

Analysis of the Artemis I Orion Spacecraft Power System Performance

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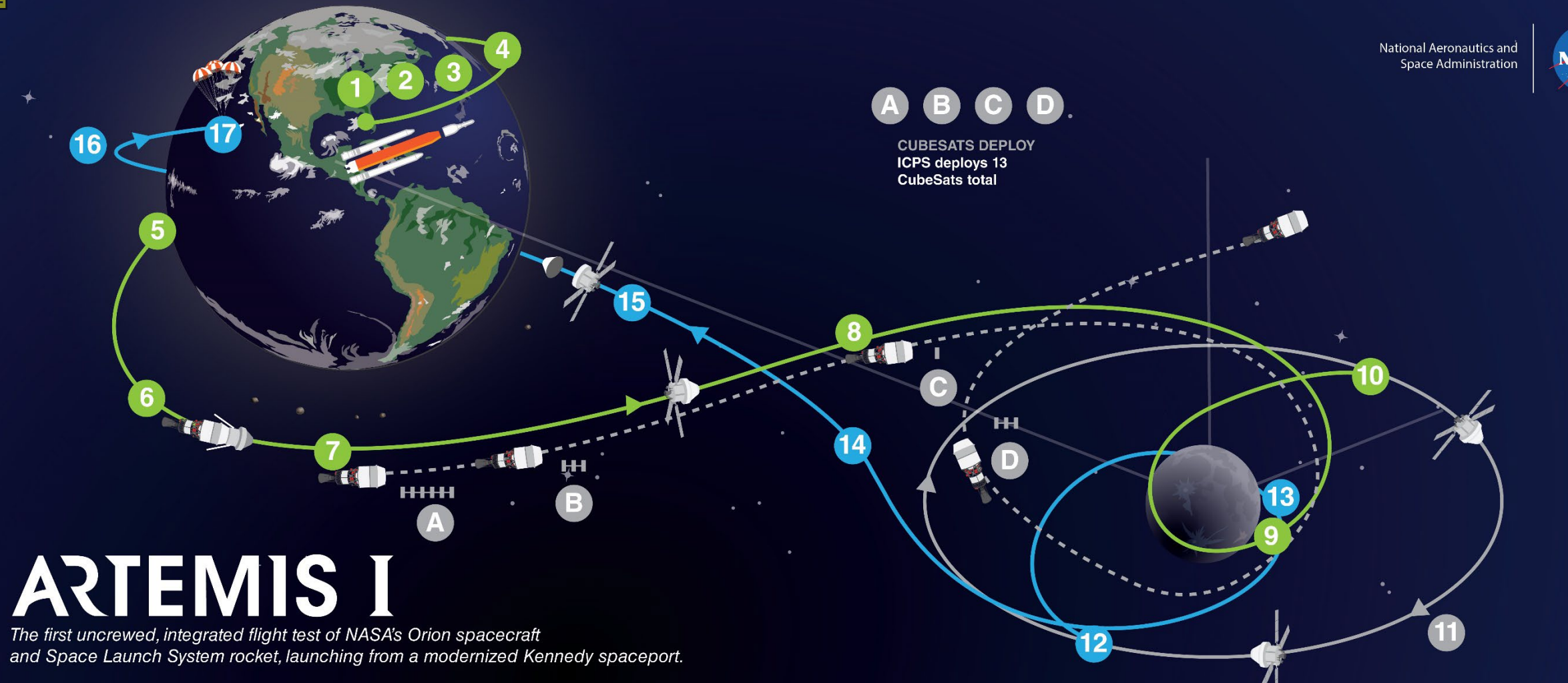
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A B C D

CUBESATS DEPLOY
ICPS deploys 13
CubeSats total

ARTEMIS I

The first uncrewed, integrated flight test of NASA's Orion spacecraft and Space Launch System rocket, launching from a modernized Kennedy spaceport.

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- The diagram illustrates the Artemis I mission profile, showing the trajectory of the Orion spacecraft and SLS rocket from launch to splashdown. The mission is divided into 17 numbered steps, with key events marked by letters A, B, C, and D. The trajectory starts at Earth (1), goes into Earth orbit (2-5), then trans lunar injection (6), lunar orbit insertion (10), and return to Earth (12-17). The diagram also shows the deployment of 13 CubeSats (A, B, C, D) and the separation of the crew module from the service module (15).
- 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**
The ICPS has committed Orion to 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 for next 6-23 days.
 - 11 DISTANT RETROGRADE ORBIT**
Perform half or one and a half revolutions in the 12 day orbit period 38,000 nmi from the surface of the Moon.
 - 12 DRO DEPARTURE**
Leave DRO and start return to Earth.
 - 13 RETURN POWER FLY-BY (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; travel time 5-11 days.
 - 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.

