NASA

November 13–14, 2024 | Online

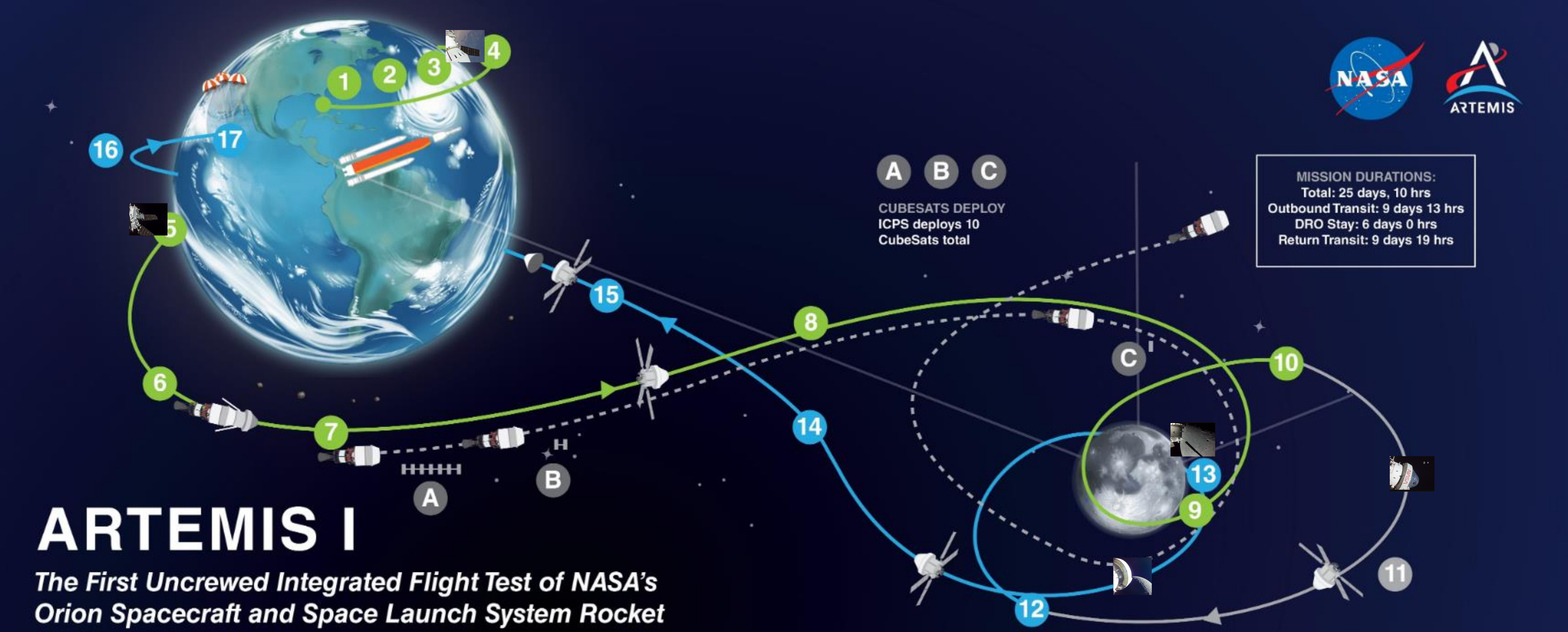
Spacecraft Power Capability (SPoC) Model for NASA Artemis Missions

Hector Hernandez, NASA

MATLAB EXPO

Agenda

- Artemis 1 Mission Overview
- Spacecraft Power Capability (SPoC) Background
- Example Challenges
  - Solar Array Performance Modeling
  - Battery Model Updates
  - Mission Planning & Design
- Conclusion



ARTEMIS I

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

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2. **JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM**
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   With separation.
4. **PERIGEE RAISE MANEUVER**
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   Systems check with solar panel adjustments.
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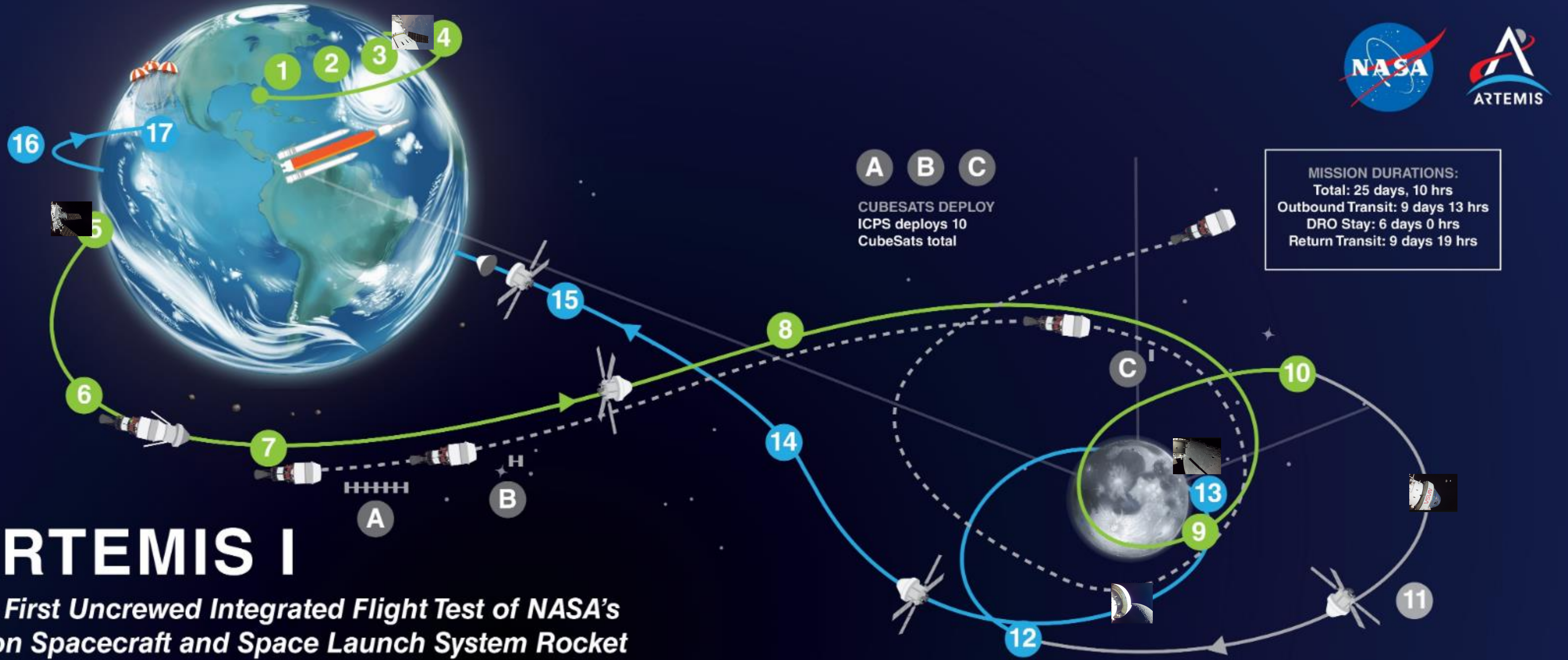
17. **SPLASHDOWN (12/11/22)**
    Pacific Ocean landing within view of the U.S. Navy recovery ship.

Flight Day 1 Post Solar Array Deployment



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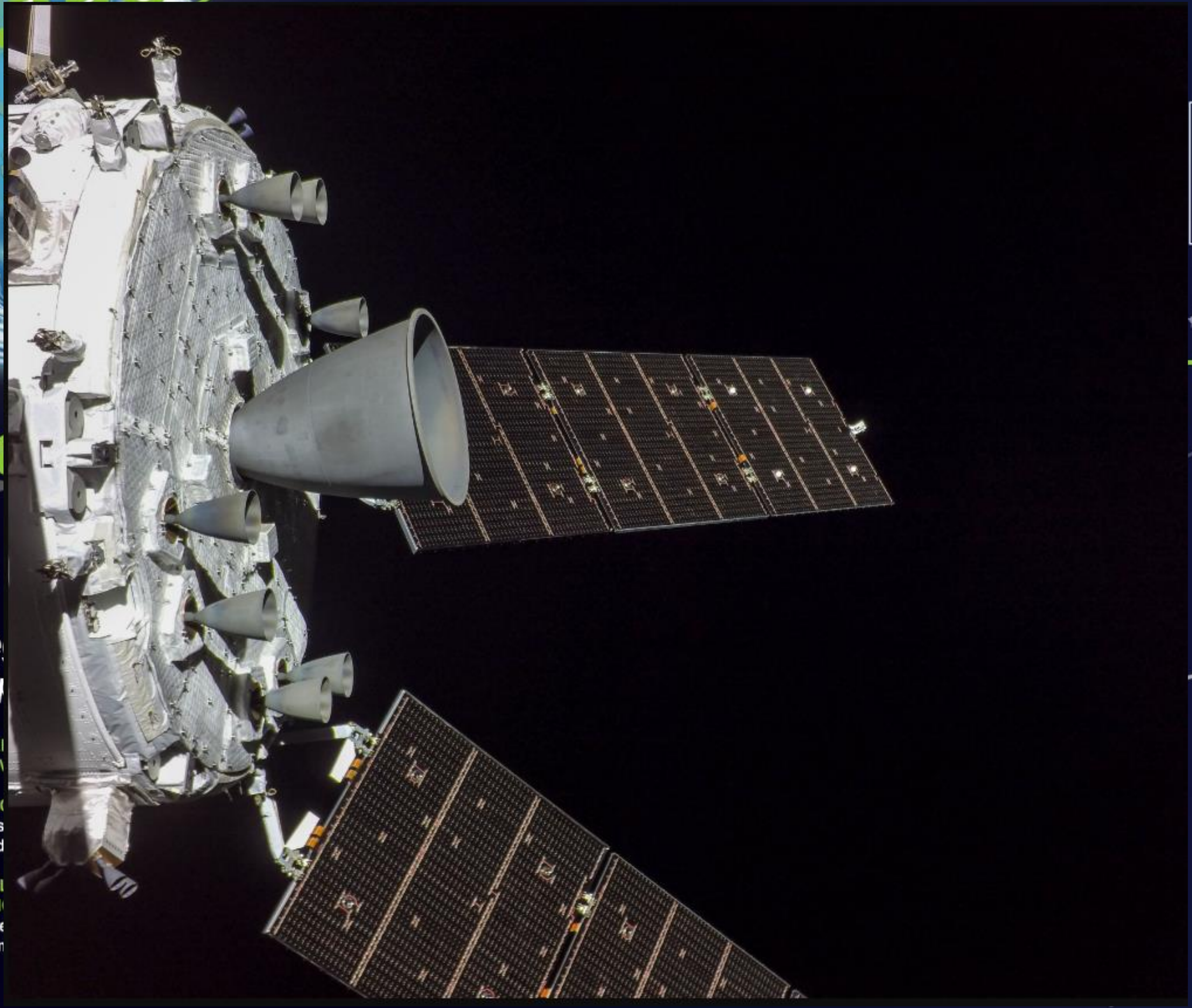
Flight Day 1 Service Module Inspection



