOW EARTH RETURN

3 HOURS
3,000°F
17,500 MPH
250 MILES

LUNAR RETURN

3 DAYS
5,200°F
24,700 MPH
240,000 MILES

MARS RETURN

9 MONTHS
6,200°F
26,800 MPH
39,000,000 MILES

*Numbers are averages

Artemis: a Foundation for Deep Space Exploration


Space Launch System


Orion spacecraft


Human Landing System


Surface Operations

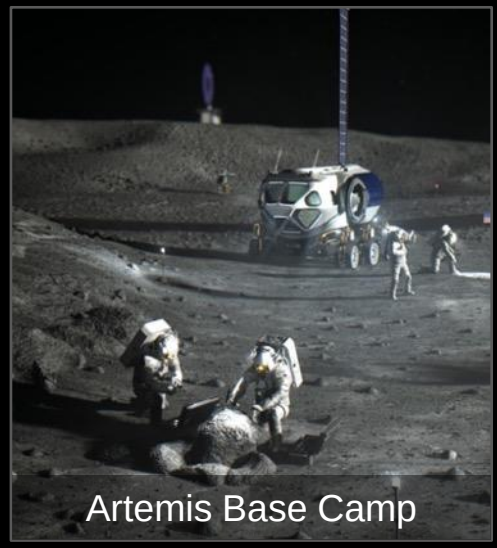

Gateway

Exploration Ground Systems

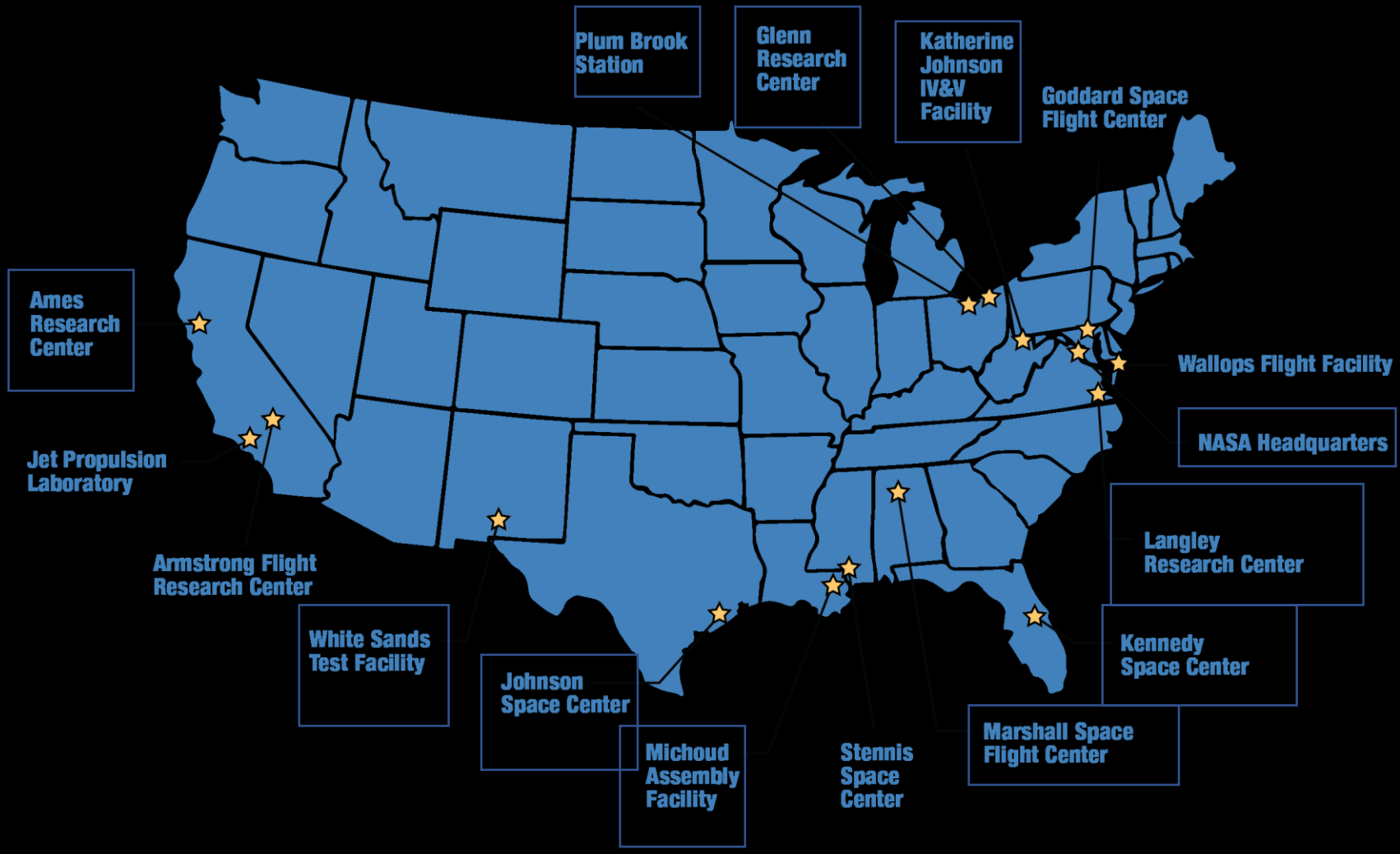

Space Communications & Navigation


Surface Mobility


Space Suits


Artemis Base Camp

Key Artemis Contributions by NASA Centers




SLS

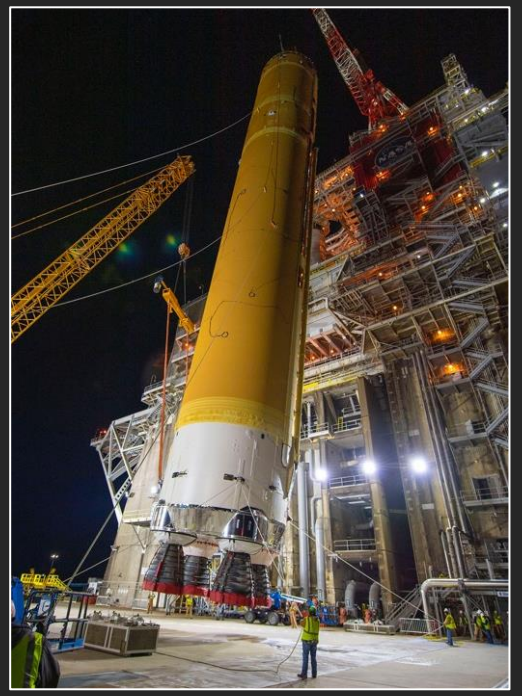
BOOSTER

Together, the SLS twin boosters provide more than 75 percent of the total SLS thrust for two minutes at launch.

ENGINES

Each of the RS-25 engines produces more than 500,000 lbs thrust for the 8 minute climb to space.

CORE STAGE

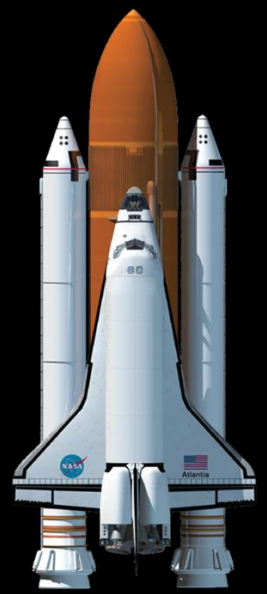


The core stage holds the hydrogen and oxygen propellant tanks and the avionics.

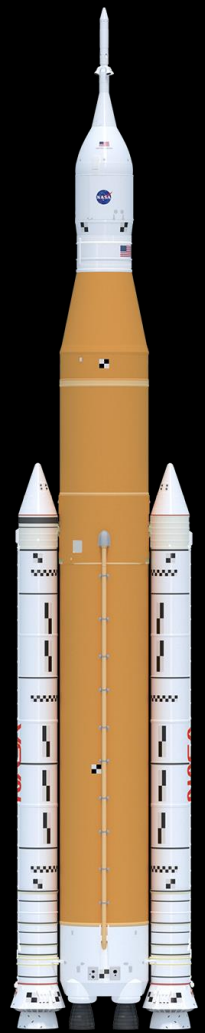
UPPER STAGE & ADAPTERS

The upper stage provides in-space propulsion with one RL10 engine. Two adapters connect elements and finish the SLS stack.

STATUE OF LIBERTY
305 ft.



SPACE SHUTTLE
184 ft.



SLS / ORION Block I
322 ft.