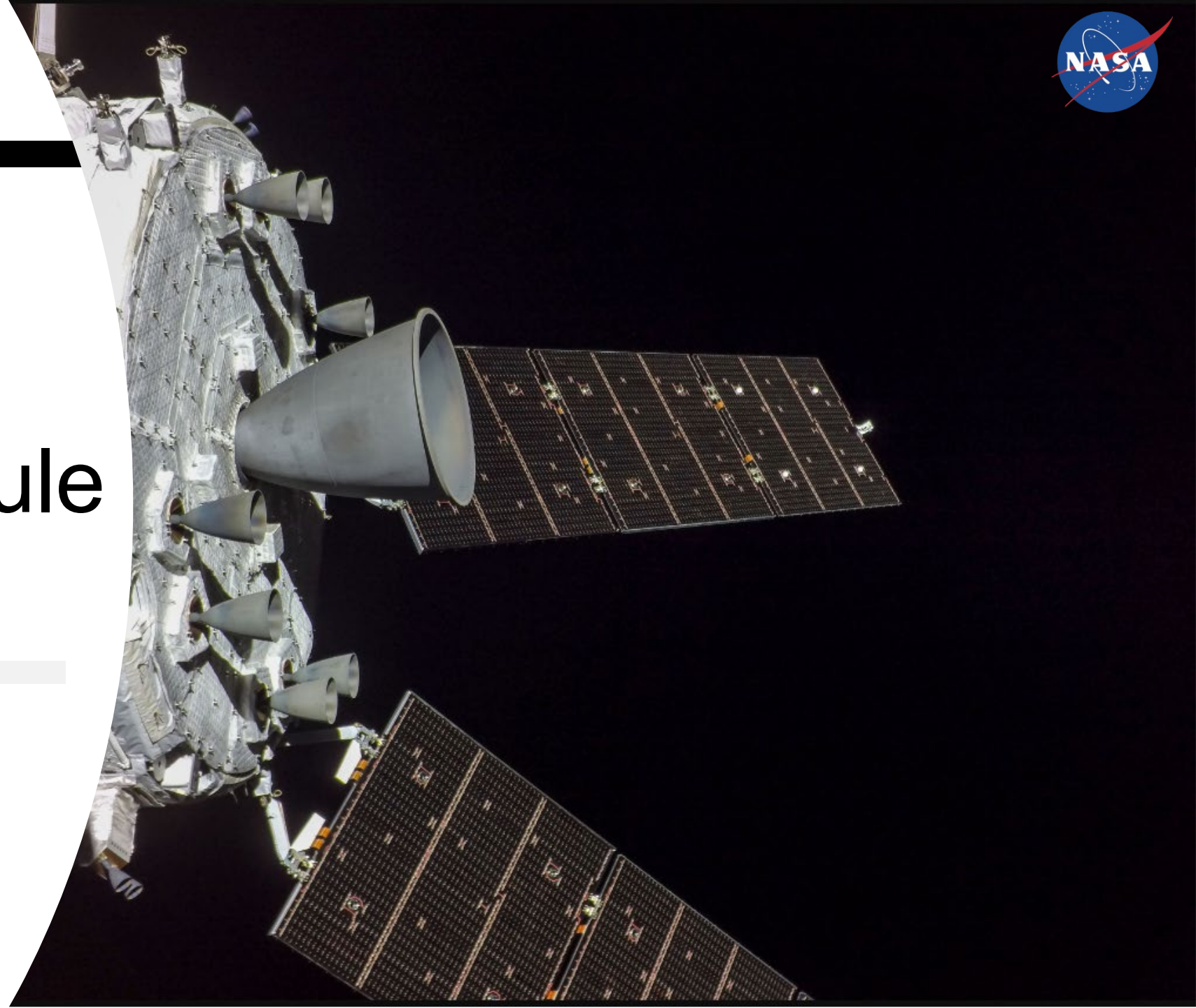


Flight Day 1 Post-Solar Array Deployment





Flight Day 1 Service Module Inspection

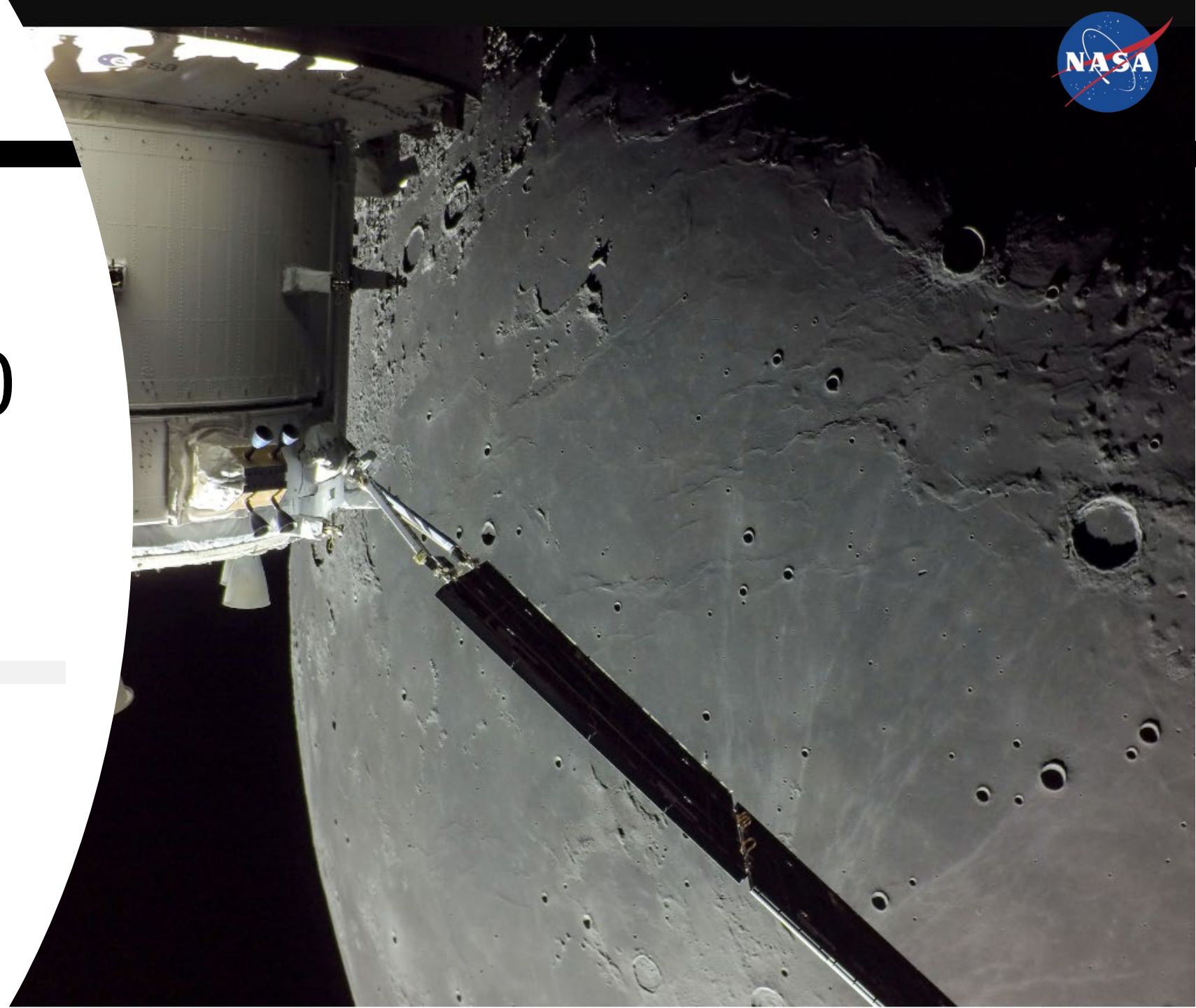


Flight Day 13 Orion Selfie



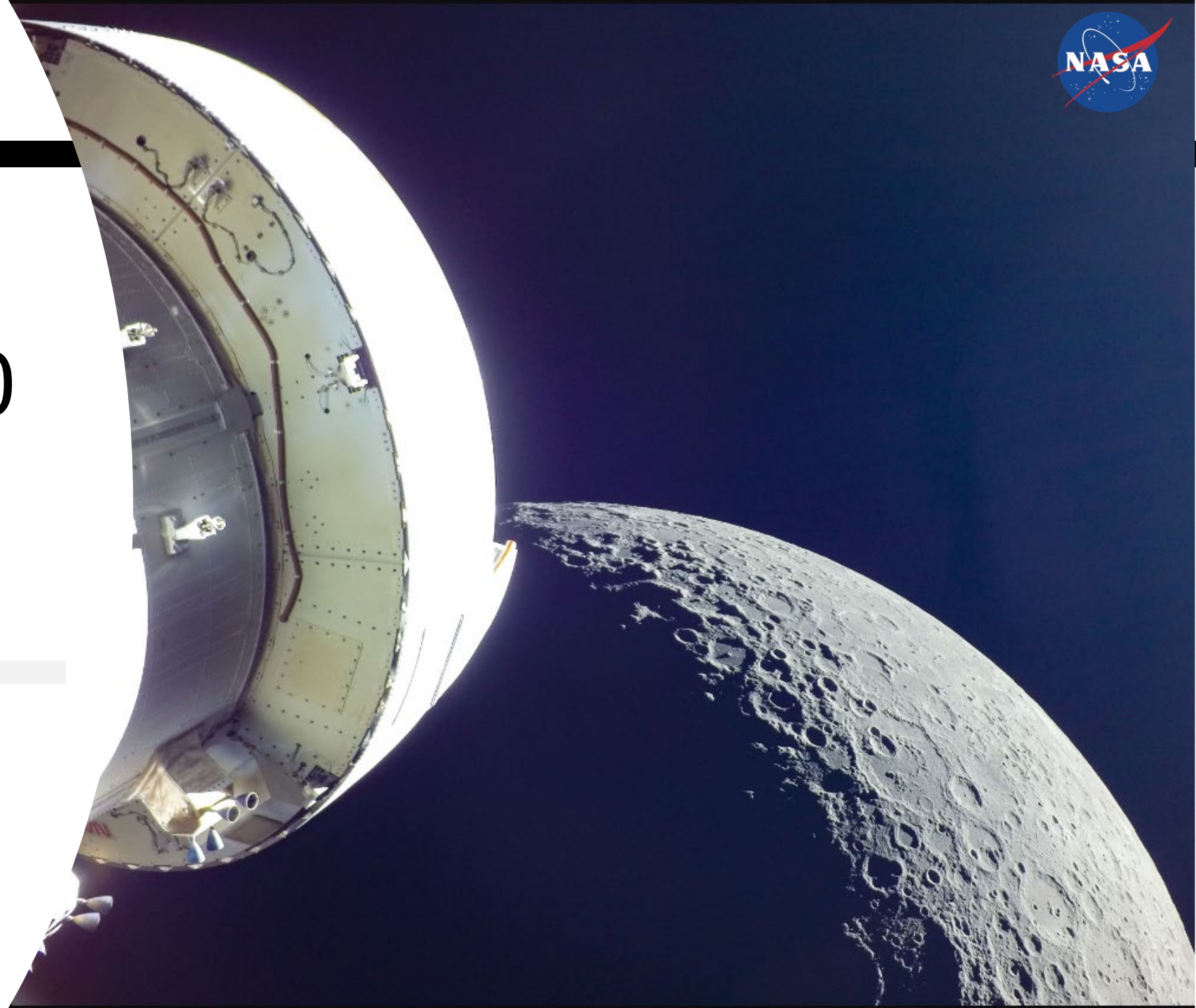


Flight Day 20 Pre- Lunar Flyby