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MISSION DURATIONS:
Total: 25 days, 10 hrs
Outbound Transit: 9 days 13 hrs
DRO Stay: 6 days 0 hrs
Return Transit: 9 days 19 hrs

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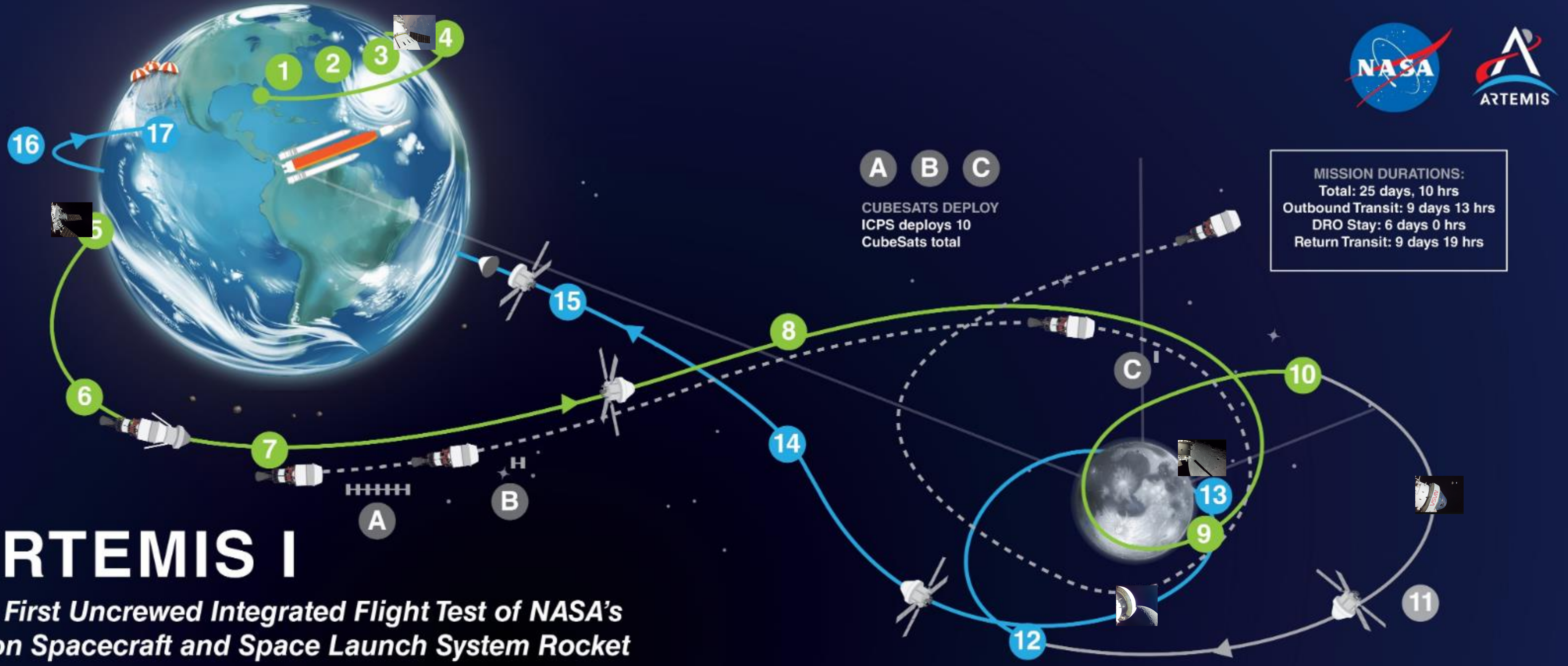

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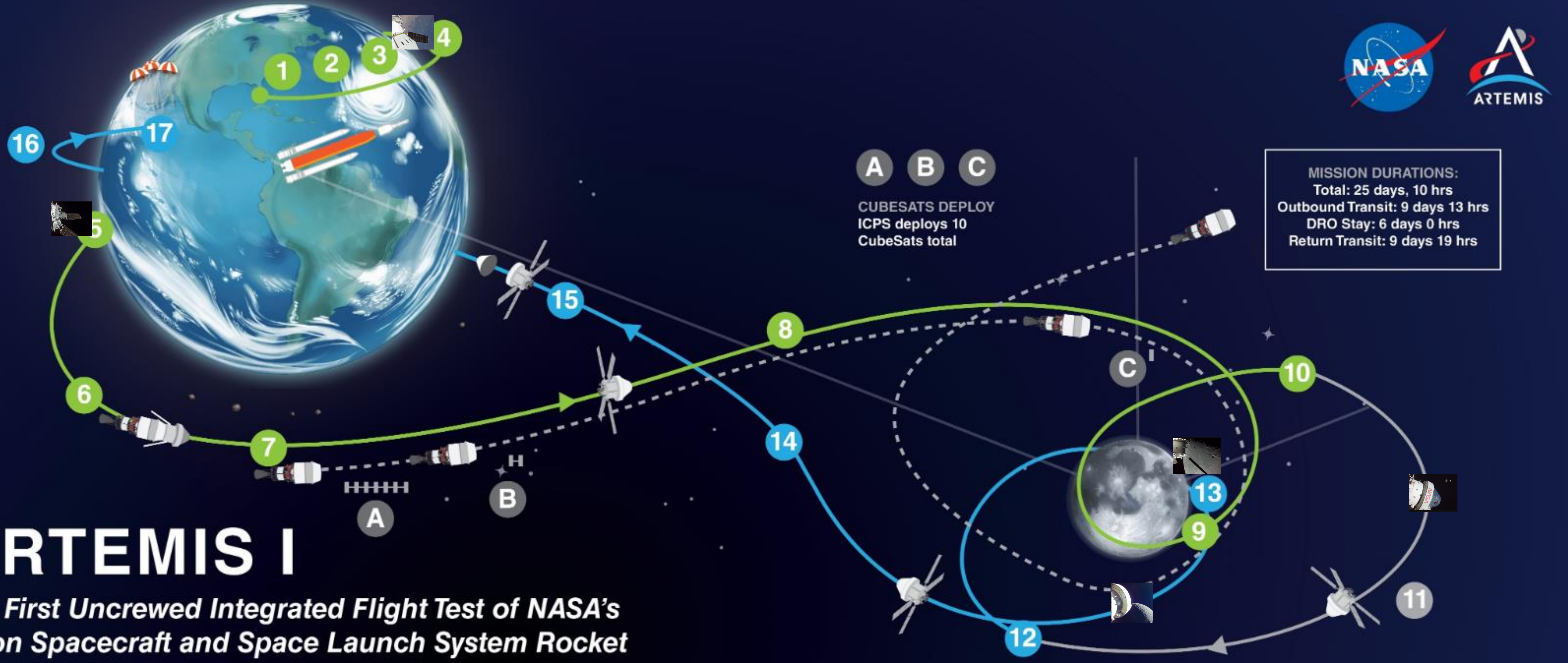
Flight Day 13 Orion Selfie