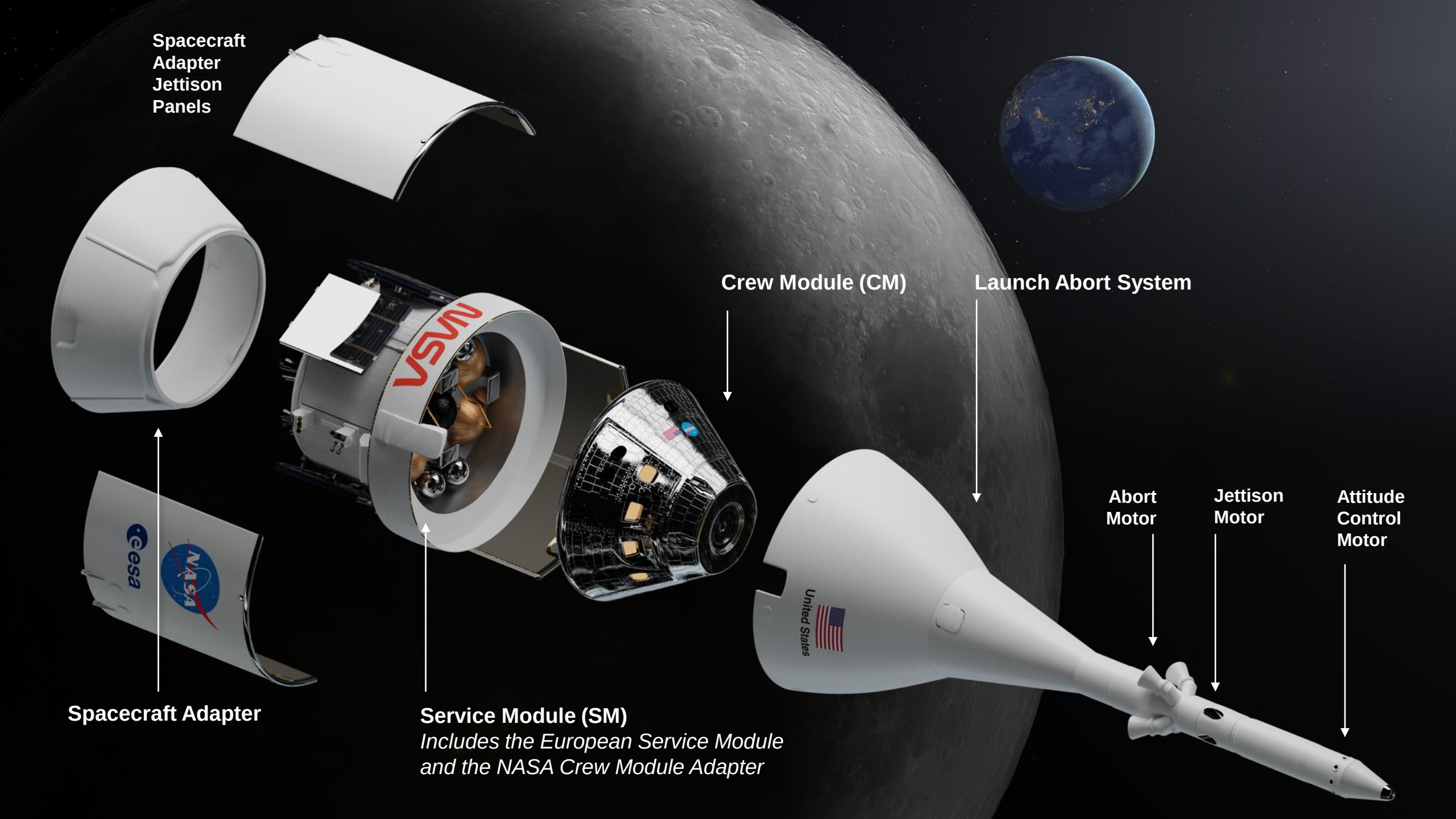
SLS / ORION Block II
364 ft.

SATURN 5
363 ft.

EGS


ARTEMIS
WE ARE GOING
ARTEMIS
Jacobs | Kennedy Space Center, Florida
ARTEMIS
WE ARE GOING!


ORION


Spacecraft Adapter Jettison Panels
Crew Module (CM)
Launch Abort System
Abort Motor
Jettison Motor
Attitude Control Motor
Spacecraft Adapter
Service Module (SM)
Includes the European Service Module and the NASA Crew Module Adapter

Artemis I Payloads

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

Moonikin Campos

The Moonikin is a male-bodied manikin previously used in Orion vibration tests. Campos will occupy the commander's seat inside and wear an Orion Crew Survival System suit

Radiation Sensors
There will be three types of sensors, including the ESA Active Dosimeters, Hybrid Electronic Radiation Assessor, and the Radiation Area Monitor.

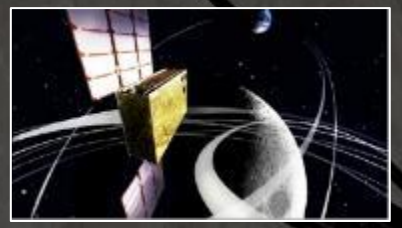
MARE
Radiation shielding Personal Protection Equipment (radiation vest) for astronauts.

Crew Interface Technology Payload (CITP)
Creates an interactive experience between Orion and the public during the mission

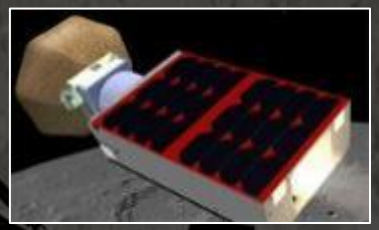
Bio-Experiment-1
Battery-powered life sciences payload for biology research beyond low-Earth orbit (LEO)

ArgoMoon

LunaH-Map



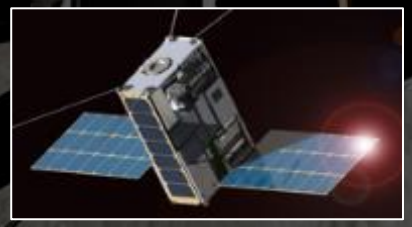
EQUULEUS



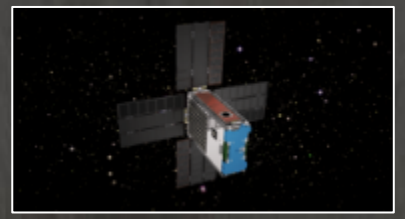
OMOTENASHI

LunIR

Near-Earth Asteroid Scout (NEA Scout)



Lunar IceCube



BioSentinel

Team Miles

CuSP

Orion Quick Facts

Performance	
Number of crew	4
Mission Duration	up to 21 days

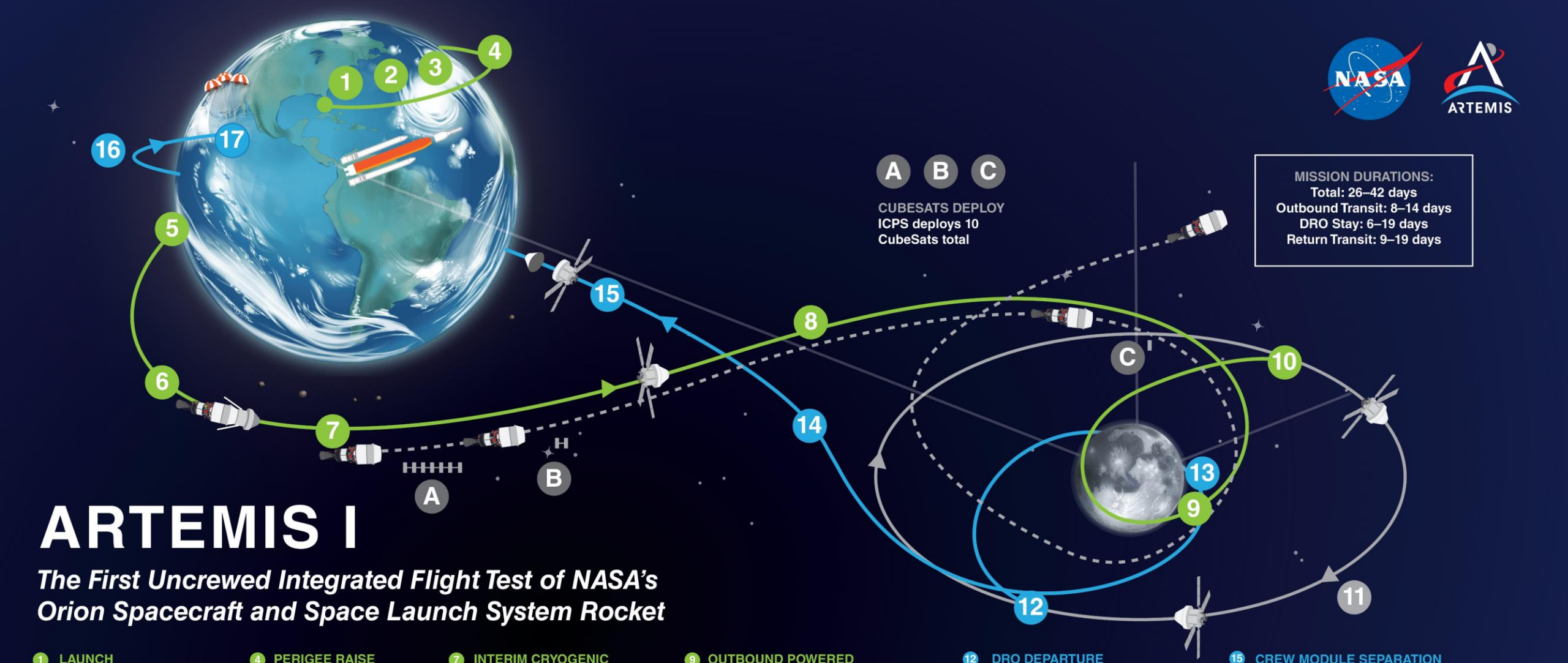
Height	
Crew module + service module	26 ft.
Orion stack (launch abort system + crew module + service module)	67 ft.
SLS Block 1 Configuration (Orion + SLS stack)	322 ft.