Flight Day 20 Post- Lunar Flyby



- **High fidelity**

- Spacecraft Power Capability (SPoC), Lockheed Martin
- System Power Analysis for Capability Evaluation (SPACE), NASA GRC
- Used for verification of requirements and validation of mission plans
- Detailed inputs and assumptions, modelling a particular case (slow to setup)
- Choosing a conservative and bounding case can be challenging

- **Screening**

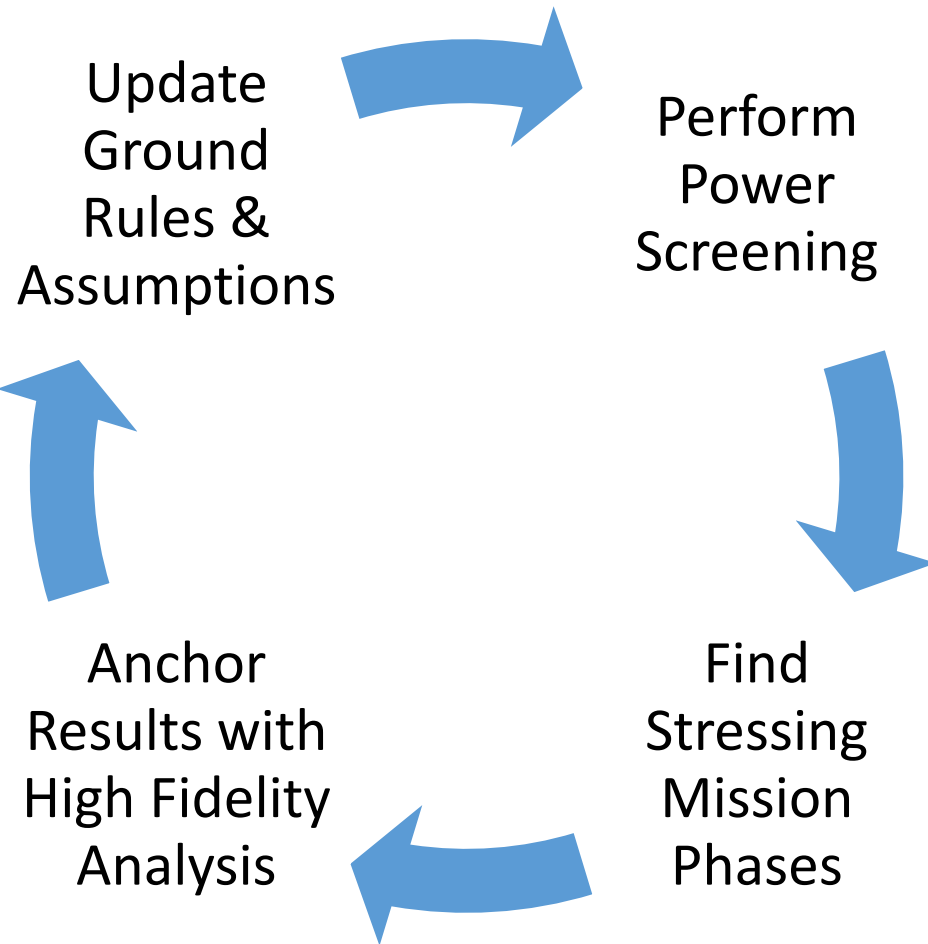
- Power screening tool, Lockheed Martin
- Simpler, conservative assumptions (fast to setup and run)
- Quickly assess thousands of possible trajectories