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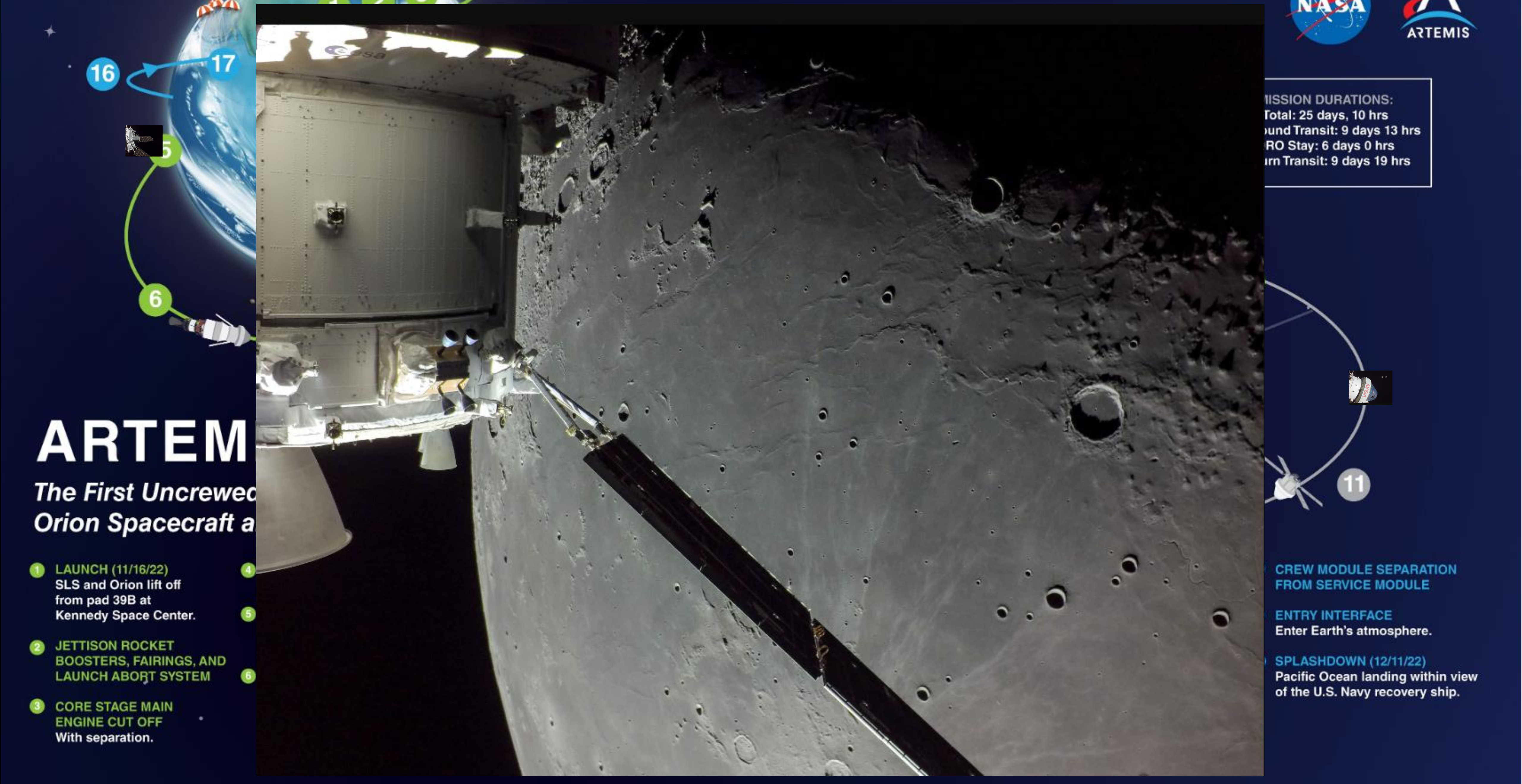
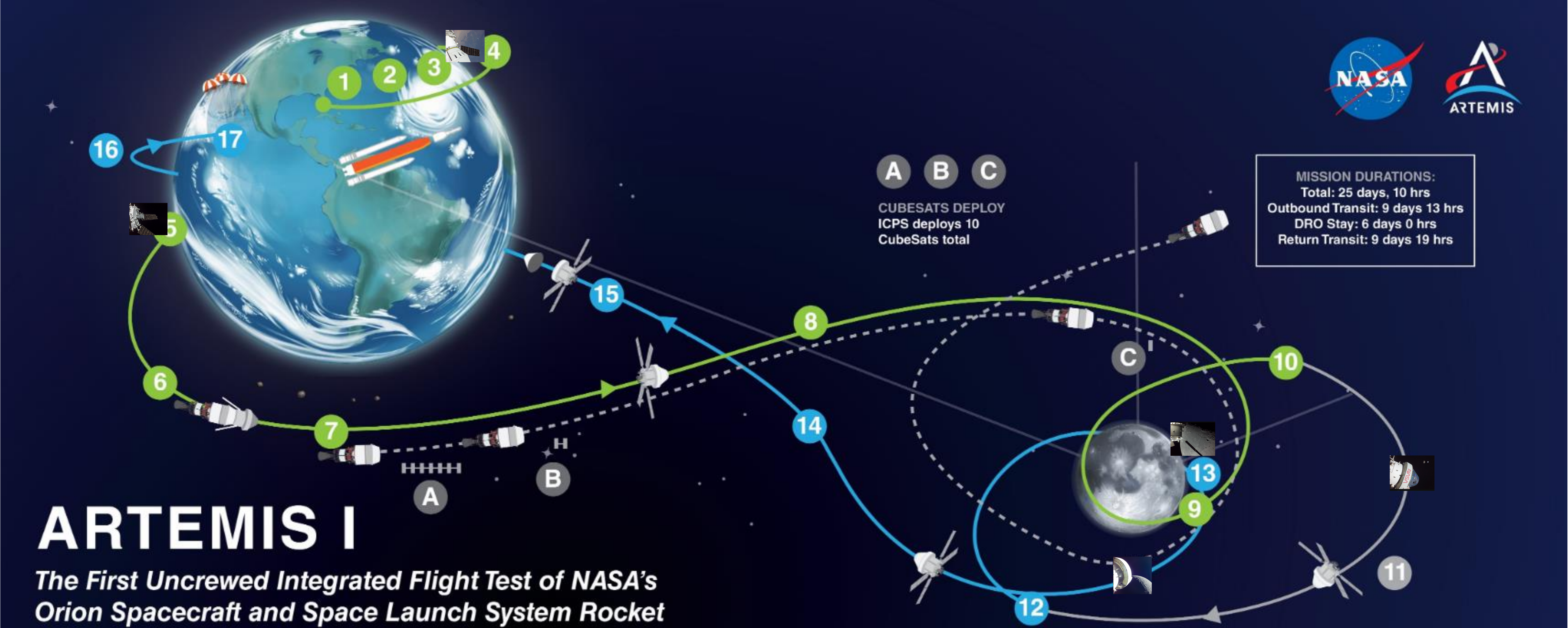
Flight Day 20 Pre Return Powered Flyby





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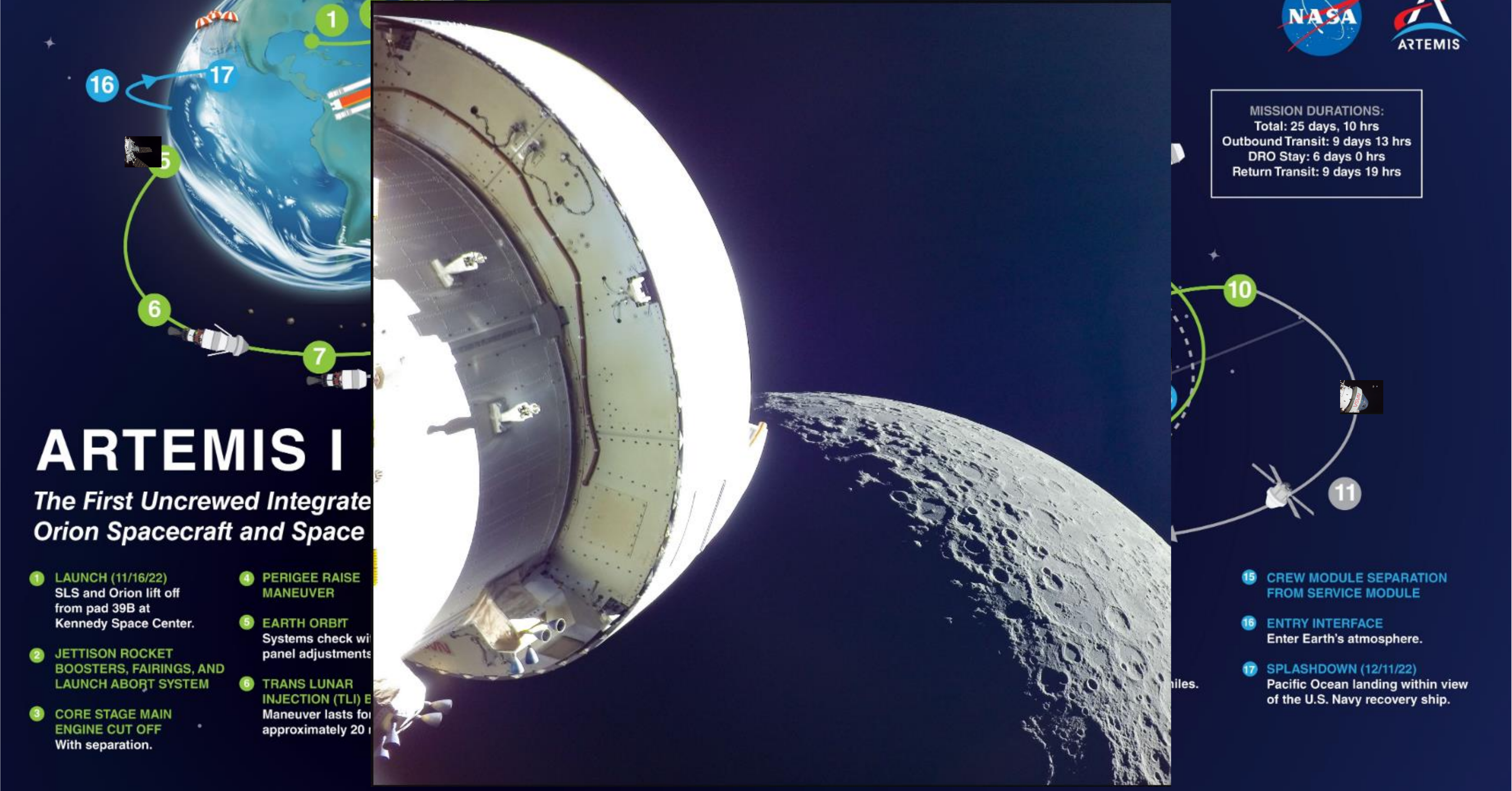
Flight Day 20 Post Return Powered Flyby



