

Human Exploration and Operations Committee

# **NASA Advisory Council**

January 18, 2023

N. Wayne Hale, Jr.



## 20 Years Ago

# Lesson learned from STS-107 are still with us

# HEO Committee meetings and Focus

#### • HEO Committee meetings:

- Virtual Meeting Oct. 31 Nov. 1
  - Avoided impacting the Artemis I mission campaign

#### • HEO Committee membership

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

# **2022 SOMD Highlights**

The NASA Authorization Act passed by Congress extended America's participation in the International Space Station through at least Sept. 30, 2030, enabling the U.S. to continue to reap the benefits for the next decade while the agency works with American industry to develop commercial destinations and markets for a thriving space economy.

This was the 22nd continuous year of human presence aboard the orbiting laboratory.

Here are some accomplishments in 2022:

 NASA and SpaceX successfully launched and returned crew members to and from the International Space Station from the agency's Kennedy Space Center in Florida.

# **ISS Operations Extended**



# 2022 ISS Highlights

•Regular crew rotation flights to and from station continue to help maximize science in space, including:

- NASA <u>astronauts</u> Kayla Barron, Raja Chari, Tom Marshburn, Kjell Lindgren, Mark Vande Hei, Bob Hines, Jessica Watkins, Frank Rubio, Nicole Mann, and Josh Cassada lived and worked aboard the station.
- This year saw Vande Hei <u>completing</u> the longest single human spaceflight mission by an American with a record-breaking 355 days in space.
- Crew-3 returned to Earth in May with Barron, Chari and Marshburn, as well as ESA (European Space Agency) astronaut Matthias Maurer. During their science expedition aboard the orbiting laboratory, the Crew-3 astronauts conducted experiments, including a study on <u>concrete hardening</u> in microgravity, research on <u>cotton varieties</u> that could help develop droughtresistant plants, and executed a <u>space archaeology</u> study that could provide information that contributes to the design of future space habitats.

# **2022 ISS Highlights**

- Crew-4 launched in April and returned in October with Hines, Lindgren, and Watkins, as well as ESA astronaut Samantha Cristoforetti after completing 170 days in orbit. Crew-4 continued work on investigations documenting how improvements to the space diet affect immune function and the gut microbiome, determining the effect of <u>fuel temperature on the flammability</u> of a material, exploring possible <u>adverse effects on astronaut hearing</u> from equipment noise and microgravity, and studying whether additives <u>increase</u> <u>or decrease the stability of emulsions</u>.
- Crew-5 arrived at station in October carrying Mann and Cassada, as well as JAXA (Japan Aerospace Exploration Agency) astronaut Koichi Wakata and Roscosmos cosmonaut Anna Kikina. Crew-5 is spending several months aboard the space station conducting new <u>scientific research</u> in areas such as cardiovascular health, bioprinting, and fluid behavior in microgravity to prepare for human exploration beyond low-Earth orbit and to benefit life on Earth.

# Humans in LEO Space



Crew 3



Crew 4



Crew 5



Mark Vande Hei



**Frank Rubio** 

# **2022 ISS Highlights**

•NASA and Boeing successfully launched and returned the company's CST-100 Starliner spacecraft from Florida's Cape Canaveral Space Force Station and landed in the desert of the western United States, <u>completing</u> the uncrewed Orbital Flight Test-2 (OFT-2) to the space station to help prove the system is ready to fly astronauts. Starliner and its crew of NASA astronauts Barry Wilmore and Sunita Williams are preparing for the first flight with astronauts in 2023, the final demonstration prior to regular flights to the microgravity complex.

•Crew members welcomed the first NASA-enabled private astronaut mission, Axiom Mission 1, to the orbital complex advancing the agency's goal of commercializing low-Earth orbit.

•NASA astronauts continued work to install the International Space Station Rollout Solar Arrays (iROSA), which will increase power generation capability by up to 30% when fully complete, and its partners continued outfitting the Nauka module and new European robotic arm.

# **Boeing Starliner Docks**

# **2022 SOMD Highlights**

•Northrop Grumman's Cygnus spacecraft completed its first limited reboost of the International Space Station – the first mission to feature this enhanced capability as a standard service for NASA.

•The International Space Station performed a critical demonstration focused on inorbit housekeeping by deploying about 172 pounds of trash from the NanoRacks Bishop Airlock for a safe disposal in Earth's atmosphere.