Challenges – Analyze the Mission Space



- **Rapidly analyze years' worth of launch opportunities (17,000+ trajectories)**
- **Sun, Earth and Moon phasing throughout the year causes eclipses to move relative to major mission events**
 - Could not use generic mission timeline analysis across the mission space
 - Mission duration variability (28-42 days) caused additional complexity
- **Ensure Orion survives with potential power faults, such as:**
 - 1 Battery Failure
 - 1 Solar Array Wing Failure
- **Provide mission ops situational awareness for potentially power stressing situations**
 - Deconflict events such as correction burns or out of attitude maneuvers (that reduce power generation)

Reducing Fidelity, Increasing Speed

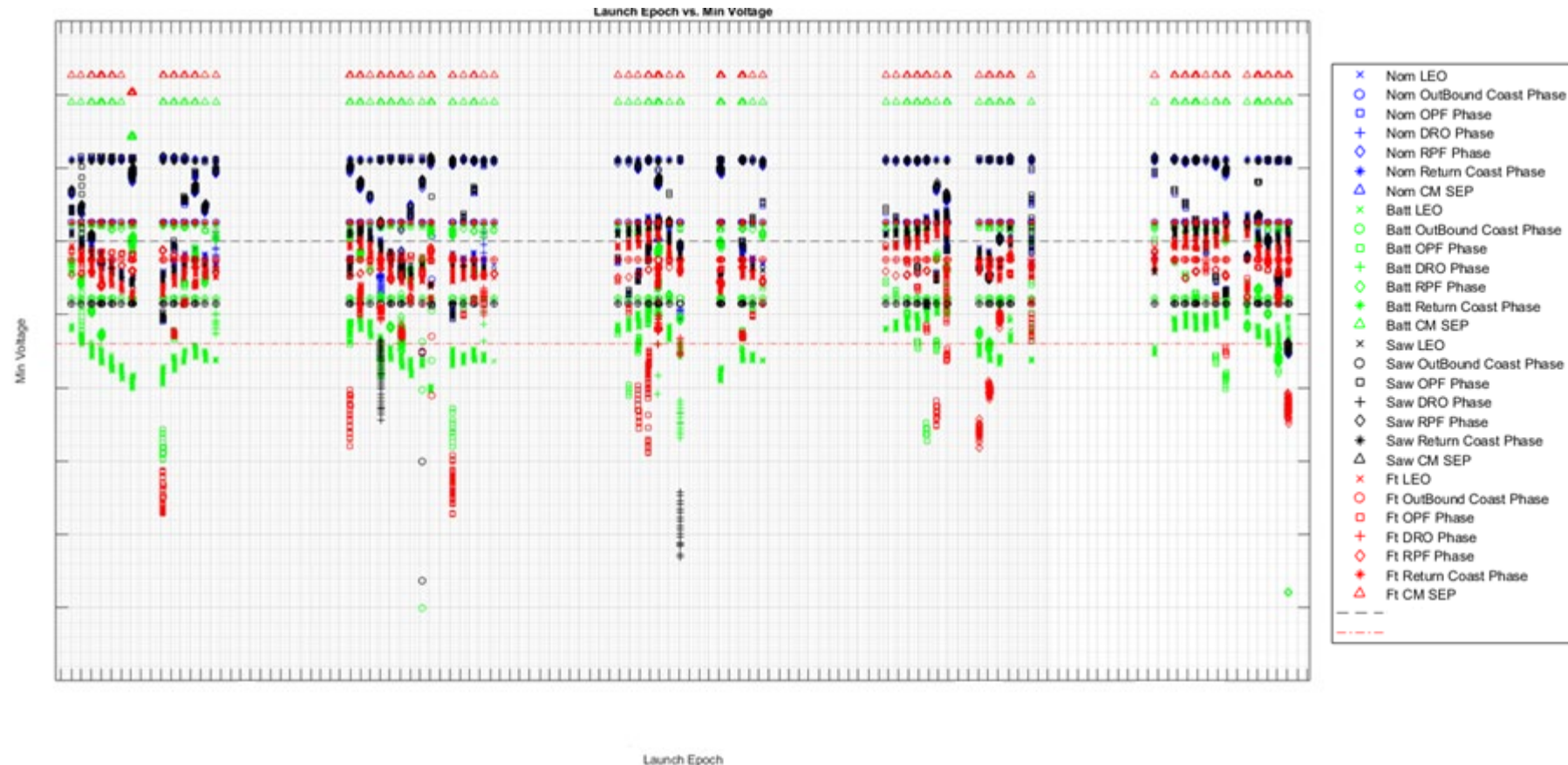