Trans-Lunar Insertion Mass	
Artemis I	53,000 lbs.
Artemis II	58,000 lbs.

Post-Trans Lunar Insertion Mass	
Artemis I	51,500 lbs.
Artemis II	57,000 lbs.
Usable Propellant	19,000 lbs.

Gross Liftoff Weight	
Artemis I	72,000 lbs.
Artemis II	78,000 lbs.

Total Change in Velocity (ΔV) with Fully Loaded Propellant Tank	
Artemis I	53,000 lbs.
Artemis II	58,000 lbs.



ARTEMIS I

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

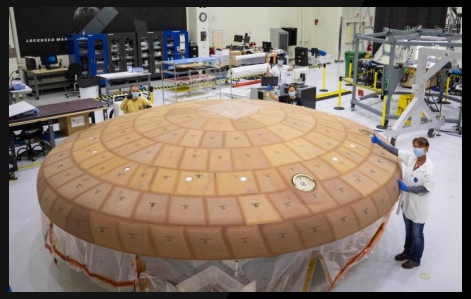
CUBESATS DEPLOY
ICPS deploys 10 CubeSats total

MISSION DURATIONS:
Total: 26–42 days
Outbound Transit: 8–14 days
DRO Stay: 6–19 days
Return Transit: 9–19 days

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.

03/28/2022

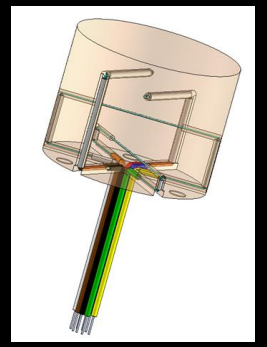
ARC Technical Support Areas



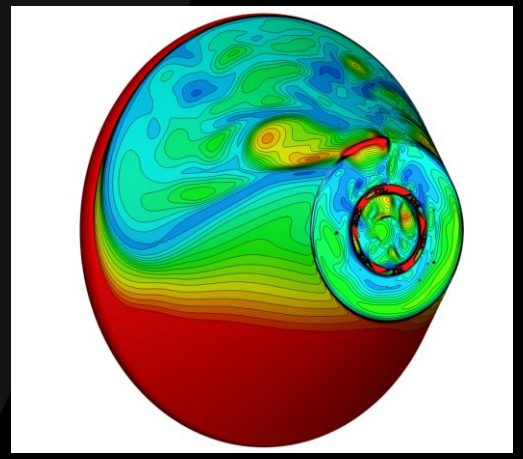
Heatshield testing, system analysis, recovery and post flight support

Backshell testing, analysis recovery and post flight support

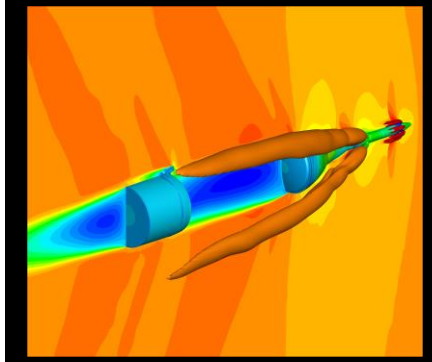
Arcjet testing



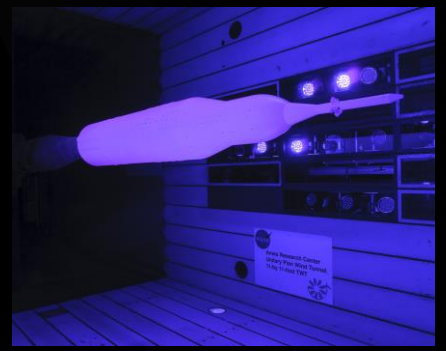
TPS Development Flight Instrumentation (DFI)



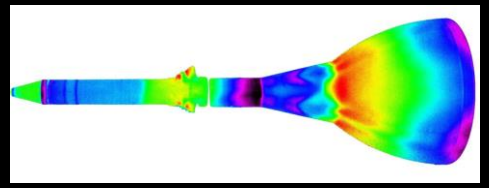
Aerothermal environment and Aerothermal database generation



Vehicle Aerodynamics, wind tunnel test support and aero database



wind tunnel testing

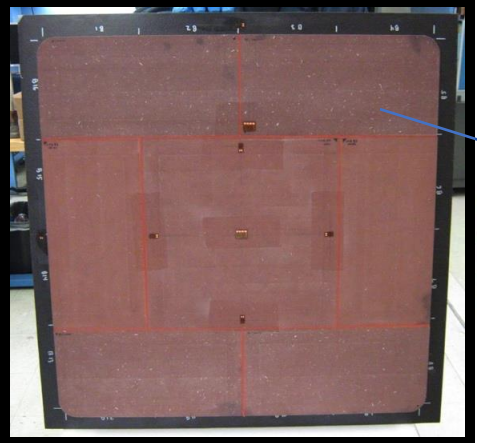


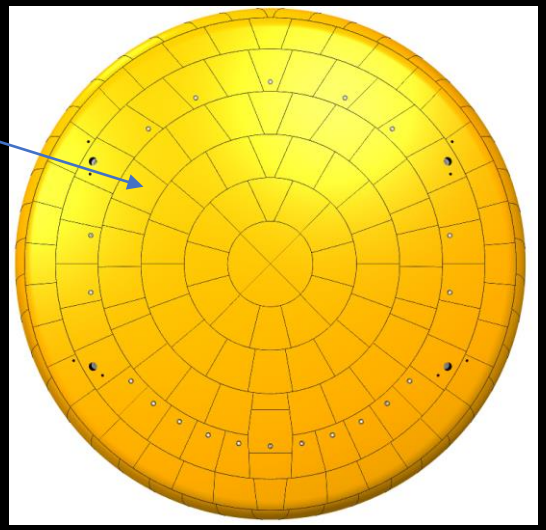
Launch abort environments, acoustics and vibrations

Orion TPS - Heat Shield

- The Apollo Honeycomb/Gunned (HC/G) system was flown on EFT-1 in 2014
  - Avcoat 5026-39 HC/G
  - Composite/Ti carrier structure

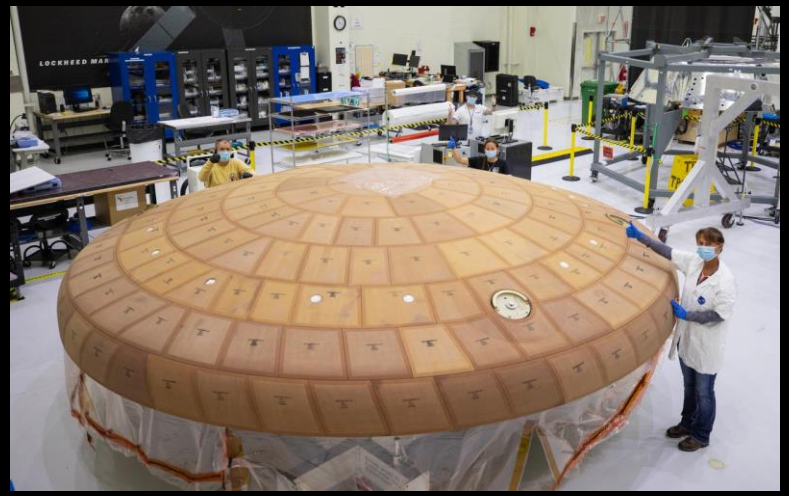
- For Artemis missions, the Orion baseline is Molded Avcoat blocks
  - Avcoat 5026-39 M
    - No honeycomb
    - Bonded to the carrier with EA9394 epoxy
  - RTV-560 between blocks
  - Composite/Ti carrier structure
    - Reduced mass from EFT-1