•Four <u>commercial cargo missions</u> delivered more than 30,000 pounds of science investigations, tools, and critical supplies to the space station, and two returned about 8,900 pounds of investigations and equipment to researchers on Earth.

•<u>Selected</u> seven new additions to the team of flight directors to oversee operations of the space station, commercial crew, and Artemis missions to the Moon.

# Four Commercial Cargo Missions



# **NASA Introduces New Flight Directors**

PACE

# **JPSS-2 and LOFTID Launch**

# **GOES-T Launch**





# SWOT Launch



## ARTEMIS

#### COMMUNICATIONS AND NAVIGATION MILESTONES



Both the Launch Communications Segment and the constellation of Tracking and Data Relay Satellites will maintain communication between the Space Launch System and Orion.



When Orion arrives at the Moon, it will enter a distant retrograde orbit, a highly stable orbit in which Orion travels opposite the direction the Moon travels around Earth. There, NASA will continue to test and demonstrate Orion's capabilities.



In low-Earth orbit, NASA's Near Space Network TDRS will maintain continuous communications with Orion and the Interim Cryogenic Propulsion Stage (ICPS), which will accelerate Orion fast enough to overcome the pull of Earth's gravity and set it on a precise trajectory to the Moon.



Returning from the Moon, the Deep Space Network will be the primary method of communication with Earth, with Near Space Network ground stations providing supplementary tracking and navigation data.

NEAR SPACE NETWORK



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Once Orion no longer needs the ICPS, the Near Space Network will monitor telemetry from the ICPS until it is out of range. The ICPS will continue towards the Moon on a heliocentric trajectory, deploying small satellites that provide additional science in translunar orbit.



During the final engine burn that places Orion on target to safely enter Earth's atmosphere, the Near Space Network will join the Deep Space Network, ultimately taking over communications for the remainder of the mission.

NSN TDRS

NSN DTE



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As Orion prepares to leave the area of near-Earth space covered by the Near Space Network, network engineers will pass communications services to the Deep Space Network.



En route to the Moon, the Deep Space Network will be the primary method of communication with Earth, with Near Space Network ground stations providing supplementary tracking and navigation data.



During re-entry, the enormous heat generated as Orion encounters the atmosphere turns the air surrounding the capsule into plasma. Until it dissipates, this can disrupt communications with the spacecraft.

DSN



The Near Space Network maintains communications through the unfurling of parachutes, splashdown in the Pacific Ocean, and recovery of the capsule by military and NASA professionals.

DEEP SPACE NETWORK



# 2023 Lookahead

#### International Space Station Utilization/Commercial Low-Earth Orbit

- Continued Resupply Flights
- Sierra Space Dream Chaser First Flight
- Private Astronaut Mission Support
- Commercial Low-Earth Orbit Progress

#### **Crew Flights to Space Station**

- Continued SpaceX Dragon Flights
- First Starliner Crew Flight Test and Continued Path to Certification For Regular Crew Rotation Flights
- US Crew on Soyuz Flight

#### Launch Services

• Psyche, VADR





## Exploration Systems Development Mission Directorate

# 2022 Highlights





- Launched on November 16 from NASA's Kennedy Space Center for a 25.5-day, 1.4-million-mile mission beyond the Moon and back. Splashed down in the Pacific Ocean, west of Baja California, on December 11.
- First integrated test of NASA's deep space exploration systems - the Orion spacecraft, SLS rocket, and the supporting ground systems - and was supported by thousands of people around the world.

- SLS performed with precision, meeting or exceeding all expectations during its debut launch and delivered Orion within about three miles of its planned orbit altitude of 975 by 16 nautical miles, well within the planned range required for the mission, at a speed of approximately 17,500 mph.
- Mobile launcher and pad systems performed as designed during launch, exceeding expectations for overall performance.





- Orion performed two lunar flybys, coming within 80 miles of the lunar surface.
- Orion traveled nearly 270,000 miles from Earth.
- Orion stayed in space longer than any spacecraft design for astronauts has done without docking to a space station.







- During re-entry, Orion endured temperatures at about 5,000 degrees Fahrenheit. All parachutes and uprighting bags deployed as designed, and ground teams recovered the spacecraft.
- Orion was transported by truck across the country from Naval Base San Diego in California to Kennedy's Multi Payload Processing Facility in Florida, where it will undergo further analysis.