- **Create a new analysis tool that would leverage existing trajectory data, assume conservative CONOPS, and simple charging and discharging models to speed up the analysis**
 - Charging and Discharging assumptions are based in high fidelity SIMULINK Integrated battery model (SPOC)
- **High Fidelity analysis takes ~20 hours to run an End-to-End power analysis**
- **New Power Screening Tool can scan over 17,000 trajectories in less than 2hrs**
- **Ensure the Power Screening tool is more conservative such that the results are bounding**

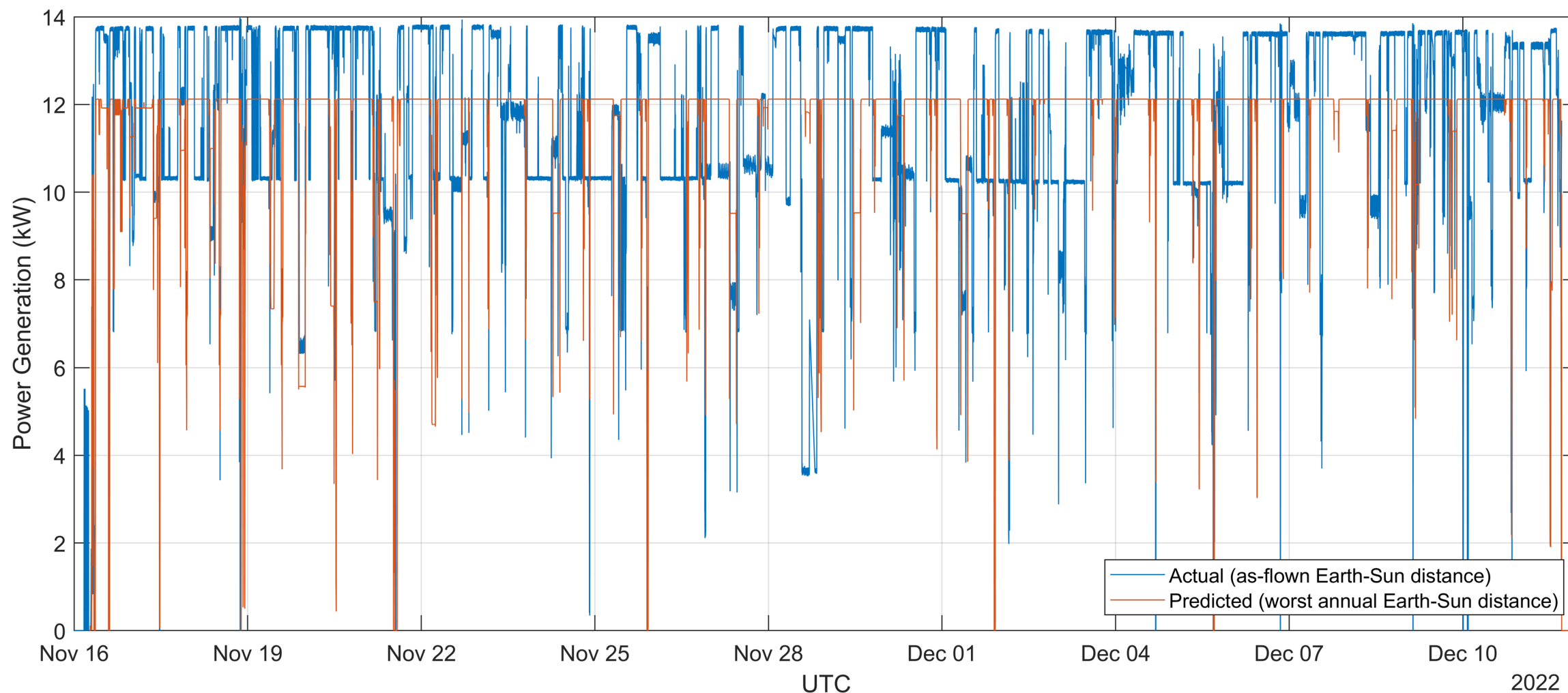
Continuous integration led to quick analysis turnaround

Go/No-Go Recommendations

- Launch window cutouts based on minimum voltage for a given epoch
- Provide situational awareness to mission ops to schedule power downs prior to stressing situations