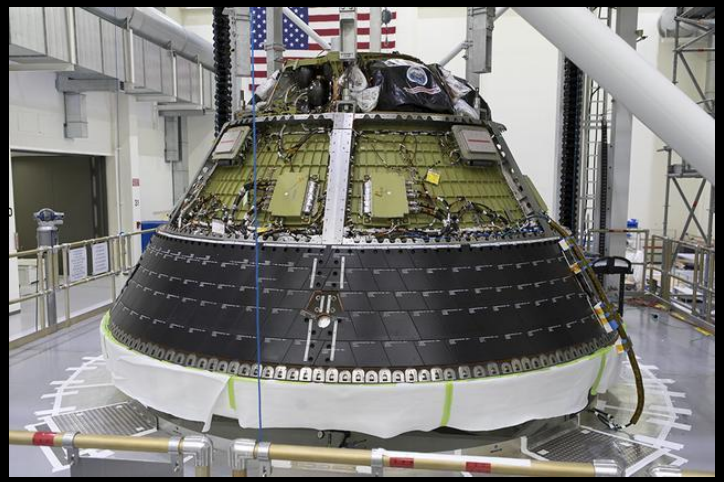




Heatshield Fun Facts

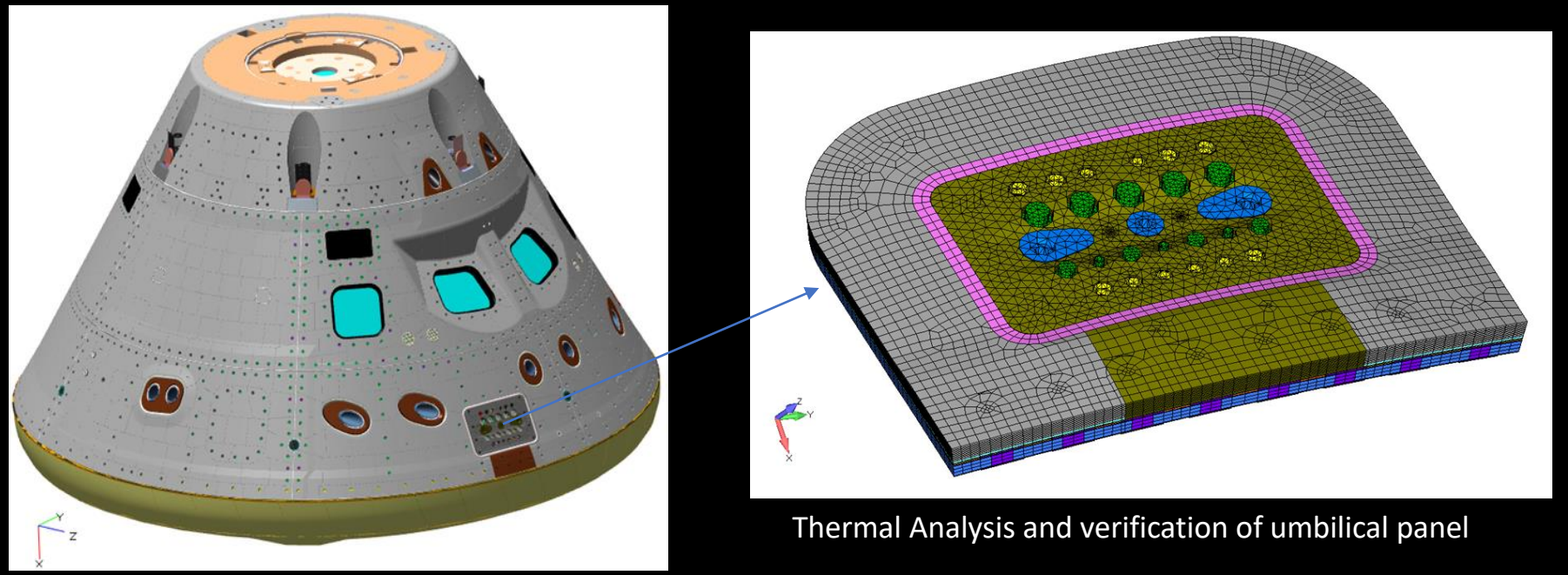
- During return to Earth from a mission to the Moon, Orion and its heat shield must protect the vehicle and crew from external temperatures up to around 5,000°F.
  - This is hotter than the melting point for titanium, which is about 3,000°F.
  - It's also about half the surface temperature of the Sun, which is about 10,000°F.
- While the outside temperatures during entry into Earth's atmosphere will reach 5,000°F, inside the spacecraft it will be in the mid-70s – hotter than molten lava on the outside and cool as a cucumber on the inside.
- The heat shield on the bottom of the crew module is 16.5 feet wide. It is the largest ablative heat shield in the world. Orion's thermal protection system is one of the most important parts of the spacecraft and is responsible for protecting the astronauts during their return.





Orion TPS – Systems Analysis

ARC System analysis group provides insight/oversight for LM analysis, thermal analysis, thermal response analysis, arc-jet and other test data interpretation, guidance in arcjet test design and planning etc.

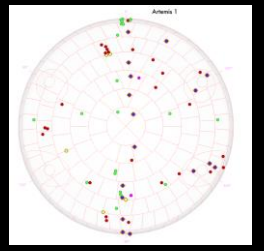


Thermal Analysis and verification of umbilical panel

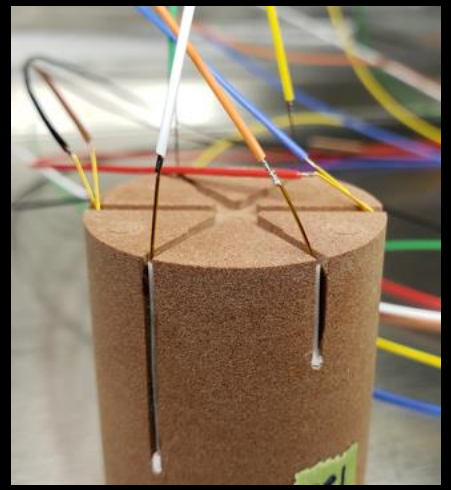
In addition, ARC TPS team is actively supporting pre and post Artemis 1 flight planning, recovery and post flight TPS analysis.

Orion TPS DFI (Developmental Flight Instrumentation)

- Objective - deliver Artemis 1, 2, 3 + instrumentation hardware (heatshield and backshell) for measuring TPS performance, aerothermal environments, vehicle wind-relative orientation, and atmospheric density during the atmospheric entry of the Crew Module (CM).
- Both heatshield as well as the backshell have numerous embedded sensors that include – Thermal plugs, Flush Air Data System (FADS), shoulder pressure transducers, Radiometer, Spectrometer and Optical recession sensors