## **Working Manifest for Technical Integration**



## **Artemis Planning Manifest**





Icons represent the calendar year in which the launch occurs. | Based on FY23 Presidents budget request. | Does not include impact from FY22 appropriations. | Selected Mars forward elements in SMD and STMD included for context.



## **ARTEMIS II**

First Crewed Test Flight to the Moon Since Apollo

**LAUNCH** Astronauts lift off from pad 39B at Kennedy Space Center.

9

2 JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM

CORE STAGE MAIN ENGINE CUT OFF With separation.

PERIGEE RAISE MANEUVER

Prox Ops Demonstration

APOGEE RAISE BURN of spacecraft.

6 PROX OPS DEMONSTRATION **Orion proximity** 

> operations demonstration and manual handling qualities assessment for up to 2 hours.

- Begin 24 hour checkout

- INTERIM CRYOGENIC **PROPULSION STAGE** (ICPS) DISPOSAL BURN
- TO HIGH EARTH ORBIT 🕕 HIGH EARTH ORBIT CHECKOUT Life support, exercise, and habitation equipment evaluations.

**O TRANS-LUNAR INJECTION** (TLI) BY ORION'S MAIN

ENGINE Lunar free return trajectory initiated with European service module.

**00 OUTBOUND TRANSIT** TO MOON

**ICPS Earth** disposal

4 days outbound transit along free return trajectory.

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.

- CREW MODULE SEPARATION FROM SERVICE MODULE
- ENTRY INTERFACE (EI) Enter Earth's atmosphere.
- **15** SPLASHDOWN Ship recovers astronauts and capsule.

PROXIMITY **OPERATIONS** DEMONSTRATION SEQUENCE



# ARTEMIS II

- Powered on the Orion crew module for the first time at Kennedy Space Center in Florida
- Selected Canoo as the Crew Transportation
  Vehicle Vendor
- Successfully tested an abort motor for the launch abort system at the Northrop Grumman facility in Promotory, UT.
- SLS's RS-25 engines were shipped to Michoud Assembly Facility, where they will be integrated with the SLS core stage.
- Manufacturing is underway for the launch vehicle stage adapter and Orion Stage Adapter
- Joined SLS's core stage forward assembly with the liquid hydrogen tank, completing assembly of four of the five large structures that make up the core stage.



# **ARTEMIS II**

ARTEMIS II CREW MODULE KENNEDY SPACE CENTER



ARTEMIS II BOOSTER MOTOR SEGMENTS COMPLETE

**ARTEMIS II RS-25 ENGINES COMPLETE** 



ARTEMIS II SERVICE MODULE KENNEDY SPACE CENTER

ARTEMIS II 4/5 CORE STAGE ASSEMBLED



ALL ARTEMIS II ENGINES DELIVERED TO MICHOUD ASSEMBLY FACILITY



NEW LH2 SPHERE AT THE PAD FOR ARTEMIS II

ARTEMIS II SPACECRAFT ADAPTER JETTISON PANELS AT MICHOUD ASSEMBLY FACILITY

National Aeronautics and Space Administration

▼ To Earth



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# ARTEMIS III

LAUNCH SLS and Orion lift off from Kennedy Space Center

2 JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM

CORE STAGE MAIN ENGINE CUT OFF With separation

 ENTER EARTH ORBIT Perform the perigee raise maneuver. Systems check and solar panel adjustments

TRANS LUNAR INJECTION BURN Astronauts committed to lunar trajectory, followed by ICPS separation and disposal

ORION OUTBOUND TRANSIT TO MOON Requires several outbound trajectory maneuver burns. ORION OUTBOUND POWERED FLYBY 60 nmi from the Moon

GATEWAY ORBIT INSERTION BURN Orion performs burn to establish rendezvous point to Gateway.

performs rendezvous and docking

CINARL LANDING PREPARATION Crew transfers to Gateway, activates Lander staged at Gateway, prepares for Lander departure

LANDER UNDOCKING AND SEPARATION FROM GATEWAY

LANDER ENTERS LOW
 LUNAR ORBIT
 Descends to lunar
 touchdown

13

LUNAR SURFACE EXPLORATION Astronauts conduct week long surface mission and

extra-vehicular activities GATEWAY/ORION REMAIN IN LUNAR GATEWAY ORBIT During lunar surface mission LANDER ASCENDS LOW LUNAR ORBIT Lander performs rendezvous and docking with Gateway