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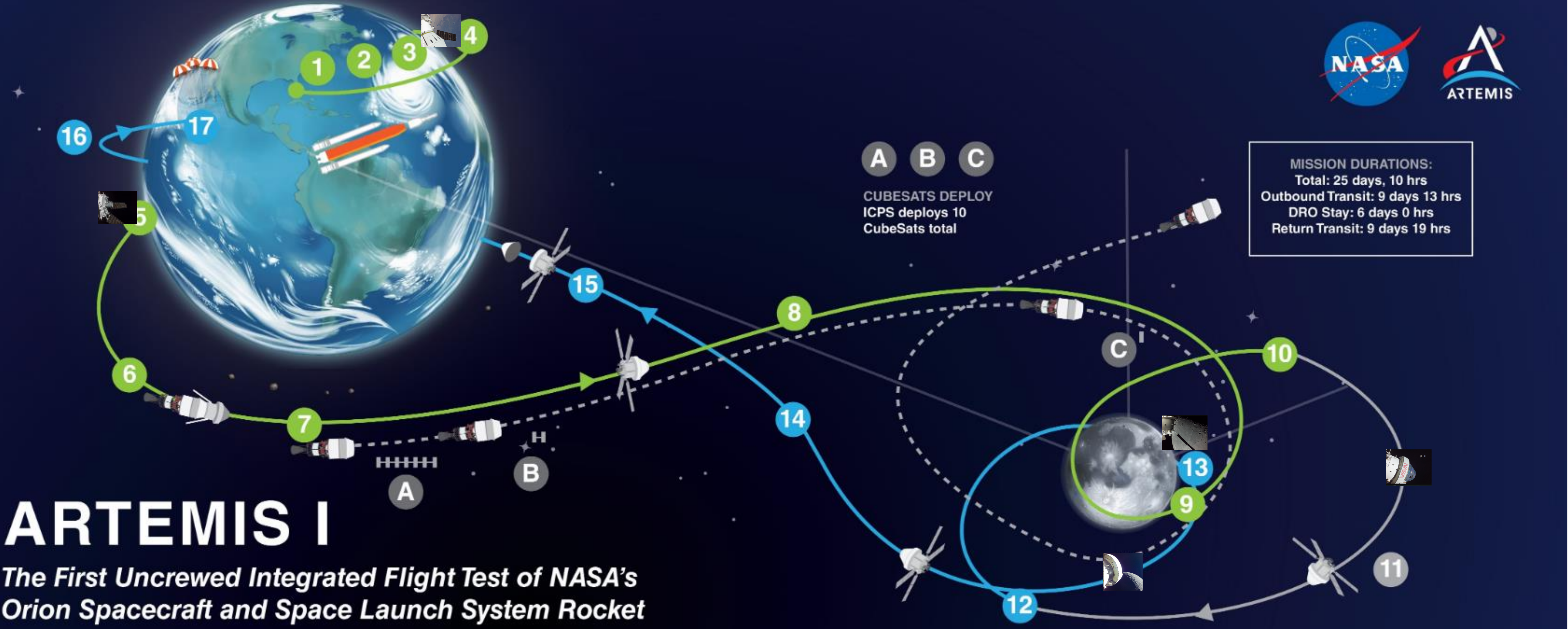

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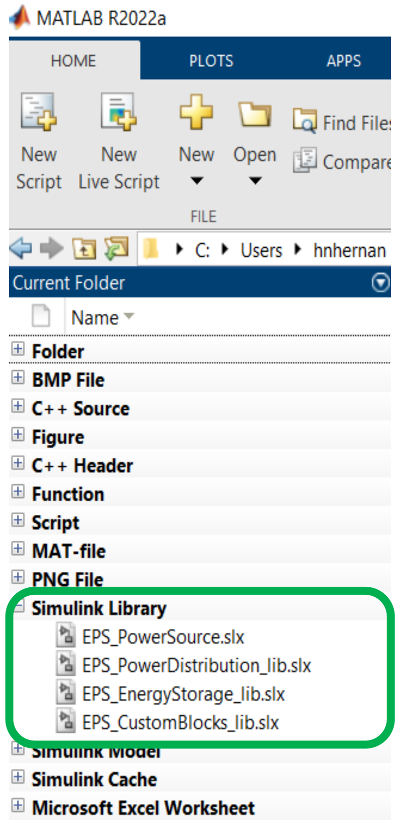
SPoC Background

- **Spacecraft Power Capability (SPoC) is a computer model originally developed for predicting the electrical performance of the Orion Exploration Flight Test-1 (EFT-1) Electrical Power Subsystem (EPS)**
  - Developed in Simulink® environment using Simscape™
  - Mix of validation techniques used in a complementary fashion to reduce risk of errors
- **Integrated power analysis (IPA) to support mission level design and vehicle performance analysis**
  - Supported the Orion Artemis 1 prelaunch, real-time and post-flight analysis
  - Currently supports Orion Artemis 2+ and other NASA programs
- **Verification and validation of EPS requirements and flight test objectives**
- **SPoC determines EPS capability and predicts the system state**
  - Power generation, battery state of charge (SoC), voltage, etc.

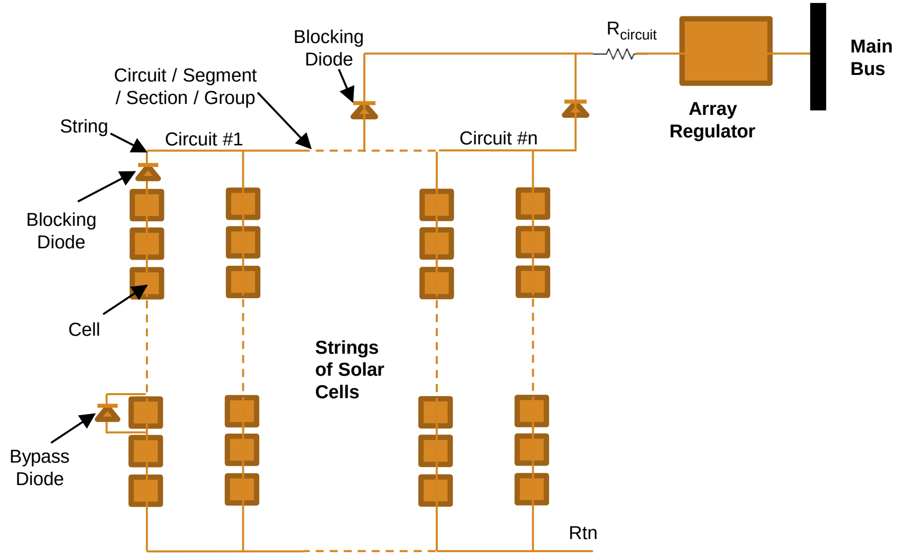
SPoC Background Cont'd

- **SPoC has three major component libraries for spacecraft power system applications**
  - *Power Source/Generation library*
    - Orion heritage-based solar cell model similar to the standard Hughes Model
    - Customized for single cell, string or segment operation and robust modeling convergence
  - *Energy Storage Library*
    - Orion heritage-based equivalent circuit models of a cell or battery
  - *Power Management & Distribution Library*
    - Generic power distribution unit templates that includes power inputs and outputs
      Usually, the most customized component for representing different power system architectures
    - Heritage-based cabling models, fuses, switches, regulators
- **Major components are built using custom blocks from the *EPS Custom Blocks Library* and have been tested & validated**
  - Custom blocks are coded using Simscape™ Language