Artemis 1 FADS pressure transducer

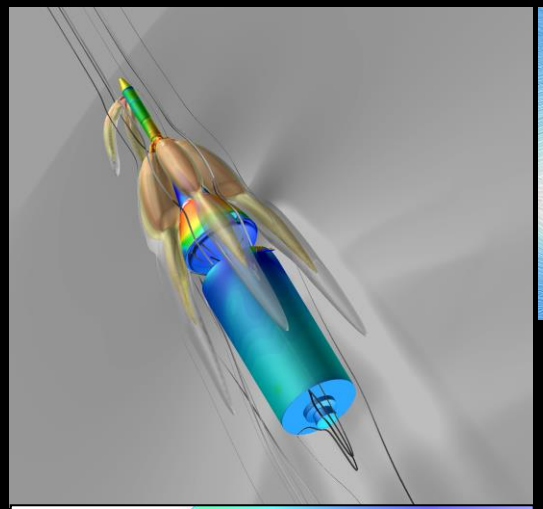
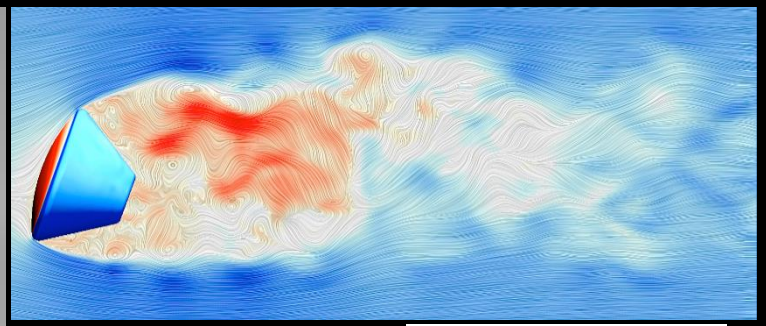
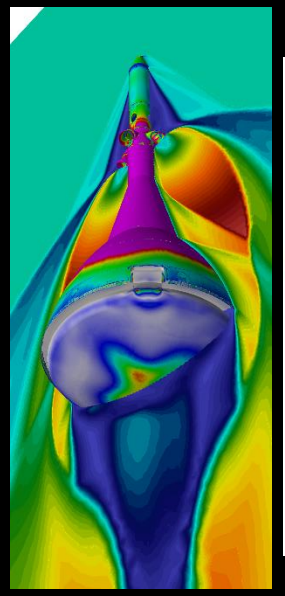
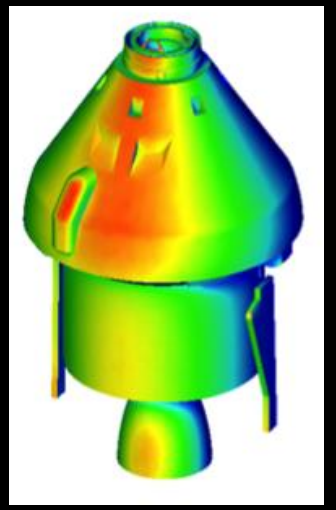
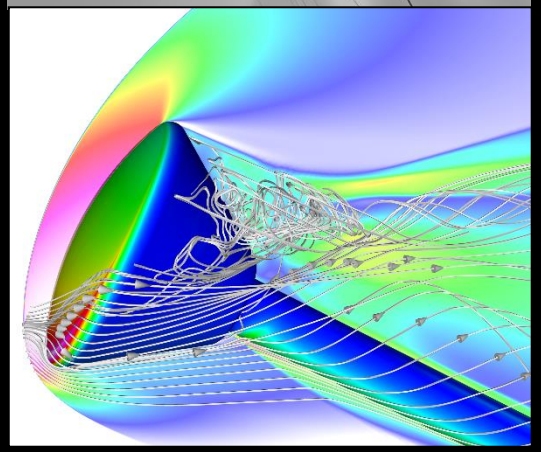


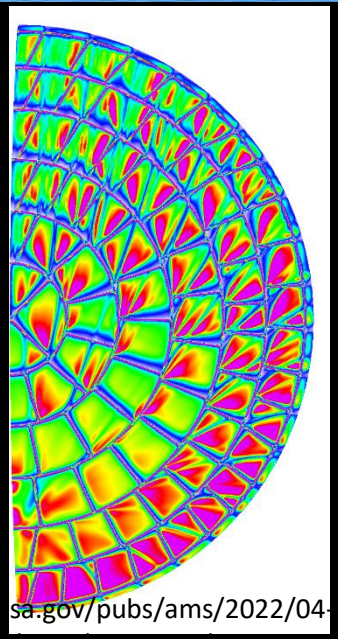
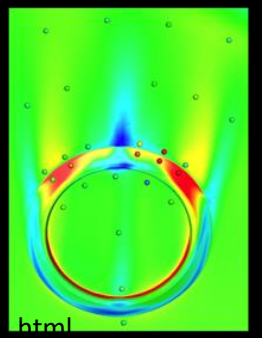
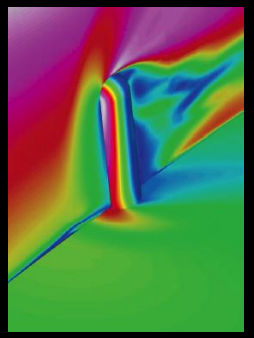
Artemis 1& 2 Thermal Plugs with embedded Thermocouples

Artemis-1 Radiometer sub-assembly

Orion Aerosciences

- **CFD is used to develop environments for Aerodynamics and Aerothermodynamics for all phases of flight**
- **CFD tools are validated utilizing ground and flight test data before applying it in design analyses**
- **Key challenges for CFD in Orion Aerosciences**
  - Aero: Complex geometries, turbulence, wake flows, plume flows, fluid-structure interaction (parachutes)
  - Aerothermal: Complex geometries, turbulence, wake flows, plume flows, gas-surface chemical interaction, radiation

eference : https://www.nas. sa.gov/pubs/ams/2022/04- html

Launch Abort System

Ensuring Astronaut Safety

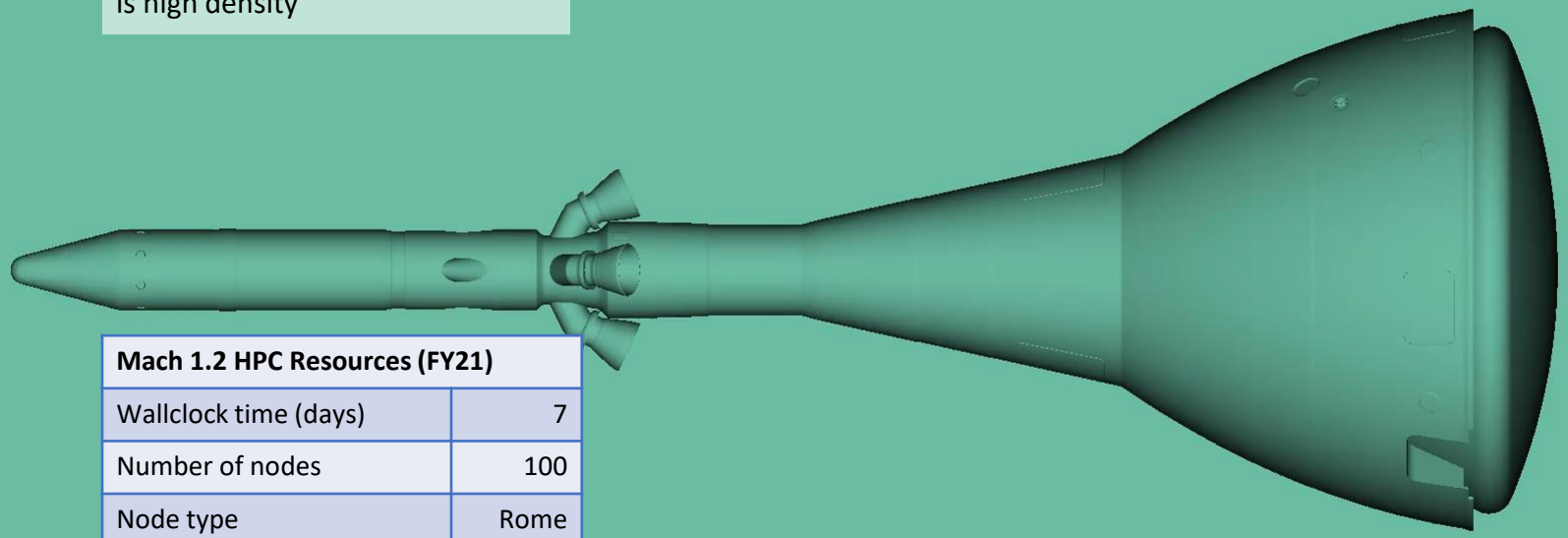
NASA is developing technologies that will enable humans to explore new destinations in the solar system. America will use the Orion spacecraft, launched atop the Space Launch System rocket, to send a new generation of astronauts beyond low-Earth orbit to places like an asteroid and eventually Mars. In order to keep astronauts safe in such difficult, yet exciting missions, NASA and Lockheed Martin collaborated to design and build the Launch Abort System.