> CREW RETURNS IN ORION Orion undocks from Gateway, performs orbit departure burn

6

ORION PERFORMS RETURN POWERED FLYBY 60 nmi from the Moon

FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN Precision targeting for Earth entry

ENTRY INTERFACE (EI) Enter Earth's atmosphere

> SPLASHDOWN Pacific Ocean landing within view of the U.S. Navy recovery ships

19

16

Gateway Orbit

7

15

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### **Artemis III Candidate Landing Regions**



KEY LANDING REGION CHARACTERISTICS

Close proximity to the geographic South Pole

Gentle slope for landing and moonwalks

Constant view to Earth for communications

Continuous sunlight throughout the surface expedition of about 6.5 days

Landing Accuracy

Surface data resolution

Combined mission vehicle capabilities: Space Launch System, Orion spacecraft, Starship Human Landing System

A landing *region* is approximately 15 km<sup>2</sup>. Each landing region includes multiple potential landing sites.



# ARTEMIS III

- Orion's crew module is undergoing assembly of the interior and exterior structures at Kennedy.
- Orion's heat shield was delivered to Kennedy via the Super Guppy aircraft.
- Teams at Airbus are working the Orion's European Service Module in Bremen, Germany.
- The SLS RS-25 engines are being prepared for flight at Aerojet Rocketdyne's facility at NASA Stennis.
- The major components for ICPS have been completed at ULA's facility in Decatur, Alabama.
- The 10 SLS rocket motor segments are complete. Teams finished manufacturing the segments for the twin SRBs.
- The core stage engine section was delivered to Kennedy Space Center.
- Candidate landing regions were identified for the Artemis III mission.
- Awarded contract to Axiom and Collins Aerospace to advance spacewalking capabilities, and selected Axiom to deliver a moonwalking system for Artemis III.



## ARTEMIS III





ARTEMIS III CREW MODULE KENNEDY SPACE CENTER

ARTEMIS III RS-25 FLIGHT SET PROCESSING



ARTEMIS III CORE STAGE LH2 TANK



ARTEMIS III ESM3 BREMEN, GERMANY





**ARTEMIS III ICPS STAGED FOR MATING** 

**ARTEMIS III BOOSTER SEGMENTS** 



**ARTEMIS III OMS-E AT JOHHSON SPACE CENTER** 



ARTEMIS III ORION HEAT SHIELD DELIVERY TO KENNEDY SPACE CENTER

ARTEMIS III ORION HEAT SHIELD KENNEDY SPACE CENTER



## **ARTEMIS III**



STARSHIP TEST FLIGHT SN8 LAUNCH (Image: SpaceX)

STARSHIP TEST FLIGHT SN15 LANDING (Image: SpaceX)

PRESSURE TESTING OF NASA'S FULLY ASSEMBLED EXPLORATION SPACESUIT



#### **Starship HLS development in work**







Propellant HLS Starship Extended loiter if Orion launch Variable Crew returns to aggregation launches needed Stay on the Moon Orion

# Microgravity Cryogenic Propellant Transfer is Key Technology Development

- Multiple (3 to 8 reported) tanker missions required for a single SpaceX landing mission
- Development of the Starship Super Heavy Launch Vehicle in work but not demonstrated
  - Required to launch the HLS, LEO Prop Depot, and Tanker vehicles
- LOX/Methane stage is much higher Isp (327-380) than Storables and temperatures between propellants are compatible
- Cryo Transfer in Space Technology Demonstrators are funded but not yet flown

# ARTEMIS IV

- Welding of Orion's pressure vessel is underway at the Michoud Assembly Facility.
- The primary structure of the European Service Module has been completed and shipped from Thales Alenia Space in Italy to Airbus in Germany.
- Manufacturing has started on test articles for the EUS at Michoud.
- Complete manufacturing of SLS's hydrogen tank barrel that will be tested as a weld confidence article.
- Propellant casting for SLS's motor segments at Northrop's facility in Utah.
- SLS's interstage simulator testing components arrived at Stennis and were lifted into the test stand. These components will be used during EUS's green run.
- Structures for Gateway's PPE, HALO, and IHAB components began to take shape.
- Awarded a contract to SpaceX to further develop the Starship human landing system and provide a second crewed landing demonstration as part of the Artemis IV mission.