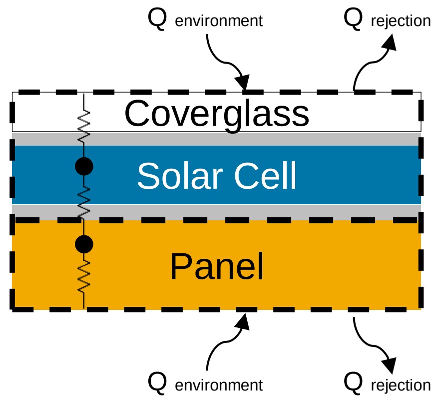


Challenges: Solar Array Performance Modeling

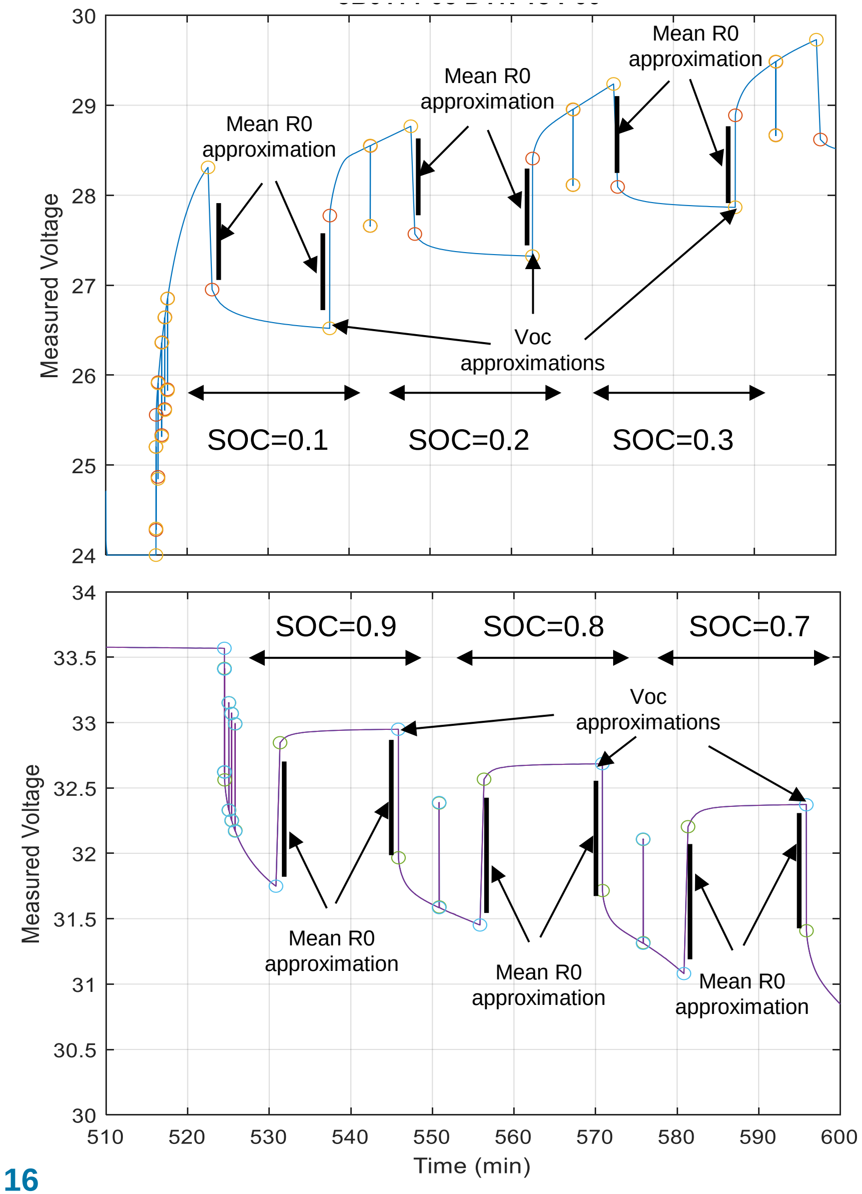
- **Modeling solar array performance requires knowledge of mission and vehicle level conditions such as:**
  - Operating environment (LEO, GEO, LLO, etc.) & duration
  - Vehicle orientation (off-pointed conditions, off-nominal attitudes)
  - Solar flux and thermal conditions
  - Cell/wing level electrical and thermal parameters
- **SPoC models the entire solar array electrical design**
  - Discrete components from cells up to the array regulator
  - Strings connected to proper channels based on drawings

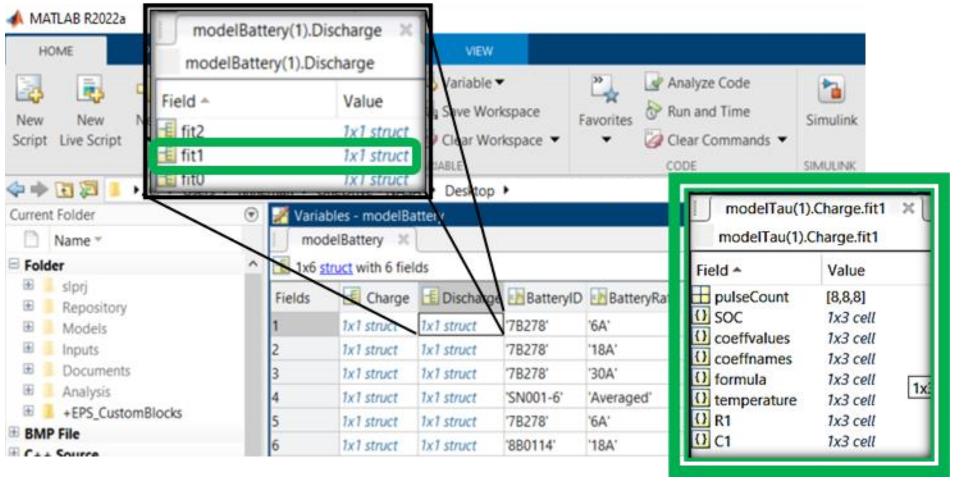


- **SPoC models the solar array operating temperatures based on mission & vehicle conditions**
  - Simplified thermal model that can accommodate different types of solar cells & substrates (flex blankets & rigid panels)
  - Time-phased predicts of array temperature in eclipse & sunlight



Challenges: Battery Model Updates





- **Processing test data for battery model parameter estimation can be challenging and time-consuming**
  - Depends on the size and quality of the data
- **Different applications require different degrees of battery model fidelity**
  - Mission level analysis (steady state voltage drop, energy balance)
  - System level analysis (power quality)
  - Dedicated State of Charge (SOC) and State of Health (SOH) estimation
- **Consequently, the same dataset(s) are processed multiple different times until the next update cycle is scheduled to occur**
  - Highly inefficient and works against completing scheduled milestones
- **The solution: auto-processed dataset(s) in MATLAB for all applications at one time until the next update cycle occurs or is required**

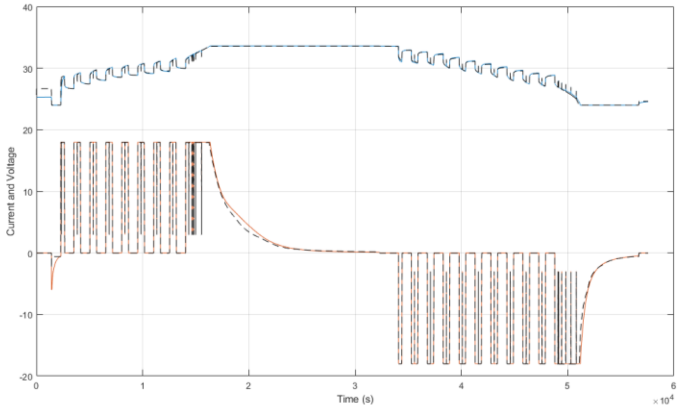
Challenges: Power Model Validation

- **Model validation process and activities to show objective evidence that the model reflects the system <u>as accurately as necessary</u>**

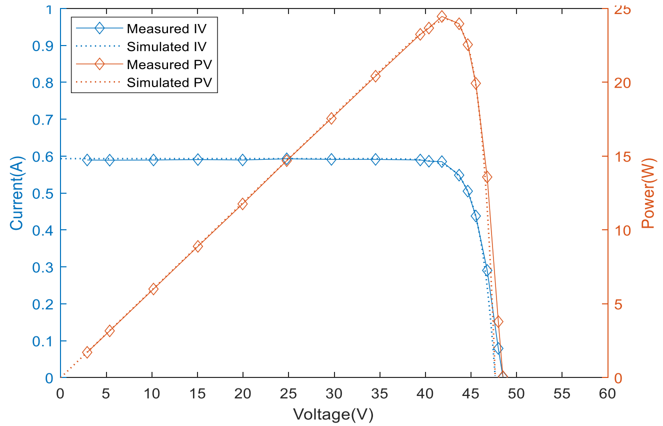
- **Implementation:**
  - Inspection of reasonable outputs
  - Internal peer reviews of model underpinnings
  - Measured data and simulation comparisons

- **Outcomes:**
  - The model behaves as expected with negligible errors
  - Some modifications were required followed by revalidation to confirm corrections
  - Some differences between the model and the real system which cannot be corrected but are quantified and understood

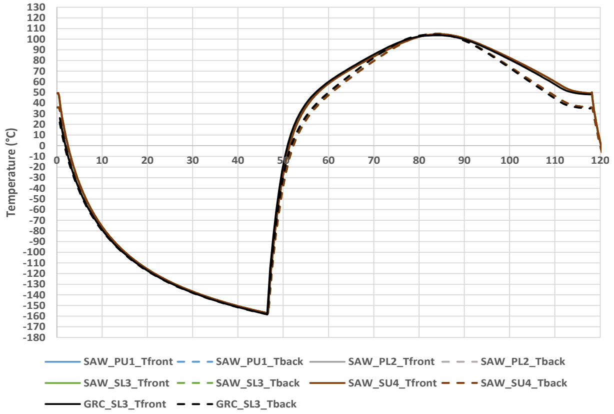
Example Battery Test and Model Comparisons