Ascent Abort Flight Test (AA-2)

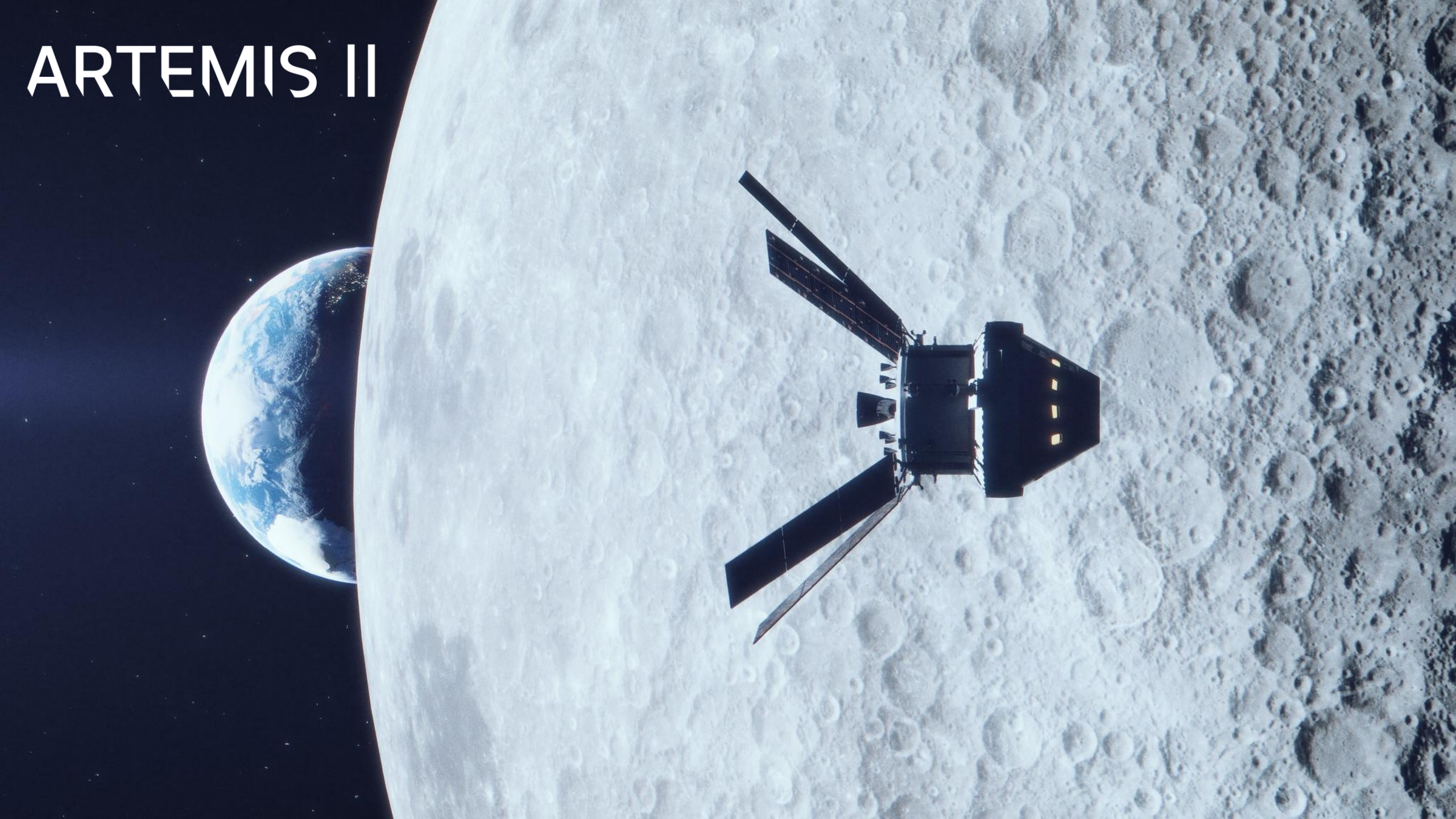
- Date: July 2, 2019
- Vehicle: Launch abort vehicle atop Northrop Grumman provided booster
- Trajectory: Abort occurs at Mach 1.17 and accelerates to Mach 1.6

AA-2 Mach 1.2 Simulation

Video from AA-2 Mach 1.615 simulation: logarithm of density on the cut plane and vehicle surface, where red is low and blue is high density



Mach 1.2 HPC Resources (FY21)	
Wallclock time (days)	7
Number of nodes	100
Node type	Rome
Total number of cores	12,800
Time simulated (seconds)	0.58
Volume data (TB)	100


ARTEMIS II


ARTEMIS III

Questions

Backup

HLS

Initial Human Landing System

Image Credit: SpaceX


GATEWAY


GATEWAY
NASA
CSA ASC
esa
JAXA

ARTEMIS BASE CAMP

Comm, Nav, Power

Surface Habitat

In-Situ Resource Utilization (ISRU)

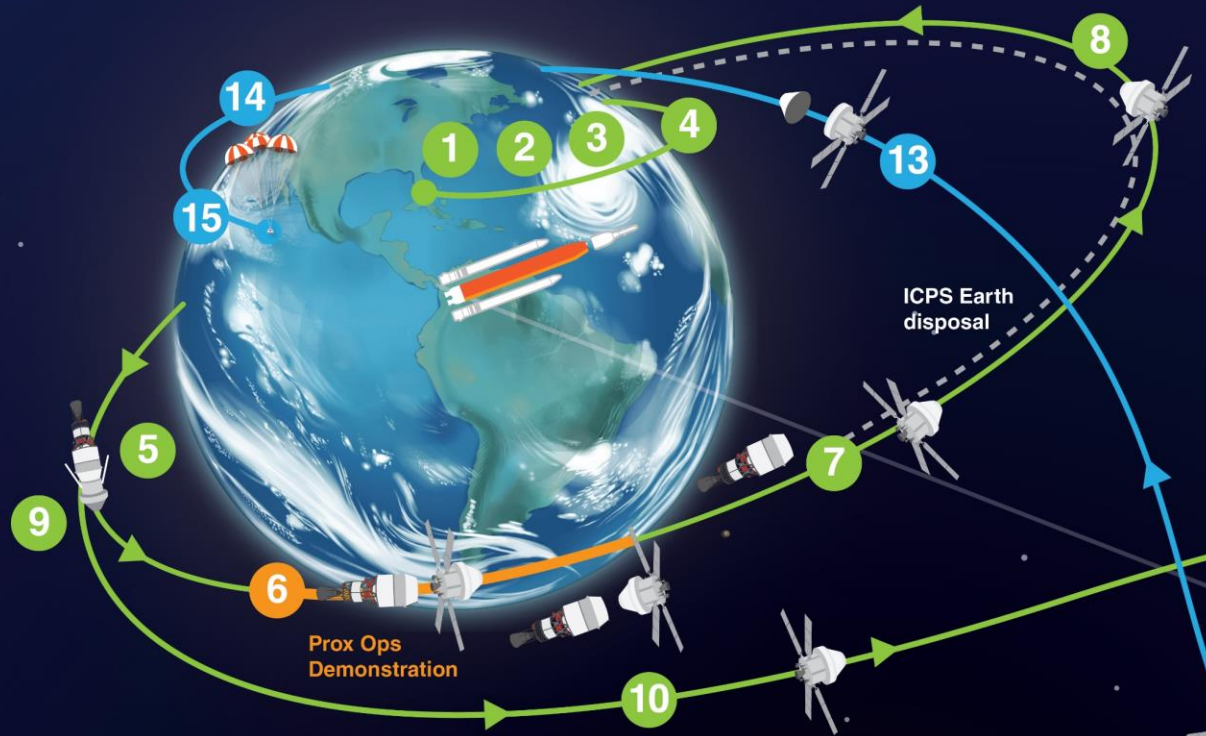
Pressurized Rover

Human Landing System

Spacesuits

Lunar Terrain Vehicle

Artist's illustration of Artemis Base Camp



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.

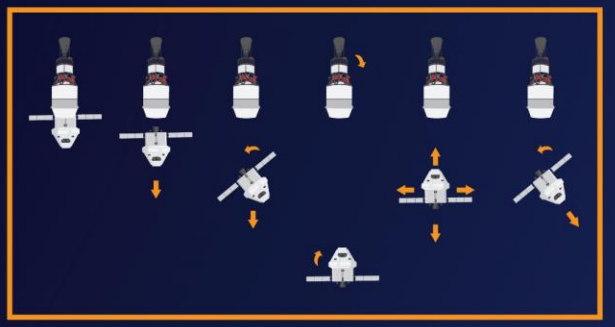
11 LUNAR FLYBY
4,000 nmi (mean) lunar farside altitude.