## Status: SLS Exploration Upper Stage and Associated Capabilities/ Block 1B Variant



- The Exploration Upper Stage (EUS) enhances SLS lift-capability, enabling Orion orbit flexibility, can deliver co-manifested payloads to the Gateway, supports lunar exploration, and future Mars mission.
- The EUS has unique human rated capability for agile repositioning, dwell, and docking maneuvers in deep space with precisions guidance, cryogenic management, and real time communications and control.
- EUS enables the SLS Block 1B variant to accomplish a 42% increase in TLI mission capture.
- Tremendous progress has been made with advance manufacturing, tooling, and preparations for structural testing.
- The Block IB CDR board is schedule for November 3, 2022 and represents a major milestone in program advancement.
- The Michoud Assembly Facility outside of New Orleans is being prepared for full production of the design and the overall status is on schedule to support the Artemis IV mission.

## Status: EGS Mobile Launcher 2 (ML-2)

- NASA's Exploration Ground Systems program is working with contractor Bechtel National Inc. to build a second mobile launcher (ML2) for NASA's Space Launch System (SLS) Block 1B and Block 2 configurations
- The ML2 project is a key component for future exploration, providing the assembly and launch platform for the Artemis IV mission and beyond that enable the power Block IB SLS operations.
- Significant progress has been made with the design with 90% design completion over the next few months
- However, the project has experienced development and production issues:
  - Completion of steel fabrication drawings has also been delayed by revisions to reduce overall weight
  - Steel supply chain issues have caused delays of both steel fabrication and delivery on the completed design
  - Significant improvements have been made in the design to accommodate weight, changes in management approach to improve performance, and additional work is being performance to address supply base issues.



## **GATEWAY UPDATE**



HABITATION AND LOGISTICS OUTPOST MOCKUP



#### POWER AND PROPULSION ELEMENT 12KW SOLAR ELECTRIC PROPULSION TEST





HABITATION AND LOGISTICS OUTPOST PRIMARY STRUCTURE ASSEMBLY

POWER AND PROPULSION ELEMENT SOLAR ARRAY POWER MODULE

### **Gateway Integrated Spacecraft**



# **GATEWAY** Capability

NASA and its international partners will add modules and capabilities, evolving a robust orbiting laboratory and a home away from home for astronauts on their way to and from the lunar surface. The Gateway will serve as a test bed and staging point for future human exploration into deep space.

#### **Power and Propulsion Element (PPE)**

- High-power solar electric propulsion spacecraft
- Transfers the initial capability to lunar orbit
- Establishes a communications relay with Earth
- Maintains the Gateway's orbit

#### Habitation and Logistics Outpost (HALO)

- Houses up to 4 crew for up to 30 days (with Orion)
- Provides high-rate lunar communication relay to support lunar surface activities and command and control systems for Gateway
- Docking port for visiting spacecraft and future modules



#### Canadian Space Agency (CSA):

External robotics system, robotic interfaces, and end-to-end robotic operations

#### European Space Agency (ESA):



International Habitat (I-HAB) and refueling modules, along with enhanced lunar communications

## The Japan Aerospace Exploration Agency (JAXA):

I-HAB's environmental control and life support system, batteries, thermal control, and imagery components



# Gateway is Key for Multiple Lunar Missions

- Artemis/Orion lunar orbit capability is limited
- Logistics (and assembly) node is needed
  - Multiple logistics missions to Gateway needed to stockpile equipment for long duration lunar sorties/outposts
- Safe Haven for contingencies is needed
- Gateway is a key technology demonstrator for long term Mars missions
  - ECLSS, Comm, Radiation Protection, etc.



**EXPLORATION UPPER STAGE UMBILICAL (EUSU)** 







**EXPLORATION UPPER STAGE STRUCTURAL TEST ARTICLE** 



IGNITION OVERPRESSURE / SOUND SUPPRESSION (IOPSS) SYSTEM FOR MOBILE LAUNCHER 2 (ML2)