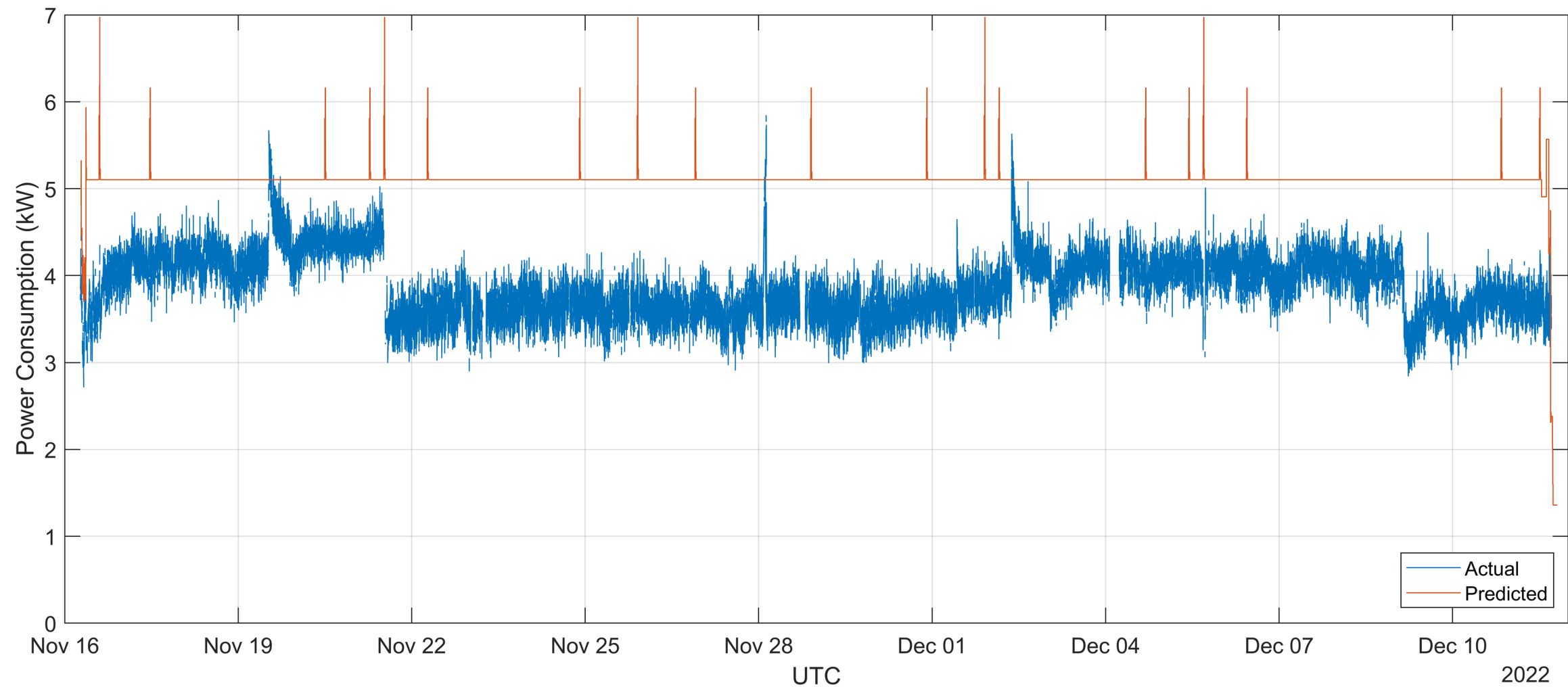
Power Generation



Significant additional power generation primarily due to higher solar flux in Nov/Dec
Model predictions were within ~3% after correcting for as-flown flux