Example of LAPSS Test and Model Comparisons

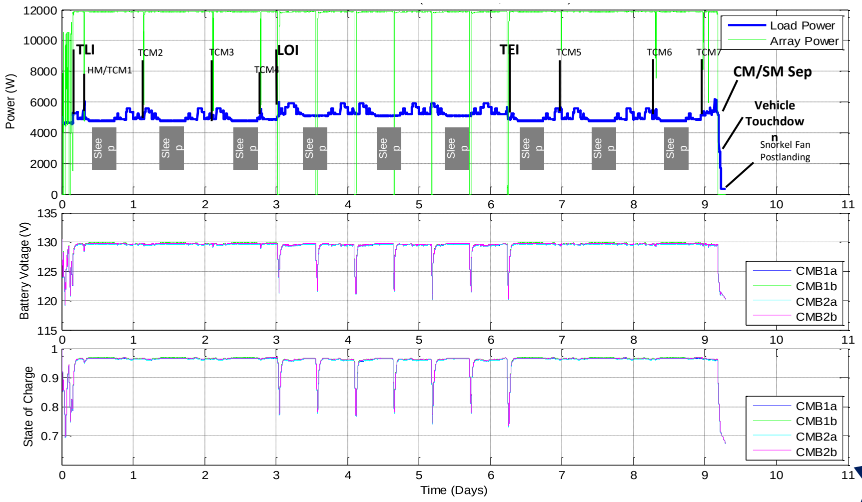


Example of Low Lunar Orbit Temp Predicts



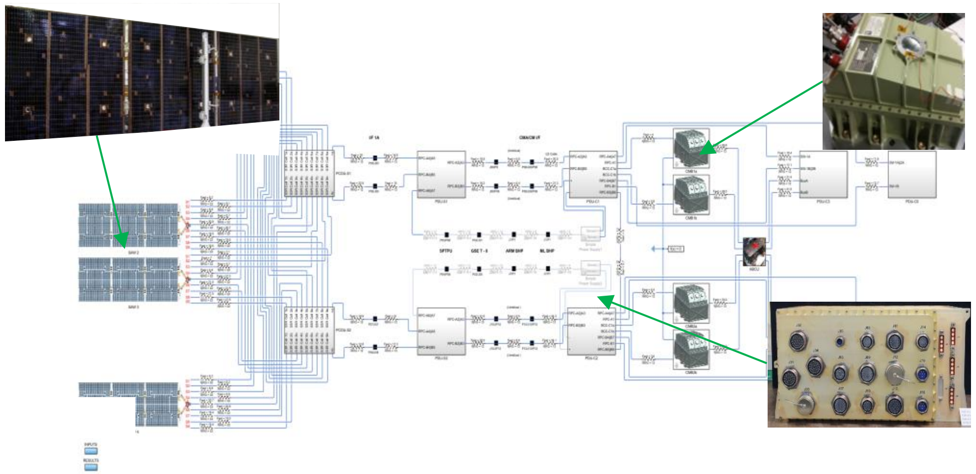
Challenges: Mission Design & System Performance

Integrated Power Analysis

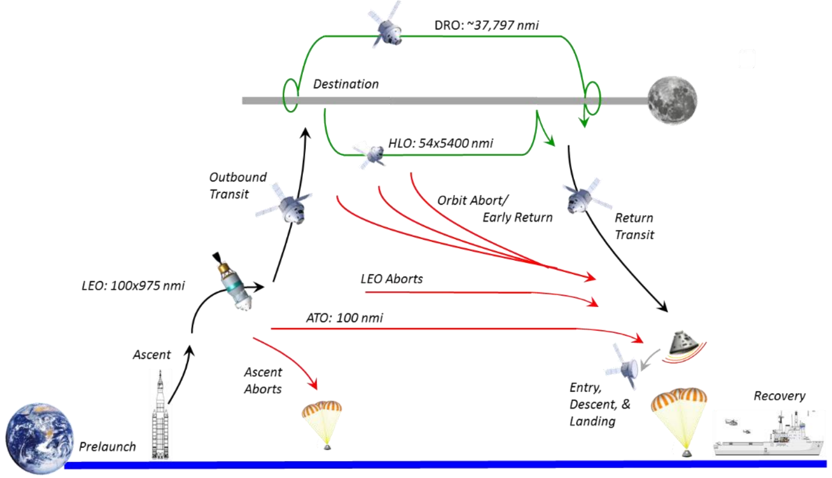


Mission Capabilities

Orion Power System Model



Mission Timelines



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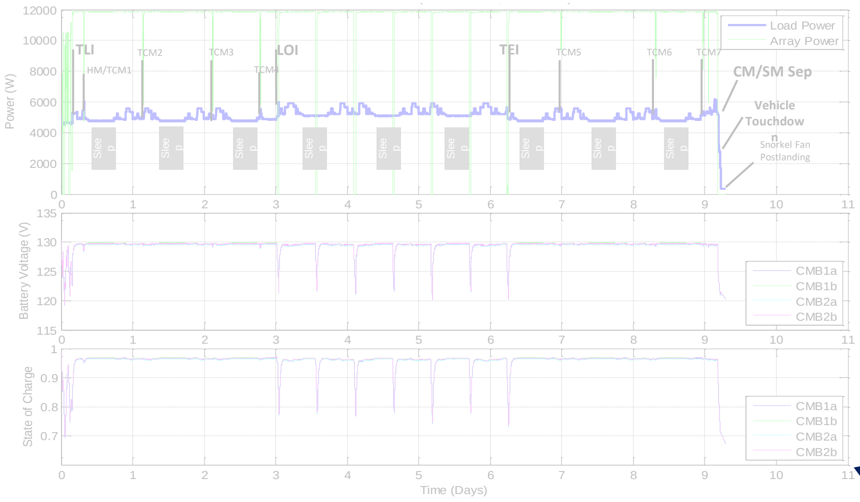

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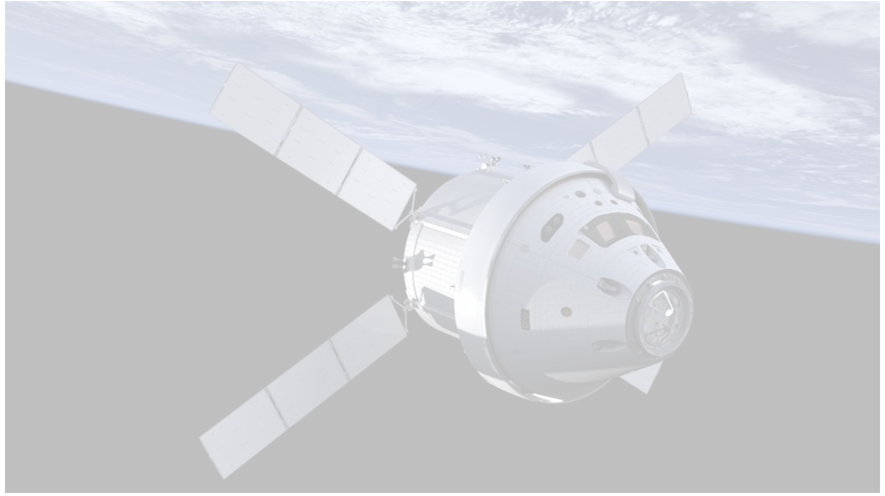

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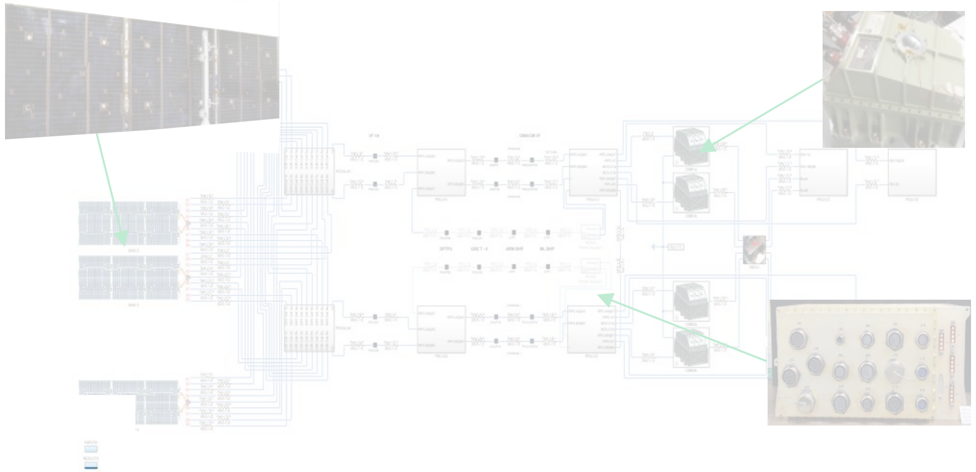

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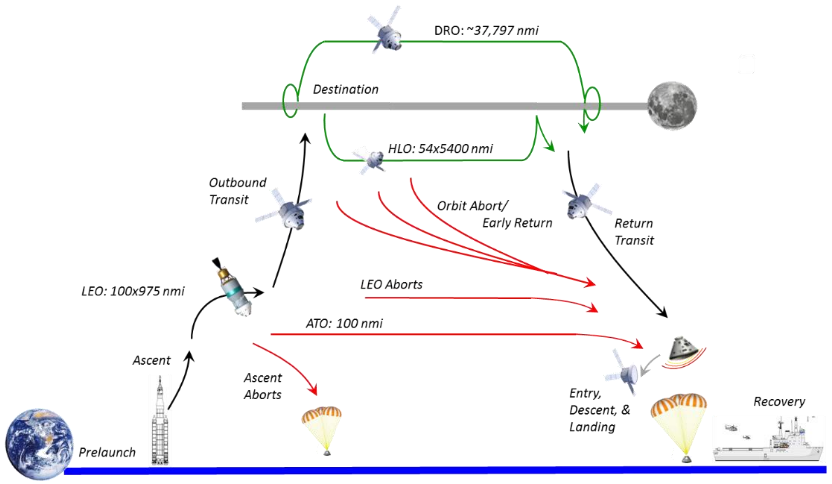

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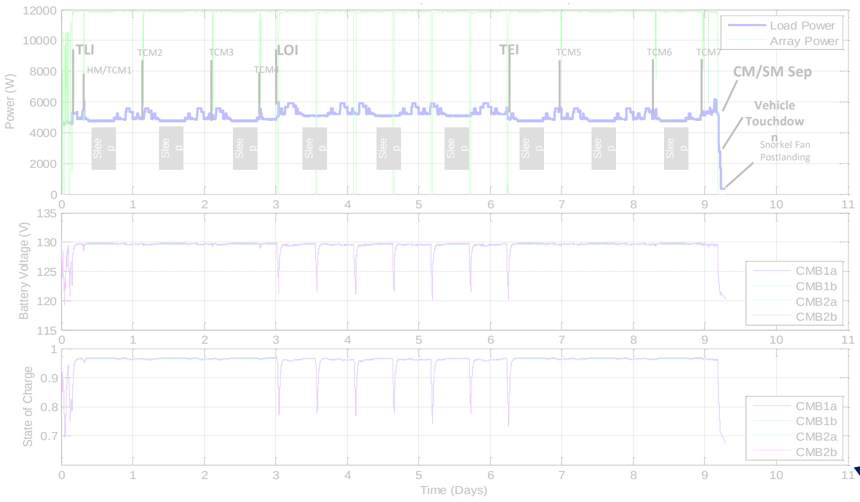