#### ARTEMIS IV SPACE LAUNCH SYSTEM ENGINE SECTION

ARTEMIS IV CREW MODULE PRESSURE VESSEL AT MICHOUD ASSEMBLY FACILITY



ARTEMIS IV CREW MODULE PRESSURE VESSEL AT MICHOUD ASSEMBLY FACILITY

**ARTEMIS IV EUROPEAN SERVICE MODULE IN BREMEN, GERMANY** 

## FUTURE ARTEMIS

- Successfully fired a subscale rocket booster for Artemis IX and beyond.
- Successfully fired a ground-based version of a booster for SLS at Northrop Grumman's facility in Utah.
- Finalized the contract with Boeing to continue to manufacture core and upper stages for future SLS rockets, including procuring critical and long-lead materials.
- Released an RFP for sustainable lunar lander development and demonstration, inviting industry to build additional landers.
- Signed an implementing agreement with Japan to provide an opportunity for a JAXA astronaut to serve as a Gateway crew member, in exchange for IHAB's ECLSS System, IHAB, HALO, and ESPRIT's batteries, and HTV-XG for logistical resupply.
- Released the draft RFP for LTV Services.



# Human Landing System

## Sustaining Lunar Transport

Using proven commercial partnership strategies, NASA is working with U.S. industry to build towards regular human lunar landings.

Companies will develop human landing systems and NASA will purchase transport services, while maintaining oversight to ensure safety standards are met.

# Initial Human Landing System

NASA will use the HLS Starship for use on Artemis III, the mission that will put the next two Americans on the surface of the Moon.

The SpaceX Option A contract includes two lunar surface missions:

- SpaceX Uncrewed Lunar Demo-A
- SpaceX Crewed Lunar Demo-A





- Initial HLS for Artemis III (SpaceX)
  - Completed SpaceX Option A contract milestones in CY22 including:
    - Landing Software and Sensor Demo
    - Software Architecture Review
    - Sea-level Raptor Engine Cold Start Demo
  - Advancing lander system design maturity; examples include:
    - Raptor development/build: demonstrated production of 7 engines in one week
    - Cryo Fluid Management: Plan in-space Propellant Transfer and Long Duration Flight Tests
  - Prep for first Starship orbital flight
- Sustaining HLS for Artemis IV+
  - Conducting Sustaining HLS studies and risk reduction tasks ("Appendix N" contracts)
  - Sustaining HLS Acquisitions
    - Impending SpaceX Option B contract mod
    - Issued HLS Sustaining Lunar Development "Appendix P" solicitation

# Lunar Landers

- SpaceX selected to develop the first demonstration lander. Requires a on-orbit cryogenic propellant transfer demonstration, an uncrewed landing demonstration on the moon (no ascent, no return), and one short term (6.5 day) 2-person lunar landing (Artemis III).
- SpaceX has been selected to develop a second-generation lunar lander ("sustainable lander") which can carry 4 people and stay on the surface up to 30 days. Schedule goal for Artemis V and subsequent.
- NASA has opened a competition for other providers to also develop second generation 'sustainable lunar landers' as well. Schedule goal for Artemis V or subsequent flights

## Exploration Campaign Segment – Sustained Lunar Presence

Includes all activities on or around the Moon that contribute to both the establishment of a sustained human lunar presence and to risk reduction for human Mars exploration.



NOTE: Crew mission duration driven by budget and mission objectives

\* Robotic deployment of the FSP and Pressurized Rover operations are critical Mars-forward tests

\*\* Initial emphasis on Mars Analog missions transitioning to lunar sustained missions; Sustained Human Lunar Surface missions continue indefinitely

## **Artemis Base Camp Buildup**

First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface

Lunar Terrain Vehicle (LTV)

Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities

Crew

Landing

Services

Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions

Pressurized

Rover

Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets

Fission Surface Power ISRU Pilot Plant

Surface Habitat

#### 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

### Exploration Extravehicular Activity (xEVA) Systems Development: Not Just Spacesuits

#### Advanced suits (Exploration Extravehicular Mobility Units or xEMUs)

- Portable Life Support Subsystem (xPLSS) which contains CO<sub>2</sub> removal and thermal control
- Pressure garment subsystem (xPGS)

#### Vehicle interfaces (VISE)

• Physical interfaces and support equipment such as don/doff fixtures, launch enclosures, umbilicals, battery chargers, and maintenance equipment



#### **Tools and equipment**

- Geology equipment for sample collection
- Construction tools for maintenance activities
- Translation support like handrails