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

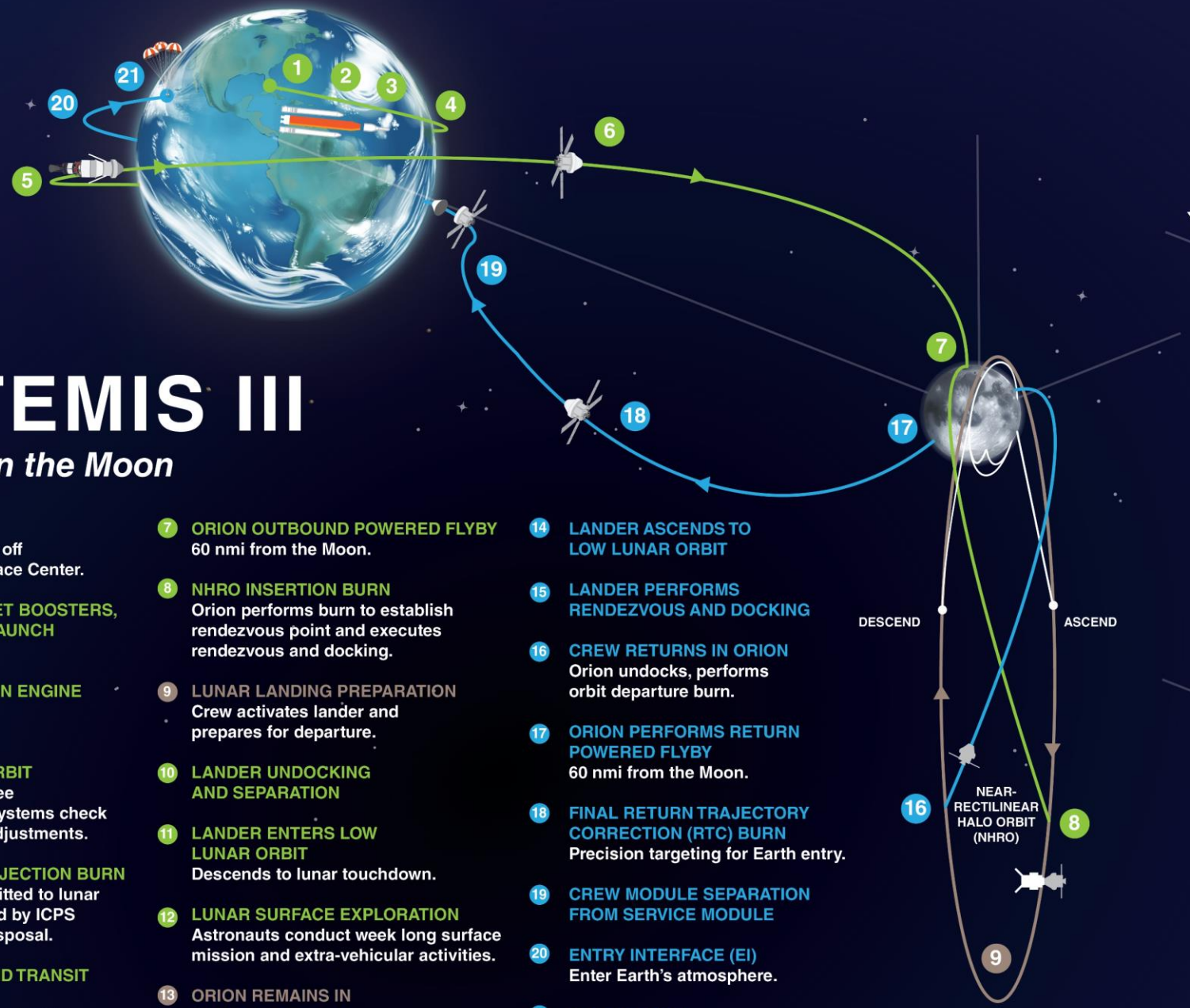
14 ENTRY INTERFACE (EI)
Enter Earth's atmosphere.

15 SPLASHDOWN
Ship recovers astronauts and capsule.



PROXIMITY OPERATIONS DEMONSTRATION SEQUENCE

03/28/2022



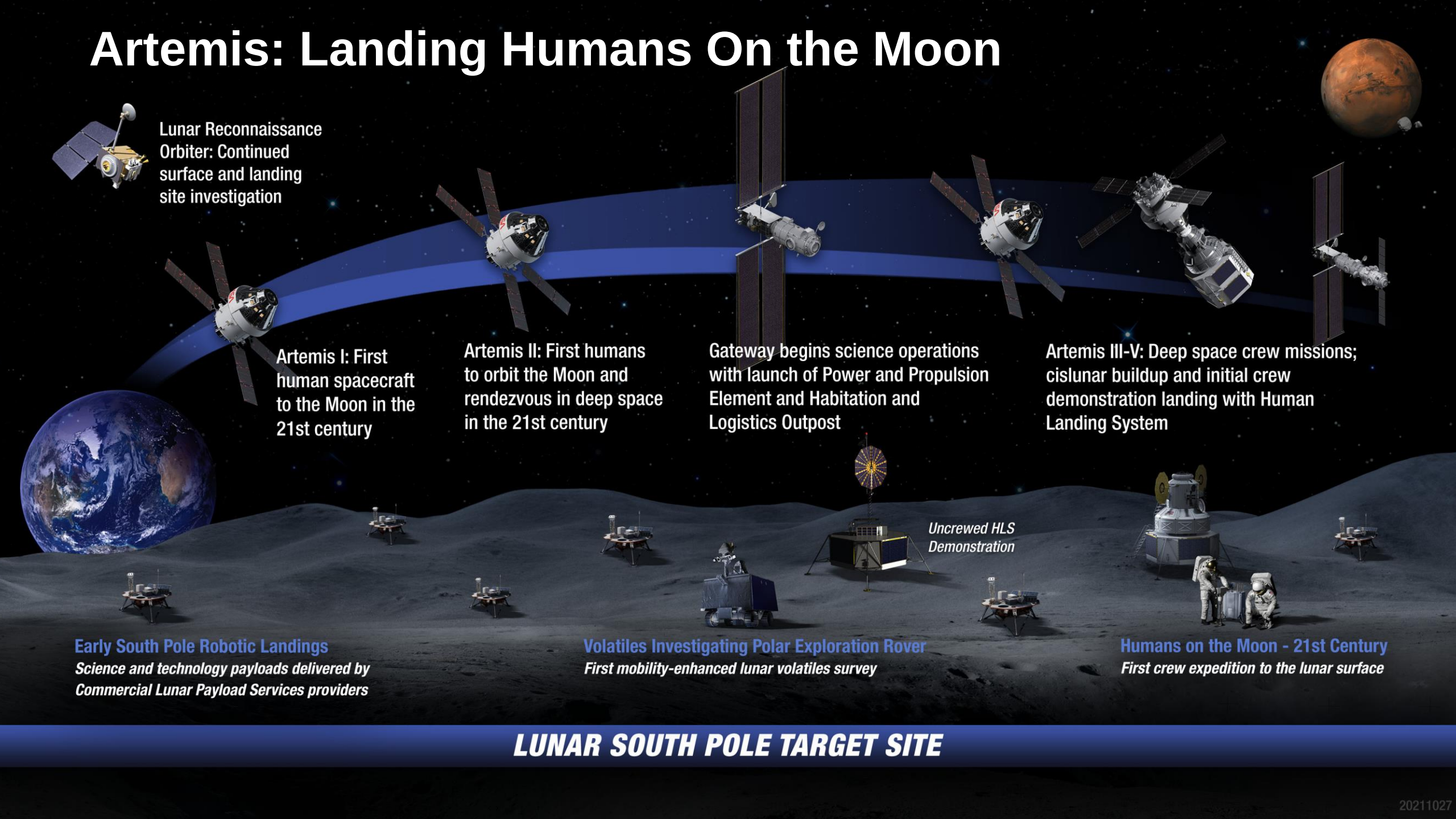
ARTEMIS III

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. **NHRO 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 NHRO 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