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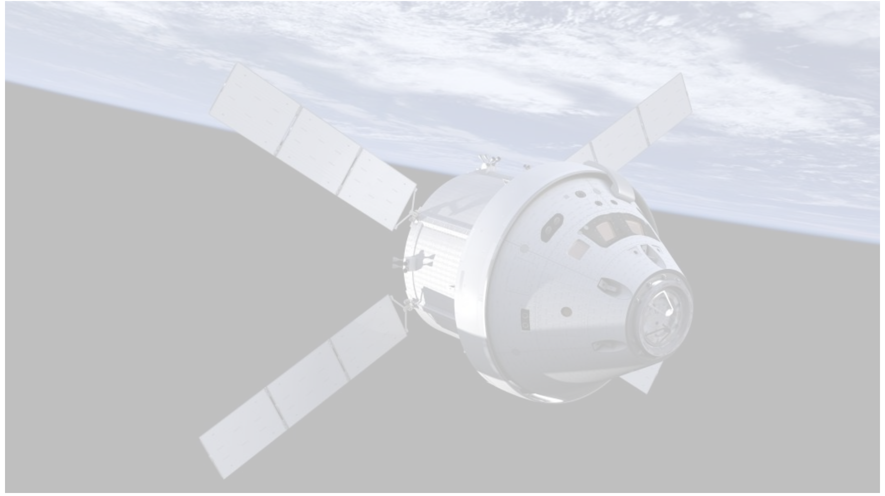

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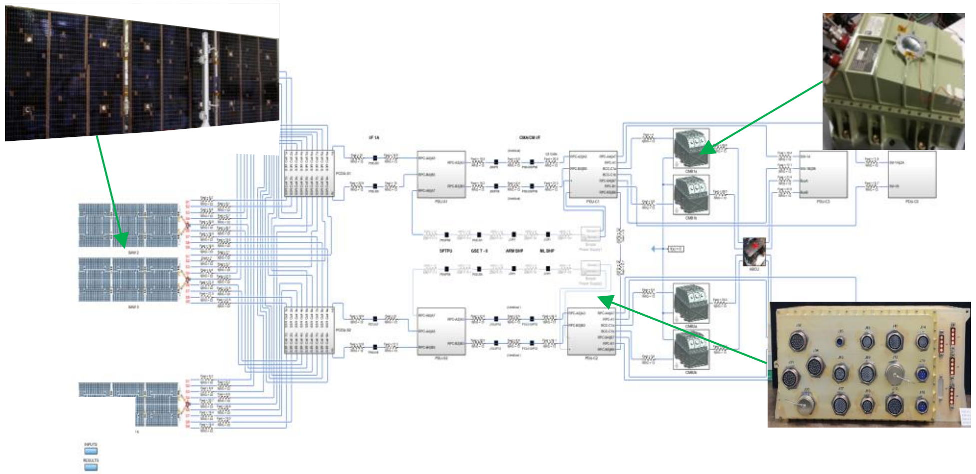

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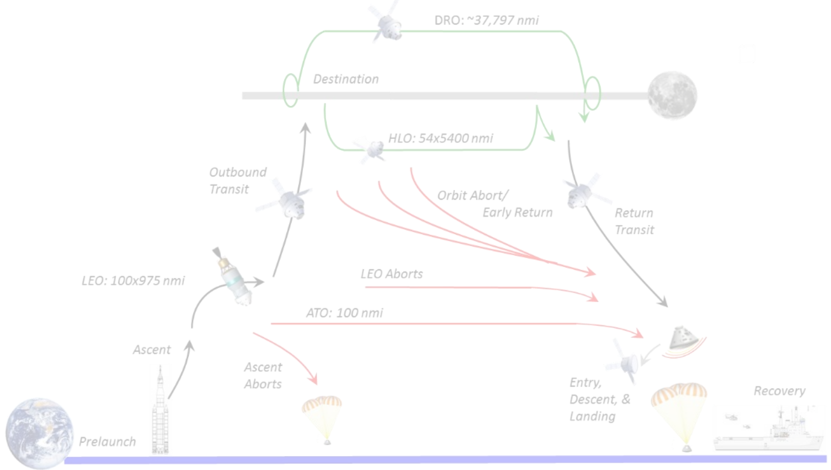

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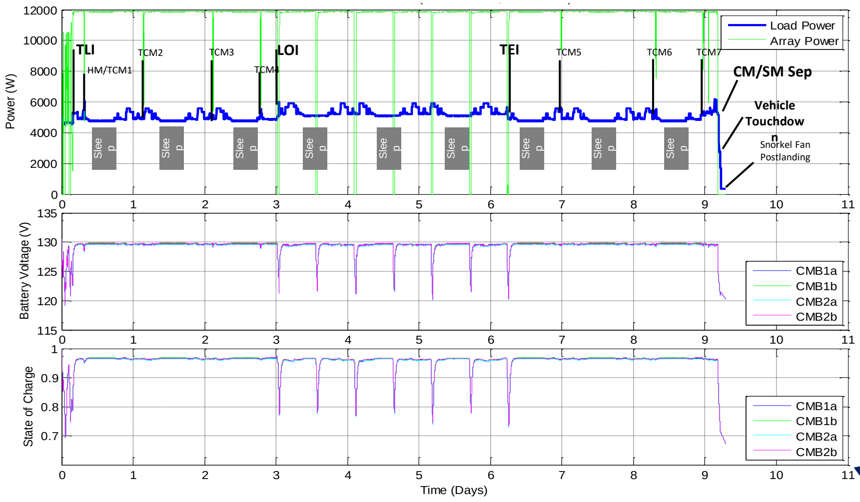

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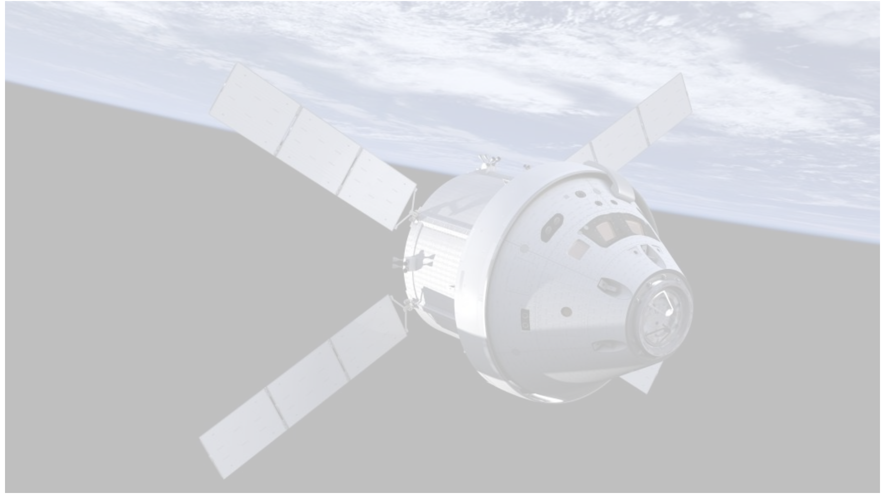

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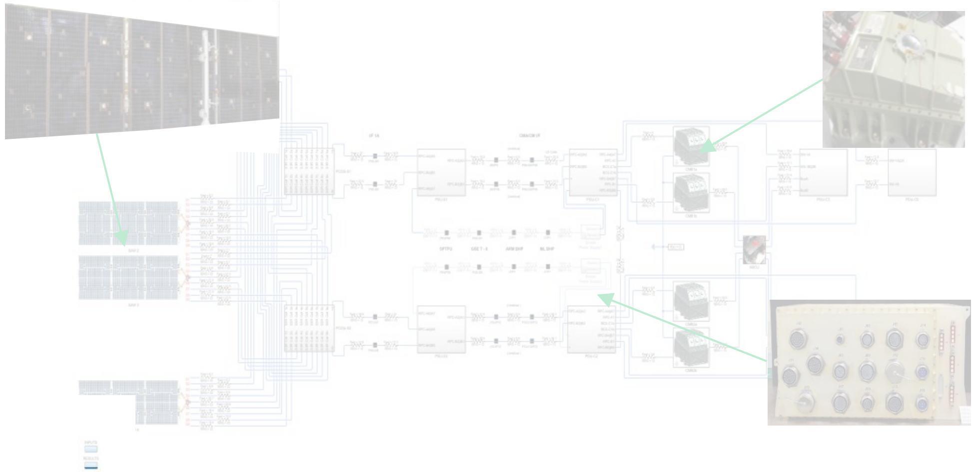