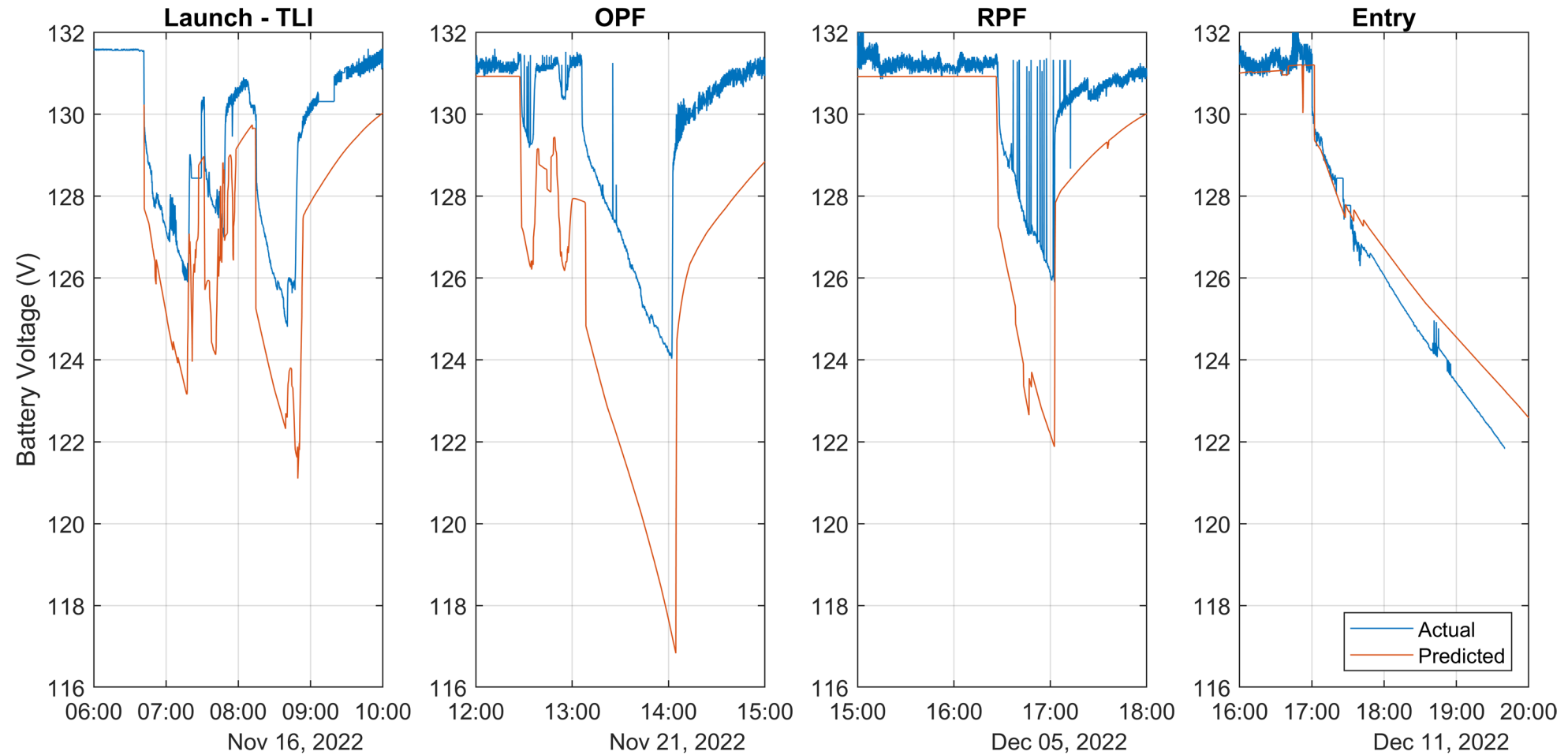


Load Demand



Lower than expected loads driven by heater usage

Battery Voltage



Battery performance benefited from low overall load demand

Anomalies and Interesting Observations



- **PCDU LCL Uncommanded Opening Anomaly**

- Uncommanded opening of latching current limiter (LCL) on Power Conditioning and Distribution Unit (PCDU) end of umbilical
- Occurred 22 times on 4 different LCLs (one at a time, always Umbilical 1)
- One similar event involving multiple 120V load LCLs
- One similar event involving 28V DC-DC converter internal to the PCDU
- Never observed in ground testing at the component, subsystem, or vehicle level
- Root cause undetermined, investigation still ongoing

- **Glint from crew module backshell**

- Planned to measure during external survey
- Observed localized current increases from increased flux

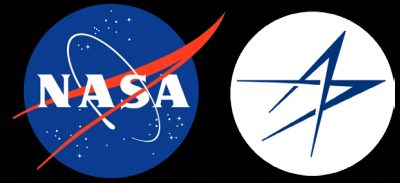


Anomalies and Interesting Observations



- **Solar array photoluminescence**
 - Partially shadowed string of solar cells
 - III-V cell photoluminescence occurs in visible spectrum
 - Happened to occur while filming upper stage separation





Questions?

Spencer Furin

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Acronym Definitions



- **CM** – Crew Module
- **CONOPS** – Concept of Operations
- **DC** – Direct Current
- **DRO** – Distant Retrograde Orbit
- **EI** – Entry Interface
- **GRC** – Glenn Research Center
- **ICPS** – Interim Cryogenic Propulsion Stage
- **LCL** – Latching Current Limiter
- **LEO** – Low Earth Orbit
- **NASA** – National Aeronautics and Space Administration
- **OPF** – Outbound Powered Flyby
- **OTC** – Outbound Trajectory Correction
- **PCDU** – Power Conditioning and Distribution Unit
- **RPF** – Return Powered Flyby
- **RTC** – Return Trajectory Correction
- **SLS** – Space Launch System
- **SPACE** – System Power Analysis for Capability Evaluation
- **SPoC** – Spacecraft Power Capability
- **TLI** – Trans-Lunar Injection