03/28/2022

Artemis: Landing Humans On the Moon



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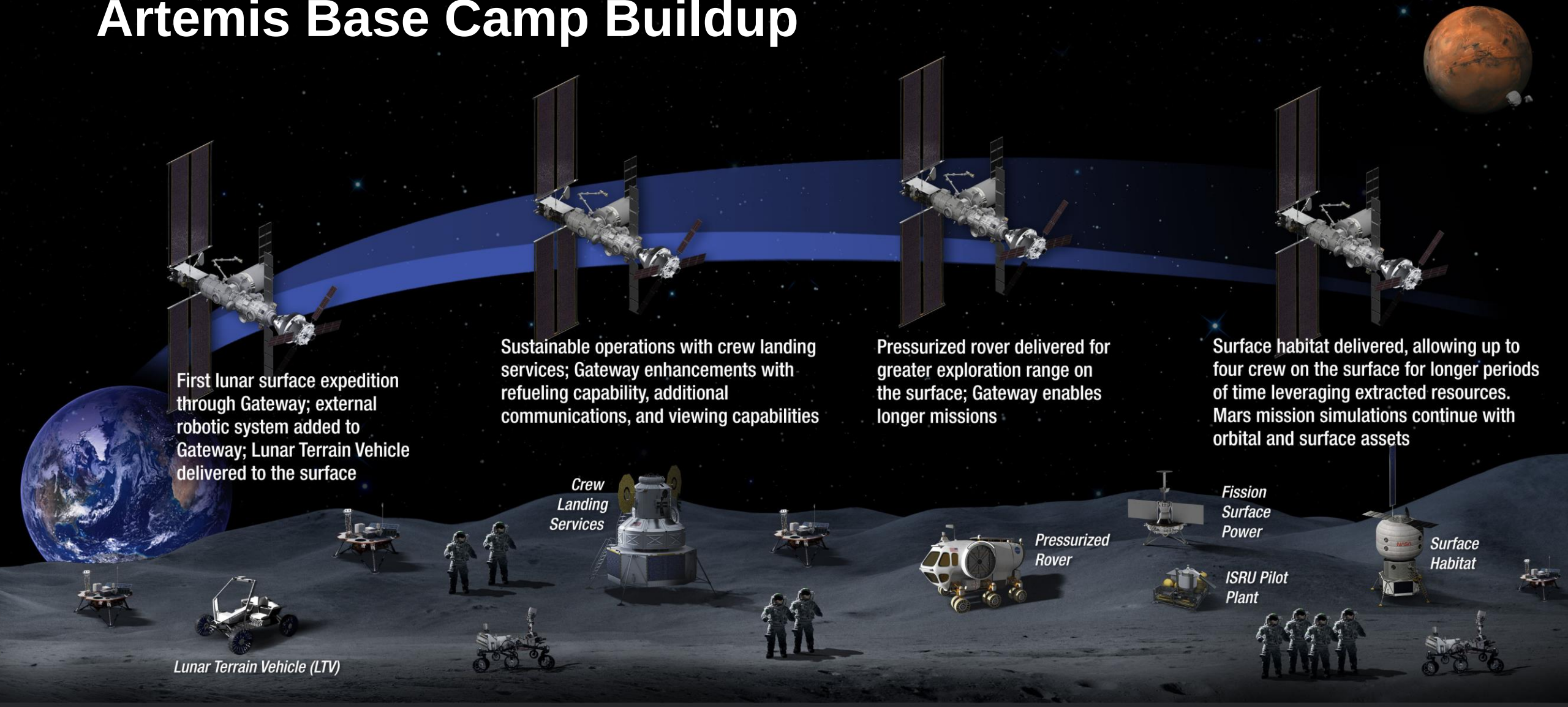
Artemis Base Camp Buildup



SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

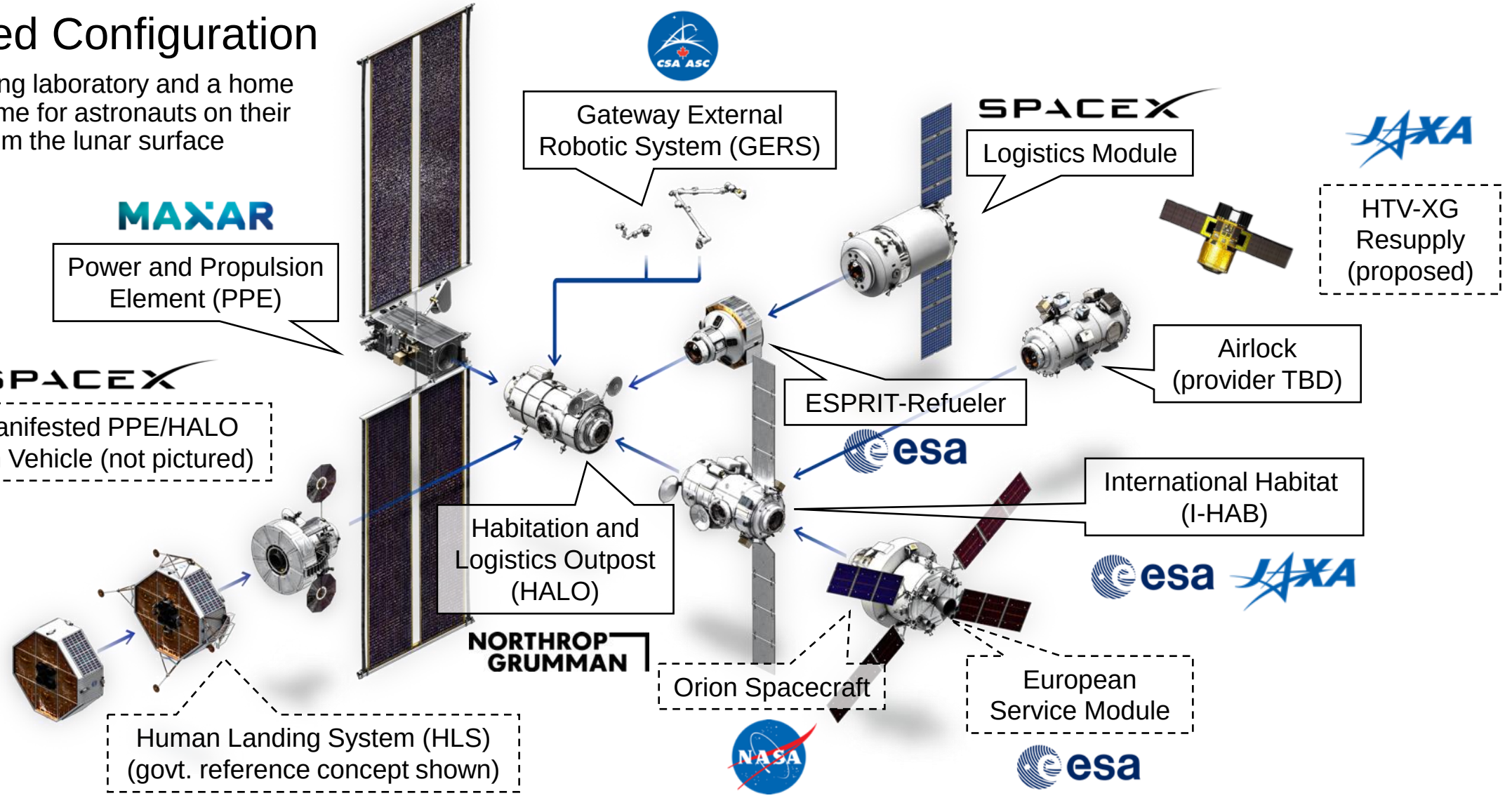
MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

20211027

GATEWAY

Expanded Configuration

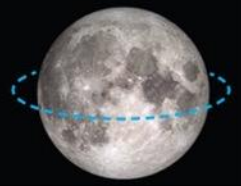
A robust orbiting laboratory and a home away from home for astronauts on their way to and from the lunar surface



GATEWAY ORBIT

Cislunar space offers innumerable orbits for consideration, each with merit for a variety of operations. The Gateway will support missions to the lunar surface and serve as a staging area for exploration farther into the solar system, including Mars.

ORBIT TYPES



LOW LUNAR ORBITS

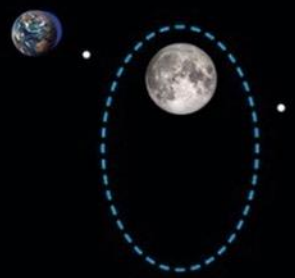
Circular or elliptical orbits close to the surface; excellent for remote sensing, difficult to maintain in gravity well.

» Orbit period: 2 hours

DISTANT RETROGRADE ORBITS

Very large, circular, stable orbits; easy to reach from Earth, but far from the lunar surface

» Orbit period: 2 weeks

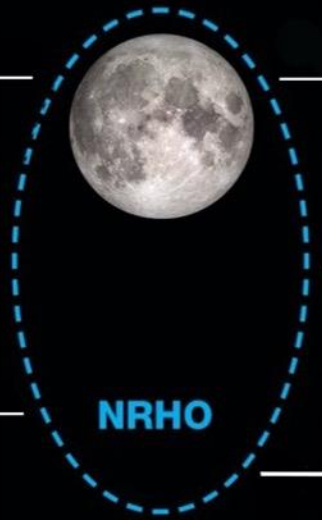


HALO ORBITS

Fuel-efficient orbits revolving around Earth-Moon neutral-gravity points

» Orbit period: 1-2 weeks

NEAR-RECTILINEAR HALO ORBIT (NRHO)



ACCESS

Easy to access from Earth orbit with many current launch vehicles; staging point for both lunar surface and deep space destinations

ENVIRONMENT

The deep space environment is useful for radiation testing and experiments in preparation for missions to the lunar surface and Mars

SCIENCE

Favorable vantage point for Earth, sun and deep space observations

COMMUNICATIONS

Provides continuous view of Earth and communication relay for lunar farside

SURFACE OPERATIONS

Supports surface telerobotics, including lunar farside; provides a staging point for planetary sample return missions

Commercial Lunar Payload Services

14 CLPS providers are currently on contract and eligible to bid on payload deliveries to the Moon