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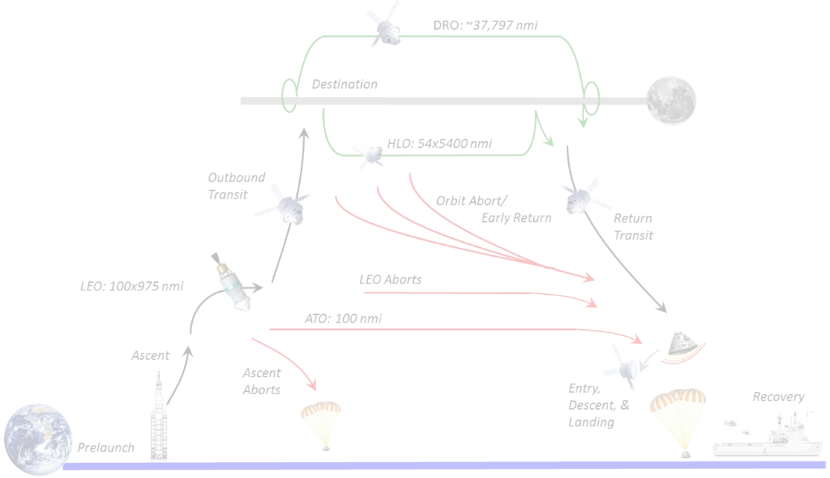

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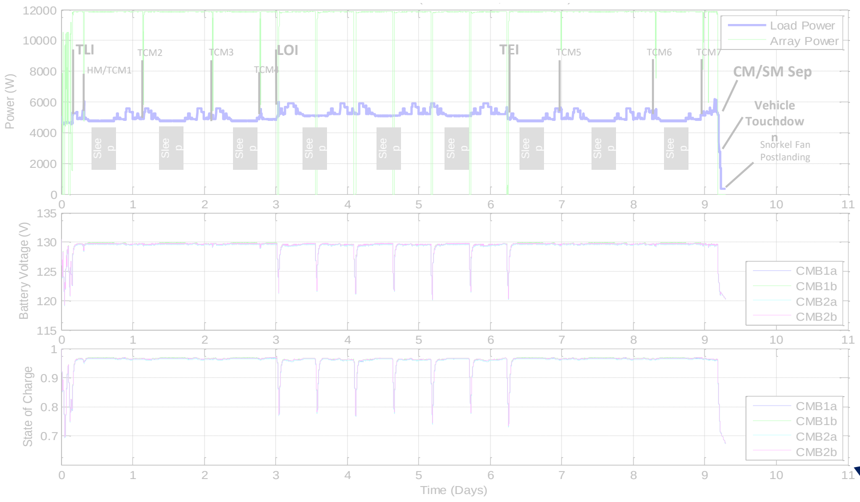

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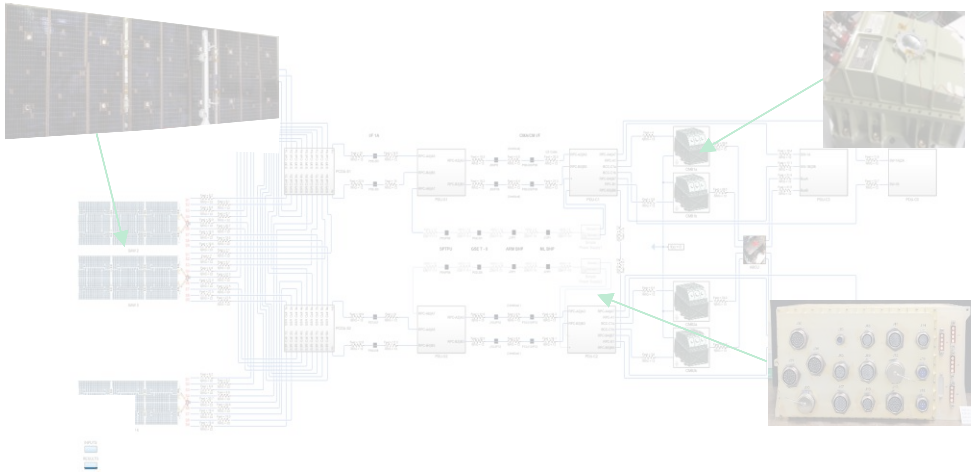
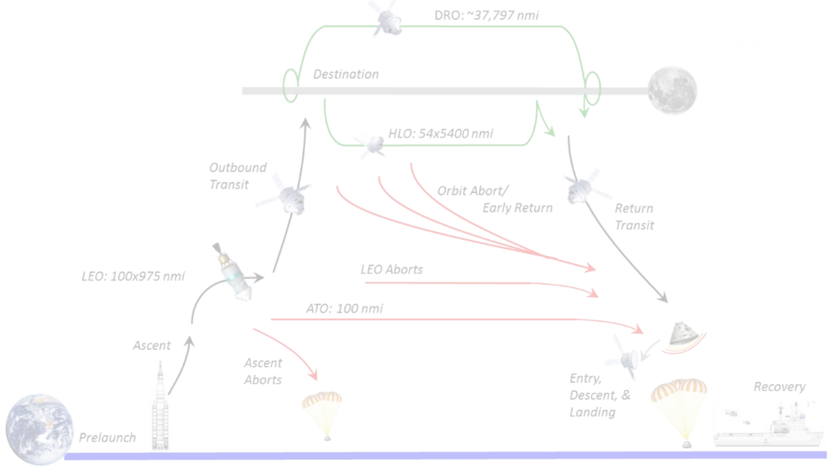
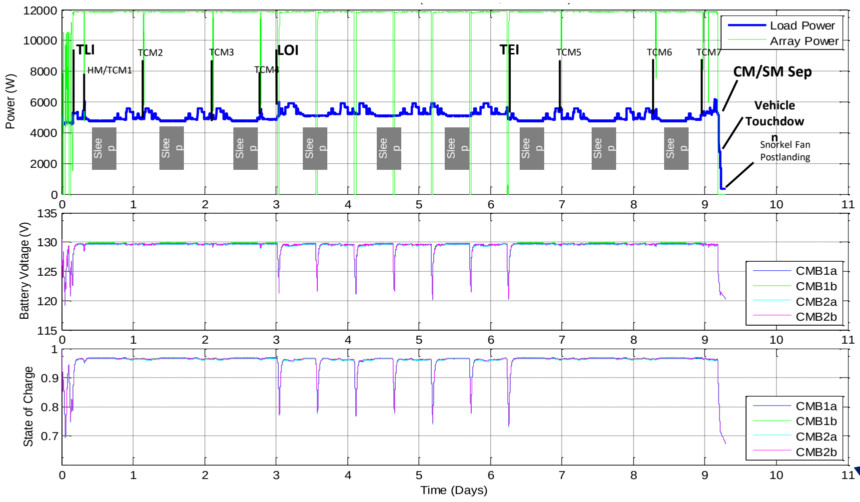


Mission Timelines



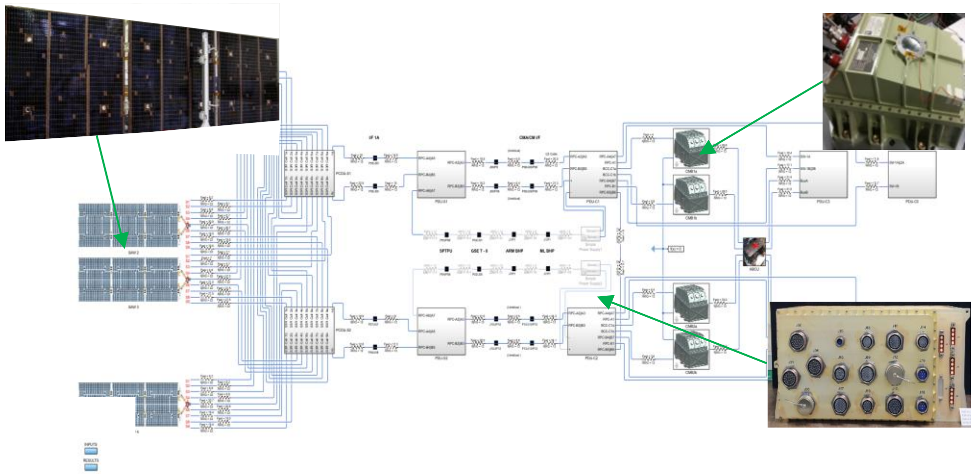
Challenges: Mission Design & System Performance

Integrated Power Analysis

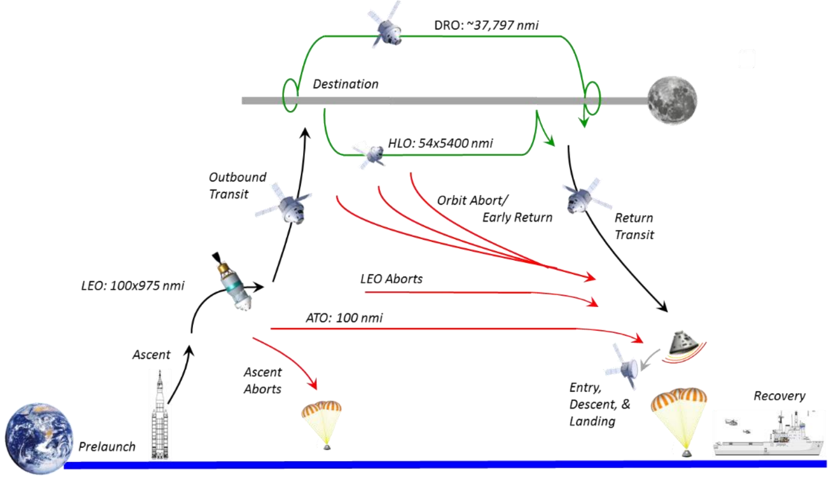


Mission Capabilities

Orion Power System Model



Mission Timelines



Conclusions

- **Accurate modeling of spacecraft power systems is essential to success as our missions increasingly become more complex**

- **SPoC is the integrated power model tool that provides that capability**
  - SPoC continues to be used in support of engineering development and operations of NASA’s spaceflight programs and will continue to do so in the future

MATLAB EXPO

Thank you!

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