**Pictured left:** ARGOS Suit and tong tool **Pictured right:** NASA Astronaut Jessica Meir in an xEMU



#### Lunar Terrain Vehicle

#### **Requirements definition is in-work**

- Ability to traverse from one landing zone to another and increase exploration range beyond maximum suited walking distance
- Reusable and rechargeable for approximate 10-year service life
- Remote operation from Human Landing System, Gateway, and Earth
- Interface with future science instruments and payloads for utilization or pre-deployment of assets
- Ability to survive eclipse periods

#### **Developing LTV: Survive the Night**

- The lunar South Pole is massively cratered, with areas bathed in sunlight and shrouded in darkness
- The craters are brutally cold but elevated areas can grow extremely hot
- NASA has initiated a new study to identify options for addressing lunar night survival
- Potential design solutions will be generated by an internal team and industry partners
- LTV will need to survive up to 100 hours of darkness with at least a 10-year lifespan

## 2023 ESDMD LOOK AHEAD

Common Exploration Systems Development

#### **Exploration Ground Systems**

- Artemis I Post Flight Analysis Review
- Artemis II Mobile Launcher 1
  Crew Mods complete
- Artemis II Launch Pad 39B LH2 Sphere complete
- Artemis II Multi-element V&V Complete
- Artemis II Start of Booster Processing
- Artemis IV Mobile Launcher 2
  Critical Design Review

#### **Space Launch System**

Artemis II

- Core Stage delivered to KSC
- ICPS, OSA, LVSA delivered to KSC
- Booster Segments delivered to KSC

#### Artemis III

- RS-25s complete
- Booster segments complete
- Core Stage manufacturing at MAF Complete
- ICPS, OSA, LVSA complete

#### Artemis IV

- RL10C-3 for EUS delivered to SSC
- EUS construction facility complete at MAF

Artemis V and Beyond

- RS-25 Recertification Engine Test Series 13 testing at SSC
- 8 of the 24 new RS-25 engines under contract

#### **Orion Spacecraft**

- Artemis IV crew module pressure vessel on dock at KSC
- Artemis II crew module heat shield install
- Artemis II crew and service modules complete and mated
- Artemis IV heat shield on dock at KSC
- Artemis III Launch Abort System motors start arriving
- Artemis II spacecraft initial power on
- ESA Service Module 3 on dock at KSC
- Artemis II Launch Abort System complete

ARTEMIS

## 2023 ESDMD LOOK AHEAD

Artemis Campaign Development

#### Human Landing System

- Starship Orbital Vehicle Launch Test Flight (SpaceX owned test)
- Certification Baseline Review (SpaceX Sustaining Lander)
- KDP-C and Agency Baseline Commitment (ABC) for HLS Initial Capability
- Sustaining Lunar Development Appendix P Award

#### Gateway

- Program Key Decision Point (KDP)-I
- HALO critical design review closeout
- PPE critical design review
- HALO delivery from Italy to Northrop Grumman in Gilbert, AZ
- Gateway External Robotics Interface (GERI) critical design review
- Gateway External Robotics Systems (GERS) preliminary design review
- HALO Lunar Communication Subsystem (HLCS) critical design review

# Extravehicular Activity and Human Surface Mobility

- Pressurized Rover Mission Concept Review (MCR)
- Program Systems Requirement Review (SRR) / System Definition Review (SDR)
- Program Key Decision Point I (KDP-I)



## Moon to Mars Architecture and Element Development and Refinement





## **Transit Habitat**

# Reused element with 15-year lifetime for multiple missions

- Keep crew healthy and productive during long duration, deep space stays including:
  - Shakedown missions at Gateway and while free-flying with interim propulsion
  - Lunar-Mars analogs

Artist's illustration

- Up to 1100-day Mars transit and orbital stays
- Demonstrate needed capabilities to live for long durations beyond low Earth orbit
- Build on ISS and commercial investment in deep space habitation

## **First Conceptual Mars Mission**

Reference architecture for analysis purposes only.

# NASA

#### TRANSIT HABITAT AND HYBRID PROPULSION STAGE

- Supports four crew on the long mission to Mars
- Two crew remain in orbit while two crew visit the Mars surface



#### PRE-DEPLOYED CARGO

- 25-ton class payload Mars lander
- Ascent vehicle propellant, Surface Power, and surface mobility/propellant transfer system

2 PRE-DEPLOYED CREW ASCENT VEHICLE

- 3 CREW
  - Two crew land/live in pressurized rover
  - Provides habitation and mobility for 30 days
  - Supports science and exploration operations